CITY OF BELLEVUE'S CRITICAL AREAS UPDATE

2005 Best Available Science (BAS) Review

Prepared for

City of Bellevue

March 2005

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Prepared for

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King County. 2004. Best Available Science. Volume I, A Review of Science Literature. King County Executive Report: Critical Areas, Stormwater, and Clearing and Grading Proposed Ordinances. Department of Natural Resources and Parks, Water and Land Resources Division. February 2004.

Sheldon, D., T. Hruby, P. Johnson, K. Harper, A. McMillan, S. Stanley, and E. Stockdale. 2003. Freshwater Wetlands in Washington State. Volume 1, A Synthesis of the Science. Draft. Publication 03-06-016. Washington State Department of Ecology. August 2003.

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Chapter 1. Executive Summary

This report presents the results of a review of best available science related to the protection and management of critical areas. It also provides recommendations regarding the management and regulation of critical areas to ensure their protection based on scientifically defensible principles. As defined by the state Growth Management Act, critical areas include geologically hazardous areas, frequently flooded areas, critical aquifer recharge areas, streams, wetlands, and wildlife habitat conservation areas.

In 1995, the Washington state legislature added a new section to the state's Growth Management Act. This new section was intended to ensure that cities and counties consider reliable scientific information when adopting policies and regulations to designate and manage critical areas. The new section, Revised Code of Washington, Section 36.70A.172 (RCW 36.70A.172), requires all cities and counties in Washington state to include "best available science" in developing policies and regulations to protect the functions and values of critical areas. One of the objectives of the Growth Management Act is to protect the functions and values of critical areas by ensuring that cities and counties (1) accurately describe these functions and values, (2) understand the likely adverse impacts on critical areas that are associated with proposed land use planning alternatives, and (3) make land use decisions that minimize or eliminate those adverse impacts to the extent possible.

In 2000, the state's Office of Community Development (now the Department of Community, Trade & Economic Development (CTED) adopted procedural criteria to implement these changes to the Growth Management Act. In addition, the Office of Community Development provided guidance for identifying best available science. The agency concluded that scientific activities included identifying and describing the functions and values of critical areas and estimating the types and likely magnitudes of adverse impacts on critical areas resulting from disturbance. Therefore, RCW 36.70A.172(1) and the corresponding regulations require the substantive inclusion of best available science in developing local policies and regulations related to critical areas. In addition, these local policies and regulations must give special consideration to the preservation or enhancement of anadromous fish species.

This report has been prepared to assist the City of Bellevue in its compliance with these GMA requirements. It includes a review of available peer-reviewed research, inventory reports, symposia literature, technical literature, and other sources of scientific information relevant to the protection of critical areas. The following text summarizes the documented science and provides concluding recommendations for geologically hazardous areas, critical aquifer recharge areas, frequently flooded areas, streams and riparian areas, wetlands, and wildlife habitat conservation areas. Also discussed are shorelines of the state (Lake Washington, Lake Sammamish, and Phantom Lake) as fish and wildlife habitat conservation areas.

1.1 Geologically Hazardous Areas

All five of the geologic hazards specified in the Growth Management Act (i.e., seismic, erosion, landslide, volcanic, and coal mine hazard areas) have the potential to adversely affect Bellevue's community functions and impair the value of human life and property. The delineation of geologically hazardous areas and mitigation of potential risks requires an understanding of the geologic processes from which these hazards arise.

A review of the best available science indicates ground shaking caused by earthquakes is the most serious hazard in Bellevue in terms of the potential for widespread damage and loss of life. However, the likelihood of a significant event in the near future is uncertain due to limited seismic information about regional faults and data related to the dynamic properties of geologic materials. Consequently, it is acceptable to delineate seismic hazard areas with a conservative margin of safety, to account for this uncertainty. In addition to damage caused by groundshaking, resulting landslide activity could lead to tsunami activity. Although tsunami inundation models have been developed for Puget Sound, those models have not been used to delineate tsunami hazard areas on Bellevue's shorelines.

The factors controlling erosion and landsliding are highly variable. Hence, site-specific investigations of geologic conditions are required to delineate erosion and landslide hazards at the resolution necessary to mitigate most hazards. The City's delineation of erosion and landslide hazard areas should be updated by incorporating historical records and new light ranging and detection (lidar) topography into the erosion and landsliding models that rate susceptibility to erosion or landsliding in terms of several relative hazard classes. The highest hazard rating should be used to determine structure setbacks in areas where site-specific investigations have not been performed.

The City is located within 160 km (99 mi) of five active volcanoes. The uncertainty related to whether ash fall from future volcanic eruptions will affect Bellevue complicates the feasibility of mitigating hazards due to volcanic eruptions.

Although the City's inventory of abandoned coal mines is based on historic mining information and not site specific investigations, the delineation of broad areas suspected of posing coal mine hazards provides a margin of safety for the hazards posed by the collapse of abandoned coal mines.

While it may not be economically feasible to retrofit or relocate all existing structures within geologically hazardous areas, at minimum, the risks to critical facilities should be reviewed and appropriate measures implemented to protect public safety. Risks posed by geologic hazards can be best mitigated by restricting new development in vulnerable areas.

1.2 Critical Aquifer Recharge Areas

The functions and values of critical aquifer recharge areas consist of providing sources of potable water and areas for the replenishment of ground water resources. Maps indicating the locations of critical aquifer recharge areas serve as the general framework for establishing a policy to protect ground water quality and quantity.

Most of the drinking water used in Bellevue is provided by the City of Seattle from a surface water source in the Cascade Mountains. Only a small percentage of Bellevue residents currently use ground water as their source of drinking water. In Bellevue, there are three Group A water systems and 11 Group B water systems that rely on local ground water. Group A systems serve 15 or more service connections, regardless of the number of people; or they serve an average of 25 or more people per day for at least 60 days within a calendar year, regardless of the number of service connections. Group B systems generally serve 2 to 14 connections and fewer than 25 people. Each of these groups of water supply systems could connect to the City-wide public water system if water quality in existing wells is compromised.

Ground water recharge areas can be grouped according to the function of the water once it enters the aquifer. The main group used in Bellevue to protect critical aquifer recharge areas is called a wellhead protection area (WHPA), which is defined as the area that provides recharge to a drinking water well. WHPAs are required for all Group A and Group B water systems. Group A water systems are responsible for identifying WHPAs based on the actual sources of recharge to their wells and are required to provide wellhead protection for those areas. Group B public water systems are required to use a WHPA radius of 600 feet for each well. Distant recharge sources to Group B water systems may not be protected when relying on a fixed WHPA radius for protection. Prohibiting potentially polluting land-use activities in critical aquifer recharge areas that are susceptible to contamination is consistent with the best available science for protecting ground water quality.

1.3 Frequently Flooded Areas

The frequently flooded areas have been mapped within Bellevue are limited to small lakes and creeks and the shoreline of Lake Sammamish. A review of the literature indicates that frequently flooded areas can be delineated both to identify flood hazards and to protect the ecological functions and values of floodplains. The Federal Emergency Management Agency assumes the primary responsibility for delineating frequently flooded areas for hazard mitigation by developing flood insurance rate maps showing the base flood elevation and the areas prone to flooding.

Changes in the hydrologic regime caused by urbanization or climate change may alter the areas currently designated as frequently flooded. Restricting development within floodplains and modernizing traditional flood control measures can both mitigate flood hazards and restore the ecological functions of frequently flooded areas. Channel migration is becoming recognized as a significant hazard associated with but not limited to frequently flooded areas.

Protection of frequently flooded areas is important because they provide unique hydrologic and ecological functions, including critical habitat for many species of fish, birds, and other wildlife. The complex vegetation structure found in riparian areas and the frequent inundation in these areas contribute to the high biodiversity found in floodplains. Protection of frequently flooded areas also sustains wetlands, which provide feeding and breeding habitat for birds and off-channel refuge and rearing habitat for migrating salmonids.

The following actions are recommended for the City of Bellevue:

- Use the most recent LIDAR topographic maps for any future update of existing flood hazard maps.
- Address increases in peak flow anticipated as a result of basin urbanization in any future flood hazard mapping. Hydrologic modeling should also consider projected changes in precipitation related to climate change.
- Consider new flood control projects that emulate natural stream processes.
- Implement public buy-out or land-stewardship programs to restore the ecological functions of frequently flooded areas.

1.4 Streams and Riparian Areas

This summary of the best available science for developing policies and regulations to protect the functions and values of stream and associated riparian areas is based on peer-reviewed research; Bellevue's 2003 *Critical Areas Update, Stream Inventory Report;* Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Streams*; symposia literature; technical literature; and other scientific information related to streams. The review focused on recommended conservation or protection measures to preserve or enhance anadromous fish species and habitat that is important for all life stages of anadromous fish. Best available science for stream and riparian protection, particularly safeguarding the processes that protect riparian functions, varies in terms of quantity, quality, and local relevance. The best available science for stream and riparian protection is neither complete nor consistently covers all functions, and it remains an active field of research. Table 1-1 summarizes the best available science positions on stream and riparian area protection and provides general recommendations for the City of Bellevue.

Human development of land and water typically affects stream functions and processes in profound ways, ultimately affecting the type and abundance of existing species. Sustaining natural functions and processes is essential to maintaining stream habitats and the species that rely on them. Streams are formed and sustained by many important physical and biological processes which include but are not limited to:

- Natural disturbances
- Hyporheic zone interactions
- Habitat-forming processes
- Stream/riparian interactions within the channel migration zone.

Table 1-1. Summary of best available science findings and general recommendations for protecting streams.

Protection Mechanism	Best Available Science Review	General Recommendations
Adopt a stream typing system to address processes that are relevant to specific types of streams and fish habitat.	The DNR water typing system considers fish habitat rather than presence or absence of fish species.	Adopt the DNR stream typing system.
Implement riparian structure setbacks which protect an area of sufficient size to provide riparian and aquatic processes and functions, protect riparian species, and buffer against development impacts.	The effectiveness of a buffer to provide multiple functions and benefits is linked to its width and other facts such as slope, vegetation characteristics, soil type, buffer design and buffer management. Many of the critical functions of riparian areas occur in those areas directly adjacent to streams and plateaus at a given distance. Buffer width established using the site potential tree height (SPTH) concept can provide the ecological functions necessary to support salmonids and most riparian and aquatic functions and processes.	The developed character of the City makes adoption of fully protective buffers impractical therefore adoption of buffers that provide the greatest riparian functionality is advised. Measure riparian structure setbacks from the channel migration zone or ordinary high water mark.
Provide stewardship programs as incentives to restore and protect riparian functions where stream buffers are not possible.	Processes and functions provided in the literature for buffers are based on areas vegetated with native plant species at densities of native plant communities. Sparsely vegetated or vegetated buffers with non-native species may not perform the needed functions of stream buffers.	Educate landowners on the importance of protecting and maintaining stream buffers. The City should provide partnerships with landowners for riparian restoration projects.
Increase the distance between human activities and stream buffers.	High-density residential, commercial, and industrial land-uses often necessitate wider structure setbacks from aquatic ecosystems to better protect streams from the higher levels of disturbances associated with more intensive land uses.	A 25-foot structural setback to stream buffers along all water types is preferred when possible to prevent disturbance of riparian functions.
Restore fish habitat and passage by daylighting stream segments.	The primary technical elements to consider when restoring a channel to the surface are channel design and floodplain.	Establish piped stream buffers based on buffer widths meeting the SPTH concept and, when possible include a 25-foot structural setback. The preserved land area will provide space for daylighting a stream segment. The developed character of the City may preclude this protective mechanism in many areas.
Implement restoration and enhancement strategies to improve or prevent additional degradation of riparian habitat.	Watershed-based strategies that address hydrology, water quality, and riparian functions are the most successful in addressing riparian areas and adequate buffers in the context of basin-wide change.	Restore degraded riparian areas using strategies which emphasize the whole watershed and ecological processes which include the following: ▪ Design and install LWD ▪ Plant native coniferous trees along streams ▪ Reduce invasive non-native plants along streams ▪ Replace or modify culverts which prevent fish passage ▪ Restore and enhance wetlands to restore off-channel habitat.

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Natural disturbances sustain species diversity and create habitat. The hyporheic zone provides surface and ground water interactions, influencing water chemistry, sustaining refuge habitat for invertebrates, and providing developmental habitat for salmon. The channel migration zone allows for habitat creation and sustainability by providing lateral areas for streams to migrate across the floodplain (see Figure 1-1). Because of the unique mix of water and biodiversity, stream and riparian areas are used by a broad range of species including by humans for recreational and aesthetic activities, fishing, and the enjoyment of natural beauty and solitude.

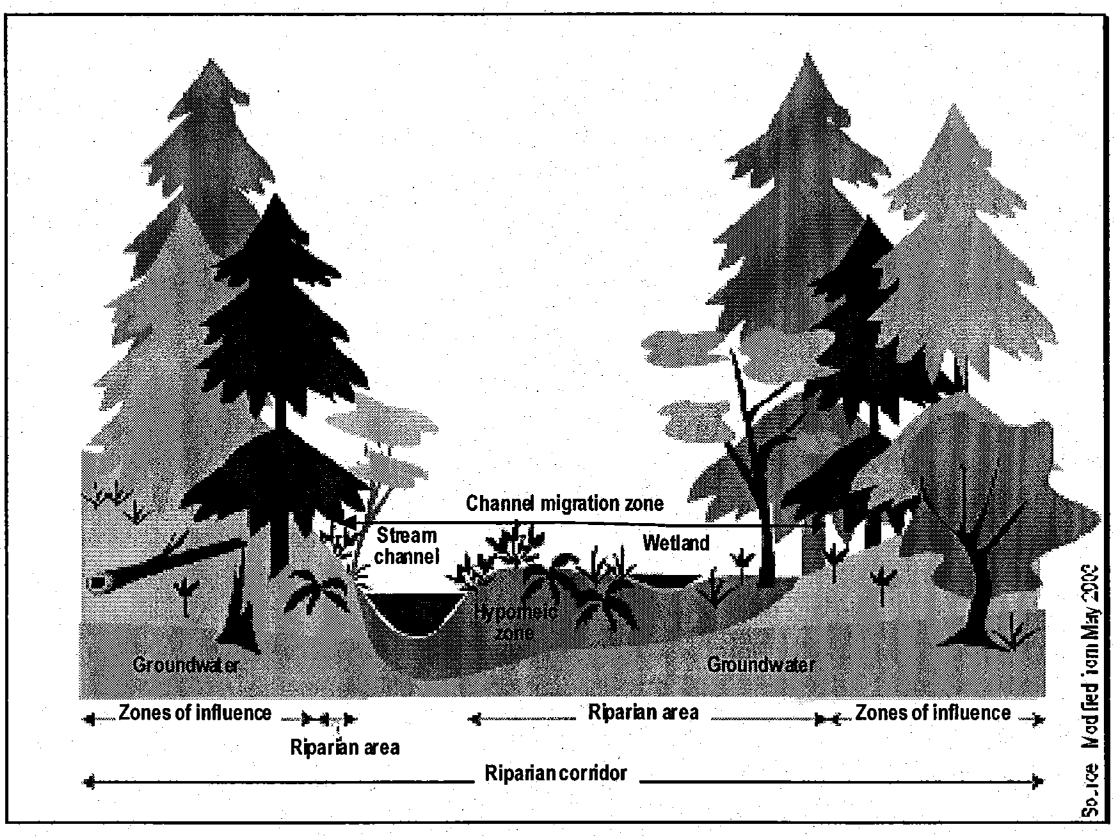

Figure 1-1. Typical stream and riparian zones.

The sustainability and restoration of habitats and species requires the protection and restoration of the ecological functions and processes that sustain them, in addition to the direct protection of the habitats themselves. Without adequate habitat protection, development will produce the following conditions in streams and riparian areas:

- Reductions in the amount and complexity of habitat
- Increased scouring of stream channels
- Reduction or loss of channel migration, sediment supply, and the recruitment of large woody debris
- Decreased productivity and species diversity.

Water body typing and designation are necessary for protecting stream and riparian functions, processes, and values. The classification of water bodies allows for the development of regulations to address functions and processes that are relevant to specific types of water bodies. The Growth Management Act (Section 5.c.vi of WAC 365-190-080 Critical Areas (vi) Waters of the state) states that counties and cities should use the classification system established in Washington Administrative Code, Chapter 222-16, Section 030 (WAC 222-16-030) to classify waters of the state. Waters of the state are defined in Title 222 WAC, the forest practices rules and regulations. Counties and cities are expected to use the classification system established in WAC 222-16-030 to classify waters of the state. WAC 222-16-030 outlines the state's classification for water bodies into three categories: Type S waters (shorelines of the state), Type F waters (fish habitat), and Type N waters (nonfish habitat). The current Bellevue riparian corridor classification (Type A-D) does not readily align with the proposed state system.

Should the City of Bellevue adopt the classification system for streams and other water bodies established by WAC 222-16-030, it will ensure consistency with the Growth Management Act and the permit requirements of state agencies. Adoption of the state's classification system will also protect the chinook salmon, a species that is protected under the Endangered Species Act because under the recommended stream typing system, stream segments classified as Type S or Type F waters could receive additional stream buffer protection.

Stream buffers are necessary to protect the functions and processes of riparian and aquatic areas. Current scientific research indicates that stream buffer requirements are best established using the site-potential tree height concept (SPTH). The height of a site potential tree for a mature Douglas-fir tree for the types of soils found within the City of Bellevue is 146 feet. A similar size buffer width of 147 feet on each side of a stream is identified in the literature as effective in providing sediment filtration, erosion control, pollutant removal, LWD recruitment, and water temperature protection. Smaller buffers may protect some level of functional effectiveness but would not be expected to fully protect stream and riparian area functions.

The stream buffer should be a "no-touch zone" in which minimal activities occur so that the ecological functions of the stream are protected. A structure setback of 25 feet is preferred, whenever possible in addition to the stream buffer to act as a regulated transition area. The structure setback should be measured from the edge of the buffer.

Buffers are also recommended for segments of piped streams in Bellevue, particularly when they are fish bearing. Piped stream segments limit available habitat, can inhibit resident fish movement and anadromous fish migration, and prevent fish from accessing upstream habitats. Piped stream segments that do not prevent fish migration may limit many aquatic processes necessary for salmonid fish production. Establishing buffers adjacent to piped streams is a means of preserving space and, when available, natural forest conditions that will allow for future opportunities to restore piped stream segments to surface-flowing streams. Although much of Bellevue is built out and piped stream segments typically are located in paved areas, planning for buffers on piped stream segments will allow for future stream restoration opportunities while providing adequate buffer protection. The stream buffer for piped stream segments can be based on a buffer width meeting the SPTH concept in addition to a structure setback of 25 feet in areas where possible.

Stewardship programs are recommended non-regulatory measures to assist in the protection and restoration of functions and values of streams and associated riparian areas. Stewardship programs often provide incentives that encourage property owners to improve degraded stream buffers and instream habitat. Examples of rehabilitation activities sponsored by a stewardship program may include matching grants to remove invasive nonnative plant species and reestablishing stream buffers with native coniferous trees.

1.5 Wetlands

This summary of the best available science for developing policies and regulations to protect the functions and values of wetlands is based on peer-reviewed research; Bellevue's *2003 Critical Areas Update, Best Available Science Paper: Wetlands,* symposia literature; technical literature; and other scientific information related to wetlands. Best available science for wetland protection, particularly safeguarding the processes that protect wetland functions, varies in terms of quantity, quality, and local relevance, and it remains an active field of research. The best available science for wetland protection is neither complete nor consistently covered for all functions.

There is more useful and locally relevant information available for wetland water quality functions and their protection than that available for other wetland functions. There is information related to the use of local wetlands by wildlife; however, with the exception of amphibians, there have been few empirical studies related to wildlife and habitat protection, especially on the population scale. The information related to impacts on wetland birds other than waterfowl, and particularly their buffer needs, comes largely from streamside riparian studies conducted in other regions. Finally, there is little local information available regarding the ground water interaction functions between wetlands and the greater watershed and landscape.

Nevertheless, the literature appears to be clear that there has been a continual loss of wetland acreage and wetland functions despite numerous agency policies and regulations requiring "no net loss." Furthermore, despite the caveats of insufficient science, several principles for protecting wetland functions can be extracted from the national and local literature:

- Wetland functions are interdependent and, to some extent, mutually exclusive.
- Wetland functions vary over time.
- Protection of wetlands is context and scale driven. That is, wetland protection is dependent on the functions of wetlands and the condition of ecological processes in the adjoining areas as well as the greater watershed and landscape area.

- Buffers alone, although necessary in many cases, may be insufficient to completely protect important wetland functions unless the buffers are exceptionally large or there is high connectivity in the landscape.
- Protection of wetland complexes is important to stem wetland isolation and habitat fragmentation, two consequences of development leading to decreased species richness and population extinctions in wetlands.
- Currently, wetland mitigation is an inexact and difficult science; therefore avoiding wetland loss remains the preferred option for meeting the "no net loss" standard.
- If mitigation is required, mitigating the loss of wetland functions is as important as mitigating the loss of wetland acreage.

Table 1-2 summarizes the best available science on wetland protection mechanisms and provides general recommendations for the City of Bellevue.

An overview of important wetland functions is provided in Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Wetlands*. In general, wetlands provide a number of different and often critical environmental and ecological functions that benefit humans, including flood storage and retention, ground water discharge/recharge, maintenance and protection of water quality, and provision of habitat for important fish and wildlife species (including some federal and state threatened and endangered species), as well as for a wide diversity of important invertebrates, amphibians, birds, furbearers, and small mammals. Results of studies of wetlands in the Puget Sound lowlands have indicated that the diversity of birds and small mammals in wetlands may exceed that in upland habitats. Because of the unique mix of water and biodiversity, wetland areas are also used for a broad range of recreational and aesthetic activities, including hunting and the enjoyment of natural beauty and solitude.

Wetland protection means maintaining the ecological integrity of wetlands so their functions remain self-sustaining. Consequently, hydrologic processes, ground water interactions, water quality enhancement, species and habitat support, and other existing functions need to persist in perpetuity, though they may vary somewhat from year to year or decade to decade within a single wetland.

The exemption of small wetlands from regulatory protection is an issue that has gained increased attention over the past 10 years. The City of Bellevue's regulations preferentially allow the filling of small wetlands because size is one of the characteristics used in determining wetland ratings at the local level. Regulatory priorities have focused on protecting larger wetlands and not protecting the smaller, seasonal wetlands that are often critical components of wetland complexes. The loss of small wetlands is one of the most common cumulative impacts on wetlands and wildlife.

The City of Bellevue currently allows a number of activities within wetlands or wetland buffers that are inconsistent with the recommendations suggested by the best available science. These

Table 1-2. Summary of best available science findings and general recommendations for protecting wetlands.

Protection Mechanism	Best Available Science Review	General Recommendations
Basing wetlands protection on wetland size	Wetland size may be a factor but is not a determinant of the functions and values provided by a wetland.	Provide protection for wetlands commensurate with wetland functions.
Measuring the functions of wetlands.	▪ The most useful methods generate parametric measures rather than general rankings. ▪ Require the same method be used to evaluate functions for wetland losses and for wetland mitigation proposals. ▪ Specify the use of wetland functional assessment methods that are appropriate to Bellevue's wetland types to improve mitigation success and provide a consistent database for mentoring and analysis.	Most Bellevue wetlands are either riparian or depressional palustrine wetlands. Hruby et al. (1999) provides methods producing parametric measures of function that are suited to the types of wetlands located in Bellevue.
Rating wetlands as a basis for more protective regulations.	The primary factors important to consider when rating wetlands for the purposed of applying commensurate protective measures are : ▪ Rarity ▪ Ability to replace it ▪ Sensitivity to disturbance ▪ Functions performed by the wetland.	Ecology (Hruby 2004) provides a wetland rating system that rates wetlands on specific criteria including, rarity, sensitivity to disturbance, and functions.
Providing protective buffers for wetlands.	▪ In urban areas a minimum of 100 feet of buffer is necessary to provide significant water quality protection and minimal wildlife habitat protection for wetlands. ▪ Additional protection for wildlife can be achieved with wider buffers and/or increased landscape connectivity.	▪ Provide a minimum of 100 feet of buffer for all Class A, B or C wetlands in Bellevue that are rated a Category I, II, or III using Hruby (2004). ▪ Where possible provide a minimum 200 foot buffer for those wetlands rated as a Category II or II by Hruby (2004). ▪ The developed character of the City may preclude the practical implementation of larger buffers, therefore the City should explore alternative strategies to increase wetland protection such as improving the connectivity of native habitat in the landscape.
Allowing for the use of buffer averaging.	The effectiveness of buffer averaging in achieving equal or increased wetland protection has not been studied and is unknown.	Allow buffer averaging when averaging will improve connectivity with adjacent native habitat.
Allowing wetland creation, restoration, enhancement and permanent protection as mitigation for wetland losses.	▪ Mitigation in general for wetland losses has achieved a poor rate of success to date, particularly wetland creation. ▪ Enhancement of wetlands in exchange for permanent loss of wetland area fails to compensate for lost wetland area and frequently fails to improve wetland functions. ▪ Allowing permanent protection of wetlands in exchange for permanent loss of wetland area fails to compensate for lost wetland area or wetland functions. ▪ Regulatory follow-up is vital to ensuring the success of wetland mitigation.	▪ Improve the instructions for applying to mitigate, from avoidance and minimization to submitting a monitoring report for a compensation wetland. ▪ Adjust replacement ratios to reflect functional losses as well as areal losses. ▪ Avoid accepting wetland enhancement or protection of wetlands in exchange for wetland losses. ▪ Increase regulatory follow-up and enforcement of compensatory mitigation projects; develop and maintain a database and filing system; allocate staff to perform compliance and enforcement activities; and implement reviews of regulatory program performance.

include the building of roads, utilities, and other essential infrastructure. There is no available data describing the extent to which these activities may have affected wetland functions in Bellevue and whether they are adequately mitigated. Incrementally and collectively, these activities continue to erode the City's wetland resources.

Reasonable use exemptions also allow encroachment on wetlands and their functions if no other onsite development possibilities are available. Unmitigated exemptions and allowed variances, although required to avoid property rights challenges, are not consistent with the best available science for wetland protection if they lead to incremental, cumulative losses in wetland area and wetland functions and values. Conditions on allowed alterations may lessen these impacts but they rarely fully mitigate the losses.

The foundation of most wetland regulatory programs is a wetland rating system. Since wetlands are highly variable and can provide very different functions, ranking them allows for the opportunity to provide appropriate levels of protection. Any wetland rating system should be based on valid scientific information regarding how a wetland functions, how sensitive a wetland is to human disturbances, how rare a wetland type is, and how easily a wetland can be replicated. The City of Bellevue's current wetland rating system ranks wetlands on size and hydrologic connectivity. The system is insensitive to other important factors such as the wetland's rarity, replaceability, sensitivity, and functions.

In the early 1990s, the Department of Ecology developed a wetland rating system for western Washington that considered all of these factors. That rating system was revised in 2004 to incorporate more recent scientific information. Local governments are encouraged to use the state's rating system because it was developed by a team of wetland specialists and planning staff to ensure both scientific validity and administrative feasibility. If a city uses its own rating system, it is likely that the wetland will also need to be rated according to the state system, if a state or federal permit or approval is needed. This duplication of effort could increase costs for applicants, while offering no protective benefits to wetlands.

Currently, the most common and widespread method of wetland protection is the application of fixed protective buffers. The purpose of a buffer is to protect wetland functions from detrimental impacts resulting from adjoining land use, either existing or expected. In Washington, protection varies considerably. The buffer widths recommended by the Department of Ecology range from 50 feet for Category IV wetlands to 300 feet for Category I wetlands. In Bellevue, the current regulatory protection consists of no buffer for Type C wetlands, a 25-foot width for Type B wetlands, and a 50-foot width for Type A wetlands. Additionally, the City of Bellevue requires a 15-foot and 20-foot structure setback from the edge of the buffer for Type B and A wetlands, respectively. However, a number of permitted uses are allowed within the structure setback, including the removal of native vegetation.

A number of studies of buffer effectiveness were examined for this review. The buffers required to protect habitat are usually larger than those needed to protect other functions such as water quality improvement. In general, it was found that buffers of less than 50 feet are generally ineffective at screening out human disturbance of wetland wildlife. Buffers of 45 to 100 feet can be effective at protecting wetlands and wildlife from disturbance in areas of low-density land uses (agriculture, recreation, and low-density residential housing [less than or equal to 4 units per acre]). Buffers of 100 to 150 feet are recommended for minimal protection of wetlands and wildlife from adjacent high-intensity land use (high-density residential [greater than 4 units per acre] and commercial/industrial development). However, larger buffers, on the order of 150 feet to 200 feet, may be needed to prevent the disturbance of waterfowl in urban areas. One report recommended a buffer of 300 feet for the protection of most species found in wetlands in western Washington that are adjacent to high-intensity land uses.

Best available science suggests that the majority of water quality functions can be achieved within a 100-foot buffer. However, the hydrologic functions of flood storage, ground water recharge, and reducing erosion are not significantly influenced by the width of the buffer. These functions need to be protected at the scale of the watershed or subbasin in which the wetland is found.

There is no information addressing the effectiveness of existing buffers specific to wetlands in Bellevue in protecting wetland functions. However, in general, best available science suggests that wetland functions are minimally protected within an urbanizing area if protection is limited to fixed-width buffers less than 100 feet.

Although much of Bellevue is built out and there are few remaining opportunities to provide wetland buffers that are greater than 100 feet, there may be ways to achieve the goal of habitat protection through long-term land-use planning. The City could plan to link remaining wetlands and pockets of natural habitat with protected riparian corridors. Major riparian networks can be used as linear landscape connectors, providing contiguous travel routes for wildlife between wetland refuges. The City of Bellevue may consider acquiring lands that will better protect wetland functions and provide connected natural areas in the Bellevue landscape. Creative urban landscape design is a promising way to meet the needs of an urban area while protecting many natural habitat functions and values.

Buffer averaging provides another opportunity to decrease the level of risk to wetland functions if buffer widths are reduced where they are unnecessary and increased where they would be beneficial. However, buffer averaging could pose an increased risk to functions if averaging results in increased buffers for one function at the expense of another. In general, wetland ecologists do not have the tools to trade off buffer widths with a high degree of certainty unless adequate information has been obtained. There are no available studies that have evaluated the effectiveness of buffer averaging for wetland protection.

Buffer averaging is encouraged when averaging will provide connectivity with adjacent native habitat areas. Buffer averaging can be useful to promote connectivity in Bellevue's landscape, while allowing more flexibility for landowners.

The term *mitigation* typically involves producing new wetland area, replacing wetland functions, or both as compensation for wetland area and functions lost as a result of a permitted activity.

Wetland mitigation generally entails providing one or more of the following types of compensation:

- Restoration of wetland conditions (and functions) in an area[1]
- Creation of new wetland area and functions
- Enhancement of functions at an existing wetland[2]
- Preservation of an existing high-quality wetland to protect it from future development.

In general, mitigating lost wetland acreage is difficult and highly risky for all types of compensation. Ensuring wetland functions are replaced is even more difficult and requires extensive training, information gathering, and monitoring. Best available science indicates that mitigation plans have not yet succeeded in replacing lost acreage or functions with any reliability. Consequently the risk associated with the replacement of wetland acreage and their functions and values remains high. Although there are a number of local and national studies evaluating the success of completed wetland mitigation projects, there are no documented examples of where a completed mitigation plan has met the goal of no net loss of area, function, and values.

Wetland enhancement is another commonly used mitigation strategy. It involves modifying a specific structural feature of an existing degraded wetland to improve one or more functions or values based on management objectives. Enhancement typically consists of the following:

- Planting vegetation
- Controlling nonnative, invasive species
- Modifying site elevations or the proportion of open water to influence hydroperiods.

Because wetland enhancement involves altering an existing wetland to compensate for the loss of other wetlands, the scientific literature mentions three main concerns related to its use:

- Enhancement fails to replace lost wetland area.

- Enhancement often fails to improve wetland functions.

- Enhancement may result in a conversion of the wetland to another type, such as converting a shallow emergent wetland (with predominantly herbaceous species) to one dominated by deep open water. Such tradeoffs may enhance certain wetland functions at the expense of others.

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[1] Restoration is the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural or historic functions to a former or degraded wetland.

[2] Enhancement is the manipulation of the physical, chemical, or biological characteristics of a biological wetland to heighten, intensify or improve specific function(s) or to change the growth stage or composition of the vegetation present.

In general, the best available science literature on wetland mitigation can be summarized as follows:

- The compliance levels of compensatory mitigation projects are generally low due to shortfalls of wetland acreage, failure to achieve performance standards, and a lack of monitoring and maintenance.
- About 50 percent of wetland mitigation projects achieve their required wetland acreage.
- Well-crafted mitigation performance standards, in addition to goals and objectives, are critical for measuring compliance.
- The requirement for monitoring as a regulatory condition will significantly improve the long-term success of wetland mitigation projects.
- Regulatory followup is vital to ensuring the success of wetland mitigation.

In general, the level of uncertainty associated with the success of wetland mitigation is not related to the compensation ratios. Rather, to a large degree, success is related to the extent of project planning, construction, monitoring, and overall oversight. Consequently, with proper funding and other resources, the uncertainty associated with mitigation success can be decreased and minimized regardless of the ratios.

There is no information documenting the success of wetland mitigation projects in Bellevue and the effect of the City's wetland mitigation regulations on the goal of no net loss. The following actions are recommended to improve the success of wetland mitigation in Bellevue.

- Improve the instructions for applying the mitigation process, from avoidance and minimization to submitting a monitoring report for a compensation wetland.
- Adjust mitigation ratios to reflect functional losses as well as area losses.
- Protect all compensatory mitigation sites in perpetuity by means of a legal mechanism, such as a deed restriction or conservation easement.
- Increase regulatory followup and enforcement of requirements imposed on compensatory mitigation projects; develop and maintain a database and filing system; allocate staff to perform compliance and enforcement activities; and implement reviews of regulatory program performance.

1.6 Shorelines

The shoreline review of best available science focused on the littoral zone within the shoreline aquatic area and its relationship with the shoreline riparian area, specifically within Bellevue's

Lake Washington, Lake Sammamish, and Phantom Lake shorelines(see Figure 1-2). Best available science for shorelines protection, particularly safeguarding the processes that protect shoreline functions, varies in terms of quantity, quality, and local relevance. The best available science for shoreline protection is neither complete nor consistently covers all functions, and it remains an active field of research. Much of the science used for developing protection of shorelines is derived from research specific to streams and riparian areas. Key findings of this review are summarized in Table 1-3 and in the following section.

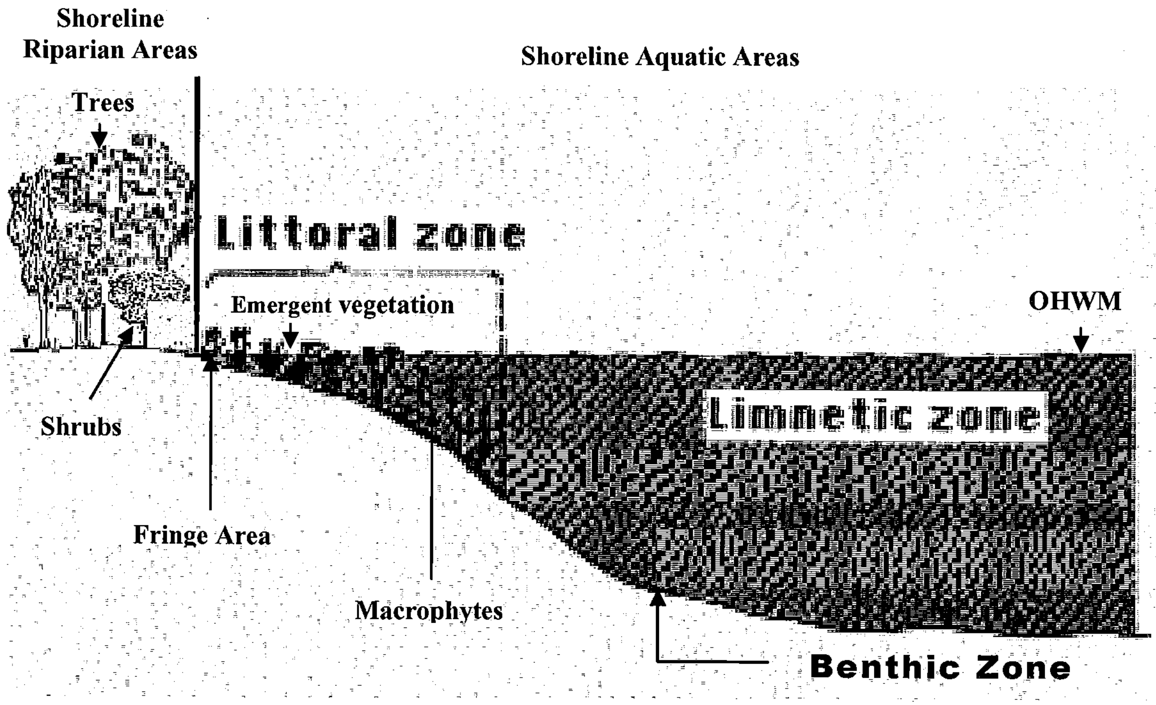

Figure 1-2. Schematic representation of shoreline riparian and aquatic areas (adapted from Kimball 2004).

Currently over 80 percent of shorelines within the City of Bellevue have some stabilization structure, over 50 percent of all parcels have structures within 50 feet of the OHWM, and virtually every shoreline lot has been developed, primarily for residential use.

In general, development along the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake have altered the physical, chemical, and biological processes that create and maintain the shoreline aquatic and terrestrial habitats typical of these natural ecosystems. Consequently, these anthropogenic changes have degraded shoreline functions and values within Bellevue.

However, Bellevue's shoreline areas still provide multiple ecological functions and values and present opportunities for habitat rehabilitation and preservation. Because of the unique mix of water and biodiversity, shoreline areas are also valued for a broad range of recreational and aesthetic activities, including swimming, fishing, and the enjoyment of natural beauty and solitude.

Table 1-3. Summary of best available science findings and general recommendations for protecting shorelines.

Protection Mechanism	Best Available Science Review	General Recommendations
Acknowledge shoreline areas as critical areas.	To be protected, it first needs to be defined and characterized. The Bellevue Land Use Code does not clearly differentiate and define shorelines or characteristics of riparian, buffer, and structure setback areas, particularly within the context of the ecological functions they provide to the shorelines.	Add the shorelines as protected areas. Characterize habitat conditions and current degree of shoreline development along Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake.
Create buffers which protect an area of sufficient size to provide shoreline riparian and aquatic processes and functions.	Regulatory buffer areas ranging from 50- to 100-foot-wide ("no touch" buffer) may be adequate to provide for the functions of Bellevue's lake shorelines. However, this adequacy is closely linked to its general conditions (i.e., whether it is disturbed or developed versus covered in native herbaceous, shrub and tree vegetation as well as width). For a shoreline buffer area to function properly it must be undisturbed.	Perform lake-specific studies to evaluate the minimum buffer width requirements needed to provide for and maintain shoreline functions and values. Allow a buffer area of variable width (buffer averaging) to offer a feasible approach to help achieve adequate buffer functions. Buffer averaging provides greater flexibility to achieve the desired ecological goals, but a minimum width of 35 feet from the lake edge should be maintained. Require a monitoring plan to report the success of created or enhanced buffer areas.
Implement specific regulations for structure setbacks.	A 25-foot-wide protective area measured from the edge of the shoreline buffer and called a structure setback is most often recommended..	A structure setback to protect the shoreline buffer is needed in order to prevent disturbance of the riparian functions that are integral to the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake. It is recommended that the shoreline buffer be measured from the OHWM and the 25-foot-wide structure setback be measured from the edge of the shoreline buffer. The OHWM should be defined based on an actual topographic elevation rather than a series of biological indicators along the shoreline.
Implement specific regulations for shoreline armoring and vegetation conservation activities.	Bulkhead maintenance or construction may result in the loss of: 1) organic material (e.g., tree litter, large woody debris, and insects) to the lakes littoral zone; 2) shade to lake's fringe habitat; 3) physical aquatic and terrestrial habitat; and 4) sediment contribution. In addition, species responses (typically associated with the habitat responses) are also triggered, including changes in the food web, salmonid fish habitat utilization and migration patterns, and predator-prey interactions.	Consider for removal or replacement (with vegetative and large woody debris structures) bulkheads needing any type of maintenance, repair, and/or retrofitting. If a complete removal is not feasible, relocate the bulkheads landward of the OHWM, and restore the shoreline with emergent and riparian plant species. There are instances where both a bulkhead and fill currently occur below the official OHWM elevation, and where the geomorphic configuration of the shoreline has been straightened, thereby eliminating natural convolution. In those instances, and in order to restore the natural shoreline configuration, it is recommended that the bulkhead replacement be accompanied by a geomorphic reconfiguration of the shoreline.

Table 1-3 (continued). Summary of best available science findings and general recommendations for protecting shorelines.

Protection Mechanism	Best Available Science Review	General Recommendations
Implement specific regulations for shoreline armoring and vegetation conservation activities (continued).		Additional recommendations: ▪ Investigate the effectiveness of alternative shoreline armoring (bioengineering) techniques through the use of prototype bulkheads. ▪ Investigate the effectiveness of supplemental beach nourishment as a restoration measure. ▪ Require a monitoring plan to evaluate the success of areas stabilized through the use of bioengineering techniques. ▪ If possible, impose or request a voluntary no-wake zone along all shorelines in a zone extending from the OHWM to 300 feet offshore to minimize wake erosion effects on the shoreline. ▪ Do not allow the construction of new breakwaters, jetties, and groins.
Implement specific regulations for moorage activities.	Over-water structures (i.e., docks, piers, boathouses, and floats) degrade habitat and habitat functions that support anadromous fish species, particularly salmon. The construction of over-water structures in Lake Washington and Lake Sammamish has increasingly eliminated shallow-water habitat, particularly affecting juvenile chinook salmon. Over-water structures may displace or degrade some normal habitat functions within their footprints. Over-water structures also generate indirect impacts through modifying aquatic habitat features.	New in- or over-water structures should not be allowed on Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake shorelines. This restriction is needed in order to stop the loss of shoreline areas and functions. In any event, compliance with the U.S. Army Corps of Engineers Regional General Permit should be required if in- or over-water structures are allowed, or for existing structures requiring retrofitting or maintenance. Cumulative effect analysis should be required as part of permitting in- or over-water structures. Studies are needed to specifically examine salmon mortality due to predation associated with over-water structures in Lake Washington and Lake Sammamish. Studies are also needed to characterize the existing habitat conditions and the degree of shoreline development in Phantom Lake.

In order to achieve ecological success, any rehabilitation and preservation actions will benefit from implementation at the watershed scale and not just within the Bellevue city limits. Nonetheless, given the current state of habitat degradation, any local protection and rehabilitation effort will contribute to the overall improvement of the natural resource and recreational functions and values that the City's lakes provide.

The existing Bellevue Land Use Code (Chapter 20.50, Definitions) defines Protected Areas as that area designated by Land Use Code 20.25H.070 where use or development is subject to special limitations due to its physical characteristics. Shorelines are currently not included as a Protected Area. The Bellevue Land Use Code also does not differentiate and define the ecological characteristics of the shoreline, buffer, and structure setback areas. These differentiations and definitions would help facilitate public understanding of the specific functions provided by each of these areas and their role in protecting Bellevue's shorelines. This could be accomplished by amending the City of Bellevue critical areas regulations to include definitions of *shoreline riparian area*, *shoreline buffer*, and *protective structure setback*.

Lake-specific literature on buffer width is almost nonexistent, and the few available sources that provide information on buffer functions as a factor of buffer width focus on protecting water quality in lakes. Following are recommendations for buffers along shorelines in Bellevue:

- Based on the literature review, a shoreline buffer ranging from 50 to 100-foot-wide may be adequate to provide for the ecological functions of Bellevue's lake shorelines.
- An additional structure setback to protect the shoreline buffer area is recommended to maintain and protect shoreline functions occurring in the buffer. The additional structure setback to protect the shoreline buffer is needed in order to prevent disturbance of the riparian functions that are integral to the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake.
- A 25 foot-wide protective structure setback measured from the edge of the shoreline buffer is most often recommended.
- The 25-foot setback would only limit structures. Lawns and gardens may be allowed within the 25-foot-wide structure setback as long as maintenance activities do not adversely affect the shoreline buffer or the functions it provides.
- Within the combined protective buffer/structure setback area, to the extent possible, provide habitat connectivity along the entire length of the shoreline. In addition, include tree, shrub, herbaceous, and emergent layers of vegetation in order to obtain a full range of buffer functions.
- Shoreline buffer averaging may be allowed. However, include a minimum width of 35 feet from the OHWM to ensure recruitment of large woody debris.

- If possible, a voluntary or imposed no-wake zone designated along all shorelines within a zone extending from the ordinary high water mark to 300 feet offshore in Lake Washington and Lake Sammamish would substantially improve shoreline habitat protection.

- A speed limit for Phantom Lake (if motor boat use is currently allowed) would improve protection of the lake's habitat.

These recommendations would apply to all the following developmental activities: agricultural uses, clearing and grading, commercial development, residential development, and design and construction of roads, railroads, and other essential public utilities.

Few studies have addressed the environmental effect of bulkheads in freshwater environments, particularly in Lake Washington, Lake Sammamish, and Phantom Lake. The available data indicate that the greatest potential for bulkhead impacts relates to shoreline aquatic and riparian habitat and species, particularly salmonids. Impacts include elimination of shallow water habitat and complex habitat features; reduction in the abundance of overhanging vegetation, other shoreline vegetation, and large woody debris; interruption of the sediment nourishment and transport processes; reduction of fine sediment; and changes in behavior of juvenile chinook salmon. Following are recommendations for managing bulkheads in Bellevue:

- Consider replacing bulkheads needing any type of maintenance, repair, or retrofitting with shoreline protection alternatives that include vegetation and large woody debris. This recommendation is based on a conservative interpretation of the best available science. If a complete removal is not feasible, relocate the bulkheads landward of the ordinary high water mark, and restore the shoreline with emergent and riparian plant species. The latter would represent a less conservative interpretation of what is indicated by the best available science to stop the loss of shoreline area and functions.

- Where bulkheads are removed, consider preventing shoreline erosion through marsh creation (bioengineering vegetation measures). Marsh plants dissipate wave energy and stabilize shoreline sediments. The exposed stems of marsh plants (e.g., emergent vegetation) form flexible masses that dissipate energy.

- Structural bioengineering techniques should be tested as alternative means of shoreline stabilization and as restoration actions. This includes the implementation of bioengineering vegetation measures and alternative engineered shoreline armoring through the use of prototype armoring structures (i.e., "prototype bulkheads"). Concurrent beach nourishment activities could be implemented in those areas where existing bulkheads have caused beach erosion. These restoration actions should focus on evaluating potential solutions for reducing upper beach loss along armored shorelines by increasing the elevation at which bulkheads are built and roughening the structures to dissipate wave and boat wake energy and trap sediment.

- Monitoring should be required to evaluate the success of areas stabilized through the use of bioengineering techniques.

The physical alterations caused by structures that dissipate the energy of waves and boat wakes, (such as breakwaters, jetties, and groins) dramatically alter the structure and functions of habitats at the site where they are constructed. These habitat alterations primarily consist of physical aquatic habitat loss at the placement site and a modification of the substrate characteristics in immediately adjacent areas due to the alteration of the sediment transport process. Following are recommendations for addressing breakwaters, jetties, and groins in Bellevue:

- Avoid construction of any new breakwaters, jetties, and groins.

- Consider removing existing breakwaters, jetties, and groins needing maintenance, repair, or retrofitting, particularly within the littoral area.

- Where such structures are removed, energy dissipation for waves and wakes (if that was the function of the structure) could be achieved through marsh creation.

Moorage-related structures (e.g., docks and piers) alter the habitat structure in the littoral zone, promoting physical, chemical, and biological changes that eliminate or diminish ecological functions and values. Such structures can alter currents, the amount and transport rates of shoreline sediment and woody debris, changes in nighttime ambient light levels (developed areas are often much brighter at night due to lighting), introductions of toxic chemicals, and reductions in the quantity and quality of habitat. Following are recommendations for in- and over-water structures in Bellevue:

- Consider not allowing new in- or over-water structures on the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake in Bellevue. This restriction is needed in order to stem the loss of shoreline area and functions.

- Develop incentives to reduce in- and over-water coverage, number of piles, and shoreline area occupied by piers and docks.

- The net reduction may be achieved by reducing the size of docks, piers, boathouses, and floats for structures that exceed the current code specifications (i.e., those with a nonconforming status).

- Request that in- or over-water structures requiring retrofitting or maintenance comply with the U.S. Army Corps of Engineers Regional

General Permit requirements. The Regional General Permit (USACE undated) provides construction specifications and conservation measures designed to reduce the effects of construction of new or expansion of existing residential over-water structures and/or drive moorage piling to provide water access and boat moorage. A determination of the cumulative effect is a recommended part of the permitting process.

- Finally, encourage that studies be done to examine salmon mortality due to predation associated with over-water structures in Lake Washington and Lake Sammamish. A study is also needed to characterize the existing habitat conditions and degree of shoreline development in Phantom Lake that could serve as a basis for adapting the general recommendations provided in this report to specific needs and conditions of Phantom Lake.

1.7 Wildlife Habitat Conservation Areas

The Growth Management Act defines *fish and wildlife habitat conservation areas* as lands that are designated and managed for maintaining targeted species within their natural geographic distribution so that isolated subpopulations are not created. Such areas are considered to be critical for the long-term viability and proliferation of certain native fish and wildlife species. The Growth Management Act includes guidelines that jurisdictions must consider when designating these areas.

The wildlife habitat types in Bellevue identified in the Bellevue's 2003 *Critical Areas Update, Wildlife Inventory*, include the following general categories:

- West-side riparian wetlands
- West-side lowland conifer/hardwood forest
- Herbaceous wetlands and open water
- Agricultural and urban environs (agriculture, pasture, and mixed environs)
- Urban and mixed environs.

Outside of vegetated habitat patches and linkages, Bellevue's current landscape matrix is urban in character, composed primarily of residential development (both single-family and multifamily) and secondarily of commercial development. Within this matrix, a few large blocks of west-side lowland forest remain; habitat linkages between these blocks, where they exist, predominantly consist of west-side riparian-wetland habitat. Open water and herbaceous wetland habitats in Bellevue are mostly associated with lakes. Agricultural habitats consist of scattered berry farms and pastures.

Because of the high level of disturbance of soil and vegetation in agricultural and urban habitats, habitats in urban areas like Bellevue support more "generalist" species and are more prone to invasion by nonnative, invasive plant and animal species. While Bellevue's urban character offers limited habitat for wildlife species, the city does provide habitat for several "special status" species that are identified in Bellevue's wildlife inventory report. This review focused on the literature pertaining to the protection of wildlife habitat in urban areas.

To protect select wildlife habitat and species, strategies for the conservation of terrestrial systems should be crafted at relevant small, medium, and large scales. For example, the neighborhood, parcel, and landscape context should all be considered in planning efforts because different factors and components can affect these scales differently and wildlife requires conservation at multiple scales. These scales should parallel the needs of wildlife. For example, breeding and nesting requirements of individuals occur at a small scale, and migratory routes occur at a large scale. Furthermore, urbanization must be anticipated, and creative ways must be found to increase native habitat and collectively manage it.

In the literature, there are two approaches for conserving species and their habitat. One approach is to protect species only within clearly identified ecological reserves (i.e., tracts of land, often large) that are relatively homogenous in terms of plant composition and structure regardless of the adjoining land use. The other approach attempts to protect species throughout an entire region by enhancing the quality of existing habitat and by providing for all important wildlife needs. This regional approach is more difficult to implement. Implicit in both approaches is the protection of ecological function, composition, and structure. Such approaches are more difficult to implement in urban environments than in large forested areas and more natural landscapes. Nevertheless, land use regulation through ordinance rules and zoning and comprehensive plan policies that guide property acquisitions and stewardship programs for habitat protection can minimize the detrimental effects on wildlife.

Wildlife habitat types and the locations of many species of concern in Bellevue are documented; however, the information could be made more helpful by prioritizing the protection of specific habitat areas in Bellevue based on their value to wildlife in the city.

- There are currently no regulatory or administrative strategies to protect upland wildlife conservation areas.
- Aquatic and riparian areas are afforded some protection through the critical areas regulations for wetlands, streams and frequently flooded areas.
- The habitats required by the special status species identified in Bellevue's wildlife inventory should be protected when they are identified on a site.
- The state or federal protection requirements for the breeding habitats of special status species should be considered in site planning, including the use of buffers and restrictions on land use activities.
- The City of Bellevue could improve wildlife habitat conservation by identifying remaining vegetated corridors throughout the city that can be further linked with high-quality streams, wetlands, and open space lands.

The goal of the network is to protect larger core wildlife habitats that still remain in the landscape and maximize connected areas of native habitat between them.

- The City of Bellevue could additionally improve the condition and extent of wildlife habitat within the city by developing stewardship programs that focus on education and incentives for landowners who retain areas of native vegetation and provide opportunities for wildlife.

- The City of Bellevue could acquire conservation easements on properties identified as having high-value wildlife habitat in order to protect those areas in perpetuity.

The City of Bellevue's provisions for buffers to protect aquatic habitat, such as streams, water bodies, and wetlands, are an important element of wildlife habitat protection. For many terrestrial species, wetlands provide water for drinking and vegetation for food and cover. Buffers around lakes, streams, and wetlands provide a number of benefits to aquatic and terrestrial wildlife including breeding and cover habitat for invertebrates and wildlife with small home ranges.

1.8 Conclusion

The following chapters of this report provide more complete explanations, supporting data, and references for the information, concepts and recommendations documented in this Executive Summary. The chapters are organized by critical area and include pertinent information from peer-reviewed research, the City of Bellevue's inventory reports, symposia literature, technical literature, and other sources of scientific information relevant to the protection of critical areas. The chapters detail current scientific thinking for critical areas protection including public safety issues for geologically hazardous areas, critical aquifer recharge areas, and frequently flooded areas, as well as resource protection mechanisms for streams, shorelines, wetlands, and wildlife habitat conservation areas.

Chapter 2. Geologically Hazardous Areas

The Washington Growth Management Act (GMA) identifies five geologically hazardous areas that must be designated and protected by local jurisdictions. Counties and Cities are required to include the best available science (as defined by WAC 365-195-900 through 925) in the development of land-use policies that not only protect critical areas that provide important ecological functions and values, but also protect critical areas where human life and property would be threatened by geologic hazards. The five geologically hazardous areas defined by the GMA are seismic, erosion, landslide, volcanic, and coal mine hazard areas. Because some geologically hazardous areas remain as relatively undisturbed greenbelt areas they may also perform valuable ecological functions. Management of geologically hazardous areas can also protect open-space functions to safeguard people and public resources in geologically unstable areas unsuitable for development.

The review of literature completed for the City of Bellevue's Critical Areas (CA) Update summarizes existing scientific information relevant to the delineation and land-use regulation of geologically hazardous areas within the City of Bellevue. Relevant information was obtained from a variety of peer-reviewed sources meeting the criteria for best available science. Information was selected from scientific journals, published books, and government reports. Additional information from peer-reviewed research studies was included if performed by qualified researchers using documented scientific methods.

2.1 Functions and Values

Geologically hazardous areas are distinguished from other critical areas defined by Washington's Growth Management Act. The distinction lies in the functions and values assigned to most geologically hazards areas. In some cases, human disturbance can aggravate natural geologic processes to result in unintended adverse consequences to natural ecosystems, public safety, and property. Unlike some other critical areas, which focus on ecological functions and values, the delineation and protection of geologically hazardous areas considers the value of human life and property. Hence, geologic hazards are identified as critical areas because of the threats they pose to public health and safety.

RCW 36.70A.030(9) defines geologically hazardous areas as those portions of the landscape that are susceptible to erosion, sliding, earthquake, or other geological events and thus not suited to the siting of commercial, residential, or industrial development consistent with public health or safety concerns. Because some geologically hazardous areas were historically recognized as inappropriate for development, they are often the last vestiges of open space within urban regions and therefore provide critical ecological functions and values. For example, historic development on steep hillslopes was limited because of their susceptibility to landsliding. Now these areas form urban greenbelts that provide beneficial functions and values to ecosystems (e.g., wildlife corridors) and the human population (e.g., parks and view sheds). Other functions and values of steep slopes are described in Section 3.1.2 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory.*

2.2 Seismic Hazard Areas

Seismic hazard areas include those areas subject to earthquake damage from ground motion and deformation (including shaking, surface ruptures, and liquefaction) and flood surge and inundation associated with a tsunami or seiche. The risk of earthquake damage can vary depending on the distance from the earthquake epicenter, earthquake type, magnitude (e.g., shallow event associated with localized fault or deep subduction zone event), regional geology, local soil conditions, and the susceptibility of structures to ground shaking. This section reviews the best available science for the delineation and mitigation of seismic hazards in the City of Bellevue.

2.2.1 Delineation

The delineation of seismic hazard areas is necessary to protect public health and safety and minimize the risks to people and property. The City of Bellevue is susceptible to risks from several hazards associated with seismic shaking. The following sections describe the best available science for the delineation of seismic hazard areas relevant to the City of Bellevue.

2.2.1.1 Review of the Literature

Seismic activity in the Puget Sound area is caused by the northeast subduction of the Juan de Fuca Plate beneath the North American Plate along the Cascadia Subduction Zone. Compression associated with plate convergence results in the accumulation of elastic potential energy within the earth's crust. This energy continues to build up until it is suddenly released when a portion of the earth's crust moves. These crustal displacements occur along fault zones. The kinetic energy produced during an earthquake is transmitted through compression waves (primary or "P-waves") and shear wave ("S-waves") that propagate through the earth. The composition of the material through which these waves move directly effects their amplitude and celerity (speed), which in turn effect the magnitude of ground motion. Thus, some areas are much more susceptible to ground motion than others. For example, areas of fine unconsolidated sediment with a high water content are much more hazardous than areas of dense bedrock. Areas where fault zones are expressed at the surface are particularly susceptible to catastrophic ground motion and displacements. Earthquakes can also trigger tsunamis, which can have catastrophic impacts over a broad area both locally and at great distance from the epicenter.

Various methods are used to delineate seismic hazard areas. The tools employed depend on the type of seismic hazard to be identified. Generally the effects of an earthquake diminish with distance from its epicenter, but some of the most dangerous seismic hazards (e.g., ground shaking, liquefaction, and tsunamis) can occur at great distances from where the earthquake originated. Portions of the City of Bellevue are susceptible to all of these seismic hazards.

2.2.1.1.1. Seismic Sources

Geophysicists have identified three major seismic source regions beneath western Washington. They include deep earthquakes, subduction-zone earthquakes, and shallow crustal earthquakes. Seismic sources in Western Washington are summarized in Table 2-1.

Table 2-1. Seismic sources in Western Washington.

Source Area	Largest Magnitude (date and location)	Largest Possible Magnitude
Deep intraplate	7.1 (1949, Olympia)	7.5
Subduction zone	9.0 (1700, Coast of WA, OR, CA, and BC	>9.0
Shallow	7.4 (ca. A.D.900, Seattle)	7.5-8.0

Adapted from USGS 2002.

Deep "intraplate" earthquakes occur within the subducting Juan de Fuca Plate as it bends beneath North America. The depth of intraplate earthquakes generally increases to the east with the depth of the subducting plate. For each seismic source region, the largest earthquakes recur at poorly known, probably irregular, intervals. On average, the recurrence interval for large intraplate earthquakes is on the order of decades (NOAA 2003). The largest deep intraplate events recorded during historical times include the 1949 Olympia (magnitude 7.1), 1965 Seattle/Tacoma (magnitude 6.5), and 2001 Nisqually (magnitude 6.8) earthquakes (Noson et al. 1988; Dewey 2002).

Subduction zone earthquakes occur along the locked interface between the Juan de Fuca and North American Plates. The rupture style of subduction zone earthquakes often involves a large segment of the subducting plate and generates large-magnitude earthquakes. The most recent subduction zone earthquake in the area had an estimated magnitude of 9.0 and occurred in January 1700 (Atwater 1987; Atwater et al. 1999). Land subsidence that flooded and killed a 300-year-old forest, as well as written accounts of tsunami damage in Japan provided key evidence for the source, timing, and magnitude of this large seismic event (Satake and Atwater 2003). Other notable subduction zone earthquakes include the 1960 Chile earthquake (magnitude 9.5), 1964 Alaska earthquake (magnitude 9.2), and the 2004 Northern Sumatra earthquake (magnitude 9.0) and devastating tsunami.

Geologic evidence suggests at least seven great earthquakes ruptured the southern Washington segment of the Cascadia subduction zone in the past 3,500 years (Atwater and Hemphill-Haley 1997). The inferred history contains six recurrence intervals that average about 500 years. Two of these intervals are centuries longer than any of the others. The longest interval, approximately 800-1,100 years, was followed by one of the shortest, about 250-420 years. The other long interval, 550-900 years, ended 304 years ago with the January 1700 earthquake.

The third seismic source in western Washington generates shallow crustal earthquakes within the North American Plate. These crustal events are related to north-south compression and shortening of the North American Plate (Sherrod et al. 2004). Though relatively smaller in magnitude, these shallow earthquakes can be quite damaging if they occur near populated areas. The Seattle Fault zone and several other local fault zones in Puget Sound represent significant shallow seismic sources in the region. The surface expression of the Seattle Fault is difficult to detect due to the relatively slow slip rate and recent glacial resurfacing of Puget Sound. However, geophysical mapping and trenching studies have delineated several strands of the Seattle Fault (Blakely et al. 2002, Sherrod et al. 2004). The Seattle Fault zone extends from west of Bainbridge Island to the Sammamish Plateau east of Lake Sammamish. The extent of the Seattle fault zone is described in Section 3.3 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*. Notable shallow crustal earthquakes in western Washington include the 1872 Chelan earthquake (estimated 6.5 to 7.0 magnitude) and the ca. A.D. 900 Seattle Fault earthquake (estimated 7.4 magnitude) (Noson 1988, Ludwin and Qamar 1995, Johnson et al. 1999). Based on trenching studies of the Seattle Fault, the best-known recurrence interval for large crustal earthquakes is on the order of millennia (NOAA 2003). Notable Pacific Northwest earthquakes are summarized in Table 2-2.

Table 2-2. Notable earthquakes in Western Washington.

Year	Magnitude [a]	Epicenter	Source Region	References
ca. A.D 900	7.4	Seattle Fault	shallow	Johnson et al. 1999
1700	9	Offshore	subduction zone	Atwater et al. 1999
1872	6.5 – 7.0	Lake Chelan	shallow	Bakun et al. 2002
1949	7.1	Olympia	deep	Baker and Langston 1987
1965	6.7	Seattle-Tacoma	deep	Langston and Blum 1977
2001	6.8	Nisqually	deep	Dewey 2002

[a] moment magnitude.

2.2.1.1.2. Ground Shaking

The severity of ground shaking depends on several factors. Earthquake magnitude and distance affect the amplitude and duration of ground shaking. The structural arrangement of geologic materials beneath a site can also influence the seismic response. Weak sediments can slow seismic waves, concentrate energy, and increase the intensity of ground shaking. It is for this reason that buildings constructed on sedimentary basins are at greater risk of damage from ground shaking (Noson et al. 1988).

Due to Bellevue's close proximity to the Seattle Fault zone and large areas of relatively unconsolidated alluvial and glacial deposits, ground shaking likely represents the most significant seismic hazard. However, large-magnitude earthquakes originating from distal sources, such as the Cascadia subduction zone, can also generate low frequency ground shaking that may last for several minutes. Horizontal motions caused by ground shaking may also trigger landslides (co-seismic landsliding). For instance, Jacoby et al. (1992) correlated landslide deposits in Lake Washington with the ca. A.D. 900 earthquake on the Seattle Fault.

Ground shaking intensity is delineated by the U.S. Geological Survey on shake intensity maps. The 2003 International Building Code (IBC) specifies the use of these maps in the calculation of earthquake loads. The intensity maps express the maximum horizontal ground acceleration as a fraction of gravity based on a 2 percent probability of exceedance in 50 years, which is equivalent to the magnitude of ground shaking with a return period of approximately 2,500 years. Within the Seattle Basin, this corresponds to a design horizontal acceleration of about 0.5-1.2g, depending on the frequency of earthquake ground motion (ICC 2003). The recent adoption of the 2003 IBC by the state of Washington in July 2004 increases the level of ground shaking that new construction is required to meet. The prior building code mandated by Washington, the 1997 Uniform Building Code (UBC), specified a 475-year return period, which corresponds to a horizontal acceleration of about 0.2-0.6g in Bellevue.

2.2.1.1.3. Surface Rupture

The potential for surface rupture during an earthquake on the Seattle Fault is described in Section 3.3 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*. Geologic maps depicting the extent of the Seattle Fault Zone (e.g., Blakely et al. 2002, Sherrod et al. 2004) and results of ongoing research have been used to delineate areas prone to surface rupture.

2.2.1.1.4. Liquefaction

Liquefaction occurs when unconsolidated granular sediments experience a sudden loss of shear strength during strong ground shaking. The loss of strength is caused by the development of excess hydrostatic pore pressure during rapid consolidation. Liquefaction typically occurs in relatively young sediments located in areas of shallow ground water. Areas in Bellevue with a high susceptibility to liquefaction are shown in Figure G-2 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*. Liquefaction hazard areas are described in detail in Section 3.6 of the inventory.

2.2.1.1.5. Tsunami and Seiche Inundation

A tsunami is a series of waves generated in a body of water by an impulsive disturbance that vertically displaces the water column from its equilibrium condition. Earthquakes, landslides (subaerial and submarine), volcanic eruptions, and explosions can generate tsunamis. In the case of earthquake-generated tsunamis, the water column is disturbed by the uplift or subsidence of the sea floor. Waves are produced as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium. Although subduction zone earthquakes tend to be the most effective at generating tsunamis, the rupture of any fault passing beneath a water body has the potential to generate a tsunami (Noson 1988).

Tsunamis affecting the City of Bellevue could be generated by movement on local crustal faults and by submarine landslides into Lake Washington and Lake Sammamish. Atwater and Moore (1992) found evidence of a tsunami in Puget Sound generated by the c.a. 900 A.D. rupture of the Seattle Fault. Model simulations suggest a potential wave height of up to 5 m is possible from a tsunami in Puget Sound (NOAA 2003; Walsh et al. 2003). Rupture of the Seattle Fault beneath lakes Washington or Sammamish could produce tsunamis of similar size that might affect the

City of Bellevue's shorelines. Landslides triggered by ground shaking (co-seismic landsliding) could result in a significant tsunami affecting the shorelines of Bellevue. Numerous submarine landslides have been mapped within Lake Washington and Lake Sammamish and are thought to have originated both on submarine delta fronts and from adjacent uplands (NOAA 2003). Landsliding is the primary geomorphic process responsible for maintaining the steep bluffs surrounding Lake Washington and Lake Sammamish. Landscape modifications coupled with the possibility of high intensity precipitation place these bluffs at risk of failure in the future.

A seiche is the oscillation of a closed body of water caused by earthquake shaking that corresponds to the natural resonance of the water body (Noson et al. 1988). Seiches are often generated in swimming pools by earthquake oscillations with a period (the time between earthquake wave crests) about twice the length of the swimming pool. Seiches generated by the 1949 Queen Charlotte Islands earthquake were reported on Lake Union and Lake Washington in Seattle and on Commencement Bay in Tacoma. The 2002 Denali earthquake (magnitude 7.9) caused minor damage to at least 20 houseboats by initiating water waves in Lake Union (Barberopoulou et al. 2003).

Based on the size of Lake Washington and Lake Sammamish, as well as the relatively large period ground motion required for seiche generation, only distal earthquakes are expected to generate a significant seiche. Wave heights from a seiche are expected to be considerably less than those estimated for a tsunami triggered by rupture of the nearby Seattle Fault. Additional information regarding tsunami and seiche hazards are described in Section 3.5 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory.*

2.2.1.2 Data Gaps

Seismic information on the Seattle Fault is limited due to the combination of slow slip rates and short historical record of earthquakes in Puget Sound. Topographic resurfacing of Puget Sound by past glaciations has obscured evidence of prehistoric ground ruptures. Consequently, the recurrence interval for rupture of shallow crustal faults in Puget Sound is poorly defined by geologic evidence from only a few displacement events. No maps of surface rupture hazard have been prepared for Bellevue. Several studies are currently underway to further delineate the extent of the Seattle Fault zone and identify individual fault strands.

Although models of tsunami inundation have been developed for Puget Sound (e.g., Walsh et al. 2003), information is lacking on the potential hazards associated with a tsunami in Lake Washington and Lake Sammamish. To date, no inundation maps of these shorelines have been prepared. Delineation of tsunami hazard areas along the shorelines of Bellevue should consider potential wave heights, lake bathymetry, and the topography of low-lying areas subject to inundation. Model results and the analysis of prehistoric tsunami deposits in Puget Sound suggest wave heights from a Seattle Fault-generated tsunami could be as much as 5 m and inundate low-lying areas for hundreds of meters inland (NOAA 2003; Walsh et al. 2003). In the absence of event-specific modeling, landsliding into Lake Washington or Lake Sammamish could be expected to produce similar wave heights. Inundation from a seiche is expected to be considerably less based on the distance to seismic source required to generate low-frequency oscillations.

2.2.1.3 Recommendations

- Several studies are underway or planned to delineate the extent of the Seattle Fault zone in Bellevue. These studies are being conducted by the USGS and geologists from the University of Washington and Boise State University with funding provided by both the USGS and the National Science Foundation. This work is coordinated under the National Earthquake Hazard Reduction Program. Consider encouraging additional fault studies to identify areas susceptible to surface rupture. The City can assist such efforts by compiling a database of geotechnical reports prepared for properties located within the Seattle fault zone.
- Delineate tsunami inundation areas along the shorelines of Lake Washington and Lake Sammamish. Modeling of inundation should account for tsunamis generated from both the rupture of the Seattle fault and landsliding in Lake Washington and Sammamish.

2.2.2 Setbacks and Mitigation

Structure setbacks from seismic hazard areas and mitigation measures can reduce risks posed to public health and safety and property by earthquakes. The following sections describe the best available science for the mitigation of risks from seismic hazards within the City of Bellevue.

2.2.2.1 Review of the Literature

Surface rupture occurs when the displacement on a fault intersects the ground surface. Displacements can be horizontal or vertical but typically involve a combination of both components (i.e., oblique). The area of surface rupture can vary depending on the style and depth of faulting. Some fault ruptures never intersect the ground surface and are referred to as "blind faults." The Northridge earthquake of 1994 occurred on a blind fault. Trenches excavated across the Seattle Fault zone on Bainbridge island found evidence for 5-7 m of co-seismic uplift during the last major earthquake approximately 1,100 years ago (ca. A.D. 900) (Bucknam et al. 1992). This event was responsible for raising the elevation of Restoration Point on Bainbridge Island by approximately 7 m. Although surface displacements of this magnitude certainly present a hazard to urban areas of Puget Sound, often the greatest uncertainty in establishing mitigating offsets is delineating the zone of potential surface rupture. The accurate delineation of active faults can provide the basis for the prescription of structure setbacks and other mitigation to reduce the risks of injury and property damage. However, most of the area within Bellevue potentially affected by seismic hazards has already been developed.

Risks from ground shaking are typically mitigated through engineering, design, or modified construction. Some risks to health and safety that cannot be eliminated through mitigation may be deemed acceptable. Schools, hospitals, and essential facilities are commonly held to a higher standard than residential structures. Schools may be designed to protect occupants while sustaining damage that is fatal to the structure, whereas hospitals and other essential facilities (i.e., power plants, fire stations) would be required to remain intact and function following an earthquake in order to provide emergency services.

Tsunami hazards along the coast of Washington are mitigated through evacuation of coastal areas using a tsunami detection and warning system. However, such a system would not provide adequate warning for the evacuation of Bellevue's shorelines due to the close proximity of Bellevue to tsunamigenic sources (i.e., the Seattle Fault and unstable bluffs). Maps delineating areas susceptible to tsunami inundation could promote awareness of the hazard and identify risks to critical facilities. Restricting new development within tsunami hazard areas could mitigate risks posed by tsunami inundation.

2.2.2.2 Data Gaps

Although several traces of the Seattle Fault have been delineated through Bellevue, it is unknown if other traces exist (either at the surface or buried) within the Seattle Fault zone. Data are limited on subsurface geologic conditions that influence the pattern and style of surface rupture. Furthermore, empirical data on the ground response in Bellevue is limited because there have been few historical earthquakes, and the City is only instrumented with one seismograph station. The mitigating of ground-rupture and tsunami hazards through structure setbacks on new construction or relocation of existing structures depends on the precision by which active faults can be delineated and the recurrence interval by which the level of risk is typically assessed.

Tsunami inundation areas have not been delineated along the shorelines of Lake Washington and Lake Sammamish. Hence, tsunami hazards along Bellevue's shorelines are currently unmitigated. This may be due to the lack of public awareness regarding the risk of shoreline inundation by an inland tsunami.

2.2.2.3 Recommendations

- Require structure setbacks for new construction within areas of the Seattle Fault zone delineated as susceptible to surface rupture. These maps should be prepared using existing studies and updated as new information becomes available.

- Inform the public of tsunami hazards along the shorelines of Lake Washington and Lake Sammamish using maps delineating areas susceptible to tsunami inundation. Results of tsunami modeling should be used to make further recommendations on new development within areas of potential tsunami inundation. Locate critical facilities outside areas subject to the effects of tsunami inundation.

- Coordinate with the Pacific Northwest Seismograph Network and U.S. Geological Survey to instrument Bellevue with additional seismograph stations.

2.3 Erosion Hazard Areas

Erosion hazard areas include source areas subject to rapid soil loss and down-slope areas impacted by soil deposition. Erosion hazard areas may overlap with other geologically hazardous areas such as landslide hazard areas and areas subject to rapid erosion or failure caused by channel migration (hazards associated with channel migration are addressed in the Frequently Flooded Areas chapter). Gully and rill development caused by excessive erosion can strip land of soil nutrients and trigger additional soil loss and slope instability. Deposition of fine sediment in streams and lakes can be detrimental to salmonids and other aquatic organisms. Excessive sedimentation can also modify the morphology of riparian areas by filling channels and diverting flow to a new side channel (i.e., channel avulsion). In addition to environmental impacts, property owners can incur economic losses from the effects of severe erosion. Channel incision and lateral migration can rapidly erode stream banks and result in the loss of property along Bellevue's streams. This section reviews the best available science for the delineation and mitigation of erosion hazards in the City of Bellevue.

2.3.1 Delineation

The delineation of erosion hazard areas is necessary to protect critical habitats from the effects of erosion and to understand potential risks to public and private property. Areas within the City of Bellevue are susceptible to hazards caused by erosion. The following sections describe the best available science for the delineation of erosion hazard areas in the City of Bellevue.

2.3.1.1 Review of the Literature

Soil loss occurs when erosion exceeds the soil production rate. Because soil typically forms very slowly, only small amounts of erosion can be tolerated without depleting the thickness of the productive soil layer. Higher erosion rates may be tolerable over a short duration if the total soil layer is not depleted. Soil deposition occurs when the supply of sediment from upland sources exceeds the ability of runoff to transport eroded sediment. An understanding of contemporary or forecasted erosion rates, their duration, acceptable thresholds for soil loss, and controls on soil deposition is necessary to delineate erosion hazard areas.

Erosion rates can be estimated using the universal soil loss equation (USLE). The USLE is an empirical model developed by the U.S. Department of Agriculture to predict soil loss from agricultural lands (Renard 1997). Widespread use of the USLE has proven to be a successful land management tool. The USLE predicts soil loss from sheet and rill erosion as a product of five factors:

$$A = RKLSCP$$

- A = the computed soil loss per unit area expressed in the units selected for K and R. Units are typically chosen to express A in terms of tons/acre/year.

- R = the rainfall and runoff factor. This factor reflects the impact of raindrops and the relative amount and rate of runoff by accounting for precipitation intensity and duration.

- K = the soil erodibility factor, which varies with soil characteristics (i.e., clay, silt, sand, and organic content). Soils high in silt content typically have a higher K value and, hence, are more erosive. Local soils in Bellevue contain various mixtures of silt, sand, and gravel. The composition of local soils reflect the heterogeneity of the region's glacial sediments from which they are derived. Soil characteristics are described in more detail in Section 3.2 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory.*

- LS = the length-slope factor, which accounts for the unobstructed slope length and gradient.

- C = the cover and management factor, which is the ratio of soil loss from a managed area relative to an otherwise identical area in tilled fallow.

- P = the support practice factor, adjusts for various surface treatments such as contouring, terracing, or track walking with a bulldozer. The P factor is practical for agricultural or construction sites lacking significant vegetative cover.

An erosion model such as the USLE could be used to rate erosion susceptibility and prepare a map of the City expressing erosion potential in terms several relative hazard classes. This map could augment the existing erosion hazard rating that is based solely on soil type and hillslope gradient. (See Figure G-2 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory* for the existing erosion hazard map).

Sediment eroded from uplands can be stored on hillslopes or in hollows, alluvial fans, and sand or gravel bars. Hence, despite high erosion rates, only a small fraction of sediment eroded from uplands may actually be delivered to a river or stream and leave the basin. The USLE can be modified by including a sediment delivery ratio that predicts sediment deposition and delivery to water bodies or sediment sinks (Renard 1997). Sediment delivery ratios depend on the sediment storage capacity of the basin and transport capacity of the receiving channel. Many of the City's streams are confined and coupled to adjacent slopes. Erosion from these slopes is expected to have a relatively high delivery ratio as opposed to streams with broad floodplains, which buffer streams from sediment delivery. Delivery ratios are expected to be highest at sites of sediment storage such as at the toe of a steep slope undergoing active erosion. Understanding processes that influence sediment transport and storage can help delineate areas susceptible to sediment deposition. Combining maps of erosion susceptibility with areas prone to sediment deposition can assist in the delineation of erosion hazard areas.

2.3.1.2 Data Gaps

Soil survey and low-resolution topographic maps may not provide the detail necessary to assess site-specific erosion hazards. The recent acquisition of high-resolution topographic maps generated using light distance and ranging (LIDAR) mapping techniques provides opportunities to update existing erosion hazard maps and evaluate the potential for soil erosion in Bellevue. In addition, the concentration of runoff from small-scale topographic convergence can form incipient rills and gullies. Localized erosion from these areas can be substantial but difficult to detect even with the aid of high-resolution LIDAR topography, particularly in areas obscured by dense forest canopy. Ground surveys may be necessary to delineate localized erosion hazards. Additional data gaps such as records of known erosion hazards and need for detailed field reconnaissance are addressed in Section 4.0 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*.

2.3.1.3 Recommendations

- New LIDAR topography could be used to delineate steep slopes and significantly improve the accuracy of existing erosion hazard maps.
- New LIDAR topography and existing soil surveys could be coupled with an erosion model such as the USLE to delineate erosion hazard areas and rate erosion susceptibility. Results could be compiled in a GIS to produce a new erosion hazard map of the City that depicts erosion potential in terms of several relative hazard classes.
- Erosion hazard classes shown on the revised maps could be used to trigger site-specific investigations of erosion hazards as a condition of permit review. Soil investigation reports could be compiled in a database and used by the City to update erosion hazard areas.

2.3.2 Mitigation

Mitigation of erosion and the effects of sediment deposition can reduce risks posed to property and critical habitats. The following sections describe the best available science for the mitigation of risks from erosion hazards within the City of Bellevue.

2.3.2.1 Review of the Literature

A variety of best management practices (BMPs) are used to mitigate erosion from disturbed areas. A detailed discussion of BMPs is included in Section 3.2 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*.

2.3.2.2 Identification of Data Gaps

Although the phenomena of soil erosion has and continues to be a global problem for civilized cultures, the factors leading to soil erosion and solutions to the problem have been studied at great length, and they are generally well understood. Hence, no significant gaps have been identified in available literature for the mitigation of erosion hazards as they relate to the City of Bellevue.

2.4 Landslide Hazard Areas

Landslide hazard areas in Bellevue include steep slopes subject to mass movement under the force of gravity and influence of water. Landslides pose a significant hazard to people, property, and infrastructure. In addition, environmentally sensitive habitats can be impacted by an increase in landslide frequency caused by land use changes. This section reviews the best available science for the delineation and mitigation of landslide hazard areas in the City of Bellevue.

2.4.1 Delineation

The delineation of landslide hazard areas is necessary to protect public safety, property, and critical habitats from the effects of landsliding. Several areas within the City of Bellevue are susceptible to landsliding. The following sections describe the best available science for the delineation of landslide hazard areas in the City of Bellevue.

2.4.1.1 Review of the Literature

Landsliding in the greater Seattle-Bellevue area is primarily confined to steep bluffs surrounding Puget Sound and Lakes Washington and Sammamish. Landslide frequency in these areas is strongly correlated with periods of seasonally high precipitation. Numerous studies have identified excess ground water as the limiting factor influencing the stability of local bluffs (Tubbs 1975, Thorson 1989, Gerstel 1996). The stratigraphy of glacial sediments and occurrence of shallow bedrock are the primary controls on ground water flow within Bellevue (see Section 3.0 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory* for a complete discussion of the regional geology). Tubbs (1975) demonstrated that there is a strong association between local contrasts in lithology (primarily hydraulic conductivity) and historical landsliding in the Seattle area. He posited that contrasts in hydraulic conductivity between the Esperance sand and Lawton clay allowed pore-water pressure to build up within the sand and weaken the steep slopes. Due to the nature of the region's glacial stratigraphy, lithologic contrasts are commonly restricted to steep bluffs where the horizontal stratigraphy is exposed. The weak correspondence between historic landslide frequency and lithology indicates that material properties alone are of secondary importance.

Landslides have also been generated by seismic ground motion. NOAA (2003) provides geologic evidence for co-seismic landsliding of the bluffs surrounding Puget Sound, Lake Washington, and Lake Sammamish. These prehistoric events are thought to have generated inland tsunamis. The magnitude-7.1 Olympia earthquake of April 13, 1949 generated a landslide at the Tacoma Narrows that also produced a tsunami. More recently, the 2001, magnitude-6.8 Nisqually earthquake caused a landslide that temporarily dammed the Cedar River near Renton, Washington. The coincidence of seismic ground shaking immediately following a period of intense precipitation could present a rare but disastrous scenario for landsliding within the city of Bellevue.

Slope modifications can also impact the stability of steep slopes. Cut and fill activities cause slope instability by increasing driving forces at the head of a slope and decreasing resisting forces at the toe. Conversion of vegetation can alter antecedent soil and ground water conditions and increase or reduce the threshold precipitation necessary to induce pore pressure-driven instability.

The delineation of landslide hazard areas should also include an evaluation of landslide run-out at the base of slopes. Landslide run-out is the distance traversed by landslide material before coming to rest. The cessation of motion occurs as a result of the re-equilibration of driving and resisting forces. This distance varies depending on the style of failure, degree of saturation, and slope morphology. For instance, rotational and translational failures may be limited to a few meters of displacement, whereas topple failures can break up and travel to the base of a slope before coming to rest. Run-out of granular flows of these types are often limited to one or two times the slope height (Iverson 1997). Landslides originating high on a slope or within a confined ravine may become saturated and turn into a debris flow. Debris flows behave as a fluid and may travel for several kilometers before coming to rest (Iverson 1997; Iverson et al. 1997). Classifying landslides on the basis of different characteristics can aid in the delineation of run-out potential by developing valid generalizations about the occurrence of different classes of landslides. One of the most commonly used landslide classifications is Varnes (1978), which is based on the type of movement and nature of the material.

Landslide hazard areas in Bellevue are currently identified on the basis of geologic materials and hillslope gradient derived from previous topographic maps (Figure G-2 in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*). As currently delineated, slopes must exceed 40 percent to be included in a landslide hazard area. The resolution of previous topographic maps used to identify steep slopes may not be sufficient to adequately depict the local hillslope gradient. Existing landslide hazard maps could be revised using more recent, high-resolution topographic maps of Bellevue. In addition to geologic conditions and slope, landslide hazard maps prepared by the City of Seattle incorporate historical landslides, ground water elevation, and the extent of mass-wasting deposits. Including an inventory of historical landslides can provide an empirical check on landslide potential on slopes gentler than 40 percent. Maps similar to Seattle that show mass-wasting and delta deposits could be prepared for Bellevue to evaluate the extent of landslide run-out.

2.4.1.2 Data Gaps

Gaps in available data regarding the delineation of landslide hazards within Bellevue include the need for an inventory of historical landslides and detailed field date to more accurately assess landslide hazards. Additional data gaps are described in more detail in Section 4.0 of the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory.*

2.4.1.3 Recommendations

- Existing landslide hazard maps should be updated with historical landslides identified in geotechnical investigations, new LIDAR topography, and geologic maps, as they become available. Landslide hazard maps could rate landslide potential in terms of several relative hazard classes, such as recommended for erosion hazard mapping. Landslide hazards could be further classified as a source region and area of potential landslide run-out.

- Areas of landslide run-out should be delineated based on potential failure mechanisms (i.e., translational, rotational, topple, or debris flow), geologic conditions (i.e., slope height, material strength, stratigraphy, ground water), and the mapping of alluvial-fan, landslide, and debris-flow deposits.

2.4.2 Setbacks and Mitigation

Structure setbacks from landslide hazard areas are necessary to reduce risks posed to property and public safety. Setbacks provide a margin of safety against the uncertainty of landslide hazard prediction by restricting development within a specified distance from unstable slopes. Setbacks also limit land alteration that can contribute to slope instability through topographic modification, removal of vegetation, and irrigation. Setbacks can be reduced through mitigation measures that either increase the stability or protect property from the effects of slope failure. The following sections describe the best available science for the mitigation of risks from landslide hazards within the City of Bellevue.

2.4.2.1 Review of the Literature

Establishing criteria for structure setbacks from landslide hazard areas requires an understanding of potential failure and run-out mechanisms, confidence in landslide hazard delineation, the effects of development on slope stability, and the level of risk that is deemed acceptable. For example, greater structure setbacks may be warranted at the top and sides of an area prone to a deep-seated, rotational landslide than for slopes characterized by shallow failures. Likewise, greater structure setbacks or prohibition on building may be required at the toe of slopes prone to energetic debris flows than for slopes that fail primarily by slumping. Site-specific investigations can delineate landslide hazards with greater precision than more generalized, regional assessments of landslide hazards and thereby recommend appropriate structure setbacks.

2.4.2.2 Data Gaps

Landslide hazards continue to threaten property and public safety because landslide hazards are either misidentified or inadequately addressed during development. Once delineated, hazards can be addressed using a wide range of mitigation measures that are well understood and supported by numerous case studies and scientific analyses. Although gaps may exist in the delineation of landslide hazard areas, no significant gaps have been identified in available literature for the mitigation of properly delineated landslide hazard areas.

2.4.2.3 Recommendations

Structure setbacks should be required at the toe of steep slopes. For slopes 15-40 percent, the minimum toe-of-slope structure setback should be equivalent to the slope height or the existing ordinance (75 feet), whichever is greater. For delineated slopes >40 percent, a minimum structure setback of 1 to 2 times the slope height should be considered. For slopes >40 percent and higher than 200 feet, a site-specific investigation should be performed by a licensed engineering geologist to evaluate debris-flow hazards. The toe-of-slope structure setback requirement could be waived for site-specific geotechnical investigations or engineered construction such as pile-supported, elevated structures.

2.5 Volcanic Hazard Areas

The City of Bellevue is located west of the Cascade Range and within 160 km (99 mi) of five active volcanoes. They include Mt. Adams, Mt. St. Helens, Mt. Rainier, Glacier Peak, and Mt. Baker. Although volcanoes present numerous hazards (e.g., ash fall, pyroclastic flows, volcanic mudflows, lateral blast, lava flows, and toxic gasses), distal hazards affecting the City of Bellevue from the eruption of any one of the Cascade volcanoes are limited to the effects from ash fall. Ash fall originates from fragments of volcanic rock blasted into the atmosphere or carried upward in convection cells by hot gases. Fragments smaller than 2 mm are considered ash and can be carried thousands of kilometers downwind from a volcano. Volcanic ash from the 1980 eruption of Mt. St. Helens deposited 15 cm (6 in) of ash approximately 1,000 km (1,600 mi) from the volcano (Sarna-Wojcicki 1981).

2.5.1 Review of the Literature

Ash usually covers a much larger area and can disrupt the lives of more people than the other more proximal types of volcano hazards (Hoblitt 1998). The extent of ash fall downwind from an erupting volcano is largely dependent on the altitude of ash injection, the size of ash particles, and atmospheric conditions (i.e., wind direction and velocity, precipitation). Bellevue is positioned favorably with respect to the Cascade volcanoes and prevailing wind direction.

The main hazard from ash fall is the disruption of infrastructure, services, and economic activity. Airborne ash impacts aviation because it can obscure sunlight and foul jet engines. Ash typically contains fine-grained fragments of volcanic glass that are highly abrasive. Fine-grained ash can enter small openings and damage the moving parts of machinery. Power and waste-water systems can clog and fail (Hoblitt 1998). Ash also poses a health hazard to animals and people with compromised respiratory systems. The effects of ash fall can last for days to months and depend on the style of eruption and climatic conditions.

2.5.2 Identification of Data Gaps

Mitigating risks from ash fall within Bellevue may not be economically feasible given the uncertainty of future eruptions, the difficulty of forecasting ash fall trajectories, and costs associated with the retrofit of machinery and infrastructure potentially impacted by volcanic ash. The mitigation of risks to transportation infrastructure, emergency response facilities, and public utilities could be assessed using a cost-benefit analysis that incorporates a level of acceptable risk and probability of an ash fall event. Geologic data on ash-fall coverage from prior eruptions are available to perform this analysis.

2.5.3 Recommendations

Consider performing a risk-benefit analysis to evaluate the need to protect critical facilities from the impacts of an ash-fall event. The analysis should consider ways to mitigate potential economic impacts to Bellevue caused by the disruption of regional commerce, emergency response facilities, and public utilities.

2.6 Coal Mine Hazard Areas

Coal seams hosted by the Renton formation are found in the extreme southern portion of Bellevue and neighboring City of Newcastle. Coal mining in Bellevue occurred between the 1860s and 1960s. In general, hazards associated with the collapse of coal mines are rare but do occur. Land subsidence can cause minor or serious damage to structures located above collapsed coal mines.

2.6.1 Delineation

Hazards associated with abandoned coal mines are directly related to mine collapse and land subsidence. The delineation of coal mine hazard areas is necessary to protect public safety, property, and the natural environment from potential impacts of land subsidence. The geology of coal-bearing rocks and description of coal mines in Bellevue are addressed in Sections 3.0 and 3.4, respectively, in the *March 2003 Bellevue Critical Areas Update Geologically Hazardous Areas Inventory*. The following sections describe additional information based on the best available science for the delineation of coal mine hazard areas within the City of Bellevue.

2.6.1.1 Review of the Literature

An assessment of the extent of underground workings and the area potentially influenced by the collapse of mine openings form the basis for the delineation of coal mine hazard areas. The potential for coal mine collapse and land subsidence is influenced by many factors. Primary factors include the height of the mine void, depth and strength of the rock roof, and the type and amount of roof support within the mine (Dunrud 1976; Crowell 1995). In general, the vertical component of subsidence does not exceed the height of the mine void. The potential for subsidence decreases with the strength and thickness of the roof rock due to bridging, which can prevent land-surface subsidence, despite collapse of the mine roof at great depth. The potential for land subsidence increases in weak or fractured rock and where abandoned mines are open to the surface. Rock strength also controls the surface area affected by mine collapse and subsidence. The minimum area of subsidence is determined by the area of roof collapse plus an additional area determined by the friction angle of the rock (an inherent property related to compressive rock strength). A greater area of subsidence will occur above weak rock with a low friction angle. The deterioration of coal or rock pillars and wooden timbers used for roof support in older mines can increase the likelihood of mine collapse, particularly for older mines.

Coal mine hazard maps were developed by Bellevue in 1992 for the City's Coal Mine Area Subdivision, Development, and Building Permit Regulations. Areas within the city limits and within Bellevue's sphere of influence that could be affected by abandoned coal mines are delineated on coal mine area maps (Exhibit A and B, Coal Mine Area Subdivision, Development, and Building Permit Regulations). The maps delineate two Coal Mine Subsidence (CMS) zones based on the potential surface tilts and strains and the potential for sinkhole development. CMS Zone 1 identifies areas of potential trough subsidence. CMS Zone 2 identifies areas of potential sinkhole development above shallow mine workings within 200 feet of the ground surface.

2.6.1.2 Data Gaps

General areas of abandoned coal mines in King County have been delineated on maps prepared by the Washington State Department of Natural Resources (Walsh 1983; Schasse 1994). These maps rely on annual reports submitted by mining companies since about 1900. However, many mines were abandoned prior to 1900 and may not be documented in filed reports. In addition, small and unregistered mines are not documented in the public record. In general, hazard maps prepared by the state delineate broad areas suspected of posing coal-mine hazards and do not show individual mines. Existing hazard maps may provide a margin of safety against the risks posed by abandoned coal mines.

2.6.1.3 Recommendations

The City of Bellevue should consider updating existing coal mine area maps as new information becomes available. Relative information would include previously undocumented mine openings identified in geotechnical investigations conducted in or near CMS Zones or investigations performed as a requirement of construction in CMS Zone 1.

2.6.2 Development Standards

Standards for development within coal mine hazard areas are necessary to reduce risks posed to property and the public. Development standards can provide a margin of safety against the uncertainty of land subsidence by restricting development within areas underlain by abandoned coal mines. The following sections describe the best available science for development standards within the coal mine hazard areas delineated within the City of Bellevue.

2.6.2.1 Review of the Literature

Structure setbacks can be applied to coal mine hazard areas much like they are for other geologic hazards and critical habitats. Restricting development within coal mine hazard areas can provide a conservative level of protection from subsidence. Development within coal mine hazard areas requires standards that consider conditions controlling mine collapse and subsidence. Structures can be designed or retrofitted to sustain damage from subsidence while protecting occupants. Once the area of abandoned mines has been delineated, a detailed geotechnical investigation of subsurface geologic conditions can be used to determine the level of risk and recommend appropriate mitigation measures. The uncertainty of the potential for coal-mine collapse and land subsidence complicates the assessment of measures to mitigate coal-mine hazards. The lack of available data requires conservative structure setback and mitigation strategies that provide a greater level of protection.

Coal mine hazards in Bellevue are managed under the City's Coal Mine Area Subdivision, Development, and Building Permit Regulations. In CMS Zone 1, the risk of property damage from subsidence is mitigated through specialized engineering and construction. Construction is permitted only after a site-specific evaluation of potential subsidence and incorporation of appropriate mitigation measures to reduce calculated surface strain and tilt to below specified tolerances. In CMS Zone 2, the risk of sinkhole development must be investigated and eliminated prior to construction. The CMS Zone designation for a property in CMS Zone 1 may be removed if it is demonstrated by site-specific evaluation of subsidence that magnitudes of potential surface strain and tilt at the property are less than the levels specified. A CMS Zone 2 designation may be changed to CMS Zone 1 if a subsurface investigation demonstrates the absence of coal mine workings or that the coal mine workings, if present, are in a fully collapsed condition.

2.6.2.2 Data Gaps

Coal mine hazards can be mitigated using a wide range of geotechnical and engineering measures that are well understood and supported by numerous case studies. No significant gaps have been identified in available literature for the mitigation of properly delineated coal mine hazard areas.

2.7 Conclusion

All five of the geologic hazards specified in the Growth Management Act (i.e., seismic, erosion, landslide, volcanic, and coal mine hazard areas) have the potential to adversely affect Bellevue's community functions and impair the value of human life and property. The delineation of geologically hazardous areas and mitigation of potential risks requires an understanding of the geologic processes from which these hazards arise.

A review of the best available science indicates ground shaking caused by earthquakes is the most serious hazard in Bellevue in terms of the potential for widespread damage and loss of life.

However, the likelihood of a significant event in the near future is uncertain due to limited seismic information about regional faults and data related to the dynamic properties of geologic materials. Consequently, it is acceptable to delineate seismic hazard areas with a conservative margin of safety, to account for this uncertainty. In addition to damage caused by groundshaking, resulting landslide activity could lead to tsunami activity. Although tsunami inundation models have been developed for Puget Sound, those models have not been used to delineate tsunami hazard areas on Bellevue's shorelines.

The factors controlling erosion and landsliding are highly variable. Hence, site-specific investigations of geologic conditions are required to delineate erosion and landslide hazards at the resolution necessary to mitigate most hazards. The City's delineation of erosion and landslide hazard areas should be updated by incorporating historical records and new light ranging and detection (lidar) topography into the erosion and landsliding models that rate susceptibility to erosion or landsliding in terms of several relative hazard classes. The highest hazard rating should be used to determine structure setbacks in areas where site-specific investigations have not been performed.

The City is located within 160 km (99 mi) of five active volcanoes. The uncertainty related to whether ash fall from future volcanic eruptions will affect Bellevue complicates the feasibility of mitigating hazards due to volcanic eruptions.

Although the City's inventory of abandoned coal mines is based on historic mining information and not site specific investigations, the delineation of broad areas suspected of posing coal mine hazards provides a margin of safety for the hazards posed by the collapse of abandoned coal mines.

While it may not be economically feasible to retrofit or relocate all existing structures within geologically hazardous areas, at minimum, the risks to critical facilities should be reviewed and appropriate measures implemented to protect public safety. Risks posed by geologic hazards can be best mitigated by restricting new development in vulnerable areas.

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Chapter 3. Critical Aquifer Recharge Areas

Critical Aquifer Recharge Areas (CARAs) are included as one of the critical areas for which Washington's Growth Management Act (GMA) (RCW 36.70) requires local government to use best available science to develop policies or regulations to protect their functions and values.

3.1 Functions and Values

The functions and values of CARAs are to provide sources of potable water and areas for replenishment of ground water resources. Water is an essential life-sustaining element and once ground water is contaminated it is difficult, costly, and sometimes impossible to clean up. Preventing contamination to CARAs is necessary to avoid exorbitant costs, hardships, and potential physical harm to people. Protection of ground water quality and quantity is interdependent so protection measures should address both. Impacts to one will cause impacts to the other.

In Washington state ground water quality protection is based on the concept of antidegradation. The potential for future use of ground water resources not currently utilized for drinking water purposes requires protection. Population increases place larger demands on available potable water sources and preservation of ground water quantity to maintain stream base flow (Ecology 2000).

3.2 Designation of Critical Aquifer Recharge Areas

3.2.1 Review of the Literature

Most of the drinking water used in Bellevue is provided by the City of Seattle from a surface water source in the Cascade Mountains. Only a small percentage of Bellevue residents currently use ground water as their source of drinking water. In Bellevue, there are 3 Group A water systems and 11 Group B water systems that rely on local ground water (Figure 3-1 and Tables 3-1 and 3-2). Group A systems serve 15 or more service connections, regardless of the number of people; or they serve an average of 25 or more people per day for at least 60 days within a calendar year, regardless of the number of service connections. Group B systems generally serve 2 to 14 connections and fewer than 25 people. Each of these groups of water supply systems could connect to the City-wide public water system if water quality in existing wells is compromised.

Ground water recharge areas can be grouped according to the function of the water once it enters the aquifer. The main regulatory group used in Bellevue to protect critical aquifer recharge areas is called a wellhead protection area (WHPA), which is defined as the area that provides recharge to a drinking water well. WHPAs are required for all Group A and Group B water systems.

Table 3-1. Group A wells Bellevue, Washington.

Rec	Well ID	Public Water System Name	Land Surface Elevation (ft)	WA DOH Well ID	DOE & USGS Well ID	Survey Date	Survey Agency	WHPA Type	6 Month WHPA Radius (ft)
1	GrpA_05160_01	BEAUX ARTS WATER DEPARTMENT	31.17	afj014	24N/05E-08D	Wed, 20 Oct 1999 00:00:00	KCDNR	none	0
2	GrpA_05160_02	BEAUX ARTS WATER DEPARTMENT	17.91	afj013	24N/05E-08D	Wed, 20 Oct 1999 00:00:00	KCDNR	none	0
1	GrpA_89050_02	TRAILS END	327.06	afj022	25N/05E-15P	Mon, 25 Oct 1999 00:00:00	KCDNR	none	0
2	GrpA_89050_03	TRAILS END	316.89	afj023	25N/05E-15P	Mon 25 Oct 1999 00:00:00	KCDNR	none	0
1	GrpA_15145_01	COUGAR MTN. PARK WT SUPPLY SYS.	1134.19	afj032	24N/05E-24R	Tue, 2 Nov 1999 00:00:00	KCDNR	none	0
1	GrpA_41980_01	KING COUNTY WATER DISTRICT #117	827.08	abr034	24N/05E-23C	Mon, 25 Oct 1999 00:00:00	KCDNR	HG	0

Source: King County 2004a.

WHPAs are delineated based on whether they provide recharge to a drinking water well. They are required for public water systems using a ground water source according to state drinking water regulations (RCW 43.20 and RCW 70.119A). Community Group A public water systems are required to develop WHPAs based on time of travel of ground water to the well (WAC-290). For transient, non-community Group A systems (e.g., park, campground), a default WHPA radius of 600 feet is used. Group B public water systems are required to use an arbitrary fixed radius of 600 feet to the well (WAC 246-291). Distant recharge sources to Group B water systems may not be protected when relying on a fixed WHPA radius for protection. WHPAs have been developed in Bellevue for two Group A public water systems, King County Water District #117 and Trails End. A WHPA developed for two wells located in the City of Beaux Arts extends into Bellevue.

The simplest method to identify recharge and discharge areas is through topography. Higher elevations tend to be recharge areas and lower elevations, discharge. This approach fails to account for localized effects caused by streams, lakes, and ground water extraction wells. The most direct and perhaps most reliable method for identifying recharge and discharge areas is to use maps of water levels or “piezometric surfaces”. Collecting measurements in water wells can identify these surfaces, but a large number of wells are needed to provide useful results.

Other methods include hydrochemical trends and soil and land surface features. As ground water moves through a flow system, total dissolved solids generally increase along the flow path. Water from recharge areas is relatively fresh and water from discharge areas is often relatively

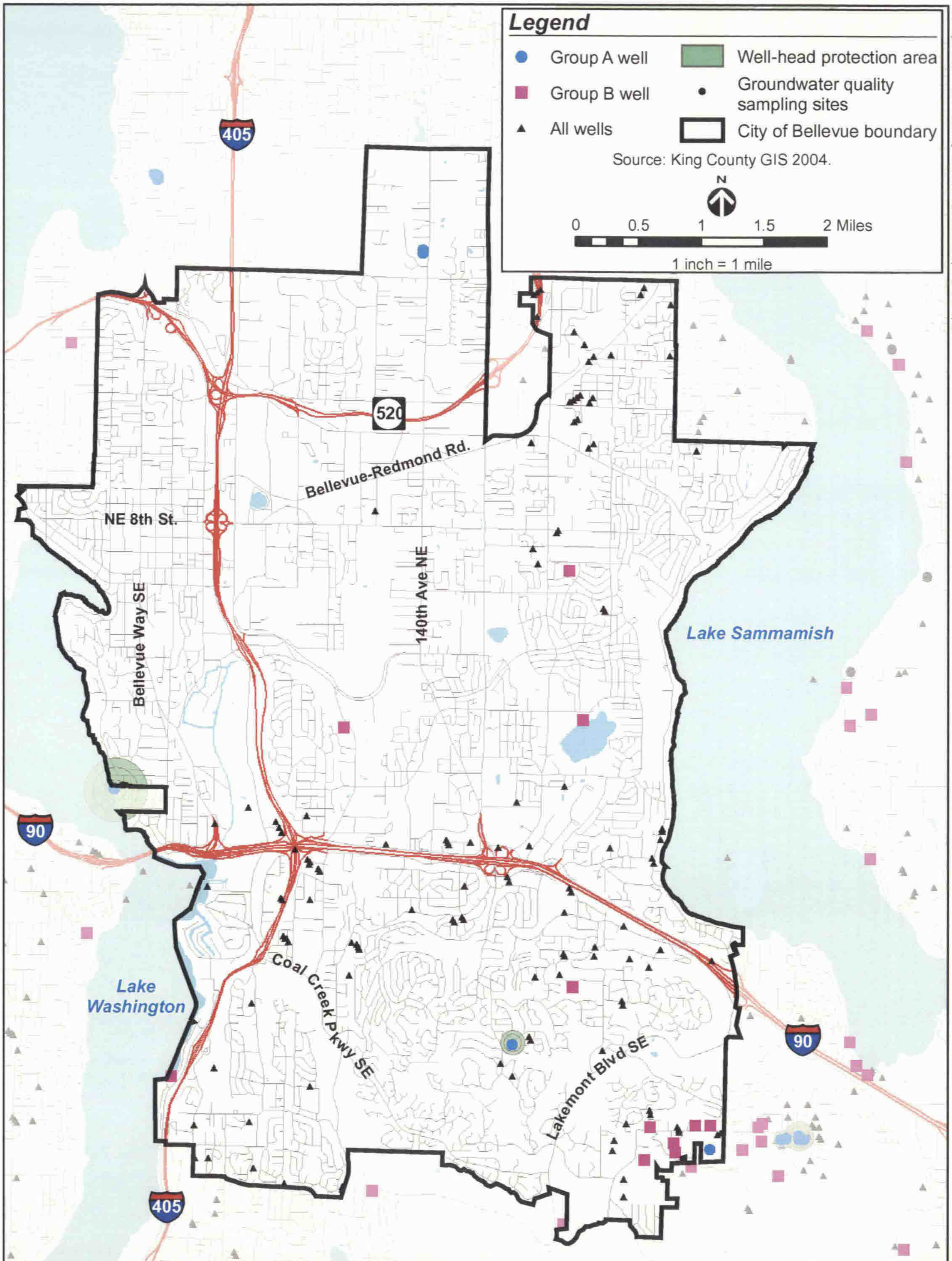

Figure 3-1. Water supply wells within the City of Bellevue, Washington.

Table 3-2. Group B wells, Bellevue, Washington.

Rec	Well ID	Parcel Number	Public Water System Name	State ID	Public Water System ID	Well Address	Type of Public Water System	Well 1 Depth (ft)	Well 2 Depth (ft)	Well 1 Capacity (gal./min)	Well 2 Capacity (gal./min)	Well 1 Water Level (ft)	Well 2 Water Level (ft)	Well Log Available?	Permit Application Number	Possible Connecting Parcel Ids	Number of Possible Connections	Number of Current Connections	Population Served
1	GrpB_13107_01	3525059047	CADE	13107Y	13107		BL	200	0	5	0	0	0	No		3525059047	2	2	5
1	GrpB_03169_01	0224059195	ARVON, HAYES	03169H	03169	16025 SE 16th St	BL	138	0	16	0	0	0	No		0224059195, 0224059013, 0224059210	2	2	5
1	GrpB_48850_01	0424059087	T.F. ASSOCIATES	48850Y	48850	1811 132nd Pl SE	BL	82	0	40	0	0	0	Yes		0424059087, 0424059093, 0424059031, 0424059067, 0424059080	5	5	13
1	GrpB_67970_01	6828700025	PLEASURE POINT PARK	67970L	67970	5243 Pleasure Pt Ln	BL	40	0	15	0	0	0	No		6828700090, 6828700060, 6828700035, 6828700015, 6828700025, 6828700026	9	5	13
1	GrpB_57590_01	1424059044	MID COUGAR MTN WELL	57590K	57590	4531 160th Pl SE	BL	340	0	25	0	60	0	No		1424059044, 1424059097, 1424059048, 1424059098	5	4	10
1	GrpB_62014_01	2424059048	SMITH, G.L.	62014M	62014	17328 SE Cougar Mtn Dr	B1	168	0	4	0	0	0	No		2424059048, 2424059108	2	1	3
2	GrpB_19032_01	2424059038	NORTH COUGAR MTN.	19032D	19032		BL	78	0	20	0	10	0	Yes		2424059038, 2424059136, 2424059134, 2424059135	4	4	10
1	GrpB_23760_01	2424059020	ERICSON, G.	23760P	23760		BL	263	0	15	0	145	0	Yes		2424059020, 2424059089, 2424059127, 2424059129, 2424059128	5	5	13
2	GrpB_16952_01	2424059035	ONE SEVENTY FOURTH SE	16952W	16952	6039 174th SE	BL	360	0	8	0	135	0	Yes	G1-22868C	2424059035, 2424059013, 2424059124	8	2	5
1	GrpB_16011_01	2424059058	FISHER, J.	160116	16011		B1	97	0	14	0	0	0	Yes		2424059058, 2424059037	2	2	0

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Table 3-2 (continued). Group B wells, Bellevue, Washington.

Rec	Well ID	Parcel Number	Public Water System Name	State ID	Public Water System ID	Well Address	Type of Public Water System	Well 1 Depth (ft)	Well 2 Depth (ft)	Well 1 Capacity (gal./min)	Well 2 Capacity (gal./min)	Well 1 Water Level (ft)	Well 2 Water Level (ft)	Well Log Avail-able?	Permit Application Number	Possible Connecting Parcel Ids	Number of Possible Connections	Number of Current Connections	Popula-tion Served
1	GrpB_15136_01	1777000030	COUGAR GLEN	15136B	15136	5932 170th SE	BL	275	0	12	0	60	0	Yes		1777000030, 1770000020, 1770000010, 1770000040, 1770000050, 1770000060, 1770000070, 1770000080, 1770000090, 1770000100	6	2	20

Source: King County 2004b.

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saline. Direct field observation of springs and seeps and the presence of water-loving plants such as willow and cottonwood can be used to map discharge areas. These methods are typically not sufficient to distinguish between recharge and discharge areas, but can be used in conjunction with water level data to help confirm different categories (Freeze and Cherry 1979).

Another example of a regulatory mechanism is to identify and regulate an area as a sole source aquifer area. Sole source aquifer areas contribute water to aquifers that have been certified by the U.S. EPA, because they contribute at least 50 percent of the water used by a public water system.

Identifying the geographic areas that are most critical for protecting Bellevue's ground water resources involves two major tasks. The first task is to identify and map areas that are most susceptible to ground water contamination. The susceptibility depends on the aquifer properties (hydraulic conductivity, porosity, hydraulic gradients) and the associated sources of water and stresses for the system (recharge, interactions with surface water, travel through the unsaturated zone, and well discharge). The second task for prioritizing CARAs is to identify and map the resource value and beneficial use where the severity of the impact to the ground water resources would be greatest. The final product is produced by overlaying the susceptibility maps with resource value maps to create a map of the most critical or high-risk areas that have high values for both aquifer susceptibility and beneficial use. Once these aquifer recharge areas are prioritized, the potential or existing contaminant loads can be overlaid to assist in protecting ground water quality. This map is often called a contaminant hazard map and can also be used to evaluate potential impacts to water quantity.

3.2.2 Identification of Data Gaps

- There is no recent review of wellhead protection plans for Group A wells
- Locations and well logs for all Group B Public Water Systems and single domestic wells are not available
- The percentage of Bellevue residents that use ground water for potable water supply is unknown
- Well locations are not plotted on soil and surficial geologic maps so recharge areas cannot currently be evaluated.

3.3 Development Standards in Critical Aquifer Recharge Areas

Many land-use activities can potentially affect the quality and quantity of ground water recharge. If these activities occur above aquifer recharge areas critical to ground water quality and quantity, it is prudent to implement ground water protection measures to protect the ground water resources of Bellevue.

Prohibiting potentially polluting land-use activities in areas susceptible to contamination is consistent with BAS for protecting ground water quality. The potential for a particular land-use activity to pollute ground water is difficult to predict. A number of characteristics will affect the potential of a particular activity to pollute ground water.

- First, contaminants that originate as mobile, high liquid volume, areally-limited sources will be more likely to overwhelm the natural attenuation capacity of the unsaturated zone than contaminants that originate from more diffuse sources. This will increase the likelihood of ground water contamination.

- Second, there is also an important difference between those activities in which the contaminant source is an integral design feature (e.g., on-site septic systems and agriculture) and those where it is an accidental component (e.g., pipeline leaks/ruptures and underground storage tank failure). When the contaminant release is an integral part of the design, it is easier to predict and mitigate for the release. Conversely, the probability of an accidental release occurring depends on design and regulatory compliance, as well as individual error, making the potential of a release difficult to predict.

3.3.1 Review of the Literature

The U.S. EPA has developed a baseline list, shown in Table 3-3, of possible contaminant sources categorized into four major land-use categories: Industrial/Commercial, Agricultural, Municipal/Residential and Miscellaneous Sources (EPA 2003).

Based on a literature review, historical data on activity related releases of contaminants, existing planning documents (e.g., Groundwater Management Plans), federal, state, and local regulatory control, and local regulatory control, and model CARA provisions from Washington state agencies (OCD 2002b; Ecology 2000), the following activities are recommended for additional protection within Bellevue:

3.3.1.1 Industrial/Commercial Land Uses

- Underground storage tanks
- Above ground storage tanks
- Mining (metals, sand, and gravel)
- Wood preserving/treatment
- Wrecking yards
- Processing, storage and disposal of radioactive waste
- Pipelines (hazardous liquid transmission)
- Hydrocarbon extraction.

Table 3-3. Potential sources of contamination categorized by land use (U.S. EPA 2003).

Commercial/Industrial

Above-ground storage tanks
Automobile, Body Shops/Repair Shops
Boat Repair/Refinishing/Marinas
Cement/Concrete Plants
Chemical/Petroleum Processing
Construction/Demolition
Dry Cleaners/Dry Cleaning
Dry Goods Manufacturing
Electrical/Electronic Manufacturing
Fleet/Trucking/Bus Terminals
Food Processing
Funeral Services/Taxidermy
Furniture Repair/Manufacturing
Gas Stations
Hardware/Lumber/Parts Stores
Historic Waste Dumps/Landfills
Home Manufacturing
Hydrocarbon Extraction
Industrial Waste Disposal Wells
Junk/Scrap/Salvage Yards
Machine Shops
Medical/Vet Offices
Metal Plating/Finishing/Fabricating
Military Installations
Mines/Gravel Pits
Office Building/Complex
Pipelines (Hazardous Liquid Transmission)
Photo Processing/Printing
Synthetic/Plastics Production
RV/Mini Storage
Railroad Yards/Maintenance/Fueling Areas
Research Laboratories
Retail Operations
Underground Storage Tanks
Wood Preserving/Treating
Wood/Pulp/Paper Processing

Agricultural/Rural

Auction Lots/Boarding Stables
Animal Feeding Operations/Confined Animal Feeding Operations
Bird Rookeries/Wildlife feeding/migration zones
Crops – Irrigated + Non-irrigated
Dairy operations
Drainage Wells
Lagoons and Liquid Waste Disposal – Agricultural
Managed Forests/Grass Lands
Pesticide/Fertilizer Storage Facilities
Residential Wastewater lagoons
Rural Homesteads

Residential/Municipal

Airports (Maintenance/Fueling Areas)
Apartments and Condominiums
Camp Grounds/RV Parks
Cemeteries
Cesspools – Large Capacity
Drinking Water Treatment Facilities
Gas Pipelines
Golf Courses
New Development (addition of impervious surfacing)
Landfills/Dumps
Public Buildings
On-site Sewage (Septic) Systems
Sewer Lines
Stormwater infiltration basins, Injection into wells (UIC Class V)
Runoff zones
Transportation Corridors
Urban Parks
Utility Stations
Waste Transfer/Recycling
Wastewater Treatment Facilities/Discharge locations (including land disposal and underground injection of sludge)

Miscellaneous

Abandoned drinking water wells (conduits for contamination)
Naturally Occurring Underground Injection Control (UIC) Wells
CLASS I – deep injection of hazardous and non-hazardous wastes into aquifers separated from underground sources of drinking water (banned in Washington)
CLASS II – deep injection wells of fluids associated with oil/gas production
CLASS III – re-injection of water/steam into mineral formations for mineral extraction (banned in Washington)
CLASS IV – inject hazardous or radioactive waste into or above underground sources of drinking water (banned in US).
CLASS V – shallow injection wells

3.3.1.2 Municipal/Residential Land Uses

- Landfills (hazardous or dangerous waste, municipal solid waste, special waste)
- Addition of impervious surface/stormwater runoff
- Golf courses
- Onsite sewage (septic) systems
- Cemeteries.

3.3.1.3 Miscellaneous Land Uses

- Abandoned wells.

This literature review indicated the following:

- Mapping CARAs provides the general framework within which to base ground water quality and quantity protection policy.
- There are three Group A water systems in Bellevue, and 11 Group B water systems.
- The WHPAs developed for two wells located in Beaux Arts extend into Bellevue.
- Group B public water systems are required to use an arbitrary fixed WHPA radius of 600 feet to the well.
- Distant recharge sources may not be included when using fixed WHPA radii.
- Prohibiting potentially polluting land-use activities in areas susceptible to contamination is consistent with BAS for protecting ground water quality.

3.3.2 Identification of Data Gaps

- Land use maps to overlay recharge areas to identify potential contaminant sources
- A list of contaminants associated with each potential source activity (See Table 3-3).

3.3.3 Recommendations

- Designate the CARAs by overlaying the WHPA or default radius of 600 feet for Group A and B wells on a susceptibility map.
- Refine the CARAs by evaluating the hydrogeology for Group A and B wells to identify potential distant recharge sources.

3.4 Conclusion

The functions and values of critical aquifer recharge areas consist of providing sources of potable water and areas for the replenishment of ground water resources. Maps indicating the locations of critical aquifer recharge areas serve as the general framework for establishing a policy to protect ground water quality and quantity.

Most of the drinking water used in Bellevue is provided by the City of Seattle from a surface water source in the Cascade Mountains. Only a small percentage of Bellevue residents currently use ground water as their source of drinking water. In Bellevue, there are three Group A water systems and 11 Group B water systems that rely on local ground water. Group A systems serve 15 or more service connections, regardless of the number of people; or they serve an average of 25 or more people per day for at least 60 days within a calendar year, regardless of the number of service connections. Group B systems generally serve 2 to 14 connections and fewer than 25 people. Each of these groups of water supply systems could connect to the City-wide public water system if water quality in existing wells is compromised.

Ground water recharge areas can be grouped according to the function of the water once it enters the aquifer. The main group used in Bellevue to protect critical aquifer recharge areas is called a wellhead protection area (WHPA), which is defined as the area that provides recharge to a drinking water well. WHPAs are required for all Group A and Group B water systems. Group A water systems are responsible for identifying WHPAs based on the actual sources of recharge to their wells and are required to provide wellhead protection for those areas. Group B public water systems are required to use a WHPA radius of 600 feet for each well. Distant recharge sources to Group B water systems may not be protected when relying on a fixed WHPA radius for protection. Prohibiting potentially polluting land-use activities in critical aquifer recharge areas that are susceptible to contamination is consistent with the best available science for protecting ground water quality.

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Chapter 4. Frequently Flooded Areas

The Washington Growth Management Act (GMA) identifies "frequently flooded areas" as one of five critical areas that must be designated and protected by local jurisdictions. Counties and Cities are required to include the best available science (as defined by WAC 365-195-900 through 925) during the development of land-use policies in order to protect the ecological functions and values of critical areas. Frequently flooded areas are considered critical not only because of the ecological functions and values, but also because of the risk that flood hazards can pose to public safety and property. In many instances these mandates can be mutually addressed by preventing development in flood-hazard areas and thereby protecting public safety, property, and ecological functions and values.

The review of literature completed for the City of Bellevue's Critical Areas Update summarizes existing scientific information relevant to the delineation and land-use regulation of frequently flooded areas within the City of Bellevue. Relevant information was obtained from a variety of peer-reviewed sources meeting the criteria for best available science (WAC 365-195-900 to 925). Information was selected from scientific journals, published books, and government reports. Additional information from peer-reviewed research studies was included if performed by qualified researchers using documented scientific methods.

4.1 Functions and Values

The value of frequently flooded areas can be assessed by the important hydrologic and ecological functions that they provide. Flooding of low-lying areas occurs when runoff exceeds the capacity of rivers and streams to convey water within their banks. Flooding can also occur in urban areas when stormwater systems become overwhelmed. Numerous studies have linked urbanization with increased peak discharge and channel degradation (Dunne and Leopold 1978; Booth and Jackson 1997; Konrad 2000). Restoring floodplain functions can diminish the effects of urbanization by temporarily storing water and mediating flow to downstream reaches. The storage capacity of a floodplain determines the degree to which floodplain inundation may buffer upstream fluctuations in discharge. The storage capacity of a floodplain may vary according to valley confinement, gradient, local relief, and flow resistance provided by vegetation. The construction of levees, filling low lying areas, and other encroachment into floodplains can dramatically reduce the local storage capacity of a floodplain and impact the hydrologic regime of a basin. The increase in impervious areas as a result of urbanization can also modify the magnitude and frequency of flooding in urban basins (Konrad 2000). Where development encroaches on frequently flooded areas, flooding can present a risk to public health and safety and to property and infrastructure.

Floodplains perform numerous ecological functions by providing critical habitat requirements for fish, birds, and other wildlife. The complex vegetation structure found in riparian areas contributes to the high biodiversity of floodplains. Shade offered by riparian vegetation reduces water temperature. Riparian vegetation also provides organic debris to stream and rivers that creates in-stream structures and cover. Woody debris creates habitat complexity in channels by trapping sediment and forming pools (Keller and Swanson 1979; Nakamura and Swanson 1993; Abbe and Montgomery 1996; Abbe 2000; Naiman et al. 1998; Beechie et al. 2001). Sediment storage and hydraulic roughness created by logjams can raise the elevation of both the channel bed and water surface, which may force additional channel migration and increase the frequency of flooding (Rapp and Abbe 2003). A reduction in wood loading (either through the removal of in-stream wood or the conversion of riparian forests) can lead to channel incision (Beschta 1979; Bilby 1984) and reduction of the ecological benefits of maintaining floodplain connectivity (Bolton and Shellberg 2001).

Floodplains also sustain wetlands, which provide feeding and breeding habitat for birds and off-channel refuge and rearing habitat for migrating salmonids. Dynamic interactions between surface water and ground water occur along river corridors within the hyporheic zone—the saturated area beneath the surface containing some portion of water flowing through the channel system. Hyporheic flow through porous subsurface sediment beneath floodplains drives hydrologic exchange processes, nutrient dynamics, and biotic lifecycles (Bolton and Shellberg 2001; Poole 2002). Heat exchange between water and subsurface materials within the hyporheic zone maintains the low water temperatures required by many aquatic species. The slow release of water stored within the floodplain and hyporheic zone can maintain base flow during the dry season. Preservation of the many ecological functions performed by frequently flooded areas are vital to the protection of salmonids and other species listed under the Endangered Species Act (ESA).

Bank erosion and channel migration are geomorphic processes that often occur in conjunction with flooding. Channel migration can modify the area designated as frequently flooded and increase risk to public safety and property (FEMA 1999; Rapp and Abbe 2003). Bank erosion supplies sediment and woody debris to channels, and creates new channels, bars, and floodplains that result in the complex assemblage of habitats found in these environments.

4.2 Delineation

The delineation of frequently flooded areas is necessary to protect the functions and values of floodplains and to safeguard the public from hazards posed by flooding. Bellevue has several small lakes and creeks that are subject to frequent flooding. Because Bellevue's urban creeks are small and drain highly urbanized areas, stream flows typically respond rapidly to storm events and are subject to higher peak flows than are thought to have occurred prior to urbanization (Booth 1991; Konrad 2000). The shoreline of Lake Sammamish is also subject to frequent flooding. The level of Lake Sammamish is controlled by inflow from Issaquah Creek and several smaller streams and outflow through the Sammamish River. Flooding along the lake shoreline may occur at different times than urban flooding elsewhere within the City and persist for a longer period of time. The following sections describe the best available science for the delineation of frequently flooded areas as it relates to the City of Bellevue.

4.2.1 Review of the Literature

Passage of the National Flood Insurance Act in 1968 created the National Flood Insurance Program (NFIP), which required detailed mapping of flood hazards to establish land-use and flood management requirements for communities participating in federal assistance programs. The Federal Emergency Management Agency (FEMA) assumed responsibility of mapping flood hazard zones following creation of the Agency in 1978. FEMA has established guidelines for flood hazard mapping. Flood hazard areas are delineated from the base flood with a 1 percent probability of occurring in any one year, which is commonly referred to as the 100-year flood. Estimates of the elevation and extent of the base flood are delineated on flood insurance rate maps (FIRMs) prepared by FEMA. Flood insurance rate maps rely on feature and topographic data obtained from the U.S. Geological Survey, U.S. Army Corps of Engineers, states, and local municipalities. Flood inundation estimates are generally based on detailed hydrologic and hydraulic modeling conducted by private engineering firms and government agencies contracted by FEMA (FEMA 2001). Modeling accuracy is dependent on the abundance and quality of input data, particularly topography (resolution and date of mapping) and hydrology (number of gauging stations, proximity to site, and period of record). Estimates of flood inundation delineated on FIRMs can be subject to significant errors, particularly if significant land-use changes (i.e., urbanization) have occurred in the watershed. Changes in channel location (both horizontal and vertical) and floodplain modifications can also have significant effects on flood inundation and necessitate updating estimates of the base flood elevation.

Flood hazard maps of Bellevue were established in the late 1970s by FEMA. The National Flood Insurance Reform Act of 1994 required additional and updated flood mapping for those areas unmapped or for areas where conditions have changed as a result of basin development. In addition, King County adopted a Flood Hazard Reduction Plan (King County 1993) as part of a countywide strategy to reduce hazards associated with flooding on six major rivers in the county. However, the county plan will not update flood data for creeks within the City of Bellevue. The City of Bellevue began a program in 1999 to conduct hydrologic modeling and update existing flood hazard maps for all major drainage basins. To date, The City has completed hydrologic modeling and calculation of the base flood elevation for all but three of the 14 basins with major drainage systems.

Bellevue's creeks once drained heavily forested watersheds. Riparian forests contributed large quantities of woody debris, which increased channel roughness and provided grade control. Deforestation followed by urbanization has resulted in the downcutting of many urban streams (Booth 1991, Nelson and Booth 2002). Most of Bellevue's creeks are incised into relatively erodible glacial sediments and are confined by steep slopes that limit the extent of frequently flooded areas to narrow riparian corridors. However, in the vicinity of small lakes or where channels are relatively unconfined, floodplains in Bellevue tend to be wider. FEMA began a map modernization program in 1997 to update floodplain features (but not flood data) and convert maps to a digital format. An inventory of frequently flooded areas delineated by FEMA within the City of Bellevue is available in digital format (Figure WT-1 in the March 2003 *Bellevue Critical Areas Update Wetland Inventory*). Frequently flooded areas in Bellevue include several streams:

- Coal Creek originates on Cougar Mountain East of the City of Bellevue and drains into Lake Washington at Newport Shores. Extensive coal mining within the basin in the late 1880s increased sedimentation rates within the creek (Kerwin 2001). Urban development within the last century further altered the creek's natural hydrologic characteristics and increased the frequency and magnitude of peak flood events. As a result, streambank erosion and streambed sedimentation have also increased (Kerwin 2001). Confinement of Coal Creek by a steep ravine through Coal Creek Park limits the extent of flooding to the immediate riparian corridor. Sediment aggradation west of I-405 has formed a delta at the mouth of Coal Creek. However, flow control at the delta provided by the retention pond east of I-405, as well as confinement of the channel by development, inhibits the base flood from inundating adjacent areas. The base flood elevation along Coal Creek was revised during the City's 1999 update.

- Vasa Creek drains into Lake Sammamish and includes reaches delineated as frequently flooded areas on both sides of I-90.

- Lewis Creek is located in the southeast corner of the City of Bellevue and flows into Lake Sammamish. No frequently flooded areas have been delineated by FEMA along Lewis Creek.

- Kelsey Creek is the largest creek in Bellevue and includes several tributaries. Kelsey Creek originates in the Phantom and Larsen Lake wetlands and flows through the Mercer Slough before draining into Lake Washington near I-90. Several frequently flooded areas have been delineated along Kelsey Creek. They include wetlands located in the Lake Hills Greenbelt Park between Phantom and Larsen lakes, wetlands near NE 8th Street and 148th Avenue SE, wetlands at Kelsey Creek Park, and portions of the Mercer Slough. The base flood elevation along Kelsey Creek and its tributaries was revised during the City's 1999 update

- Sunset, Richards, and East creeks are tributaries to Kelsey Creek and include several narrow corridors delineated as frequently flooded areas. These creeks were included in the 1999 update to the Kelsey Creek Basin.

- Valley Creek is a tributary to Kelsey Creek and flows south along 150th Avenue NE within a narrow valley. Frequently flooded areas were delineated along the narrow riparian corridor of the lower reach of Valley Creek during the 1999 update.

- West Tributary and Goff Creek flow south and join Kelsey Creek at Kelsey Creek Park. Frequently flooded areas were delineated along the lower reach of West Tributary above the confluence with Kelsey Creek as part of the 1999 update to the Kelsey Creek Basin.

- Yarrow Creek is located in northwest Bellevue and drains into Lake Washington. Frequently flooded areas were delineated along a portion of Yarrow Creek within the City of Bellevue.
- Meydenbauer Creek is located south of the Yarrow Creek Basin and drains west into Lake Washington. No frequently flooded areas are delineated in the Meydenbauer Creek basin. However, a hydraulic model has been developed for the basin.

Frequently flooded areas in Bellevue also include the shorelines of several lakes:

- Lake Bellevue is located at the headwaters of Sturtevant Creek, a small tributary to Kelsey Creek. The immediate shoreline of Lake Bellevue is designated as a frequently flooded area.
- Larsen Lake is located at the headwaters of Kelsey Creek. Portions of the Lake Hills Greenbelt Park surrounding the lake are designated as a frequently flooded area. An approximately 2,000-foot stretch of 148th Avenue SE runs through this area.
- Phantom Lake formed the historical headwaters of Kelsey Creek before the lake outlet was redirected to Lake Sammamish in the late 1880s (KCM 1993). The immediate shoreline of Phantom Lake is designated as a frequently flooded area.
- The Lake Sammamish shoreline is designated as a frequently flooded area. Because of the steep bluffs along the lake, the frequently flooded area is limited to the immediate shoreline east of West Lake Sammamish Parkway.

In addition to floodplain mapping by FEMA, floodplain delineation can also incorporate analytical methods that consider the variability in factors that influence base flood elevation and the extent of flooding. FEMA's map modernization program is exploring the use of a new generation of GIS-based hydrologic and hydraulic models integrated with digital watershed and topographic models, which will allow periodic revisions to FIRMs as conditions change (FEMA 2002). However, current FEMA guidelines for the delineation of flood hazard areas are based on fixed floodplain and basin conditions.

Changes in several key factors can influence base flood elevation and the extent of flooding. Bank erosion and channel migration can alter the hydraulic characteristics of a channel reach through changes in channel location, bed elevation, and flow resistance (Rapp and Abbe 2003). Both the state of Washington and King County have established guidelines for the delineation of channel migration zones (CMZs) (WFPB 2001; WDOE 2004).

Channel migration zones also include vertical adjustments in grade due to changes in sediment supply, wood loading, and stream flows (Rappe and Abbe 2003). Vertical changes within frequently flooded areas can result in elevating the area of flood risk by destabilizing banks through incision and aggradation. Changes in planform, land use, or vegetative cover within floodplain corridors can result in significant changes to the base flood elevation. Although most creeks in Bellevue are small and confined by steep banks, some may be susceptible to channel migration, particularly vertical changes in stream bed elevations. Incision or downcutting in response to increased peak flows from urbanization and lack of in-stream woody debris is common in Puget Sound lowland streams and can be severe enough to destabilize adjacent hillslopes (Booth 1991).

Wolman (1967) presented a general description of stream responses to urbanization. Initial development within a watershed begins with a significant increase in sediment supply as vegetation is removed and slopes are disturbed. Eventually sediment production is reduced below the natural background as impervious surfaces, hardened stormwater drainage systems, and erosion control measures limit sediment sources. The long-term effect of urbanization is generally a large increase in peak flows, a reduction in sediment supply, lower summer low flows, and channel incision or entrenchment. Channel incision destabilizes banks and results in a loss of critical floodplain habitat by lowering water levels.

Increases in impervious area and stormwater routing within urban basins can increase the magnitude of the hydrologic response of small creeks. Runoff and discharge patterns can also be altered by changes in the regional precipitation regime caused by rapid global climate change (Payne et al. 2004). Hydraulic modeling can evaluate land use planning scenarios, forecast changes in base flood elevations, and delineate new areas deemed likely to become inundated, given current projections of basin development and other factors that might affect the frequency of flooding. Modeled projections of twenty first-century climate change in the Pacific Northwest region indicate region-wide warming, increased precipitation, declining snowpack, earlier spring runoff, and declining trends in summer streamflow. For the Pacific Northwest, an increase in average annual temperature of 2.7°F (range: 0.8-4.7°F) by the 2020s and 4.1°F (range: 2.7-5.8°F) by the 2040s is likely (Mote et al. 2003). Projected changes in annual precipitation are less certain than projected temperature changes. Most models project warmer, wetter winters and warmer, drier summers for the Pacific Northwest (Mote et al. 2003). Model results imply increases in the risk for more winter flooding in low (rain dominant) and midelevation (rain/snow mix) basins, possibly requiring more active management of floods and floodplains (Hamlet and Lettenmaier 1999).

4.2.2 Identification of Data Gaps

Errors in the delineation of frequently flooded areas can result from invalid model assumptions, inaccurate mapping of floodplain topography, insufficient characterization of basin properties, poor topographic resolution, and changes in the hydrologic regime. Long-term historical records of precipitation, runoff, and flooding in western Washington are limited to the period of record keeping since the late nineteenth-century settlement of the region. Limited hydrologic data can complicate the calibration of models used to evaluate flood base levels. Changes in runoff and discharge patterns from urban development not accounted for in flood mapping may also underestimate the degree of future flooding and place properties along floodplain margins at risk.

The uncertainties of predicted climate change can also lead to errors in delineation. Although most climate change models predict warmer, wetter winters and warmer, drier summers for the Pacific Northwest, projected changes in annual precipitation are less certain than projected temperature changes.

The hydrologic and geomorphic responses of Bellevue's creeks to changes in the sediment and hydrologic regimes caused by urbanization are unknown but reasonable assumptions can be made based on studies of other Puget Sound lowland creeks (Konrad 2000, Booth 1991). It can be safely assumed that Bellevue's creeks have been subjected to both increases in peak flows and decreases in channel roughness and grade control once provided by vegetation and woody debris. Future trends are difficult to forecast because pre-settlement trends in channel incision and lateral migration of urban creeks in Bellevue were not documented prior to deforestation and development of Bellevue.

Currently, there is no national standard on how to delineate CMZs as there is for flood hazard zones. Prior studies suggest delineation depends on the factors influencing migration, the time period over which the channel is expected to move, and how those factors might change during this period. King County has begun delineating CMZs for larger rivers but not for smaller rivers and streams. To date, CMZs have not been delineated for creeks in Bellevue.

4.2.3 Recommendations

The recent acquisition of high-resolution digital elevation models (DEMs) of topography generated using light distance and ranging (LIDAR) mapping techniques provides opportunities to update existing maps of frequently flooded areas and evaluate the potential for channel migration. The resolution of DEMs produced using LIDAR can be an order of magnitude greater than conventional topographic maps (e.g., 1-meter-grid resolution compared with older 10-meter-grid maps) and can significantly increase the accuracy of mapping geologic and flood hazard areas. The mapping of flood hazard areas is typically undertaken by FEMA; however, there are no plans to update existing FIRMs with the new LIDAR topographic data. The City could undertake a program to update existing maps of frequently flooded areas, with priority given to urban floodways that experience chronic flooding. The LIDAR data could also be used as an aid in delineating CMZs along Bellevue's creeks. A summary of recommendations are offered based on a review of available literature and existing data gaps:

- Use the most recent LIDAR topographic maps to update existing flood hazard maps.
- Address increases in peak flow anticipated as a result of basin urbanization in future flood hazard mapping. Ensure the hydrologic modeling takes into account the projected changes in precipitation related to climate change.
- Evaluate historical trends in vertical channel adjustment and related bank instability caused by urbanization in Bellevue creeks using a licensed

geologist with expertise in the field of fluvial geomorphology. Conduct stream surveys within stream reaches where potential bank failures may pose a significant risk to adjacent property and infrastructure. Recent LiDAR topography could be used to identify potentially hazardous reaches and guide field efforts aimed at their characterization.

4.3 Development Standards

Standards for the management of frequently flooded areas are necessary to reduce flood-related hazards to the public, minimize economic losses, and protect critical habitats. Additional pressures are place on the management of flood hazard areas where they overlap with areas of rapid urbanization. Development within the frequently flooded areas of Bellevue is limited by the naturally steep topography that confines many of the city's small creeks but channel changes can still impact adjacent hillslopes. Many of these areas have been designated as parks and greenbelts.

To qualify for flood insurance under the NFIP, local jurisdictions must adopt floodplain management regulations at least as stringent as the federal minimum standards established by FEMA. Chapter 86.16 RCW directs the Washington State Department of Ecology to coordinate the state floodplain management regulations of the NFIP and approve floodplain management ordinances for local jurisdictions. Regulations for the management of floodplains in Washington are contained in WAC 173-158 through 120.

Bellevue's existing ordinance for special flood hazard areas meets the minimum requirement of the Washington floodplain management ordinance. The minimum requirements of the Washington model floodplain management ordinance are appropriate for the frequently flooded areas delineated in Bellevue. The minimum requirement for residential construction and manufactured homes is that the lowest floor be elevated to or above the base flood elevation. Non-residential construction carries the same requirement as residential construction, with the additional requirement that the area below the base flood elevation be floodproofed. The model floodplain management ordinance also includes the basis for establishing areas of special flood hazard, provisions for reducing flood losses, penalties for noncompliance, administration of the flood ordinance, conditions for variances, and construction standards for critical facilities.

4.3.1 Review of the Literature

Standards for the management of frequently flooded areas include conventional approaches that address risks to public safety and property, as well as more comprehensive plans that incorporate the best available science to address environmental impacts of flood control measures. Traditionally jurisdictions have limited development within frequently flooded areas to non-essential infrastructure and development that can sustain frequent inundation (i.e., roads, parking lots, parks, agricultural land, and buildings on pilings). More recently, comprehensive floodplain management plans have acknowledged the need for a balanced approach that preserves or restores riparian values while protecting the public and property and also comply with the Shoreline Management Act, the Growth Management Act, and requirements for salmon habitat preservation under the ESA.

Although the risk of flooding in Bellevue is relatively low, Washington State remains one of the most flood-prone states in the United States (WDOE 2004). Consequently, numerous policies have been promulgated by both state and local governments for the management of frequently flooded areas and development within these areas:

- Modernize outdated flood control measures. Replacing traditional flood control measures with projects that emulate natural riverine processes can restore the ecological functions of frequently flooded areas. The reclamation of land required for flood storage, conveyance, and riparian functions can be achieved through public buy-out or land-stewardship programs.
- Prohibit new construction in the floodplain. Buildings, roadways, and fill placed within floodways increase hydraulic roughness and can raise the base flood elevation. The reduction in storage volume and conveyance can affect flood elevations both upstream and downstream from development (FEMA 2001). Construction of new development and substantial improvements to existing properties within floodplains is prohibited in Washington. The state mandate prohibiting new construction in floodplains is consistent with the best available science aimed at preserving the ecological function of floodplains and reducing flood hazards.
- Elevate and floodproof. Engineering controls that minimize flood damage to property are forms of floodproofing. Examples of floodproofing include the installation of floodwalls, foundation anchoring, and sewage system backflow protection. Most types of homes can be elevated and possibly raised above the base flood elevation.
- Maximize floodplain storage. The temporary storage of stormwater in retention basins can buffer streams against flashy hydrologic conditions typical of urban streams. Compensatory storage provisions—ordinances that require developments to compensate for loss of flood storage from filling by removing equal amounts of material in the floodplain—address reductions in floodway conveyance.
- Protect critical facilities. Flood waters can isolate critical facilities such as fire/police stations and hospitals at a time when they are needed most. In addition, hazardous storage sites and industrial facilities can impact water quality if inundated by flood waters. For these reasons, new critical facilities should be located outside of frequently flooded areas, and existing structures should be retrofitted to maintain their functionality.

- Protect aquatic habitat. Ecological functions performed by floodplains are protected indirectly through the delineation of wetlands and establishment of riparian corridors for the protection of salmonid species listed under the ESA. For instance, wetlands delineated along many of Bellevue's small creeks encompass frequently flooded areas.

4.3.2 Identification of Data Gaps

Comprehensive floodplain management plans that propose alternatives such as floodplain reclamation rely on predictions of how the channel will respond to restoration activities. Although riverine ecology has been studied extensively, the literature describing the techniques for design, construction, and monitoring of restoration projects is limited. Likewise, due to the infancy of river restoration science and lack of long-term monitoring programs, technical information on the long-term outcomes of different restoration techniques is limited.

To date, King County is the only local jurisdiction with an ordinance regulating land use in areas mapped as channel migration zones (WDOE 2004). The potential for bank erosion caused by vertical incision and lateral channel migration along creeks in Bellevue is unknown.

4.3.3 Recommendations

- Replace traditional flood control measures with projects that emulate natural stream processes.
- Implement public buy-out or land-stewardship programs to restore the ecological functions of frequently flooded areas.
- Consider restricting development in areas along specific channel reaches that have been identified as undergoing historical bed incision. Most of these areas may already be protected by riparian and wetland buffers. Where protection is deemed inadequate, additional restrictions on development in these sensitive areas should be implemented to protect against the loss of property caused by historical channel change and the related failure of adjacent banks.

4.4 Conclusion

The frequently flooded areas have been mapped within Bellevue are limited to small lakes and creeks and the shoreline of Lake Sammamish. A review of the literature indicates that frequently flooded areas can be delineated both to identify flood hazards and to protect the ecological functions and values of floodplains. The Federal Emergency Management Agency assumes the primary responsibility for delineating frequently flooded areas for hazard mitigation by developing flood insurance rate maps showing the base flood elevation and the areas prone to flooding.

Changes in the hydrologic regime caused by urbanization or climate change may alter the areas currently designated as frequently flooded. Restricting development within floodplains and modernizing traditional flood control measures can both mitigate flood hazards and restore the ecological functions of frequently flooded areas. Channel migration is becoming recognized as a significant hazard associated with but not limited to frequently flooded areas.

Protection of frequently flooded areas is important because they provide unique hydrologic and ecological functions, including critical habitat for many species of fish, birds, and other wildlife. The complex vegetation structure found in riparian areas and the frequent inundation in these areas contribute to the high biodiversity found in floodplains. Protection of frequently flooded areas also sustains wetlands, which provide feeding and breeding habitat for birds and off-channel refuge and rearing habitat for migrating salmonids.

The following actions are recommended for the City of Bellevue:

- Use the most recent LIDAR topographic maps for any future update of existing flood hazard maps.
- Address increases in peak flow anticipated as a result of basin urbanization in any future flood hazard mapping. Hydrologic modeling should also consider projected changes in precipitation related to climate change.
- Consider new flood control projects that emulate natural stream processes.
- Implement public buy-out or land-stewardship programs to restore the ecological functions of frequently flooded areas.

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Chapter 5. Streams and Riparian Areas

This summary of the best available science for developing policies and regulations to protect the functions and values of stream and associated riparian areas is based on peer-reviewed research; Bellevue's 2003 *Critical Areas Update, Stream Inventory Report;* Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Streams*; symposia literature; technical literature; and other scientific information related to streams. Best available science for stream and riparian protection varies in terms of quantity, quality, and local relevance. The best available science for stream and riparian protection is neither complete nor consistently covers all functions, and it remains an active field of research. The review focused on recommended conservation or protection measures to preserve or enhance anadromous fish species and habitat that is important for all life stages of anadromous fish.

In 2003, the City of Bellevue documented conditions of local streams in a report titled "*Bellevue Critical Areas Update Stream Inventory*" and also published a review of best available science for streams in a paper titled "*Bellevue Critical Areas Update Best Available Science Paper: Streams*". This report provides a peer review of these documents using current best available science sources for stream protection. It updates current knowledge and provides recommendations for policies to protect local streams.

This document incorporates a discussion of the aquatic area processes and functions not discussed in the 2003 best available science paper on streams. In addition, this document includes critical area protection recommendations to protect the functions and values of streams with special consideration given to conservation and enhance of anadromous fish species, particularly salmon. The stream protection issues reviewed include:

- Stream typing systems
- Stream buffers
- Piped stream buffers
- Structure setbacks
- Stewardship programs.

Relevant information was obtained from a variety of peer-reviewed sources meeting the criteria for best available science (WAC 365-195-900 to 925). Information was selected from scientific journals, published books, and government reports. Additional information from peer-reviewed research studies was included if performed by qualified researchers using documented scientific methods.

This report and findings should be used in conjunction with the 2003 *Bellevue Critical Areas Best Available Science: Streams Paper* (BAS Streams Paper) and the 2003 *Bellevue Critical Areas Update Stream Inventory Report* (Stream Inventory Report) to help provide information for policy recommendations for the management of streams and riparian areas in the City.

5.1 Functions and Values

The 2003 BAS Streams Paper specifically investigated stream processes and biological requirements of salmonids, salmon habitat needs, and the functions and values of riparian areas. While salmonids as well as many other aquatic organisms are confined to the stream aquatic environment, the various elements necessary for healthy salmonid and aquatic life populations do not rely solely on in-stream processes. Understanding how aquatic species and habitats are formed and sustained is essential in devising a strategy for their protection.

This section focuses on aquatic area processes and functions that should be considered when managing stream critical areas— with special consideration given to local core and satellite salmonids. Major paradigms of aquatic area processes not discussed in the 2003 report but addressed in this document include:

- The Role of Natural Disturbances
- River Continuum Concept
- Channel Migration Zone
- Hyporheic Zone.

Figure 5-1 illustrates the different zones affecting stream and riparian processes. Because of the unique mix of water and biodiversity, stream and riparian areas are used by a broad range of species including by humans for recreational and aesthetic activities, fishing, and the enjoyment of natural beauty and solitude.

5.1.1 The Role of Natural Disturbances

The interplay between water, soil, plants, and animals occurs in cycles of intensity driven by climatic and geological processes. Stochastic (random) processes and natural disturbances place stresses on the stream and associated riparian areas (stream corridor) and have the potential to reshape, rejuvenate, or impair its ability to perform ecological functions. Disturbances can occur anywhere within the stream corridor and can vary in terms of frequency, duration, and intensity. A single disturbance event may trigger a variety of disturbances that differ in frequency, duration, intensity, and location (NRC 1997). Ecologists (Holling 1973; White and Picket 1985) have long recognized the dynamic nature of aquatic and terrestrial ecosystems and how the associated biota and physical characteristics change through time due to stochastic processes and natural disturbances. Floods, fire, lightning, earthquakes, insects and disease, landslides, temperature extremes, and drought are among the many natural disturbances affecting structure and functions in the stream corridor (NRC 1997).

Natural disturbances can: (1) increase biological diversity; (2) be crucial for the persistence of some organisms and the habitat that supports them; and (3) express and maintain key ecological processes (Turner et al. 1994). The frequency and magnitude of disturbance events over time define the disturbance regime for an area. The disturbance regime largely defines the conditions in which native species adapt—plants and animals have evolved to cope with environmental perturbation (Reeves et al. 1995).

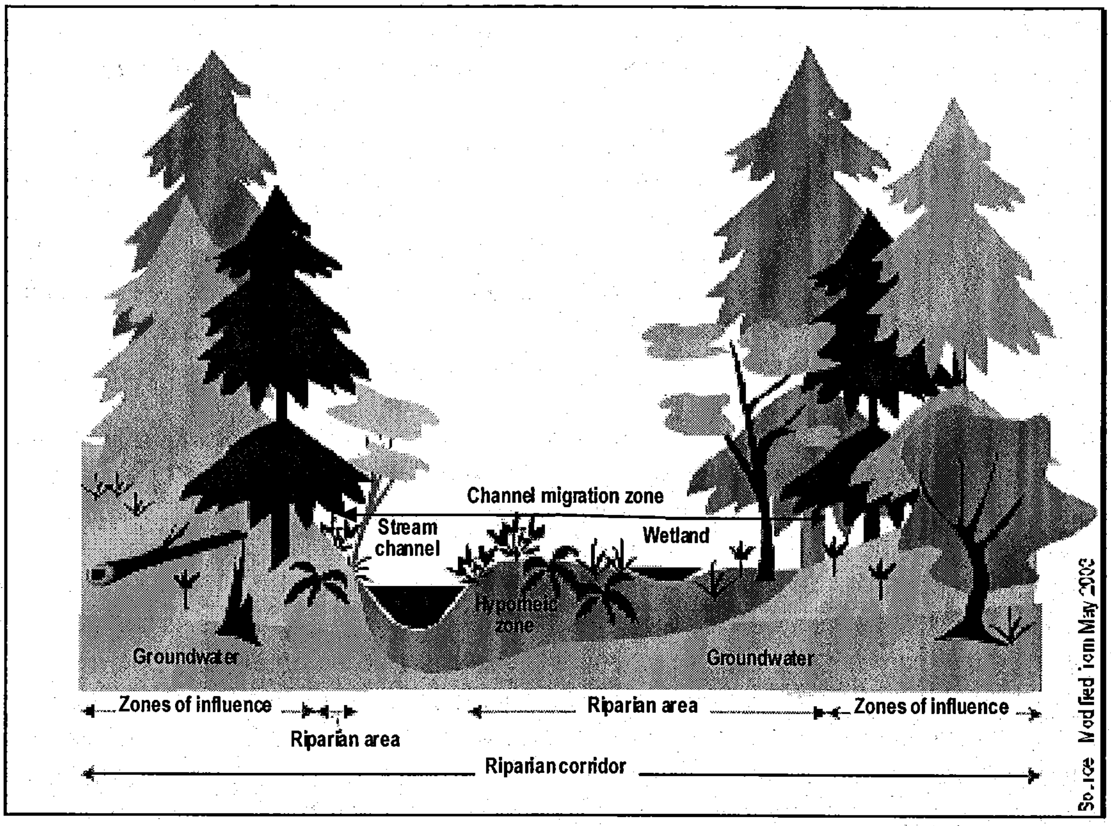

Figure 5-1. Typical stream and riparian zones.

Management efforts to suppress natural disturbances have often resulted in less biodiversity and ecosystem health (Averill et al. 1995); the literature refers to these actions as human-induced disturbance because they also stress the stream corridor and affect its ecological structure and function.

The majority of the degraded basin conditions in Bellevue are attributed to human-induced disturbances such as impervious surfaces, piped streams segments and urban encroachment into riparian areas (Bellevue 2003b). These human-induced disturbances affect the infiltration and movement of water and alter the structure of plant communities and soils—thereby alter riparian functions and values (Bellevue 2003a).

Natural disturbances increase biological diversity while human-induced disturbances decrease biological diversity (Averill et al. 1995); therefore, managers should strive to address human-induced disturbances through in stream corridor restoration. Flooding, drought, diseases, insects, and wind affect streamside areas located within Bellevue where streamside vegetation is present and streams are not piped. Habitat structure in the riparian area could be improved by allowing these potential disturbance processes to occur and, following the occurrence of disturbances, by not removing snags or downed trees but rather retaining them.

Metapopulations are groups of local populations that are distributed across a heterogeneous landscape and genetically linked by dispersal of individuals (Hanski 1991; Hanski and Gilpin 1991). Metapopulation theory directly links populations to the natural disturbance regimes that shape landscape structure and function. The linkage is the balance between the extinction of local populations after severe habitat disturbance and the subsequent recolonization of previously disturbed habitats as they recover. This extinction-colonization balance depends on the dispersal of individuals and the connectivity between habitats occupied by populations making up the metapopulation. If the frequency of disturbance that degrades a species' habitat exceeds its ability to maintain a balance between extinction and recolonization, the individual populations and eventually the entire metapopulation will go extinct (Opdam 1991).

Metapopulation theory has only recently been used to interpret salmonid population structure and ecology and to formulate management strategies (National Research Council 1996; Independent Scientific Group 1996). The core-satellite model describes the structure of Pacific salmon metapopulations (Li et al. 1995; Schlosser and Angermeier 1995; Independent Science Group 1996). Core populations are large, usually occupying extensive and productive habitats. Under natural conditions, core populations are expected to persist indefinitely. Core subareas are river and stream systems that are the primary spawning grounds for core population. Satellite subareas are marginal habitat occupied by satellite populations. The abundance of satellite populations may fluctuate widely in response to changes in climate, and they may go extinct after severe disturbance events. Salmon will disperse from a large core population and will colonize vacant habitat, reestablishing satellite populations and generally minimizing the possibility of total extinction of the metapopulation (Harrison 1994). Degraded habitat conditions in core subareas may lead to satellite populations supporting core populations. In this case, identifying and protecting all areas that support core populations and satellite populations is critical to prevent the extinction of the metapopulation and to ensure the possibility of recovery.

The Washington Conservation Commission (2001) identifies Kelsey Creek as a satellite subarea which supports local chinook core populations in the Greater Lake Washington Basin. Protecting and restoring habitat forming processes in Kelsey Creek is important to ensuring the survival of the Kelsey Creek satellite population and the core population of the Greater Lake Washington Basin.

5.1.2 The River Continuum Concept

Vannote et al. (1980) proposed the river continuum concept to describe freshwater habitat and the importance of various physical, chemical, and biological processes. According to the river continuum concept the distribution of stream characteristics reflects a headwater to mouth gradient of physical conditions that affect the biological components in a river including the location, type, and abundance of food resources with a given stream size. For example, the productivity of small streams is more dependent on riparian vegetation for their nutrients than larger streams which are dominated by primary production (Vannote et al. 1980). Overall the river continuum concept describes how the influence of riparian and landscape factors varies depending on stream size and how biological communities might change from headwater streams to larger rivers.

Vannote et al. (1980) also examined the role of aquatic areas along the river continuum that are fishless or isolated. Aquatic areas with no fish or potential for fish can occur in hydrologically connected waters or isolated waterbodies. In the case of small streams originating as spring seeps, water flows sometimes go underground before making a surface connection with a fish-bearing streams. In other situations there are lakes and ponds that have no surface connection to a fish-bearing stream or have waters that are unsuitable for fish (e.g., bogs that are too acidic). Regardless, isolated or otherwise fishless isolated waters can be used extensively by other animals, especially amphibians and macroinvertebrates for breeding, rearing, or refuge (Muchow and Richardson 2000). When these waters infiltrate below ground they contribute to the local aquifers that may ultimately supply fish-bearing waters with cool, clean ground water. Consequently fishless and isolated waters can function as habitat for non-fish species and indirectly provide for the water quality and hydrologic functioning of waters with fish.

In summary, the river continuum concept illustrates the importance of riparian vegetation for small streams and the functions and values of fishless aquatic areas. Within Bellevue the majority of the stream systems are small and several fishless areas are documented in the Stream Inventory Report. Small streams are highly dependent on organic matter deposited by the riparian forest, such as leaves, bark, and wood for nutrient inputs and therefore riparian vegetation along small streams should be maintained. Maintaining riparian vegetation around fishless aquatic areas is also vital to protect the function and values of these habitats for aquatic organisms, water quality and hydrologic functions.

5.1.3 Channel Migration Zone

The channel migration zone (CMZ) is the area where the active channel of a stream is prone to move laterally within the floodplain over time (May 2003). Fish and wildlife are dependent on the habitat created when a river is allowed to migrate. For example, gravel and vegetation that falls into rivers as they migrate create spawning areas and provide nutrients for salmonids. Usually, channel migration is a gradual process; however, it can occur abruptly through a process called avulsion (Dunne and Leopold, 1977). The primary ecological process that drives channel migration is flooding which delivers large volumes of water, sediment, and large woody debris (LWD). The process of flooding in an area has the potential to fill, create, or sustain stream habitat—the most commonly affected habitats during flooding are side channels and oxbow ponds.

Identification of CMZs requires site-specific analysis by qualified fluvial geomorphologists. However, in some instances, the CMZ can be roughly approximated by the 100-year flood zone as mapped by FEMA. The 100-year flood plains within the City of Bellevue have been mapped and are shown in Figure W-1 in the 2003 *Bellevue Critical Areas Update Wetland Inventory*. Kelsey Creek is the largest creek in Bellevue and it is likely to have an extensive CMZ in unconfined portions of the drainage. In other smaller streams flowing in ravines or narrow valleys of Bellevue the CMZ may be non-existent. CMZ functions should be considered when developing protective strategies for riparian functions and values.

Providing protection for channel migration zones goes beyond protecting existing habitats and focuses on the processes that create and maintain that habitat. Urban development near streams often leads to a reduction or loss of habitat forming processes associated with the CMZ due to concerns about flood hazards. Where flood control structures, including dikes, levees, or roads are constructed to control the flow of water and reduce flood hazards in an area; spatially these structures decrease the potential habitat quantity and quality formed in the CMZ. Channel migration zones are further discussed in Chapter 3 Frequently Flooded Areas of this report.

5.1.4 Hyporheic Zone

The hyporheic zone lies under the floodplain in a shallow unconfined aquifer that is hydraulically connected with a stream or river. The hyporheic zone typically extends for a considerable distance laterally across the width of the floodplain and many yards beneath the surface of the ground. Aquatic invertebrates depend on the extensive intergravel habitat of the hyproheic zone for refugee during droughts and high-flow events. After such events, invertebrate populations in the hyproheic zone are capable of replenishing the population in an area. Likewise salmonid fish species depend on hyporheic flows for the success and survival during intergravel developmental stages (Baxter and Hauer 2000). Urban development above the hyporheic zone may result in a reduced exchange of dissolved oxygen and nutrients between surface and subsurface waters and between aquatic and terrestrial ecosystems, thereby reducing the functionality of the hyporheic zone for invertebrates (Naiman and Bilby 1998; PSMFC 1999).

In summary the hyporheic zone in urbanized basins within Bellevue are expected to provide surface and ground water interactions influencing water chemistry but more importantly they provide functional habitat for invertebrates (refuge) and developmental habitat for salmon (inter-gravel incubation).

The sustainability and restoration of the habitats and species require protection and restoration of the ecological processes that sustain them in addition to direct protection of the habitat themselves. Without adequate habitat protection, development will cause reductions in the amount and complexity of habitat; increased scouring of the stream channel; reduction or loss of channel migration, sediment supply, and LWD recruitment; and decrease productivity and species diversity (Bolton and Shellberg 2001).

There are a number of strategies for implementing protection and restoration for stream and riparian systems. These include creating a classification system to identify streams and protect riparian ecosystems, establishing buffer zones, designating structures setbacks, and establishing buffers for piped streams.

The following sections provide management strategies based on best available science for protecting the functions and values of streams and riparian systems. The recommendations are strongly influenced by anadromous fish needs. The rationale and other supporting statements are based on previously cited literature in the 2003 streams inventory report and BAS streams paper; however, statements based on new information are referenced by citations.

5.2 Stream Typing System

Stream typing and designation is necessary to protect riparian and stream functions, processes and values. The typing and designation of streams allows for the development of regulations to address processes that are relevant to specific types and sizes of streams. For example, the river continuum concept demonstrates the importance of fishless waterbodies—stream typing will allow for the application of appropriate protections strategies to these areas.

The GMA states that "counties and cities should use the classification system established in WAC 222-16-030 to classify waters of the state." Since the completion of the previous BAS review (Bellevue 2003a), the stream classification used by Washington Department of Natural Resources (DNR) has been modified. DNR in cooperation with the Departments of Fish and Wildlife (WDFW) and Ecology, has prepared a draft map described in and based upon the classification system established in WAC 222-16-030. The new DNR typing system classifies waters by fish, wildlife, and human use, as well as the physical characteristics of the drainage basin (e.g., basin size, gradient, and elevation).

Adoption of the DNR classification system by local jurisdictions is not mandatory—GMA grants counties and cities discretion in the method by which they choose to classify, designate, and protect critical areas, including streams. However, if a county or city opts to use an alternate water classification system, it must show that the system classifies fish habitat. The City of Bellevue presently uses a riparian corridor classification system to identify riparian areas but lacks a traditional stream typing system similar to other local jurisdiction to classify stream types. The present riparian classification system is heavily based on stormwater conveyance and not the elements described in WAC 222-16-030; therefore, the City should consider adopting a new system that recognizes all stream functions or revise its' current system to better reflect the range of stream functions.

5.2.1 Review of the Literature

The DNR water typing system places streams into four major categories: S, F, Np, and Ns. The typing is based on a multi-parameter, field verified geographic information system logistic regression model. The model is habitat-driven and uses geomorphic parameters such as basin size, gradient, elevation, and other indicators to determine the end of fish habitat locations. The modeled end of fish habitat is considered in the waterbody classification rather than the presence or absence of any particular species of fish. Currently DNR is finalizing classifications for individual waterbodies. The following is a summary of the state's type system, based on WAC 222-16-030:

- Type S include waters within ordinary high-water marks, inventoried as "shorelines" of the state under chapter 90.58 RCW but do not include such waters' associated wetlands as defined in chapter 90.58 RCW.
- Type F include all segments of natural waters (other than type S waters) within the bankfull widths of defined channels or within lakes, ponds, or

impoundments having a surface area of 0.5 acre or greater at seasonal low water. These waters are described as having fish habitat or by one of the following three categories if it does not contain fish habitat:

- 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.
- Waters which are within a federal, state, local, or private campground having more than 10 camping units.
- Waters which are diverted for use by federal, state, tribal, or private fish hatcheries.

- Fish habitat means habitat that is used by fish at any life stage at any time of the year including potential habitat likely to be used by fish that could be recovered by restoration or management and includes off-channel habitat. Fish habitat will be established based upon a multi-parameter, field-verified, peer-reviewed GIS logistic regression model using geomorphic parameters such as basin size, gradient, elevation and other indicators.
- Type N include all segments of natural waters other than type S or F waters within the bankfull widths of defined channels and which are either perennial streams or physically connected by an above-ground channel system to downstream waters such that water or sediments initially delivered to such waters will eventually be delivered to a type S or F water.

The state's water typing systems established under WAC 222-16-030 meets the state's best available science requirements (as related to the classification of aquatic habitats) because it is based on fish habitat requirements and it therefore protects habitat for salmonids. Native communities of aquatic organisms also share similar habitat requirements as salmonids (TFW LWAG 1998); therefore protection will be provided for a wide spectrum of aquatic species.

5.2.2 Identification of Data Gaps

The state will not designate stream types within the City of Bellevue. Each stream should be divided into distinct stream segments based on fish habitat. The Stream Inventory Report (Bellevue 2003b) documents streams with salmonid habitat rather than streams with fish habitat. The presence of fish habitat will need to be determined for streams, if the City elects to use the state's classification system.

5.2.3 Recommendations

Consider adopting the typing system adopted by the Washington state legislature for streams and other waterbodies (WAC 222-16-030). The system is based on providing fish habitat and therefore offers protection for ESA listed species. Adoption of the proposed typing system would ensure the appropriate and functional designation of all natural waterbodies within Bellevue. Waterbodies with fish, which are currently designated as type A, B, C, or D riparian corridors, would be separated as either shorelines of the state (type S) or waterbodies with fish habitat (type F). The only stream designated as shorelines of the state within Bellevue is Kelsey Creek east of I-405. The proposed system provides a means to designate type F waterbodies based solely upon physical and geomorphic characteristics (e.g., channel width, gradient, size of contributing basin), which simplifies the designation process for fish habitat. Waterbodies without fish habitat would be designated by flow regime as perennial (type Np) or seasonal (type Ns).

Adoption of the state typing system will ensure consistency with the GMA and subsequently provide protection for ESA listed chinook species.

5.3 Stream Buffers

The terms "buffer" or "stream buffer" are often loosely used as synonyms for riparian areas. However, the term buffer is typically applied in a specific management context to denote an area set aside and managed to protect a natural area from the effects of surrounding land-use or human activities (May 2003; Knutson and Naef 1997). Depending on the context, buffers may be designed to perform a specific function or set of functions, such as filtering pollutants or providing shade (May 2003). The use of the term "stream buffer" in this report and the recommendations therein are directed to protect the area needed for the ecological functions of streams.

Buffer widths associated with a stream are intended to protect an area of sufficient size to provide functions considered important for protecting aquatic processes, riparian species and to buffer against development impacts. Riparian vegetation within stream buffers provide nutrients that sustain the principles of the river continuum concept and the spatial scale of buffer provides lateral space for the channel migration and hyporheic zones.

Stream buffer designation is necessary to protect aquatic area processes and functions. The typing and designation of streams using the stream typing system allows for the development of stream buffer regulations that address functions that are relevant to specific types of streams. For example, the stream typing system separates aquatic areas with fish habitat from those without fish habitat; therefore the stream buffer regulations for fishless areas can be specific to meet the needs of these areas (note: the river continuum concept demonstrates the importance of fishless waterbodies).

A City code outlining requirements for stream buffers is one tool for maintaining the functions, processes and values of streams and salmonid habitat as described in the 2003 Stream Inventory Report and Stream BAS Paper. The 2003 Stream Inventory concluded that riparian areas in the City of Bellevue have been extensively modified due to urbanization. All of the City's stream basins were rated "high" for the number of riparian breaks indicating that buffer functions are highly compromised due to alterations in the longitudinal integrity or connectivity of the riparian corridor. Riparian breaks can be reduced using regulations or incentives that address the protection, enhancement, and restoration of riparian corridors.

5.3.1 Review of the Literature

The 2003 BAS stream paper provided a review of riparian functions as a factor of buffer width. Table 5-1 is a summary of buffer width requirements from the literature as documented in the BAS stream paper to protect stream and riparian system functions. As indicated in the BAS stream paper, there is no consensus in the literature recommending a single buffer width for a particular function or to accommodate all functions. Knutson and Naef (1997) resolved the variability in the literature by averaging effective buffers widths reported for specific riparian functions. Table 5-2 illustrates the results of the Knutson and Naef (1997) literature review and shows that a buffer width of 147 feet is effective in providing 5 of the 7 riparian functions including: sediment filtration, erosion control, pollutant removal, LWD, and water temperature protection.

Table 5-1. Riparian buffer functions and appropriate widths identified by May (2003).

Riparian Function	Range of Effective Buffer Widths (feet)	Minimum Recommended Widths (feet)	Notes on Function
Sediment Removal/Erosion Control	26 – 600	98	For 80% sediment removal
Pollutant Removal	13 – 860	98	For 80% nutrient removal
LWD Recruitment	33 – 328	164	1 SPTH based on long-term natural levels
Water Temperature	36 – 141	98	Based on adequate shade
Wildlife Habitat	36 – 141	328	Coverage not inclusive
Microclimate	148 – 656	328	Optimum long-term support

Table 5-2. Riparian functions and appropriate widths identified by Knutson and Naef (1997).

Function	Range of Effective Buffer Widths (feet)	Average of Reported Widths (feet)
Sediment filtration	26 – 300	138
Erosion Control	100 – 125	112
Pollutant Removal	13 – 600	78
LWD Recruitment	100 – 200	147
Water Temperature Protection	35 – 151	90
Wildlife Habitat	25 – 984	287
Microclimate	200 – 525	412

5.3.1.1 Site Potential Tree Height Concept (SPTH)

Much of the work regarding adequate riparian buffer widths has been based on site-potential tree height, defined as the height that mature trees in a climax forest will reach given local conditions (Sedell et al. 1996; Pollock and Kennard 1998). SPTH is considered the maximum horizontal distance from which LWD will be recruited to the stream by falling trees.

The Federal Ecosystem Management Team (FEMAT) while assessing riparian protection strategies for national forest lands first proposed the STPH concept. FEMAT reasoned that tree height is a good scaling factor for buffers because they are a dominant factor determining habitat conditions and their heights reflect inherent productivity and constraints of a site when left unmanaged. FEMAT documents that when buffer widths equivalent to one SPTH are established, a variety of ecological functions are protected including shade, litter fall, root strength and a potential LWD recruitment. Additionally, FEMAT proposed that a buffer width equivalent to three SPTH would fully protect microclimate functions (soil moisture, radiation, soil temperature, air temperature, wind speed, and relative humidity).

The actual height that a dominate tree would grow at a site depends on the species, soils, climate, and disturbance history of a site (Sedell et al. 1993). Pollock and Kennard (1998) provide that SPTH for Douglas fir ranges from 198 to 218 feet for two riparian plant association groups on the Mount Baker-Snoqualmie National Forest. SPTH data are not readily available for other trees, such as western red cedar, or sitka spruce, which can be as tall or taller than Douglas fir, depending on site conditions, or for black cottonwood, red alder and bigleaf maple, which are smaller in maximum height and therefore would likely have smaller SPTH values than for Douglas fir. There is a lack of mature trees along most streams within Bellevue; and little information on dominant riparian vegetation or species diversity; however, there is a mixture of deciduous and coniferous forest occurring along some streams within Bellevue (Bellevue 2003b).

Soil surveys conducted by the U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS), provide site indexes for tree height. Site indexes are based on certain tree ages and the local soil characteristics. The information provided by NRCS is limited to growth achieved in 50 or 100 years and thus do not represent a true SPTH for longer lived species such as Douglas fir. The dominant soils within Bellevue are Alderwood soils (Bellevue 2003c). NRCS reports a site index of 146 feet for a 100-year-old Douglas-fir growing on Alderwood soils (USDA 1973). A tree height of 146 feet is equal to roughly 67 to 74 percent of the SPTH provided by Pollock and Kennard for mature forest. The literature supports that 100 years provides adequate time for the growth of a tree to a size which is capable of functioning as LWD (Franklin and Thomas 1983; Montgomery et al. 2003). Furthermore, studies have shown that more than half of all large woody debris is recruited from within 15 feet of streams, and about 90 percent comes from trees growing within about 50 feet of streams (McDade et al.1990; Van Sickle and Gregory 1990). Therefore, the growth of a tree at 100 years at a distance of 146 feet perpendicular to a stream channel is adequate for LWD recruitment within Bellevue's streams.

Table 5-3 is a summary of buffer width requirements in terms of SPTH to protect ecological functions. Generally speaking a buffer width roughly equal to one SPTH will provide the ecological functions necessary to support salmonids and most stream ecosystems; the exception to one SPTH distance is wildlife habitat and microclimate processes which may need much larger areas. As stated previously soil maps for the Bellevue area indicate that a 100-year-old Douglas fir tree would be 146 feet. Using 147 feet as a standard buffer width for streams would be consistent with buffer width requirements for riparian functions identified by Knutson and Naef (sediment filtration, erosion control, pollutant removal, LWD recruitment and temperature regulation – see Table 5-2) and buffer width requirements identified using the SPTH concept.

Table 5-3. Riparian function and appropriate widths identified from FEMAT (1993).

Function	Number of SPTH	Equivalent Based on SPTH of 200 (feet)
Shade	0.75	150
Microclimate	Up to 3	Up to 600
LWD Recruitment	1.0	200
Organic Litter	0.5	100
Sediment Control	1.0	200
Bank Stabilization	0.5	100
Wildlife Habitat	0.5 to 3.0	98-600

5.3.1.2 Three- and Two-Zone Buffer Width Approach

Besides using a single fixed buffer width prescription tailored after the SPTH concept there are other options for protecting streams using buffers. The Three-Zone Buffer Concept provides a framework for thinking about the establishment and maintenance of long-term stream buffers. Zone 1 is adjacent to the water's edge and Zone 3 is the outermost area from the stream. The important function of Zone 1 is to protect the physical integrity of the stream ecosystem; acceptable uses in Zone 1 include flood control, utility right of way and footpaths. Zone 2 is designed to provide distance between upland development and the innermost zone; Zone 2 is for uses such as outdoor recreation, bike paths and wildlife habitat. The outer zone or Zone 3 prevents encroachment and filters surface water runoff; allowable uses in Zone 3 include unrestrictive residential uses such as lawn, gardening and compost piles (Stormwater Center 2004) but excluding structures. All three zones provide wildlife habitat.

The 2003 BAS Stream Paper discussed the Two-Zone Buffer Concept and used the Snohomish County system as an example. The Snohomish buffer system separates the traditional buffer zone into two areas, an inner "no touch" zone and an outer "management zone." The Snohomish County system recognizes that the land directly adjacent to streams has the potential to offer higher levels of functions and values than areas farther from the stream. This method reflects, in large part, the findings of literature reviews that show many of the critical functions of riparian areas occur in those areas directly adjacent to streams and that the ability of the buffer to provide beneficial functions and values plateaus at a given distance (relative to the function that is the focus of the investigation). Under the Snohomish County system, the interior one-half of the regulated area, known as the "buffer," is managed to allow very limited disturbance. A higher level of alteration or use is allowed in the outer one-half of the regulated area, known as the "management zone," but more intensive development is still discouraged.

In summary, riparian areas (native vegetation adjacent to streams) provide numerous ecological functions and resource management benefits. Establishing buffers adjacent to streams is one way to protect and maintain riparian area functions and benefits. The ability of a buffer to provide multiple functions and benefits is closely linked to its width but other factors such as slope, vegetation, soil type, buffer design, and buffer management also determine its effectiveness. Riparian forest studies discussed in this report correlate buffer widths to riparian functions. Tables 5-1, 5-2, and 5-3 summarize relevant literature by providing a range of buffer widths for achieving each riparian function.

A vegetated stream buffers established using the SPTH concept can adequately provide the ecological functions necessary to support salmonids and most aquatic area processes. Aquatic area processes such as nutrients from the river continuum and natural disturbances such as flooding will continue to function along small streams protected with buffer widths established using the SPTH concept. Because much of the riparian forests in Bellevue are significantly modified it is necessary to reference the historical conditions of forests to determine the height of mature dominant tree species under normal local growing conditions.

5.3.2 Identification of Data Gaps

The majority of scientific studies that critically examine the functions and values associated with stream buffers have been conducted in forested environments. As such, fundamental differences between forested and urban areas, including land use (zoning) and hydrology (stormwater conveyance systems), are not considered. Moreover, there is a lack of literature concerning the scientific basis for using riparian buffers as landscape structures in maintaining landscape-level processes such as natural disturbances within urban areas.

5.3.3 Recommendations

Establishing buffers adjacent to streams is one way to protect and maintain riparian areas and thereby the functions and values they provide. Based on the literature review, adequate buffers can be established using the SPTH concept, which is consist with the literature review and other best available science reviews by local jurisdictions. For example, a buffer width of 147 feet on each side of a stream is effective in providing sediment filtration, erosion control, pollutant removal, LWD recruitment, and water temperature protection is (May 2003). Similarly, a buffer width equivalent to one SPTH provides a variety of riparian ecological functions including shade, litter fall, root strength (stabilizes streambanks), and potential for LWD recruitment. The height of a site potential tree for a mature Douglas-fir tree for the types of soils found within the City of Bellevue is 146 feet. Both 147 feet and 146 feet are within the range of recommended buffers for shade, water temperature, erosion control, removal of sediment and pollution, and LWD recruitment. Three times the height of a site-potential tree (438 feet) would provide effective wildlife habitat and microclimate functions.

Narrower buffers can provide some ecological functions. A 100-foot buffer vegetated with native plant species would provide approximately 80 percent of sediment and pollutant removal functions but inadequate LWD recruitment potential (see Table 5-1). In general, larger buffer widths provide greater environmental protection and resource management benefits. The City should consider what functions are desired of buffers and choose a buffer width requirement that would provide those benefits. Based on the river continuum and natural disturbance concepts, important ecological function occur along small streams protected with buffer widths established using the SPTH approach. Therefore, the selected buffer width should be applied to all waterbody types regardless of whether fish species are present.

In general, a buffer width meeting the SPTH concept will provide the ecological functions necessary to support salmonids and most aquatic area processes; however, additional protective regulations to protect the functions of the stream buffer are discussed in a section on setbacks which follows.

Stream buffers should be measured from the CMZ if one is present. If a CMZ is not present, the measurement should be made from the ordinary high water mark (OHWM). The CMZ is an area where natural riverine processes are allowed to distribute sediment, recruit woody debris, and provide high quality habitat for salmonids and other wildlife. Vegetation management in the CMZ should be regulated consistent with DNR Forest and Fish Rules. The Forest and Fish Rules [222-30-020(12) WAC)] have been determined by NOAA Fisheries to be consistent with the best available science for protection of endangered species (NOAA Fisheries 2003).

Within the City continuous buffers are not possible in most areas due to existing development. Alternatively, buffer width designs may allow for averaging buffer widths to improve the protection of functions and values of streams. No scientific information is available to determine if averaging widths of buffers actually protects stream functions. In general buffer averaging should only be considered under the following three conditions:

1. The total area of the buffer after averaging is equal to the area required without averaging;

2. Low intensity land uses will be adjacent to the reduced buffer widths;

3. Stream functions and/or values will not be adversely impacted.

Furthermore, if buffer averaging is permitted, buffers should still include the structure setbacks recommended in the following section.

5.4 Setbacks

Structure setbacks provide protection to aquatic area processes and riparian functions and values by increasing the distance between human activities and the stream buffers which protect riparian functions. Stream buffers sustain riparian functions and stream processes while the structural setbacks protect stream buffers from urban encroachment. The recommended stream buffer widths in the previous section will provide for adequate riparian functions along Bellevue's streams; however, this adequacy is closely linked to absence of active urban encroachment adjacent to and within the stream buffer. Structure setbacks are areas adjacent to stream buffers where buildings and other facilities are not constructed; however, these areas may allow low impact activities such as gardening and lawns.

5.4.1 Review of the Literature

As stated in the previous section buffers are areas set aside and managed to protect a natural area from the effects of surrounding land-use or human activities (May 2003; Knutson and Naef 1997). The scientific literature supports the maintenance of stream buffers as restricted-use zones to provided ecological functions necessary to support salmonids and most aquatic area processes (Knutson and Naef 1997).

Encroachment of human land-use activities into the stream-riparian ecosystem has the potential to degrade the structural and functional integrity of aquatic systems (May 2003). Land uses adjacent to stream buffers such as residential development or commercial development may degrade the quality of riparian functions due to light, noise and human intrusion (Leavitt 1998). The degree of these disturbances within the riparian area may preclude some of its ecological functions. Higher intensity land uses, such as high-density residential development or commercial development, located adjacent to stream buffers could result in greater impacts than lower density single-family residential uses (Leavitt 1998). As the degree of disturbance increases, the loss of functions increases (e.g., loss of LWD recruitment; Christensen et al. 1996). Hence, a structure setback is needed in order to prevent disturbance of the riparian functions occurring within the stream buffer.

A structure setback in conjunction with a stream buffer is recommended in the literature in order to limit disturbance to riparian functions that occur within the buffer. The most often recommended structure setback to buffers is an additional 25 feet (Illinois Environmental Protection Agency 1996). May (2003) recommends that "the type and intensity of the surrounding land-use determine the additional [protective buffer] width required to protect the [stream buffer]". Land uses that present greater risk of damage to aquatic ecosystem include high-density residential, commercial, or industrial; May (2003) states that these areas merit larger structure setbacks.

5.4.2 Identification of Data Gaps

The characterization of land uses adjacent to streams was not reported in the 2003 stream inventory report. This information is needed in order to merit additional protection to specific segments of streams which present greater risk of damage to stream functions and values.

5.4.3 Recommendations

A structure setback to stream buffers can prevent disturbance of the riparian functions that are integral to stream. A structure setback of 25 feet to the stream buffer is the most commonly recommended setback in the literature (Illinois Environmental Protection Agency 1996). Structure setbacks are recommended along all water types within Bellevue due to the extensive degradation of all its riparian areas.

5.5 Piped Stream Buffers

In the City of Bellevue, streams segments have been placed in pipes to accommodate development. Piped stream segments limit available habitat, can inhibit fish movement, migration, and prohibit fish from accessing upstream habitats. Piped stream segments that do not prevent fish migration may still limit many aquatic area processes necessary for salmonid fish production including riparian functions (Bellevue 2003a) and aquatic area processes.

Establishing buffers adjacent to piped streams is a means of preserving space and, when available, natural forest conditions for future opportunities to daylight piped stream segments and return streams to surface flows. Although much of Bellevue is built out and piped streams segments are typically located in paved areas, planning for buffers on piped stream segments will allow for future stream restoration opportunities while providing adequate buffer protection. Restoring piped streams to a more natural condition by opening segments and providing stream buffers may improve overall watershed conditions for aquatic resources by reestablishing aquatic area processes and functions. Some of the potential benefits of restoring streams to surface flows include improvements to the functional values of waterways and urban stormwater systems through increased hydraulic capacity for flood control, lowering of water velocities to reduce downstream erosion, and removal of water from combined sewers thereby improving water quality. Additionally restoring piped stream segments can reestablish the processes sustained by interactions between streams and adjacent riparian areas in which salmonids and other aquatic resources rely on such as regulating temperatures, sources of LWD, and aquatic areas processes described in this report (i.e., natural disturbance, river continuum concept, hyporheic zone and channel migration zones).

5.5.1 Review of the Literature

A review of projects that restored buried streams to surface flows provides a framework to examine buffer widths for piped streams. Pinkham (2000) summarized a range of projects that reestablished surface flows to buried stream channels. The primary technical elements to consider when restoring a channel to the surface are channel design and floodplain. Whether the channel meanders and if it has an associated floodplain will determine what buffer widths around a piped stream would be adequate for restoring the stream to a surface flow. Consideration should also be given to the potential for CMZ and buffer width requirements. This will ensure that all necessary ecological functions are provided, once the stream piped segment is restored.

5.5.2 Identification of Data Gaps

The locations of piped stream segments are not plotted against current land uses within Bellevue. This information will be needed to evaluate potential environmental benefits of daylighting streams and would provide rationale to support establishing set aside buffers for future projects to restore piped stream segments. The scientific literature does not provide a recommendation for buffers adjacent to piped streams.

5.5.3 Recommendations

There is no scientific justification for establishing buffers adjacent to piped streams to maintain current functions. Establishing piped stream buffers is a matter of preserving future restoration opportunities. Restoring fish passage by daylighting stream segments is an effective way to increase the quality and accessibility of habitat and can result in relatively large increases in potential fish production at a nominal cost (Roni et al. 2002). If the City would like to establish stream buffers to protect piped streams that will be daylighted in the future, the buffer width can be based on the SPTH concept. A structure setback of 25 feet from the buffer of daylighted stream segments would be adequate.

5.6 Stewardship Program

Stream buffers and structure setbacks separate streams from uplands and surrounding development, protecting streams from human encroachment. The purpose of a stewardship program is to provide opportunities to establish or mitigate stream buffer widths in areas where is it not possible. A stewardship program can include incentives that improve the conditions of degraded stream buffer and streams functions and values.

Site-specific conditions or land-use constraints may necessitate that a reduced stream buffer be designated along streams. For example, a stream may flow through an already developed area, with roads, homes, and other structures currently limiting the extent of the riparian corridor. In these cases, riparian quality may be degraded significantly. Riparian areas along Bellevue's streams are extensively modified due to urbanization and all of the streams rate high for the number of riparian breaks (Bellevue 2003b). Stream buffers and structure setbacks may not be effective in some of these areas.

5.6.1 Review of the Literature

The analysis of buffer width functions in the literature are based on areas vegetated with native plant communities (Table 5-1). Sparsely vegetated or vegetated buffers with non-native species may not perform the needed functions of stream buffers. In cases where the buffer is not well vegetated, it is necessary to either increase the buffer width or require that the standard buffer width be revegetated (May 2003). Until the newly planted buffer is established the near term goals for buffer functions may not be attained. Newly established buffers do not provide desired riparian buffer functions such as species migration, sediment filtration, or nutrient and woody debris inputs (Knutson and Naef 1997).

One of the greatest impacts of urbanization on wildlife species comes from riparian breaks and habitat fragmentation (May 2003; Stenberg et al. 1997). The concept of metapopulation contributes to an understanding of how isolated remnant habitat parcels make utilization and recolonization difficult or impossible for wildlife species. Habitat fragmentation that prevents the source and sink dynamics of the metapopulation concept to occur may result in permanent loss of populations due to the lack of connectivity. This is of particular concern for species with low mobility such as amphibians (Richter 1995). The restoration of degraded areas to habitat used by fish and wildlife is needed to rebuild healthy fish and wildlife populations.

Instream restoration projects should be planned carefully in the context of basin-wide conditions. In one study of 15 streams in Oregon and Washington, more than half of instream LWD restoration structures failed before the expected lifetime of 20 years (Frissell and Nawa in McClean 2000). Roni et al. (2002) reported highly variable results; some studies suggested that 85 percent of wood remains in place and contributes to habitat formation. Often in urban systems, more engineered methods of bed and bank stabilization may be necessary to address high hydraulic forces, space constraints, and infrastructure and property protection restrictions (Miller et al. 2001).

5.6.2 Identification of Data Gaps

The City of Bellevue will need to examine locations in basins where a restoration program would be appropriate and select locations and activities so that restoration efforts match conditions downstream.

5.6.3 Recommendations

Landowners should be educated on the importance of protecting and maintaining stream buffers and encouraged to take an active role in stewardship. Instream channel restoration in addition to riparian restoration may improve the functions and values of streams. Restoration opportunities are identified in the following section.

5.7 Additional Approaches to Protecting Salmonids

Best available science of what constitutes salmonid habitat is still evolving. It is currently shifting from site-specific structures and ecological functions to aquatic area and landscape-scale processes (e.g., natural disturbances, hyporheic zones, and core populations) that shape and maintain salmonid habitat and populations. These changes in what we consider stream habitat and how salmonids use that habitat are important to consider when developing policies. The simple application of prescriptive buffers may not be adequate to restore urban streams because most of the source functions of buffers have been compromised by past land use actions

(Bellevue 2003a). Additionally, along most urban streams it will be difficult to restore LWD recruitment due to the difficulties in restoring mature forests. Actions will need to occur that maintain or restore ecological processes, functions, and the natural disturbance regimes along streams.

Management and restoration of habitat must also consider the whole watershed and ecological processes for salmonids to complete their life histories. It may be necessary to develop new watershed-based strategies that address hydrology, water quality, and riparian functions to successfully address the issue of riparian areas and adequate buffers in the context of basin-wide change. Some restoration opportunities to improve Bellevue's streams include:

- Designing and installing LWD to provide hydraulic refuge areas during peak flows in Lakehurst, Yarrow, South Sammamish, and Lewis Creek.
- Planting native coniferous trees in the riparian areas along all of Bellevue's streams. The first priority should be the mainstem of Kelsey Creek.
- Reducing invasive non-native plants along stream reaches with salmonids use.
- Modifying existing culverts that are partial barriers by placing low-flow deflectors on multi-channel box culverts to increase depth of low-flow channel.
- Replacing culverts that are barriers to fish passage.
- Restoring and enhancing degraded wetlands to restore off-channel and riparian wetland habitats along stream segments.

Furthermore, the City of Bellevue may consider identifying projects that would allow unimpeded access to all potential natural spawning and rearing habitats for all life stages of the Kelsey Creek satellite chinook salmon population. Specific action alternatives to restore and protect fish habitat for the Kelsey Creek population are outlined by the Lake Washington, Cedar, and Sammamish Watershed Steering Committee (WRIA 8 Steering Committee 2002).

5.8 Conclusion

This summary of the best available science for developing policies and regulations to protect the functions and values of stream and associated riparian areas is based on peer-reviewed research; Bellevue's 2003 *Critical Areas Update, Stream Inventory Report;* Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Streams*; symposia literature; technical literature; and other scientific information related to streams. The review focused on recommended conservation or protection measures to preserve or enhance anadromous fish species and habitat that is important for all life stages of anadromous fish. Best available science for stream and riparian protection, particularly safeguarding the processes that protect riparian functions, varies in terms of quantity, quality, and local relevance. The best available science for stream and riparian protection is neither complete nor consistently covers all functions, and it remains an active field of research. Table 5-4 summarizes the best available science positions on stream and riparian area protection and provides general recommendations for the City of Bellevue.

Human development of land and water typically affects stream functions and processes in profound ways, ultimately affecting the type and abundance of existing species. Sustaining natural functions and processes is essential to maintaining stream habitats and the species that rely on them. Streams are formed and sustained by many important physical and biological processes which include but are not limited to:

- Natural disturbances
- Hyporheic zone interactions
- Habitat-forming processes
- Stream/riparian interactions within the channel migration zone.

Natural disturbances sustain species diversity and create habitat. The hyporheic zone provides surface and ground water interactions, influencing water chemistry, sustaining refuge habitat for invertebrates, and providing developmental habitat for salmon. The channel migration zone allows for habitat creation and sustainability by providing lateral areas for streams to migrate across the floodplain (see Figure 5-1). Because of the unique mix of water and biodiversity, stream and riparian areas are used by a broad range of species including by humans for recreational and aesthetic activities, fishing, and the enjoyment of natural beauty and solitude.

The sustainability and restoration of habitats and species requires the protection and restoration of the ecological functions and processes that sustain them, in addition to the direct protection of the habitats themselves. Without adequate habitat protection, development will produce the following conditions in streams and riparian areas:

- Reductions in the amount and complexity of habitat
- Increased scouring of stream channels
- Reduction or loss of channel migration, sediment supply, and the recruitment of large woody debris
- Decreased productivity and species diversity.

Water body typing and designation are necessary for protecting stream and riparian functions, processes, and values. The classification of water bodies allows for the development of regulations to address functions and processes that are relevant to specific types of water bodies. The Growth Management Act (Section 5.c.vi of WAC 365-190-080 Critical Areas (vi) Waters of the state) states that counties and cities should use the classification system established in Washington Administrative Code, Chapter 222-16, Section 030 (WAC 222-16-030) to classify

Table 5-4. Summary of best available science findings and general recommendations for protecting streams.

Protection Mechanism	Best Available Science Review	General Recommendations
Adopt a stream typing system to address processes that are relevant to specific types of streams and fish habitat.	The DNR water typing system considers fish habitat rather than presence or absence of fish species.	Adopt the DNR stream typing system.
Implement riparian structure setbacks which protect an area of sufficient size to provide riparian and aquatic processes and functions, protect riparian species, and buffer against development impacts.	The effectiveness of a buffer to provide multiple functions and benefits is linked to its width and other facts such as slope, vegetation characteristics, soil type, buffer design and buffer management. Many of the critical functions of riparian areas occur in those areas directly adjacent to streams and plateaus at a given distance. Buffer width established using the site potential tree height (SPTH) concept can provide the ecological functions necessary to support salmonids and most riparian and aquatic functions and processes.	The developed character of the City makes adoption of fully protective buffers impractical therefore adoption of buffers that provide the greatest riparian functionality is advised. Measure riparian structure setbacks from the channel migration zone or ordinary high water mark.
Provide stewardship programs as incentives to restore and protect riparian functions where stream buffers are not possible.	Processes and functions provided in the literature for buffers are based on areas vegetated with native plant species at densities of native plant communities. Sparsely vegetated or vegetated buffers with non-native species may not perform the needed functions of stream buffers.	Educate landowners on the importance of protecting and maintaining stream buffers. The City should provide partnerships with landowners for riparian restoration projects.
Increase the distance between human activities and stream buffers.	High-density residential, commercial, and industrial land-uses often necessitate wider structure setbacks from aquatic ecosystems to better protect streams from the higher levels of disturbances associated with more intensive land uses.	A 25-foot structural setback to stream buffers along all water types is preferred when possible to prevent disturbance of riparian functions.
Restore fish habitat and passage by daylighting stream segments.	The primary technical elements to consider when restoring a channel to the surface are channel design and floodplain.	Establish piped stream buffers based on buffer widths meeting the SPTH concept and, when possible include a 25-foot structural setback. The preserved land area will provide space for daylighting a stream segment. The developed character of the City may preclude this protective mechanism in many areas.
Implement restoration and enhancement strategies to improve or prevent additional degradation of riparian habitat.	Watershed-based strategies that address hydrology, water quality, and riparian functions are the most successful in addressing riparian areas and adequate buffers in the context of basin-wide change.	Restore degraded riparian areas using strategies which emphasize the whole watershed and ecological processes which include the following: ▪ Design and install LWD ▪ Plant native coniferous trees along streams ▪ Reduce invasive non-native plants along streams ▪ Replace or modify culverts which prevent fish passage ▪ Restore and enhance wetlands to restore off-channel habitat.

waters of the state. Waters of the state are defined in Title 222 WAC, the forest practices rules and regulations. Counties and cities are expected to use the classification system established in WAC 222-16-030 to classify waters of the state. WAC 222-16-030 outlines the state's classification for water bodies into three categories: Type S waters (shorelines of the state), Type F waters (fish habitat), and Type N waters (nonfish habitat). The current Bellevue riparian corridor classification (Type A-D) does not readily align with the proposed state system.

Should the City of Bellevue adopt the classification system for streams and other water bodies established by WAC 222-16-030, it will ensure consistency with the Growth Management Act and the permit requirements of state agencies. Adoption of the state's classification system will also protect the chinook salmon, a species that is protected under the Endangered Species Act because under the recommended stream typing system, stream segments classified as Type S or Type F waters could receive additional stream buffer protection.

Stream buffers are necessary to protect the functions and processes of riparian and aquatic areas. Current scientific research indicates that stream buffer requirements are best established using the site-potential tree height concept (SPTH). The height of a site potential tree for a mature Douglas-fir tree for the types of soils found within the City of Bellevue is 146 feet. A similar size buffer width of 147 feet on each side of a stream is identified in the literature as effective in providing sediment filtration, erosion control, pollutant removal, LWD recruitment, and water temperature protection. Smaller buffers may protect some level of functional effectiveness but would not be expected to fully protect stream and riparian area functions.

The stream buffer should be a "no-touch zone" in which minimal activities occur so that the ecological functions of the stream are protected. A structure setback of 25 feet is preferred, whenever possible in addition to the stream buffer to act as a regulated transition area. The structure setback should be measured from the edge of the buffer.

Buffers are also recommended for segments of piped streams in Bellevue, particularly when they are fish bearing. Piped stream segments limit available habitat, can inhibit resident fish movement and anadromous fish migration, and prevent fish from accessing upstream habitats. Piped stream segments that do not prevent fish migration may limit many aquatic processes necessary for salmonid fish production. Establishing buffers adjacent to piped streams is a means of preserving space and, when available, natural forest conditions that will allow for future opportunities to restore piped stream segments to surface-flowing streams. Although much of Bellevue is built out and piped stream segments typically are located in paved areas, planning for buffers on piped stream segments will allow for future stream restoration opportunities while providing adequate buffer protection. The stream buffer for piped stream segments can be based on a buffer width meeting the SPTH concept in addition to a structure setback of 25 feet in areas where possible.

Stewardship programs are recommended non-regulatory measures to assist in the protection and restoration of functions and values of streams and associated riparian areas. Stewardship programs often provide incentives that encourage property owners to improve degraded stream buffers and instream habitat. Examples of rehabilitation activities sponsored by a stewardship program may include matching grants to remove invasive nonnative plant species and reestablishing stream buffers with native coniferous trees.

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Chapter 6. Wetlands

Wetlands provide important functions and values for both the human and biological environment—these functions include flood control, water quality improvement, and habitat. This paper builds on the information provided in the 2003 *Bellevue Critical Areas Update and Best Available Science paper: Wetlands*. It includes a review of available peer-reviewed research, inventory reports, symposia literature, technical literature, and other sources of scientific information relevant to wetlands. Important gaps in information are noted where applicable. General recommendations are provided where appropriate.

6.1 Functions and Values

A comprehensive overview of important wetland functions is provided in the *Bellevue Critical Areas Update Best Available Science paper: Wetlands*. In general, wetlands provide a number of different and often critical environmental and ecological functions benefiting humans (Kusler and Opheim 1996; NRC 1992, 2001), including flood storage and retention, ground water discharge/recharge, maintaining and protecting water quality, and providing habitat for important fish and wildlife species, including some federally and state threatened and endangered species, as well as for a wide diversity of important invertebrates, amphibians, birds, furbearers and small mammals. Studies of wetlands in the Puget Sound lowland found that the diversity of birds (Richter and Azous 2001a) and small mammals (Richter and Azous 2001b) in wetlands may exceed that found in upland habitats. Because of the unique mix of water and biodiversity, wetland areas are also used for a broad range of recreational and aesthetic activities including hunting and the appreciation of natural beauty and solitude.

The capacity of a particular wetland for performing a specific function is dependent on (1) wetland characteristics (e.g., size, morphometry); (2) adjoining environment; (3) watershed characteristics; (4) position of wetland in the watershed; and (5) greater landscape condition (Mitsch and Gosselink 1993; Keddy 2000; Fairbairn and Dinsmore 2001; NRC 1991, 1995, 2001, 2002). Typically, wetlands adjoining forests and other natural habitats exhibit high diversity of plants and wildlife because of their sheltered condition and joint use by aquatic as well as upland species (Mitsch and Gosselink 1993; Keddy 2000; Azous and Horner 2001).

Hydrology is the single most important determinant of the establishment, characteristics, and maintenance of specific types of wetlands and wetland processes (Mitsch and Gosselink 1993). Consequently, direct impacts to hydrologic functions such as a change in flow from dredging or the partial filling of a wetland effects flood storage and secondarily effects water quality functions. Changes in these functions produce alterations in vegetation which sometimes affect wildlife use. Similarly, if wetlands are altered to increase their flood control functions they will often exhibit flashy water level fluctuations, which affect vegetation associations (Azous and Richter 1995; Azous and Cooke 2001), the presence and character of amphibian communities (Azous and Richter 1995), and whether waterfowl will successfully breed (Euliss and Mushet 1996).

Wetland conditions may appear to remain relatively stable over short time frames; however, periodic disturbance can be essential to maintain some functions (NRC 1995; Middleton 1999) while also directing a wetland's evolution and subsequent functions (Middleton 1999). Disturbance can also undermine the inherent functional benefits that wetlands provide, if the frequency of disturbance is exceeded beyond a wetland's natural capacity and threshold (Horner 1995; Horner et al. 2001).

For example, hydrological benefits such as flood control are functions of a wetland's water-storage. However, if flooding events occur more frequently than the normal historical range, sediment loading may increase, plant communities may change, and water-storage may ultimately decrease. Consequently, the impacted wetland may no longer provide the flood control benefits exhibited by the preexisting wetland. Moreover, altered flood regimes may also change the ability of a wetland to provide water quality enhancement. Water quality enhancement can be maintained only as long as the wetland vegetation is dense enough to reduce the flow velocity, allowing sediments to settle out and pathogens to be immobilized; and as long as the wetland contains diverse enough plant species to enable the plants to incorporate nutrients and detoxify toxins (Mitsch and Gosselink 1993). If wetland plant communities are disturbed too frequently, the wetlands may no longer effectively improve water quality and may themselves become polluted, discharging contaminants to streams, lakes, ponds, and wetlands or transferring contaminants to aquifers.

Wetland protection means maintaining the ecological integrity of wetlands so their functions remain self-sustaining. Consequently, hydrological processes, ground water interactions, water quality enhancement, species and habitat support, and other existing functions need to persist in perpetuity, though they may vary somewhat from year to year or decade to decade within a single wetland.

6.2 Wetland Size Exemptions and Allowed Variances

6.2.1 Review of the Literature

Exempting small wetlands from regulatory protection is an issue that has gained increased attention over the past 10 years. Many regulations have preferentially allowed for filling of small wetlands because size is one of the most common characteristics used in determining wetland ratings at the local level. Regulatory priorities have focused on protecting larger wetlands and not protecting the smaller, seasonal wetlands that are often critical components of wetland complexes (Naugle et al. 2001). The loss of small wetlands is one of the most common cumulative impacts on wetlands and wildlife (Weller 1988; Tiner 2002).

In addition to the obvious loss of habitat for wildlife, fragmentation of habitat increases as small wetlands are removed, resulting in greater distances between wetlands in the landscape. Semlitsch and Bodie (1998) found that creating greater distances between wetlands can have a significant effect on the ability of a landscape to support viable populations of amphibians, as juveniles dispersing from a source wetland may not be able to travel far enough to recolonize other surrounding (now distant) wetlands. Regulatory practices that focus on protecting large wetlands at the expense of smaller wetlands ignore source-sink dynamics and other aspects of metapopulation processes and may weaken conservation of habitat for wetland dependant species (Richter and Azous 1995; Semlitsch 2003). While large wetlands can be diverse and productive, small wetlands are critical elements of the landscape, serving as refugia and providing a source of recruitment for species, and providing connectivity to both other small and large wetlands. Small wetlands may be critical to amphibian metapopulation dynamics by providing an important source of juvenile recruits and connectivity between remaining populations. In King County, small and isolated wetlands exhibited equal or greater amphibian species richness than larger wetlands (Richter and Azous 2001c). Therefore, protecting larger wetlands to a greater degree than smaller, often hydrologically isolated wetlands, may not insure the protection of all species (Richter and Azous 1995).

Wetland size is often correlated with habitat complexity (e.g., vegetation diversity, open water) and insulation from disturbance (Milligan 1985; Brown and Dinsmore 1986; Hruby et al. 1999; Richter and Azous 2001a). Wetland habitat complexity alone, regardless of other conditions such as wetland size may account for the higher avian diversity found in larger wetlands (Milligan 1985; Martin-Yanney 1992). Groups of smaller wetlands in proximity to each other also exhibit large bird-species diversity (Brown and Dinsmore 1986). Moreover, Richter and Azous (2001a) found that the highest bird richness at the most diverse of 19 wetlands only represented 65 percent of the regional biodiversity suggesting that the avifauna of each wetland, regardless of size and other characteristics, was essential for maximum regional biodiversity.

Snodgrass et al. (2000) determined that amphibian species richness increases with length of hydroperiod and not wetland size. They also concluded that smaller temporarily ponded wetlands are also important in maintaining biological diversity in that they support species not found in larger wetlands with longer hydroperiods. The species they found in small wetlands were not a subset of those in larger wetlands but rather a unique group of species.

Similarly, amphibian richness in Puget Sound wetlands was found to have no correlation with wetland size. High richness occurred in some of the smallest wetlands (Richter and Azous 1995). The study indicates that small wetlands that are vegetatively simple can serve adequately as breeding habitats as long as favorable nonbreeding habitat is present nearby.

Gibbs (1993) conducted a simulation model in Maine from which she theorized that small wetlands may be most important for wetland organisms with low population growth rates and low densities. The model demonstrated that the loss of small freshwater wetlands would result in a 19 percent decline in total wetland area and a 62 percent decline in the number of wetlands, while the average distance between wetlands would increase by 67 percent (Gibbs 1993).

The model showed that the loss of small wetlands would result in a decline in the probability (from 90 percent to 54 percent) that a wetland would lie within the maximum migration distance of terrestrial-dwelling and aquatic-breeding amphibians. The study indicated that the risk of extinction would significantly increase for local populations of turtles, small birds, and small mammals with the loss of small wetlands in the landscape.

The study that modeled the effects of the loss of small wetlands in Maine showed that local populations of small mammals faced a significant risk of extinction following the loss of small wetlands (Gibbs 1993). In a study of Puget Sound wetlands, Richter and Azous (2001b) concluded that wetland size alone was not a predictor of mammal richness or abundance. They noted that small mammal richness was determined by the combined factors of wetland size, the extent of retention of forest adjacent to the wetland, and the quantity of large woody debris within the wetland and its buffers.

6.2.2 Identification of Data Gaps

Data on the number and extent of permitted wetland and buffer alterations, mitigation requirements, and mitigation success are unavailable.

6.2.3 Recommendations

The City of Bellevue allows a number of activities within a wetland or wetland buffer that are inconsistent with recommendations suggested by best available science. These include the building of roads, utilities, and other essential infrastructure. Exemptions to wetland protection regulations for all wetlands types are also allowed if no other on-site development possibilities are available. This allows for continued encroachment on wetlands and their functions. Data describing the extent to which these activities impact wetland functions and whether they are adequately mitigated is unavailable. Incrementally and collectively these allowed alterations likely continue to erode the wetland base in Bellevue, and therefore reduce the multiple functions wetlands provide. Consequently, the exemptions and allowed alterations to wetlands and their buffers are not consistent with best available science for wetland protection if they lead to incremental, cumulative losses in wetland area, functions and values. Conditions on allowed alterations may lessen these impacts but do not mitigate for their losses.

If wetlands under a certain size are exempted from mitigation or variances are allowed which affect wetland area or functions, the decision is best made after reviewing the information generated from a landscape analysis for the geographic area that would be affected by the wetland loss. It may be important to limit the total acreage of wetlands affected by exemptions or variances within a subbasin.

6.3 Wetland Functional Assessment Methods

6.3.1 Review of the Literature

Wetland functions are defined as processes that occur within a wetland, such as the storage of water, cycling of nutrients, and maintenance of diverse plant communities. Wetland functions can be grouped together into three broad categories: habitat functions, hydrologic functions, and water quality functions.

Wetlands are well known for their habitat functions, which benefit wildlife. Wetlands provide food, water, and shelter for fish, shellfish, birds, and mammals, and they serve as a breeding ground and nursery for numerous species. Hydrologic functions are those related to the quantity of water that enters a wetland, is stored in a wetland, or leaves a wetland. Hydrologic functions include reducing the velocity of stormwater, recharging and discharging ground water, and providing flood storage. Water quality functions include the potential for removing sediment, nutrients, heavy metals, and toxic organic compounds.

The goal of no net loss refers to both wetland acres and wetland function, as the functions contribute to the watershed where the wetland is located. Therefore, when setting compensatory mitigation goals, the functions of a wetland proposed for fill need to be precisely characterized and, if possible, quantified, as should the functions of the proposed compensatory mitigation project. Even if the mitigation goal does not seek in-kind replacement of functions, functional assessment provides a foundation for considering the watershed consequences of out-of-kind mitigation. Functional assessment helps determine whether the location and design of a compensation wetland will secure the functions that are emphasized for the watershed (NRC 2001).

Complete characterization of a compensatory mitigation site requires an assessment of the level of performance attainable for each wetland function under different site designs. This would include consideration of various natural hydrological, geochemical, and ecological attributes and processes. In addition, functional assessment of prospective compensation sites will help establish the design and the monitoring and assessment procedures for the wetland to be created or restored.

Most wetland scientists argue that science-based, regionally standardized procedures are preferable to best professional judgment in comprehensively evaluating wetland function for both impacted and mitigation sites. The general absence of a uniform approach to assessing wetlands as multifunctional ecosystems have likely encouraged less complex wetland mitigation designs and rudimentary measures of achieving mitigation goals.

In the mid-1990s, the Corps and Natural Resources Conservation Service (NRCS) agreed to the formal adoption of the hydrogeomorphic (HGM) approach as a uniform procedure for functional assessment in the Clean Water Act's Section 404 program and the U.S. Department of Agriculture programs (Smith et al. 1995). Because it is exclusively based on wetlands and not social processes and has applicability at both the watershed and the landscape scales, HGM was generally accepted by wetland scientists. It was seen as particularly applicable to wetland mitigation because target hydrology could be based on the influence of water sources, wetland type, and the relative ease or difficulty of establishing certain hydrological regimes (NRC 2001).

Another of the recognized strengths of HGM is the assessment of functional performance based on a domain of reference systems that capture the presumed optimum natural function. Reference sites enable the precise identification of specific wetland attributes and processes for the mitigation site (e.g., hydrologic functions in terms of saturation duration, depth, and frequency not only seasonally but also annually). In addition, fundamental incorporation of reference wetlands suggests that assessments can be sensitive to regional variations in the functional performance of hydrogeomorphic subclasses. However, in one respect, HGM and similar assessment procedures are still deficient at assessing the effect of wetland mitigation at the landscape scale. Although they may effectively assess the functions of a wetland site in a hydrogeomorphic, landscape setting, these procedures will not necessarily examine whether the development of a wetland will reduce the functional value of adjacent wetlands or put at risk significant other areas (NRC 2001).

All wetland functional assessment methods do not directly measure ecological function; rather, they rely on structural indicators (e.g., vegetation diversity, dominance, maturity, and degree of interspersion) as surrogates of function. For example, the presence of mature trees (based on diameter), and tree type (conifer vs. deciduous) may be used as an indicator of habitat available for cavity nesting birds (Thomas et al. 1979). Most HGM based methods are a significant improvement over previous methods that relied primarily on the judgment of the ecologists with limited scientific basis (World Wildlife Fund 1992).

6.3.2 Identification of Data Gaps

There remains great variation in the sophistication, repeatability, and scientific foundation of wetland functional assessment methods and most methods still require refinement, calibration, and validation to closely represent wetland functions (Smith et al. 1995; Hruby 1999).

6.3.3 Recommendations

The City of Bellevue regulations governing wetlands (Bellevue Land Use Code, Title 20, Part 20.25H.110.B) do not specify what methods are appropriate for evaluating wetland functions. A preferred method would generate parametric and dimensioned units, rather than nonparametric rankings. The same functional assessment method used for evaluating functional losses to a wetland should be used to evaluate the functions gained at the mitigation site. Hruby et al. (1999) provides methods that are suitable to the predominantly riparian and depressional wetlands found within Bellevue.

6.4 Wetland Rating System

6.4.1 Review of the Literature

Jurisdictions such as the State of Washington and Bellevue typically have wetland classification schemes that are the foundation of their wetland regulatory programs, although, using ecological criteria for their classifications, these agency arrangements differ significantly from the ecologically based systems such as that developed by the U.S. Fish and Wildlife Service (Cowardin et al. 1979) in that ecological traits are used to rank wetlands according to their relative value. Moreover, these ranked classifications are then directly tied to suggested or required wetland protection measures (Bartoldus 1999). These systems allow ecologically diverse wetland systems to be ranked by a limited number of criteria and then categorized for management purposes.

Bartoldus (1999) summarized 40 different tools that had been developed (up until 1998) that are used to rate wetlands for purposes of regulating and managing wetlands. Although many different rating tools have been developed, there are no analyses of the effectiveness of rating systems at protecting wetland resources. There is an inherent assumption that better protection for wetlands is provided with improved understanding of wetland functions and values (e.g., Roth et al. 1993; National Research Council 1995). But the scientific rigor required to understand the functions and values of wetlands is often time consuming and costly. Therefore, regulatory uses tend to require tools that provide some information on the functions and values of wetlands in a time- and cost-effective way. Categorization methods, such as rating systems, are relatively rapid but can still provide some scientific rigor (Hruby et al. 1999).

Ecology developed a wetland rating system for Western Washington in the early 1990s that was based on the agency's understanding of wetland science at the time. That rating system has been revised to incorporate more recent scientific information. However Ecology's revised ranking and classification system remains heavily weighted towards habitat functions.

Nevertheless, local governments are encouraged to use the state's rating system because it was developed by a team of wetland specialists and local planning staff to ensure both scientific validity and administrative feasibility. If a city uses its own rating system, it is likely that, if state or federal permit or approval is needed, the wetland will also need to be rated under the state system. This duplication of effort could increase costs for applicants while offering no scientific or protective benefits to wetlands.

A wetland rating system is a useful tool for dividing wetlands into groups that have similar needs for protection. Wetlands occur in a wide variety of locations as a result of very different influences (geomorphology, geology, water source, etc.) and have a wide range of characteristics that contribute to different types and degrees of functions. Wetland rating systems allow for tailoring of protection standards to the specific needs of different types of wetlands. They offer a scientifically defensible approach to assigning protection standards as well as provide a significant degree of predictability for applicants. For example, buffer widths and mitigation replacement ratios can be calculated based on a wetland's rating. A wetland rating system should divide wetlands into categories based on an understanding of how wetlands function and how they are affected by human activities. A rating system should use clear criteria for determining wetland categories and include methods for making category determinations. Without detailed methods it is not possible to consistently apply rating criteria. The primary factors that should be used to rate wetlands are:

- The **rarity** of the wetland type
- The **irreplaceability** of the wetland type
- The **sensitivity** of the wetland type to adjacent human disturbances
- The **functions** performed by the wetland type.

6.4.2 Identification of Data Gaps

There is no data substantiating that Ecology's revised wetland rating system has improved protection of wetland functions.

6.4.3 Recommendations

The City of Bellevue's existing wetland rating system ranks wetlands only on size and hydrologic connectivity. The system does not consider other important factors such as the rarity, replaceability, sensitivity, or the functions performed by a wetland. Use of the April 2004 revised Washington State Wetland Rating System for rating wetlands within the city will address these factors as well as provide consistency with other jurisdictions and state guidance.

6.5 Buffer Widths

6.5.1 Review of the Literature

Currently, the most common and widespread method of wetland protection is the application of fixed protective buffers (NRC 2001). The purpose of a buffer is to protect wetland functions from detrimental impacts created by adjoining land use, either existing or expected. Buffers are fixed regulatory constructs, demarcated by policy-determined distances such as 100 or 200 feet from the water's edge (Raedeke 1988b). In contrast, ecologically defined buffers would be determined based on the area needed to protect riparian areas; these are lands transitional between terrestrial and aquatic ecosystems that are distinguished by gradients of biophysical conditions, ecological processes and biota through which surface and subsurface waters connect with their adjoining uplands (NRC 2002). These often extend beyond administrative boundaries. Fixed-width, administrative buffers may not protect wetland integrity in the long-term. Buffer widths based on wetland functions, however, would significantly help in wetland conservation.

Wide ranges of buffer widths are recommended by scientists and engineers for the protection of wetlands and their respective functions (Brown et al. 1990; Castelle et al. 1992a; Castelle et al. 1994; McMillan 2000). In general, narrower buffers are suggested or required by regulatory agencies than what are specified by best available science (see Table 6-1). In Washington state, the Shoreline Management Act (SMA), the Water Pollution Control Act (WPCA) and the Growth Management Act (GMA) all provide for some degree of protection for wetlands through suggested buffer widths. However, some scientists suspect none of these laws adequately protect all wetland types and functions (McMillan 2000).

In Washington, protection varies considerably. The Department of Ecology (DOE) suggests buffers of 50 feet for Category IV to 300 feet for Category I wetlands (Washington State Office of Community Development 2002). In Bellevue, current regulatory protection provides no buffer for Type C wetlands, a 25-foot-wide buffer for Type B wetlands, and a 50-foot-wide buffer for Type A wetlands. Additionally, the City of Bellevue requires a 15-foot and 20-foot-wide structure setback from the edge of the buffer. However, a number of permitted uses are allowed within the structure setback, including the removal of native vegetation.

Recent literature suggests that buffers alone, although important to help minimize impacts, might be insufficient to fully safeguard all the varied functions of wetlands (Correll 1997; McMillan 2000; Thom et al. 2001). Buffer effectiveness and benefits also have been found to vary depending on their widths, vegetation, wetland functions, and geographic context (Castelle et al.

Table 6-1. Summary of wetland buffer width performance.

Protected Function	Citation	Buffer Width (ft)	Buffer Vegetation	Reported Performance
Water quality	Young et al. 1980	82	Grass	Sediment 92%
	Young et al. 1980	89	Grass	Nitrogen 84%
	Horner and Mar 1982	200	Grass	Sediment 80%
	Dillaha et al. 1989	13-30	Grass	Sediment 84%, phosphorus 79%, nitrogen 73%
	Magette et al., 1989	16-30	Grass	Nutrients <50%
	Schwer and Clausen 1989	85	Grass	Concentrations: sediment 45%, phosphorus 78%, Total Kendall N 76%, ammonia 2%
	Ghaffarzadeh et al., 1992	30	Grass	Sediment 85%
	Madison et al. 1992	16	Grass	Nitrate and orthophosphorus 90%
	Young et.al. 1980	115	Grass	Microorganisms <1,000/100 ml.
	Grismer 1981	100	Grass	Fecal Coliform 60%
	Schellinger and Clausen 1992	75	Grass	Fecal coliform 30%
	Chaubey, 1994	80	Grass	Nitrate 96%, phosphorus 88%, sediment 80%, bacteria 0%
	Mickelson et al. 1995	16-30	Grass	Herbicides 28-72%
	Arora et al. 1996	65	Grass	Herbicides 8-100%, sediment 40-100%
	Daniels and Gilliam 1996	20-59	Grass	Ammonia 20-50%, nitrate 50-90%, phosphorus 60%, orthophosphorus 50%
	Nichols et al. 1998	59	Grass	Estrogen 98%
	Lee et al. 1999	10-20	Grass	Sediment 66-77%, total-N 28-42%, nitrate 25-42%, total-P 37-52%, orthophosphorus 34-43%
	Lee et al. 2000	23-52	Mixed	Sediment 70-90%, total-N 50-80%, nitrate 41-92%, total-P 46-93%, orthophosphorus 28-85%
	Lynch et al. 1985	100	Forest	Sediment 75-80%
	Shisler et al. 1987	62	Forest	Nitrogen 89%, phosphorus 80%
	Lowrance 1992	23	Forest	Nitrate (groundwater) 100°/a
	Doyle et al. 1997	100	Forest	Nitrogen 98%
	Cooper and Gilliam 1987	52	Forest	Phosphorus 50%
	Peterjohn & Correll 1984	62	Forest	Phosphorus 74%
Amphibian breeding, feeding and cover habitat	Richter 2003	3,281 1,600 1,000	Forest	99% 85% 75%
	Semlitsch and Bodie 2003	521 - 951	Native Vegetation	
	Raymond and Hardy 1991	984	Forest	100 %
Reptile breeding, feeding and cover habitat	Semlitsch and Bodie 2003	416 - 948	Native Vegetation	No value provided
Bird habitat	Richter and Azous 2001d	1,640	Forest	100 % species richness of birds that avoid human activities
	Cronquist and Brooks 1993	82	Forest	100 % species richness for sensitive passerine species
Mammal breeding, feeding and cover habitat	Richter and Azous 2001b	1,640	Forest	100 % species richness

1992). Specifically, wetland hydrology, ground water recharge/discharge and plant and animal habitat functions may not be well protected by buffers alone because these functions are in large part driven by adjoining area and larger watershed conditions (Reinelt et al. 1998; Azous and Cooke 2001; Richter and Azous 2001a). Under some rare circumstances in which buffers are degraded, such as having erosive soils and little or no vegetation, buffers may even be detrimental, in that they may provide sediment sources to lakes, ponds, and wetlands as opposed to removing them (Dillaha and Inamdar 1997).

Fixed buffer regulations assume that buffers are diversely vegetated strips of land surrounding wetlands that provide appropriate protection. However, fixed buffers may vary widely in their characteristics and ability to protect wetland functions. For instance, buffer areas may include bare soil, grasslands, cleared forests, second growth forests or even old-growth forest, each offering a different type and level of protection. Evidence also suggests that in urban locations local residents and other people encroach on or alter buffers such that there is increased risk to wildlife and other functions and therefore the buffer no longer provides the intended protection for wetland functions (Milligan 1985; Baker and Haemmerle 1990).

A review of buffer functions conducted by King County (2004) found that that buffers of 300 feet or less and regardless of characteristics, are unable to maintain their existing characteristics because they are vulnerable to climatic influences from adjacent areas. Predominantly, windthrow affects edge trees that often fall from sudden and unaccustomed exposure to wind. Moreover, wind, humidity, temperature and other microclimatic conditions will change within buffers of less than 300 feet, potentially leading to greater levels of drying and hence changes in soil fungi and invertebrates, surface litter and organic condition, flora, and fauna. There are a large number of studies reporting relationships between buffer widths and water quality improvement (e.g., reduction of sediments, nutrients, pathogens, toxins, water temperatures) but only a small number of studies relating buffer widths to hydrologic, ground water recharge/discharge and various vegetation and wildlife habitat functions. Ground water interaction in wetlands is largely determined by surficial geology and land use setting, although buffer widths may also influence this process (Dunne and Leopold 1978). The hydrology of wetlands in high recharge areas of outwash soil with deep organic matter and vegetative complexity may be sustained by a sufficiently wide buffer. However, in bedrock and till areas with low organic soils and sparse vegetation structure fixed buffers may not protect wetland hydrological functions. In these situations, protecting watershed characteristics, especially infiltration areas, organic soils, and diverse native vegetation is critical.

Wetland dependent wildlife habitat protection is best achieved through a landscape approach to wetlands protection which considers wetlands in context of a mosaic of wetland and upland habitat patches across which organisms move, settle, reproduce, and eventually die (Forman and Godron 1986). This approach can reduce wetland isolation and fragmentation by providing protection of populations and metapopulation dynamics. The landscape approach should also include protecting the watershed to manage stormwater flows. Reductions in vegetative cover greater than 35 percent and impervious areas that exceed 10 percent within a watershed potentially alters its hydraulic characteristics resulting in increased water level fluctuations, which can decrease plant and animal diversity (Schueler 1994; Hicks 1995; Reinelt et al. 1998; NRC 2002).

Buffers may filter water prior to entering wetlands depending on slope, vegetation, and width (McMillan 2000). Specifically, sediments and sediment-borne pollution may be expected to be trapped by fixed buffers although the success of buffers will depend on dispersed rather than concentrated flows, steepness of slope, soil permeability, and vegetation cover (Desbonnet et al. 1994). Ideal filtering conditions of gradual slopes, organic soils, and forest and grass-vegetated buffers slow flow velocities (Mitsch and Gosselink 1993). Buffers also control particulate phosphorus associated with sediments. However, dissolved nitrogen and phosphorus, although taken up by vegetation, nevertheless are less effectively controlled by buffers. To enable 80 percent of total sediments and heavy metals to settle out, buffers need to be between 100 and 200 feet (Horner and Mar 1982; Lynch et al. 1985). Herbicides and pesticides require greater distance for attenuation whereas pathogens (fecal coliforms) and estrogens are not as readily filtered out. Summaries of the effectiveness of various widths of vegetated buffers and their effectiveness in pollutant removal as well as in wetland wildlife protection are provided in Desbonnet et al. (1994), Castelle et al. (1992), Castelle and Johnson (2000), McMillan, (2000), NRC (2002), and Fuerstenberg (2003) and King County (2004).

Buffers of less than 50 feet are generally ineffective at screening out human disturbance to wetlands (Cooke 1992). Shisler et al. (1987) found that buffers 45 to 100 feet are most effective at protecting wetlands and wildlife (Desbonnet et al. 1994) from disturbance in areas of low-density land uses (agriculture, recreation, and low-density residential housing). Buffers of 100 to 150 feet were recommended for minimal protection of wetlands and wildlife from adjacent high-intensity land use—high-density residential, commercial/industrial development (Shisler et al. 1987; Desbonnet et al. 1994). However, other studies indicate that larger buffers, on the order of 400 feet to 1,600 feet, may be needed to prevent disturbance of wildlife, particularly amphibians and mammals (Richter 2003; Semlitsch and Bodie 2003; Raymond and Hardy 1991; Richter and Azous 2001b and 2001c).

The buffers required to protect habitat are usually larger than those needed to protect other functions such as water quality improvement. The hydrologic functions of flood storage, ground water recharge, and reducing erosion are not significantly influenced by the width of the buffer. These functions need to be protected at the scale of the watershed or sub-basin in which the wetland is found.

Sheldon et al.'s (2003) review of wetland buffer literature indicates that buffers necessary to protect wildlife habitat functions of wetlands range from 100 to 600 feet or more. One synthesis recommended a buffer of 300 feet as adequate to protect most species found in wetlands in western Washington that are adjacent to high-intensity land uses (Castelle et al. 1992).

Wetlands with important wildlife habitat functions should have protected connections to other natural habitats in order to successfully support a wide range of species. The best available science literature repeatedly identifies fragmentation and the disruption of the vegetated corridors between undeveloped areas as a major cause of the loss of species richness (biodiversity). Protecting wetland wildlife also entails protecting existing natural area connections and corridors.

Particularly in urban areas, the simple application of prescriptive buffers may not be adequate to protect urban wetlands because most of the source functions of buffers have been compromised by past land use actions. Due to the type and degree of cumulative impacts to urban wetlands (and streams) that have already occurred as a result of high levels of past disturbance to wetlands, it may be necessary to develop new strategies to successfully address the issue of adequate buffers in the context of basin-wide change (Booth 2000; Azous and Horner 2001; Booth and Reinelt 1993).

Several conclusions regarding the use of buffers for the protection of wetland functions can be extracted from the national and local literature. These include the following:

- Protection of wetlands is context and scale driven. That is, wetland protection is dependent on the functions of wetlands and the condition of ecological processes in adjoining areas as well as the greater watershed and landscape area.
- Protection of wetland functions is currently achieved primarily through the use of buffers. Buffers alone, although necessary in many cases, may be insufficient to completely protect important functions unless exceptionally large.
- Fixed-width vegetated buffers between 50-200 feet significantly reduce most pollutants entering wetlands (exceptions are microorganism and pharmaceuticals).
- Fixed-width buffers of 50-300 feet play mixed roles in protecting ground water interaction functions.
- Fixed-width buffers of 50-300 feet play marginal roles in permanently protecting fish and wildlife habitat functions of wetlands.
- Protection of wetland complexes is important to stem wetland isolation and habitat fragmentation, two consequences of development leading to decreased species richness and local extinctions of plant and wildlife species at wetlands.

6.5.2 Identification of Data Gaps

Specific information relative to wetlands in Bellevue does not exist regarding effectiveness of existing buffers adjacent to wetlands in protecting wetland functions.

6.5.3 Recommendations

In general, best available science suggests that wetland functions are minimally protected by fixed buffers of 25 to 100 feet within an urbanizing area.

Provide a minimum of 100 feet of buffer for all Class A, B or C wetlands in Bellevue that are rated a Category I, II or III using Hruby (2004). Where possible provide a minimum 200 foot buffer for those wetlands rated as a Category I or II by Hruby (2004). Best available science suggests that the majority of water quality functions can be achieved within a 100-foot buffer. Type A wetlands are associated with Bellevue's creeks and lakes and provide important wildlife functions as well as water quality and hydrologic functions. A buffer of 200 feet for wetlands rated as Category I or II would allow adequate area for water quality treatment and a buffer area sufficient to grow trees for the long-term recruitment of woody debris to support wetland and buffer habitat functions. However, a 200-foot buffer would not provide the same level of protection for wetland-dependant wildlife in Bellevue as that provided by a 300-foot or greater buffer.

Much of Bellevue is built out and there are few remaining opportunities to provide wetland buffers that are greater than 100 feet. The City may achieve a comparable or better level of wetland protection by developing a plan to link remaining wetlands and pockets of natural habitat with protected riparian corridors. Major riparian networks can be used as linear landscape connectors, providing contiguous travel routes for wildlife between wetland refuges (Stenberg et al. 1997). The City of Bellevue may consider acquiring lands that will better protect wetland functions and provide connected natural areas in Bellevue's landscape. Creative urban landscape design is a promising way to meet the needs of an urban area while protecting many natural habitat functions and values (Goldstein et al. 1983).

6.6 Buffer Averaging

6.6.1 Review of the Literature

Buffer averaging is consistent with best available science if implemented to increase buffer widths and wetland functions at specific sites and concurrently not degrade functions by reducing widths elsewhere. If used, buffer averaging should result in an equal total buffer area and a net increase in select functions, a goal supported by best available science.

Buffer averaging provides the opportunity to decrease the level of risk to wetland functions if buffer widths are reduced where they are unnecessary and increased where they would be beneficial. However, buffer averaging could pose an increased risk to functions if averaging results in increases buffers for one function at the expense of another. In general, wetland ecologists do not have the tools to trade off buffer widths with a high degree of certainty unless adequate information has been obtained.

The implementation of ecologically supported buffer averaging may prove difficult without standardized empirically and scientifically accepted methods of consistently identifying and determining functions. In general, wetland ecologists do not have the tools to trade off buffer widths with a high degree of certainty unless adequate information has been obtained. Any certainty that does exist varies depending on the function to be gained through the buffer increase. Consequently, the certainty of improving the water quality enhancement function by a wider buffer is greater than the certainty of improving ground water recharge or wildlife functions. Finally, the increase in wetland buffers allowed by buffer averaging might only marginally benefit functions. For example, wildlife may additionally be protected from adjoining noises and other disturbances by wider buffer widths at certain locations but most likely will not benefit appreciably by the relatively small increases in habitat from buffer averaging.

6.6.2 Identification of Data Gaps

There are no available studies that evaluate the effectiveness of buffer averaging for wetland protection (King County 2004).

6.6.3 Recommendations

Buffer averaging may be allowed and encouraged when averaging will improve connectivity with adjacent native habitat areas. Buffer averaging can be useful to promote connectivity in Bellevue's landscape, while allowing more flexibility for landowners.

6.7 Mitigation

6.7.1 Review of the Literature

The term *mitigation* typically involves producing new wetland area, functions, or both as compensation for wetland area and function lost as a result of a permitted activity. Wetland mitigation generally entails providing one or more of the following types of compensation:

- Restoration of wetland conditions and functions in an area[3]
- Creation of new wetland area and functions
- Enhancement of functions at an existing wetland[4]
- Preservation of an existing high-quality wetland to protect it from future development.

The use of compensatory mitigation for wetland loss emerged in the 1980s (Roberts 1993; National Research Council 2001). The U.S. Army Corps of Engineers considered the process of

[3] Restoration is the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural or historic functions to a former or degraded wetland.
[4] Enhancement is the manipulation of the physical, chemical, or biological characteristics of a biological wetland to heighten, intensify or improve specific function(s) or to change the growth stage or composition of the vegetation present.

mitigation as part of the National Environmental Policy Act of 1969. However, it wasn't until 1980 when the Environmental Protection Agency (EPA) issued new guidelines for Section 404(b)(1) of the Clean Water Act that mitigating for wetland losses by creating or restoring another wetland as compensation became widely acceptable (National Research Council 2001). Compensatory mitigation was seen as a way to speed up an arduous process of documenting avoidance and minimization efforts, while satisfying concerns about the loss of ecosystems and functions (Roberts 1993). Creating or restoring wetland area to compensate for permitted wetland losses was viewed and publicized as a way to allow development while preventing a net loss of wetland areas.

By the late 1980s, studies of the effectiveness of compensatory mitigation were emerging, with mixed results. The primary indication was that replacing or replicating an existing wetland was difficult, if not impossible (Kusler and Kentula 1990; National Research Council 2001). However, some wetland types and functions could be approximated given the proper conditions (Kusler and Kentula 1990; National Research Council 2001).

Mitigation involves six steps (often referred to as mitigation sequencing) to determine what types of impacts may be permitted and what types of compensatory mitigation may be appropriate. Wetland impacts can be significantly reduced or avoided altogether by following the first four steps in the sequence (avoiding, minimizing, rectifying, and reducing or eliminating impacts). When wetland impacts are unavoidable, the fifth and sixth steps in the sequence are implemented (compensatory mitigation for impacts and monitoring the compensatory actions). Generally, this sequencing process is described as 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, such as project redesign, relocation, or timing, to avoid or reduce impacts;

3. **Rectifying** the impact by repairing, rehabilitating, or restoring the affected environment to the conditions existing at the time of the initiation of the project;

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

6. **Monitoring** the required compensation and taking remedial action when necessary.

Step five is commonly referred to as compensatory mitigation. Local regulations on compensatory mitigation need to address the issue of how best to replace the wetland functions and values that will be lost due to the proposed impacts. In general, compensatory mitigation regulations need to address the following issues:

- The training and funding of regulatory staff to review, implement, and follow through with proposed compensation plans
- Standards for the type, location, amount, and timing of the compensatory actions
- Clear guidance on the design considerations and reporting requirements for compensation plans. This requirement allows the local agency to make a decision about the adequacy of the proposed compensatory mitigation.

Compensatory wetland mitigation projects are intended to compensate for the loss of wetland area and functions. Hence, permits and mitigation plans often identify a specific acreage of compensation required to offset those losses. Establishing the required acreage is therefore a critical criterion of regulatory compliance.

Five studies of compensatory wetland mitigation have focused on projects in Washington state during the past decade. The studies examined success, ecological functioning, permit compliance, and achievement of required wetland area, though not all studies looked at the same factors in the same way. The results suggest that compensatory mitigation in Washington is neither fully successful nor completely unsuccessful.

Most studies found that less than half of wetland compensation projects are fully effective. In the most recent and comprehensive evaluation of compensation projects, Johnson et al. (2002) found that 13 percent of compensatory wetland mitigation projects were fully successful and 33 percent were moderately successful. In western Washington, Storm and Stellini (1994) determined that 24 percent of compensation projects functioned well. In King County, Mockler et al. (1998) indicated that 3 percent of projects replaced lost wetland functions (though the report provides no explanation for how this determination was made). In terms of compliance, Johnson et al. (2000) determined that 29 percent of projects were in full compliance, while for King County, Mockler et al. (1998) found that 21 percent of projects were meeting their required performance standards.

Kentula et al. (1992) examined Section 404 permit decisions for Washington from 1980 through 1986. Data indicated that permit decisions resulted in a wetland loss of 40 acres (16 ha). Johnson et al. (2002) determined that 24 acres (10 ha) of wetland were lost due to projects that did not successfully establish wetland area and due to the frequent permitting of enhancement of wetlands in exchange for wetland acreage losses.

In Washington state, four studies evaluating compliance with wetland mitigation permit requirements have been conducted in the past decade (Storm and Stellini 1994; Mockler et al.

1998; Johnson et al. 2000; Johnson et al. 2002), and two studies have been conducted in Oregon (Gwin and Kentula 1990; Shaich and Franklin 1995). The studies in Washington found that less than one-third of compensation projects complied with their regulatory requirements. In Oregon, studies revealed that compliance of projects ranged from zero to 36 percent. Studies from other states demonstrated more variability in levels of compliance. Results ranged from less than 20 percent to about 80 percent of projects in compliance (Holland and Bossert 1994; De Weese 1998; Morgan and Roberts 1999; Michigan Department of Environmental Quality 2000; Brown and Veneman 2001; Balzano et al. 2002; Sudol and Ambrose 2002). More recent studies (published in 2000 or after) did not report higher levels of compliance than studies conducted in the 1990s.

In general, mitigating for lost wetland acreage is difficult and highly risky for all types of compensation. Functional replacement is even more difficult and requires extensive training, information gathering and monitoring. Best available science indicates that mitigated wetlands have not yet succeeded in replacing lost acreage or functions with any predictability. Consequently the risk to replacement of wetland acreage and their functions and values remains high.

6.7.1.1 Establishment of Wetland Acreage

In studies of wetland mitigation projects in Washington and Oregon, over half of projects achieved the required wetland area (Shaich and Franklin 1995; Johnson et al. 2002). In fact, the majority of studies reviewed determined that about half of the compensation projects established the required acreage of wetland. However, three studies found that less than 30 percent of projects met their acreage requirements (McKinstry and Anderson 1994; Balzano et al. 2002; Morgan and Roberts 2003). In New Jersey, only 7 percent of projects achieved the wetland acreage requirements (Balzano et al. 2002). For the total acreage of wetland achieved versus required, a Washington study determined that overall 84 percent of the required acreage of compensatory wetlands was established (Johnson et al. 2002), while a study in Oregon found about 70 percent of the required wetland acreage was established (Gwin and Kentula 1990). Results from other states indicated between 44 and 74 percent of the required wetland acreage had been established.

Recognizing the fact that mitigation is not 100 percent reliable in replacing wetland acreage and function, "mitigation replacement ratios" are commonly used. These ratios are used to address risk of failure, temporal loss (due to the length of time it takes sites to be fully functioning), and the frequent tradeoffs in wetland functions that occurs in mitigation. Numerical ratios, and the mitigation process in general, are based on requiring "no net loss" of acreage, are ill-suited tools to addressing technical shortcomings of mitigation design, which include lack of suitable water regimes, inadequate soil or plant conditions, poor design and inadequate followup by regulatory agencies (NRC 2001; Johnson et al. 2000, 2002). Though higher ratios attempt to attain the policy goal of no net loss of acreage, requiring higher mitigation ratios has not produced this result.

Some ways to reduce risks of failure in wetland mitigation projects are listed below (NRC 1992):

- Adherence to goal of no net loss in wetland acreage and function
- More detailed assessment of functions prior to wetland damage or destruction
- More detailed plans
- Higher standards for success
- More expertise
- Larger buffers
- More detailed and longer-term surveillance and monitoring
- Greater midcourse correction capability
- Longer-term and greater maintenance responsibilities
- More detailed reports with broader distribution
- Larger bonds
- Complete restoration or creation before allowing damages (in mitigation projects).

6.7.1.2 Performance Standards

Performance standards, performance criteria, success criteria, success measures, standards of success, and other terms all refer to regulatory conditions used to determine how effective a mitigation project is at meeting regulatory requirements, which may or may not include compensating for wetland loss. Ideally performance standards should serve as "measurable benchmarks used to evaluate the development of ecological characteristics associated with specific wetland functions" (Azous et al. 1998). Performance standards allow regulators to determine if a compensatory mitigation project has fulfilled its goals, and also provides a mechanism for regulators to implement enforcement actions against unsuccessful projects (Streever 1999).

Sheldon and Dole (1992) studied eight compensatory mitigation projects in King and Snohomish Counties in Washington. The authors observed that "none of the goal statements provided a quantifiable method of determining success, thus they provided no means for an agency to assess success/failure or to require remediation." The Michigan Department of Environmental Quality (2000) similarly found, "The practice of including no specific performance standards, or only very general performance standards (regarding the size and possibly the type of wetland to be constructed), resulted in many unenforceable permits and contributed to the poor quality mitigation wetlands." Johnson et al. (2000), in their study of 45 compensatory mitigation wetlands, noted some problems with performance standards, such as:

- Standards that are too general or "easy to attain" and, therefore, are not indicative of ecological development at a site
- Standards that are not measurable and, therefore, cannot be used to evaluate the success or compliance of projects
- Standards that include confusing or ambiguous language and, therefore, result in inaccurate assessment or preclude assessment.

Approved mitigation projects can also lack performance standards for important wetland functions or conditions. Breaux and Serefiddin (1999) discovered in their review of 110 projects in San Francisco, California, that only 22 percent had quantitative standards focusing on hydrological parameters. Johnson et al. (2000) reviewed 179 performance standards from 36 projects and observed that 8 percent of the performance standards related to hydrological conditions. The Michigan Department of Environmental Quality (2000) found that "none of the permits examined contained any specific criteria regarding vegetation or hydrology by which the mitigation wetland could be judged for success or failure." Johnson et al. (2002) noted that most of the projects evaluated in their study of 24 compensation wetlands lacked basic standards for wetland area, water regime, area of Cowardin classes, percent cover of native wetland vegetation, and maximum percent cover of invasive vegetation.

Azous et al. (1998) support the use of reference wetlands to develop performance standards: *By collecting data on the ecological characteristics associated with reference wetlands, and created or restored wetlands, standards of comparison can be established by which to judge the development of wetland characteristics in compensatory mitigation projects. The use of regional reference wetland characteristics provide greater assurance that project performance standards will be reasonable (i.e.: attainable) and useful gauges of the development of wetland functions.* Ehrenfeld (2000) recommends that reference sites be identified in urban areas and used to develop attainable performance standards for compensatory wetland mitigation projects that are also located in urban areas. The author states: "Measures of restoration success and functional performance must start with an appreciation and assessment of the particular conditions imposed by the urban environment."

Two studies conducted in Washington determined that 21 percent of projects met their performance standards (Mockler et al. 1998; Johnson et al. 2002), while a third study from Washington found that 35 percent of projects met performance standards (Johnson et al. 2000). The percent of projects that had performance standards appeared to increase with more recent projects. For example, Storm and Stellini (1994) and Cole and Shafer (2002) evaluated compensation projects that were permitted in the mid to late 1980s or early 1990s. Performance standards may not have been as rigorously required (Cole and Shafer 2002) or they may not have been specifically identified as performance standards. For example, of 10 projects that did not contain performance standards, 30 percent were permitted in the late 1980s and 80 percent were permitted prior to 1995, while 20 percent were permitted in the late 1990s (Cole and Shafer 2002). Time does not appear to be a factor in whether projects met their performance standards. Cole and Shafer (2002) did not find that performance standards noticeably changed in terms of content from projects permitted in the late 1980s to the late 1990s. The more recent projects did not appear any more likely to meet performance standards than earlier projects.

6.7.1.3 Monitoring and Maintenance

To determine if a compensatory wetland mitigation project is in compliance, it is necessary to monitor the project over time. Monitoring requirements are typically identified in the wetland mitigation plan. The duration, frequency, and methods of monitoring depend on the goals, objectives, and performance standards for the project. Monitoring is the process through which data about site conditions are gathered. Monitoring data are used to determine whether a project is achieving its performance standards, and therefore its goals and objectives, within a predicted timeframe. Monitoring also provides critical information about whether a site requires maintenance or contingency actions. Monitoring is therefore essential for a project to achieve compliance. In general, studies conducted more recently found that monitoring was required for a greater percentage of projects than was required in older projects. Data from four studies indicate monitoring was required for at least three-fourths of projects (Erwin 1991; Morgan and Roberts 1999; Johnson et al. 2000; Michigan Department of Environmental Quality 2000). Two other studies, which examined compensation projects permitted in the late 1980s and early 1990s, found that monitoring was required for a third to half of projects (Holland and Kentula 1992; Storm and Stellini 1994). Less than half of the projects appeared to have been monitored. However, the studies did not determine whether the monitoring was conducted or whether there was simply no record of the monitoring reports on file with the regulatory agencies. If monitoring is not conducted there is no means to trigger maintenance or contingency actions.

Compensatory wetland mitigation sites require maintenance to help ensure that performance standards and goals will be achieved. Maintenance includes implementing corrective actions to rectify problems, such as an insufficient water supply or inappropriate water regime, invasive species infestation (e.g., reed canarygrass or bull frogs), trash, vandalism, or anything else that may result in noncompliance with permit requirements. Johnson et al. (2002) observed that a lack of maintenance was one of the main reasons for poor success of mitigation projects. Results revealed that permitting agencies did not require all compensation projects to provide maintenance. Studies discovered that permits required site maintenance for 41 to 78 percent of projects (Erwin 1991; Storm and Stellini 1994; Michigan Department of Environmental Quality 2000). However, even fewer projects (20 to 60 percent) complied with their maintenance requirements (Erwin 1991; Michigan Department of Environmental Quality 2000).

6.7.1.4 Regulatory Follow-up

Once compensatory wetland mitigation is required, it is the responsibility of the regulatory agencies to track the project over time and determine if it complies with permit requirements. A regulatory agency follows up on compensatory mitigation projects by:

- Ensuring that required monitoring reports are submitted on schedule
- Performing site visits to confirm monitoring results and attainment of performance standards
- Ensuring maintenance actions are undertaken on schedule
- Ensuring that appropriate contingency measures are enacted.

Studies in Washington and Oregon indicated that about half of compensatory wetland mitigation projects received some regulatory follow-up in the form of site visits, phone calls, or letters (Kentula et al. 1992; Johnson et al. 2002). In Michigan only about a quarter of projects received any kind of follow-up after the permit was issued (Michigan Department of Environmental Quality 2000). A few studies also examined the effect of regulatory follow-up on project compliance, success, or both. Robb (2002) alluded to the fact that the high number of non-compliant compensation projects resulted from a lack of follow-up and enforcement actions. In Washington, a study noted that all of the projects lacking regulatory follow-up were either minimally or not successful, while two-thirds of the projects receiving some kind of follow-up were either fully or moderately successful (Johnson et al. 2002). One team of researchers observed: *The most ecologically successful sites were generally those that had received follow-up work in the form of maintenance, replanting, or improvements to grading or water control structures in accordance with recommendations made by NJDEP [New Jersey Department of Environmental Protection] and other regulatory agencies after initial compliance inspections revealed problems* (Balzano et al. 2002). Studies indicated that regulatory follow-up can help to ensure the effectiveness of compensation sites. It is assumed that applicants will be more likely to abide by monitoring requirements and submit monitoring reports if regulatory agencies are actively following up on projects. Since monitoring reports are meant to identify what is working and where there are shortfalls, maintenance actions can be initiated or contingency measures can be triggered to correct the shortfalls and problems as soon as possible. Therefore, follow-up may improve the compliance of compensation projects.

6.7.1.5 Wetland Enhancement in Lieu of Creation or Restoration

Enhancement involves modifying a specific structural feature of an existing degraded wetland to improve one or more functions or values based on management objectives (Gwin et al. 1999; Johnson et al. 2000). Enhancement typically consists of:

- Planting vegetation
- Controlling non-native, invasive species
- Modifying site elevations or the proportion of open water to influence hydroperiods (Gwin et al. 1999).

Because enhancement involves altering an existing wetland to compensate for the loss of wetland area, enhancement fails to replace lost wetland area. In addition, enhancement often fails to improve wetland functions. Enhancement may also result in a conversion of the wetland to another type, such as converting a shallow emergent wetland (with predominantly herbaceous species) to one dominated by deep open water. Such tradeoffs may enhance certain wetland functions at the expense of others.

Studies indicated that more than one-third of compensation projects used enhancement of existing wetlands as compensatory mitigation (Shaich and Franklin 1995; Gwin et al. 1999; organ and Roberts 1999, Johnson et al. 2000; Johnson et al. 2002). The effectiveness of enhanced compensation wetlands was evaluated by only two studies, both conducted in Washington. The researchers found less than 13 percent of enhanced wetlands were in complete compliance, none of the enhanced compensation wetlands were fully successful, and 89 percent were minimally or not successful (Johnson et al. 2000, 2002).

6.7.2 Identification of Data Gaps

There is no information documenting the success of wetland mitigation projects within Bellevue and the effect of the City's wetland mitigation regulations on the goal of no net loss.

6.7.3 Recommendations

- Improve the instructions for applying the mitigation process, from avoidance and minimization to submitting a monitoring report for a compensation wetland.
- Mitigation replacement ratios should reflect functional losses as well as areal losses.
- Avoid accepting wetland enhancement or protection of wetlands in exchange for wetland losses.
- Increase regulatory follow-up and enforcement of compensatory mitigation projects; develop and maintain a database and filing system; allocate staff to perform compliance and enforcement activities; and implement reviews of regulatory program performance.

6.8 Conclusion

This summary of the best available science for developing policies and regulations to protect the functions and values of wetlands is based on peer-reviewed research; Bellevue's *2003 Critical Areas Update, Best Available Science Paper: Wetlands,* symposia literature; technical literature;

and other scientific information related to wetlands. Best available science for wetland protection, particularly safeguarding the processes that protect wetland functions, varies in terms of quantity, quality, and local relevance, and it remains an active field of research. The best available science for wetland protection is neither complete nor consistently covered for all functions.

There is more useful and locally relevant information available for wetland water quality functions and their protection than that available for other wetland functions. There is information related to the use of local wetlands by wildlife; however, with the exception of amphibians, there have been few empirical studies related to wildlife and habitat protection, especially on the population scale. The information related to impacts on wetland birds other than waterfowl, and particularly their buffer needs, comes largely from streamside riparian studies conducted in other regions. Finally, there is little local information available regarding the ground water interaction functions between wetlands and the greater watershed and landscape.

Nevertheless, the literature appears to be clear that there has been a continual loss of wetland acreage and wetland functions despite numerous agency policies and regulations requiring "no net loss." Furthermore, despite the caveats of insufficient science, several principles for protecting wetland functions can be extracted from the national and local literature:

- Wetland functions are interdependent and, to some extent, mutually exclusive.
- Wetland functions vary over time.
- Protection of wetlands is context and scale driven. That is, wetland protection is dependent on the functions of wetlands and the condition of ecological processes in the adjoining areas as well as the greater watershed and landscape area.
- Buffers alone, although necessary in many cases, may be insufficient to completely protect important wetland functions unless the buffers are exceptionally large or there is high connectivity in the landscape.
- Protection of wetland complexes is important to stem wetland isolation and habitat fragmentation, two consequences of development leading to decreased species richness and population extinctions in wetlands.
- Currently, wetland mitigation is an inexact and difficult science; therefore avoiding wetland loss remains the preferred option for meeting the "no net loss" standard.
- If mitigation is required, mitigating the loss of wetland functions is as important as mitigating the loss of wetland acreage.

Table 6-2 summarizes the best available science on wetland protection mechanisms and provides general recommendations for the City of Bellevue.

An overview of important wetland functions is provided in Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Wetlands*. In general, wetlands provide a number of different and often critical environmental and ecological functions that benefit humans, including flood storage and retention, ground water discharge/recharge, maintenance and protection of water quality, and provision of habitat for important fish and wildlife species (including some federal and state threatened and endangered species), as well as for a wide diversity of important invertebrates, amphibians, birds, furbearers, and small mammals. Results of studies of wetlands in the Puget Sound lowlands have indicated that the diversity of birds and small mammals in wetlands may exceed that in upland habitats. Because of the unique mix of water and biodiversity, wetland areas are also used for a broad range of recreational and aesthetic activities, including hunting and the enjoyment of natural beauty and solitude.

Wetland protection means maintaining the ecological integrity of wetlands so their functions remain self-sustaining. Consequently, hydrologic processes, ground water interactions, water quality enhancement, species and habitat support, and other existing functions need to persist in perpetuity, though they may vary somewhat from year to year or decade to decade within a single wetland.

The exemption of small wetlands from regulatory protection is an issue that has gained increased attention over the past 10 years. The City of Bellevue's regulations preferentially allow the filling of small wetlands because size is one of the characteristics used in determining wetland ratings at the local level. Regulatory priorities have focused on protecting larger wetlands and not protecting the smaller, seasonal wetlands that are often critical components of wetland complexes. The loss of small wetlands is one of the most common cumulative impacts on wetlands and wildlife.

The City of Bellevue currently allows a number of activities within wetlands or wetland buffers that are inconsistent with the recommendations suggested by the best available science. These include the building of roads, utilities, and other essential infrastructure. There is no available data describing the extent to which these activities may have affected wetland functions in Bellevue and whether they are adequately mitigated. Incrementally and collectively, these activities continue to erode the City's wetland resources.

Reasonable use exemptions also allow encroachment on wetlands and their functions if no other onsite development possibilities are available. Unmitigated exemptions and allowed variances, although required to avoid property rights challenges, are not consistent with the best available science for wetland protection if they lead to incremental, cumulative losses in wetland area and wetland functions and values. Conditions on allowed alterations may lessen these impacts but they rarely fully mitigate the losses.

The foundation of most wetland regulatory programs is a wetland rating system. Since wetlands are highly variable and can provide very different functions, ranking them allows for the

Table 6-2. Summary of best available science findings and general recommendations for protecting wetlands.

Protection Mechanism	Best Available Science Review	General Recommendations
Basing wetlands protection on wetland size	Wetland size may be a factor but is not a determinant of the functions and values provided by a wetland.	Provide protection for wetlands commensurate with wetland functions.
Measuring the functions of wetlands.	▪ The most useful methods generate parametric measures rather than general rankings. ▪ Require the same method be used to evaluate functions for wetland losses and for wetland mitigation proposals. ▪ Specify the use of wetland functional assessment methods that are appropriate to Bellevue's wetland types to improve mitigation success and provide a consistent database for mentoring and analysis.	Most Bellevue wetlands are either riparian or depressional palustrine wetlands. Hruby et al. (1999) provides methods producing parametric measures of function that are suited to the types of wetlands located in Bellevue.
Rating wetlands as a basis for more protective regulations.	The primary factors important to consider when rating wetlands for the purposed of applying commensurate protective measures are : ▪ Rarity ▪ Ability to replace it ▪ Sensitivity to disturbance ▪ Functions performed by the wetland.	Ecology (Hruby 2004) provides a wetland rating system that rates wetlands on specific criteria including, rarity, sensitivity to disturbance, and functions.
Providing protective buffers for wetlands.	▪ In urban areas a minimum of 100 feet of buffer is necessary to provide significant water quality protection and minimal wildlife habitat protection for wetlands. ▪ Additional protection for wildlife can be achieved with wider buffers and/or increased landscape connectivity.	▪ Provide a minimum of 100 feet of buffer for all Class A, B or C wetlands in Bellevue that are rated a Category I, II, or III using Hruby (2004). ▪ Where possible provide a minimum 200 foot buffer for those wetlands rated as a Category II or II by Hruby (2004). ▪ The developed character of the City may preclude the practical implementation of larger buffers, therefore the City should explore alternative strategies to increase wetland protection such as improving the connectivity of native habitat in the landscape.
Allowing for the use of buffer averaging.	The effectiveness of buffer averaging in achieving equal or increased wetland protection has not been studied and is unknown.	Allow buffer averaging when averaging will improve connectivity with adjacent native habitat.
Allowing wetland creation, restoration, enhancement and permanent protection as mitigation for wetland losses.	▪ Mitigation in general for wetland losses has achieved a poor rate of success to date, particularly wetland creation. ▪ Enhancement of wetlands in exchange for permanent loss of wetland area fails to compensate for lost wetland area and frequently fails to improve wetland functions. ▪ Allowing permanent protection of wetlands in exchange for permanent loss of wetland area fails to compensate for lost wetland area or wetland functions. ▪ Regulatory follow-up is vital to ensuring the success of wetland mitigation.	▪ Improve the instructions for applying to mitigate, from avoidance and minimization to submitting a monitoring report for a compensation wetland. ▪ Adjust replacement ratios to reflect functional losses as well as areal losses. ▪ Avoid accepting wetland enhancement or protection of wetlands in exchange for wetland losses. ▪ Increase regulatory follow-up and enforcement of compensatory mitigation projects; develop and maintain a database and filing system; allocate staff to perform compliance and enforcement activities; and implement reviews of regulatory program performance.

opportunity to provide appropriate levels of protection. Any wetland rating system should be based on valid scientific information regarding how a wetland functions, how sensitive a wetland is to human disturbances, how rare a wetland type is, and how easily a wetland can be replicated. The City of Bellevue's current wetland rating system ranks wetlands on size and hydrologic connectivity. The system is insensitive to other important factors such as the wetland's rarity, replaceability, sensitivity, and functions.

In the early 1990s, the Department of Ecology developed a wetland rating system for western Washington that considered all of these factors. That rating system was revised in 2004 to incorporate more recent scientific information. Local governments are encouraged to use the state's rating system because it was developed by a team of wetland specialists and planning staff to ensure both scientific validity and administrative feasibility. If a city uses its own rating system, it is likely that the wetland will also need to be rated according to the state system, if a state or federal permit or approval is needed. This duplication of effort could increase costs for applicants, while offering no protective benefits to wetlands.

Currently, the most common and widespread method of wetland protection is the application of fixed protective buffers. The purpose of a buffer is to protect wetland functions from detrimental impacts resulting from adjoining land use, either existing or expected. In Washington, protection varies considerably. The buffer widths recommended by the Department of Ecology range from 50 feet for Category IV wetlands to 300 feet for Category I wetlands. In Bellevue, the current regulatory protection consists of no buffer for Type C wetlands, a 25-foot width for Type B wetlands, and a 50-foot width for Type A wetlands. Additionally, the City of Bellevue requires a 15-foot and 20-foot structure setback from the edge of the buffer for Type B and A wetlands, respectively. However, a number of permitted uses are allowed within the structure setback, including the removal of native vegetation.

A number of studies of buffer effectiveness were examined for this review. The buffers required to protect habitat are usually larger than those needed to protect other functions such as water quality improvement. In general, it was found that buffers of less than 50 feet are generally ineffective at screening out human disturbance of wetland wildlife. Buffers of 45 to 100 feet can be effective at protecting wetlands and wildlife from disturbance in areas of low-density land uses (agriculture, recreation, and low-density residential housing [less than or equal to 4 units per acre]). Buffers of 100 to 150 feet are recommended for minimal protection of wetlands and wildlife from adjacent high-intensity land use (high-density residential [greater than 4 units per acre] and commercial/industrial development). However, larger buffers, on the order of 150 feet to 200 feet, may be needed to prevent the disturbance of waterfowl in urban areas. One report recommended a buffer of 300 feet for the protection of most species found in wetlands in western Washington that are adjacent to high-intensity land uses.

Best available science suggests that the majority of water quality functions can be achieved within a 100-foot buffer. However, the hydrologic functions of flood storage, ground water recharge, and reducing erosion are not significantly influenced by the width of the buffer. These functions need to be protected at the scale of the watershed or subbasin in which the wetland is found.

There is no information addressing the effectiveness of existing buffers specific to wetlands in Bellevue in protecting wetland functions. However, in general, best available science suggests that wetland functions are minimally protected within an urbanizing area if protection is limited to fixed-width buffers less than 100 feet.

Although much of Bellevue is built out and there are few remaining opportunities to provide wetland buffers that are greater than 100 feet, there may be ways to achieve the goal of habitat protection through long-term land-use planning. The City could plan to link remaining wetlands and pockets of natural habitat with protected riparian corridors. Major riparian networks can be used as linear landscape connectors, providing contiguous travel routes for wildlife between wetland refuges. The City of Bellevue may consider acquiring lands that will better protect wetland functions and provide connected natural areas in the Bellevue landscape. Creative urban landscape design is a promising way to meet the needs of an urban area while protecting many natural habitat functions and values.

Buffer averaging provides another opportunity to decrease the level of risk to wetland functions if buffer widths are reduced where they are unnecessary and increased where they would be beneficial. However, buffer averaging could pose an increased risk to functions if averaging results in increased buffers for one function at the expense of another. In general, wetland ecologists do not have the tools to trade off buffer widths with a high degree of certainty unless adequate information has been obtained. There are no available studies that have evaluated the effectiveness of buffer averaging for wetland protection.

Buffer averaging is encouraged when averaging will provide connectivity with adjacent native habitat areas. Buffer averaging can be useful to promote connectivity in Bellevue's landscape, while allowing more flexibility for landowners.

The term *mitigation* typically involves producing new wetland area, replacing wetland functions, or both as compensation for wetland area and functions lost as a result of a permitted activity. Wetland mitigation generally entails providing one or more of the following types of compensation:

- Restoration of wetland conditions (and functions) in an area[5]
- Creation of new wetland area and functions
- Enhancement of functions at an existing wetland[6]
- Preservation of an existing high-quality wetland to protect it from future development.

[5] Restoration is the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural or historic functions to a former or degraded wetland.

[6] Enhancement is the manipulation of the physical, chemical, or biological characteristics of a biological wetland to heighten, intensify or improve specific function(s) or to change the growth stage or composition of the vegetation present.

In general, mitigating lost wetland acreage is difficult and highly risky for all types of compensation. Ensuring wetland functions are replaced is even more difficult and requires extensive training, information gathering, and monitoring. Best available science indicates that mitigation plans have not yet succeeded in replacing lost acreage or functions with any reliability. Consequently the risk associated with the replacement of wetland acreage and their functions and values remains high. Although there are a number of local and national studies evaluating the success of completed wetland mitigation projects, there are no documented examples of where a completed mitigation plan has met the goal of no net loss of area, function, and values.

Wetland enhancement is another commonly used mitigation strategy. It involves modifying a specific structural feature of an existing degraded wetland to improve one or more functions or values based on management objectives. Enhancement typically consists of the following:

- Planting vegetation
- Controlling nonnative, invasive species
- Modifying site elevations or the proportion of open water to influence hydroperiods.

Because wetland enhancement involves altering an existing wetland to compensate for the loss of other wetlands, the scientific literature mentions three main concerns related to its use:

- Enhancement fails to replace lost wetland area.
- Enhancement often fails to improve wetland functions.
- Enhancement may result in a conversion of the wetland to another type, such as converting a shallow emergent wetland (with predominantly herbaceous species) to one dominated by deep open water. Such tradeoffs may enhance certain wetland functions at the expense of others.

In general, the best available science literature on wetland mitigation can be summarized as follows:

- The compliance levels of compensatory mitigation projects are generally low due to shortfalls of wetland acreage, failure to achieve performance standards, and a lack of monitoring and maintenance.
- About 50 percent of wetland mitigation projects achieve their required wetland acreage.
- Well-crafted mitigation performance standards, in addition to goals and objectives, are critical for measuring compliance.

- The requirement for monitoring as a regulatory condition will significantly improve the long-term success of wetland mitigation projects.

- Regulatory followup is vital to ensuring the success of wetland mitigation.

In general, the level of uncertainty associated with the success of wetland mitigation is not related to the compensation ratios. Rather, to a large degree, success is related to the extent of project planning, construction, monitoring, and overall oversight. Consequently, with proper funding and other resources, the uncertainty associated with mitigation success can be decreased and minimized regardless of the ratios.

There is no information documenting the success of wetland mitigation projects in Bellevue and the effect of the City's wetland mitigation regulations on the goal of no net loss. The following actions are recommended to improve the success of wetland mitigation in Bellevue.

- Improve the instructions for applying the mitigation process, from avoidance and minimization to submitting a monitoring report for a compensation wetland.

- Adjust mitigation ratios to reflect functional losses as well as area losses.

- Protect all compensatory mitigation sites in perpetuity by means of a legal mechanism, such as a deed restriction or conservation easement.

- Increase regulatory followup and enforcement of requirements imposed on compensatory mitigation projects; develop and maintain a database and filing system; allocate staff to perform compliance and enforcement activities; and implement reviews of regulatory program performance.

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Chapter 7. Shorelines

This report reviews available peer-reviewed research, inventory reports, symposia literature, technical literature, and other sources of scientific information relevant to shorelines. The purpose of this report is to summarize and discuss a best available science review relating to shoreline functions and values, particularly as they pertain to anadromous fish species. In addition, this report provides recommendations as to how shoreline management and regulations should be modified to ensure they are ecologically sound, scientifically defensible, and protect shoreline functions and values, with special consideration for conserving and enhancing anadromous fish species, particularly salmon.

Shorelines can be legally and ecologically defined. The legal definition of shorelines is provided in RCW 90.58.030 and can be summarized as all the water areas, including reservoirs, and their associated shorelands, together with their underlying lands. This includes shorelines on segments of streams downstream of a point where the mean annual flow is 20 cubic feet per second or greater. Also included are shorelines on lakes more than 20 acres in size.

For the purpose of this review, the shorelines are the areas where direct functional interactions (e.g., sediment supply, wood debris recruitment, nutrient input) occur between the riparian (upland) and the aquatic area habitats.

The focus of this review is on freshwater system shorelines. However, scientific literature derived from marine shoreline studies was used, where freshwater-specific scientific literature was not available to support the discussion of ecological processes, functions, and values of freshwater shoreline. Nonetheless, the use of any marine shoreline literature source was limited to those areas where current scientific knowledge permits the inference or hypothesis that similar (parallel) processes and functions exist in freshwater shorelines.

7.1 Functions and Values

As previously stated, various functional interactions occur between the riparian and the aquatic areas within the shoreline (Figure 7-1). The shoreline riparian area is the upland that lies adjacent to the shoreline aquatic area (see Figure 7-1). It typically includes trees and shrub layers of vegetation. It may also include riparian wetlands. The shoreline aquatic area includes the littoral, limnetic, and benthic zones. The shoreline aquatic area typically includes emergent and aquatic (macrophyte) vegetation.

This review focuses on the littoral zone within the shoreline aquatic area and its relationship to the shoreline riparian area.

7.1.1 Shoreline Riparian Areas

The riparian areas of streams and wetlands have been studied intensely in recent years because of their critical functional relationships to stream and wetland ecosystems. These studies have generated abundant data on riparian functions. They have contributed to scientific understanding of the overall ecological process they control and on which they depend. In contrast little research has been conducted on lake riparian areas and the ecological functions they provide to the aquatic environment.

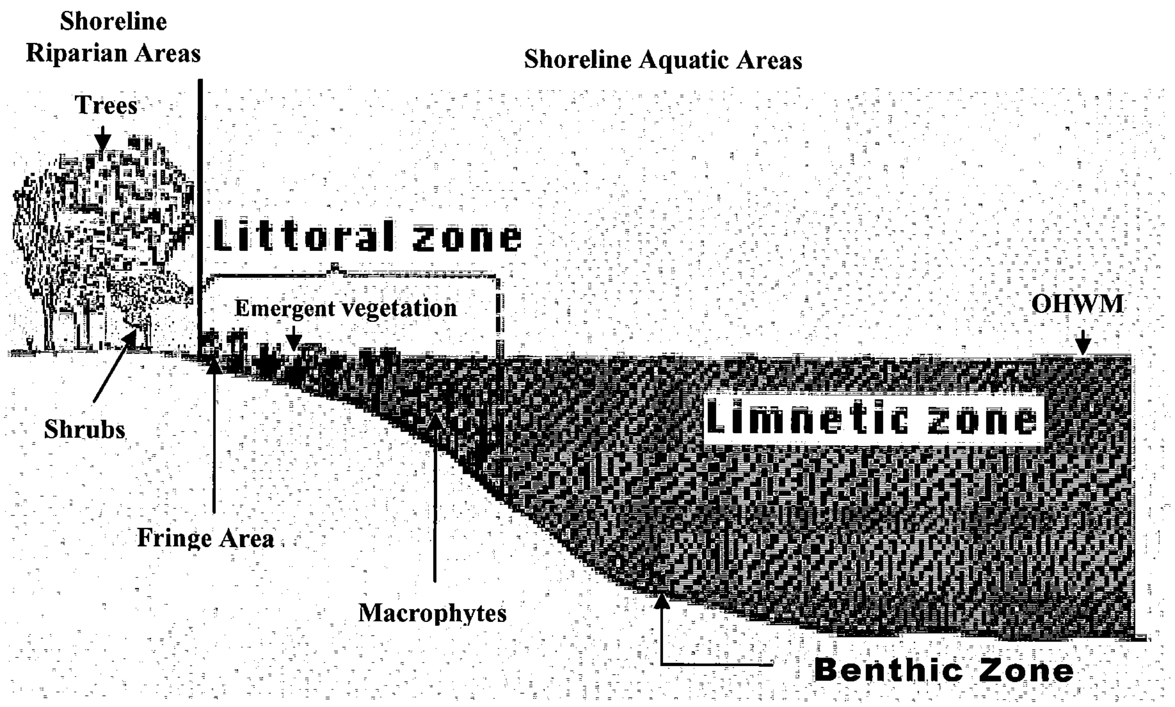

Figure 7-1. Schematic representation of shoreline riparian and aquatic areas (adapted from Kimball 2004).

The National Research Council (NRC 2002) defines riparian areas as follows:

> *Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes and biota. They are areas through which surface and subsurface hydrology connect waterbodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines.*

Riparian areas provide a variety of functions including shade, temperature control, water purification, woody debris recruitment, channel, bank and beach erosion, sediment delivery, and terrestrial-based food supply (Gregory et al. 1991; Naiman et al. 1993; Spence et al.1996). These functions are potentially affected when development occurs within riparian areas (Waters 1995; Stewart et al. 2001; Lee et al. 2001). Because of the ecological functions they provide, riparian areas can be considered as "zones of influence" between terrestrial and aquatic ecosystems (NRC 2002).

7.1.2 Shoreline Aquatic Areas

For the purpose of this review, the shoreline aquatic areas include three distinct zones of biological communities, including a limnectic zone, a littoral zone, and a benthic zone. These three distinct zones or habitats are coupled by biological, physical, and chemical processes (Schindler and Scheuerell 2002).

The limnectic (pelagic) zone is the open water area where light does not penetrate to the bottom. Typically, the pelagic habitats of lakes are inhabited by microscopic bacteria, viruses, protozoa, phytoplankton, zooplankton, planktonic life-stages of insects, and fishes (Schindler and Scheuerell 2002).

The littoral zone (including the fringe area, see Figure 7-1) is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants (macrophytes) to grow. The extent of this area depends on the lake morphometry (i.e., physical dimensions of its basin) as well as the water clarity on any given day. Tree and large woody debris in the littoral zone, in addition to being a food source and a substrate for algae and invertebrates (Schindler and Scheuerell 2002), provide habitat for fish and other organisms (Piaskowski and Tabor 2001; Tabor and Piaskowski 2002). In addition, the littoral zone is of great importance to anadromous fish species, particularly salmon. It provides migration corridors, spawning habitat, and rearing habitat for salmonids species (Buckley 1964; Berge and Higgins 2003; Fresh 2000; Piaskowski and Tabor 2001; Tabor and Piaskowski 2002). In addition, the littoral zone can provide habitat for insects such as dragonflies (Odonata), mayflies (Ephemeroptera), stoneflies (Plecoptera), caddis flies (Trichoptera) and midges (Diptera).

The benthic zone occurs in the lake bottom (see Figure 7-1). The term benthic applies to flora and fauna living at the lake bottom and those species that live by burrowing in the lake bottom. Benthic organisms can live in the substrate (in mud and sand), move on the substrate surface, and/or grow attached to the surface or move freely in the bottom. Typically, much of the lake bottom beyond the littoral zone is covered with mud, with particle size and organic content dependant on conditions specific to a lake.

The three zones described above comprise the aquatic area of the shorelines. However, the focus of this review is on the littoral zone, as it pertains to shoreline aquatic areas. This is due to the importance of the littoral zone to anadromous fish species, particularly salmon.

Shorelines provide a wide variety of functions related to aquatic and riparian habitat, flood control and water quality, economic resources, and recreation, among others. Each function is a product of physical, chemical, and biological processes at work within the overall landscape. In lakes, these processes take place within an integrated system (ecosystem) of coupled aquatic and riparian habitats (Schindler and Scheuerell 2002). Hence, it is important to have an ecosystem approach which incorporates an understanding of shoreline functions and values. The discussion presented herein emphasizes this ecosystem approach.

Shoreline function "means the work performed or role played by the physical, chemical, and biological processes that contribute to the maintenance of the aquatic and terrestrial environments that constitute the shoreline's natural ecosystem" (Washington Administrative Code [WAC], WAC 173-26-020). The ecological functions of lake shorelines include but are not limited to (WAC 173-26-201):

- **Hydrologic functions:** Storing water and sediments, attenuating wave energy, removing excessive nutrients and toxic compounds, and recruiting large woody debris and other organic material.

- **Shoreline vegetation functions:** Maintaining temperature, removing excessive nutrients and toxic compounds, attenuating wave energy, removing sediments, stabilizing shorelines, and providing woody debris and other organic matter.

- **Hyporheic functions:** Removing excessive nutrients and toxic compounds; providing water storage, supporting vegetation, and storing sediment; maintaining base flows.

- **Habitat functions (pertaining to aquatic and shoreline-dependent birds, invertebrates, mammals; amphibians; and anadromous and resident native fish):** Providing space or conditions for reproduction, resting, hiding, and migration; and providing food production and delivery.

7.2 Shoreline Overlay District

Section 20.25E.010 of the Bellevue Land Use Code provides a definition of the Shoreline Overlay District. The definition encompasses:

- Lake waters 20 acres in size or greater, and underlying lands

- Stream waters with a mean annual water flow exceeding 20 cubic feet per second, and underlying lands

- Lands extending 200 feet in all directions from lakes and streams in the overlay district as measured from the ordinary high water mark (OHWM) on a horizontal plane

- Floodways and contiguous floodplain areas within 200 feet of floodways associated with such streams and lakes

- Marshes, bogs, swamps and river deltas associated with such streams and lakes.

Specifically included within the Bellevue Shoreline Overlay District are the following:

- Lake Washington, including Mercer Slough upstream to Interstate 405; lake waters, underlying lands and the area 200 feet landward of the ordinary high water mark, plus associated floodways, floodplains, marshes, bogs, swamps, and river deltas
- Lake Sammamish, including the lake waters, underlying lands and the area 200 feet landward of the OHWM, plus associated floodways, floodplains, marshes, bogs, swamps and river deltas
- Lower Kelsey Creek, including the creek waters, underlying lands, and territory within 200 feet on either side of the top of the banks, plus associated floodways, floodplains, marshes, bogs, swamps and river deltas
- Phantom Lake, including the lake waters, underlying lands and the area 200 feet landward of the ordinary high water mark, plus associated floodways, floodplains, marshes, bogs, swamps and river deltas.

Lake Washington, Lake Sammamish and Phantom Lake are all lentic systems. In contrast, Kelsey Creek is a fluvial system and the lower portion is the only fluvial system included within the Shoreline Overlay District. Therefore, the focus of this review is on lake shorelines, with specific emphasis on Lake Washington, Lake Sammamish and Phantom Lake. Nonetheless, the scientific information, analysis, and recommendations included within this report could be applied to all shoreline areas included within the Shoreline Overlay District. The review of best available science pertaining to streams and their associated riparian areas can also be applied to the Lower Kelsey Creek system (see Chapter 4 of this report).

The following section discusses existing conditions within Lake Washington, Lake Sammamish and Phantom Lake, within the context of the functions and values they provide.

7.2.1 Lake Washington

With a surface area of 22,138 acres, Lake Washington is the second largest natural lake in Washington state. The Lake Washington system includes Lake Washington and the Lake Washington Ship Canal, which is an artificial waterway 8.6 miles long. The Lake Washington Ship Canal comprises the following areas (from east to west): Union Bay, Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and Salmon Bay (Kerwin 2001).

The main inflow to Lake Washington is the Cedar River, which contributes about 55 percent of the mean annual inflow. The Sammamish River contributes approximately 27 percent of the surface flow to the lake. Lake Washington drains to Puget Sound via the Lake Washington Ship Canal (Kerwin 2001).

Lake Washington has a history of anthropogenic alterations to its hydrology, including construction of the Lake Washington Ship Canal and diversion of several river systems (Chrzastowski 1983). These dramatic physical and limnological changes began in 1916 when the natural outlet of the lake, the Black River, was blocked, and the outlet was changed to the Ballard Locks, thus linking Lake Washington to Puget Sound. With the completion of the Ballard Locks, the water level of Lake Washington was lowered 8.8 feet. In addition, flow from the Cedar River was diverted into Lake Washington to improve flushing of the lake (Chrzastowski 1983).

The shoreline of Lake Washington, including Bellevue's shoreline area, is extensively developed (Weitkamp and Ruggerone 2000; Toft 2001). Currently, the majority of Lake Washington's shoreline is urban residential, with the exception of a few commercial and industrial developments. Thirteen incorporated cities border the lake (Kerwin 2001). As the watershed has been developed, dredging, filling, bulkheading, and the construction of piers, docks, and floats have all occurred in shoreline areas.

As of the year 2000, there were 2,737 docks along the shoreline of Lake Washington, the majority of which are recreational docks that are constructed low (<2 m) above the water. Overall, 70.65 percent of the Lake Washington shoreline is armored with either riprap or bulkheads, while 29.35 percent of the shoreline is unarmored and consists of beach, natural vegetation, or landscaping (Toft 2001).

As of 2003, 75 percent of the shoreline between Shilshole Bay and Lake Washington (including most of Lake Washington's western shoreline) was armored (Toft et al. 2003a). Vertical concrete bulkheads and riprap were the predominant armoring structures. This type of shoreline modification results in the loss of shallow water areas. In fact, shallow littoral areas with small substrate are rare in Lake Washington in comparison to armored shorelines (Toft 2001). These shallow littoral areas are utilized by juvenile salmon (Fresh 2000; Piaskowski and Tabor 2001; Tabor and Piaskowski 2002).

Existing data on shoreline armoring specifically within Bellevue's Lake Washington shoreline is incomplete. Therefore, in order to provide a basis for a review of Bellevue's shoreline, additional data were gathered. Specifically, the length of the Lake Washington shoreline within the City of Bellevue was classified, as either armored or unarmored, using GIS resources. To this end, a 2001 color aerial photograph obtained by the City of Bellevue, and a City of Bellevue file of bulkheads within the City (Bellevue 1999) were used as guides. The scale of digitization and analysis was approximately 1:480. An estimated 5 percent error was assumed on the resultant lengths of armored and unarmored shoreline due to the scale at which the shoreline was digitized and the inherent difficulty with assessing armoring through aerial photographic analysis without field verification.

Based on this analysis, of an estimated 39,187 feet of shoreline, 32,054 feet of Bellevue's Lake Washington shoreline was armored as of 1999 (82 percent), all of which appears to have been constructed below the OHWM. Although the current extent of shoreline armoring is unknown, it likely has increased since 1999. With this degree of shoreline armoring, it is expected that a significant amount of aquatic and riparian habitat has been physical eliminated and many shoreline processes and functions are currently precluded.

The riparian shoreline of Lake Washington is highly altered from its historic state. Current and likely future land-use practices preclude the possibility of the shoreline functioning as a natural shoreline to benefit salmonids. This is due to the lack of structure and shoreline vegetation, as well as hydraulic changes due to bulkheads and docks (Kerwin 2001; Kahler 2000; Carrasquero 2001).

The hardstem bulrush and willow that once dominated the shoreline community have been replaced by developed shorelines with landscaped yards (Kahler et al. 2001). The few "natural" shoreline areas are relatively small (most <820 feet in length) and separated by long distances (Tabor and Piaskowski 2002). As a result, the loss of natural shoreline has changed and reduced the amount of complex shoreline features such as overhanging vegetation, submerged root systems, emergent vegetation, woody debris, and substrate (Kahler 2000; Carrasquero 2001).

Much of the large woody debris that was once associated with the shoreline of Lake Washington has been eliminated. The remaining natural shoreline in Lake Washington is in the vicinity of St. Edwards Park and represents less then 5 percent of the lake's total shoreline length (Kerwin 2001).

All seven native salmon and trout of the genus *Oncorhynchus* (i.e., chinook, coho, chum, sockeye, and pink salmon, and steelhead and cutthroat trout) as well as bull trout (*Salvelinus confluentus*) (collectively referred to as salmonids in this report) occur in Lake Washington Kerwin 2001). The WRIA 8 Technical Committee identified the following factors of salmonid population decline for the Lake Washington subarea: altered trophic interactions (predation, competition); degradation of riparian shoreline conditions; altered hydrology; invasive exotic plants; poor water quality (phosphorus, alkalinity, pH, temperature); and poor sediment quality (King County 2002b).

In summary, anthropogenic changes in Lake Washington have altered the physical, chemical, and biological processes that create and maintain the aquatic and terrestrial environments that constitute the shoreline's natural ecosystem. These alterations limit Lake Washington's shoreline functions and values within Bellevue and the Lake Washington watershed. However, although degraded to various degrees by urbanization, Bellevue's Lake Washington shorelines still provide multiple ecological functions that support anadromous and resident fish as well as wildlife species, and provide a wide range of recreational and natural resource benefits.

7.2.2 Lake Sammamish

Situated within the northern end of the 223 square kilometers Sammamish Watershed, Lake Sammamish is approximately 18.1 miles long and 1.2 miles wide with a surface area of 19.8 square kilometers, a maximum depth of 105 feet and a mean depth of 58 feet (Kerwin 2001; King County 2004c). Lake Sammamish is designated as a "resource of statewide significance" under the Shoreline Management Act. It provides holding, migratory, foraging, and rearing habitat for salmonid species and spawning habitat for sockeye and kokanee salmon.

Issaquah Creek, the major tributary to the lake, enters at the south end and contributes approximately 70 percent of the surface flow. The West Lake Sammamish Basin (King County 2002a) contains several streams and tributaries including Idylwood Creek, Wilkins Creek, Phantom Creek, Vasa Creek, and several smaller streams that drain directly into Lake Sammamish. Surface water discharge from Lake Sammamish into Lake Washington is through the Sammamish River. At the north end of Lake Sammamish, at Marymoor Park, a flow control weir controls the discharge of lake water into the Sammamish River (Kerwin 2001).

As with Lake Washington, existing data on the extent of armored shoreline are incomplete for Lake Sammamish. Therefore, using the same protocol as described above for Lake Washington, to supplement this review, the length of the Lake Sammamish shoreline within Bellevue was classified as either armored or unarmored (Bellevue 1999). Based on this analysis, of an estimated 26,190 feet of Bellevue Lake Sammamish's shoreline, 21,206 feet of was armored as of 1999. This represents an 81 percent of the total Lake Sammamish shoreline within Bellevue's city limits. As with Lake Washington, although the current extent of shoreline armoring is unknown, it is expected to have increased since 1999. With this degree of shoreline armoring, a significant amount of aquatic and riparian habitat has been physical eliminated and many shoreline processes and functions are currently precluded.

The relationship of armored shoreline to the OHWM in Lake Sammamish was also determined as part of this review. To accomplish this, 1-foot contour lines were created from light detection and ranging (lidar) data obtained by the Puget Sound LIDAR Consortium and flown in early 2000 and 2001. Averaging the OHWM to 32 feet above sea level (actual OHWM is 31.8 feet), apparent bulkheads were classified as either above or below the OHWM using GIS resources. Due to errors inherent in the lidar when analyzing at elevations close to the lake water level, these totals can be expected to contain a margin of error of approximately 10 percent.

Based on a GIS analysis of the estimated 21,206 feet of Bellevue's Lake Sammamish armored shoreline, 6,438 feet (30 percent) of armored shoreline were constructed below the OHWM. This represents an important physical habitat loss. In particular, a loss of habitats associated with the fringe area and the shallow water portion of the littoral zone.

The presence of chinook (*O. tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), kokanee (*O. nerka*), salmon; steelhead (*O. mykiss*); and rainbow (*O. mykiss*) and coastal cutthroat (*O. clarki clarki*) trout has been documented recently in Lake Sammamish. According to Kerwin (2001), anthropogenic-derived factors affecting the natural production of salmonids in Lake Sammamish include:

- Alteration of the type and abundance of salmonid predators;
- Areas containing elevated concentrations of sediment associated contaminants;

- Reduced levels of dissolved oxygen (below minimum requirements for salmonids) and decreased overall diversity of macrophytes due to the presence of Eurasian milfoil; and

- Inadequate and fragmented riparian buffer areas.

In addition, the WRIA 8 Technical Committee identified the following factors of salmonid fish population decline for Lake Sammamish: predation; degradation of riparian shoreline conditions; poor water quality (temperature and nutrients); invasive exotic plants; degraded sediment quality; altered trophic interactions; altered macrophyte conditions; and fish access and passage barriers (King County 2002b; King County 2004d).

In summary, anthropogenic changes in Lake Sammamish have altered the physical, chemical, and biological processes that create and maintain the shoreline aquatic and terrestrial environments typical of natural ecosystems. These alterations limit Lake Sammamish's functions and values within the Bellevue shorelines and the Lake Sammamish watershed. However, although degraded to various degrees by urbanization, the Bellevue shorelines of Lake Sammamish provide multiple ecological functions that support fish and wildlife, and provide a wide range of recreational and natural resource opportunities.

7.2.3 Phantom Lake

Phantom Lake is located west of Lake Sammamish in the Lake Hills Greenbelt area. The lake has a surface area of 63 acres and a maximum depth of 45 feet (King County 2004e). Historically, Phantom Lake was surrounded by a wetland complex, and it drained to the west, emptying into Lake Washington. What is currently known as Larsen Lake was likely part of this wetland complex. In the late 1880s, to drain and convert some of the surrounding wetland areas into farmland, a channel was dynamited on the east side of the Phantom Lake and its flow was redirected a half-mile to the east, into Lake Sammamish (KCM 1993). More recently, Phantom and Larsen Lakes were modified to provide stormwater flood attenuation and water quality functions to improve the water quality in both lakes (Comings et al. 2000; KCM 1993).

Today, Phantom Lake drains into Lake Sammamish via Phantom Creek. Phantom Creek flows through a wooded ravine below Phantom Lake (Bellevue 2003). Upstream of the lake, the stream consists of a narrow, sediment- filled channel with low flow (Kerwin 2001).

Phantom Creek is inhabited by coho and sockeye salmon downstream of an impassable culvert under West Lake Sammamish Parkway. Approximately 15 percent of Phantom Creek contains gradients exceeding 12 percent. Cutthroat trout are present in reaches upstream of West Lake Sammamish Parkway to Phantom Lake. Warmwater fish that originated from Phantom Lake may also be present in Phantom Creek (Kerwin 2001; Bellevue 2003).

The Phantom Lake and Larsen Lake/Lake Hills Greenbelt wetland complex is the headwater for Kelsey Creek, which enters the East Channel of Lake Washington at Interstate 90. Historically, chinook salmon had access to the entire mainstem Kelsey Creek upstream to Phantom Lake. However, there are no recent documented observations of chinook salmon in this area. Within the Larsen Lake area, large areas of blueberry farms dominate the riparian vegetation (Kerwin 2001; Bellevue 2003).

In summary, anthropogenic changes in Phantom Lake have altered the physical, chemical, and biological processes that create and maintain the shoreline aquatic and terrestrial environments. These alterations limit Phantom Lake's functions and values and preclude access and habitat utilization by anadromous fish species including salmon. However, although degraded to various degrees, Phantom Lake still provides multiple ecological functions that support fish and wildlife, as well as social value for the residents of the City of Bellevue.

7.3 Review of the Literature

7.3.1 Functions and Values

As stated previously, shorelines provide a wide variety of functions. These include the physical, chemical, and biological processes that contribute to the maintenance of the aquatic and terrestrial environments constituting the shoreline's natural ecosystem. The following section discusses the functions and values of Bellevue's shorelines as seen through a review of existing conditions.

In general, anthropogenic changes along the shorelines of Lake Washington, Lake Sammamish and Phantom Lake have altered the physical, chemical, and biological processes that create and maintain the shoreline aquatic and terrestrial habitats typical of these natural ecosystems. Consequently, these anthropogenic changes have lessened shoreline functions and values within Bellevue. Currently over 80 percent of shorelines within the City of Bellevue have some stabilization structure, over 50 percent of all parcels have structures within 50 feet of the OHWM, and virtually every shoreline lot has been developed, primarily for residential use.

However, Bellevue's shoreline areas still provide multiple ecological functions and values and present habitat rehabilitation and preservation opportunities. Because of the unique mix of water and biodiversity, shoreline areas are also valued for a broad range of recreational and aesthetic activities, including swimming, fishing, and the enjoyment of natural beauty and solitude. Any rehabilitation and preservation actions would have to be implemented at the watershed scale and not just within the City of Bellevue boundaries, in order to achieve ecological success. Nonetheless, given the current state of habitat degradation, any local protection and rehabilitation effort will contribute to the overall improvement of the natural resource and recreational functions and values that these lakes provide.

As stated earlier, the ecological functions of a lake's shoreline pertain, but are not limited to: hydrologic conditions, shoreline vegetation, the hyporheic zone, and habitat functions (WAC 173-26-201). Based on empirical knowledge and inferred and hypothetical associations, additional known and expected shoreline ecological functions can be summarized for Lake Washington, Lake Sammamish and Phantom Lake.

7.3.1.1 Lake Washington and Lake Sammamish Ecological Functions

From the ecological viewpoint, the shorelines of Lake Washington and Lake Sammamish provide the following ecological functions, particularly in remnant natural unarmored areas (King County 2004; City of Seattle 2004; Tabor et al. 2004b; Berge and Higgins 2003; Tri-County Salmon Conservation Coalition 2002; Tabor and Piaskowski 2002; Piaskowski and Tabor 2001; Carrasquero 2001; Kahler et al. 2001; Kerwin 2001; Koehler 2002; Greenberg and Sibley 1994; Buckley 1964):

- Nutrient cycling.
- Primary and secondary production.
- Shoreline erosion protection (from remnant natural unarmored areas): Tree roots hold the shoreline soils together and tree stems protect the shoreline by deflecting the cutting action of waves, boat wakes, and stormwater runoff.
- Canopy and shade (from remnant natural unarmored areas): Shading by lake vegetation can moderate water temperature along the shoreline fringe area providing relief for aquatic life in the hot summer months.
- Organic matter input (riparian vegetation and large woody debris [LWD]): Leaves and woody debris fall into the lakes and provide food and habitat for fish and other aquatic species that are critical to the aquatic food chain.
- Sediment input: Sand provides rearing habitat for juvenile chinook salmon. Gravel provides spawning habitat for sockeye and kokanee salmon.
- Wildlife support and refugia: The shoreline riparian areas, particularly on remnant natural unarmored areas, offers habitat for many wildlife species. This habitat can provide linkages between natural areas and act as a migration corridor for a wide variety of plants and animals.
- Adult salmon migration corridor and holding habitat.
- Sockeye and kokanee salmon spawning substrate.
- Juvenile salmon rearing habitat and migration corridor.
- Salmonid rearing habitat.
- Substrate for aquatic (submerged) vegetation, macroinvertebrates, and fish.
- Food for bird species.
- Wind wake and boat wake buffering (aquatic and emergent vegetation in the littoral fringe, and LWD along unarmored shoreline segments).

- Sediment trapping (emergent vegetation in the littoral fringe).
- Flood attenuation and water quality improvement: Rain that runs off the land can be slowed and infiltrated in the riparian area, which helps settle out sediment, nutrients and other pollutants before they reach Lake Washington and Lake Sammamish. In addition, nutrients from fertilizers and animal waste that originate on land are taken up by tree roots. Phosphorus and nitrogen are stored in leaves, limbs and roots instead of reaching the lakes.

7.3.1.2 Phantom Lake Ecological Functions

Phantom Lake provides the following ecological functions (Kerwin 2001; Comings et al. 2000; KCM 1993):

- Nutrient cycling
- Primary and secondary production
- Organic matter input (riparian vegetation and woody debris)
- Cutthroat trout and warm water fish habitat
- Wildlife support and refugia
- Substrate for aquatic (submerged) vegetation, macroinvertebrates, and fish
- Food for bird species
- Wind wave and boat wake (if motor boat use is currently allowed) buffering
- Sediment trapping (emergent vegetation in the littoral fringe)
- Flood attenuation: Rain that runs off the land can be slowed by the lake and by the associated riparian upland and wetland areas. Slowing the velocity of runoff allows the water to recharge the ground water supply. Ground water can then enter Phantom Creek at a much slower rate and over a longer period of time than water that has traveled as surface water. This helps control flooding and maintains stream flow during the driest times of the year.
- Water quality improvement: Rain that runs off the land can be slowed and infiltrated in the adjacent riparian upland and wetland areas, which helps settle out sediment, nutrients and other pollutants before they reach Lake Sammamish. In addition, nutrients from fertilizers and animal waste that originate on land are taken up by the roots of diverse vegetation.

These ecological functions may be impaired not only by shoreline development and modifications, but also by past actions, unregulated activities, and development that is exempt from permit requirements (WAC173-26-186). Shoreline modifications mean those actions that modify the physical configuration or qualities of the shoreline area, usually through the construction of physical structures such as bulkheads, breakwaters, jetties, groins, docks and piers as well as dredged basins, and fill. Shoreline modifications can include other (related) actions, such as clearing, grading, or the application of chemicals (WAC 173-26-020).

In accordance with the Shoreline Master Program Guidelines (WAC 173-26), local agency regulations shall assure that no net loss of shoreline ecological functions will result from residential development. Such provisions should include (among others) specific regulations for structure setbacks and buffer areas, shoreline armoring, and vegetation conservation requirements. The conditions and protection of functional buffers can also provide important market and long-term aesthetic value.

For example, using buffers to set-back development and land uses from the shoreline is a cost effective way to protect many of the natural features and water quality that are an essential component in establishing the market value of lakefront properties. A recent study of lakes in north-central Minnesota found that clear water can boost the value of lakeshore property (Krysel et al. 2003). Actions such as mowing to the waters edge with sloping land, removing emergent vegetation, armoring heavily, and loading the riparian zone with docks and boatlifts after removing indigenous vegetation makes the property environmentally vulnerable (Krysel et al. 2003).

7.4 Buffers

The term "buffer" is typically used to describe an area needed to provide protection to a given waterbody or sensitive area. For example, King County defines buffers as "a designated area contiguous to a steep slope or landslide hazard area intended to protect slope stability, attenuation of surface water flows and landslide hazards or a designated area contiguous to a stream or wetland intended to protect the stream or wetland and be an integral part of the stream or wetland ecosystem" (Chapter 21A.06.122, Ord. 10870 § 70, 1993).

The existing Bellevue Land Use Code (Chapter 20.50, Definitions) defines Protected Areas as that area designated by Land Use Code 20.25H.070 where use or development is subject to special limitations due to its physical characteristics (Ord. 4654, 6-6-94, § 80; Ord. 3775, 5-26-87, § 29). The Bellevue Land Use Code does not clearly differentiate and define the characteristics of riparian, buffer, and structure setback areas, particularly within the context of the ecological functions they provide. Instead, the code defines Riparian Corridors as "the area mapped or defined as a Riparian Corridor in the City of Bellevue Sensitive Area Notebook."

The code definition classifies the riparian coridor by four types: Type A, Type B,Type C, and Type D. Of these four types, only three include a primary structure setback: Type A, which extends away from the stream on each side a distance of 50 feet; Type B, which extends away from the stream on each side a distance of 25 feet; and Type C, which extends away from the stream on each side a distance of 10 feet. In addition, this code defines a setback as "a space unoccupied by structures except where intrusions are specifically permitted by this Code." The Bellevue Land Use Code definitions do not clearly state that the riparian area is an ecological zone needed to provide and maintain shoreline ecological functions and values, and that buffers are areas needed to provide protection to the shoreline. These differentiations and definitions are important to facilitate public understanding of each of these areas and the specific functions they provide to protect Bellevue's shorelines.

It is worth mentioning that the term buffer should only be used to denote an area prescribed or set aside and managed to protect a natural environment from the effects of surrounding land-use or human activities. Buffers should not be confused with the natural riparian area, which is an integral part of an aquatic ecosystem. Lake shoreline riparian areas provide more diverse and a greater variety of ecological functions than buffers typically afford. For example, riparian areas are composed of a mixture of herbs and grasses, shrubs, deciduous trees, and coniferous stands of various ages. In contrast, buffers can be landscaped areas or even grassy swales or vegetated filter strips typically designed for water quality treatment (May 2003).

Hence, more comprehensive definitons are needed in the Land Use Code in order to focus and facilitate the implementation of measures aimed to protect Bellevue's shoreline functions and values. However, to simplify the discussion presented in this chapter, the term buffer is used in reference to both the shoreline riparian area and the protective area that is needed for its preservation. In other words, a buffer includes area sufficient to protect the shoreline riparian area function as well as the lake.

7.4.1 Review of the Literature

Most of the information on buffer prescriptions has been derived from the literature for stream, river, and wetland systems. The genesis of this literature resides in buffer studies conducted in those systems. Unfortunately, buffer habitat studies of lakes are nearly nonexistent and the few available have been limited to water quality issues. Therefore, although buffer areas for lakes have also been prescribed, especially for protection of water quality (e.g., Woodward and Rock 1995), they typically have been derived from the literature for streams, rivers, and wetlands. Consequently, they do not fully address lake-specific ecological functions.

Nonetheless, many of the functions associated with stream and wetland buffers also apply to lakes. A brief discussion of buffer functions as they likley relate to lakes is provided in this report. A more detailed discussion of buffer functions is provided in the 2003 *Bellevue Critical Areas Update Best Avaiolable Science Paper: Streams.*

7.4.1.1 Lake Buffer Functions

Buffers, in the context of wetland protection, typically are vegetated upland areas immediately adjacent to the wetland. Most buffer regulations focus almost exclusively on the buffer width.

Many literature searches have been published summarizing the effectiveness of various buffer widths (e.g., Castelle et al. 1992a and 1992b; Castelle and Johnson 2000; Desbonnet et al. 1994; FEMAT 1993).

As in streams and wetlands, buffers may support healthy lake conditions. Buffer areas encompass complex above- and below-ground habitats created by the convergence of biophysical processes in the transition zone between aquatic and terrestrial ecosystems (NRC 2002). They provide a variety of functions including shade, temperature control, water purification, woody debris recruitment, channel, bank and beach erosion, sediment delivery, and terrestrial-based food supply (Gregory et al. 1991; Naiman et al. 1993; Spence et al. 1996).

Buffers may act as sinks by removing unwanted elements before they affect the lake environment, as reported for wetlands (Castelle and Johnson 2000). Sink functions include:

- Storm and Flood water control including erosion control
- Sediment and pollutant retention
- Water temperature moderation through shade.

Buffers retain sediments, nutrients, pesticides, pathogens, and other pollutants that may be present in runoff (Woodward and Rock 1995; Washington Department of Ecology 1996). As with wetlands, reduction of sediment and pollutant discharge to lakes likely prevents "sediment filling," which causes degradation of water quality in lakes, and alterations to plant and animal communities. Buffers infiltrate surface flows, reducing the effect of water level fluctuations within lakes. Buffers (forested and shrub habitats), provide shade for moderating water temperatures, particularly in a lake's fringe areas.

Buffers may also provide source inputs that are important for lake aquatic species, as reported for wildlife in wetland habitats (McMillan 2000; Castelle and Johnson 2000). Source inputs include:

- Habitat for wetland-dependent wildlife species that also require terrestrial habitats (wildlife habitat)
- Large woody debris for habitat structure
- Insects and nutrient export for food supply
- Protection from human disturbance.

7.4.1.2 Lake Buffer Function and Buffer Width

Lake-specific literature on buffer width is almost nonexistent and the few available sources that provide information on buffer functions as a factor of buffer width focus on water quality in lakes (Table 7-1).

Table 7-1. Lake-specific references on buffer width conclusions and recommendations, regarding protection of ecological functions provided by buffers.

References	Conclusions/Recommendations	Function Protected/Provided
Woodward and Rock (1995)	Concludes that a 50 foot undisturbed buffer strip (mixed growth, uneven age stand, predominantly hardwood) is enough to reduce the concentration of total suspended solids (TSS) and return phosphorus concentration to background levels. Presence of forest litter and understory vegetation to "anchor" the soil is critical in determining the efficiency of the buffer. If these elements are lacking, the buffer strip itself can contribute P and TSS. The condition of the buffer strip seems to be as important as the length.	Water quality: removes sediment and nutrients (phosphorus).
NCWRC 2002	Recommends a minimum 50–100 feet structure setback (measured from the edge of a lake's riparian area) for sewer lines, water lines, and other utility infrastructure (NCWRC 2002). In addition, recommends a minimum 200-foot-wide native forested buffer for the protection of aquatic endangered species habitats in a North Carolina lake (i.e., Randleman Lake; NCWRC 2002).	Protects riparian areas and aquatic endangered species habitats.
King County 2004a	Recommends a strip of natural plants between the water and buildings, lawns, or cleared areas.	Water quality: filters sediment and nutrients out of surface runoff and moderates water temperature. Provides food and a habitat for a variety of other wildlife species. Stabilizes sloped areas, helps stop erosion, and dissipates floodwaters. Discourages resident Canada geese from moving in.
Illinois Environmental Protection Agency (1996)	A 25-foot buffer is most often recommended. Wider buffers (50 to 100 feet) for larger or more sensitive lakes.	Water quality: removes sediment, nutrients, and other pollutants.
Hardesty and Kuhns (1998)	Recommends a buffer width of 50 to 250 feet, depending on the degree of slope. Buffers should span the entire length or width of the developed area being shielded.	Water quality: traps sediments, excess nutrients, and other pollutants; prevents erosion; and helps to stabilize sloped areas and the shoreline.
Kipp and Callaway (2003)	Recommends a 100-foot buffer with an additional 10 feet for every 1% slope. If rock outcrops or wetlands are adjacent, the width of these features should be added.	Water quality: removes sediment and nutrients. Provides habitat.
Christensen et al. (1996)	Shoreline residential development located within 33 feet of lakes adversely affects the abundance of coarse woody debris.	Provides habitat support: Structure, coarse woody debris recruitment.
Francis (2004 personal communication)	Large woody debris in lowland Puget Sound lakes appears to originate from trees growing within about 35 feet of the lake's OWHM	Provides habitat support: Structure, large woody debris recruitment.
Odum and Prentkis (1978)	The magnitude of leaf litter input is directly related to the extent of wooded shoreline (riparian area) for at least 35 feet.	Provides leaf litter input.
OMNR (2000)	Maintain high canopy closure in areas within 492 feet of the pond.	Provides habitat support: Woodland amphibian breeding habitat.
OMNR (2000)	Maintain a 320-foot buffer. Within the 320-foot buffer, vegetation should not be removed and no deposition of fill should occur.	Provides habitat support: Waterfowl nesting/breeding habitat.
USEPA (2002)	The forest buffer width shall be adjusted to include contiguous sensitive areas, such as steep slopes or erodible soils, where development or disturbance may adversely affect water quality.	Water quality: removes sediment

Although only few literature sources exist, the recommended width of lake buffers varies widely. A 25-foot-wide buffer is often recommended but wider buffers (50 to 100 feet) are typically thought to be more appropriate for larger and more sensitive lakes. A national survey conducted in the United States in 1993, found a buffer width range of 20 to 200 feet, with a median width of 100 feet (Illinois Environmental Protection Agency 1996). However, the sources of this information appear to have been derived from studies conducted in stream and river systems and not in lakes (see Heraty 1993).

Many literature reviews have been published summarizing the effectiveness of various buffer widths, mainly for streams (Knutson and Naef 1997), but also for wetlands (Castelle et al. 1992a; Castelle and Johnson, 2000; Desbonnet et al. 1994; FEMAT 1993). A comprehensive list of functions that are provided by various stream buffers is presented in Knutson and Naef (1997). McMillan (2000) provides the most recent literature review specific to wetlands in western Washington.

In addition, literature reviews have been prepared to provide guidance to address secondary and cumulative development impacts on water quality, habitat, and fish and wildlife, particularly threatened and endangered species (NCWRC 2002; OMNR 2000; Knutson and Naef 1997). For example, the North Carolina Wildlife Resources Commission recommends a minimum of 50 to 100 feet setback for sewer lines, water lines, and other utility infrastructure, measured from the edge of the riparian area of all streams, lakes, and wetlands (NCWRC 2002). In addition, the North Carolina Wildlife Resources Commission recommends a minimum 200-foot-wide native, forested buffer for the protection of aquatic endangered species habitats in a North Carolina lake (i.e., Randleman Lake; NCWRC 2002).

Table 7-1 provides lake-specific references on buffer width conclusions and recommendations that are aimed to protect the ecological functions that buffers provide. It should be noted that although some of the information provided came from lake-specific literature (e.g., Illinois Environmental Protection Agency 1996), such literature may have been derived from papers on stream and/or wetland studies (e.g., Heraty 1993).

Nonetheless, many studies addressing wetland buffer functions are at least partially applicable to lakes. In fact, Corwadin et al.(1979) includes streams and lakes within the wetland category (riverine and lucustrine wetlands respectively). Therefore, many of the functions and buffer width recommendations discussed in the available wetland literature also apply to lakes.

7.4.1.3 Water Quality and Buffer Width

The stream and wetland buffer literature indicates that particularly for sink functions, the relationship between buffer width and effectiveness is logarithmic, so that after a certain width an incremental increase in buffer width provides diminishing functional effectiveness.

As with stream and wetlands, the lake literature also indicates the existance of this logarithmic relationship. For example, on gently sloping sites, phosphorus removal to background concentrations can be accomplished within the first 50 feet of a buffer, but an additional 100 feet of buffer is needed to remove just 10 percent more phosphorus (Woodward and Rock 1999).

Indigenous vegetation present in buffer areas slows down runoff rates and reduces the quantity of surface runoff thereby facilitating the removal of pollutants (Wenger 1999; Woodward and Rock 1995). The removal of pollutants is by infiltration, deposition, absorption (uptake), and filtration. For example, it has been shown that buffer strips protect receiving waterbodies from contaminated surface runoff by removing sediment and nutrients (Woodward and Rock 1995).

In Maine, Woodward and Rock (1995) examined four specific experimental buffer strips and a control site on a lakeshore area where vegetation typically consisted of mixed growth, various ages of stands, predominantly hardwood. The buffer strips were at least 150 feet in length with a width of 50 feet. The buffer strips received elevated inputs of suspended solids and phosphorus, from eight storm events, and from a subdivision or condominium development. A variety of slopes were used and ranged from 2.3 percent to 12.0 percent (Woodward and Rock 1995).

In their study, a 50 foot undisturbed buffer strip brought phosphorus levels to within average control values. They concluded that for sites with moderate to dense ground cover and a stabilized soil matrix, a 50-foot buffer is sufficient to return phosphorus concentrations to background levels. Steeper slopes, however, may require extending the 50-foot buffer for an additional 25 to 50 feet. In their study, the condition of the buffer strip was also important. For example, exposed soils within the buffer strip actually contributed to total suspended solids. The study report recommended the use of source controls, including seeding with grass immediately after construction begins, rather than waiting until construction is finished (Woodward and Rock 1995).

7.4.1.4 Large Woody Debris and Buffer Width

Large woody debris is an important habitat component of the shoreline riparian (upland) and aquatic (littoral) areas. In the riparian areas, large woody debris provides forest nourishment, substrate, and support (Abbe 1996; Fetherston et al. 1995; Harmon et al. 1986; McKee et al. 1984) as well as wildlife habitat (Christensen et al. 1996; Knutson and Naef 1997). In the aquatic areas, large woody debris provides habitat complexity and structure (Christensen et al. 1996; Schindler and Scheuerell 2002), fish habitat, cover, and refugia (Christensen et al. 1996; Tabor and Piaskowski 2002), fish production support (Schindler et al. 2000), nutrient input (Schindler and Scheuerell 2002), and potential shoreline protection against the erosive boat wake forces. In addition, large woody debris occurring along the shoreline may help to retain sediments of particular importance to beach spawning salmon species (i.e., sockeye and kokanee).

As previously stated, many buffer functions associated with streams also likely pertain to lakes. For example, more than half of all large woody debris is recruited from within 15 feet of streams. Further, about 90 percent of all large woody debris comes from trees growing within about 50 feet of streams (Murphy and Koski 1989; Van Sickle and Gregory 1990). According to unpublished research data, most of the large woody debris in 25 lowland Puget Sound lakes appears to originate from trees growing within about 35 feet of the lake's OHWM (Francis 2004 personal communication).

These studies indicate that shoreline residential development located within 33 feet of lakes adversely affects the abundance of coarse woody debris, due to clearing of vegetation (Christensen et al. 1996). In addition, the magnitude of leaf litter input is directly related to the extent of wooded shoreline (buffer area) for at least 35 feet (Odum and Prentkis 1978).

Christensen et al. (1996) studied 16 lakes with varying degrees of shoreline residential development in northern Wisconsin and Michigan's upper peninsula. They found a significant reduction in the amount of course woody debris as the density of shoreland development increased. This occurs through two mechanisms: 1) direct removal of fallen tree trunks and branches from the lake and 2) cutting of trees along the shoreline. The authors conclude that because of the time scales involved in both recruitment of coarse woody debris and decay rate, the reduction of coarse woody debris along the lakeshore may have dramatic long-term consequences for lake ecosystems.

Vegetated shoreline buffers also preserve habitat for many wildlife species, particularly those that are semi-aquatic species (Knutson and Naef 1997).

An overall conclusion from the review of the applicable buffer literature is that the buffer width required to protect a given shoreline habitat function or group of functions depends on various site-specific factors. This includes plant community (species, density, age); slope; amount of natural organic matter covering the soil; and soil type. In general, literature on lake buffers indicates that the appropriate buffer width is site- and function-specific, and a 50-foot-wide buffer appears to be adequate to provide water quality functions and recruitment of leaf litter and large woody debris.

7.4.2 Identification of Data Gaps

Additional lake-specific studies are needed on the subject of minimum buffer width requirements to provide for and maintain shoreline functions and values. The existing literature is extremely limited. It does not address the relationship between buffer width and buffer effectiveness for all inferred, hypothetical, or known functions. Specific areas for further study include the following.

- Characterization of current habitat conditions and the degree of shoreline development along Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake
- Determination of minimum buffer area width required to protect the functions listed for Lake Washington in the functions and values section of this report. This would include studying areas where buffers are not currently provided, as well as areas where existing buffers are improved.

7.4.3 Recommendations

Based on the literature review, regulatory buffer areas ranging from 50 to 100-foot-wide comprised of native vegetation with multiple strata may be adequate to provide for the functions of Bellevue's lake shorelines. However, this adequacy is closely linked to the buffer's general conditions (i.e., whether it is disturbed or developed versus covered in native herbaceous, shrub and tree vegetation). The degree of disturbance within the buffer area may preclude some of its ecological functions. As the degree of disturbance increases, the loss of functions increases. For example, shoreline hardening and the associated placement of fill and deforestation along the shoreline are likely to eliminate or partially preclude many of the lake shoreline buffer functions (e.g., recruitment of woody debris or shade; Christensen et al. 1996).

Therefore, for a shoreline buffer area to function properly it must be undisturbed (Woodward and Rock 1995). Hence, an area of buffer to protect the riparian functions occurring in the shoreline buffer is needed in order to prevent disturbance of the riparian functions that are integral to the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake. A 25 foot-wide protective buffer measured from the edge of the shoreline buffer is most often recommended (Illinois Environmental Protection Agency 1996).

Implementation of this recommendation may require the inclusion and definition of a shoreline buffer (riparian area) as one of the critical areas. This level of protection will achieve the following:

- Protect and enhance aquatic and terrestrial species (including their prey and predators) that depend upon the shorelines and adjacent habitat areas (OMNR 2000)
- Improve and protect water quality (Woodward and Rock 1995; Illinois Environmental Protection Agency 1996; Hardesty and Kuhns 1998; EPA 2002; Kipp and Callaway 2003)
- Provide for and improve littoral habitat structure (large woody debris; Francis 2004 personal communication; Christensen et al. 1996)
- Protect and enhance the natural geomorphic configuration of the shoreline (Gasith and Hasler 1976)
- Restore, enhance, and maintain a functional riparian zone (OMNR 2000).

The combined protective shoreline buffer area and structure setback will protect ecological functions and is recommended for all lots to rehabilitate, maintain, and protect shoreline functions and values. It is recommended that any structure should be located 25 feet from the edge of the shoreline buffer. The 25-foot structure setback from the protective shoreline buffer area would limit only structures. Lawns and gardens may be allowed within the 25-foot-wide structure setback as long as their maintenance does not adversely affect the shoreline buffer or the functions it provides.

Consequently, it is recommended that the City of Bellevue code be amended to include definitions of both structure setback and shoreline buffer (riparian) areas. These definitions should be consistent with the buffer functions and width recommendations described in this document.

In addition, it is recommended that the shoreline buffer be measured from the OHWM. The OHWM should be defined based on an actual topography elevation rather than a series of biological indicators along the shoreline. This would allow for a consistent application of shoreline buffer requirements.

Within the combined shoreline buffer and structure setback area, the shoreline buffer should provide habitat connectivity along the entire length of the shoreline. In addition, it should at least include tree, shrub, herbaceous, and emergent layers of vegetation in order to obtain a full range of buffer functions. To this end, shoreline buffer averaging may be allowed. Allowing buffer averaging can be an important regulatory tool, particularly when implemented in conjunction with the removal or conversion of bulkhead structures to vegetative and large woody debris shoreline protection alternatives.

Buffer averaging permits a buffer to become narrower at some points along the lake, as long as the average buffer width meets the minimum requirement and an equal area of buffer is provided elsewhere. However, although shoreline buffer averaging may be allowed, it should always include a minimum width of 35 feet from the lake edge to ensure recruitment of large woody debris (Francis 2004 personal communication; Christensen et al. 1996). This minimal width is critical to ensure that the desired ecological functions are realized. A path 6-feet wide or less and perpendicular to the shoreline may be allowed through the buffer for access to a dock or pier. The use of chemical fertilizer, herbicides, and pesticides should be avoided within the buffer area.

Given current management practices and the existing conditions of Bellevue's Lake Washington and Lake Sammamish shorelines, allowing a buffer area of variable width may offer a feasible approach to help achieve adequate buffer functions. Buffer averaging provides greater flexibility to achieve the desired ecological goals. Indeed, variable width buffers are thought to be more ecologically sound because they can reflect complex environmental and management goals (IMST 2001; Haberstock et al. 2000).

Furthermore, allowing averaging in the buffer area can be used to promote pocket habitats with overhanging vegetation and woody debris, and may favor the use of natural shoreline stabilization techniques over bulkheads. This is consistent with recent research findings which suggest the need for a diverse shoreline with open areas as well as areas with woody debris and overhanging vegetation. The variety is important to accommodate juvenile chinook and coho salmon habitat utilization preferences during the day, nighttime, and at different times of the year (Tabor and Piaskowski 2002).

Under existing conditions, the buffer areas of Lake Washington and Lake Sammamish mostly consist of manicured lawns. However, the feasibility of creating more functional conditions along Bellevue's shorelines is not precluded by these existing conditions. Rather the existing conditions provide opportunities to implement buffer restoration strategies. For example, a planting strategy that incorporates a 25 foot structure setback plus 50 feet of shoreline buffer, includes a minimum width of 35 feet from the lake edge, and allows buffer averaging can be illustrated through photographic simulation (Figures 7-2 and 7-3). Figure 7-2 depicts a representative view of the western Lake Sammamish shoreline under existing conditions. Figure 7-3 depicts the same western Lake Sammamish shoreline with a photographic simulation of the buffer tree, shrub, and emergent vegetation layers (shown on a 2001 aerial photograph) added to represent how the shoreline buffer area can be averaged. As can be seen in these photographs, it is feasible to implement a 50-foot buffer area using buffer averaging, even considering the current state of development and buffer conditions along Bellevue's shorelines.

A monitoring plan could be implemented to evaluate the success of created or enhanced buffer areas. For this purpose, performance standards would be used as the basis for monitoring the success of the buffer, and should be quantifiable. The monitoring plan would be implemented together with demonstration projects to test the effectiveness of various buffer widths for Lake Washington, Lake Sammamish, and Phantom Lake. These demonstration projects could be implemented in combination with demonstration projects that remove bulkheads.

In general, and during the early implementation of the buffer requirements, maximum shoreline protection is needed. This is true in natural (unarmored) shoreline areas as well as in those areas where bulkhead structures are removed or converted using bioengineering techniques. For example, boat wakes erode shorelines and wash soil from the roots of emergent vegetation; boat traffic close to shore has the greatest erosive effect. Subsequently, the emergent vegetation is uprooted by the wakes (Asplund 2000; Bonham 1983; Carrasquero 2001). Hence, to minimize wake erosion effects on the shoreline, a permanent no-wake zone should be imposed along all shorelines within a zone extending from the OHWM to 300 feet offshore in Lake Washington and Lake Sammamish.

A permanent speed limit should be imposed in Phantom Lake (if motor boat use is currently allowed). Given the smaller size of this lake and the fact that the boat speed that will produce the maximum wake depends on the depth of the water and the speed of the boat (Johnson 1957), the speed limit should be based on the lake's depth, particularly the depth along the littoral zone.

These recommendations are consistent with the goals and recommendations from the WRIA 8 Technical Committee for Lake Washington and Lake Sammamish which include the following (King County 2002b):

> *Protect and restore habitat-forming processes and habitat conditions in the Lakes Washington and Sammamish environment that contribute to the ecological requirements of adult and juvenile salmon, such as feeding, migration, rearing, spawning, and refuge areas.*

In addition, these recommendations may help to recreate a system of habitat nodes and linkages that will enhance and protect ecological functions and wildlife values within Bellevue's

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Figure 7-2. Representative view of the western Lake Sammamish shoreline under existing conditions, Bellevue, Washington.

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Figure 7-3. **Photographic simulation of a 50-foot-wide averaged riparian area on the western Lake Sammamish shoreline with tree, shrub, herbaceous, and emergent vegetation layers, Bellevue, Washington.**

urbanizing landscape and beyond, within adjacent cities. A successful example of this is a wildlife habitat network for the East Sammamish Community Plan using GIS resources (Stenberg et al. 1997). This wildlife habitat network demonstrated the feasibility of connecting valuable streams and wetlands, forming continuous networks across the planning area and, making connections to large blocks of public ownership outside of the planning area (Stenberg et al. 1997). As depicted in Figure 7-3, an averaged 50-foot-wide buffer area can contribute to reconnect riparian networks (landscape connectors), providing contiguous travel routes between refuges for wildlife.

Finally, the buffer recommendations provided herein are suggested for all the following development activities in order to ensure consistency in the rehabilitation and protection of shoreline buffer areas and the habitat and processes they create and support:

- Agricultural Uses
- Clearing and Grading
- Commercial Development
- Residential Development
- Road and Railroad Designs and Construction.

7.5 Bulkheads (Shoreline Protection)

The effects of bulkhead structures have been broadly studied in marine environments, particularly when used as the means to armor the shoreline for protection against wave-induced erosion (from ambient waves and boat wakes). In contrast, very few studies have addressed the environmental effect of these structures in freshwater environments (Carrasquero 2001). Therefore, where freshwater-specific scientific knowledge to support the discussion of ecological processes, functions, and values, was unavailable, an inference or hypothesis of the existence of similar (parallel) processes and functions was made based on the marine literature.

The City of Bellevue defines a bulkhead as "a wall or embankment used for holding back earth" (Bellevue City Code Chapter 20.50, Definitions). Bulkheads are one of many structural stabilization measures used for shoreline protection, which include "hard" and "soft" stabilization measures (i.e., armoring). Hard structural stabilization measures refer to those with solid, hard surfaces, such as concrete bulkheads, while soft structural measures rely on less rigid materials, such as bioengineering vegetation measures. Generally, the harder the construction measure, the greater the impact on shorelines, including sediment transport, geomorphology, and biological functions (WAC 173-26). For the purpose of this review bulkheads are any of the hard stabilization measures that exist along the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake. Vertical concrete and riprap bulkheads are the dominant armoring structures along the shorelines of these lakes.

7.5.1 Review of the Literature

As stated previously, shorelines provide a variety of functions pertaining to aquatic and riparian habitat, food web support, flood control and water quality, economic resources, recreation, etc.

Of this variety of functions, the greatest potential for bulkhead impacts is on shoreline aquatic and riparian habitat and species, particularly salmonids.

Table 7-2 provides a lake-specific summary of references regarding bulkhead impacts on shoreline habitat areas and functions. As can be seen in Table 7-2, the available pertinent literature is limited. Nonetheless, where additional empirical data are needed to understand the mechanisms of potential bulkhead impacts on shoreline functions, inferred and hypothetical associations can be made, based on available scientific literature (e.g., Carrasquero 2001; Kahler et al. 2001). These includes the potential mechanisms of impacts, which for the purpose of this review are the actions associated with bulkhead maintenance or construction. These actions are likely compounded and incrementally cumulative in nature, and primarily include riparian and aquatic vegetation removal, placement of the bulkhead structure and associated fill along the shoreline, and removal of woody debris.

In turn, the mechanisms of impact trigger habitat responses resulting in the loss of: 1) organic input (e.g., tree litter, large woody debris, and insects) to the lakes littoral zone; 2) shade to lake's fringe habitat; 3) physical aquatic and terrestrial habitat; and 4) sediment input. In addition, species responses (typically associated with the habitat responses) are also triggered, including changes in the food web, salmonid fish habitat utilization and migration patterns, and predator-prey interactions. Following is a brief discussion of each of these habitat and species responses.

7.5.1.1 Loss of Organic Input: Tree Litter, Large Woody Debris, and Insects

Structural shoreline stabilization in lakes often results in vegetation removal and damage to aquatic and riparian habitat (Carrasquero 2001; Kahler et al. 2001). In turn, vegetation removal induces a reduction in organic input including tree litter, large woody debris and insects. While the effect of a loss of organic matter input to urbanized mesotrophic lakes such as Lake Washington and Lake Sammamish may not be easily perceived, a loss of insects and large woody debris to these lakes is critical as they respectively provide food sources and habitat structure for salmonid and nonsalmonid fish species that inhabits these lakes (Tabor et al. 2004a and 2004b; Piaskowski and Tabor 2002). Indeed, bulkheads isolate and starve the aquatic portions of lake ecosystems of the natural elements that contribute to the food web such as leaf litter and insects falling into the water from overhanging vegetation (USACE et al. 2001).

In addition, the simplification of the shoreline due to the construction of bulkheads further reduces insect population and the presence of large woody debris. A mechanism of simplification is likely to occur through the shoreline straightening process that results from the construction of bulkheads and the placement of associated fill material, even when placed above the OHWM. As fill placement behind the bulkhead structures occurs, the natural geomorphic shoreline configuration and physical habitat areas are reduced, thus also reducing the perimeter to area ratio (fewer convolutions). In this regard, it is known that lakes with a high degree of shoreline convolution have stronger ties to riparian habitats because of the increased perimeter to area ratio (Gasith and Hasler 1976; Schindler and Scheuerell 2004). Therefore, unarmored, more

Table 7-2. Lake-specific references regarding bulkhead impacts on shoreline habitat areas and functions. Additional supporting impact assessment information is provided with reference source indicated.

References	Study Area	Habitat Area or Function	Bulkhead Impacts
Carrasquero 2001	Washington shorelines [a]	Littoral habitat	Elimination of shallow water habitat and complex habitat features that may function as critical refuge for juvenile chinook and coho salmon.
Kahler et al. 2001	Lake Washington [a] Lake Sammamish [a]	Overhanging vegetation and woody debris	Reduction in the abundance of overhanging vegetation and woody debris. This may increase diel temperature fluctuation in the littoral zone due to loss of shade. An increase in water temperature can promote temperature barriers, thus limiting the range and survival of certain fish species such as bull trout (Donald and Alger 1993). Overhanging vegetation and woody debris are preferred habitat type for juvenile chinook salmon (Tabor et al 2004b). Therefore, their reduction is likely to affect juvenile chinook salmon.
Kahler et al. 2001	Lake Washington [a] Lake Sammamish [a]	Detritus and terrestrial insect input Salmonid forage base	Loss of shoreline vegetation, which reduces allocthonous input of detritus and terrestrial insects to the littoral zone. In turn, this may affect forage base of salmonids.
Kahler et al. 2001	Lake Washington [a] Lake Sammamish [a]	Juvenile salmonids refuge and forage habitat	Loss of complex habitat features (i.e., woody debris, overhanging vegetation, emergent vegetation), and shallow water habitat, which reduces the availability of refuge and forage habitat for juvenile salmonids. This may increase predation risk on juvenile chinook and coho salmon (Tabor and Piaskowski 2002).
Burnett 1991	Lake Ontario, Canada	Fine sediment supply (sand)	Interruption of natural sediment nourishment process
Lawrence and Davidson-Arnott 1997	Lake Huron, Ontario, Canada	Fine sediment supply (sand)	Interruption of natural sediment nourishment process
Kahler et al. 2001	Lake Washington [a] Lake Sammamish [a]	Fine sediment supply (sand)	Reduction of fine sediment supply and shallow water areas, which may reduce the availability of shallow sandy habitat. This habitat type is preferred by juvenile chinook salmon (Tabor and Piaskowski 2002; Piaskowski and Tabor 2001; Fresh 2000). In addition, stream deltas areas along the shorelines of Lakes Washington and Sammamish are utilized by juvenile chinook salmon (Tabor 2003; Tabor et al 2004b). Also, sockeye, kokanee, and occasionally chinook salmon spawn along some shoreline areas of Lakes Washington and Sammamish (Buckley 1964; Berge and Higgins 2003) and of Lake Washington (Roberson 1967). Therefore, any reduction on the sediment supply to these deltas is likely to affect this fish species.
Kerwin 2001	Lake Washington	Salmonid habitat	Elimination of shallow water habitat. This habitat type is preferred by juvenile chinook salmon, especially from February to May when they are relatively small (Tabor and Piaskowski 2002; Piaskowski1 and Tabor 2001; Fresh 2000).
Piaskowski and Tabor 2001	Lake Washington	Predatory fish habitat	Creation of habitat for trout, smallmouth bass, and sculpin (predators of juvenile salmon).
Tabor and Piaskowski 2002	Lake Sammamish [a] Lake Sammamish	Salmonid habitat/ behavioral response	Changes in juvenile chinook salmon behavior, including avoidance of steep and deep areas created by bulkheads. This avoidance could result in increased predation risk on juvenile chinook salmon.
Piaskowski and Tabor 2001	Lake Washington	Salmonid habitat/ behavioral response	Changes in juvenile chinook salmon behavior, including avoidance of steep and deep areas created by bulkheads. This avoidance could result in increased predation risk on juvenile chinook salmon.

[a] Study included Bellevue's shoreline areas.

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convoluted shorelines contain more physical habitat area and receive more nutrient and organic matter than bulkheaded shorelines.

Another mechanism of shoreline simplification includes structure removal (i.e., woody debris), which adversely affects shoreline habitat (Francis 2004 personal communication; Carrasquero 2001; Christensen et al.1996). For example, Christensen et al. (1996) found that removal of coarse woody debris and shoreline vegetation as a result of bulkhead construction reduced refuge habitat for fish.

In this regard, recent surveys performed in Lake Sammamish indicate that shoreline areas with woody debris and overhanging vegetation have a higher overall density of chinook and coho salmon than open sites do. In February and March juvenile chinook salmon in Lake Sammamish appear to use woody debris during the day but as they grow, the use decreases. In May and June, woody debris is not used extensively but may still serve as a refuge from predators (Tabor and Piaskowski 2002). Coho salmon (*O. kisutch*) have a much stronger affinity towards woody debris during the day, than do chinook salmon. At night, coho salmon inhabit open sites and are not closely associated with woody debris or overhanging vegetation. In addition, this diel and seasonal variation in habitat utilization by chinook and coho salmon illustrates the importance of maintaining natural habitat diversity and complexity along the Lake Washington and Lake Sammamish shorelines.

7.5.1.2 Loss of Shade to Lake's Littoral and Fringe Habitats

In large stratified lakes such as Lake Washington and Lake Sammamish, water temperature moderation is unlikely to be driven by the riparian vegetation when analyzed at the whole-lake scale. The overall thermal condition of these lakes is regulated more by air temperature and the temperature of tributaries than by microclimatic controls provided by surrounding riparian forests. However, streams and surface water runoff into these lakes can create localized temperature gradients. Hence, deforestation of riparian areas associated with stream tributaries to Lakes Washington and Sammamish likely adversely affects water temperature in these lakes.

In contrast, when analyzed at the habitat scale, the riparian vegetation likely moderates summer water temperatures along the fringe area of the lake's littoral zone. In the fringe habitat area, temperature is likely influenced by the height, width, and species composition of adjacent riparian forests.

Juvenile chinook salmon in Lake Washington and Lake Sammamish are abundant in littoral areas (Fresh 2000; Piaskowski and Tabor 2001; Tabor and Piaskowski 2002). Shoreline areas with overhanging vegetation have a higher overall density of chinook salmon than do open sites (Tabor and Piaskowski 2002). Because of the chinook salmon's dependence on the littoral zone's fringe area, a loss of shade resulting in higher water temperatures is likely to adversely affect juvenile salmonid habitat utilization, and thus their survival.

For example, annual water temperatures along the shorelines of Lakes Washington and Sammamish typically exceed the range of water temperature preferred by juvenile chinook and coho salmon (53.6° to 57.2° Fahrenheit [12° to 14° Celsius]; Brett 1952). For example, King County (2002a) collected annual water temperatures at a depth of 3.3 feet (1 meter) in the vicinity of the mouth of Coal Creek in Lake Washington (Figure 7-4) and in the vicinity of Lewis Creek in Lake Sammamish (Figure 7-5) between 1998 and 2002. These water temperature data indicated that the range of water temperature preferred by juvenile chinook and coho salmon was consistently exceeded in these lakes between late May and mid October. Even when considering juvenile chinook salmon temperature for optimum growth (59° Fahrenheit [15° Celsius]; Brett 1952), water temperatures experienced in Lakes Washington and Sammamish shoreline typically exceeded this maximum between late May and mid October (see Figures 7-4 and 7-5; King County 2002a). In fact, according to Brett (1952) temperatures from 73.4° to 77° Fahrenheit (23° to 25° Celsius) could be lethal for juvenile chinook salmon and were actively avoided in his study.

Consequently, a reduction in abundance of overhanging vegetation may result in increased diel temperature fluctuation in the littoral zone due to loss of shade. An increase in water temperature can promote temperature barriers, thus limiting the range and survival of chinook salmon and bull trout (Donald and Alger 1993).

7.5.1.3 Loss of Physical Aquatic and Terrestrial Habitat

Most of the literature on the effects of bulkheads is based on studies and observations performed in marine environments. In fact, the effects of bulkheads have been broadly studied in marine environments, particularly when used as the means to armor the shoreline for protection against wave-induced erosion (from ambient waves and boat wakes; Williams and Thom 2001; Nightingale and Simenstad 2001). In contrast, very few studies exist that directly address the environmental effect of these structures in freshwater environments (Carrasquero 2001; Kahler et al. 2001; Toft 2001).

Quantitative evidence gathered in a recent scientific study along Thurston County's marine shoreline clearly demonstrated that shoreline bulkheads have reduced beach habitat areas. In these areas, shoreline bulkheads invoke adverse physical changes to beach and riparian habitat. These adverse physical changes include the elimination of physical habitat, lowering of beach profile, reduction of sediment (sand and small gravel) recruitment, coarsening of sediment in front of the bulkheads, and loss of riparian vegetation and large woody debris (Herrera 2004). In addition, when bulkheads are built to protect existing shorelines or to create additional land by placing fill material, shallow water habitat for fish and other aquatic species is lost. Chinook salmon in Lake Washington and Lake Sammamish are likely affected by bulkhead structures that adversely modify the shoreline environment and reduce available habitat area. This is supported by the fact that in Lake Washington and Lake Sammamish, juvenile chinook salmon occurred in shallow, gradually slopped areas with small to fine substrate (<2 inches in diameter) (Piaskowski and Tabor 2001; Tabor and Piaskowski 2002) and these areas are lost through bulkheading.

Bulkheads constructed below the OHWM have the greatest impact on the littoral fringe as they eliminate both aquatic habitat below and terrestrial habitat above OHWM. The reason is that bulkheads constructed below the OHWM are typically accompanied by landward fill placement.

These activities physically eliminate shallow water area as well as the fringe area of the littoral zone. This habitat loss is likely to affect aquatic species that utilize these habitat types. For example, Collins et al. (1995) compared fish use of fringe zones adjacent to lawns with their use of undeveloped shorelines in Lake Rosseau, Ontario. They found shallow water to be critical for foraging, refuge, and migration of small fishes.

7.5.1.4 Loss of Sediment Input

Bulkheads isolate and starve the aquatic portions of the lake ecosystem of the natural elements that contribute to the structural elements of complex diverse habitat such as sand, gravel, and woody debris (USACE et al. 2001).

Erosion of an unarmored shoreline by wave action results in a continuous input of sediment. The sediment is episodically supplemented by large sediment deposits from mass wasting. Sediment added to the system by erosion or slope failure is transported along the shore by wave energy, in the direction of prevailing winds (Burnett 1991; Lawrence and Davidson-Arnott 1997).

Shoreline areas lacking in sediment supply are prone to increased erosion of existing beach substrate, and the reduction of sediment sources in one area results in erosion in other areas (Burnett, 1991; Lawrence and Davidson-Arnott 1997). Bulkheads can potentially interrupt the process of sediment transport by preventing the input of sediment from the shore, increasing reflective wake energy, or even blocking the movement of sediment along the shoreline if they are located below the OHWM.

Loss of sediment sources, particularly sand, is likely to affect juvenile chinook salmon in Lake Washington and Lake Sammamish. A shallow sandy habitat type is preferred by juvenile chinook salmon (Tabor and Piaskowski 2002; Piaskowski and Tabor 2001; Fresh 2000). In addition, sand-dominated stream deltas areas along the shorelines of Lake Washington and Lake Sammamish are utilized by juvenile chinook salmon (Tabor 2003; Tabor et al 2004b). Therefore, any reduction in sand supply to these shallow sandy areas or deltas is likely to affect this fish species.

In addition, loss of sediment supply, particularly gravel, is likely to affect spawning habitat of sockeye and kokanee salmon (and potentially chinook salmon) in Lake Washington and Lake Sammamish. Sockeye, kokanee, and occasionally chinook salmon spawn along some shoreline areas of Lake Washington and Lake Sammamish (Buckley 1964; Roberson 1967; Berge and Higgins 2003). Therefore, any reduction in the gravel supply to these shallow sandy areas or deltas is likely to affect spawning habitat necessary for these fish species.

7.5.1.5 Changes in Food Web Dynamics, Habitat, and Utilization

Bulkheads cause loss of shoreline vegetation, which reduces allochthonous sources of detritus and terrestrial insects to the littoral zone. In turn, this may affect the forage base as well as direct food sources for salmonid species, particularly chinook salmon.

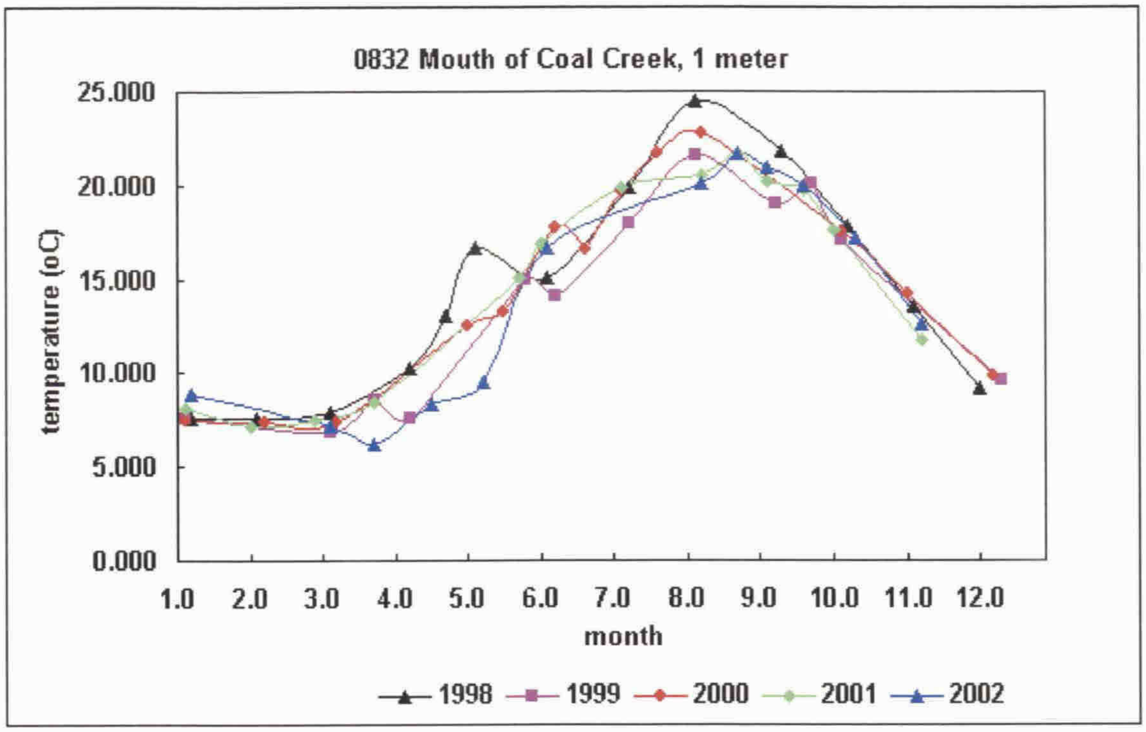

Figure 7-4. Annual water temperature data collected on the eastern Lake Washington shoreline in the vicinity of the mouth of Coal Creek (King County 2002a).

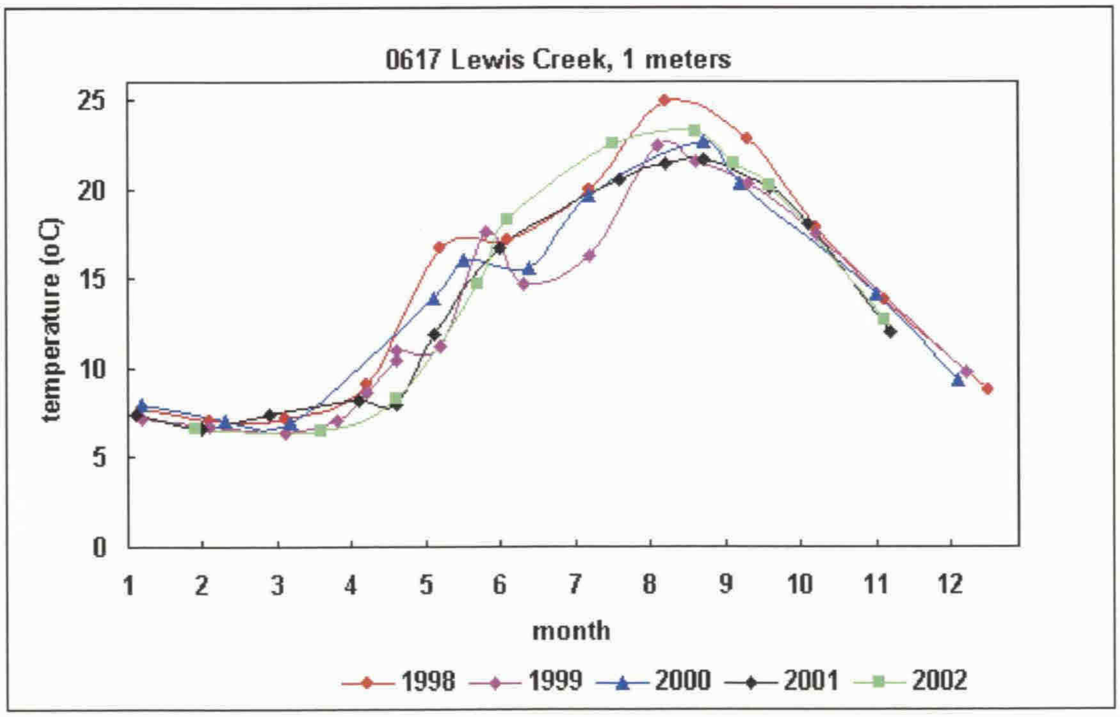

Figure 7-5. Annual water temperature data collected on the western Lake Sammamish shoreline in the vicinity of the mouth of Lewis Creek (King County 2002a).

A basic principal in ecology is that organisms respond to variation in the structure of the physical environment (Vannote et al. 1980; Minshall 1988). For example, Piaskowski and Tabor (2001) studied chinook salmon nocturnal habitat use in littoral areas of southern Lake Washington. They found that at night, juvenile chinook salmon avoid the steep and deep areas created by the bulkheads. They also found that water depths and the particle size of the dominant substrate type used by juvenile chinook salmon increases as salmon mature.

Based on their distribution relative to piscivorous fishes, it appears that juvenile chinook salmon in Lake Washington select littoral habitats according to the predation risk associated with the substrate and depth of a given location (Piaskowski and Tabor 2001). In this regard, it has been suggested that juvenile fish move offshore when they reach a size at which they are no longer vulnerable to most fish predators (Jackson 1961; Werner 1986). Consequently, an increase in substrate particle size and/or deepening of the littoral area (loss of shallow water habitat) caused by bulkheads is likely to primarily affect juvenile chinook salmon survival, by eliminating their preferred habitat and migration corridor and by increasing their predation risk.

7.5.2 Identification of Data Gaps

- The current habitat conditions and the degree of shoreline development along Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake are partially unknown.
- The effectiveness of alternative shoreline armoring (bioengineering) techniques is unknown.
- The maximum rehabilitation potential of the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake is unknown.
- The effectiveness of supplemental beach nourishment as a restoration technique in these lakes is unknown.

The review of the best available science leaves some remaining questions on the subject of bulkhead impacts. These questions should be answered through lake-specific studies. The remaining questions are:

- What are the sediment sources in Lake Washington, Lake Sammamish, and Phantom Lake for juvenile chinook rearing habitat (sand) and sockeye and kokanee salmon spawning habitat (gravel)?
- What is the transport mechanism of these sediments?
- Do bulkheads in Lake Washington, Lake Sammamish, and Phantom Lake cause sediment coarsening thus eliminating chinook rearing habitat (sand) and sockeye and kokanee salmon spawning habitat (gravel)?

- How do bulkheads in Lake Washington, Lake Sammamish, and Phantom Lake affect sediment transport and accretion?

7.5.3 Recommendations

In order to avoid habitat alterations and stop the loss of shoreline areas and functions (see Table 7-2), bulkheads needing any type of maintenance, repair, and/or retrofitting should be considered for removal or replacement with vegetative and large woody debris structures as shoreline protection alternatives. This recommendation is based on a conservative interpretation of the best available science. If a complete removal is not feasible, the bulkheads should be relocated landward of the OHWM, and the shoreline should be restored with emergent and riparian plant species. The latter would represent a less conservative interpretation of what is indicated by the best available science to stop the loss of shoreline areas and functions.

There are instances where both a bulkhead and fill currently occur below the official OHWM elevation, and where the geomorphic configuration of the shoreline has been straightened, thereby eliminating natural convolution. In those instances, and in order to restore the natural shoreline configuration, it is recommended that the bulkhead replacement be accompanied with a geomorphic reconfiguration of the shoreline.

Where bulkheads are removed, shoreline erosion prevention could be addressed through the implementation of bioengineering vegetation measures such as marsh creation. Plant marshes perform two functions in controlling shore erosion: dissipation of energy and stabilization of shoreline sediments. Energy dissipation is achieved through the exposed stems of plants (e.g., emergent vegetation), which form flexible masses that dissipate energy.

Shoreline stability is obtained by root cohesion provided by the marsh shrub and trees layers of vegetation. Additional shoreline stability is achieved through dense stands of marsh vegetation, which create depositional areas that cause sediment accretion along the shoreline (USEPA 1993). Created marsh areas could be counted towards the required buffer width when located in areas of previous fill. Additional bioengineering techniques that should also be implemented include heavy planting of cedar trees and willows and other riparian shrubs in conjunction with structural large woody debris inclusions along the shoreline edge.

In addition, engineered prototype bulkheads that include bioengineering vegetation measures and structural woody components could be implemented along the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake, in places where bulkheads currently occur below the official OHWM and a complete removal is not feasible. The prototype bulkheads should always be relocated landward of the OHWM and may be performed concurrently with beach nourishment activities (matching historical substrate). These restoration actions should focus on evaluating potential solutions for reducing upper beach loss along armored shorelines by increasing the elevation at which bulkheads are built and roughening the structures to dissipate wave and boat wake energy and to trap sediment.

A monitoring plan should be implemented to evaluate the success of areas stabilized through the use of bioengineering techniques. For this purpose, quantifiable criteria included in the performance standards should be used as the basis for monitoring success. The monitoring plan should be implemented together with demonstration (pilot) projects to test the effectiveness of various bioengineering techniques in Lake Washington, Lake Sammamish, and Phantom Lake.

A no-wake zone should be imposed along all shorelines on a zone extending from the OHWM to 300 feet offshore in Lake Washington and Lake Sammamish to minimize wake erosion effects on the shoreline. A boat speed limit should be imposed in Phantom Lake (if motor boat use is currently allowed).

7.6 Breakwaters, Jetties and Groins

The physical alterations caused by wave/wake energy-dissipating structures such as breakwaters, jetties, and groins, dramatically alter the structure and functions of habitats at the site where they are constructed (direct impacts). This primarily includes physical aquatic habitat loss at the placement site, and a modification of the substrate characteristics on immediate adjacent areas due to the alteration of the sediment transport process (indirect impacts).

7.6.1 Review of the Literature

The effect of breakwaters, jetties and groins may extend for a considerable distance beyond the site where they are constructed (Burnett, 1991; Lawrence and Davidson-Arnott 1997). In marine ecosystems, the primary consequences of these effects are manifested through chronic changes in regional hydrology, as well the direct impacts on structural aspects of the site (Williams and Thom 2001).

Typically, erosion of an unarmored shoreline by wave action together with the transport of sediments by longshore currents replenishes sand beaches (Burnett 1991; Lawrence and Davidson-Arnott 1997). However, shoreline armoring, jetties, breakwaters, and other artificial structures partially or completely disrupt the natural alongshore transport process (Shteinman and Kameni 1999). These structures physically prevent sand from eroding in one place and depositing in another (Burnett 1991).

For example, in Lake Ontario, jetties, breakwaters, and other artificial structures have been found to stop sand from traveling by way of longshore currents because they are barriers. Consequently, sand is deposited in particular places as a result of the position of the structures, rather than due to the natural current. In some areas of the Great Lakes, sand beaches must be artificially replenished every year to make up for the loss in sediment from longshore transport (Burnett 1991).

As stated previously, bulkheads in marine and freshwater environments eliminate shallow water areas and induce sediment coarsening (Herrera 2004; Williams and Thom 2001; Nightingale and

Simenstad 2001; Carrasquero 2001; Kahler et al. 2001). Breakwaters, jetties, and groins have many of the same physical impacts of bulkheads (see Bulkhead section).

7.6.2 Identification of Data Gaps

No data gaps were identified for breakwaters, jetties, and groins.

7.6.3 Recommendations

In order to avoid the loss and alteration of aquatic habitat as well as the loss of shoreline processes and functions, the construction of new breakwaters, jetties, and groins should not be allowed in the shoreline overlay district. In general, the existing breakwaters, jetties, and groins should be considered for removal or replacement particularly within the littoral area. Structures needing any type of maintenance repair, and/or retrofitting must be studied to determine the purpose and need for their existence and should be considered for removal.

Where such structures are removed, wave/wake energy dissipation (if that is their structural function) could be obtained through marsh creation. In addition, a no-wake zone is recommended along all shorelines on a zone extending from the OHWM to 300 feet offshore in Lake Washington and Lake Sammamish. This will minimize need for wake dissipation structures and wake erosion effects on the shoreline.

7.7 Moorage: In- and Over-Water Structures

Moorage related structures (e.g., docks and piers) alter the littoral zone habitat structure, promoting physical, chemical, and biological changes that eliminate or diminish ecological functions and values. The effects of such structures include changes in currents, amount and transport rates of shoreline sediment and woody debris, changes in night-time ambient light levels (developed areas are often much brighter at night due to lighting), introductions of toxic chemicals, and reductions in the quantity and quality of habitat (Kelty and Bliven 2003).

These structures can thereby affect the biological community and the environment by altering predator–prey relationships, fish behavior, or habitat function. Additional construction and operation impacts of moorage structures includes riparian vegetation removal, increased boating activities (and a consequent increase in pollutants), and dredging aimed at maintaining minimal navigation depths (NOAA Fisheries 2003; Kahler et al. 2001; Carrasquero 2001).

The City of Bellevue defines moorage as "any device or structure used to secure a vessel for anchorage, but which is not attached to the vessel, such as a pier, buoy, dock, ramp, boat lift, pile, or dolphin" (Chapter 20.50, Definitions) (Ord. 3145, 9-27-82, § 79; Ord. 4055, 3914, 9-25-89, § 25).

For the purpose of this review, moorage related structures are grouped into two categories including:

1. In-water structures, including piles, boat launch rails and ramps, and bulkheads (riprap and concrete)

2. Over-water structures, including docks, piers (and pier skirting), boathouses, boatlifts, and floats.

The potential impacts of each of these moorage structure categories are briefly discussed below. Detailed descriptions of in- and over-water structure impacts are provided in Carrasquero (2001) and Kahler et al. (2001).

7.7.1 Review of the Literature

The shoreline effect of moorage related structures has been recently reviewed (Jones & Stokes 2003; Kelty and Bliven 2003; Carrasquero 2001; Kahler et al. 2001; Williams and Thom 2001; Nightingale and Simenstad 2001). Of these reviews, Carrasquero (2001) and Kahler (2001) provide an assessment of the state of knowledge on the effect of these in-, on-, and over-water structures on Lake Washington and Lake Sammamish shorelines.

Since these two reviews were completed, additional Lake Washington and Lake Sammamish-specific studies have been published on the shoreline characterization of these lakes (Toft 2001; Toft et al. 2003a and 2003b); salmonids and non-salmonid fish distribution and habitat utilization (City of Seattle 2004; Piaskowski and Tabor 2001; Tabor 2003; Berge and Higgins 2003; Tabor and Piaskowski 2002); juvenile chinook salmon habitat utilization and diet (Tabor et al. 2004b); and predatory-prey interactions affecting juvenile chinook and coho salmon (Tabor et al. 2004a). All of these studies have contributed to increased understanding of the effects of development, particularly moorage associated structures on the Lake Washington and Lake Sammamish shorelines.

In addition, the following document provides a biological evaluation of the impacts of over-water structures on salmonid species, particularly chinook salmon and bull trout (Jones & Stokes 2003): *Regional General Permit for Construction of New or Expansion of Existing Residential Overwater Structures and Driving of Moorage Piling in Lake Washington, Lake Sammamish, the Sammamish River, and Lake Union, Including the Lake Washington Ship Canal, in the State of Washington – Final Biological Evaluation.* This document supports the requirements of a Regional General Permit (USACE undated) currently under review by NOAA Fisheries and the U.S. Fish and Wildlife Service.

The Regional General Permit (USACE undated) would authorize certain activities in or affecting waters of the United States including Lake Washington, Lake Sammamish, the Sammamish River and Lake Union, including the Lake Washington Ship Canal. The Regional General Permit (USACE undated) provides construction specifications and conservation measures designed to reduce the effects of construction of new or expansion of existing residential over-water structures and/or drive moorage piling to provide water access and boat moorage. The specific construction specifications conservation measures included in the Regional General Permit (USACE undated) are summarized in Table 7-3.

7.7.1.1 In-Water Structures

In-water structures (i.e., piles, boat launch rails and ramps, and bulkheads) are known to adversely affect the habitat of anadromous fish species. In addition, these in-water structures alter habitat utilization and behavior (including migration patterns) of anadromous fish species, including salmon. Except for the piles, all of these in-water structures, particularly bulkheads, can physically eliminate both terrestrial and aquatic habitat (Carrasquero 2001; Kahler et al. 2001). The effect of bulkhead structures is discussed in the Bulkhead section of this review and therefore is not further discussed here.

Dock and pier piles can adversely affect anadromous fish species and their habitat through construction and operation impacts. Construction impacts include a temporary increase of water turbidity and underwater sound due to pile driving (NOAA Fisheries 2003). Water turbidity has been linked to a number of behavioral and physiological responses in salmonids (i.e., gill flaring, coughing, avoidance, increase in blood sugar levels) that indicate some level of stress (Bisson and Bilby 1982; Sigler et al. 1984; Berg and Northcote 1985; Servizi and Martens 1992). However, Gregory and Northcote (1993) showed that moderate levels of turbidity (35-150 NTU) accelerate foraging rates among juvenile chinook salmon, likely because of reduced vulnerability to predators due to a camouflaging effect. The adverse effect of increase water turbidity in large lakes such as Lake Washington and Lake Sammamish are expected to be temporary. On the other hand, the effects of increased turbidity in Phantom Lake could be more significant given its smaller basin and size.

Pile driving activities cause temporary, intense underwater sound events. The extent to which the sound can affect fish is related to the distance between the sound source and affected fish, and also by the duration and intensity of the pile driving activity. The sound events caused by pile driving can elicit an evasive response from salmonids near the sound source. This evasive response could in turn result in juvenile salmonids abandoning predator refugia or local foraging areas, temporarily increasing risks of predation or diminishing foraging opportunities (NOAA Fisheries 2003; Carrasquero 2001; Kahler et al. 2001).

Dock and pier piles can also adversely affect anadromous fish by providing habitat for predatory fish species that occur in Lake Washington and Lake Sammamish (Tabor and Piaskowski 2002) and by modifying these anadromous species behavior (NOAA Fisheries 2003; Carrasquero 2001; Kahler et al. 2001).

Finally, boat launch rails and ramps physically eliminate benthic habitat. In addition, these structures can induce changes in anadromous species habitat utilization. For example, in Lake Sammamish, Tabor and Piaskowski (2002) found a great number of juvenile chinook salmon utilizing gently sloped concrete boat ramps areas. Presumably, the sandy appearance of the

Table 7-3. Summary of the construction specifications and conservation measures included in the Regional General Permit (RGP) for new or expansion of existing residential over-water structures and/or drive moorage piling to provide water access and boat moorage (USACE undated).

	Specifications and Conservation Measures
1. Number of Over-water Structures	Authorizes construction or expansion of only one noncommercial, residential moorage facility per residential waterfront property owner or one joint-use moorage facility for two or more adjacent waterfront property owners.
2. Existing In-Water Structures	Any existing in-water and over-water structures within 30 feet of the ordinary high water (OHW) line, other than the proposed pier or dock, must be removed, and no additional over-water structures shall be constructed in this nearshore area over the entire length of the property.
3. Pier, Ramp, Float, and Ell Specification Options	Only piers and ramps can be within the first 30 feet from shore. All floats and ells must be 30 feet waterward of OHW. No skirting is allowed on any structure. a. Surface Coverage (includes all floats, ramps, and ells): (1) Single property owner: 480 square feet (2) Two property owners (residential): 700 square feet (3) Three or more residential property owners: 1000 square feet. b. Height above the water surface: except for floats, the bottom of all structures must be at least 1.5 feet above OHW. c. Widths and lengths: (1) Piers - 4-feet wide and fully grated with at least 60% open area. (2) Ramps - must not exceed a width of 3 feet and must be fully grated. (3) Ells - must be in water with depths of 9 feet or greater at the landward end of the ell. - Up to 6-feet wide by 20-foot long with a 2-foot strip of grating down the center. - Up to 6-feet wide by 26-foot long with grating providing 60% open area over the entire ell. (4) Floats- must be in water with depths of 10 feet or more at the landward end of the float. Floats can be up to 6 feet wide and 20 feet long, but must contain a minimum of 2 feet of grating down the center.
4. Length of Structures Compared to Adjacent Structures	The length of a pier is limited by the maximum square footage allowed (see item no. 3 above).
5. Piling Specifications	The first (nearest shore) piling shall be steel, 4 inches piling and at least 18 feet from the OHW. Piling sets beyond the first shall also be spaced at least 18 feet apart and shall not be greater than 12 inches in diameter. Piles shall not be treated with pentachlorophenol, creosote, CCA or comparably toxic compounds. If ACZA piling are proposed, the applicant will meet all of the Best Management Practices, including a post-treatment procedure, as outlined in the amended Best Management Practices of the Western Wood Preservers. Steel piles will be installed using approved sound attenuation measures.
6. Treatment of Over-water Structural Materials	Any paint, stain or preservative applied to components of the over-water structure must be leach resistant, completely dried or cured prior to installation.

Table 7-3 (continued). Summary of the construction specifications and conservation measures included in the Regional General Permit (RGP) for new or expansion of existing residential over-water structures and/or drive moorage piling to provide water access and boat moorage (USACE undated).

	Specifications and Conservation Measures
7. Existing Habitat Features	Existing habitat features (e.g., large and small woody debris, substrate material, etc.) shall not be removed.
8. Mooring Piles	No more than 2 mooring piles (includes all existing mooring piles). Not within 30 feet of the OHW line; Not placed any further water-ward than the end of the pier; and Not be placed more than 12 feet from any point on the pier.
9. Future Maintenance of Facilities	Authorized provided: There is no change in size, configuration, or use of the facility; All maintenance is conducted in accordance with all conditions; RGP has not been modified; and As long as no new species have been listed under the Endangered Species Act.
10. Impact Reduction Measures	Planting emergent vegetation (if site appropriate) and a buffer of vegetation a minimum of 10-feet wide along the entire length of the shoreline immediately landward of OHW. Path 6-feet wide or less is allowed through the buffer for access to the pier. Buffer will consists of native shrubs and trees and, when possible, emergent vegetation. 5 native trees (1 or more evergreen) and 2 or more trees that like wet roots (e.g., willow species).
11. Impact Reduction Planting Performance Standards	One hundred percent survival of during the first and second years after planting. During the third through fifth years 100 percent of the trees must survive and 80 percent survival of the remaining native plants is required.
12. Impact Reduction Reports	Impact reduction reports must be submitted to the U.S. Army Corps of Engineers including a status report on impact reduction and a planting monitoring report.

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ramps may trigger this behavior because juvenile chinook salmon have affinity for shallow sandy beach areas (Fresh 2000; Piaskowski and Tabor 2001). Induced habitat utilization changes in juvenile chinook salmon may result in an increased predation risk.

7.7.1.2 Over-Water Structures

Over-water structures (i.e., docks, piers, boathouses, and floats) degrade habitat and habitat functions that support anadromous fish species, particularly salmon. The construction of over-water structures in Lake Washington and Lake Sammamish has increasingly eliminated shallow-water habitat (Carrasquero 2001; Kahler et al. 2001; Toft 2001), particularly affecting juvenile chinook salmon (Fresh 2000; Piaskowski and Tabor 2001).

Over-water structures may displace or degrade some normal habitat functions within their footprints. Because these structures typically adjoin both shoreline and aquatic environments, their effects may be distributed across multiple habitat zones. For instance, the construction of these structures is typically preceded or followed by the removal of riparian vegetation. Subsequently, riparian functions important to salmonids are lost, including shading, refugia, nutrients (from leaf litter and large woody debris), and shoreline stabilization. Once the shoreline is developed, these over-water structures (and associated pilings) provide habitat for salmon predators (Tabor et al 2004a, 2004b).

Over-water structures also generate indirect impacts through modifying aquatic habitat features. One of the most significant is by creating habitat for species that prey on salmonids (Tabor et al. 2004a and 2004b). In particular, over-water structures may provide predators with locations for ambushing prey, locations for spawning, or refuge from other predators. While some of these benefits may also apply to salmonids, over-water structures may inequitably favor predators (particularly relative to juvenile salmonids) because they displace the complex habitat elements that would otherwise provide salmonids with cover and refuge from predators (Carrasquero 2001; Kahler et al. 2001). However, no studies were found that specifically examined salmon mortality due to predation associated with over-water structures.

Residential docks, pier, and floats are likely to have high levels of boating activity in their immediate vicinity. Specifically, they may serve as a mooring area for boats or a staging platform for recreational boating activities. There are several impacts that boating activity may have on anadromous fish species and aquatic habitat including displacement of nearby fishes, increased turbidity in shallow waters, uprooting of aquatic macrophytes in shallow waters, spreading exotic plants and plankton species, and aquatic pollution (through exhaust, fuel spills, or release of petroleum lubricants) (NOAA Fisheries 2003; Carrasquero 2001; Kahler et al. 2001).

Table 7-4 provides a lake-specific summary of references regarding the impacts of moorage-related structures on shoreline habitat areas and functions. Impacts from associated armoring structures are discussed in the Bulkhead section of this review (see Table 7-2) and therefore are not included in this table. As can be seen in Table 7-4, the available pertinent literature is limited. Nonetheless, inferred and hypothetical associations can be made based on available

Table 7-4. Lake-specific references regarding impact of docks and piers on shoreline habitat areas and functions.

References	Study Area	Habitat Area or Function	Moorage Structure Impacts
Carrasquero 2001	Washington shorelines [a]	Shoreline habitat and functions	Alteration of the shoreline habitat structure, promoting changes in fauna and flora assemblages. Thereby affect the biological community and the environment by altering predator–prey relationships, fish behavior, or habitat function.
NOAA Fisheries 2003	Washington shorelines [a]	Shoreline habitat and functions	Docks reduce habitat quality and affect the biological community and the environment by altering predator–prey relationships, fish behavior, or habitat function.
Carrasquero 2001	Washington shorelines [a]	Shoreline: Littoral zone	Loss of complex habitat features (i.e., woody debris, overhanging vegetation, emergent vegetation).
Kahler et al. 2001	Lake Washington [a] Lake Sammamish [a]	Shoreline: Juvenile salmonids refuge and forage habitat	Reduction of the abundance of overhanging vegetation and woody debris. Cause the loss of complex habitat features (i.e., woody debris, overhanging vegetation, emergent vegetation).
Brown 1998	Lake Joseph, Ontario	Shoreline fish habitat	Reduction of density of coarse woody debris.
Kelty and Bliven 2003			Change in currents, amount and transport rates of shoreline sediment and woody debris, changes in night-time ambient light levels (developed areas are often much brighter at night due to lighting), introductions of toxic chemicals, and reductions in the quantity and quality of habitat.
Burnett 1991	Lake Ontario, Canada	Fine sediment supply (sand)	Interruption of natural sediment nourishment process.
Lawrence and Davidson-Arnott 1997	Lake Huron, Ontario, Canada	Fine sediment supply (sand)	Interruption of natural sediment nourishment process.
Kahler et al. 2001	Lake Washington [a] Lake Sammamish [a]	Fine sediment supply (sand)	Reduction of fine sediment supply and shallow water areas, which may reduce the availability of shallow sandy habitat.
Tabor and Piaskowski 2002	Lake Sammamish [a] Lake Sammamish	Salmonid habitat/behavioral response	Change in juvenile chinook salmon behavior, including avoidance of areas beneath over-water structures (April through May and at night time). This avoidance could result in increased predation risk on juvenile chinook salmon.
Piaskowski and Tabor 2001	Lake Washington	Predatory fish habitat	Creation of habitat for trout, smallmouth bass, and sculpin (predators of juvenile salmon)
Piaskowski and Tabor 2001	Lake Washington	Salmonid habitat/behavioral response	Change in juvenile chinook salmon behavior, including avoidance of areas beneath over-water structures. This avoidance could result in increased predation risk on juvenile chinook salmon.
Jennings et al. 1999	Northern temperate lakes	Shoreline habitat	Modification of habitat which leads to changes in fish assemblages as a response to diverse accumulated incremental changes.

[a] Study included Bellevue's shoreline areas.

scientific literature. Additional supporting impact assessment information is provided indicating the reference source.

7.7.2 Identification of Data Gaps

- The current habitat conditions and degree of shoreline development along Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake are unknown.
- No information was found on the existing habitat conditions in Phantom Lake.
- No information was found on the past or current number and type of in- and over-water structures that have been constructed in Phantom Lake.
- No studies were found that specifically examined salmon mortality due to predation associated with over-water structures.
- No studies were found that address the cumulative effect of in- and over-water structure on Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake shorelines.

7.7.3 Recommendations

Based on a conservative assessment of the best available science, new in- or over-water structures should not be allowed on Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake shorelines. This restriction is needed in order to stop the loss of shoreline areas and functions. A net reduction in over-water coverage, number of piles, and shoreline area occupied by piers and docks should be obtained. This will decelerate the alteration of shoreline habitat that promotes adverse changes in fauna and flora assemblages. These changes affect the biological community and the environment by eliminating physical habitat and by altering predator–prey relationships, fish behavior, and habitat functions.

A net reduction of in- or over-water structures may be achieved by requiring dock, pier, boathouse, and float size reductions in those structures that currently exceed code specifications (i.e., those with a nonconforming status). Conformance should be required even for those structures that currently do not require retrofitting or maintenance. In any event, compliance with the U.S. Army Corps of Engineers Regional General Permit (USACE undated) should be required if in- or over-water structures are allowed, or for existing structures requiring retrofitting or maintenance. The Regional General Permit (USACE undated) provides construction specifications and conservation measures designed to reduce the effects of construction of new or expansion of existing residential over-water structures and/or drive moorage piling to provide water access and boat moorage.

The analysis of alterations used to prepare this regional general permit occurred primarily at the spatial scale of individual recreational and residential properties and did not consider cumulative adverse effects. In this regard, it is known that the effects of docks and piers (and associated in- and over-water structures) are incremental and cumulative in nature (Jennings et al. 1999). Therefore, allowing the construction or expansion of one noncommercial, residential moorage facility per residential waterfront property or one-joint-use moorage facility for two or more adjacent waterfront properties will continue the current trend of degradation, loss of ecological functions, and loss of physical habitat. Cumulative effect analysis is essential to effectively manage the consequences of human activities on Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake shorelines and thus should be required as part of permitting in- or over-water structures.

Finally, studies are needed to specifically examine salmon mortality due to predation associated with over-water structures in Lake Washington and Lake Sammamish. Studies are also needed to characterize the existing habitat conditions and the degree of shoreline development in Phantom Lake.

7.8 Conclusion

The shoreline review of best available science focused on the littoral zone within the shoreline aquatic area and its relationship with the shoreline riparian area, specifically within Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake shorelines(see Figure 7-1). Best available science for shorelines protection, particularly safeguarding the processes that protect shoreline functions, varies in terms of quantity, quality, and local relevance. The best available science for shoreline protection is neither complete nor consistently covers all functions, and it remains an active field of research. Much of the science used for developing protection of shorelines is derived from research specific to streams and riparian areas. Key findings of this review are summarized in Table 7-5 and in the following section.

Currently over 80 percent of shorelines within the City of Bellevue have some stabilization structure, over 50 percent of all parcels have structures within 50 feet of the OHWM, and virtually every shoreline lot has been developed, primarily for residential use.

In general, development along the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake have altered the physical, chemical, and biological processes that create and maintain the shoreline aquatic and terrestrial habitats typical of these natural ecosystems. Consequently, these anthropogenic changes have degraded shoreline functions and values within Bellevue.

However, Bellevue's shoreline areas still provide multiple ecological functions and values and present opportunities for habitat rehabilitation and preservation. Because of the unique mix of water and biodiversity, shoreline areas are also valued for a broad range of recreational and aesthetic activities, including swimming, fishing, and the enjoyment of natural beauty and solitude.

Table 7-5. Summary of best available science findings and general recommendations for protecting shorelines.

Protection Mechanism	Best Available Science Review	General Recommendations
Acknowledge shoreline areas as critical areas.	To be protected, it first needs to be defined and characterized. The Bellevue Land Use Code does not clearly differentiate and define shorelines or characteristics of riparian, buffer, and structure setback areas, particularly within the context of the ecological functions they provide to the shorelines.	Add the shorelines as protected areas. Characterize habitat conditions and current degree of shoreline development along Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake.
Create buffers which protect an area of sufficient size to provide shoreline riparian and aquatic processes and functions.	Regulatory buffer areas ranging from 50- to 100-foot-wide ("no touch" buffer) may be adequate to provide for the functions of Bellevue's lake shorelines. However, this adequacy is closely linked to its general conditions (i.e., whether it is disturbed or developed versus covered in native herbaceous, shrub and tree vegetation as well as width). For a shoreline buffer area to function properly it must be undisturbed.	Perform lake-specific studies to evaluate the minimum buffer width requirements needed to provide for and maintain shoreline functions and values. Allow a buffer area of variable width (buffer averaging) to offer a feasible approach to help achieve adequate buffer functions. Buffer averaging provides greater flexibility to achieve the desired ecological goals, but a minimum width of 35 feet from the lake edge should be maintained. Require a monitoring plan to report the success of created or enhanced buffer areas.
Implement specific regulations for structure setbacks.	A 25-foot-wide protective area measured from the edge of the shoreline buffer and called a structure setback is most often recommended..	A structure setback to protect the shoreline buffer is needed in order to prevent disturbance of the riparian functions that are integral to the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake. It is recommended that the shoreline buffer be measured from the OHWM and the 25-foot-wide structure setback be measured from the edge of the shoreline buffer. The OHWM should be defined based on an actual topographic elevation rather than a series of biological indicators along the shoreline.
Implement specific regulations for shoreline armoring and vegetation conservation activities.	Bulkhead maintenance or construction may result in the loss of: 1) organic material (e.g., tree litter, large woody debris, and insects) to the lakes littoral zone; 2) shade to lake's fringe habitat; 3) physical aquatic and terrestrial habitat; and 4) sediment contribution. In addition, species responses (typically associated with the habitat responses) are also triggered, including changes in the food web, salmonid fish habitat utilization and migration patterns, and predator-prey interactions.	Consider for removal or replacement (with vegetative and large woody debris structures) bulkheads needing any type of maintenance, repair, and/or retrofitting. If a complete removal is not feasible, relocate the bulkheads landward of the OHWM, and restore the shoreline with emergent and riparian plant species. There are instances where both a bulkhead and fill currently occur below the official OHWM elevation, and where the geomorphic configuration of the shoreline has been straightened, thereby eliminating natural convolution. In those instances, and in order to restore the natural shoreline configuration, it is recommended that the bulkhead replacement be accompanied by a geomorphic reconfiguration of the shoreline.

Table 7-5 (continued). Summary of best available science findings and general recommendations for protecting shorelines.

Protection Mechanism	Best Available Science Review	General Recommendations
Implement specific regulations for shoreline armoring and vegetation conservation activities (continued).		Additional recommendations: ▪ Investigate the effectiveness of alternative shoreline armoring (bioengineering) techniques through the use of prototype bulkheads. ▪ Investigate the effectiveness of supplemental beach nourishment as a restoration measure. ▪ Require a monitoring plan to evaluate the success of areas stabilized through the use of bioengineering techniques. ▪ If possible, impose or request a voluntary no-wake zone along all shorelines in a zone extending from the OHWM to 300 feet offshore to minimize wake erosion effects on the shoreline. ▪ Do not allow the construction of new breakwaters, jetties, and groins.
Implement specific regulations for moorage activities.	Over-water structures (i.e., docks, piers, boathouses, and floats) degrade habitat and habitat functions that support anadromous fish species, particularly salmon. The construction of over-water structures in Lake Washington and Lake Sammamish has increasingly eliminated shallow-water habitat, particularly affecting juvenile chinook salmon. Over-water structures may displace or degrade some normal habitat functions within their footprints. Over-water structures also generate indirect impacts through modifying aquatic habitat features.	New in- or over-water structures should not be allowed on Bellevue's Lake Washington, Lake Sammamish, and Phantom Lake shorelines. This restriction is needed in order to stop the loss of shoreline areas and functions. In any event, compliance with the U.S. Army Corps of Engineers Regional General Permit should be required if in- or over-water structures are allowed, or for existing structures requiring retrofitting or maintenance. Cumulative effect analysis should be required as part of permitting in- or over-water structures. Studies are needed to specifically examine salmon mortality due to predation associated with over-water structures in Lake Washington and Lake Sammamish. Studies are also needed to characterize the existing habitat conditions and the degree of shoreline development in Phantom Lake.

In order to achieve ecological success, any rehabilitation and preservation actions will benefit from implementation at the watershed scale and not just within the Bellevue city limits. Nonetheless, given the current state of habitat degradation, any local protection and rehabilitation effort will contribute to the overall improvement of the natural resource and recreational functions and values that the City's lakes provide.

The existing Bellevue Land Use Code (Chapter 20.50, Definitions) defines Protected Areas as that area designated by Land Use Code 20.25H.070 where use or development is subject to special limitations due to its physical characteristics. Shorelines are currently not included as a Protected Area. The Bellevue Land Use Code also does not differentiate and define the ecological characteristics of the shoreline, buffer, and structure setback areas. These differentiations and definitions would help facilitate public understanding of the specific functions provided by each of these areas and their role in protecting Bellevue's shorelines. This could be accomplished by amending the City of Bellevue critical areas regulations to include definitions of *shoreline riparian area*, *shoreline buffer*, and *protective structure setback.*

Lake-specific literature on buffer width is almost nonexistent, and the few available sources that provide information on buffer functions as a factor of buffer width focus on protecting water quality in lakes. Following are recommendations for buffers along shorelines in Bellevue:

- Based on the literature review, a shoreline buffer ranging from 50 to 100-foot-wide may be adequate to provide for the ecological functions of Bellevue's lake shorelines.
- An additional structure setback to protect the shoreline buffer area is recommended to maintain and protect shoreline functions occurring in the buffer. The additional structure setback to protect the shoreline buffer is needed in order to prevent disturbance of the riparian functions that are integral to the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake.
- A 25 foot-wide protective structure setback measured from the edge of the shoreline buffer is most often recommended.
- The 25-foot setback would only limit structures. Lawns and gardens may be allowed within the 25-foot-wide structure setback as long as maintenance activities do not adversely affect the shoreline buffer or the functions it provides.
- Within the combined protective buffer/structure setback area, to the extent possible, provide habitat connectivity along the entire length of the shoreline. In addition, include tree, shrub, herbaceous, and emergent layers of vegetation in order to obtain a full range of buffer functions.
- Shoreline buffer averaging may be allowed. However, include a minimum width of 35 feet from the OHWM to ensure recruitment of large woody debris.

- If possible, a voluntary or imposed no-wake zone designated along all shorelines within a zone extending from the ordinary high water mark to 300 feet offshore in Lake Washington and Lake Sammamish would substantially improve shoreline habitat protection.
- A speed limit for Phantom Lake (if motor boat use is currently allowed) would improve protection of the lake's habitat.

These recommendations would apply to all the following developmental activities: agricultural uses, clearing and grading, commercial development, residential development, and design and construction of roads, railroads, and other essential public utilities.

Few studies have addressed the environmental effect of bulkheads in freshwater environments, particularly in Lake Washington, Lake Sammamish, and Phantom Lake. The available data indicate that the greatest potential for bulkhead impacts relates to shoreline aquatic and riparian habitat and species, particularly salmonids. Impacts include elimination of shallow water habitat and complex habitat features; reduction in the abundance of overhanging vegetation, other shoreline vegetation, and large woody debris; interruption of the sediment nourishment and transport processes; reduction of fine sediment; and changes in behavior of juvenile chinook salmon. Following are recommendations for managing bulkheads in Bellevue:

- Consider replacing bulkheads needing any type of maintenance, repair, or retrofitting with shoreline protection alternatives that include vegetation and large woody debris. This recommendation is based on a conservative interpretation of the best available science. If a complete removal is not feasible, relocate the bulkheads landward of the ordinary high water mark, and restore the shoreline with emergent and riparian plant species. The latter would represent a less conservative interpretation of what is indicated by the best available science to stop the loss of shoreline area and functions.
- Where bulkheads are removed, consider preventing shoreline erosion through marsh creation (bioengineering vegetation measures). Marsh plants dissipate wave energy and stabilize shoreline sediments. The exposed stems of marsh plants (e.g., emergent vegetation) form flexible masses that dissipate energy.
- Structural bioengineering techniques should be tested as alternative means of shoreline stabilization and as restoration actions. This includes the implementation of bioengineering vegetation measures and alternative engineered shoreline armoring through the use of prototype armoring structures (i.e., "prototype bulkheads"). Concurrent beach nourishment activities could be implemented in those areas where existing bulkheads have caused beach erosion. These restoration actions should focus on evaluating potential solutions for reducing upper beach loss along armored

shorelines by increasing the elevation at which bulkheads are built and roughening the structures to dissipate wave and boat wake energy and trap sediment.

- Monitoring should be required to evaluate the success of areas stabilized through the use of bioengineering techniques.

The physical alterations caused by structures that dissipate the energy of waves and boat wakes, (such as breakwaters, jetties, and groins) dramatically alter the structure and functions of habitats at the site where they are constructed. These habitat alterations primarily consist of physical aquatic habitat loss at the placement site and a modification of the substrate characteristics in immediately adjacent areas due to the alteration of the sediment transport process. Following are recommendations for addressing breakwaters, jetties, and groins in Bellevue:

- Avoid construction of any new breakwaters, jetties, and groins.
- Consider removing existing breakwaters, jetties, and groins needing maintenance, repair, or retrofitting, particularly within the littoral area.
- Where such structures are removed, energy dissipation for waves and wakes (if that was the function of the structure) could be achieved through marsh creation.

Moorage-related structures (e.g., docks and piers) alter the habitat structure in the littoral zone, promoting physical, chemical, and biological changes that eliminate or diminish ecological functions and values. Such structures can alter currents, the amount and transport rates of shoreline sediment and woody debris, changes in nighttime ambient light levels (developed areas are often much brighter at night due to lighting), introductions of toxic chemicals, and reductions in the quantity and quality of habitat. Following are recommendations for in- and over-water structures in Bellevue:

- Consider not allowing new in- or over-water structures on the shorelines of Lake Washington, Lake Sammamish, and Phantom Lake in Bellevue. This restriction is needed in order to stem the loss of shoreline area and functions.
- Develop incentives to reduce in- and over-water coverage, number of piles, and shoreline area occupied by piers and docks.
- The net reduction may be achieved by reducing the size of docks, piers, boathouses, and floats for structures that exceed the current code specifications (i.e., those with a nonconforming status).
- Request that in- or over-water structures requiring retrofitting or maintenance comply with the U.S. Army Corps of Engineers Regional General Permit requirements. The Regional General Permit (USACE

undated) provides construction specifications and conservation measures designed to reduce the effects of construction of new or expansion of existing residential over-water structures and/or drive moorage piling to provide water access and boat moorage. A determination of the cumulative effect is a recommended part of the permitting process.

- Finally, encourage that studies be done to examine salmon mortality due to predation associated with over-water structures in Lake Washington and Lake Sammamish. A study is also needed to characterize the existing habitat conditions and degree of shoreline development in Phantom Lake that could serve as a basis for adapting the general recommendations provided in this report to specific needs and conditions of Phantom Lake.

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Chapter 8. Wildlife Habitat Conservation Areas

This chapter focuses on the protection of wildlife habitat and presents an update to the literature review found in the 2003 *Bellevue Critical Areas Update Best Available Science Paper: Wildlife.* It includes a review of available peer-reviewed research, inventory reports, symposia literature, technical literature, and other sources of scientific information relevant to wetlands. Discussions of fish and wildlife habitat requirements for aquatic systems can be found in this report in Chapters 5, 6, and 7 covering streams, wetlands and shorelines, respectively. Important gaps in existing information are noted where applicable and recommendations for regulatory and conservation strategies to protect upland wildlife conservation areas are provided.

Wildlife habitat types reported in the 2003 *Bellevue Critical Areas Update Wildlife Inventory* include the following general categories:

- West-side riparian wetlands
- West-side lowland conifer/hardwood forest
- Herbaceous wetlands and open water
- Agriculture and urban environs (agriculture, pasture, and mixed environs
- Urban and mixed environs).

Outside of vegetated habitat patches and linkages, Bellevue's current landscape matrix is urban in character, comprised primarily of residential development, both single-family and multifamily, and secondarily of commercial development. Within this matrix, a few large blocks of west-side lowland forest remain; habitat linkages between these blocks, where they exist, are predominantly comprised of west-side riparian-wetland habitat. Open water and herbaceous wetland habitats in the City are mostly associated with lakes. Agricultural habitats consist of scattered berry farms and pastures.

Due to the high level of disturbance to soil and vegetation in agricultural and urban habitats, habitats in urban areas like Bellevue support more "generalist" species and are more prone to invasion by non-native, invasive plant and animal species (Edge, 2001; Ferguson et al. 2001). Unlike species adapted to particular habitat types ("specialist" species), generalist species can use a variety of vegetation cover types for breeding and foraging and include both native and non-native species tolerant of human disturbance. In contrast, many specialist species require specific habitat characteristics that are either limited or no longer present in developed landscapes.

While Bellevue's urban character offers limited habitat for wildlife species, the City does provide habitat for several "special status" species that are identified in the City's 2003 wildlife inventory report. This review focuses on the literature pertaining to protecting wildlife habitat in urban areas.

8.1 Functions and Values

Wildlife areas are land-based (terrestrial) ecosystems composed of unique interacting systems of soil, geology, topography, and plant and animal communities (Johnson and O'Neil 2001). For this analysis, wildlife areas are defined as those areas in which priority mammals, birds, amphibians, reptiles, and invertebrates of Bellevue are likely to be found.

Large terrestrial areas facilitate homing, migrations, dispersal, and other activities crucial to maintaining wildlife populations (Blake and Karr 1984; Fahrig 2002; Dawson 1994; Carey et al 1992). Concurrently, these inclusive wildlife areas protect air and water quality and provide other critical ecological processes and functions that contribute to the conservation of healthy habitats and ecosystems (Franklin 1993; Rubec 1997). Terrestrial areas are formed in response to a wide variety of natural- and anthropogenic-driven physical and biological factors interrelated on a local, watershed, and regional scale. Consequently, in natural environments, fire, erosion, floods, and other disturbances alter habitat and animal behavior, often on a grand scale. In populated urban and rural areas natural disturbances are usually controlled or minimized. In urban areas, humans and their activities determine land cover, displace wildlife, or otherwise influence the ability to retain species and viable populations from outright habitat loss, alteration, and fragmentation (Vitousek et al. 1997).

Humans are important agents of landscape and ecosystem change. Humans are a part of the landscape: they influence and are influenced by ecosystems, are an integral part of ecosystems, and are fully dependent upon ecosystems for their well being (Kaufmann et al. 1994). Natural ecosystems perform fundamental life support functions that allow humans to thrive (Daily et al. 1999; Costanza et al. 1997). Ecologists are beginning to examine the human landscapes as they would any other ecological system—as an arena to test general theory and examine the relationship of structure and function (McDonnell and Pickett 1990). Anthropogenic disturbances are being compared and contrasted with natural ones, and the cumulative effects are being studied for clues to ecosystem integrity.

Natural- and human-dominated landscapes differ in the source and type of disturbance, with natural disturbances (e.g., fire, severe flooding) being replaced by human-caused disturbances (e.g., land clearing, habitat fragmentation) in human-dominated landscapes. Human use of the land alters the structure and functioning of ecosystems (Vitousek et al. 1997). Moreover, wildlife populations and home ranges expand and contract over time (Dasmann 1981). Simultaneously, greenbelts, remnant forests, and other urban habitats (Agee 1995) set aside for their protection also transform over time. Historically, and in natural environments, variability of habitat provided a continuous source of environmental replenishment and resources for species. Today, in human-dominated landscapes, sources of environmental replenishment may be limited, especially in smaller and increasingly isolated habitats. Even though patches of forest are retained, the sizes of forest patches are smaller and they are less likely to be connected in the landscape, such that the forests are dominated by edge processes.

The wildlife habitat function within human landscapes may vary significantly with intensity of land-use change and human activity. A study by McDonnell et al. (1997) revealed a complex urban-rural environmental gradient: "The urban forests exhibit unique ecosystem structure and function in relation to the suburban and rural forest stands; these are likely linked to stresses of the urban environment such as air pollution." Changes in bird communities in urban areas have been well documented and exhibit trends that include increasing bird relative abundance with decreasing bird species richness (Beissinger and Osborne 1982; Donnelly 2002). Specifically, densities of relatively few dominant urban ground gleaners increase and a concomitant decrease is observed in forest insectivores, canopy foliage gleaners, and bark drillers (Beissinger and Osborne 1982).

When humans alter a natural environment with roads and development, the result is a matrix of fragmented habitats. As a result of fragmentation, remaining populations of native wildlife are smaller (Marzluff and Ewing 2001). Native birds are exposed to a number of threats, including competition with non-native species (e.g., European starlings), exposure to more predators and parasites (e.g., domestic cats), greater disturbance from human activity, and restricted dispersal corridors. Additionally, key resources are often removed, such as snags and logs, ground cover, and shrub patches. Nutrient and hydrological cycles are also negatively impacted by fragmentation (Marzluff and Ewing 2001). A serious yet frequently ignored effect of fragmentation on wildlife species is the increased predation on avian species by house cats. Domestic cats were estimated to kill between 7.8 and 217 million birds per year in Wisconsin (Coleman and Temple 1996, as cited in Marzluff and Ewing 2001). A single house cat can decimate entire populations within a patch of habitat.

8.2 Wildlife Habitat Protections

To protect select wildlife habitat and species, strategies for conservation of terrestrial systems should be crafted at relevant small, medium, and large scales. For example, the neighborhood, parcel, and landscape context should all be considered in planning efforts because different factors and components can affect these scales differently, and because wildlife requires conservation at multiple scales (Gutzwiller 2002; Peterson and Parker 1998; Bissonette 1997; Forman 1995). These scales should parallel the needs of wildlife. For example, breeding and nesting requirements of individuals occur at a small scale, and migratory routes occur at large scales. Marzluff and Ewing (2001) said of avian diversity that in order to restore it, reproduction, survivorship, and dispersal must be maintained, restored, and monitored in fragmented landscapes. The same could be said of any of the priority species. Further, urbanization must be anticipated, and creative ways must be found to increase native habitat and collectively manage it (Marzluff and Ewing 2001).

Existing methods of conserving individual wildlife species are diverse and complex, in part because habitat needs vary between vertebrate species and classes and over time (Leopold 1933; Teague 1971; Shaw 1985; Rodiek and Bolen 1991; Magnusson 1994; Morrison et al. 1998). Consequently, programs affecting wildlife protection and management are numerous. In 1971, 550 domestic programs administered by federal agencies alone already existed (Almond 1971). Numerous state laws and local laws, ordinances, and special provisions also exist that may be used to conserve wildlife and their habitat. However, within many urban environments, traditional techniques for wildlife conservation are seldom used, conservation planning for wildlife is fundamentally a fragmented and reactionary process, and no one agency or group sets a high priority on wildlife (McKinnon 1987). In Washington state, the Washington Department of Fish and Wildlife provides distributions, descriptions, and management guidelines for priority species and habitats, such as inclusive short reports (e.g., Rodrick and Milner 1991) and well-referenced long reports such as those on invertebrates (e.g., Larsen 1995), amphibians and reptiles (e.g., Larsen 1997), snags (e.g., WDFW 1995), and others.

Local agencies influence anthropogenic impacts to habitat and their wildlife through their diverse regulations, including environmental (e.g., air and water quality standards, initially often federal standards), natural resource (e.g., resource extraction, agriculture, forestry practices), and development (e.g., comprehensive plans, zoning, critical areas) regulations. Land use is determined by local jurisdictions, but the state provides guidance and information for the regulation of wildlife. The Maryland Department of Natural Resources (2001:24) summarizes widespread problems in the field of wildlife conservation: Most conservation efforts in this country are still reactive not proactive; haphazard not systematic; piecemeal not holistic; single purpose not multifunctional; too focused on the local or project-level scale and not enough on the watershed, regional or landscape scales critical to understanding the environmental context. Conservation efforts too often result in protected 'islands' too isolated to deliver effective habitat.

Biologists agree on the importance of protecting actively used critical areas such as nesting trees (for examples, see Rodrick and Milner 1991; Van Horne and Wiens 1991). Equally recognized is the fact that such specific ecosystem and habitat attributes vary in usage and distribution in time and space. For example, bald eagle and red-tailed hawk nesting trees and snags blow down or rot over time. Therefore, these birds must find new trees and snags on a regular basis. To maintain sustainable breeding populations of these priority species, alternate trees, and snags must be available (Thomas 1979; Marzluff and Ewing 2001). Likewise, other breeding and non-nesting critical habitats must be available for occupancy—naturally or through anthropogenic actions—so that all life stage requirements for species and populations are met. Conservation of active breeding, foraging, and sheltering habitats through buffers and other means is essential; however, it is equally important to provide alternative habitats for all these and all other crucial needs, which may be widely dispersed within the varied ecosystems of watersheds and larger landscapes (Gutzwiller 2002; Peterson and Parker 1998; Bissonette 1997; Forman 1995).

There are two approaches to conserving species and their habitat in the literature. The first is to protect species only within clearly identified ecological reserves (i.e., tracts of land, often large in area) that are relatively homogenous in plant composition and structure regardless of adjoining land use (Soulé and Wilcox 1980; Frankel and Soulé 1981; Wright 1998). The second approach attempts to protect species across an entire region by enhancing the quality of existing habitat and by providing for all important wildlife needs (Franklin 1993; Morrison et al. 1998). This second approach is more difficult to implement. Implicit in both approaches, but perhaps not emphasized, is the protection of ecological function, composition, and structure. In urban environments, such approaches are more difficult to implement than in large forested areas and more natural landscapes. Nevertheless, land use regulation through ordinance rules and zoning and Comprehensive Plan policies guiding habitat restoration, property acquisitions, and other short- and long-term actions can minimize detrimental effects to wildlife by providing guidance on area size, locations, configuration, and other characteristics necessary to support populations.

Wildlife habitat protection should be based on several internal (site-specific) and external (contextual) habitat considerations. Internal considerations include:

1. How structurally diverse (vertically and horizontally) is the habitat? Vertical diversity is derived from the amount and distribution of vegetation and other structural elements in various zones ranging from underground to the tops of the tallest trees. Horizontal diversity is determined by the size and distribution of vegetation patches across the landscape.

   Greater structural diversity generally increases the area's wildlife diversity (MacArthur et al. 1962; MacArthur 1964; Balda 1975; Erdelen 1984; Vivian-Smith 1997; Trevithic et al. 2001). A wetland with a patch of trees or open water is generally more valuable than a uniform stand of Douglas fir in a plantation. A forest with a well-developed understory is generally more valuable than a uniform stand of cattails or spirea, or a dense forest with no understory. Areas with low structural diversity may be enhanced and become more valuable to fish and wildlife through restoration efforts, particularly in areas that have been degraded by humans.

2. What are the "edge" conditions? Edges are used by relatively greater numbers of species, which may be harmful or beneficial to native species depending on the taxa adapted to and occupying the edge (Hansson 1983; Logan et al. 1985; Yahner 1988; Lidicker and Koenig 1996). An area, with a mosaic of habitat types that provide an undulating edge is more valuable to wildlife than an area of equal size but with a linear edge. Increased amounts of edge along wetlands or streams, provided they have adequate buffers, increase the value to wildlife species. In contrast, a terrestrial area adjacent to human habitation and certain land uses may have greater numbers of species, but typically they will contain harmful exotic species and aggressive native species (Richter and Azous 2001; Blair 1996).

   Edges in human-created and occupied environments, although diverse in species, are often dominated by generalist, competitive, synanthropic (human associated, tolerant) edge species and fewer interior core species. Edges created by human development are often straight and abrupt with little transition. In natural environments edges are generally gradual transition zones, non-linear, and characterized by higher species diversity than areas with straight edges (Meffe and Carroll 1994; Yoakam and

Dasmann 1971). In aquatic systems, convoluted edges include coves, lobes, and peninsulas that enable better positive interactions between aquatic and terrestrial organisms than straight edges: (1) by increasing the length of beneficial transition habitat (the productive shallow shoreline); and (2) by facilitating the dispersal of organisms that have biphasic life stages (invertebrates, amphibians) between aquatic and terrestrial systems (Meffe and Carroll 1994; Dramstad et al. 1996). Edge processes near human development may include "increased wind; reduced humidity; increased predation on amphibians, birds, and small mammals; increased predation and parasitism on bird nests; increased exposure to invasive plants; and increased clearing, pruning, and trampling of native vegetation" (Marzluff and Bradley, in press).

3. Are snags or large trees present? Snags serve many important functions for wildlife, especially nesting, cover, and food sources for cavity-nesting birds and mammals. If snags are removed for safety reasons but stumps are not removed, even decaying stumps only a few feet high can be beneficial to wildlife.

4. Are downed logs present? Logs also serve a number of important functions for some wildlife species, particularly in or near streams and wetlands. Coarse woody debris, including logs, are critical elements of healthy, productive, and biologically diverse forests (Bull 2002). Thomas (1979) identified 179 vertebrate species that use coarse woody debris (snags and down wood) in the Blue Mountains of Oregon and Washington. Loss of rotten-log communities may affect some woodpeckers, such as the pileated woodpecker, because of the resultant decline in carpenter ants (Marzluff and Ewing 2001). Logs may also contain moisture, and the cool microclimate may protect certain species during short-term droughts.

5. Is water present or can it be safely accessed nearby by wildlife? Water is one of the essential components of habitat. Wetlands and riparian areas are especially important for wildlife as they may provide all needs in close proximity to each other (Kaufman et al. 2001). Often they provide year-round surface water. Their often high vegetation productivity of grasses, herbs and shrubs provide food sources for a multitude of invertebrate and vertebrates herbivores. In turn, these animals attract carnivores and omnivores. The diverse vegetation structure of wetlands also provides cover from predators and a unique and benign microclimate that is often warmer in winter and cooler in the summer than adjoining uplands and other terrestrial areas.

6. In general, large patches of a given habitat type are more valuable than small patches. Most native forest species were present at sites larger than 100 acres in the urbanizing area around Seattle. However, the case can be

made to protect relatively smaller patches (e.g., 5-20 acres) of diverse vegetation that are more widely distributed across the urban landscape, because these areas may be "stepping stones" between larger areas for some birds that persist in smaller patches (Potter 1990; Burel 1989; Fahrig and Merriam 1994). Woodlots, for example, often serve as "island refuges" for species that would otherwise not be found in residential neighborhoods.

Corridors of native vegetation are valuable in facilitating movement of animals between essential breeding, feeding, and roosting habitat and in minimizing negative attributes (e.g., reduced numbers, inbreeding, greater vulnerability to local extinction) of isolated populations. Although corridors may have negative effects, such as providing a pathway for the transmittal of invasive weeds or diseases (e.g., Hess 1996a), the positive effects of corridors are believed to outweigh the potential negative effects. Riparian areas provide especially important movement corridors in urban-rural landscapes.

Buffers can be especially important to wildlife protection when human activity may affect the area. Wildlife may be positively or negatively affected by adjacent habitat or land uses. An area adjacent to an existing park with native vegetation will be more valuable to wildlife than a similar area adjacent to commercial or industrial development. Buffers may be visual or auditory, and they may also serve to act as a barrier for unwanted species. For example, a buffer would have increased value if it were effective in keeping domestic cats away from nesting birds (Simberloff and Cox 1987) or in keeping mice and rats away from bird eggs.

Wildlife management in urban areas is extremely difficult because of the competing and simultaneous demands on the land. Trading wildlife benefits and urban benefits as well as trading some wildlife species for others are inescapable consequences attributed to this demand. Moreover, not all wildlife and habitat management issues are relevant in urban areas, nor are all wildlife species appropriate for natural habitats although their home ranges may encompass both natural and human-dominated landscapes (Milligan-Raedeke and Raedeke 1995). In urban, rural, and other areas, existing protective mechanisms of species have been formulated by weighing habitat and wildlife needs along with human and economic needs.

Restoration of wildlife habitat should not be underestimated for stemming and reversing the loss of wildlife. Strategic planning, in which temporal patterns of demography and dispersal as well as the spatial distribution of habitat and its conservation of target species are protected, restored, and overall managed, can significantly contribute to the persistence and recovery of certain populations (Scott et al. 2001). Results from a Puget Sound lowland study by Rohila and Marzluff (2002) suggest that if at least 30 percent of forest is protected in settled areas, and high live-tree density and large tree diameters are maintained, cavity-nesting birds may be maintained for up to several decades. They recommend that forest be retained in the largest patches possible 75 acres, and that the smallest average forest patch size does not fall below 7.5 acres.

Wildlife populations must be understood within daily and seasonal home ranges and the greater landscape context. In some instances, species presence may indicate habitat quality, such as specific species of invertebrates in streams or the spotted owl in old-growth forests. Alternatively, the presence of snags and other favorable habitat features may not ensure the site will be otherwise suitable for snag-dependent or other habitat-dependent species.

A site where a species nests or is otherwise observed may be an ecological sink, which is an area that attracts species or populations, but from which the species don't emerge or don't reproduce successfully. Sinks are isolated areas of habitat and do not provide habitat for sustainable populations. It has been argued by Foppen et al (2000) that under some circumstances, sinks or small landscape elements that are linked by corridors can promote larger overall metapopulation size, and, therefore, prolong the survival of declining metapopulations. However, isolated sinks are generally considered to not contribute to maintaining populations.

8.3 Data Gaps

Wildlife habitat types and the locations of many species of concern are documented within the 2003 Wildlife Inventory for the City of Bellevue; however, the information could be made more helpful by prioritizing the protection of specific habitat areas within the city based on their value to Bellevue's wildlife.

8.4 Recommendations

The City of Bellevue currently has no regulatory or administrative strategies to protect upland wildlife conservation areas. Aquatic and riparian areas are afforded some protection through the critical areas regulations for streams, wetlands and frequently flooded areas.

The habitats required by the special status species identified in Bellevue's 2003 Critical Areas Update Wildlife Inventory should be protected as critical areas (Wildlife Habitat Conservation Areas) when they are identified on a site. The state or federal protection requirements for these breeding habitats should be considered in site planning including the use of buffers and restrictions on land use activities.

If these species inhabit a site, it is recommended they be protected based on state and federal management guidelines. Because the protections are based upon state and federal guidelines (or other current literature), it is assumed that recommended habitat protections are consistent with best available science.

It is recommended that Bellevue engage in a wildlife habitat conservation planning process. This process would identify a potential network of vegetated corridors throughout the City that can be used to link high quality streams, wetlands, and open space lands, in order to minimize habitat fragmentation. The goal of the network is to protect larger core wildlife habitats that still remain in the landscape. Wildlife migration corridors, in general, are at risk in Bellevue. Developing a habitat network for wildlife is one strategy to address this issue.

The design of the wildlife habitat network should meet the following design standards:

- When possible, maintain a width of 300 feet of native habitat to connect core wildlife areas. The network width should avoid widths less than 150 feet at any point.
- The network should be designed to be contiguous with and include critical area tracts and their areas.
- When feasible, the wildlife habitat network should be sited in order to meet the following conditions:
    - ☐ Connect isolated critical areas or habitat
    - ☐ Connect with wildlife habitat network, open space tracts or wooded areas on adjacent properties, if present.

Buffers provisions will help protect aquatic habitat, such as streams, water bodies, and wetlands. The diversity of birds and small mammals in wetland and riparian habitats may exceed that found in upland habitats. Wetlands provide required habitat for aquatic-breeding wildlife such as invertebrates, amphibians, and waterfowl. Wetlands also provide essential habitat for rearing or for the adult life stages of numerous species of fish, amphibians, turtles, and some mammals.

For many terrestrial species wetlands provide water for drinking and vegetation for food and cover. Protecting the riparian areas around aquatic areas and wetlands will provide a number of benefits to aquatic and terrestrial wildlife. Breeding and cover habitat for invertebrates and wildlife with small home ranges may be protected within the fixed buffers.

The City of Bellevue could additionally improve the condition and extent of wildlife habitat within the City by developing stewardship programs that focus on education and incentives to encourage landowners o retain areas of native vegetation and practice best wildlife management practices.

The City of Bellevue may acquire conservation easements on properties identified as having high value wildlife habitat in order to protect those areas in perpetuity.

8.5 Conclusion

The Growth Management Act defines *fish and wildlife habitat conservation areas* as lands that are designated and managed for maintaining targeted species within their natural geographic distribution so that isolated subpopulations are not created. Such areas are considered to be critical for the long-term viability and proliferation of certain native fish and wildlife species. The Growth Management Act includes guidelines that jurisdictions must consider when designating these areas.

The wildlife habitat types in Bellevue identified in the Bellevue's 2003 *Critical Areas Update, Wildlife Inventory*, include the following general categories:

- West-side riparian wetlands
- West-side lowland conifer/hardwood forest
- Herbaceous wetlands and open water
- Agricultural and urban environs (agriculture, pasture, and mixed environs)
- Urban and mixed environs.

Outside of vegetated habitat patches and linkages, Bellevue's current landscape matrix is urban in character, composed primarily of residential development (both single-family and multifamily) and secondarily of commercial development. Within this matrix, a few large blocks of west-side lowland forest remain; habitat linkages between these blocks, where they exist, predominantly consist of west-side riparian-wetland habitat. Open water and herbaceous wetland habitats in Bellevue are mostly associated with lakes. Agricultural habitats consist of scattered berry farms and pastures.

Because of the high level of disturbance of soil and vegetation in agricultural and urban habitats, habitats in urban areas like Bellevue support more "generalist" species and are more prone to invasion by nonnative, invasive plant and animal species. While Bellevue's urban character offers limited habitat for wildlife species, the city does provide habitat for several "special status" species that are identified in Bellevue's wildlife inventory report. This review focused on the literature pertaining to the protection of wildlife habitat in urban areas.

To protect select wildlife habitat and species, strategies for the conservation of terrestrial systems should be crafted at relevant small, medium, and large scales. For example, the neighborhood, parcel, and landscape context should all be considered in planning efforts because different factors and components can affect these scales differently and wildlife requires conservation at multiple scales. These scales should parallel the needs of wildlife. For example, breeding and nesting requirements of individuals occur at a small scale, and migratory routes occur at a large scale. Furthermore, urbanization must be anticipated, and creative ways must be found to increase native habitat and collectively manage it.

In the literature, there are two approaches for conserving species and their habitat. One approach is to protect species only within clearly identified ecological reserves (i.e., tracts of land, often large) that are relatively homogenous in terms of plant composition and structure regardless of the adjoining land use. The other approach attempts to protect species throughout an entire region by enhancing the quality of existing habitat and by providing for all important wildlife needs. This regional approach is more difficult to implement. Implicit in both approaches is the protection of ecological function, composition, and structure. Such approaches are more difficult to implement in urban environments than in large forested areas and more natural landscapes. Nevertheless, land use regulation through ordinance rules and zoning and comprehensive plan policies that guide property acquisitions and stewardship programs for habitat protection can minimize the detrimental effects on wildlife.

Wildlife habitat types and the locations of many species of concern in Bellevue are documented; however, the information could be made more helpful by prioritizing the protection of specific habitat areas in Bellevue based on their value to wildlife in the city.

- There are currently no regulatory or administrative strategies to protect upland wildlife conservation areas.
- Aquatic and riparian areas are afforded some protection through the critical areas regulations for wetlands, streams and frequently flooded areas.
- The habitats required by the special status species identified in Bellevue's wildlife inventory should be protected when they are identified on a site.
- The state or federal protection requirements for the breeding habitats of special status species should be considered in site planning, including the use of buffers and restrictions on land use activities.
- The City of Bellevue could improve wildlife habitat conservation by identifying remaining vegetated corridors throughout the city that can be further linked with high-quality streams, wetlands, and open space lands. The goal of the network is to protect larger core wildlife habitats that still remain in the landscape and maximize connected areas of native habitat between them.
- The City of Bellevue could additionally improve the condition and extent of wildlife habitat within the city by developing stewardship programs that focus on education and incentives for landowners who retain areas of native vegetation and provide opportunities for wildlife.
- The City of Bellevue could acquire conservation easements on properties identified as having high-value wildlife habitat in order to protect those areas in perpetuity.

The City of Bellevue's provisions for buffers to protect aquatic habitat, such as streams, water bodies, and wetlands, are an important element of wildlife habitat protection. For many terrestrial species, wetlands provide water for drinking and vegetation for food and cover. Buffers around lakes, streams, and wetlands provide a number of benefits to aquatic and terrestrial wildlife including breeding and cover habitat for invertebrates and wildlife with small home ranges.

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