Lake Sammamish Watershed Assessment Report

prepared in support of the City of Bellevue Watershed Management Plan for areas and tributaries that drain to Lake Sammamish within the City of Bellevue

Revision 3 (final)

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Bellevue Utilities Department

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Watershed Management Plan
Our streams, our future

Document history and status

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Preface

Urban development in the lowland regions of the Puget Sound over the past 150 years has resulted in the conversion of large tracts of forested area to residential, industrial, and commercial land uses. Changing environmental conditions that resulted from this land conversion have dramatically impacted the health of the region's streams, lakes, and marine water bodies. Common symptoms of water resource degradation from urbanization include poor water quality, loss of riparian and aquatic habitat, and stream channel erosion. In combination, these impacts have resulted in widespread disruption in the ecological function of water bodies causing sensitive aquatic life to decline in abundance or disappear completely. To address this problem, state and local jurisdictions are making a concerted effort to rehabilitate these water bodies through coordinated planning efforts that direct new storm and surface water management practices to existing urban development that was built without stormwater detention or water quality controls that do not meet current requirements and standards.

Commensurate with these regional efforts, the City of Bellevue (City) is committed to improving and protecting the aquatic health of water bodies within its boundaries. To that end, the City is developing a Watershed Management Plan (WMP) that will focus on improving the health and condition of the City's streams using a toolbox of holistic storm and surface water management practices. The WMP will direct investments to high-priority watersheds providing measurable environmental benefits to stream health within a shorter time frame than past or current approaches. The WMP will also help prevent further degradation in non-priority watersheds. The WMP will include an implementation plan with recommended projects, policies, programs, and operational plans to meet performance goals for Bellevue's streams, and to provide multiple benefits that help advance City objectives across departments and programs.

The City is preparing a series of watershed assessment reports and watershed improvement plans that will provide the basis for the recommended actions in the WMP. A Watershed Assessment Report (AR) will be prepared for each of the City's major watersheds: Coal Creek, Greater Kelsey Creek, the Lake Sammamish tributaries within Bellevue (including Lewis Creek), and the small Lake Washington tributaries within Bellevue.

This report is an assessment of the current conditions in the Lake Sammamish Watershed, which includes the area within the City of Bellevue that drains to Lake Sammamish. This information, along with other subsequent reports, will be used to develop the final WMP.

City of Bellevue Watershed Management Plan

Lake Sammamish Watershed Assessment

EXECUTIVE SUMMARY

Purpose of This Assessment

The purpose of this report is to assess the conditions in the portion of the Lake Sammamish Watershed within the City of Bellevue that are limiting the health of its streams. This assessment includes the evaluation of potential limiting factors that describe the primary effects of urban runoff on streams and their consequences for stream health.

The City is preparing a series of Watershed Assessment Reports (ARs) that will provide the basis for the recommended actions to improve stream health culminating in a city-wide Watershed Management Plan (WMP).

One AR will be prepared for each major watershed in the City of Bellevue (City): Coal Creek, Greater Kelsey Creek, the Lake Sammamish tributaries within Bellevue (including Lewis Creek), and the small Lake Washington tributaries within Bellevue.

In addition to the watershed condition assessment, each AR will include limiting factors, data gaps (if any), and identified opportunities for improving in-stream watershed conditions. The ARs are based on data from three primary sources: 1) the recent Open Streams Condition Assessment (OSCA) performed by the City; 2) existing data collected by the City from past projects and ongoing monitoring efforts; and 3) existing project and environmental monitoring data collected by the City and a variety of public resource agencies.

Watershed Management Plan
Our streams, our future

Description and History of the Lake Sammamish Watershed Within the City of Bellevue

The area draining to Lake Sammamish within the City of Bellevue has been broken down into ten subbasins and areas. (A subbasin generally includes open channel streams whereas an area may have several individual discharge locations to its receiving water body and may either be piped or open channel.) The Lewis Creek and Vasa Creek subbasins are the largest within the City portion of the Lake Sammamish Watershed. The City refers to all the other subbasins and areas but Lewis Creek and Vasa Creek as the “lesser tributaries to Lake Sammamish” because of their relative size. The Ardmore/ Idylwood Creek Area and Redmond 400 Area both drain to the City of Redmond before discharging to Lake Sammamish.

Each of the subbasins and areas draining to Lake Sammamish are steep with narrow but intact riparian areas, often in ravines. Many of the subbasins and areas have large tracts of City-owned property in the form of City Parks. Interstate 90 (I-90) runs east-west through the Vasa Creek and Lewis Creek subbasins and the South Sammamish area. Similar to the other watersheds within the City of Bellevue, the subbasins and areas that drain to Lake Sammamish have been affected by urban development, yet much of this development is residential with little to no industrial/commercial land use, so these subbasins and areas have been less affected than other subbasins and areas within the City. That said, because of the relatively steep channel slopes, runoff from impervious surfaces causes issues with channel scour and erosion.

Streams in the Lake Sammamish Watershed have been highly affected by urbanization, including altered riparian vegetation, high-flow bypasses, dams, detention facilities, ditching and confinement by roadways, and long stretches that are piped underground. Dense residential development surrounding the majority of the Lake Sammamish shoreline has resulted in the installation of bulkheads and other shoreline armoring to reduce potential erosion along the lakeshore. Due to the steep topography found in much of the Lake Sammamish Watershed, many of the tributaries have naturally confined floodplains and long sections of piped stream that alter sediment transport and convey high-velocity flows that result in channel incision and streambank erosion.

Human intervention in proximate waterbodies has affected the Lake Sammamish Watershed. In the late 1800s, the outlet of Phantom Lake was diverted to Lake Sammamish. Human use and activity within the City's portion of the Lake Sammamish Watershed includes unauthorized encampments, recreational use of riparian areas, roadway and vehicle pollutants, and numerous other urban residential pollutants which all have the potential to negatively impact water quality.

The Lake Sammamish Watershed also has a number of regional stormwater facilities and high-flow bypasses and smaller detention facilities. High-flow bypasses are designed to divert high stream flows during extreme flow events out of the main channel and into storm drainage pipes that carry these flows away from vulnerable areas. The high-flow bypasses in the Lake Sammamish Watershed were implemented to reduce erosion and flooding downstream but may have potential negative effects on fish populations, particularly when sediment and debris accumulation and streambed aggradation result in base flows being diverted out of the stream channel. Additionally, high-flow bypasses can substantially alter sediment transport dynamics (often starving a stream of bed material) and channel morphology where bypassed flows reenter the stream channel, and throughout the portion of stream that is bypassed.

Given the generally steep topography in the Lake Sammamish Watershed, off-channel habitat is naturally limited, therefore restoring lost off-channel habitat where possible, particularly around the creek mouths, is an important consideration. The Lake Sammamish Watershed subbasins include multiple areas that are designated as a priority aquatic and terrestrial habitat by the Washington State Department of Fish and Wildlife (WDFW 2021c). Weowna Park (which extends throughout the North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area) and Lakemont Community Park and Open Space (within Lewis Creek Subbasin) are designated as priority terrestrial habitat. Lewis Creek, Vasa Creek, Phantom Creek, and Phantom Lake are designated as priority aquatic habitat for various salmonid species.

The natural topography of the Lake Sammamish Watershed limits fish use, and subsequently there is limited fish use data for the tributaries within the watershed. In many of the subbasins/areas, salmonid species do not go farther upstream than the tributary mouths at Lake Sammamish. However, in three subbasins and areas (*i.e.*, Lewis Creek Subbasin, Vasa Creek Subbasin, and the South Sammamish Area), salmonids are present, with Lewis Creek and Vasa Creek being the best-studied "fish" streams within the Lake Sammamish Watershed.

The Lake Sammamish Watershed is important for salmonids, as it has historically provided extensive spawning and rearing habitat for a larger number of anadromous and migratory

salmonids and other fish species. Priority fish species within Lake Sammamish Watershed, as designated by WDFW, include Chinook Salmon *(Oncorhynchus tshawytscha)*, Coho Salmon *(Oncorhynchus kisutch)*, Sockeye Salmon *(Oncorhynchus nerka)*, and resident Cutthroat Trout *(Oncorhynchus clarkii)*. Chinook, Coho, and kokanee (lake-dwelling *Oncorhynchus nerka*) salmon are City of Bellevue Species of Local Importance, per Bellevue Land Use Code 20.25H.150A. Additionally, Chinook Salmon are a listed Federally Endangered Species. Lake Sammamish kokanee have been the topic of significant study and investment, a recent partnership between the Cities of Bellevue, Issaquah, Redmond and Sammamish, the Snoqualmie Tribe, and King County was formed to help recover kokanee salmon.

Factors that Limit the Health of the Lake Sammamish Watershed Within the City of Bellevue

The following were identified as limiting factors for the City of Bellevue portion of the Lake Sammamish Watershed, in general order of importance across all ten subbasins and areas within the Watershed:

1. **Stormwater Runoff from Effective Impervious Surfaces:** Increased stormwater runoff flow rates and volumes during storm events from impervious surfaces in the Lake Sammamish Watershed, in combination with historic channel alterations for flood risk reduction purposes or land development, are contributing to negative effects on water quality and instream habitat quality, including fish and wildlife habitat. Although the City required stormwater flow control for new development beginning in the mid-1970s, facilities designed and built through the mid-1990s have been shown to be not very effective at protecting streams from erosion and other negative effects of runoff.

2. **Pollutant Loading:** Stormwater runoff from impervious surfaces (Limiting Factor #1) causes erosion from higher flows, and transports pollutants (metals, nutrients, fecal coliform, and others) associated with urban development that are detrimental to the health of aquatic organisms and people. Road runoff, illicit discharges, and possibly septic systems are the likely sources of these pollutants.

3. **Road Culverts and Other Physical Barriers:** A number of physical barriers to fish passage have been identified throughout the Lake Sammamish Watershed. In addition, there are undocumented barriers on private properties throughout the Watershed. These barriers prevent fish from accessing areas for spawning and/or rearing, effectively reducing their activities to areas of the stream downstream of these barriers.

4. **Loss of Floodplain and Riparian Function:** Urban development has confined many of the stream reaches in the Lake Sammamish Watershed. This effectively reduces the amount of floodplain storage and reduces wood from entering the stream, leading to high velocities and flowrates with limited channel complexity. Since many of the streams in the City's portion of the Watershed flow through ravines, the riparian canopy in these ravines have remained intact, though is often very narrow with limited or no buffer.

Past and Present Investments in the City's Portion of the Lake Sammamish Watershed

The City has implemented in-stream projects that include repairing stormwater outfalls, stabilizing stream slopes, removing fish passage barriers, catching and removing fine sediment, and improving conveyance. The City has also invested in protecting critical infrastructure.

Future Opportunities

Future investments in the City's portion of the Lake Sammamish Watershed will address the limiting factors identified here and include both in-stream investments and investments in the contributing areas so as to address the pollutant loading and stormwater runoff challenges in the Watershed.

Prepared by Jacobs HERRERA

1. Introduction

This section discusses the watershed management planning process, introduces the tributaries to the Lake Sammamish Watershed that are within the City of Bellevue, and describes the document organization.

1.1 The Watershed Management Planning Process

For all documents prepared as part of the City's Watershed Management Plan, the word 'watershed' will be used to describe the boundaries of the large areas that drain to creeks and waterbodies. The word 'subbasin' will be used to describe the smaller drainages within the watersheds. For this planning effort, the City has defined the following four (4) watersheds: Kelsey Creek, Coal Creek, Lake Washington Tributaries, and Lake Sammamish Tributaries. These four (4) watersheds are made up of a total of twenty-six (26) subbasins, as shown in Figure 3.

The City of Bellevue (City) is developing the Watershed Management Plan (WMP) using a stepwise process that builds on information obtained from each proceeding step to ensure the final plan is comprehensive, makes the best use of new and existing data and information, and reflects the community's values and goals. As shown in Figure 1, this stepwise process leading up to WMP development includes the following major components:

- **Foundational Element Memoranda** will be prepared at the onset of WMP development to define critical inputs to the process including the overarching framework for the plan (Foundational Element #1), the metrics that will be used to measure progress towards meeting stream health goals (Foundational Element #2), and the approach that will be used for prioritizing watersheds (Foundational Element #3).
- The **Open Streams Condition Assessment (OSCA)** was initiated by the City in 2018 to survey approximately 80 miles of open stream within the City limits. Completed in the fall of 2020, the data generated from this effort will be used in three aspects of the WMP: 1) provide a current understanding of the physical habitat of Bellevue streams through the development of stream habitat reports; 2) provide baseline data to assess if future improvements to stream health are successful; and 3) provide a comprehensive "boots-on-the ground" assessment of opportunities to improve the physical, chemical, and biological health of the streams.
- **Watershed Assessment Reports (ARs)** will be prepared to characterize existing conditions in the City's watersheds: Greater Kelsey Creek, Coal Creek, Small Lake Washington Tributaries, and Lake Sammamish Tributaries (including Lewis Creek). Each Watershed AR will identify limiting factors, data gaps (if any), and opportunities for improving watershed health. These ARs will be developed based on data from three primary sources: 1) the OSCA described above; 2) existing data collected by the City from past projects and ongoing monitoring efforts; and 3) existing project and environmental monitoring data collected by a variety of public resource agencies.
- **A Watershed Management Toolbox** will be prepared to identify and document the different tools (or strategies) that could be used to meet the WMP goals. These tools could include stormwater Best Management Practices (BMPs), policy/regulatory changes, operational strategies, engineered solutions, management strategies, etc. The toolbox will also indicate which stressors on stream health are addressed by each individual tool or management strategy.
- **Initial and Revised Watershed Prioritizations** will be performed to identify which subbasins within the City's watersheds would have the quickest positive response to rehabilitation efforts, with the goal of maximizing return on the City's investments in stream health. The initial prioritization (performed

before and during AR development) will also provide the technical basis for meeting regulatory requirements for watershed planning that stem from the City's Phase II Municipal Stormwater Permit (Phase II Permit). The revised prioritization (performed after the ARs are complete) will include input from Community Metrics (see below) and other stakeholders and will guide all subsequent phases of WMP development.

- **Community Metrics** will be identified based on community values and goals for quantifying ancillary benefits that may be realized from the WMP in addition to those directly related to improved stream health. These metrics will be formed during a robust public engagement process. For example, these metrics might quantify benefits from the plan related to increased access to open space, educational opportunities, enhanced aesthetics, and/or environmental and social justice issues.

- **Watershed Improvement Plans (WIPs)** will be prepared for each watershed that list and describe each of the solutions and/or opportunities recommended for watershed improvement with associated costs and a schedule for implementation. These plans will provide details on the tools and opportunities considered for watershed improvement, provide information on how the opportunities were evaluated, and the results of those evaluations. The WIPs will focus on investments to improve stream health rather than broader community goals, which will be addressed in the WMP itself.

All the work performed to develop these components of the WMP will be informed by a conceptual model (Figure 2) that was created by the City to describe the primary effects of urbanization on stream health. This model shows the linkages between specific sources of stress on stream health (e.g., stormwater runoff) and the consequences, impacts, and outcomes that collectively contribute to degraded stream health. This model will be particularly important for identifying the specific limiting factors that are responsible for impaired stream health during preparation of the ARs and the appropriate solutions for improving conditions during preparation of the WIPs.

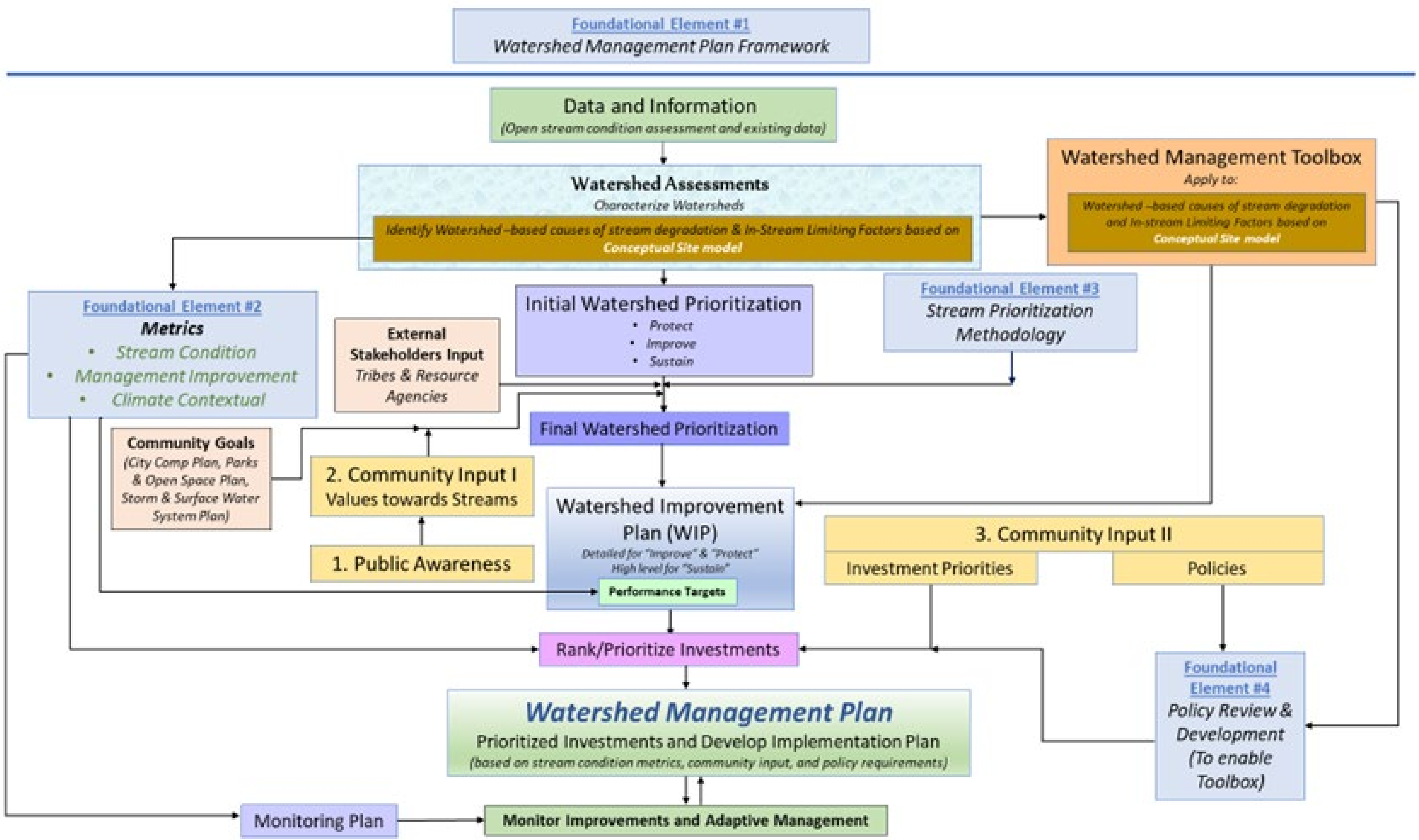


Figure 1. Watershed Management Plan Development Process.

1.2 The Lake Sammamish Watershed

The Lake Sammamish Watershed includes approximately 5,240 acres within the City's boundary (Figure 3). The remaining portions of the Watershed are within the cities of Redmond, Issaquah, Sammamish, and unincorporated King County. The City's portion of the Lake Sammamish Watershed is comprised of 10 individual subbasins and areas that are briefly characterized below, with more detail provided within this report:

- Lewis Creek Subbasin includes Lewis Creek, which flows approximately 3.2 miles from its present-day headwaters southeast of Lewis Creek Park to Lake Sammamish. The Lewis Creek Subbasin contains one of the two largest wetland areas in the City's portion of the Lake Sammamish Watershed, located within Lewis Creek Park. The Lewis Creek Subbasin has the lowest percent impervious surface of all the subbasins and areas within the City's portion of the Lake Sammamish Watershed with 30% impervious surface. The Lewis Creek Subbasin has the highest percentage of park land of all subbasins within the Watershed, with 17%.
- Vasa Creek Subbasin includes Vasa Creek, which flows approximately 2.7 miles from its headwaters at Saddleback Park to Lake Sammamish. The Vasa Creek Subbasin includes both Vasa Creek and a major Lake Sammamish Tributary called Tributary 0160. The Vasa Creek Subbasin, in contrast to the Lewis Creek Subbasin, has relatively little park land (2%) with 15% of its area in commercial, highway, industrial, mixed use, and multi-family land uses. Of that 15%, 3% is in highway land use.
- Ardmore Area/Idylwood Creek Subbasin includes area tributary to Idylwood Creek, which flows into the City of Redmond before entering Lake Sammamish. The Ardmore Area/Idylwood Creek Subbasin has the highest impervious surface coverage (45%) of all subbasins and areas within the City's portion of the Lake Sammamish Watershed.
- Redmond 400 Area consists of area draining into the City of Redmond before entering Lake Sammamish. This Area is predominantly single family residential (94%) with the remainder in park land use. This Area has the lowest urban tree canopy of any other subbasin or area in the watershed at 26%.
- Rosemont Area is the smallest of the 10 subbasins and areas and is located right along the Lake Sammamish shoreline. This Area has no major tributaries. Similar to Redmond 400 Area, this Area is 97% single family residential with the rest in park land use.
- Wilkins Creek Subbasin is entirely within the City of Bellevue and has one of the highest impervious surface coverages in the Watershed at 44%. Similar to the lesser tributaries to Lake Sammamish within the City limits, the dominant land use is single family residential (96%) with the remaining in park and multi-family land use.
- North Sammamish Area is entirely within the City of Bellevue and has numerous small unnamed tributaries running down relatively steep slopes towards Lake Sammamish. This Area has 87% single family land use, with the remainder in parks land use.
- Phantom Creek Subbasin includes Phantom Lake which is the largest surface water feature in all the Lake Sammamish Watershed subbasins and areas. The Phantom Creek Subbasin contains one of the two largest wetland areas in the City's portion of the Lake Sammamish Watershed, located proximate to Phantom Lake. The Phantom Creek Subbasin has 27% commercial/office land use, the highest by far of any subbasin or area within the City's portion of the Lake Sammamish Watershed.

The land draining to Lake Sammamish within the City of Bellevue is designated as either an area or a subbasin. A subbasin generally includes one major open channel stream discharging to one location whereas an area may have several individual discharge locations to its receiving water body and may either be piped or open channel.

- Spirit Ridge Area is one of the smallest subbasins or areas within this Watershed. This Area has one of the highest impervious surface coverages (44%) and has 89% single family land use and the rest park land use.
- South Sammamish Area is the only area (other than the Vasa Creek Subbasin) that has highway land use (at 6%), with an additional 10% as mixed use and multi-family land use. This Area has one of the lowest park land use percentages in the Watershed with only 1%. The remaining area is single family residential. This Area has several tributaries that each cross I-90.

Lewis Creek and Vasa Creek (and tributaries) are the largest streams within the City portion of the Lake Sammamish Watershed. The City refers to all but Lewis Creek and Vasa Creek as the "lesser tributaries to Lake Sammamish" because of their relative size.

The City defines a subbasin as draining to one outlet (either now or in its historic condition). In contrast, the City defines an area as having multiple outlets. Within this AR, subbasins and areas are referred to consistent with this practice. Areas may be primarily piped or may be open channel.

This Watershed AR was prepared to meet the following objectives:

- Characterize the portion of the Lake Sammamish Watershed within the City of Bellevue and instream conditions in those areas and to identify any trends compared to previously collected data
- Identify limiting factors to stream health, data gaps (if any), and opportunities for improvement
- When combined with the other three ARs, provide input into prioritizing subbasins for the improvement of stream health

1.3 Organization

This Watershed AR is organized to include the following information for the Lake Sammamish Watershed under separate sections:

Existing conditions - a summary of existing conditions for the following attributes: watershed characteristics, built infrastructure, and natural systems.

Limiting factors – based on an analysis of existing conditions, a summary of the primary factors from the conceptual model in Figure 2 that are limiting aquatic health in the Watershed.

Past and present investment – a summary of investments that have already been made to improve stream health in the Watershed.

Future opportunities – a summary of future opportunities that could be implemented to improve stream health in the Watershed based on the current understanding of existing conditions and limiting factors.

Data gaps – missing or incomplete information that were not available to inform this Watershed AR or future phases of WMP development.

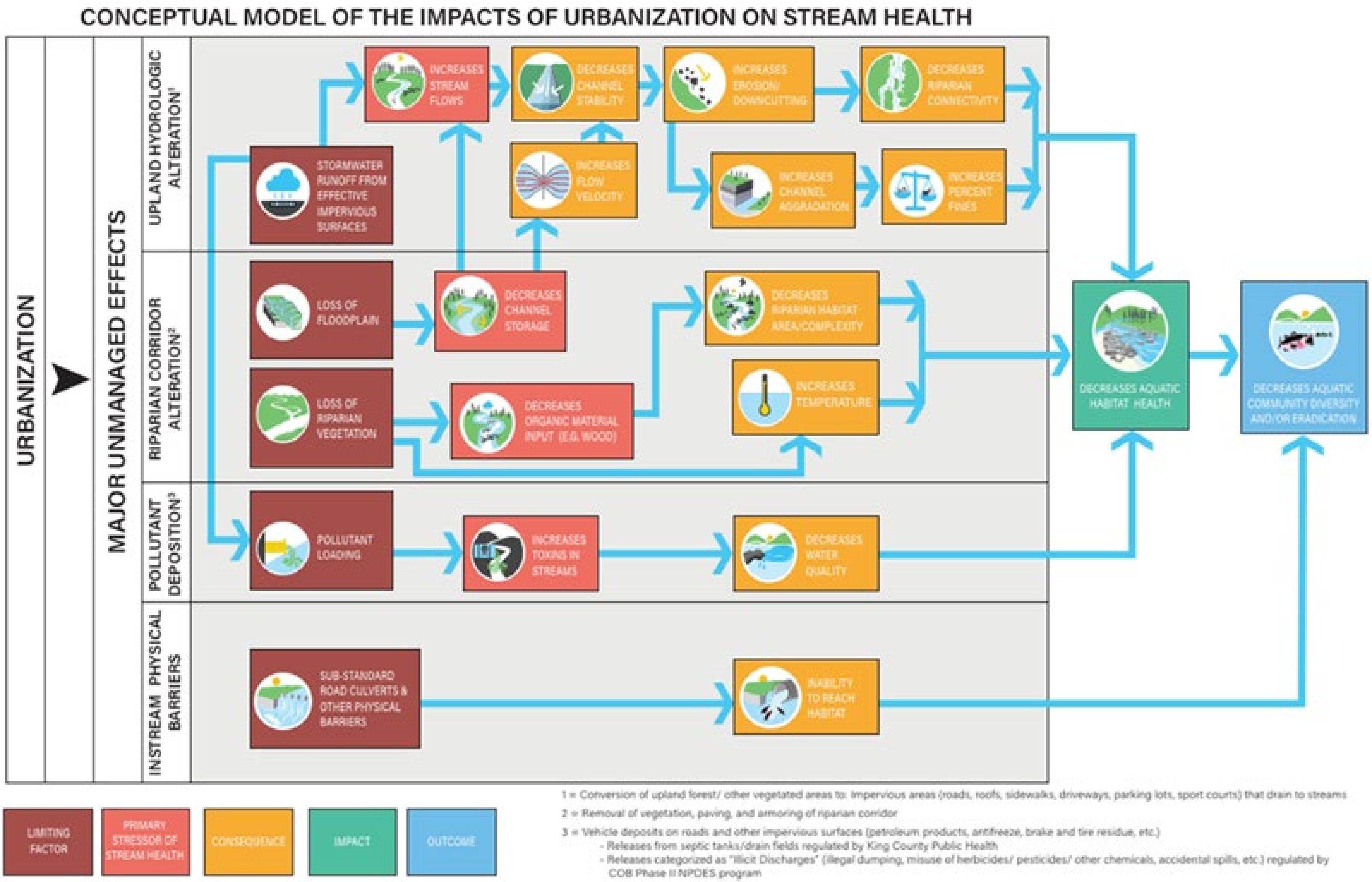


Figure 2. Conceptual Model for the Impacts of Urbanization on Stream Health.

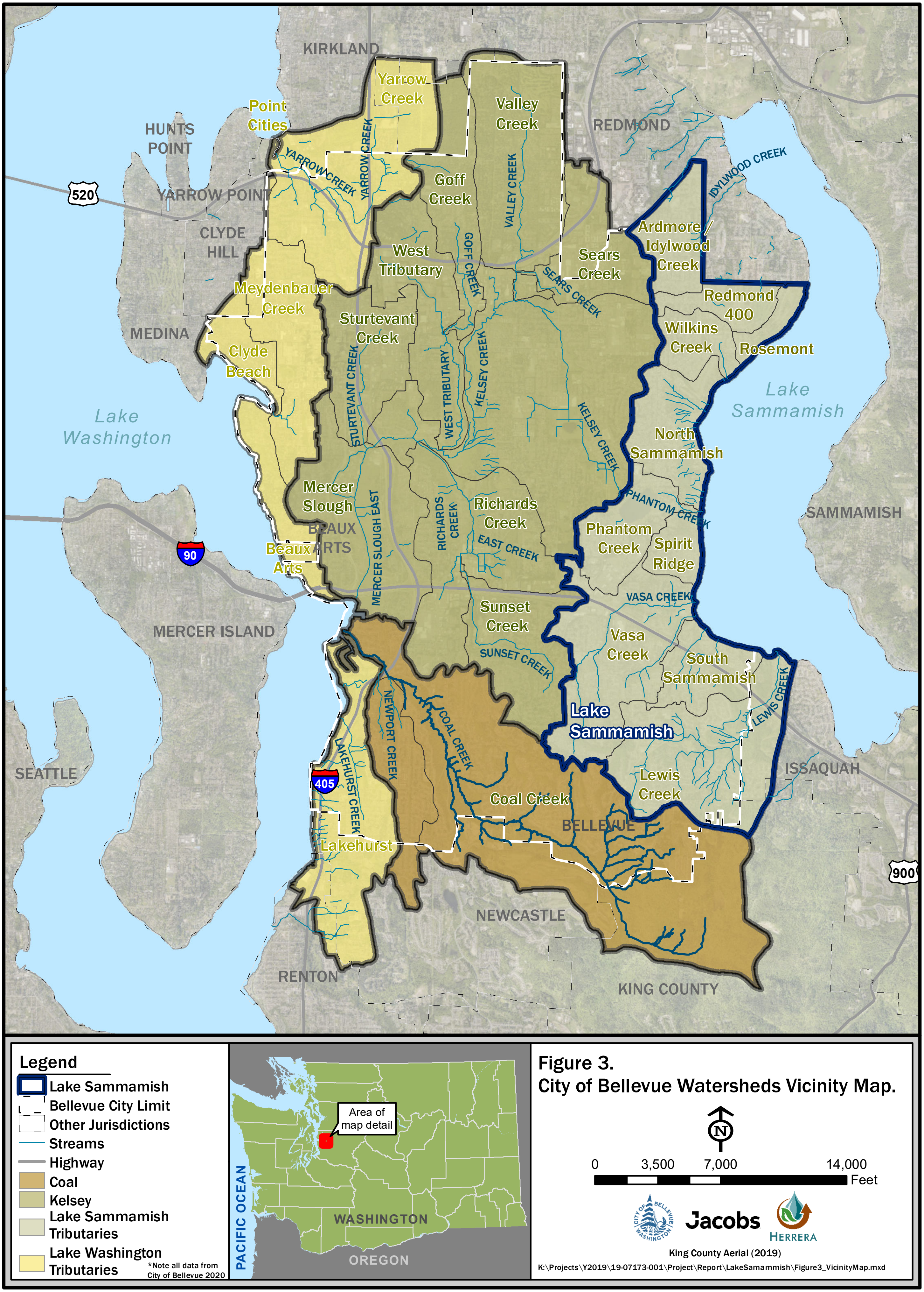


Figure 3.
City of Bellevue Watersheds Vicinity Map.

2. Existing Conditions

This section documents existing conditions in the Lake Sammamish Watershed under separate subsections for the following attributes: watershed characteristics; built infrastructure; and natural systems. Data sources and methods used to summarize geospatial attributes in this section are presented in Appendix A.

2.1 Watershed Characteristics

Existing conditions in the Lake Sammamish Watershed are summarized herein for the following attributes: climate, geology and soils, topography and geomorphology, surface water features, groundwater, and human and wildlife interaction. Figures 4-7 show surface water features for the Lewis Creek Subbasin, Vasa Creek Subbasin, Ardmore Area/Idylwood Creek Subbasin, Redmond 400 Area, Rosemont Area, Wilkins Creek Subbasin, North Sammamish Area, Phantom Creek Subbasin, Spirit Ridge Area, and South Sammamish Area.

2.1.1 Climate

As shown in the conceptual model (Figure 2), precipitation falling on impervious surfaces causes stormwater runoff. This alteration of the natural hydrology is associated with erosive peak flows and pollutant transport. These stressors degrade both aquatic habitat and water quality.

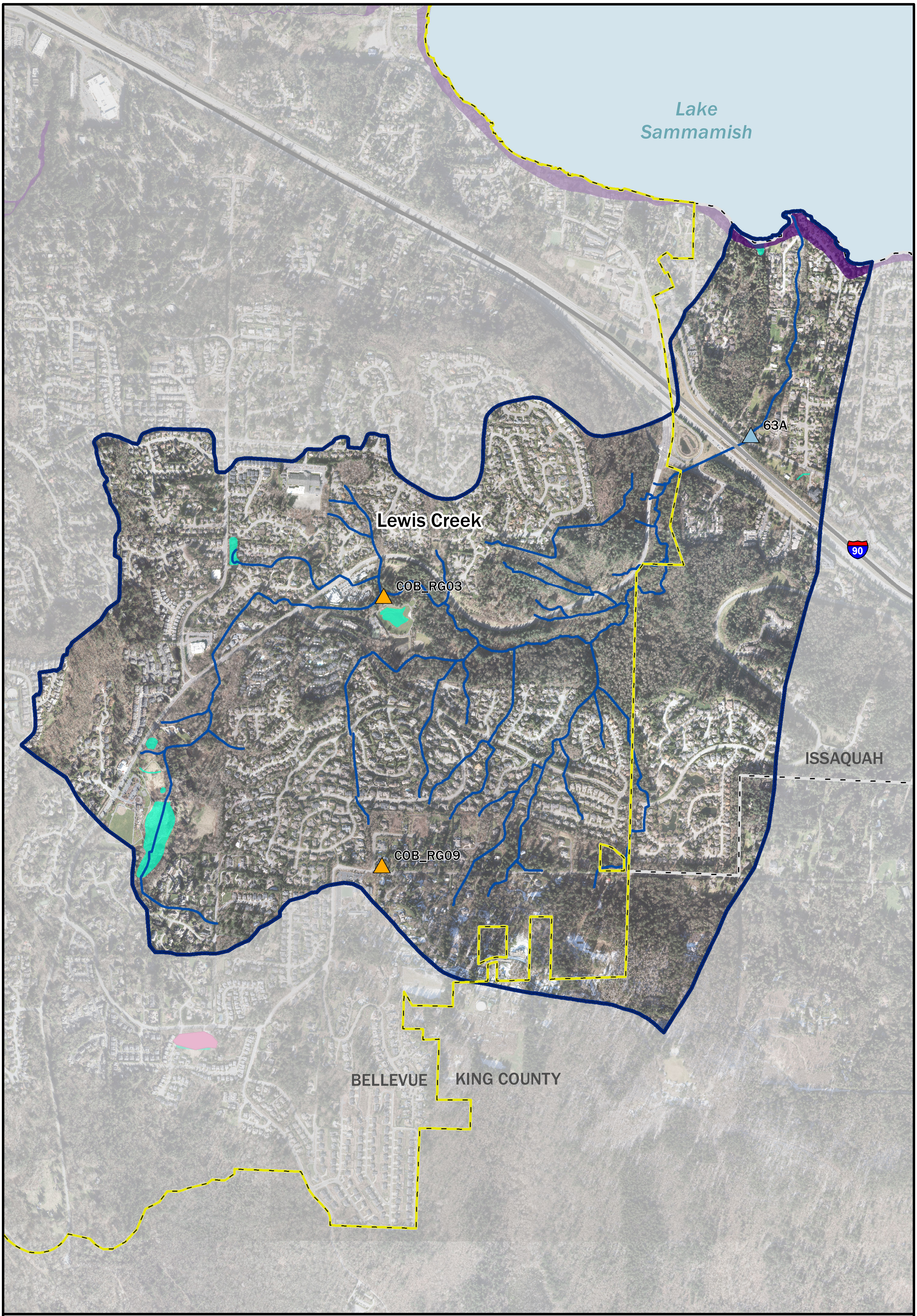
Existing climatic conditions in the Lake Sammamish Watershed are characterized by cool, dry summers and mild, wet winters that are typical of maritime regions (Tetra Tech *et al*. 2006). Seasonal and spatial precipitation patterns within the watershed were analyzed based on data collected from two rain gauges in the watershed that are maintained by King County, with data accessed via the King County Hydrologic Information Center (HIC):

- COB_RG11 – City of Bellevue Phantom Lake Rain Gage – Approximate elevation 265 ft NAVD88
- COB_RG03 – City of Bellevue Lakemont Rain Gage -Approximate elevation 615 ft NAD88

The COB_RG11 rain gauge is located near the northeastern shoreline of Phantom Lake, approximately 0.2 miles southwest of the intersection of 168th Ave SE and SE 17th St (Figure 6). COB_RG11 is located in the Phantom Creek Subbasin of the Lake Sammamish Watershed . The COB_RG03 rain gauge is located northeast of the intersection of Village Park Dr SE and Lakemont Blvd SE, within the Lewis Creek Subbasin, at an approximate elevation of 615 ft (Figure 4).

The aforementioned rain gauges were analyzed based on data availability. COB_RG11 and COB_RG03 were analyzed for the period spanning from January 1, 2015, to December 31, 2019. For this time period, the average annual precipitation for COB_RG11 was 40.41 inches, and the average annual precipitation for COB_RG03 was 46.46 inches. On average, the watershed received the most precipitation during the months of November and December. As shown in Figure 8, COB_RG11 and COB_RG03 measured similar amounts of precipitation over that period, with COB_RG03 recording a slightly higher level of precipitation (but not statistically significant) month over month. These data suggest that the entire Lake Sammamish Watershed receives spatially consistent rainfall over the month period.

While this limited data from the gauges identified above makes it difficult to infer any long-term trends, regional studies on climate change are predicting a modest increase (15 percent) in the average of the annual daily maximum rainfall total over the period from 2020 to 2050, with larger storms (storms with over 3 inches of rain per 24-hour period) generally predicted to be larger and smaller storms generally predicted to be smaller (King County 2014). Based on this shift in precipitation patterns, the impacts from urbanization noted above are anticipated to become more severe as impervious surfaces intercept additional rainfall that would normally have infiltrated to groundwater under natural, forested conditions.



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- FEMA 100 year floodplain
- NWI Wetlands (2020)
- King County Sensitive Area Ordinance Wetlands (2020)
- Highway (City of Bellevue 2020)
- Stream (City of Bellevue 2020)

King County Monitoring (King County 2020)

- Precipitation Gauge, Active
- Stream Gauge, Active

Note: Federal Emergency Management Area (FEMA), National Wetland Inventory (NWI).

Figure 4. Lewis Creek Subbasin Surface Water Features.

0 550 1,100 2,200 Feet

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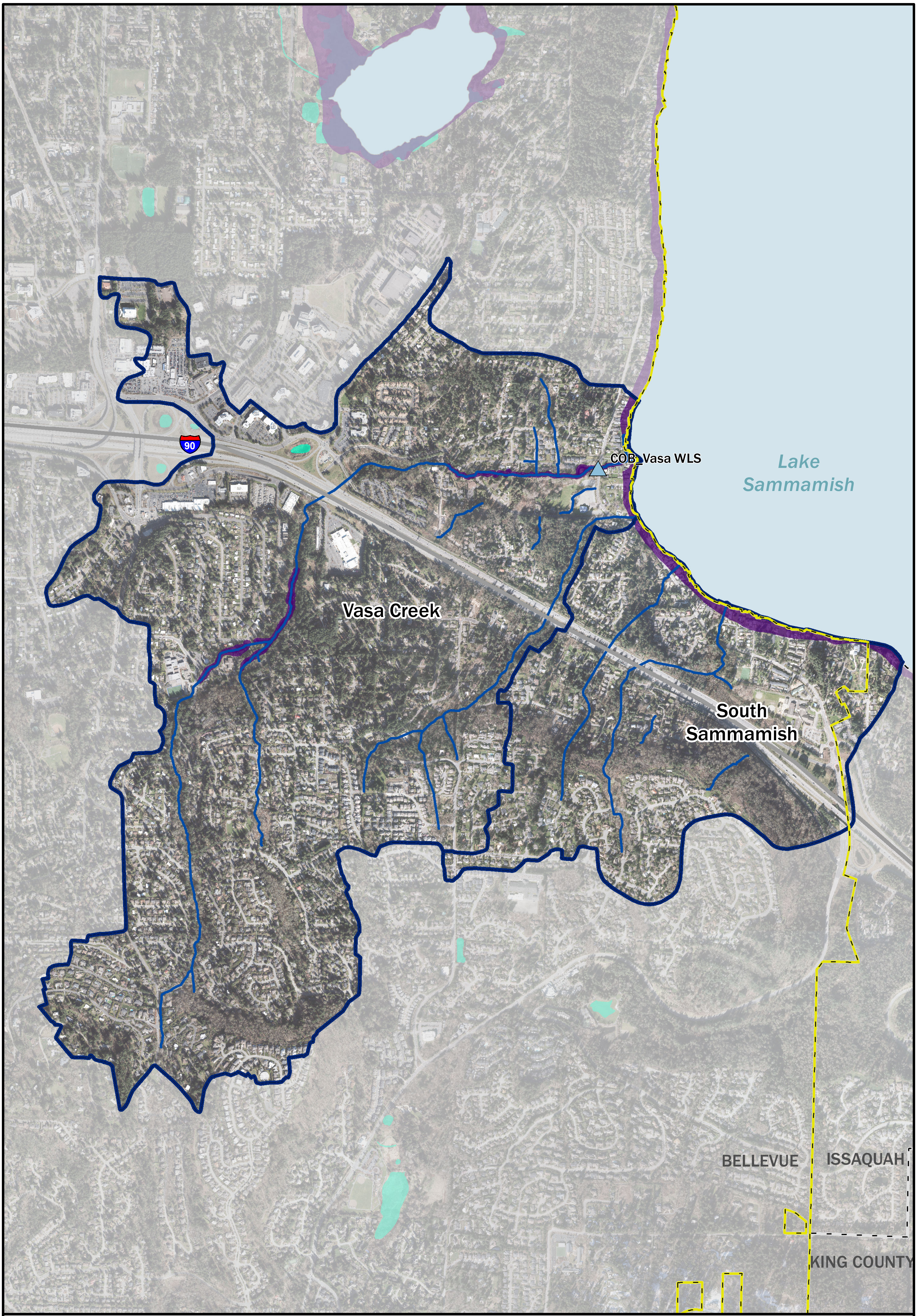

Legend

- Subbasin (City of Bellevue 2020)
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- FEMA 100 year floodplain
- NWI Wetlands (2020)
- Highway (City of Bellevue 2020)
- Stream (City of Bellevue 2020)

King County Monitoring (King County 2020)

- Stream Gauge, Active

Note: Federal Emergency Management Area (FEMA), National Wetland Inventory (NWI).

Figure 5. Vasa Creek Subbasin and South Sammamish Area Surface Water Features.

0 650 1,300 2,600 Feet

CITY OF BELLEVUE WASHINGTON Jacobs HERRERA

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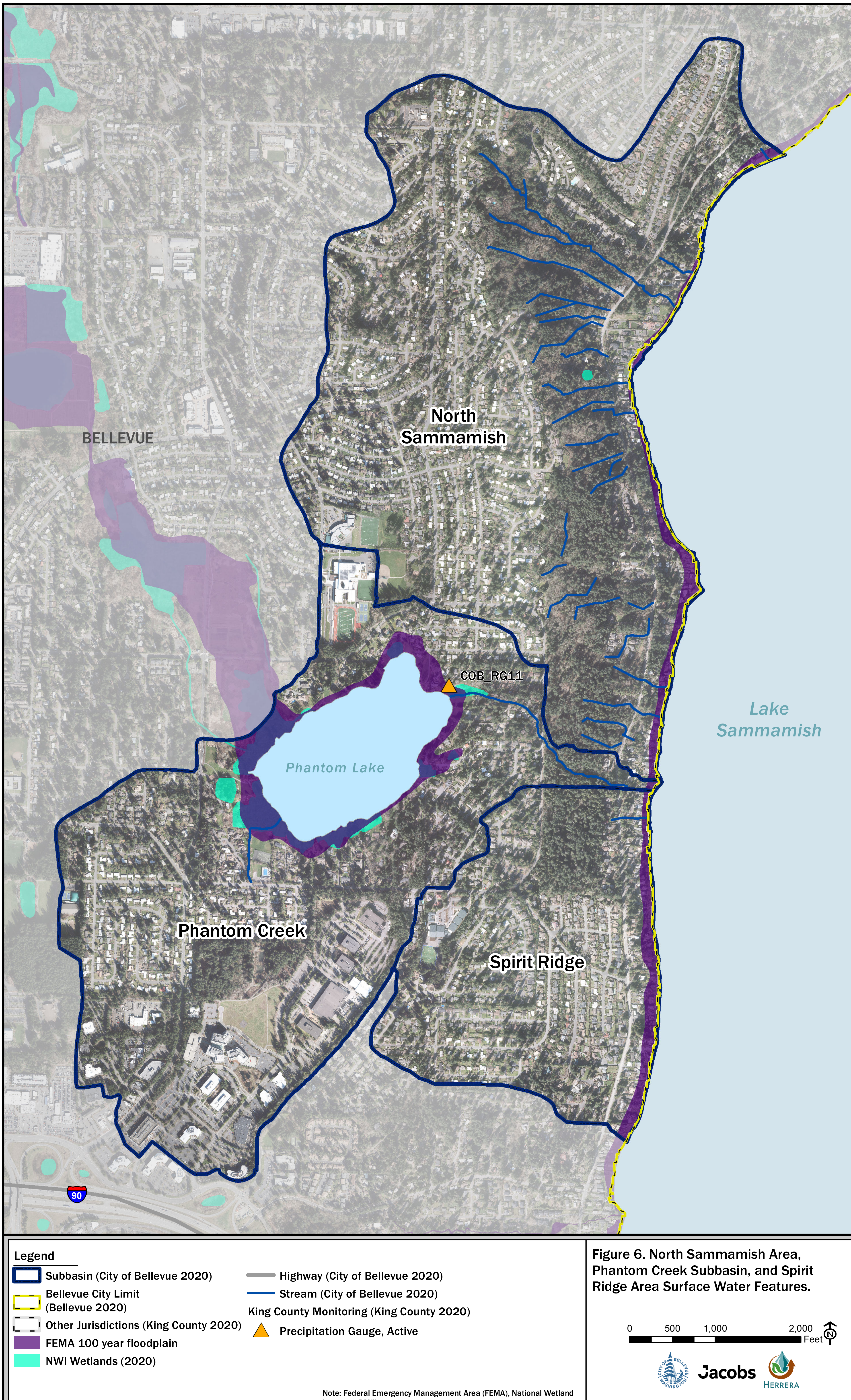
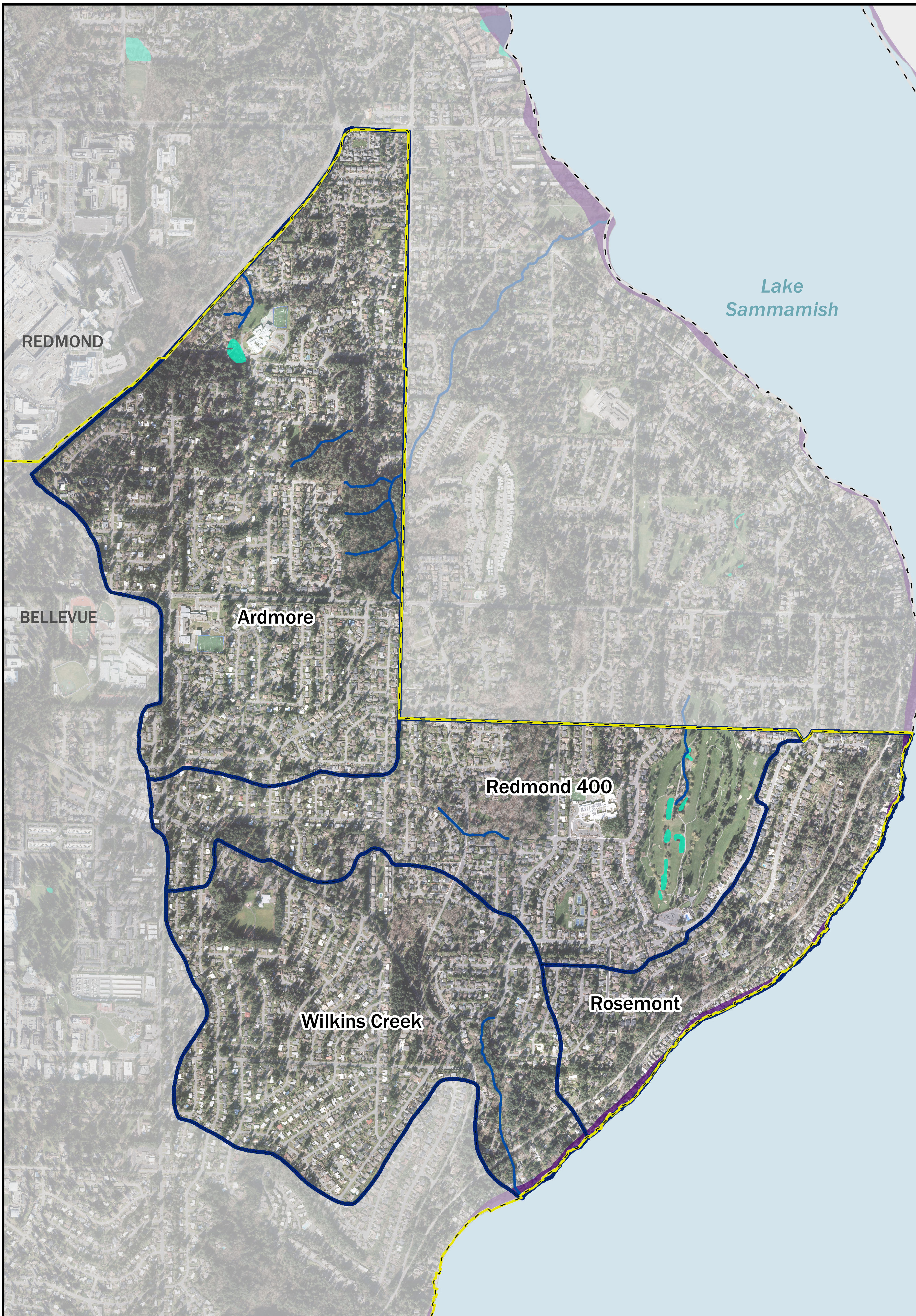


Figure 6. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Surface Water Features.



Legend

Subbasin (City of Bellevue 2020)

Bellevue City Limit (Bellevue 2020)

Other Jurisdictions (King County 2020)

FEMA 100 year floodplain

NWI Wetlands (2020)

Stream (City of Bellevue 2020)

Note: Federal Emergency Management Area (FEMA), National Wetland Inventory (NWI).

Figure 7. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Surface Water Features.

0 500 1,000 2,000 Feet

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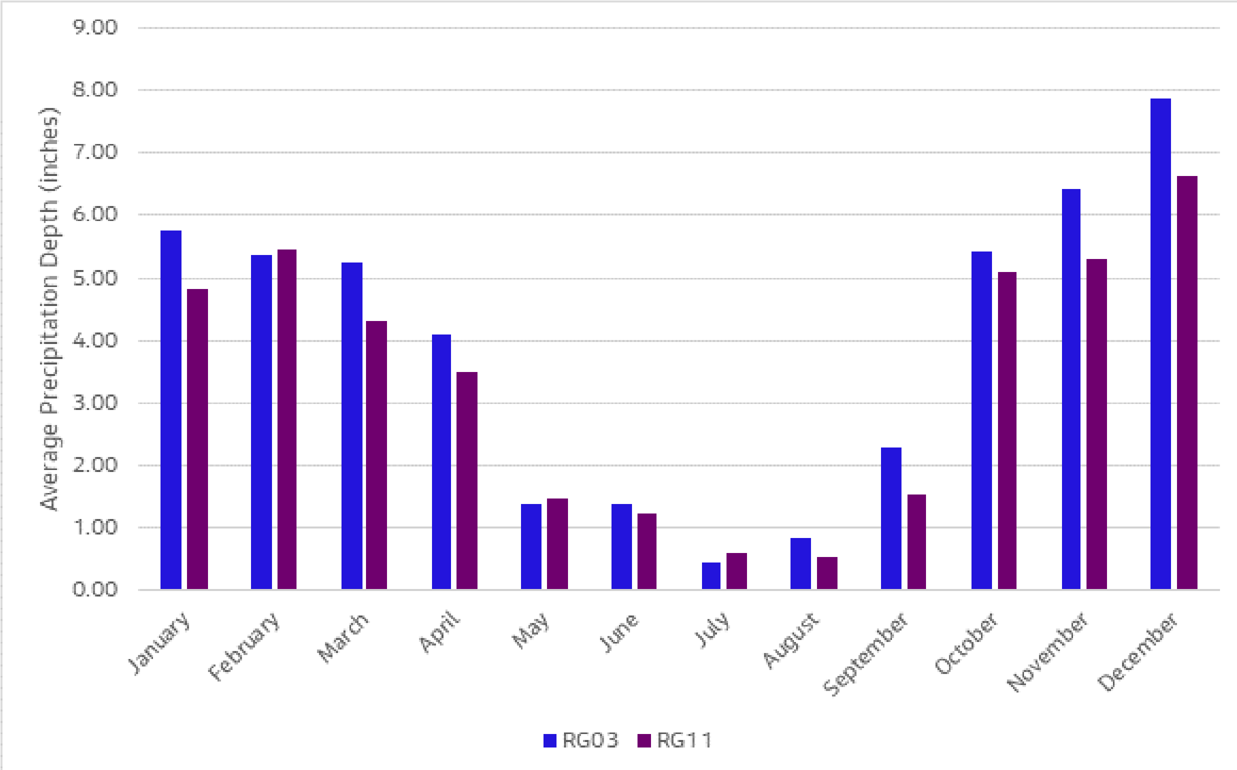


Figure 8. Precipitation Depth by Month in the Lake Sammamish Watershed

2.1.2 Geology and Soils

The regional and local geologic setting has a considerable influence on the physical characteristics of a watershed, such as the watershed area, the geometry of the channel, floodplain, and valley, and how water and sediment move through the watershed and its channels. These physical characteristics in turn influence the responsiveness of a river or stream to changes (whether anthropogenic impacts or attempted restoration efforts) and therefore drive the levels of biological activity that are even possible in a watershed. As illustrated by the conceptual model presented in Figure 2, understanding the relationships between these physical characteristics and the biological functioning in watersheds is important for both the identification of limiting factors as well as the development of opportunities for improvement.

The majority of the Lake Sammamish Watershed is underlain by Fraser-age continental glacial till, glacial outwash, and nearshore sedimentary rocks. The heavily compacted glacial till is a deposit that is generally more resistant to change, thus affording the watershed some resiliency from the full force of the hydrologic changes that would otherwise result from upland urbanization and unmanaged stormwater runoff.

2.1.2.1 Geology

As a part of the Puget Lowland, the Lake Sammamish Watershed has been formed by a long history of tectonic and depositional processes. The geologic episode with the greatest influence on the current landscape was the most recent Fraser Glaciation, which occurred approximately 13,000 to 16,000 years ago. The Lake Sammamish trough was formed by subglacial fluvial erosion (i.e., water flowing in meltwater channels beneath the active glacier), resulting in its north-south trending shape (Bethel 2004). The active, east-west trending Seattle Fault Zone runs through Lake Sammamish (Johnson *et al*. 2016) and encompasses the entire Lake Sammamish Watershed. Uplift caused by thrust along the Seattle Fault Zone exposes bedrock (i.e., the Blakely Formation) in the southern portion of the Vasa Creek Subbasin (McHugh Britton 2013). These geologic events have contributed to the unique features of the Lake Sammamish Watershed, namely many moderate to high gradient streams, confined by steep ravines.

As a result of the aforementioned geological processes, the surface geology of the Lake Sammamish Watershed is primarily characterized by a combination of glacial and post-glacial deposits. This includes three basic geologic units; recent alluvium; semi-consolidated to unconsolidated fluvial, glacial, and marine Pleistocene sediments; and tertiary or older sedimentary and crystalline bedrock (Adolfson Associates, Inc. 2006). Table 1 provides a summary of the percentages of the mapped surface geologic types by subbasin as well as for the City of Bellevue portion of the Lake Sammamish Watershed (USGS 2016).

The Lewis Creek Subbasin is primarily underlain by glacial and post-glacial deposits, with areas of nearshore sedimentary rock beneath the confluence of Lewis Creek and its many tributaries in the central region of the Subbasin (see Figure 9). The northern region of the Vasa Creek Subbasin is mainly composed of glacial outwash, while the southern region is a mix of glacial till and nearshore sedimentary rocks (see Figure 10). Much of Vasa Creek and its eastern tributary have eroded into the glacial deposits, forming gorges and steep side slopes (over 40 percent) (Tetra Tech 2014).

The Ardmore Area/Idylwood Creek Subbasin is underlain mostly by glacial till, with portions of glacial outwash underlying Idylwood Creek and its tributaries within the City (see Figure 12). The Redmond 400 Area and Wilkins Creek Subbasin have similar geologic compositions, primarily a mix of glacial till and glacial outwash; while the Rosemont Area is dominated by glacial outwash and a small inclusion of sedimentary deposits or rock (see Figure 12). Within the North Sammamish Area, the northernmost tributaries to Lake Sammamish are underlain by advance glacial outwash, with remaining area is underlain by glacial outwash and glacial till (Figure 11). The majority of the Phantom Creek Subbasin and Spirit Ridge Area is underlain by glacial outwash (see Figure 11). Like the abutting southern region of the Vasa Creek Subbasin, the South Sammamish Area is predominantly underlain by glacial till, with a large area of nearshore sedimentary rocks (see Figure 10).

2.1.2.2 Soils

As described below, the soils at the surface of the Lake Sammamish Watershed tend to be highly erodible and the soils just below the surface tend to have a low permeability. Table 2 provides a summary of the percentages of different soil types within individual subbasins and areas as well as the City of Bellevue Lake Sammamish Watershed. Figures 13 through 16 show the hydrologic group of the soils with the Lewis Creek Subbasin, Vasa Creek Subbasin, Ardmore Area/Idylwood Creek Subbasin, Redmond 400 Area, Rosemont Area, Wilkins Creek Subbasin, North Sammamish Area, Phantom Creek Subbasin, Spirit Ridge Area, and South Sammamish Area.

Alderwood and Arent (Alderwood material) soils are the predominant soil types found in the Lake Sammamish Watershed, covering 32 and 28 percent of the watershed, respectively. Beausite soils cover an additional 23 percent, while Arent soils (Everett material) cover an additional 12 percent. The remaining two percent of the Lake Sammamish Watershed area is underlain by unclassed/unidentified soils, which are present within the Rosemont Area, Vasa Creek Subbasin, and Phantom Creek Subbasin (beneath Phantom Lake).

Alderwood soils belong to hydrologic soil Group B and consist of moderately deep, moderately well-drained gravelly sandy loams that sit on top of a very slowly permeable layer of consolidated glacial till. Arent soils (Alderwood material or Everett material) consist of soils that have been disturbed through urbanization such that they are no longer classified as Alderwood or Everett (Snyder *et al*. 1973). The Arents (Alderwood material) soils belong to hydrologic soil Group B/D, as they have moderate infiltration potential in a drained condition, and very slow infiltration potential in an undrained/high water table condition. The extents of Arent (Alderwood material) soil have likely expanded with the area's extensive development since the King County Soil Survey took place in 1973. Beausite soils (gravelly sandy loam) belong to hydrologic soil group C and consist of well-drained gravelly sandy loams that form on top of sandstone. The Arents (Everett material) soils are gravelly sandy loam underlain by very gravelly sand and belong to hydrologic soil Group A with high infiltration potential

Hydrologic soil group is a way of characterizing the relative infiltration potential, which is the ability of that soil to accept rainfall instead of that rainfall becoming runoff. Soils are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D), with Group A having the greatest infiltration potential (low runoff potential) and Group D having the lowest potential for infiltration (highest runoff potential). If a dual hydrologic group is assigned, the first letter is for drained areas and the second is for undrained areas. Only the soils that are in their natural condition in group D are assigned to dual classes. (United States Department of Agriculture, Natural Resources Conservation Service website, accessed 7/2/21)

Both Alderwood and Beausite soils are found in glaciated foothills of Western Washington with rolling to very steep slopes (Snyder *et al.* 1973). Alderwood and Beausite soils have severe erosion potential for slopes greater than 15 percent. As such, the steep narrow ravines in the Lake Sammamish Watershed underlain by Alderwood and Beausite soils (for example those in the North Sammamish Area and Lewis Creek Subbasin) have a naturally severe potential for erosion. This severe erosion potential is easily exacerbated by increased delivery of concentrated flows and stormwater runoff leading to increased rates of upper slope instability, mass-wasting, channel incision, and the delivery of fine sediment to streams and subsequent transport to downstream depositional reaches in the watershed.

The Lewis Creek Subbasin is primarily underlain Group B and C soils, with an area of Group A soils along a portion of Lewis Creek that runs under Interstate 90 (I-90). Thus, the majority of Lewis Creek Subbasin has moderate to slow relative infiltration potential, aside from aforementioned narrow area of soils with high infiltration potential adjacent to Lewis Creek. See Figure 13 for a representation of the hydrologic group of the soils within the Lewis Creek Subbasin.

Within the Vasa Creek Subbasin, the northern region is primarily composed of hydrologic Group A soils, with a mix of hydrologic Group B, B/D, and C soils as you travel south. As such, this subbasin has higher infiltration potential in the north and moderate to slow relative infiltration potential across the majority of its area. The South Sammamish Area is underlain by a mix of soils with slow to moderate relative infiltration potential (Group C and B soils, respectively). See Figure 14 for a representation of the hydrologic group of the soils within the Vasa Creek Subbasin and South Sammamish Area.

The North Sammamish Area is mostly underlain by hydrologic Group B/D soils, with hydrologic Group B soils underlying the northernmost Lake Sammamish tributaries, and hydrologic Group A soils abutting Lake Sammamish. This means that in the North Sammamish Area, soils are better drained adjacent to Lake Sammamish. The Spirit Ridge Area has similar soil characteristics to the North Sammamish Area, with higher infiltration soils abutting Lake Sammamish. The Phantom Creek Subbasin encompasses mostly hydrologic Group B/D soils, with inclusions of hydrologic Group A and C soils south of Phantom Lake. See Figure 15 for a representation of the hydrologic group of the soils within the North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area.

The Ardmore Area/Idylwood Subbasin consists primarily of a mix of hydrologic Group B and B/D soils, exhibiting moderate infiltration potential, except in undrained/high water table condition areas, which have high runoff potential. The central region of the Redmond 400 Area is underlain by well drained hydrologic Group A soils, and surrounded by less well drained hydrologic Group B, B/D, and C soils. Similarly, the Wilkins Creek Subbasin (which abuts the Redmond 400 Area) is well drained in the east and moderately well drained in the west. The Rosemont Area is almost entirely underlain by moderately drained Group B soils. See Figure 12 for a representation of the hydrologic group of the soils within the Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin.

Overall, the Lake Sammamish Watershed soil surface is composed of highly erodible surface soils, with lower permeable soils below the surface. These factors, in combination with very low permeability of the glacial till geology, often limits the effectiveness of infiltration-focused stormwater management techniques in the Watershed. However, this is not uniformly the case in the Lake Sammamish Watershed as there are sizeable areas within the Vasa Creek Subbasin, North Sammamish Area, Phantom Creek Subbasin, Spirit Ridge Area, Wilkins Creek Subbasin, and Redmond 400 Area which have high capacity for infiltration.

Table 1. Surface Geology in the City of Bellevue Portion of the Lake Sammamish Watershed

Subbasin	Geologic Map Unit	Geologic Unit Age	Geologic Type	Geologic Description	Area (Acres)	Subbasin Area (Acres)	Percent of Subbasin (%)	Percent of Kelsey Creek Watershed (%)
Lewis Creek	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	733.4	997.9	73%	14%
Lewis Creek	OEn	Oligocene-Eocene	nearshore sedimentary rocks	Tertiary sedimentary rocks and deposits	264.5	997.9	27%	5%
Vasa Creek	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	620.6	1266.9	49%	12%
Vasa Creek	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	485.4	1266.9	38%	9%
Vasa Creek	OEn	Oligocene-Eocene	nearshore sedimentary rocks	Tertiary sedimentary rocks and deposits	100.3	1266.9	8%	2%
Vasa Creek	Qa	Quaternary	alluvium	Quaternary alluvium	37.5	1266.9	3%	1%
Vasa Creek	Mvc(2)	Miocene, middle to upper	volcaniclastic deposits or rocks	Tertiary fragmental volcanic rocks and deposits (includes lahars)	23.0	1266.9	2%	0%
Vasa Creek	wtr	Holocene	Water	Water	0.1	1266.9	0%	0%
Ardmore/ Idylwood	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	395.4	450.5	88%	8%
Ardmore/ Idylwood	Qga	Pleistocene	Advance continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	34.2	450.5	8%	1%
Ardmore/ Idylwood	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	20.9	450.5	5%	0%
Redmond 400 Area	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	193.9	281.9	69%	4%
Redmond 400 Area	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	88.0	281.9	31%	2%
Rosemont Area	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	90.4	150.2	60%	2%
Rosemont Area	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	36.7	150.2	24%	1%
Rosemont Area	Qc	Quaternary	continental sedimentary deposits or rocks	Quaternary - continental sedimentary deposits or rocks	14.1	150.2	9%	0%
Rosemont Area	Qga(t)	Pleistocene	Pleistocene continental glacial drift	Advance continental glacial outwash, Fraser-age	5.7	150.2	4%	0%
Rosemont Area	wtr	Holocene	Water	Water	3.2	150.2	2%	0%
Wilkins Creek	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	166.1	305.1	54%	3%
Wilkins Creek	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	115.6	305.1	38%	2%
Wilkins Creek	Qga	Pleistocene	Advance continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	23.0	305.1	8%	0%
Wilkins Creek	wtr	Holocene	Water	Water	0.3	305.1	0%	0%
North Sammamish	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	251.9	618.5	41%	5%
North Sammamish	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	192.6	618.5	31%	4%
North Sammamish	Qga	Pleistocene	Advance continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	171.3	618.5	28%	3%
North Sammamish	wtr	Holocene	Water	Water	2.8	618.5	0%	0%
Phantom Creek	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	415.8	530.0	78%	8%
Phantom Creek	wtr	Holocene	Water	Water	56.2	530.0	11%	1%

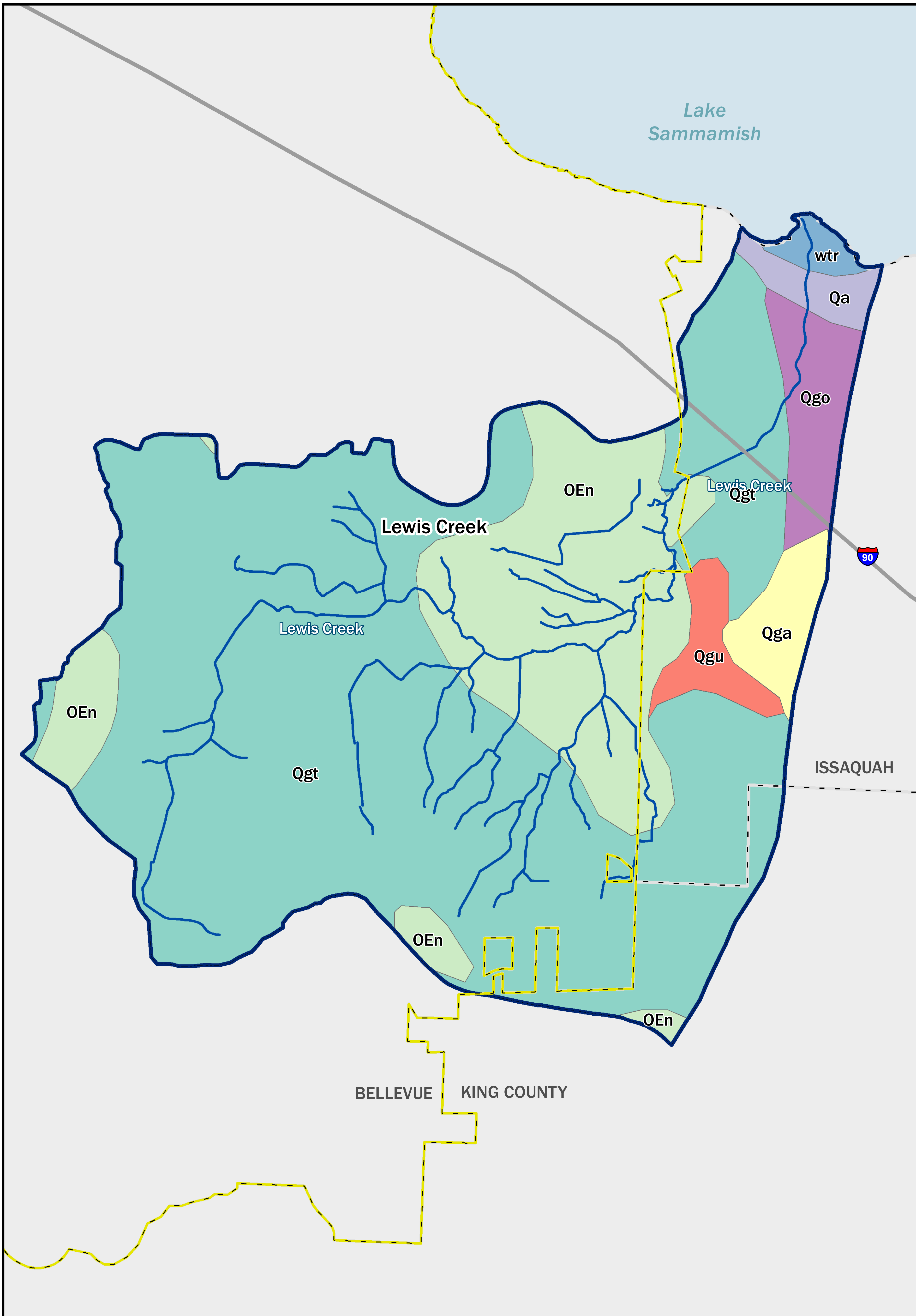
Subbasin	Geologic Map Unit	Geologic Unit Age	Geologic Type	Geologic Description	Area (Acres)	Subbasin Area (Acres)	Percent of Subbasin (%)	Percent of Kelsey Creek Watershed (%)
Phantom Creek	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	41.2	530.0	8%	1%
Phantom Creek	Qga	Pleistocene	Advance continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	16.8	530.0	3%	0%
Spirit Ridge Area	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	186.5	223.2	84%	4%
Spirit Ridge Area	Qga	Pleistocene	Advance continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	35.0	223.2	16%	1%
Spirit Ridge Area	wtr	Holocene	Water	Water	1.8	223.2	1%	0%
South Sammamish	Qgt	Pleistocene	Continental glacial till, Fraser-age	Pleistocene continental glacial till	302.4	419.4	72%	6%
South Sammamish	OEn	Oligocene-Eocene	nearshore sedimentary rocks	Tertiary sedimentary rocks and deposits	71.8	419.4	17%	1%
South Sammamish	Qgo	Pleistocene	Continental glacial outwash, Fraser-age	Pleistocene continental glacial drift	36.7	419.4	9%	1%
South Sammamish	Qa	Quaternary	alluvium	Quaternary alluvium	8.1	419.4	2%	0%
South Sammamish	wtr	Holocene	Water	Water	0.3	419.4	0%	0%

SOURCE 100k USGS: Washington Division of Geology and Earth Resources, 2016, Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010

Table 2. Soils in the City of Bellevue Portion of the Lake Sammamish Watershed

Soil Classification	Relative Infiltration Potential	Lewis Creek	Vasa Creek	Ardmore/ Idylwood	Redmond 400 Area	Rosemont Area	Wilkins Creek	North Sammamish	Phantom Creek	Spirit Ridge Area	South Sammamish	Lake Sammamish Tributaries Watershed
Arents, Everett material Everett gravelly sandy loam, 0 to 5 percent slopes Everett gravelly sandy loam, 15 to 30 percent slopes Everett gravelly sandy loam, 5 to 15 percent slopes Indianola loamy fine sand, 4 to 15 percent slopes Ragnar-Indianola association, moderately steep Ragnar-Indianola association, sloping	High	0%	23%	1%	19%	9%	29%	26%	19%	49%	0%	16%
Norma sandy loam Orcas peat	High (drained condition); Very low (undrained/high water table condition)		1%									0%
Alderwood and Kitsap soils, very steep Alderwood gravelly sandy loam, 0 to 8 percent slopes Alderwood gravelly sandy loam, 15 to 30 percent slopes Alderwood gravelly sandy loam, 8 to 15 percent slopes Everett-Alderwood gravelly sandy loams, 6 to 15 percent slopes	Moderate	35%	40%	50%	25%	91%	11%	17%	1%		59%	32%
Arents, Alderwood material, 0 to 6 percent slopes Arents, Alderwood material, 6 to 15 percent slopes Seattle muck Shalcar muck Tukwila muck	Moderate (drained condition); Very slow (undrained/high water table condition)		16%	48%	23%		61%	56%	59%	50%		28%
Beausite gravelly sandy loam, 15 to 30 percent slopes Beausite gravelly sandy loam, 6 to 15 percent slopes Kitsap silt loam, 15 to 30 percent slopes Kitsap silt loam, 2 to 8 percent slopes	Slow	65%	19%	2%	31%				8%		38%	23%
Bellingham silt loam Snohomish silt loam					2%						3%	0%
Pits Urban land Water	NA		1%			1%	0%	0%	12%	0%	0%	2%
N/A	N/A	997.9	1266.9	450.5	281.9	150.2	305.1	618.5	530.0	223.2	419.4	5243.5

SOURCE: Bellevue Soils, retrieved City of Bellevue GIS portal 2020



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

USGS Geology 100k (2020)

- Qgu:glacial drift, undivided:Pleistocene
- OEn, Nearshore sedimentary rocks, Oligocene-Eocene
- Qa, Alluvium, Quaternary
- Qga, Advance continental glacial outwash Fraser-age, Pleistocene
- Qgt, Continental glacial till Fraser-age, Pleistocene
- Qgo, Continental glacial outwash Fraser-age, Pleistocene
- Wtr, Water, Present

Note: United States Geological Survey (USGS).

Figure 9. Lewis Creek Subbasin Geology.

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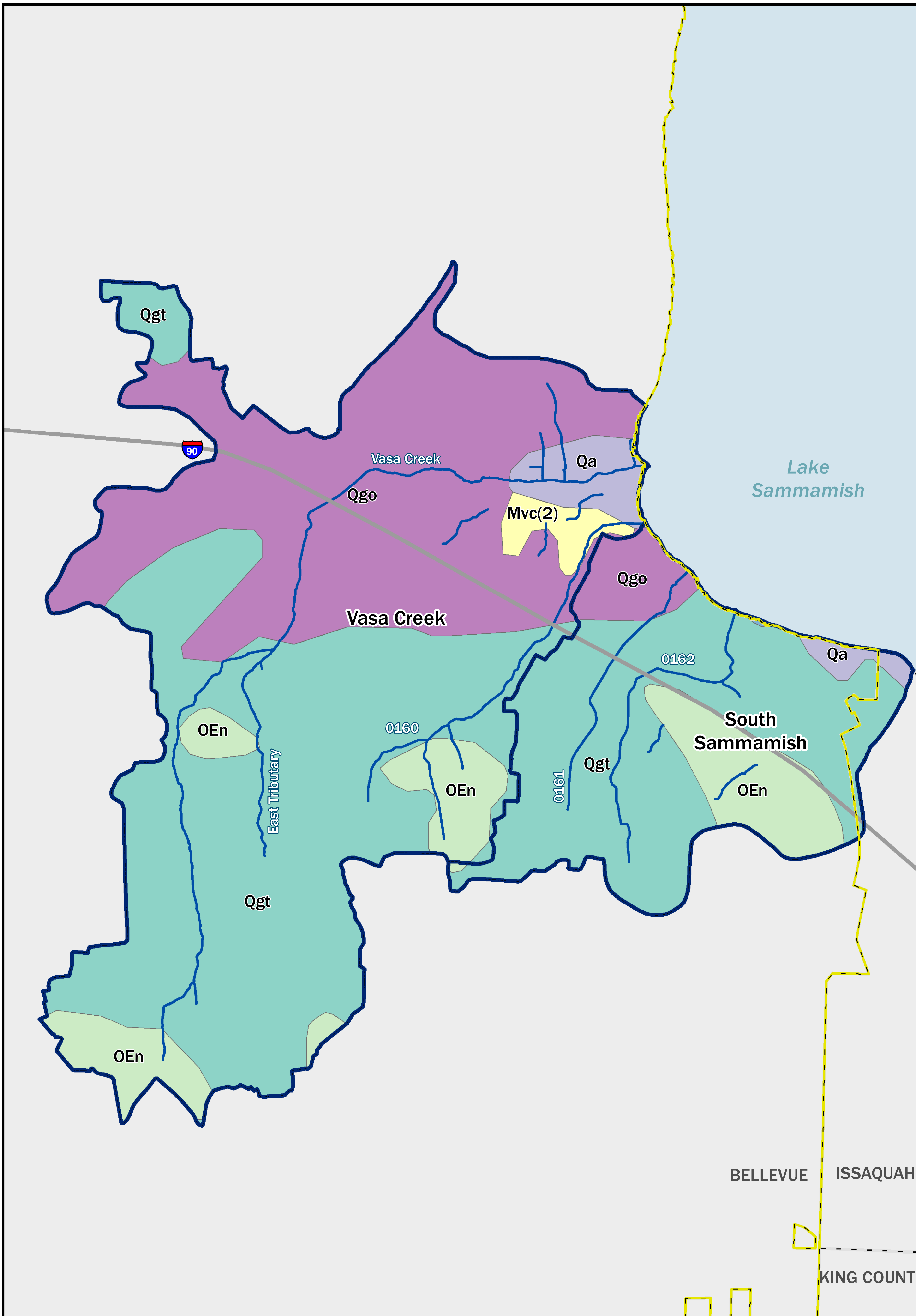

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Subbasin (City of Bellevue 2020)

Bellevue City Limit (Bellevue 2020)

Other Jurisdictions (King County 2020)

Stream (City of Bellevue 2020)

Highway (City of Bellevue 2020)

USGS Geology 100k (2020)

- Mvc(2):volcaniclastic deposits or rocks:Miocene, middle to upper
- OEn, Nearshore sedimentary rocks, Oligocene-Eocene
- Qa, Alluvium, Quaternary
- Qgt, Continental glacial till Fraser-age, Pleistocene
- Qgo, Continental glacial outwash Fraser-age, Pleistocene
- Wtr, Water, Present

Note: United States Geological Survey (USGS).

Figure 10. Vasa Creek Subbasin and South Sammamish Area Geology.

N

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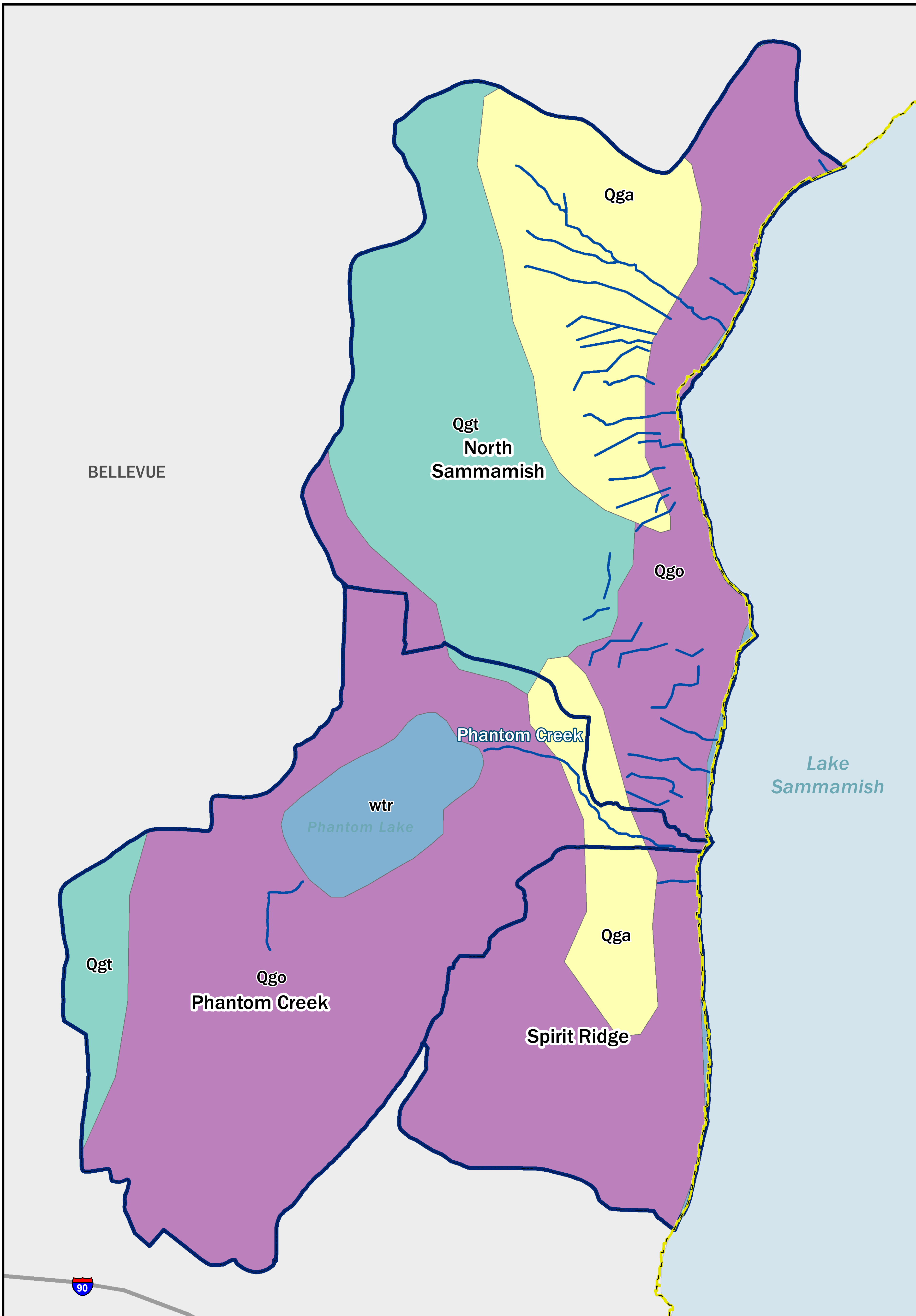

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- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

USGS Geology 100k (2020)

- Qga, Advance continental glacial outwash Fraser-age, Pleistocene
- Qgt, Continental glacial till Fraser-age, Pleistocene
- Qgo, Continental glacial outwash Fraser-age, Pleistocene
- Wtr, Water, Present

Note: United States Geological Survey (USGS).

Figure 11. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Geology.

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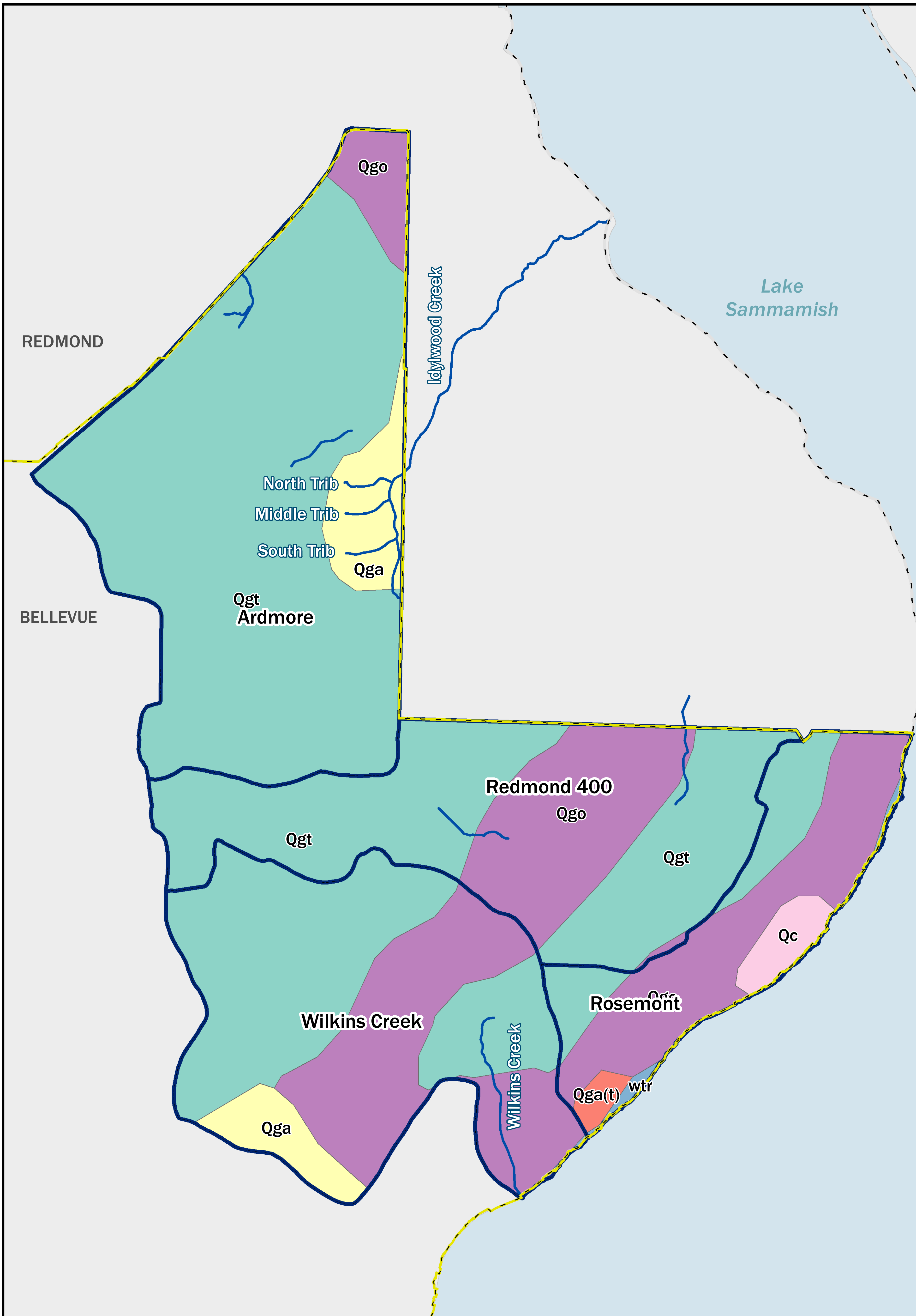

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Subbasin (City of Bellevue 2020)

Bellevue City Limit (Bellevue 2020)

Other Jurisdictions (King County 2020)

Stream (City of Bellevue 2020)

USGS Geology 100k (2020)

Qc:continental sedimentary deposits or rocks:Quaternary

Qga(t):advance continental glacial outwash, Fraser-age:Pleistocene

Qga, Advance continental glacial outwash Fraser-age, Pleistocene

Qgt, Continental glacial till Fraser-age, Pleistocene

Qgo, Continental glacial outwash Fraser-age, Pleistocene

Wtr, Water, Present

Note: United States Geological Survey (USGS).

Figure 12. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Geology.

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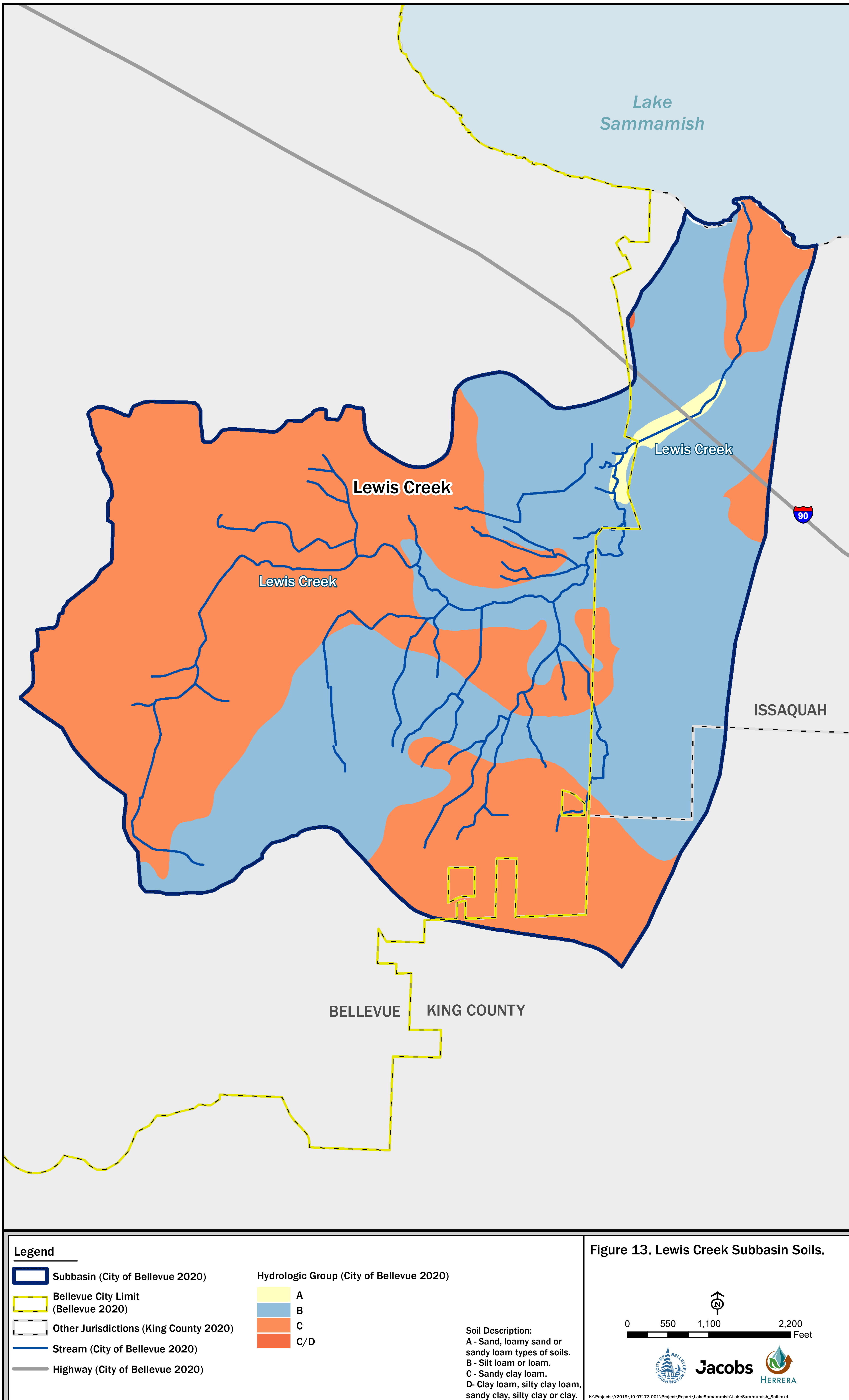
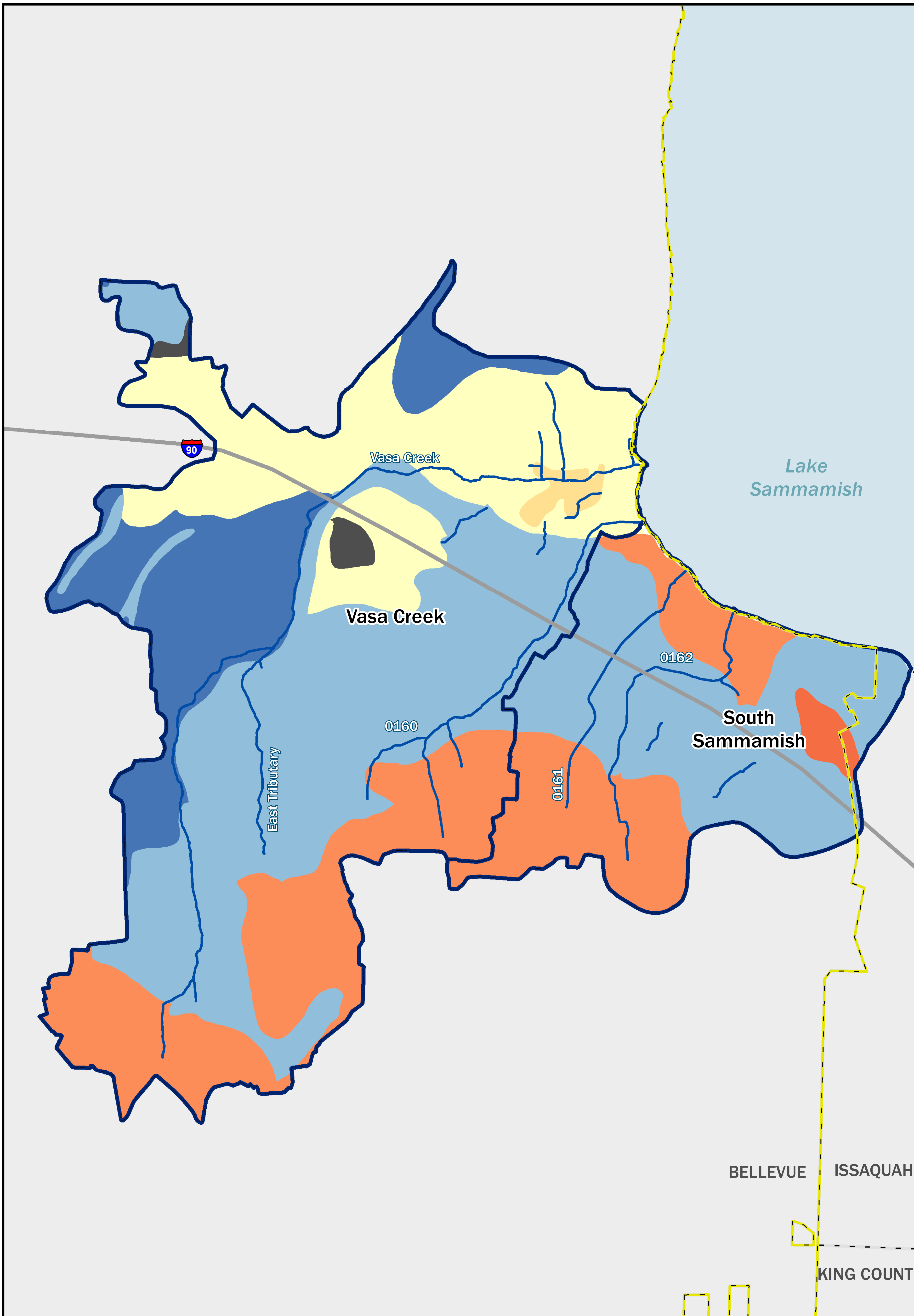


Figure 13. Lewis Creek Subbasin Soils.



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- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

Hydrologic Group (City of Bellevue 2020)

- Not identified (high impervious)
- A
- A/D
- B
- B/D
- C
- C/D

Soil Description:
A - Sand, loamy sand or sandy loam types of soils.
B - Silt loam or loam.
C - Sandy clay loam.
D- Clay loam, silty clay loam, sandy clay, silty clay or clay.

Figure 14. Vasa Creek Subbasin and South Sammamish Area Soils.

N

0 650 1,300 2,600 Feet

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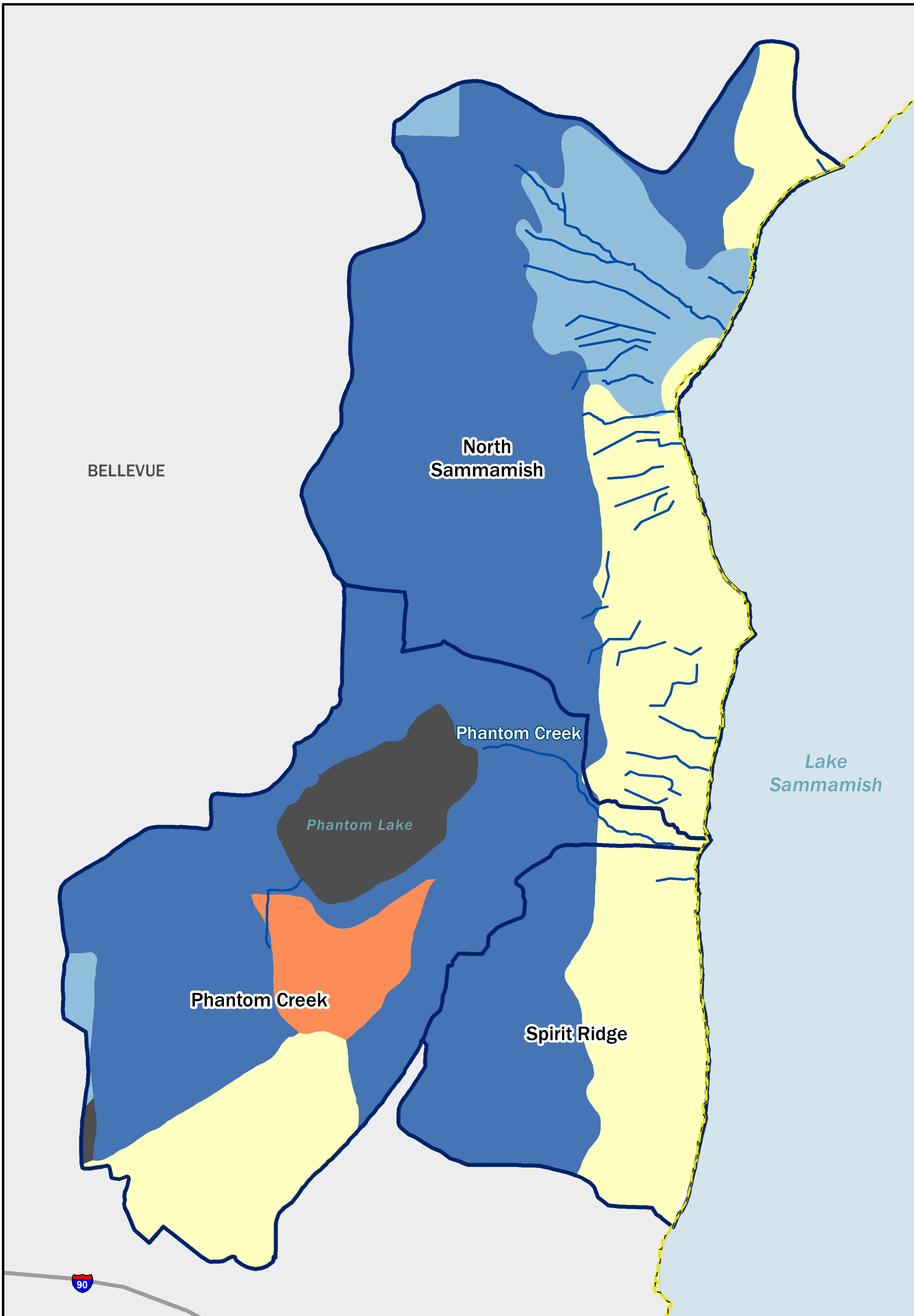

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- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

Hydrologic Group (City of Bellevue 2020)

- Not identified (high impervious)
- A
- B
- B/D
- C

Soil Description:
A - Sand, loamy sand or sandy loam types of soils.
B - Silt loam or loam.
C - Sandy clay loam.
D- Clay loam, silty clay loam, sandy clay, silty clay or clay.

Figure 15. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Soils.

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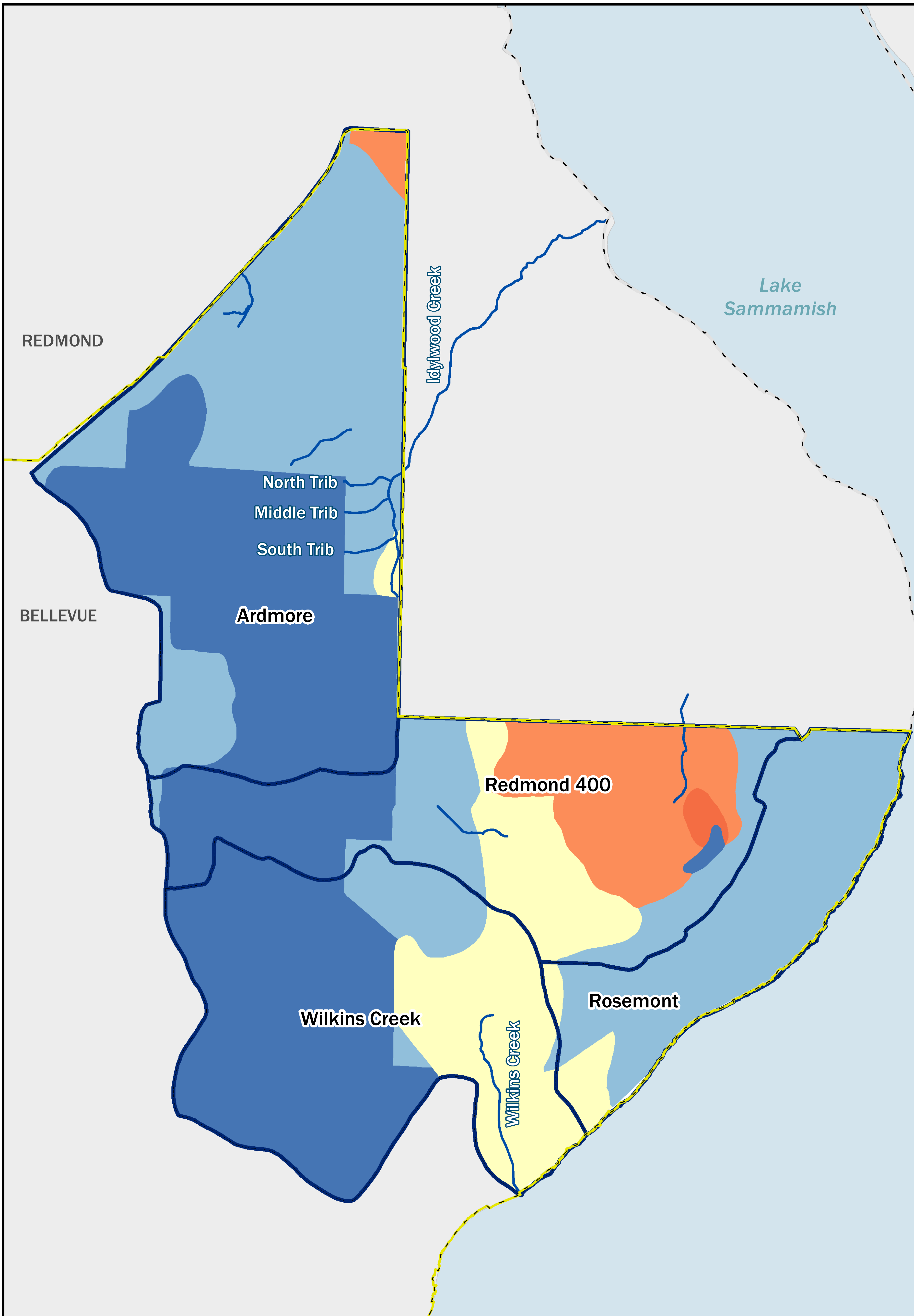

Legend

Subbasin (City of Bellevue 2020)
Bellevue City Limit (Bellevue 2020)
Other Jurisdictions (King County 2020)
Stream (City of Bellevue 2020)

Hydrologic Group (City of Bellevue 2020)

A
B
B/D
C
C/D

Soil Description:
A - Sand, loamy sand or sandy loam types of soils.
B - Silt loam or loam.
C - Sandy clay loam.
D- Clay loam, silty clay loam, sandy clay, silty clay or clay.

Figure 16. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Soils.

0 500 1,000 2,000 Feet

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2.1.3 Topography and Geomorphology

The topography within the City of Bellevue's portion of the Lake Sammamish Watershed is shown in Figure 17. Topography slopes generally east and northeast towards Lake Sammamish, with many high gradient streams confined by ravines and steep slopes (greater than 40 percent). The City's Open Streams Condition Assessment showed that of the subbasins surveyed, the six with the highest stream gradients in the City are within the Lake Sammamish Watershed (See Appendix B for further detail). The steep and urbanized nature of the Lake Sammamish Watershed contributes to a lack of wetland complexes and wide floodplains relative to other City watersheds. In many cases streams are incised and enter Lake Sammamish via piped conveyance.

Multiple ridges and large hills exist within the Lake Sammamish Watershed. In the Wilkins Creek Subbasin (ranging in elevation from 31 to 446 feet), Wilkins Creek originates near the top of the north-to-south till ridge which separates Lake Washington and Lake Sammamish. A ridge within the Spirit Ridge Area (with a high point of 343 feet), north of Vasa Creek, exhibits a subtle south and southeast slope which helps delineate the Phantom Creek Subbasin (ranging in elevation from 31 to 426 feet) and Spirit Ridge Area (Bellevue 2021a). Within portions of the South Sammamish Area and Lewis Creek Subbasin, there is a hill, with a high point of 747 feet, that slopes towards Lake Sammamish, conveying water towards Lewis Creek and its tributaries and the lake itself (Bellevue 2021a). The most significant tributary to Lake Sammamish is Lewis Creek, with headwaters originating near Cougar Mountain (Bellevue 2001). The headwater portion of Lewis Creek flows along the top of a flat hill, through low gradient ditches in pastureland, while most of its tributaries are steep, dynamic channels with gradients exceeding 20 percent (Bellevue 2001).

Along with local topography, streams in the Lake Sammamish Watershed have been highly affected by urbanization, including altered riparian vegetation, high-flow bypasses, dams, detention facilities, ditching and confinement by roadways, and long stretches that are piped underground. Dense residential development surrounding the majority of the Lake Sammamish shoreline has resulted in the installation of bulkheads and other shoreline armoring to reduce erosion potential along the lakeshore.

Due to the steep topography found in some areas of the Lake Sammamish Watershed, many of the tributaries to Lake Sammamish have limited floodplains. Where creeks are piped, sediment transport is forced. Areas of channel incision and streambank erosion are a source of sediment. Increasing sedimentation is an issue in many of the subbasins throughout the City, including portions of the Phantom Creek Subbasin, North Sammamish Area, and Ardmore Area/Idylwood Creek Subbasin (OCI 2019a, OCI 2019b, King County 2016b, King County 2016d). Further details on the relationship of sedimentation to contaminant and transport of large woody material are included in later sections of this report.

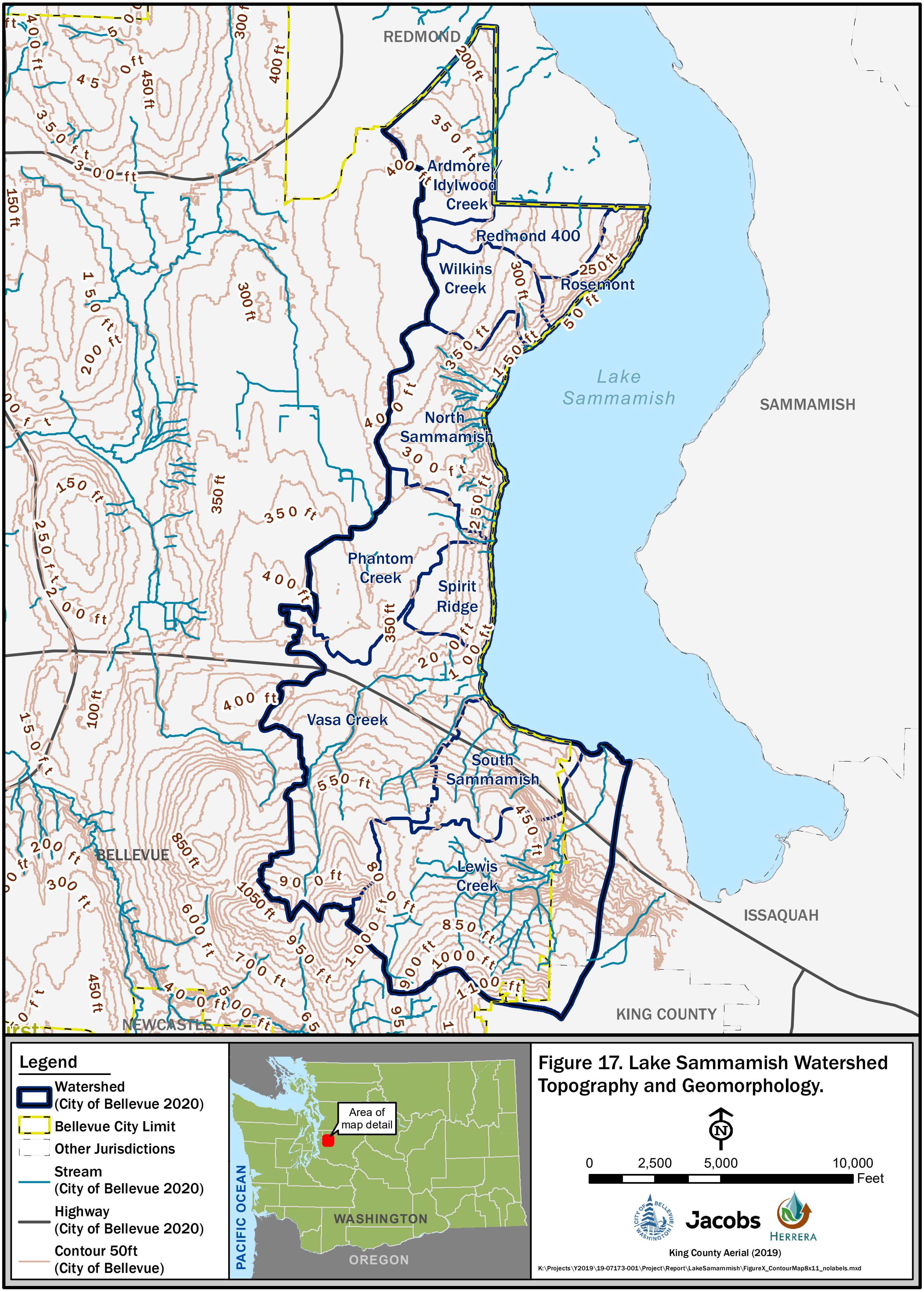


Figure 17. Lake Sammamish Watershed Topography and Geomorphology.

2.1.4 Surface Water Features

The presence, type, and distribution of surface water features are important factors that can influence the severity of impacts from urbanization described in the conceptual model (Figure 2). For example, wetlands play an important role in storing stormwater from impervious surfaces that might otherwise flow directly to streams. Natural processes provided by wetlands are effective at storing sediments, nutrients, and many common pollutants present in stormwater runoff.

The Lake Sammamish Watershed is comprised of 10 subbasins and areas that drain to Lake Sammamish. As shown in Figures 4 and 5, Lewis Creek and Vasa Creek are the two largest drainage features in the Lake Sammamish Watershed. The mainstem of Lewis Creek flows approximately 3.2 miles from its present-day headwaters southeast of Lewis Creek Park to Lake Sammamish; the mainstem of Vasa Creek flows approximately 2.7 miles from its headwaters at Saddleback Park to Lake Sammamish. The lesser tributaries to Lake Sammamish, as well as the majority of the remaining streams within the watershed, also flow to Lake Sammamish. In addition to fluvial channels and tributaries, surface water features in the Lake Sammamish Watershed include floodplains, wetlands, and lakes. However, much of the Lake Sammamish Watershed is characterized by urbanized areas that do not support broad floodplains, pollute existing wetlands, and often limit the size and health of wetlands within the watershed.

Channel incision exacerbated by upland hydrologic changes coupled with streambank armoring and development that confine alluvial processes have separated the channels within the watershed from their floodplains and reduced the effectiveness of the floodplain's ability to attenuate peak flows, store nutrients, attenuate pollutants, and support the channel complexity needed for aquatic species to thrive.

Human intervention in proximate waterbodies has affected the Lake Sammamish Watershed. In the late 1800s, the outlet of Phantom Lake was diverted to Lake Sammamish, effectively reducing flow to Kelsey Creek, and creating a new subbasin in the Lake Sammamish Watershed. This change in outlet location lowered the level of Phantom Lake, thereby reducing its footprint and draining some of the surrounding wetlands which were subsequently converted to agricultural land.

Figures 4-7 depict the FEMA-mapped floodplains and wetlands present in the Lake Sammamish Watershed. Note that Vasa Creek and Phantom Lake have mapped FEMA floodplains but none of the other creeks in the City that drain to Lake Sammamish have mapped floodplains. Figures 4-7 do show where mapped floodplains exist along the shore of Lake Sammamish. The geology depicted in Figures 9-12 (predominately till and outwash) and the topography shown in Figure 17 suggest that the floodplain widths along the creek are severely limited when compared to natural, pre-development conditions.

Figures 4-7 show the wetlands that have been both delineated and mapped by the National Wetland Inventory (NWI, USFWS 2021) as well as King County (King County 2021). In the Lake Sammamish Watershed, there are 74 acres of wetlands, equating to 1.4 percent of the total watershed area within the City of Bellevue (Table 3). Lewis Creek Park and Phantom Lake are the two largest wetland areas in the Lake Sammamish Watershed, making up most of the watershed's wetlands (USFWS 2021). These are described here:

- Lewis Creek Park is located in the Lewis Creek Subbasin near the headwaters of Lewis Creek. The park is owned and operated by the City of Bellevue and is located at 5808 Lakemont Boulevard. The park provides a community facilities and programming, such as self-guided trails, informational kiosks, an interpretive exhibit, ranger-led naturalist programs and interpretation, and visitor center that all act as points for education and outreach about the Lake Sammamish Watershed. Lewis Creek Park has 4.1 acres of freshwater emergent wetland, and 1.5 acres of forested/shrub wetland (NWI 2021).
- Phantom Lake is located in the Phantom Creek Subbasin approximately 0.5 miles away from Lake Sammamish. Around the perimeter of Phantom Lake, there are several small emergent and

forested/shrub wetlands. Some of the wetlands around the perimeter of Phantom Lake are within the Lake Sammamish Watershed, while others are connected to the Greater Kelsey Creek Watershed. Historically, all of Phantom Lake and its associated wetlands were part of the Greater Kelsey Creek Watershed.

Table 3. Wetlands in the City of Bellevue Portion of the Lake Sammamish Watershed by Subbasin / Area

Subbasin / Area	Wetland Area (acres)	NWI Wetlands AND Sensitive Area Ordinance King County Wetlands 2016 - percent
Lewis Creek	17.9	1.8%
Vasa Creek	17.7	1.4%
Ardmore/Idylwood	2.6	0.6%
Redmond 400 Area	1.7	0.6%
Rosemont Area	1.4	0.9%
Wilkins Creek	0.9	0.3%
North Sammamish	5.9	1.0%
Phantom Creek	20.3	3.8%
Spirit Ridge Area	0.2	0.1%
South Sammamish	5.4	1.3%
Lake Sammamish Watershed (within the City of Bellevue)	74.0	1.4%

2.1.5 Groundwater

In areas that have not been disturbed by urbanization, very little precipitation contributes to direct surface flow. Precipitation typically infiltrates into the surface soils until meeting the low permeability Vashon till layer below. Groundwater accumulates above this impermeable layer and flows laterally, either emerging as seeps or springs or interacting with the hyporheic flow associated with stream channels. City staff have observed perennial seeps and springs in the Wilkins Creek Subbasin, Rosemont Area, and North Sammamish Area (Bellevue 2021c). Rainfall that does not flow laterally through the soils can slowly penetrate to deeper groundwater aquifers before eventually discharging at surface openings into the stream channel.

2.1.6 Wildlife and Human Interaction within the Lake Sammamish Watershed

2.1.6.1 Beaver Activity

Many of the streams throughout the watershed that feature wetlands and riparian areas also host piped conveyance and detention facilities. These conditions are attractive to wildlife, including beavers. Beaver activity has the potential to cause destructive flooding if it is not properly managed. While beaver activity in certain areas may have negative effects for people, beavers can restore and enhance habitat with significant benefits for fish and wildlife. Beaver activity can reduce water velocities, increase sediment and stormwater retention, increase habitat complexity, and increase water depths (for example, behind beaver dams) that results in cooler stream temperatures.

Most of the streams in the Lake Sammamish Watershed tend to be steep without large wetland complexes. Therefore, beaver activity in the Lake Sammamish Watershed has been limited to a few locations at or near road crossings or piped conveyance near the stream outlets to Lake Sammamish.

Because of all the potential benefits and negative impacts of beaver activity depending on location of the beaver activity, the City is working towards a Beaver Management Plan. This Beaver Management Plan will identify locations to attract beaver activity to maximize habitat benefits that are the result of beaver activity and will identify locations to discourage beaver activity. The Beaver Management Plan will work in concert with the City's Beaver Maintenance Manual (currently being revised).

2.1.6.2 Human Interaction within the Lake Sammamish Watershed

Like many communities in King County, the City is experiencing a large growth in population that contributes to environmental stressors. As the City becomes more urban, it is important to recognize the impact of human activity on the City's portion of the Lake Sammamish Watershed. Unauthorized encampments, recreational use of riparian areas, and unremoved pet waste are a few examples of environmental stressors that have the potential to negatively impact water quality.

Pet waste, discarded needles, litter, illegal dumping, and other pollutants decrease the quality and safety of the water in the City's portion of the Lake Sammamish Watershed. Despite current enforcement approaches, threats to public health and safety were observed proximate to streams in the Ardmore Area/Idylwood Creek Subbasin, the Phantom Creek Subbasin, the Vasa Creek Subbasin, and the South Sammamish Area. Because of the relative steepness of the streams in the Lake Sammamish Watershed, 'social trails' (trails that are the result of use, rather than through planned or engineered means) are often located directly adjacent the streams, resulting in streambank erosion. There are areas of the East Tributary to Vasa Creek that were historically an old dump. Appendix B documents stream impacts from human activity observed during the City's OSCA surveys. Additional water quality issues are discussed in Section 2.3.2.

2.2 Built Infrastructure

Existing conditions are summarized below for the following built infrastructure attributes: land cover and land use, and stormwater and non-stormwater infrastructure.

2.2.1 Land Cover and Land Use

The land cover in the Lake Sammamish Watershed is atypical of urban watersheds in that urban tree canopy and impervious surfaces have nearly equal land coverage. Existing land cover in the Lake Sammamish Watershed is predominantly impervious surfaces and urban tree canopy (both at 38 percent), and 17 percent non-canopy vegetation (Bellevue 2013, 2017) (Table 4). Bare soil, scrub/shrub, and water surface together comprise less than 7 percent of total land cover. Notably, the Lewis Creek Subbasin, Rosemont Area, and South Sammamish Area all have greater amounts of urban tree canopy land cover than impervious surface cover. The subbasins and areas within the Lake Sammamish Watershed have noticeably similar land cover characteristics, when compared to the wider range of subbasins exhibited by other watersheds within the City.

Figures 18-21 show the land cover and tree canopy of the Lewis Creek Subbasin; Vasa Creek Subbasin and South Sammamish Area; North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area, Ardmore Area/Idylwood Subbasin, Redmond 400 Area, Wilkins Creek Subbasin, and Rosemont Area, respectively.

Table 4. Land Cover in the City of Bellevue Portion of the Lake Sammamish Watershed

Subbasin	Bare Soil and Dry Vegetation (%)	Impervious (%)	Non-Canopy Vegetation (%)	Scrub/Shrub (%)	Urban Tree Canopy (%)	Water (%)
Lewis Creek	2%	30%	19%	0%	48%	0%
Vasa Creek	5%	39%	17%	0%	38%	0%
Ardmore Area/Idylwood Creek	8%	45%	15%	0%	31%	0%
Redmond 400 Area	11%	42%	21%	0%	26%	0%
Rosemont Area	7%	33%	18%	0%	42%	0%
Wilkins Creek	12%	44%	15%	0%	29%	0%
North Sammamish	7%	36%	15%	0%	42%	0%
Phantom Creek	4%	38%	14%	1%	30%	12%
Spirit Ridge Area	6%	44%	18%	0%	33%	0%
South Sammamish	5%	35%	20%	1%	40%	0%
Lake Sammamish Watershed within the City of Bellevue	6%	38%	17%	0%	38%	1%

As shown in Figures 22-25 (and Table 5), the land use of the subbasins of the Lake Sammamish Watershed reflects land cover. The predominant land use type is single family residential (84 percent), followed by park space (8 percent), commercial/office (4 percent), and multi-family residential (2 percent). All other land use categories, account for 1 percent or less of the total land use for the Watershed. The areas with developed land use types (e.g., commercial, industrial, mixed use, and single- or multi-family residential) within the Lake Sammamish Watershed include approximately 135 miles of streets (mostly local access streets). Highways, streets, industrial, and commercial land use have higher pollutant loading compared to residential land usage and parks.

As the second most prevalent land use type in the Watershed, park space correlates with the most concentrated urban tree canopy land cover present within the riparian corridors of the Lake Sammamish Watershed. These park areas include Lewis Creek Park, Lakemont Community Park, Weowna Park, Ardmore Park, and several smaller City parks, as well as privately owned parks and natural areas. Publicly-owned land (including parks and land owned by the City’s Utilities Department) represent site opportunities to investment in stream health. When individual investments are developed in future phases of the WMP, sites on publicly-owned land will be evaluated first as a way to provide benefits for the least cost.

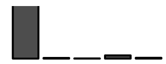
Table 5. Land Use in the City of Bellevue Portion of the Lake Sammamish Watershed

Subbasin	Commercial/ Office (%)	Highway (%)	Industrial (%)	Mixed-use (%)	Multi-Family (%)	Park (%)	Single-family (%)	Total (ac)
Lewis Creek	0%	0%	0%	0%	0%	17%	83%	998
Vasa Creek	5%	3%	0%	4%	3%	2%	82%	1267
Ardmore/ Idylwood	0%	0%	0%	0%	0%	7%	93%	450
Redmond 400 Area	0%	0%	0%	0%	0%	6%	94%	282
Rosemont Area	0%	0%	0%	0%	0%	3%	97%	150
Wilkins Creek	0%	0%	0%	0%	2%	1%	96%	305
North Sammamish	0%	0%	0%	0%	0%	13%	87%	618
Phantom Creek	27%	0%	0%	0%	0%	8%	65%	530
Spirit Ridge Area	0%	0%	0%	0%	1%	10%	89%	223
South Sammamish	0%	6%	0%	2%	8%	1%	83%	419
Lake Sammamish Watershed (within the City of Bellevue)	4%	1%	0%	1%	2%	8%	84%	5241

Table 6 compares the change in canopy cover and impervious surfaces between 2006 and 2017 for the ten subbasins and areas within the Lake Sammamish Watershed (HRCD 2021). The South Sammamish Area experienced the largest tree canopy loss, while the Phantom Creek Subbasin experienced the greatest impervious surface increase out of all the Lake Sammamish Watershed subbasins and areas.

Table 6. Change in Tree Canopy and Impervious Surface from 2006 to 2017 in the City of Bellevue portion of the Lake Sammamish Watershed

Subbasin	Tree Canopy Loss (2006 – 2017)		Impervious Surfaces Increase (2006 – 2017)		Primary Agent of Change
	Change	Trend	Change	Trend	
Ardmore	0.6 %		1.0 %		Development
Redmond 400	0.9 %		0.8 %		Development
Rosemont	0.3 %		0.4 %		Development
Wilkins Creek	0.8 %		0.4 %		Tree Removal
North Sammamish	0.4 %		0.3 %		Development

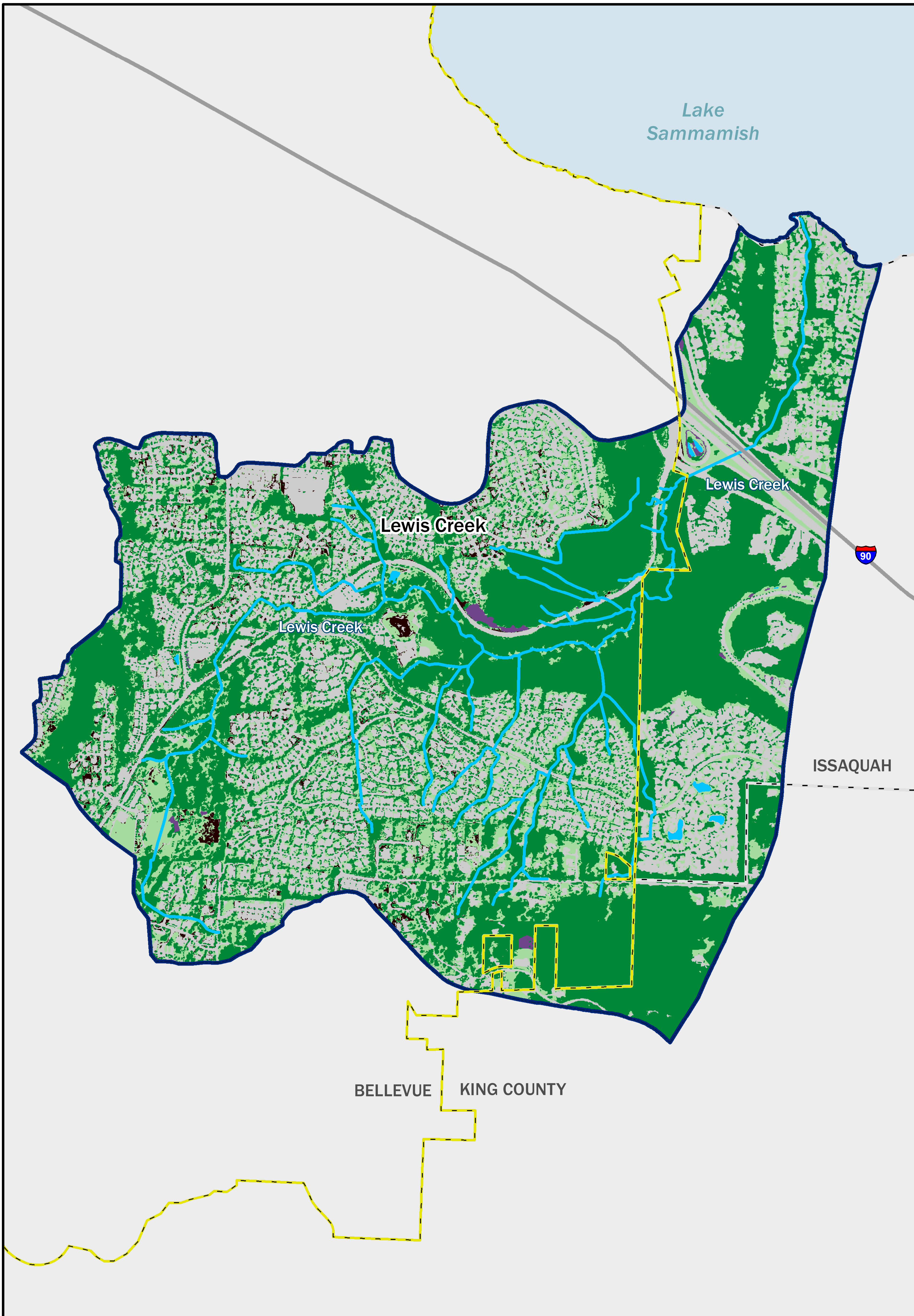
Subbasin	Tree Canopy Loss (2006 – 2017)		Impervious Surfaces Increase (2006 – 2017)		Primary Agent of Change
	Change	Trend	Change	Trend	
Phantom Creek	1.1 %		1.6 %		Development
Spirit Ridge	0.3 %		0.2 %		Redevelopme nt
Vasa Creek	1.1 %		0.5 %		Development
South Sammamish	1.6 %		0.7 %		Development
Lewis Creek	1.4 %		0.9 %		Development
Total Lake Sammamish Watershed (within the City of Bellevue)	1.0 % (57 acres)		0.7 % (42 acres)		Development

data source: https://hrcd-wdfw.hub.arcgis.com/

Trend bars represent the time intervals used by the WDFW High Resolution Change Detection database: 2006-2009, 2009-2011, 2011-2013, 2013-2015, 2015-2017.

Based on changes in tree canopy and impervious area data, since 2006 there has been development in all of the subbasins and areas within the Lake Sammamish Watershed. Table 6 shows the decrease in tree canopy and increase in impervious surfaces associated with rapid development and urbanization—where development indicates the conversion of a vegetated lot or parcel into a built lot or parcel, and redevelopment indicates building on a previously developed lot. With development across so much of the Lake Sammamish Watershed, it is important to consider the impacts of the City's growth on water quality and habitat within the riparian corridor.

Within Bellevue, ownership of the riparian corridor (within 100 linear feet of the stream) across all of the subbasins within the Lake Sammamish Watershed is approximately 76 percent private property and 24 percent publicly owned (primarily parks). Developing stream improvement plans in collaboration with private property owners is essential for the Lake Sammamish Watershed. The City's current approach limits using public resources that improve stream channel conditions or riparian corridors to City-owned property only. A future tool to improve riparian corridors within the Watershed may be a City program to provide funds and/or information to assist streamside residents in improving steams and riparian corridors or incentive programs promoting green stormwater infrastructure on private properties.



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

Landcover Class (City of Bellevue 2020)

- Bare Soil and Dry Vegetation
- Impervious
- Non-Canopy Vegetation
- Tree Canopy
- Scrub/Shrub
- Water

Figure 18. Lewis Creek Subbasin Land Cover/Tree Canopy.

N

0 550 1,100 2,200 Feet

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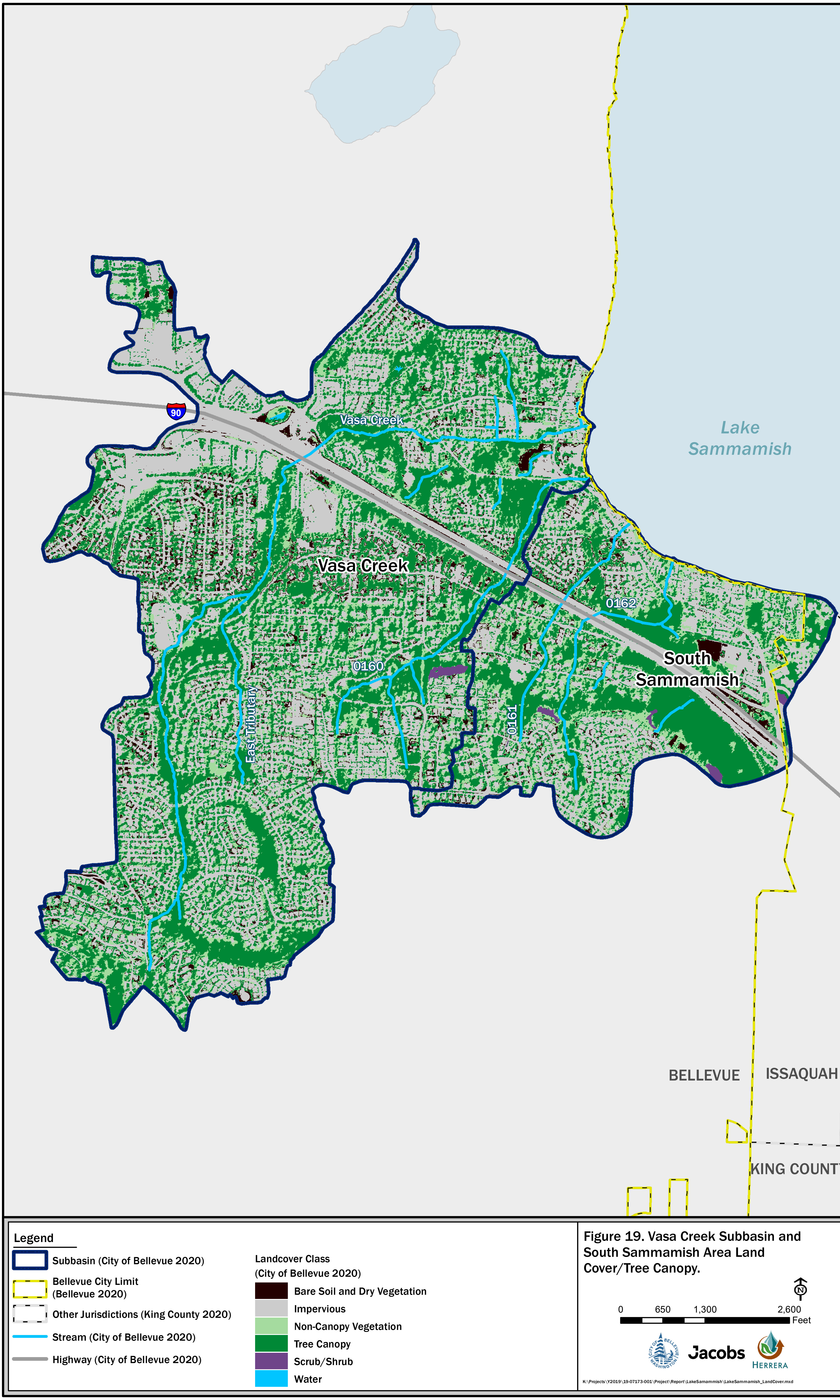

Figure 19. Vasa Creek Subbasin and South Sammamish Area Land Cover/Tree Canopy.

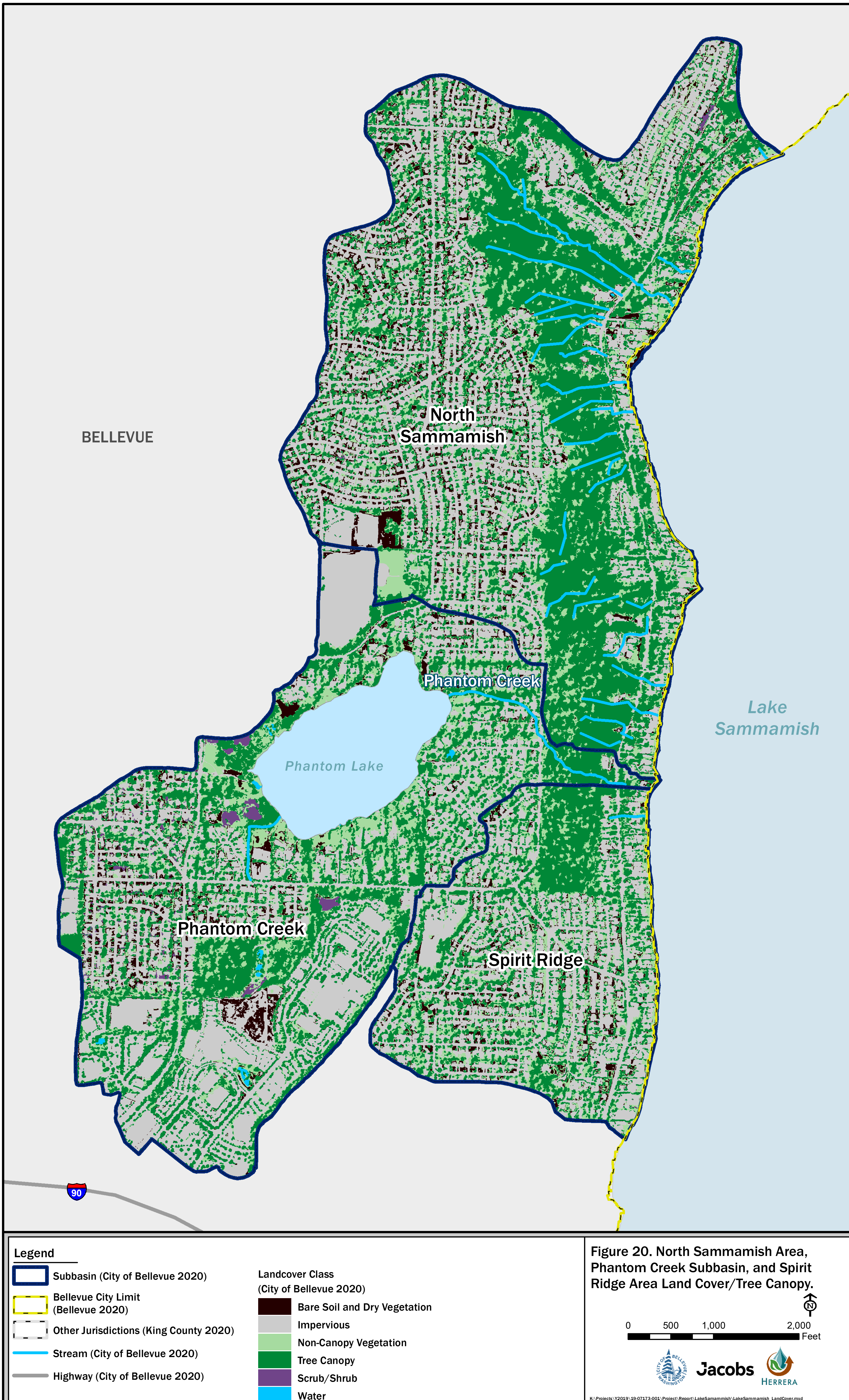

Figure 20. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Land Cover/Tree Canopy.

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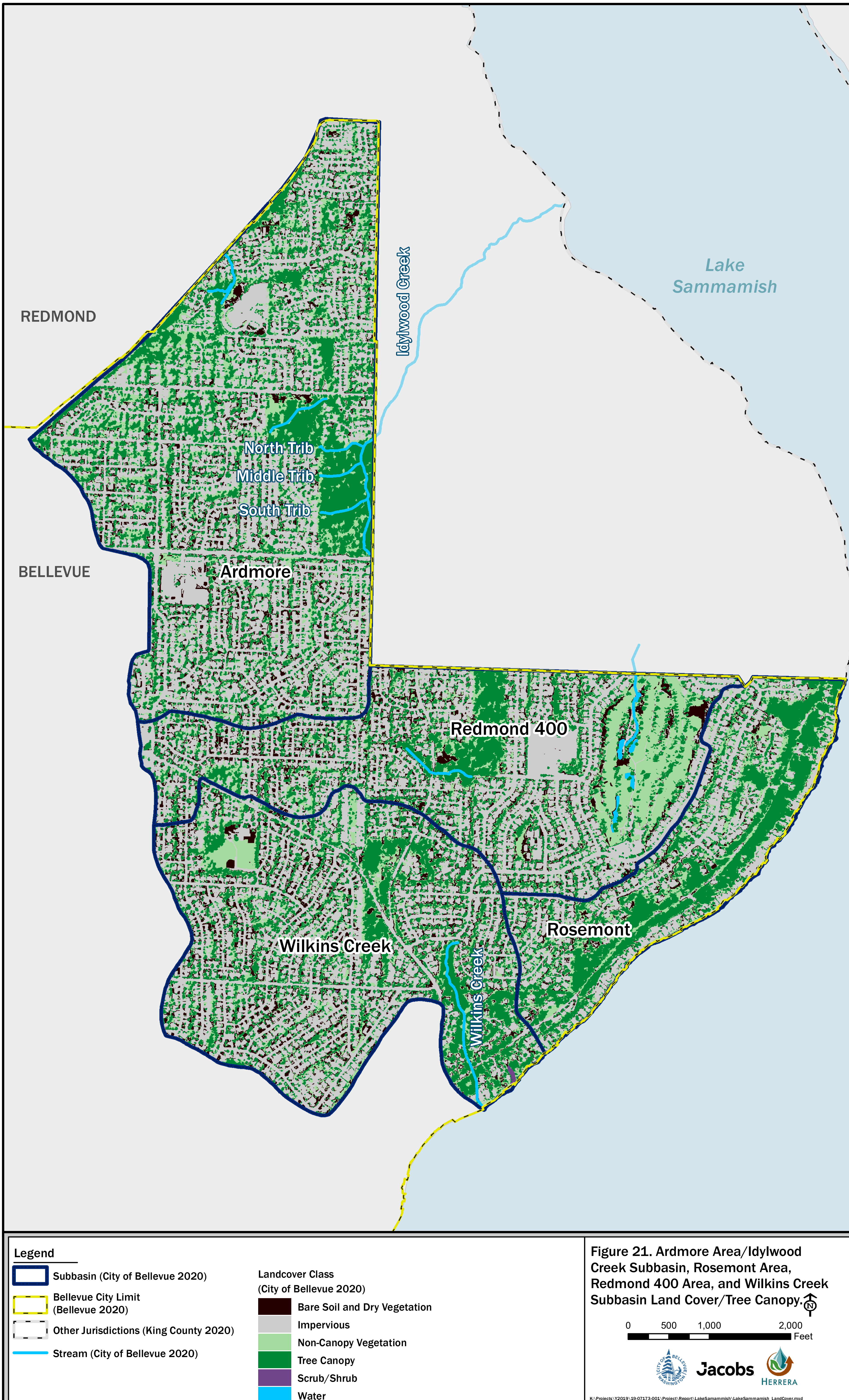

Figure 21. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Land Cover/Tree Canopy.

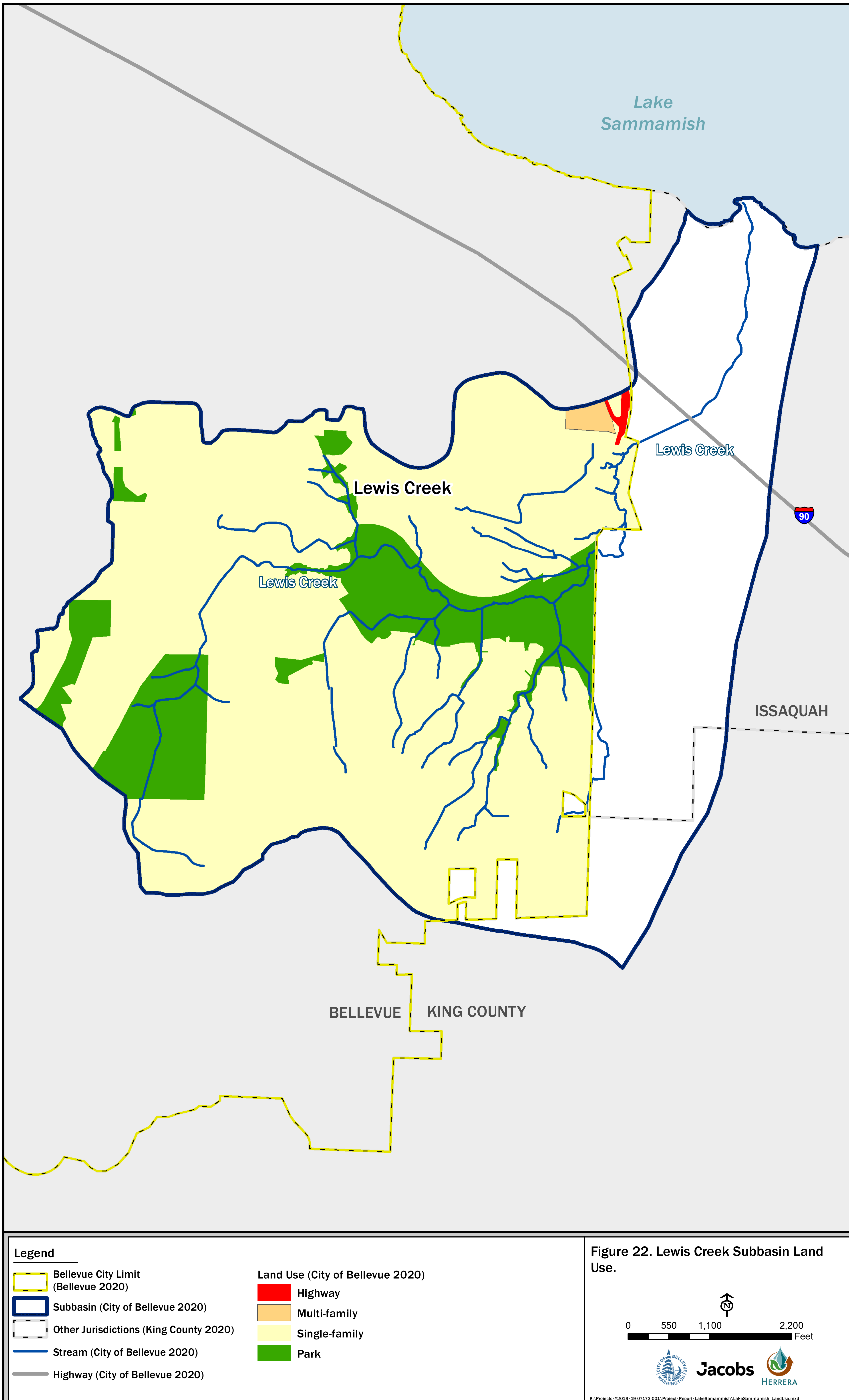

Figure 22. Lewis Creek Subbasin Land Use.

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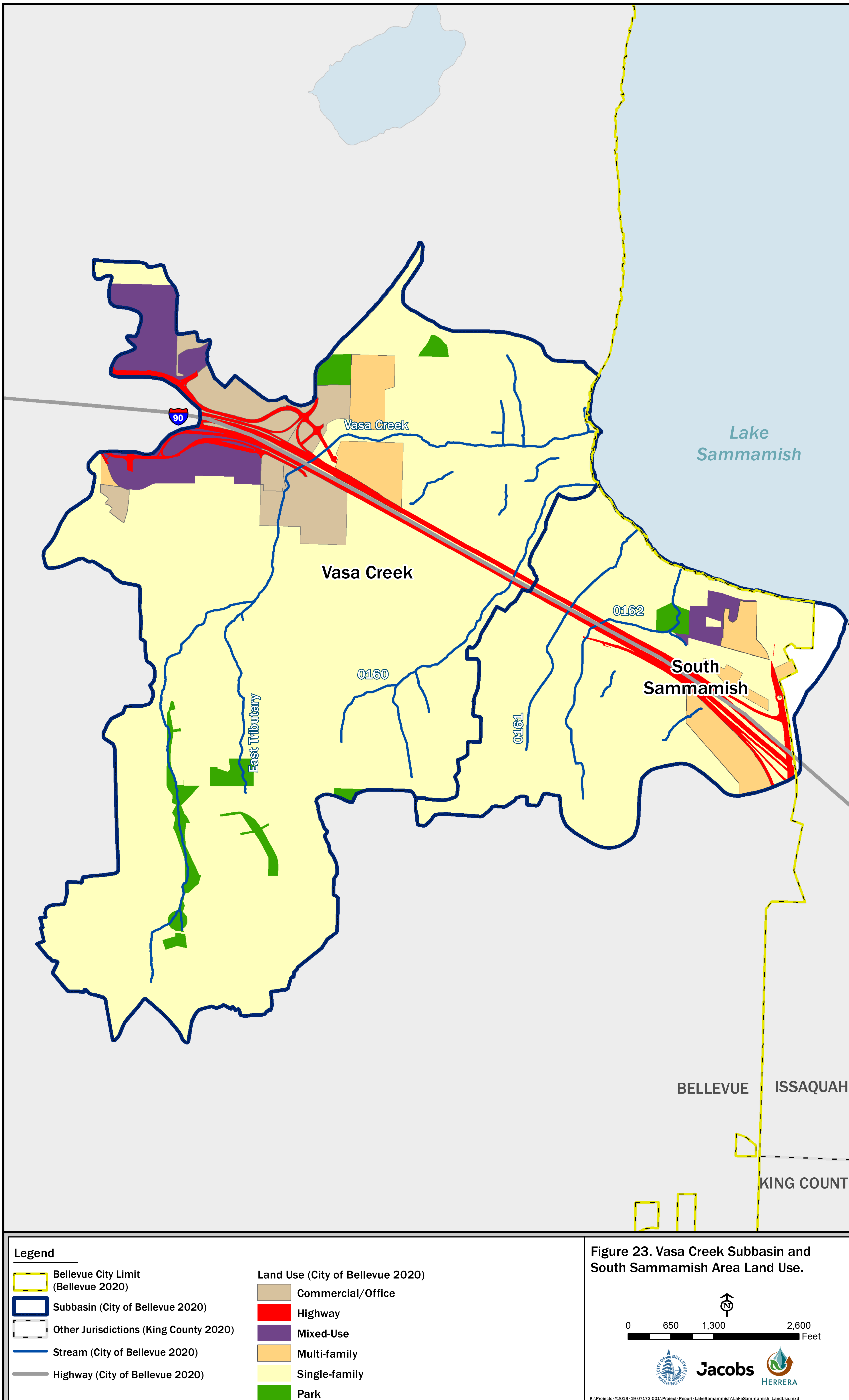

Figure 23. Vasa Creek Subbasin and South Sammamish Area Land Use.

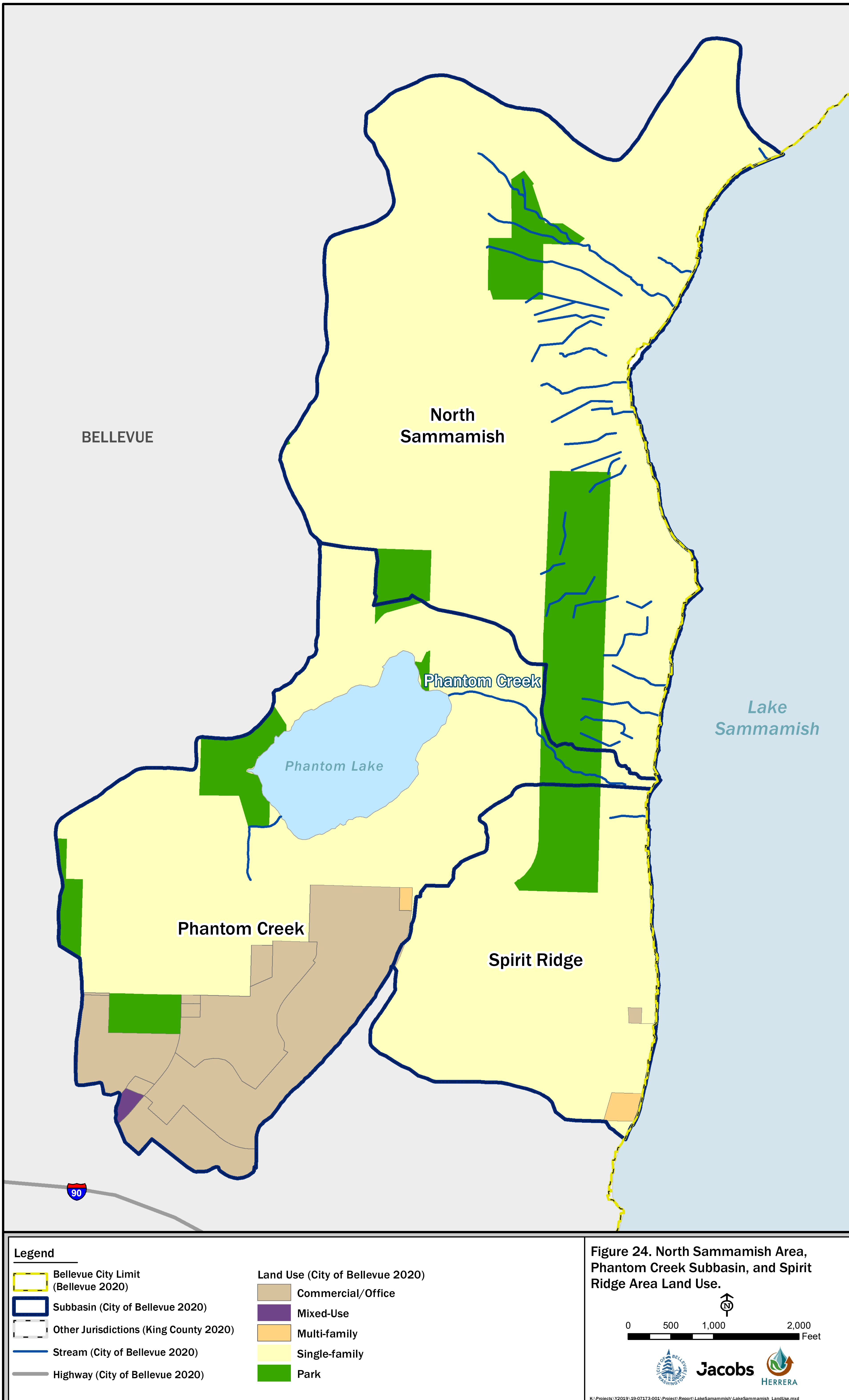

Figure 24. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Land Use.

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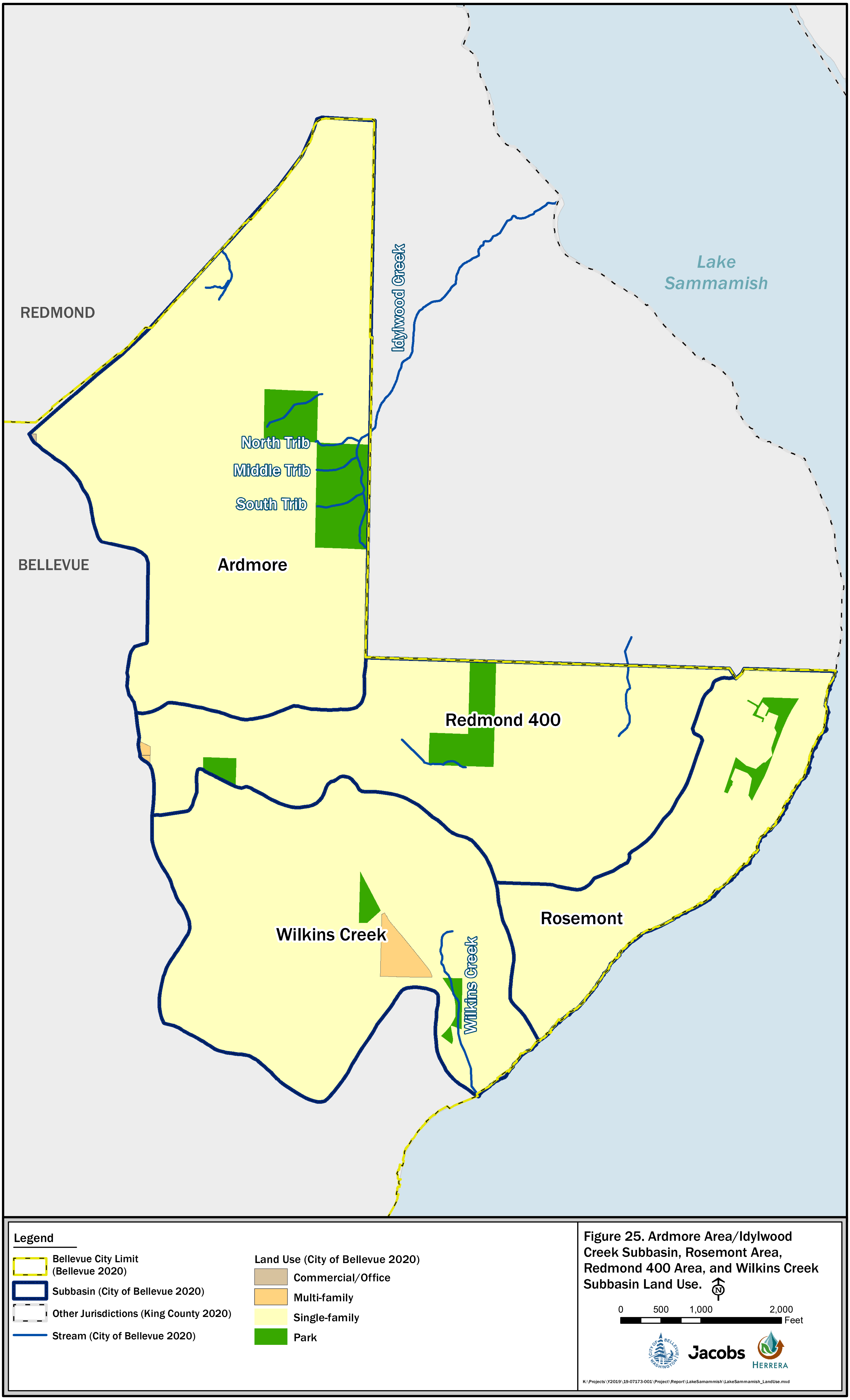

Figure 25. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Land Use.

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2.2.2 Built Stormwater Infrastructure

Built stormwater infrastructure, which includes pipes, curb inlets, catch basins, curb-and-gutter drainage, outfalls, and culverts, can cause and/or exacerbate impacts from urbanization by increasing stormwater velocity and by concentrating rather than dispersing runoff. Streams that flow through pipes move at faster velocities than their open-channel counterparts. Stormwater infrastructure built before and during the 1970s was typically built to address flooding concerns and tends to be very effective at sending that stormwater downstream quickly. Built stormwater infrastructure also provides benefits, including preventing flooding (or reducing flood risk), and/or providing flow control and water quality treatment.

While built stormwater infrastructure has had negative effects on streams, stormwater infrastructure can also be used as a watershed management tool to address urbanization by providing the following benefits:

- Promote hydrologic processes that naturally occurred prior to urbanization such as infiltration, filtration, storage, and evaporation (on-site stormwater management or low impact development)
- Reduce the peak flow rate and volume of stormwater that is delivered to a water body (flow control)
- Remove pollutants from stormwater (runoff treatment)

Stormwater infrastructure in developed areas of the Lake Sammamish Watershed is primarily comprised of formal curb and gutter conveyance with some areas drained by more informal drainage with roadside ditches and driveway culverts. Runoff from impervious surfaces is collected and discharged through numerous outfalls along Lake Sammamish and its tributaries. Table 7 shows the percentage of stream length that flows through pipes for each subbasin or area within the Lake Sammamish Watershed. The Wilkins Creek Subbasin, South Sammamish Area, and Vasa Creek Subbasin have the highest amount of piped stream length at 26.8, 22.4, and 19.6 percent respectively.

Table 7. Piped Stream Channel Length by Subbasin/Area within the City of Bellevue Portion of the Lake Sammamish Watershed

Subbasin / Area	Percent of the Stream Channel that is Piped
Lewis Creek Subbasin	6.8%
Vasa Creek Subbasin	19.6%
Ardmore Area/Idylwood Subbasin	1.8%
Redmond 400 Area	3.6%
Rosemont Area	Not Applicable*
Wilkins Creek Subbasin	26.8%
North Sammamish Area	9.2%
Phantom Creek Subbasin	7.4%
Spirit Ridge Area	Not Applicable*
South Sammamish Area	22.4%
Total Lake Sammamish Watershed (within the City of Bellevue)	12.1%

* This Lake Sammamish area does not contain perennial open streams

The Lake Sammamish Watershed also has a number of regional stormwater facilities and high-flow bypasses (Table 8 and Figure 26) and smaller detention facilities. High-flow bypasses are designed to divert excess streamflow out of the main channel and into storm drainage pipes that carry these flows away from vulnerable areas during extreme flow events. The high-flow bypasses in the Lake Sammamish Watershed were implemented to reduce erosion and flooding downstream but may have potential negative effects on fish populations, particularly when sediment and debris accumulation and streambed aggradation result in base flows being diverted out of the stream channel. Additionally, high-flow bypasses can substantially alter sediment transport dynamics (often starving a stream of bed material) and channel morphology where the bypass outfalls back into the stream channel as well as in the portion of stream that is bypassed. Current flood control and stream restoration practice is to implement process-based designs that simulate the resiliency of natural systems to those high flows and reduce maintenance as compared to high-flow bypasses. Evaluation of these existing facilities is recommended to restore natural processes and improve stream health, consistent with current flood control and stream restoration practices.

Table 8. Existing Stormwater Facilities in the City of Bellevue Portion of the Lake Sammamish Watershed

Facility Type	Facility Name	Subbasin	Location
In-stream detention/sedimentation	WSDOT instream detention/sedimentation	Vasa Creek	Located just upstream of I-90 Crossing, approx. Constructed in late 1970s or early 1980s Lat: 47.57666° N, Long: 122.13041° W.
Stormwater Treatment/Flow Control Facility	Lakemont Stormwater Treatment Facility	Lewis Creek	In Lakemont Community Park ,5170 Village Park Drive, built in 1990s. Lat: 47.55710° N. Long: 122.11310° W.
Regional detention	Lakemont Blvd Detention Pond	Lewis Creek	Built in the WSDOT ROW in the 1990s at the intersection of Lakemont Blvd SE, SE Newport Way & I-90. Lat: 47.56340° N, Long: 122.09826° W. Collect runoff from Lakemont Boulevard in Bellevue. City leases land from WSDOT but owns & operates pond. WSDOT will be daylighting Lewis Creek adjacent to this pond and some City infrastructure will be impacted, but the pond will remain intact.
High-Flow Bypass	Wilkins Creek Bypass	Wilkins Creek	Begins in unaddressed Tract, approximately 200 feet east of the intersection of NE 8th Street & Northup Way) – Manhole asset # 327313 -Approx. Lat: 47.61683° N, Long: 122.10639° W. Bypass pipe is underneath open stream channel. 30-inch HDPE pipe ends @ 501 W Lake Sammamish Parkway NE. Low flow from bypass pipe and steam flow outfall into an area originally designed as a treatment wetland. High flow from bypass and wetland/pond outfall connect to piped system. Constructed in 1998, modified in early 2000s.

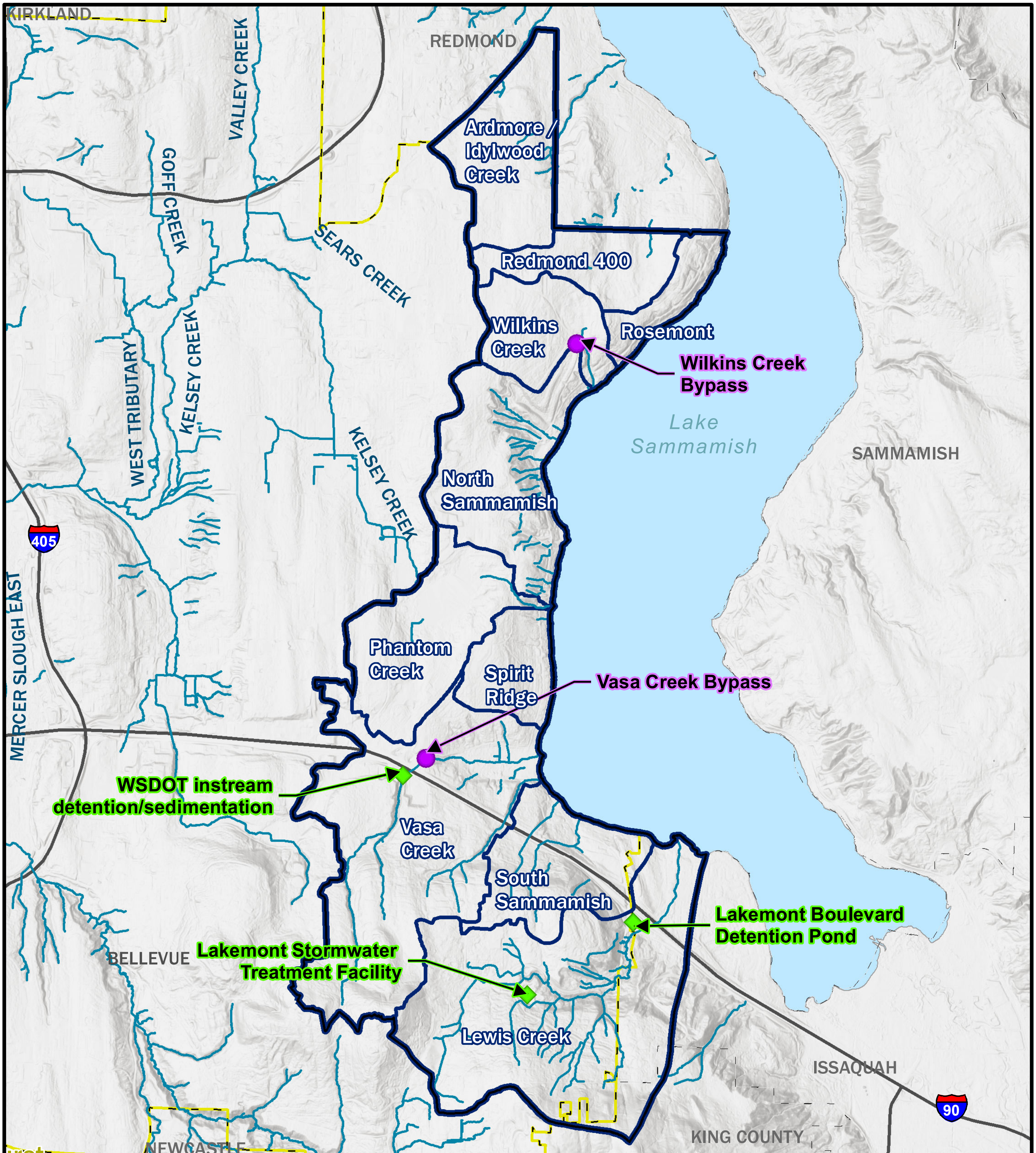
Facility Type	Facility Name	Subbasin	Location
High-Flow Bypass	Vasa Creek Bypass	Vasa Creek	Begins in WSDOT ROW at approximately northeast of I-90 crossing, @ Lat: 47.57826° N, Long: 122.12724° W @ Manhole asset #364354. 48-inch concrete pipe carries flow all the way to Lake Sammamish. Constructed in late 1970s or early 1980s.

In addition to the facilities described in Table 8, there are numerous smaller flow control and water quality facilities (both publicly-owned and privately owned) in the Lake Sammamish Watershed. The City, through its NPDES permit, is required to maintain the publicly-owned facilities and inspect the privately-owned facilities. It should be noted that facilities designed and built in the mid-1970s through the mid-1990s provide little or no benefit to the stream in terms of flow control to protect from streambank erosion and other negative effects of runoff. They were primarily designed for flood control.

The year in which a parcel was developed has a significant influence on the amount and types of infrastructure present for managing stormwater, especially on-site stormwater management, flow control, and runoff treatment. In general, older development was either built with no stormwater infrastructure or facilities that do not meet current standards. To understand the adequacy of stormwater management in the Lake Sammamish Watershed, the age of development was used to classify specific areas into one of five categories that indicate when requirements for improved stormwater management infrastructure became effective in the City (Table 9). This information illustrates the relative degree of flow control and water quality treatment within the Watershed, and highlights where stormwater retrofits may be useful. Note that water quality treatment of stormwater runoff was not required in the City until 2010. This means that water quality treatment facilities were not required for approximately 97.1 percent of the current *developed* area in the Bellevue portion of the Lake Sammamish Watershed, including road projects.

More than 33.9 percent of the Lake Sammamish Watershed was developed before 1974 with nearly half (48.3 percent) developed before the mid-1980s. The subbasin developed the least before 1975 was Lewis Creek Subbasin (4.8 percent). The development that occurred in the City in the late 1980s and early 1990s changed the land use in the Lewis Creek and Phantom Creek Subbasins most dramatically as compared to the other subbasins in the City. By 1996, 56.4 percent of the land area within the Lake Sammamish Watershed had been developed.

Figures 27-30 show the age of development for the Lewis Creek Subbasin; the Vasa Creek Subbasin and South Sammamish Area; the North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area; and the Ardmore Area/ Idylwood Creek Subbasins, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin, respectively.



Legend
- Bypass Structures (City of Bellevue 2020)
- Stormwater Detention Facilities (City of Bellevue 2020)
- Watershed (City of Bellevue 2020)
- Bellevue City Limit (City of Bellevue 2020)
- Other Jurisdictions (City of Bellevue 2020)
- Stream Reach (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

*Note all data from City of Bellevue 2020

Figure 26. Regional Stormwater Facilities in the Lake Sammamish Watershed.

N

0 2,500 5,000 10,000 Feet

Jacobs HERRERA

King County Aerial (2019)

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Table 9. Development Age Categories for Assessing Stormwater Management Infrastructure Requirements

Category	Stormwater Management Requirements	Lewis Creek Subbasin	Vasa Creek Subbasin	Ardmore Area/ Idylwood Creek Subbasin	Redmond 400 Area	Rosemont Area	Wilkins Creek Subbasin	North Sammamish Area	Phantom Creek Subbasin	Spirit Ridge Area	South Sammamish Area	City of Bellevue Portion of Lake Sammamish Watershed
2017-Current	The 2017 Surface Water Engineering Standards updated the On-site Stormwater Management requirements (List #1, List #2, or LID Performance Standard) and adopted the 2012/14 Department of Ecology Stormwater Management Manual for Western Washington.	0.4%	1.0%	0.3%	0.8%	1.7%	0.4%	0.4%	0.5%	0.7%	1.8%	0.7%
2010-2016	The 2010 Surface Water Engineering Standards added water quality requirements, flow control requirements, and continuous modeling per the 2005 Department of Ecology Stormwater Management Manual for Western Washington. On-site Stormwater Management was also included either applying default LID credits or deriving LID credits with demonstrative modeling.	2.1%	0.9%	0.2%	0.8%	1.9%	0.4%	0.9%	0.6%	1.1%	1.8%	1.1%
1996-2009	Bellevue adopts the Department of Ecology's1992 Stormwater Management Manual for the Puget Sound Basin (Technical Manual) ▪ 2-year peak develop flow matches 50% of 2-year pre-developed flow ▪ 10-year peak developed flow	12.8%	4.9%	1.8%	3.8%	5.3%	2.4%	7.0%	5.0%	5.5%	3.5%	6.1%

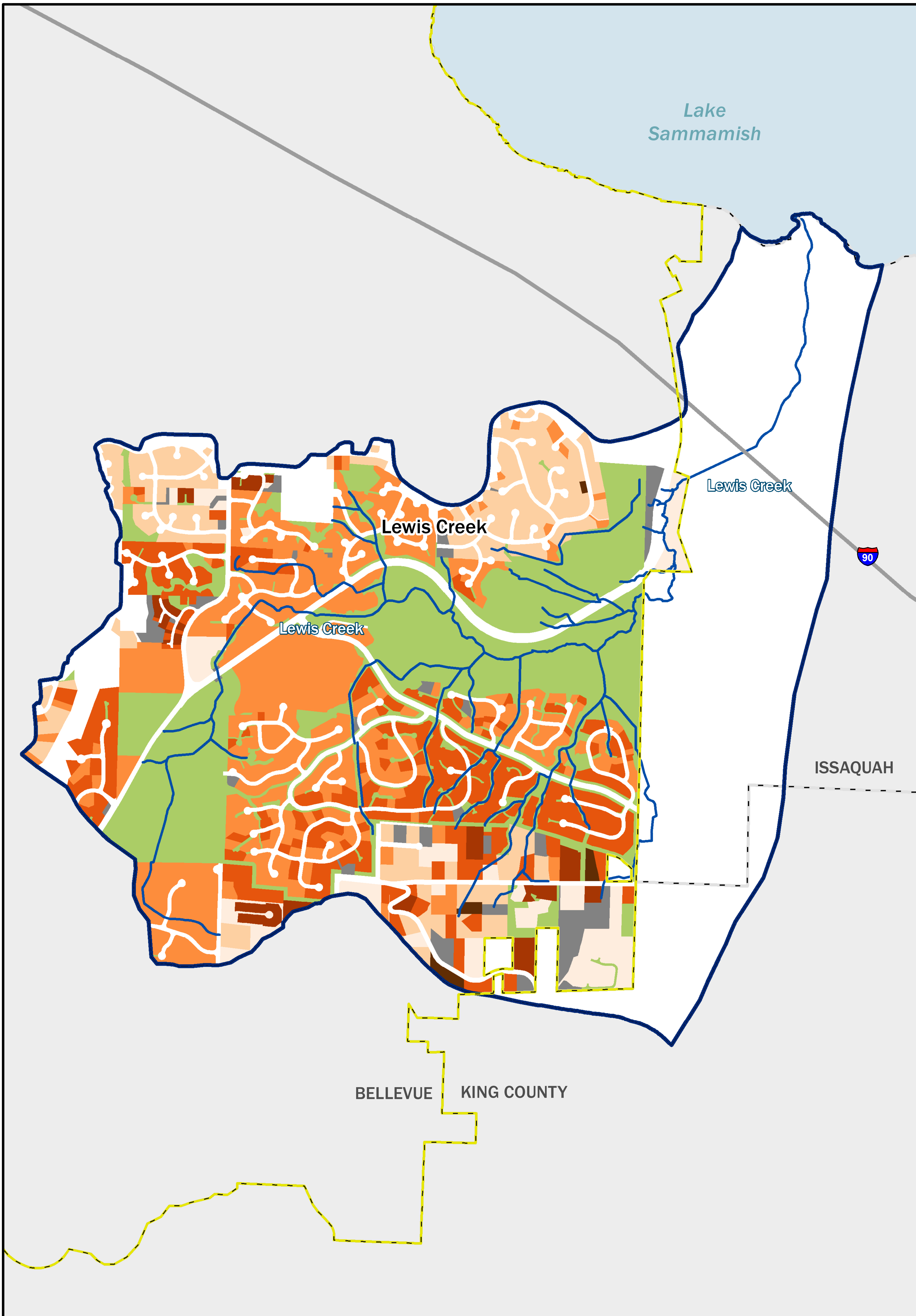
Category	Stormwater Management Requirements	Lewis Creek Subbasin	Vasa Creek Subbasin	Ardmore Area/ Idylwood Creek Subbasin	Redmond 400 Area	Rosemont Area	Wilkins Creek Subbasin	North Sammamish Area	Phantom Creek Subbasin	Spirit Ridge Area	South Sammamish Area	City of Bellevue Portion of Lake Sammamish Watershed
	matches 10-year pre-developed flow ▪ 100-year peak developed flow matches 100-year pre-developed flow ▪ Unit-hydrograph method required for detention sizing ▪ 1.18 to 1.5 safety factor required for pond sizing dependent on percent impervious area											
1988-1995	Bellevue introduces Large Site stormwater controls for sites serving more than 5 acres and within ¼-mile of a stream: ▪ 10-year peak developed flow matches the 2-year peak pre-developed flow (using computer modeling), 24-hour event ▪ 100-year peak developed flow matches the10-year peak pre-developed flow (using computer modeling), 24-hour event	22.5%	4.6%	7.2%	0.8%	4.9%	1.0%	1.9%	11.0%	4.8%	4.5%	8.2%
1975-1987	The first set of Storm and Surface Water Utility Engineering Standards (published in 1975) focused on detention that could store the difference in runoff volume between the post-development 100-year, 4-hour	11.2%	23.0%	7.8%	6.1%	16.3%	5.1%	3.0%	22.4%	6.4%	25.2%	14.4%

Category	Stormwater Management Requirements	Lewis Creek Subbasin	Vasa Creek Subbasin	Ardmore Area/ Idylwood Creek Subbasin	Redmond 400 Area	Rosemont Area	Wilkins Creek Subbasin	North Sammamish Area	Phantom Creek Subbasin	Spirit Ridge Area	South Sammamish Area	City of Bellevue Portion of Lake Sammamish Watershed
	storm and the pre-development 10 year, 4-hour event. To meet this requirement, a maximum allowable release rate of 0.2 cfs per acre and a storage requirement of 1.0 inch per impervious acre and 0.5 inch per pervious acre were required (Also known as the "Cookbook Method").											
Prior to 1975	No stormwater management required.	4.8%	34.2%	52.9%	45.6%	47.2%	62.1%	47.6%	32.3%	54.4%	19.9%	33.9%

LID: low impact development

cfs: cubic feet per second

Source: City of Bellevue Age of Development and Land Classifications 2013, 2017 received 2020



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

Age of Development Rating (City of Bellevue 2020)
(City of Bellevue 2020)

- 6 (2017-Current)
- 5 (2010-2016)
- 4 (1996-2009)
- 3 (1988-1995)
- 2 (1975-1987)
- 1 (1974 and earlier)
- Park, Open or Tract
- Vacant or Undeveloped

Figure 27. Lewis Creek Subbasin Age of Development Ratings.

0 550 1,100 2,200 Feet

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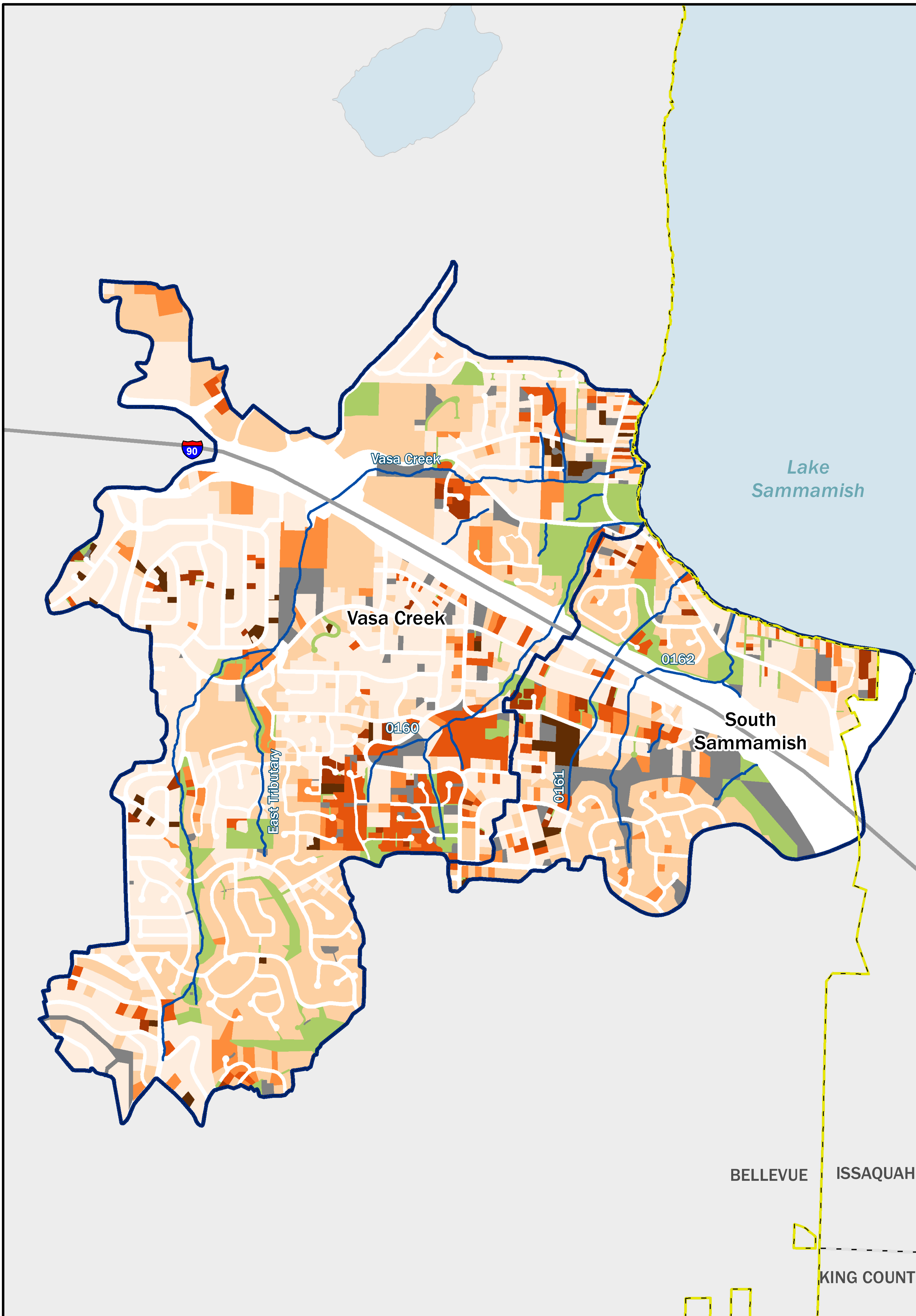

Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- Highway (City of Bellevue 2020)

Age of Development Rating (City of Bellevue 2020)
(City of Bellevue 2020)

- 6 (2017-Current)
- 5 (2010-2016)
- 4 (1996-2009)
- 3 (1988-1995)
- 2 (1975-1987)
- 1 (1974 and earlier)
- Park, Open or Tract
- Vacant or Undeveloped

Figure 28. Vasa Creek Subbasin and South Sammamish Area Age of Development Ratings.

0 650 1,300 2,600 Feet

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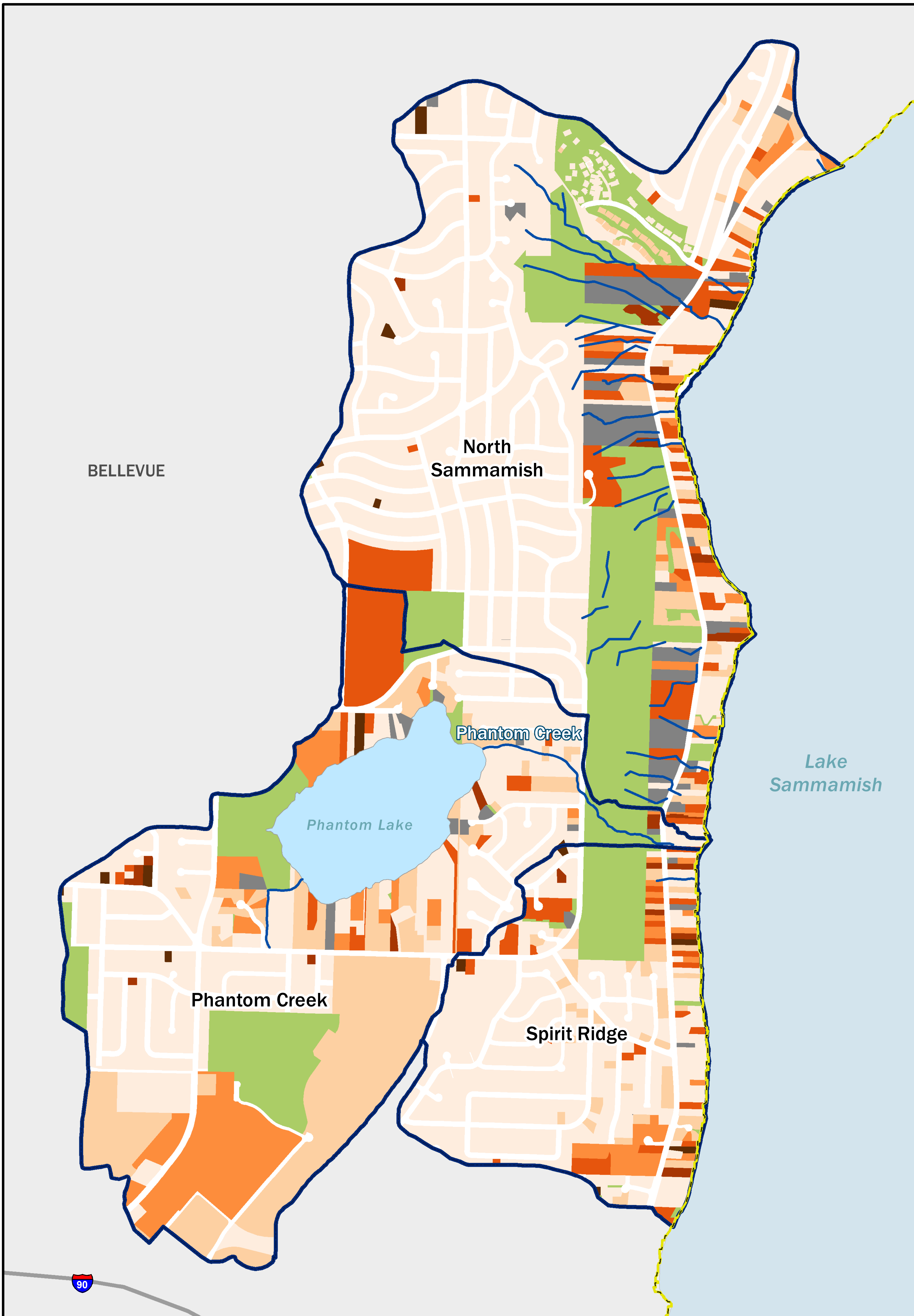

Legend

Subbasin (City of Bellevue 2020)
Bellevue City Limit (Bellevue 2020)
Other Jurisdictions (King County 2020)
Stream (City of Bellevue 2020)
Highway (City of Bellevue 2020)

Age of Development Rating (City of Bellevue 2020)
(City of Bellevue 2020)
6 (2017-Current)
5 (2010-2016)
4 (1996-2009)
3 (1988-1995)
2 (1975-1987)
1 (1974 and earlier)
Park, Open or Tract
Vacant or Undeveloped

Figure 29. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Age of Development Ratings.

0 500 1,000 2,000 Feet

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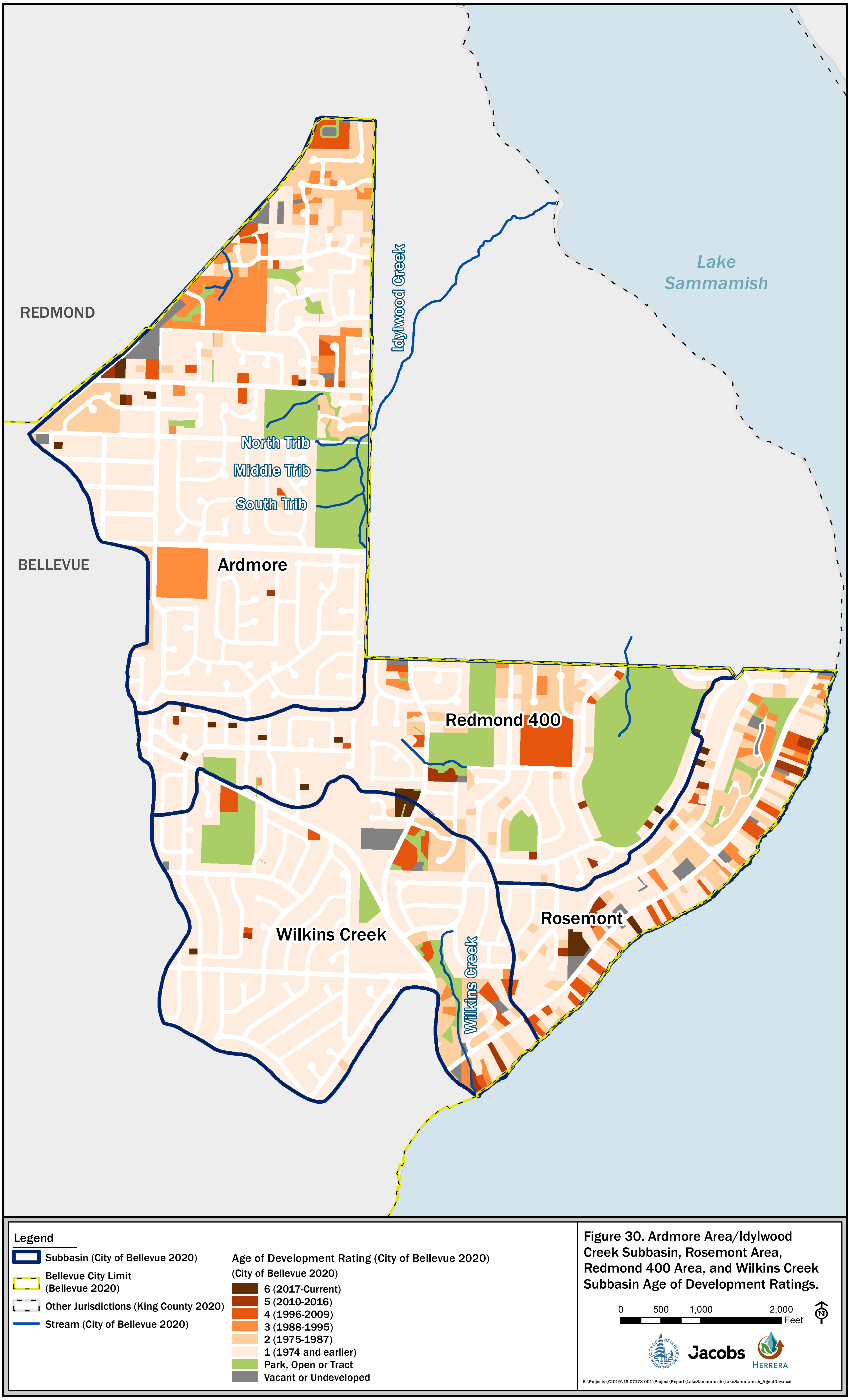


Figure 30. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Age of Development Ratings.

2.2.3 Other Non-Stormwater Built Infrastructure

Similar to developed areas throughout the Puget Sound region, power lines, transportation corridors (roads, rail, trails), sewer lines, and other types of infrastructure exist throughout the City's portion of the Lake Sammamish Watershed, impacting natural stream and hydrologic processes and function.

The presence of this built infrastructure may limit where investments in stream and watershed health may be located. When potential investments in stream and watershed health are identified during future phases of this WMP development, the locations of this existing built infrastructure will be identified. These built infrastructure systems may also present opportunities for partnerships in future investments in stream and watershed health.

2.3 Natural Systems

Existing conditions are summarized below for the following natural system attributes: stream flow, surface water quality, groundwater quality, riparian corridor, instream habitat, and aquatic species.

2.3.1 Stream Flow

As watersheds urbanize, natural vegetation and forest is replaced by impervious surfaces such as buildings, driveways, roadways and other hard surfaces. These impervious surfaces cause rainfall to quickly flow toward local streams instead of infiltrating into the ground where it can slowly migrate to the stream via shallow interflow or groundwater flow. One consequence is that streamflow becomes increasingly "flashy" as the response to rainfall is more immediate when compared to a forested watershed. Commensurate with these changes to the hydrograph form are increases in peak flows within the stream and the duration of higher flows. As shown in Figure 2, these and other related changes in streamflow characteristics can negatively impact stream habitat in several ways including decreased channel stability, increased channel erosion and/or aggradation, and decreased floodplain connectivity.

Streamflow data are available from two stream gauges in the Lake Sammamish Watershed that are or were operated and maintained by King County (2020a). Both of these gauges are located downstream of I-90 in the lower reach of their respective creek. Gauge 63a – Lewis Creek at West Lake Sammamish Parkway is located on Lewis Creek just downstream W Lake Sammamish Parkway SE (Figure 4). Gauge COB-Vasa WLS – Vasa Creek at West Lake Sammamish, is located approximately 2 miles northwest of Gauge 63a, on Vasa Creek, just upstream of W Lake Sammamish Parkway SE (Figure 5) and downstream of the existing high flow bypass on Vasa Creek.

Although Gauge COB-Vasa WLS was active from 2014 through 2017, only enough data was provided for the entirety of the 2015 water year to allow for a complete Hydrologic Metric Score Analysis (Table 10). Data from Gauge-63a is summarized in Figure 31. The resultant hydrograph from this data shows the characteristic flashy signal described above that is typical for streams in an urban or suburban setting.

To evaluate the effects of urbanization on the hydrology of the Lake Sammamish Watershed, scores for the following stream hydrologic metrics were computed using data from both gauges for individual water years having a complete dataset: High Pulse Count, High Pulse Range, Richards-Baker Flashiness Index (RBI), and TQ mean. Table 11 provides a definition for each stream hydrologic metric with their expected response to urbanization. Gauge-63a had datasets available for 17 years while COB-Vasa WLS was only available for one year (2015).

The computed stream hydrologic metrics are summarized in Table 10 with a comparison to metrics obtained from a highly urbanized watershed and a forested watershed. The highly urbanized watershed is

Tyler's Creek in the City of Redmond. The Tyler's Creek Watershed has a drainage area of 168 acres with 35 percent of this area covered by impervious surfaces. This Watershed is a control site for a long-term study of Redmond's watersheds (Herrera 2015). The forested Watershed is Big Beef Creek in Kitsap County. The Big Beef Creek Watershed has a drainage area of 8,649 acres with 2.7 precent of this area covered by impervious surfaces (Rosburg *et al.* 2017). It serves as the forested reference watershed for the Ecology Watershed Health Monitoring Program. For comparison, the Lake Sammamish Watershed has a drainage area of approximately 5,241 acres; 38 percent of this area is covered by impervious surfaces. To aid in the interpretation of these results, Table 10 also provides representative TQ mean values from Konrad et al. (2002) from watersheds categorized as urban (road density 9.1 to 11.3 kilometers per square kilometer [km/km^2]), suburban (road density 4.7 to 7.9 km/km^2), and rural (road density 2.1 to 2.6 km/km^2).

As shown in Table 10, scores computed for Lewis Creek in the Lake Sammamish Watershed are between the scores for forested Big Beef Creek and urbanized Tyler's Creek. In predictable fashion, the scores for Tyler's Creek are biased towards the expected responses from urbanization shown in Table 11 whereas the scores from Big Beef Creek are biased in the opposite direction. The one exception was the scores for TQ mean where the median scores for Tyler's Creek and Big Beef Creek were relatively similar at 0.29 and 0.30, respectively. The TQ mean values in Lewis Creek are within the range of scores for both Tyler's Creek and Big Beef Creek, while Vasa Creek's TQ mean is above the range for both Big Beef and Tyler's Creek. However, the fact that Vasa Creek's stream gauge 63a is located downstream of the high flow bypass structure suggests that the single year of stream flow data does not accurately reflect the condition of the Vasa Creek. Collectively, these data generally suggest there is a moderate degree of hydrologic alteration in the Lake Sammamish Watershed relative to these other creeks with highly urbanized and forested watersheds, respectively.

Table 10. Hydrologic Metrics Compared to Metrics from Other Watersheds

Water Year	Watershed Type	High Pulse Count (number per year)	High Pulse Range (days)	Richards-Baker Flashiness Index	TQ Mean (fraction of the year)
Lewis Creek: COB-63a					
2021	Suburban	11	132	0.47	0.22
2020	Suburban	9	162	0.60	0.26
2019	Suburban	14	168	0.42	0.18
2018	Suburban	13	181	0.41	0.27
2017	Suburban	25	215	0.44	0.37
2016	Suburban	12	149	0.46	0.34
2015	Suburban	17	312	0.40	0.33
2014	Suburban	16	306	0.45	0.29
2008	Suburban	12	305	0.52	0.23
2007	Suburban	10	145	0.32	0.33
2006	Suburban	11	216	0.43	0.24

Water Year	Watershed Type	High Pulse Count (number per year)	High Pulse Range (days)	Richards-Baker Flashiness Index	TQ Mean (fraction of the year)
2005	Suburban	12	224	0.55	0.22
2004	Suburban	12	309	0.54	0.27
2003	Suburban	8	153	0.38	0.29
2002	Suburban	19	172	0.43	0.32
2001	Suburban	3	93	0.30	0.41
2000	Suburban	15	247	0.35	0.34
Median (Range)	**Suburban**	**12 (3 – 25)**	**181 (93 – 312)**	**0.43 (0.30 – 0.60)**	**0.29 (0.18 – 0.41)**
Vasa Creek – COB VasaWLS					
2015	Suburban	10	88	0.20	0.44
Tyler's Creek: TYLMO Station					
2019	Urbanized	16	317	0.57	0.30
2018	Urbanized	27	243	0.57	0.30
2017	Urbanized	33	221	0.76	0.28
2016	Urbanized	30	326	0.82	0.24
Median (Range)	**Urbanized**	**29 (16 – 33)**	**280 (221 – 326)**	**0.67 (0.57 – 082)**	**0.29 (0.24 – 0.30)**
Big Beef					
2019	Forested	5	57	0.23	0.24
2018	Forested	9	174	0.20	0.30
2017	Forested	12	140	0.24	0.39
2016	Forested	4	109	0.23	0.30
2015	Forested	6	135	0.23	0.33
2014	Forested	7	113	0.18	0.30
Median (Range)	**Forested**	**7 (4 – 12)**	**124 (57 – 174)**	**0.23 (0.18 – 0.24)**	**0.30 (0.24 – 0.39)**
Konrad et al. 2002					
Median (Range)	**Urban**	**ND**	**ND**	**ND**	**0.29 (0.25 – 0.30)**
Median	**Suburban**	**ND**	**ND**	**ND**	**0.33**

Water Year	Watershed Type	High Pulse Count (number per year)	High Pulse Range (days)	Richards-Baker Flashiness Index	TQ Mean (fraction of the year)
(Range)					**(0.31 – 0.39)**
Median (Range)	**Rural**	**ND**	**ND**	**ND**	**0.35** **(0.27 – 0.35)**

https://green2.kingcounty.gov/hydrology/GaugeMap.aspx

Table 11. Definitions of Hydrologic Metrics

Component	Metric Name	Definition	Units	Expected Response to Urbanization
Frequency	High Pulse Count	Number of high pulse events per year. A high pulse event occurs when daily flow exceeds twice the water year average daily flow. A single event covers all consecutive days then this condition is met. Thus, consecutive high pulse days comprise a single event.	Count	Increase
Duration	High Pulse Range	Number of days between the first and last pulse event of the water year.	Days	Increase
Flashiness	Richards-Baker Index	An index of flow oscillations relative to total flow based on daily average discharge during the water year.	Unitless	Increase
Flashiness	TQ mean	The fraction of the time during the water year that the daily average flow rate is greater than the annual average flow.	Fraction of the year	Decrease

(source: https://green2.kingcounty.gov/hydrology/SummaryDataGraphs.aspx)

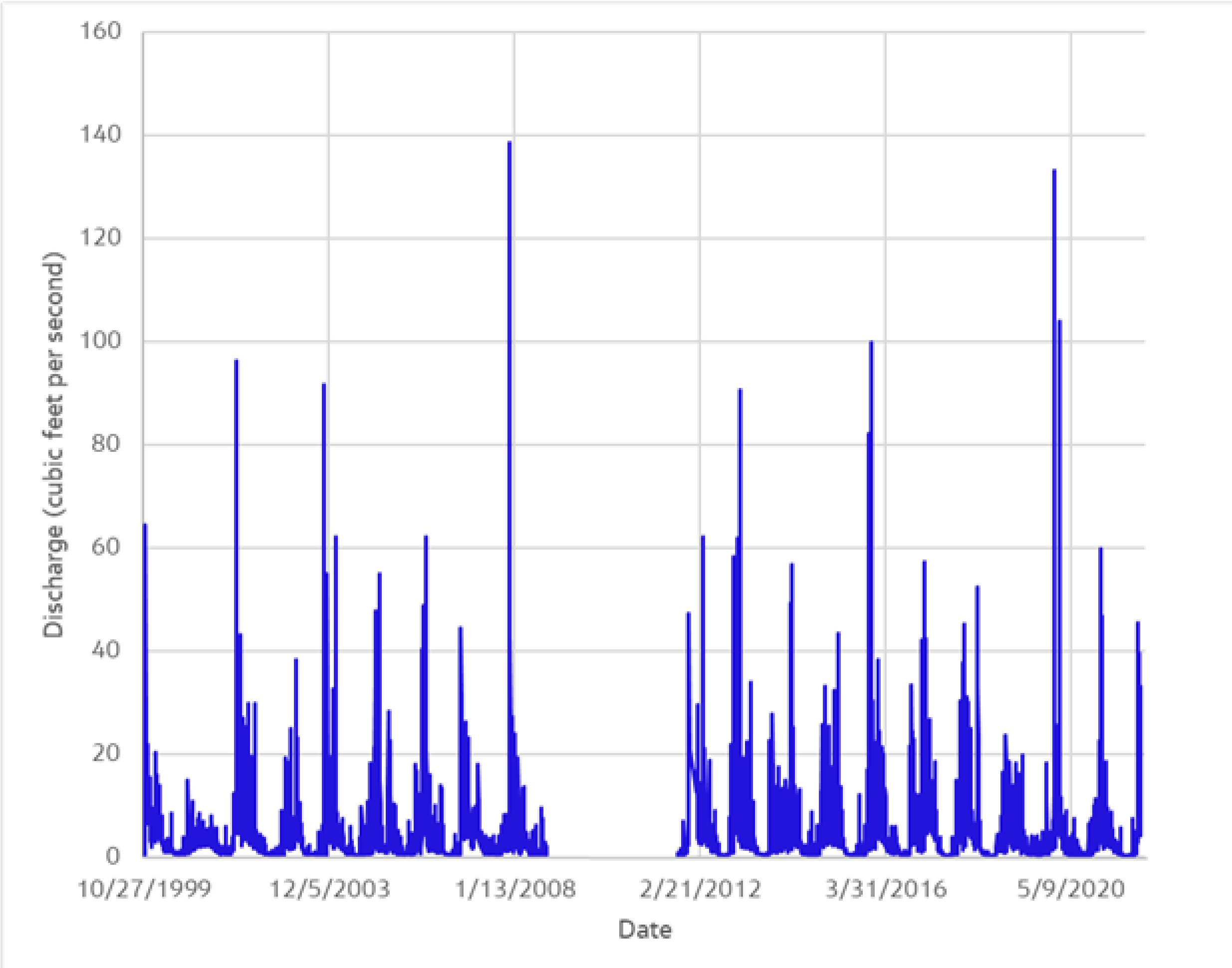


Figure 31. Lewis Creek Gauge Hydrograph

2.3.2 Surface Water Quality

Stormwater runoff from impervious surfaces that is untreated is a primary cause of pollutant loading and transport to surface waters (See conceptual model shown in Figure 2). As described earlier in this report, the majority of the Lake Sammamish Watershed was developed prior to the requirement for water quality treatment; hence, most runoff that enters Lake Sammamish and its tributaries is untreated. Common pollutants from urbanized areas that are detrimental to aquatic health include nutrients (i.e., nitrogen and phosphorus), heavy metals (i.e., Pb, Zn, Cu, Cd), organics (e.g., petroleum hydrocarbons), pathogens, suspended solids, and salts. Many of these pollutants can cause acute toxicity in fish and other aquatic organisms. Runoff from warm impervious surfaces on sunny days can raise stream temperatures causing a host of negative impacts to receiving waters from altering the benthic invertebrate community to the making it difficult for native salmonids to thrive.

Recent studies have shown a compound found in automobile tires is responsible for Coho Salmon (*Oncorhynchus kisutch*) mortality in urban creeks (Tian *et al.* 2020). Pollutants can also cause chronic toxicity that may be directly lethal or produce sublethal effects such as decreased growth, reduced reproduction, or behavioral changes. In a study of streams in the Puget Sound lowlands, May *et al.* (1997) found concentrations of pollutants (primarily metals) were insufficient to produce these adverse effects during baseflow conditions and storm events in streams with a low to moderate percentage of effective impervious surfaces in their watersheds; however, the potential for these effects increases markedly in highly urbanized basins when effective impervious surfaces occupy greater than 45 percent of the total watershed area. For reference, impervious surfaces occupy approximately 38 percent of the Lake Sammamish Watershed within Bellevue and have increased by 0.6 percent over the period from 2006 to 2017.

Water quality data for the Lake Sammamish Watershed are available from sampling conducted by King County, the City, and Ecology. Water quality impairment is assessed herein based on the following data and information:

- Washington State Department of Ecology's 303(d) list
- Water Quality Index (WQI) scores that were computed by King County

2.3.2.1 Stream Water Quality Impairments

Section 303(d) of the Clean Water Act requires Ecology to assess water bodies in Washington State to determine if their quality is adequate to fully support designated beneficial uses (such as for drinking, recreation, aquatic habitat, and industrial use). The assessed water bodies are placed into one of five categories on the 303(d)-list based on their water quality status. Water bodies that are not supporting beneficial uses are placed in the polluted water category (Category 5) and prioritized for water cleanup plans. The most recent assessment for the 303(d) list was completed in 2014.

Three segments within the Lake Sammamish Watershed are identified as Category 5 water bodies on the 303(d)-list, two of which are located in the Lewis Creek Subbasin, and one that is located in the Vasa Creek Subbasin. As shown in Table 12, the Category 5 sites are located in the lower reaches of the Lewis and Vasa Creek subbasins and were placed on the 303(d) list because stream temperatures and bioassessments did not meet water quality standards for Washington State (WAC 173-201A). It should be noted that the lower reaches of Lewis Creek that were identified by the list are only partially located in the City of Bellevue and that the data are from 2014 and may not be representative of current conditions. High stream temperatures can have negative impacts on the benthic invertebrate community and other aquatic species including fish. Restoring riparian canopy cover may increase shading, decreasing water temperatures, and also increase dissolved oxygen.

The bioassessment score is assessed using Benthic Index of Biotic Integrity (B-IBI) scores that are calculated from samples of benthic macroinvertebrates. These scores provide a broad indication of stream health that integrates potential impairment from multiple sources (e.g., poor water quality and/or physical habitat). As shown in Table 12, one segment of Vasa Creek was placed on the 303(d)-list due to biotic impairment because B-IBI scores indicate stream health conditions were poor (see additional details in Section 2.3.6 Aquatic Species). The data are from 2014 and may not be representative of current conditions. The segment is located on the mainstem of Vasa Creek extending from Lake Sammamish up to SE 48th Drive.

The lower part of Vasa and tributaries in the South Sammamish subbasins receive untreated runoff from I-90. Highway runoff is some of the most contaminated runoff from an urban environment (Minton 2011).

Illicit discharges have occurred in the Lake Sammamish Watershed though are difficult to quantify (in terms of both amount discharged and impact). Discharges and spills that are the result of traffic accidents occur frequently within the Lake Sammamish Watershed. I-90 passes through the boundaries of the Watershed and is a major source of stormwater pollution. In addition to spills from traffic accidents, illicit discharges in the form of dumping and food waste have also been documented.

2.3.2.2 Water Quality Index

The WQI is computed using data from the following parameters: fecal coliform bacteria, dissolved oxygen, pH, total suspended solids, temperature, turbidity, total phosphorus, and total nitrogen. It provides a broad assessment of water quality that can be used to categorize waters in terms of the 'level of concern' for potential impairment. In general, stations scoring 80 and above are meeting water quality standards or guidelines and are of "low concern", scores 40 to 80 indicate "moderate concern", and scores below 40 are of "high concern."

While the WQI provides an easy method for categorizing water quality and for comparing between water bodies, like all indices it has weaknesses. For example, a parameter that has a high degree of variability, such as fecal coliform bacteria, can easily skew the results based on one or a few high values. The WQI also does not provide any evidence for why a water body may be rated low. For this reason, it continues to be important to evaluate the individual parameters that comprise the WQI. Finally, it should be noted that sampling conducted by King County to obtain data for computing WQI scores has not explicitly targeted storm events. Hence, the scores may underestimate the true level of impairment from parameters that are commonly associated with stormwater runoff.

King County (2020b) computed WQI scores based on data from monthly grab samples that were collected at Site A617 on Lewis Creek, and A620 on Idylwood Creek over the period from 2000 to 2008 and 2014 to 2020. Site A617 is located at a bridge near the intersection of 187th Ave SE and 185th Place SE, near the mouth of Lewis Creek (see Figure 4 for location of A617). Site A620 is located in the City of Redmond, at the footbridge in Idylwood Park near the mouth of Idylwood Creek. Each monthly grab sample was analyzed for the suite of parameters used to calculate WQI scores.

Average annual WQI scores from both stations are shown in Figure 32 for the period extending from 2000 through 2020. The median value from these data (61 and 58) generally indicates water quality is a "moderate concern" for Lewis and Idylwood creeks, with 2020 being the only year rated a "low concern." This outlier may be due to a temporary yet substantial change in pollutant loading caused by a decrease in vehicular traffic due to the Covid-19 pandemic. As shown in Table 13, high fecal coliform bacteria and total phosphorus concentrations are the primary factors lowering the score for the two creeks; all other parameters generally score very near or within the low concern range. Sources of fecal coliform bacteria in urban streams include pet waste, homeless encampments, cross connections between sewer and stormwater conveyance systems, septic systems, and urban wildlife.

In connection with Ecology's Stormwater Action Monitoring (SAM) program, data for computing WQI index scores were collected from 52 sites in streams located in the Puget Lowland ecoregion from January to December 2015; 24 of these sites were located in streams outside the urban growth area (UGA) in more rural settings while 28 of these sites were located in streams within the UGA in more urban settings. These data provide a good frame of reference for comparing the scores from Lewis and Idylwood creeks to scores from other streams in the region. DeGasperi *et al.* (2018) found that a greater proportion of stream length outside the UGA was in good condition (67 percent) relative to streams within the UGA (43 percent). Median annual WQI scores for streams within and outside the UGA were 75.3 and 86.9, respectively, while Lewis Creek and Idylwood Creek have median scores of 61 and 58, respectively. These data suggest water quality in the Lake Sammamish Watershed is poor, based on recent WQI scores relative to conditions in comparable streams located within the UGA from this study.

Table 12. Lake Sammamish Tributaries within the City of Bellevue on the 303(d) List (Category 5).

Parameter	Listing ID	Year Listed	Location
Temperature	4807	1998-2002	Lewis Creek – Lake Sammamish to SE 45th Street
Temperature	72577	2006-2010	Lewis Creek – SE 45th Street to Lakemont Park
Bioassessment	70109	2006-2010	Vasa (Squibb) Creek – Lake Sammamish to SE 48th Drive

Table 13. Water Quality Index Scores by Year and Parameter for the Lake Sammamish Tributaries within the City of Bellevue
Source: https://green2.kingcounty.gov/streamsdata/WQI.aspx

Subbasin or Area	Year	WQI Score	WQ Concern	Fecal Coliform	DO	pH	TSS	Temperature	Turbidity	TP	TN
Lewis Creek	2020	85	Low	82	80	92	100	75	99	80	97
Lewis Creek	2019	66	Moderate	62	80	93	79	75	83	70	97
Lewis Creek	2018	56	Moderate	41	76	90	84	66	88	65	100
Lewis Creek	2017	67	Moderate	50	81	87	94	75	93	78	91
Lewis Creek	2016	47	Moderate	58	85	90	69	81	72	51	74
Lewis Creek	2015	63	Moderate	53	78	84	92	73	92	76	87
Lewis Creek	2014	48	Moderate	43	78	92	74	73	83	73	93
Lewis Creek	2008	70	Moderate	53	81	93	92	85	94	79	91
Lewis Creek	2007	47	Moderate	43	73	94	76	79	77	50	71
Lewis Creek	2006	61	Moderate	50	80	92	83	85	82	53	78
Lewis Creek	2005	58	Moderate	44	74	90	88	81	91	65	89
Lewis Creek	2004	61	Moderate	50	76	74	99	78	98	73	70
Lewis Creek	2003	60	Moderate	44	78	92	97	83	97	72	86
Lewis Creek	2001	68	Moderate	55	79	86	97	82	98	63	87
Lewis Creek	2000	46	Moderate	43	76	72	87	79	87	72	80
Lewis Creek	**Median**	**61**	**Moderate**	**50**	**78**	**90**	**88**	**79**	**91**	**72**	**87**
Idylwood Creek	2020	81	Low	66	83	94	95	86	94	78	100
Idylwood Creek	2019	65	Moderate	52	76	96	83	82	89	78	97
Idylwood Creek	2018	56	Moderate	49	74	94	75	82	78	52	98

Subbasin or Area	Year	WQI Score	WQ Concern	Fecal Coliform	DO	pH	TSS	Temperature	Turbidity	TP	TN
Idylwood Creek	2017	59	Moderate	48	81	91	88	85	86	61	93
Idylwood Creek	2016	58	Moderate	40	79	93	90	85	92	73	96
Idylwood Creek	2015	58	Moderate	42	81	92	84	81	88	83	100
Idylwood Creek	2014	64	Moderate	55	77	93	84	77	85	76	100
Idylwood Creek	2008	63	Moderate	41	79	92	98	84	92	80	100
Idylwood Creek	2007	23	Moderate	21	60	95	65	75	59	53	57
Idylwood Creek	2006	60	Moderate	42	77	80	92	81	92	74	97
Idylwood Creek	2005	56	Moderate	43	67	91	93	74	92	81	99
Idylwood Creek	2004	58	Moderate	53	71	92	100	71	98	86	88
Idylwood Creek	2003	55	Moderate	46	67	96	99	74	95	85	96
Idylwood Creek	2002	-	-	-	-	-	-	-	-	-	-
Idylwood Creek	2001	56	Moderate	36	79	83	96	80	96	60	99
Idylwood Creek	2000	29	Moderate	8	79	88	68	81	66	58	72
Idylwood Creek	**Median**	**58**	**Moderate**	**43**	**77**	**92**	**90**	**81**	**92**	**76**	**97**

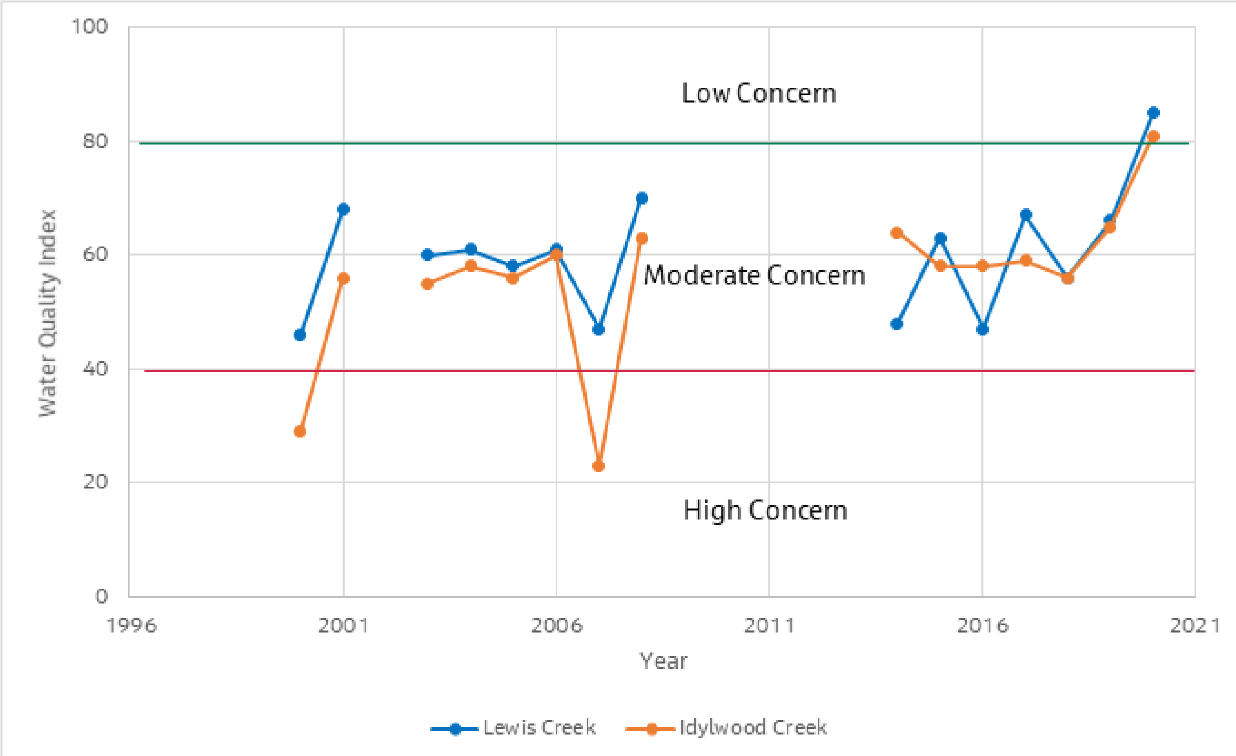


Figure 32. Water Quality Index Scores

2.3.3 Groundwater Quality

The South Sammamish Area has the highest density of parcels that are connected to septic systems, while the Vasa Creek Subbasin has the largest total number of septic systems. In total there are 218 acres of parcels presumed to be managed by septic systems across the Lake Sammamish Watershed. Septic systems that are improperly maintained or that have fallen into disrepair may contaminate groundwater sources. Failing septic systems can cause groundwater to have toxic concentrations of nitrogen, phosphorous, and or fecal coliform. While existing septic systems are mapped, there is no information available on the number and location of these septic systems that may be failing.

The presence of drinking water wells in the City portion of the Lake Sammamish Watershed stresses the importance of groundwater quality. In Washington state, Group A drinking systems —including groundwater wells— are defined as systems which have 15 or more service connections or serve 25 or more people 60 or more days per year, while Group B systems serve fewer than 15 connections or 25 people per day, and Group D wells are used for irrigation only (Washington State Department of Health 2022). Although there are no Group A wells registered with King County, records indicate that there are several Group B wells within the watershed and many Group D wells. The presence of Group B wells in the Lake Sammamish Watershed makes groundwater quality a high priority, as some water systems use groundwater as source for potable water. No additional ground water quality information was found to assess the quality of the groundwater for the Lake Sammamish Watershed.

2.3.4 Riparian Corridor

Riparian corridors are complex ecological systems located at the land-water interface adjacent to streams, rivers, lakes, ponds, and wetlands. Riparian corridors serve important functions related to nutrient cycling, soil and bank stabilization, soil and water chemistry and quality, interception of rainfall, and terrestrial and aquatic habitat. As described in the conceptual model (Figure 2), reductions in riparian corridor width and loss of riparian vegetation due to urbanization is associated with decreased large woody material inputs, decreased riparian habitat, decreased rainfall interception, and increased bank instability and stream temperatures.

Tree canopy cover and impervious cover in the riparian corridor of the Lake Sammamish Watershed was assessed based on land cover data from 2013 and 2017, including the area within 100 feet on both sides of the stream (Bellevue 2018) for all (at least partially open stream reaches) in each subbasin (excluding reaches that are completely piped or those that were not assigned a SegmentID in the City's GIS database). Within the Lake Sammamish Watershed, riparian tree canopy cover across subbasins ranges from a low of 55.9 percent in Phantom Creek Subbasin to a high of 85.3 percent in the Ardmore Area/Idylwood Creek Subbasin (Table 14). In addition, riparian impervious cover across subbasins ranges from a low of 1.1 percent in Ardmore Area/Idylwood Creek Subbasin to a high of 17.7 percent in the South Sammamish Area. On average, riparian cover in the Lake Sammamish Watershed is better than in the Greater Kelsey Creek Watershed but lower than in the Coal Creek Watershed. These riparian cover percentages are indicators of overall stream condition. The OSCA summary in Appendix B summarizes how riparian cover varies at the reach level. Developed areas tend to have less riparian canopy cover and greater impervious surface. Parks and green spaces typically have greater riparian canopy cover and less impervious surface. Areas where the terrain inhibits development, such as the steep ravines in the Lake Sammamish Watershed, also tend to have better riparian canopy and less impervious cover.

Table 14. Riparian Canopy Cover and Riparian Impervious Surface Cover in the Bellevue Portion of the Lake Sammamish Watershed by Subbasin

Subbasin / Area	Riparian Canopy Cover (%)	Riparian Impervious Surface Cover (%)
Lewis Creek Subbasin	64.8	17.2
Vasa Creek Subbasin	65.8	13.2
Ardmore Area/Idylwood Creek Subbasin	85.3	1.1
Redmond 400 Area	Not Applicable*	Not Applicable*
Rosemont Area	Not Applicable*	Not Applicable*
Wilkins Creek Subbasin	70.3	9.1
North Sammamish Area	76.1	10.2
Phantom Creek Subbasin	55.9	16.5
Spirit Ridge Area	Not Applicable*	Not Applicable*
South Sammamish Area	62.8	17.7

* = This Lake Sammamish subbasin or area does not contain perennial open streams

In addition to the quantity of riparian cover, the quality of riparian cover is also important. Throughout the Lake Sammamish Watershed, OSCA surveys note that stream reaches within residential areas generally exhibit less canopy cover (Bellevue 2022). Within the Lewis Creek and Vasa Creek Subbasins, riparian vegetation is predominantly composed of a canopy of mixed conifers, Red Alder (*Alnus rubra*), and big leaf maple (*Acer macrophyllum*), with an understory of vine maple (*Acer circinatum*), salmonberry (*Rubus spectabilis*), Devil's club (*Oplopanax horridus*), and ferns. Within the lesser tributaries to Lake Sammamish, riparian vegetation has been generally conserved because these streams tend to be located in steep ravines with minimal adjacent development. In these riparian corridors, the canopy is generally composed of Douglas fir (Pseudotsuga menziesii), western red cedar (Thuja plicata), and big leaf maple, with an understory including vine maple, salmonberry, and sword fern.

Across the Lake Sammamish Watershed, invasive species such as Himalayan blackberry and English ivy (*Hedera helix*) can become very dense. Overall, within the Lewis Creek Subbasin, such invasive species are less dominant compared to the other subbasins in the City (Bellevue 2022). In areas where invasive plants are prevalent with sparse canopy cover, increased coniferous species and riparian diversity are needed to reduce the extents of invasive and noxious vegetation. This would aid in development of a sustainable forest canopy and provide natural recruitment of large woody material to the stream channels (Bellevue 2022).

2.3.5 Instream Habitat

Instream habitat conditions for Lewis Creek Subbasin and Vasa Creek Subbasin, Lake Sammamish's lesser tributaries (including Idylwood Creek, Wilkins Creek, Phantom Creek, and two unnamed tributaries in the Vasa Creek Subbasin and South Sammamish Area designated as Sammamish Tributary 0160 and 0162, respectively) were surveyed during the OSCA survey efforts in 2018 through 2020 (Bellevue 2022). The data presented here in this AR are summarized at the watershed level. Stream- or subbasin-level summaries can be found in Appendix B and detailed stream reach-level summaries will be included in the forthcoming Lake Sammamish Watershed OSCA Reach Reports (expected in 2022, currently under development by the City).

2.3.5.1 Channel Morphology

Channel morphology, or the shape of the channel, is described by a variety of metrics, such as the width and depth of the channel, the bed material size and overall bed form (cascade, riffle/pool, etc.), floodplain height and characteristics, bank materials and stability, sinuosity, bar formation. This morphology is the result of the interaction of three principal landscape drivers – hydrology, sediment supply, and vegetation (Barnard *et al.* 2013). Native species have evolved over time to utilize habitat that results from natural channel morphologies. Human alterations to the landscape have often resulted in changes to the landscape drivers, which in turn have changed the channel morphology, often to the detriment of stream habitat. In an urbanized setting such as the Lake Sammamish Watershed, understanding the present channel morphology and how it differs from a more natural morphology can help identify the extent to which the channel has been altered by human activity, and provide insight into what might be done to restore it to a condition more beneficial as habitat for native species and resilient to a changing climate.

A combination of non-typical topography and human alterations makes it difficult to neatly classify the sediment dynamics of the streams using the Montgomery and Buffington (1993) categories of Source, Transport, and Response. Source reaches are reaches where sediment erosion is the dominant factor, and therefore where sediment largely originates (typically in steep headwater areas). Transport reaches are reaches where erosion and deposition are generally in balance, and sediment largely passes through over time. Response reaches are reaches where sediment deposition is the driving factor of stream morphology and where sediment tends to accumulate or be deposited. Human alterations have created the need for a few additional classifications, such as "Forced Transport", "Transport/Source", and simply "NA" to describe channels that would not fit into other typical categories.

Streams in the Lake Sammamish Watershed are generally characterized as high gradient channels confined by ravines. Lewis Creek and Vasa Creek have average gradients between 7.3 percent and 7.5 percent, which is higher than most streams in the City, but lower than most of the OSCA-surveyed streams in the Watershed, which range up to 10 percent. (The streams that were not surveyed as part of the OSCA efforts may have even steeper gradients.) As a result of the steep gradients and bank slopes, source and transport reaches make up nearly 70 percent of the channels classified. The steep slopes of the ravines that convey streams in the Lake Sammamish Watershed have also discouraged development which has protected riparian vegetation.

The prevalence of naturally erosive soil types at the ground surface sitting above consolidated glacial material present opportunities for soil slippage and high erosion potential in those reaches that are steep. Other common sources of erosion and sediment supply in the watershed result from streambank and terrace erosion, streambed and bar incision, and hydrologic changes from land clearing activities and development. The existing geomorphic conditions within the Lake Sammamish Watershed are a product of the topography, geology and soil conditions, combined with the hydrologic changes and hydromodifications associated with land use and land cover change within the last century.

The most pertinent geomorphic characteristics of each of the subbasins in the Lake Sammamish Watershed are summarized in Table 15.

Table 15. Geomorphic Characterizations by Subbasin within the City of Bellevue portion of the Lake Sammamish Watershed

Subbasin	Geomorphology Characterization
Lewis Creek	▪ Among the higher gradient fish-bearing streams in Bellevue, but also among the healthiest streams in the City.
	▪ Includes the Lakemont Stormwater Filtration and Detention Facility, which treats over 250 acres of runoff to remove phosphates and other pollutants and attenuate peak flows.
	▪ Primarily cascade and plane-bed channel forms. Because cascade channels are classified as riffle habitat units, riffle habitat is the dominant habitat in the Lewis Creek Subbasin.
	▪ Second lowest pool frequency in Watershed and third lowest in City, but cascade reaches have numerous small "pocket pools" that don't qualify as pools in the habitat assessment protocol but provide good habitat.
	▪ Mainstem has generally good riparian conditions due to combination of residential development and two large greenspaces.
	▪ Streambed materials are among coarsest in the City, with 33% cobble and 22% boulder. 17% fines is lowest in the City, and 2% streambank armoring is also lowest in the City.
Vasa Creek	▪ Somewhat lower gradient than other Lake Sammamish Watershed streams, but still twice the average gradient of other Bellevue streams.
	▪ Dominated by cascade and plane-bed channel forms, with numerous anthropogenic grade control structures and the highest density of fish passage barriers in the City.
	▪ Riffle habitat dominates, and pool frequency is average for the City, with pools commonly associated with channel alterations (weirs, culverts, etc.).
	▪ Nearly 20% of the mainstem channel length is piped.
	▪ Big large woody material results in highest volume of wood per mile in the City, but still well below target.
	▪ Prevalence of bank erosion is about average for the City, but more than 20% of erosions is from banks 10 feet or higher.
	▪ Substrate dominated by gravel upstream of I-90 and fine gravel downstream of I-90, with percentage of fines generally lower than other streams in the City .

Lesser Tributaries to Lake Sammamish	Includes Ardmore Area/Idylwood Creek Subbasin, Phantom Creek Subbasin, and South Sammamish Area (the lesser tributaries to Lake Sammamish that were surveyed as part of the OSCA efforts).
	▪ Typically, high-gradient, well-vegetated ravines.
	▪ Morphologies vary from plane-bed to cascade to bedrock.
	▪ Riffle habitat dominates, and pool habitat, where present, is associated with hydraulic drop or pocket pools scoured into hardpan and are small, with depths ranging from 0.6 to 1.1 feet.
	▪ Virtually no off-channel habitat due to channel gradients and steep-walled ravines that house the channels.
	▪ Moderate to low levels of large woody material, with most reaches well below reference levels, and nearly all of it natural in origin.
	▪ Substrate is variable, generally decreasing in size with stream gradient. Methodology likely underreports boulder and hardpan, which are important factors in these streams.

2.3.5.2 Habitat Unit Composition and Off-Channel Habitat

Riffle habitat dominates in the Lake Sammamish Watershed, in large part because cascade channels, which are common in the steep channel of the watershed, are classified as riffle habitat. As a result, Lewis Creek has the second highest proportion of riffle habitat (83 percent) in the City, after Newport Creek Subbasin (91 percent). Within the Lake Sammamish Watershed, pool habitat varies. The Lewis Creek Subbasin has just 2 percent of habitat classified as pool habitat, with 6 pools per mile, and the Phantom Creek Subbasin has just 2 pools per mile. Lewis Creek has pools in its cascade habitat that don't qualify as pools based on the protocol employed during the OSCA surveys, but still provide the function of pools. By contrast, the Ardmore Area/Idylwood Subbasin has 58 pools per mile, which is among the highest pool frequency in the City. Most of these pools are pocket pools in hardpan. Contrastingly, Phantom Creek Subbasin (2) has the least number of pools per mile in the City, along with Newport Creek Subbasin (2).

Based on information obtained from OSCA survey efforts, the median residual pool depth in the Lake Sammamish Watershed is 1.0 feet. This is less than what is considered "properly functioning" (NOAA 1996).

Given the generally steep topography in the Lake Sammamish Watershed, off-channel habitat is naturally limited, and restoring lost off-channel habitat where possible is an important consideration. Observations during the OSCA surveys indicate that there are opportunities to improve off-channel habitat and access by reconnecting the channel with its floodplain. Specifically, within Lewis Creek mainstem Reaches 4 and 5 and Tributary 0162K Reach 1, installing large woody material would allow natural stream processes to reconnect the floodplain.

Figures 33 and 34 show the habitat unit composition by percent area and percent length, respectively, within Lewis Creek. This information is only available for Lewis Creek because a reduced survey level was used for the smaller streams. Note that these data are not necessarily representative of the Lake Sammamish Watershed.

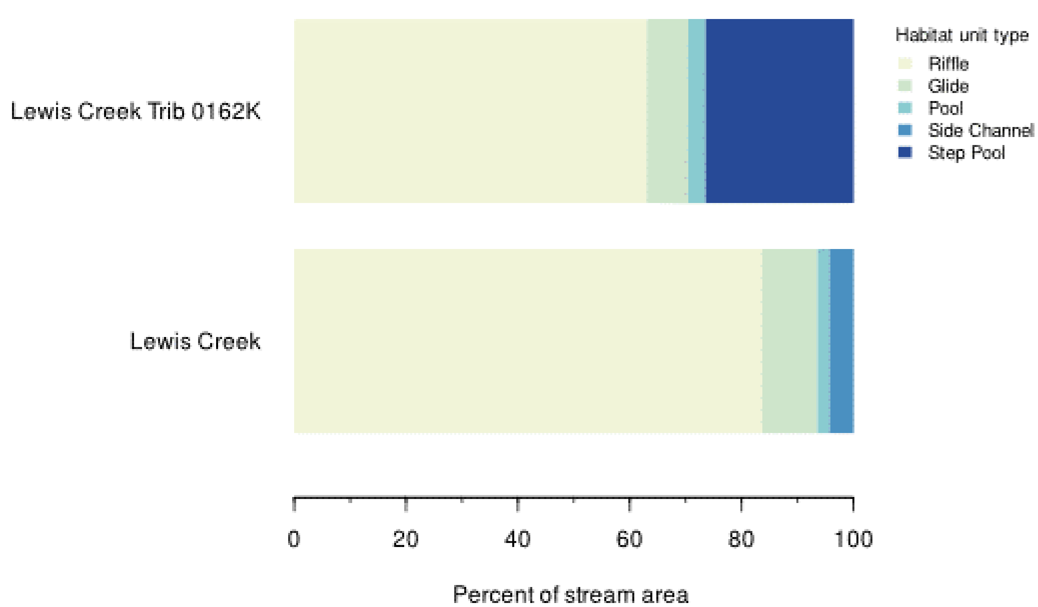


Figure 33. Habitat Unit Composition (by percent area) of Lewis Creek

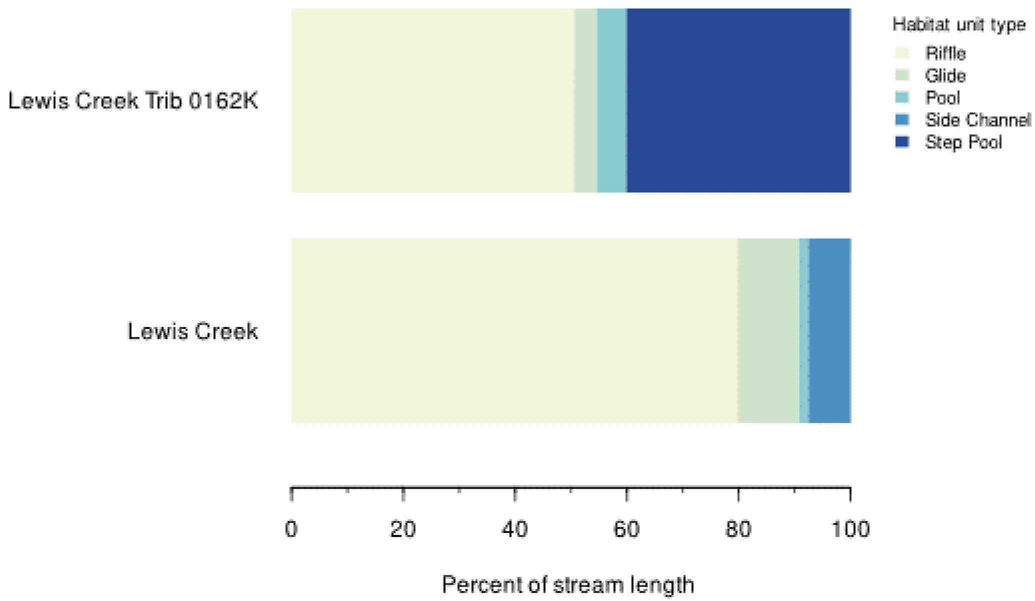


Figure 34. Habitat Unit Composition (by percent length) of Lewis Creek

2.3.5.3 Large Woody Material

Despite moderately high frequencies of large woody material (LWM) found in the streams of the Lake Sammamish Watershed (as compared to the Greater Kelsey Creek and Lake Washington watersheds), levels still fall below reference conditions. Within the Lake Sammamish Watershed, most large woody material is found within wetted and bankfull stream zones. Overall, the watershed has an average of 301 pieces of wood per mile of stream.

Within the Lake Sammamish Watershed, the Vasa Creek Subbasin (within OSCA-surveyed reaches upstream of I-90) has the highest concentration of LWM at 356 pieces per mile, which is the third highest abundance of LWM found in the City (following Coal Creek and Newport Creek subbasins), along with the greatest volume of wood per mile within the City (at 9,624 cubic feet per mile). The Lewis Creek Subbasin has the second greatest concentration of LWM per mile, at 325 pieces. These moderately high concentrations and volume of wood can be attributed to the more mature riparian vegetation found in these two subbasins. The Wilkins Subbasin has the lowest LWM abundance in the City portion of the Lake Sammamish Watershed.

Almost all pieces of wood observed in the Lake Sammamish Watershed were presumed to be of natural origin, which can be attributed to the fact that the watershed overall has an intact and relatively mature riparian canopy. This riparian canopy includes mixed conifers, alder, and big leaf maple which provide natural LWM recruitment. Using percent riparian tree canopy cover as a surrogate for recruitment potential, the Ardmore Area (85.3 percent), North Sammamish Area (76.1 percent), and Wilkins Creek Subbasin (70.3 percent) have the highest recruitment potential, while the Phantom Creek Subbasin (55.9 percent) has the lowest recruitment potential. The other subbasins range between 63.8 and 64.8 percent. Despite an overall dense forested canopy throughout the watershed, there are areas within the subbasins that could be enhanced to remove non-native vegetation and ensure the potential for natural LWM recruitment in the future.

Figure 35 shows the frequency of large woody material in the Ardmore Area/Idylwood Subbasin, Lewis Creek Basin, Vasa Creek Subbasin, South Sammamish Area, Phantom Creek Subbasin, and Wilkins Creek Subbasin, as compared to reference levels.

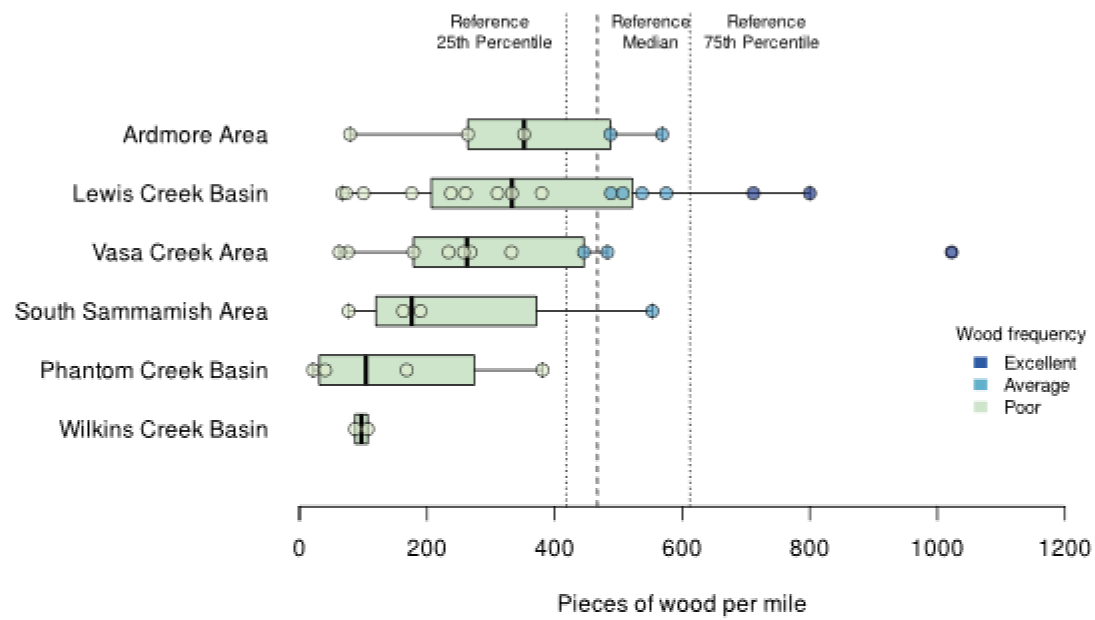


Figure 35. Large Woody Material Frequency in the surveyed Lake Sammamish tributaries compared to reference levels (Fox and Bolton 2007)

2.3.5.4 Substrate Conditions

Overall, substrate composition within the Lake Sammamish tributaries is dominated by gravels and cobble. The watershed has a higher proportion of boulders and exposed bedrock/hardpan and a lower proportion of fines as compared to the other watersheds in the City. Streambed substrate composition within the Lewis Creek and the lesser tributaries to Lake Sammamish are varied, while the Vasa Creek is dominated by gravels.

The Lewis Creek Subbasin maintains some of the coarsest substrate observed in the City during OSCA survey efforts. Within riffle habitats in reaches surveyed, the substrate was composed of 33 percent cobble, 24 percent gravel, 22 percent boulders, 17 percent fines and 3 percent glacial till (Bellevue 2021). This low proportions of fines makes reaches within the Lewis Creek Subbasin ideal for gravel-spawning fish such as resident trout and migratory salmonids.

The Vasa Creek Subbasin has highly variable streambed substrate. Upstream of I-90, streambed substrate is dominated by gravels, with levels of fines observed being lower than other City subbasins (OSCA 2021). Gravels also dominate streambed substrate observed downstream of I-90, where coarser substrate is often a result of streambank armoring or large angular rocks positioned as weirs for grade control. Within multiple reaches of Vasa Creek, streambeds showed scouring down to hardpan glacial till, which was particularly noticeable within the mainstem of Reach 11 and in the East Tributary Reach 3. According to a 2014 assessment of Vasa Creek fish habitat between the mouth of Vasa Creek and the I-90 crossing, substrates ranged from fines to cobbles, but the dominant substrate type is fine gravel (City of Bellevue 2014b). Boulders placed for bank protection were commonly observed.

Within the lesser tributaries to Lake Sammamish surveyed during OSCA efforts, including Idylwood Creek (within the Ardmore/Idylwood Area), Wilkins Creek, Phantom Creek, and Sammamish Tributaries 0160 and 0162 (within the South Sammamish Area), streambed substrate composition is varied. Despite this variation, the percent of fines tended to be inversely proportional to the streambed gradient (i.e., low gradient reaches often had a higher proportion of fines. Due to a relatively small sample size and profiles being taken in riffle habitat in order to avoid boulder cascades where possible, the City found that the extent of hardpan is likely underestimated and substrate composition likely slightly biased towards smaller substrate class sizes. Out of these lesser tributaries to Lake Sammamish, Phantom Creek (which has the lowest gradient) and Wilkins Creek (non-fish bearing) have the highest proportion of fines.

Figure 36 shows the substrate composition of rifle habitat for surveyed reaches within the Lewis Creek mainstem and Lewis Creek Tributary 0162K.

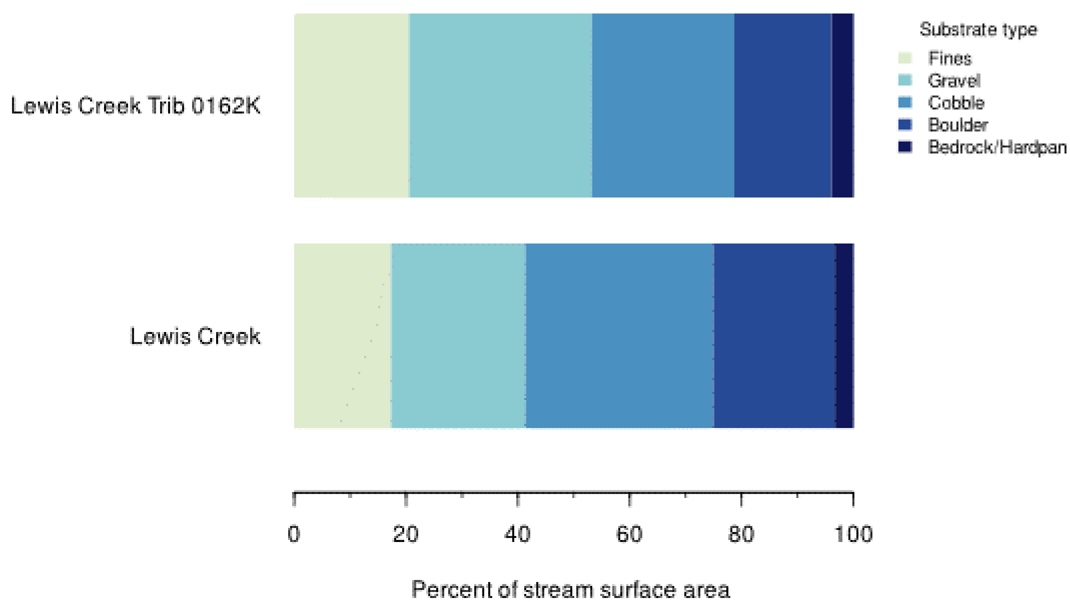


Figure 36. Substrate Composition of Riffle Habitat in Surveyed Reaches of Lewis Creek

2.3.5.5 Streambank Conditions

Streambank armoring and erosion varies throughout the Lake Sammamish Watershed. OSCA survey efforts gathered information related to armoring percentage, composition, erosion, and undercutting with the Lewis Creek Subbasin, Vasa Creek Subbasin, and lesser tributaries to Lake Sammamish, including those within the Ardmore Area, Phantom Creek Subbasin, South Sammamish Area, and Wilkins Creek Subbasin. In surveyed reaches throughout the watershed, armoring covers an average of 7% of the streambanks while 13% of the streambanks are eroding and 6% are undercut.

The Lewis Creek Subbasin presents the least amount of streambank armoring observed in the City. Throughout the OSCA-surveyed reaches, just 2 percent of streambanks in the Lewis Creek Subbasin are armored, with two-thirds of the OSCA-surveyed reaches exhibiting no armoring. Armored streambanks in this subbasin are generally associated with residential land use and the armoring is composed of traditional or "hard" armoring, made up of pieces of concrete or large angular rock. Streambank erosion within the Lewis Creek Subbasin is fairly low, with 10 percent exhibiting erosion and 5 percent of streambanks showing undercutting. This is the lowest percentage of erosion in the Lake Sammamish Watershed and lower than average across subbasins City-wide. However, there is evidence of mass wasting events in the Lewis Creek mainstem (Reaches 4 through 6) and in Tributary 0162D (Reach 1), as well as localized streambed scour and head cutting in Tributary 0162K (Reach 1), which is likely associated with a stormwater outfall.

Within OSCA-surveyed reaches of the Vasa Creek Subbasin, streambank armoring is around the average for subbasins in the City. Most of this is traditional armoring, but 2 percent of the streambank, associated with the Horizon Heights Open Space, is bioengineered with materials like wood and rock weirs (consisting of logs, root wads, and large boulders) placed along the streambank. In general, Vasa Creek has a higher amount of armoring that is greater than 5 feet in height as compared to other subbasins in the City. Streambank erosion varies within this subbasin. Upstream of I-90, erosion is intermittent and ranges from low scour and channel incision to large areas of mass wasting. Across the OSCA-surveyed reaches within the Vasa Creek Subbasin, 14 percent of streambanks exhibit erosion and 6 percent show undercutting. Vasa Creek Subbasin is experiencing some larger scale erosion issues, with more than 3 percent of the streambank showing erosion greater than 10 feet in height. This erosion is associated with mass wasting events that have been observed within the upper portion of Reach 4 and in Reach 5, near the confluence with the East Tributary.

The lesser tributaries to Lake Sammamish have highly variable levels of armoring, but armoring is most prevalent in residential areas. The Phantom Creek Subbasin and South Sammamish Area have a higher-than-average proportion of armored streambanks, at 17 percent and 18 percent, respectively. Contrastingly, the Ardmore Area has some of the least armoring observed in the City, with just 2 percent of streambanks armored. Generally, streambank armoring consists of large angular rocks or chunks of concrete, less than 5 feet in height. Corresponding to varying levels of armoring is variable levels of streambank erosion within the lesser tributaries to Lake Sammamish, ranging from 0 percent to 33 percent. The Ardmore Area exhibits the highest amount of erosion (21 percent) within the Lake Sammamish Watershed.

In the Lake Sammamish Watershed, the vertical extent of the erosion is generally greater than what is observed in the rest of the City. This is because a majority of these streams are incised into steep ravines, allowing for scour from high flows to result in greater bank instability.

Figure 37 shows the proportion of armored streambank for traditionally armored streambank versus bioengineered armoring for surveyed reaches within the Lake Sammamish Watershed. Figure 38 shows the percent of each surveyed reach within Lake Sammamish that is experiencing erosion.

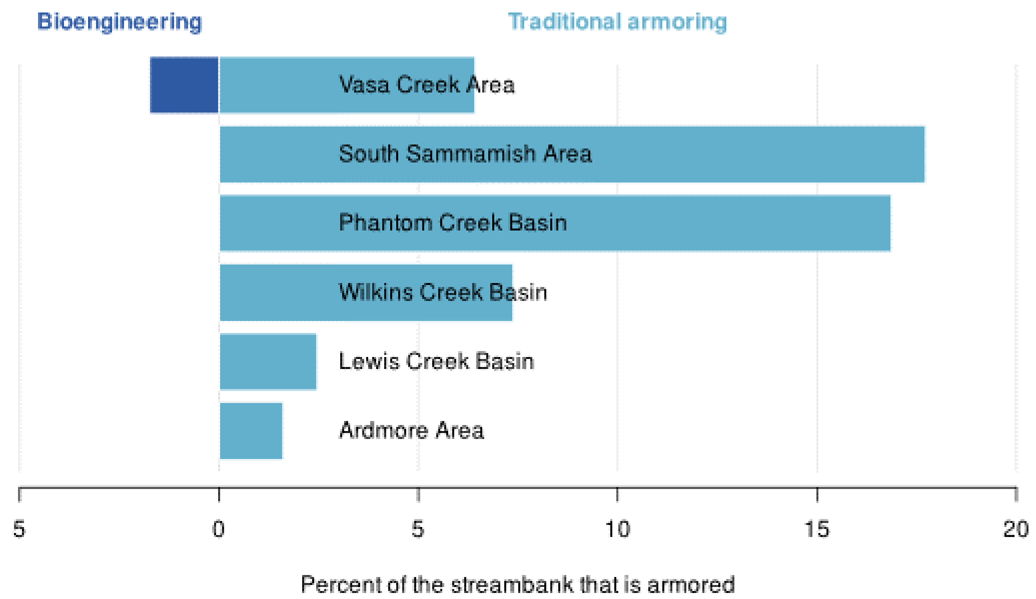


Figure 37. Proportion of Armored Streambank in Surveyed Lake Sammamish Tributaries

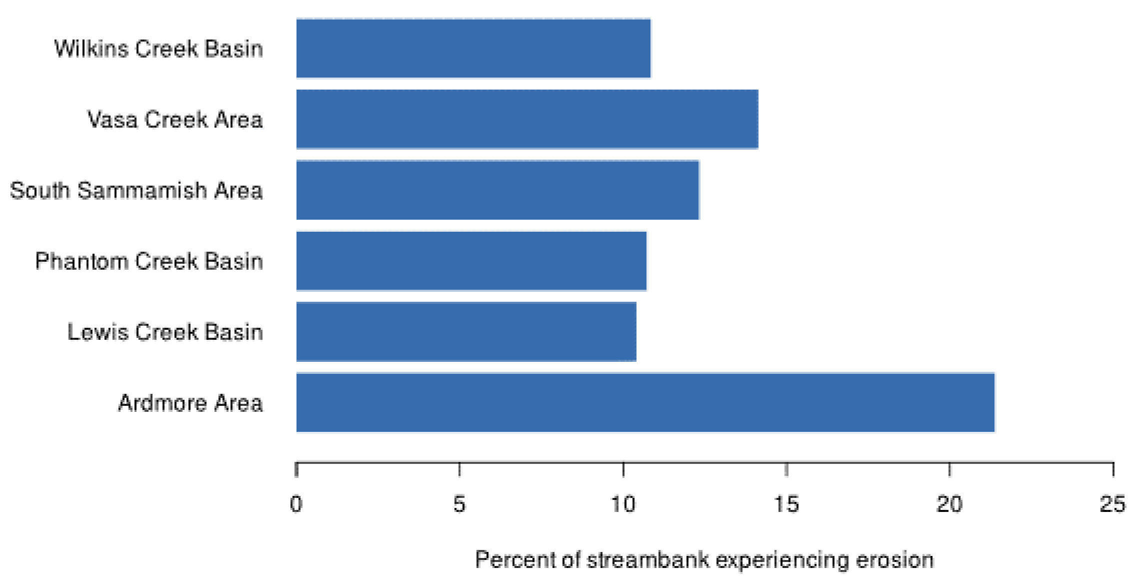


Figure 38. Percentage of Surveyed Lake Sammamish Tributaries that are Experiencing Erosion

2.3.5.6 Fish Habitat and Passage Barriers

The high gradient channels and ravines within the Lake Sammamish Watershed (as well as manmade fish passage barriers) limit fish use in Lake Sammamish Watershed. The quality of fish habitat throughout the watershed is variable, ranging from good to poor, with some subbasins/areas containing no suitable habitat (i.e., Wilkins Creek Subbasin). Fish habitat and use has been best documented in the Lewis Creek and Vasa Creek subbasins, with OSCA survey efforts aiding in information related to other subbasins/areas in the watershed.

The quality of fish habitat in the Lake Sammamish Watershed is moderately variable and ranges from good to poor. During OSCA surveys, fish were most abundant in Lewis Creek pocket pools found within riffle and cascade habitat, yet few fish observations were made throughout the remaining watershed. Fish observations during OSCA surveys and a Tetra Tech habitat assessment were made in the mainstem of Lewis Creek, the portion of Vasa Creek downstream of the I-90 crossing, Idylwood Creek, and the outlet of Phantom Lake. The highest quality fish habitat in the watershed is found in Lewis Creek, due to this system's channel complexity, instream cover, healthy riparian vegetation, and streambed substrate (which contains a low proportion of fines, ideal for gravel-spawning fishes). High gradients found throughout the watershed limit wetlands and adjoining floodplains which provide valuable fish habitat (including adequate shade, channel complexity, consistently deep water).

High gradients found in subbasins/areas within the Lake Sammamish Watershed limit fish passage and habitat for both resident fish and migratory salmonids. Regional studies suggest that gradients of 5 to 7 percent may represent a threshold for some Pacific salmon, particularly Coho Salmon (Burett *et al.* 2007; Seixas *et al.* 2019). The subbasins/areas within the Lake Sammamish Watershed have some of the highest gradients in the City, which contributes to just 5 out of the 10 subbasins/areas containing potentially fish-bearing streams. Average stream gradient of surveyed reaches throughout the Lake Sammamish Watershed ranges from 7.3 percent (Lewis Creek Subbasin) to 10 percent (South Sammamish Area). These gradients are above the upper limit of suitable habit for some salmonids and over twice the average gradient for streams throughout the City. Additionally, although streambed gravels suitable for salmonid spawning (i.e., streambed material containing a low proportion of fines) can be found within the Lewis Creek and Vasa Creek Subbasins, a high proportion of fine substrate is present within reaches of Phantom Creek, Wilkins Creek (which is non-fish-bearing) and some reaches of Idylwood Creek and its tributaries, which inhibits successful spawning and incubation. The most suitable spawning gravels with a low proportion of fines are in Lewis Creek and Vasa Creek.

Throughout the Lake Sammamish Watershed, many factors impact the quality of fish habitat. Limited habitat complexity and the general lack of quality pool habitat is likely resultant from channel confinement (primarily attributed to topography), low frequency of LWM, and altered hydrology associated with urban development. Summer low-flow barriers may make some habitat seasonally unfavorable; this may be a particular challenge within portions of the Lewis Creek Subbasin, Vasa Creek Subbasin, and South Sammamish Area. Additionally, monthly water quality samples recorded by King County within Lewis Creek (median temperature of 10.4 degrees Celsius) and Idylwood Creek (median temperature of 12.7 degrees Celsius), documented temperatures high enough to constitute a water temperature violation per Ecology's 303(d) list (at a median temperature of 10.4 degrees Celsius and 12.7 degrees Celsius, respectively) (King County 2016b, King County 2016c). Information related to temperature is limited within other subbasins/areas. The amount of overhanging vegetation and quality edge habitat beneficial to fish species varies throughout the watershed. Generally, residential areas have less canopy cover, which aligns with the fact that the Lewis Creek Subbasin (which includes Lewis Creek Park and has the lowest percent impervious surface of all the subbasins/areas within the watershed) has the highest amount of healthy vegetation and overhanging vegetation observed during OSCA survey efforts.

There are multiple barriers that impede fish movement and habitat access in the Lake Sammamish Watershed. These barriers include built infrastructure (culverts, weirs, etc.), natural barriers, and natural processes likely exacerbated by human actions. Namely, steep gradients (oftentimes in conjunction with other limiting factors such as modification and piping, fish barriers, and low water flow) limit fish use.

Piped stream channel makes up a great deal of the length of Vasa Creek, Wilkins Creek, and streams in the South Sammamish Area within the Lake Sammamish Watershed. Based on the generally steep topography, which limits the formation of wetlands, barriers caused by beaver activity are rare.

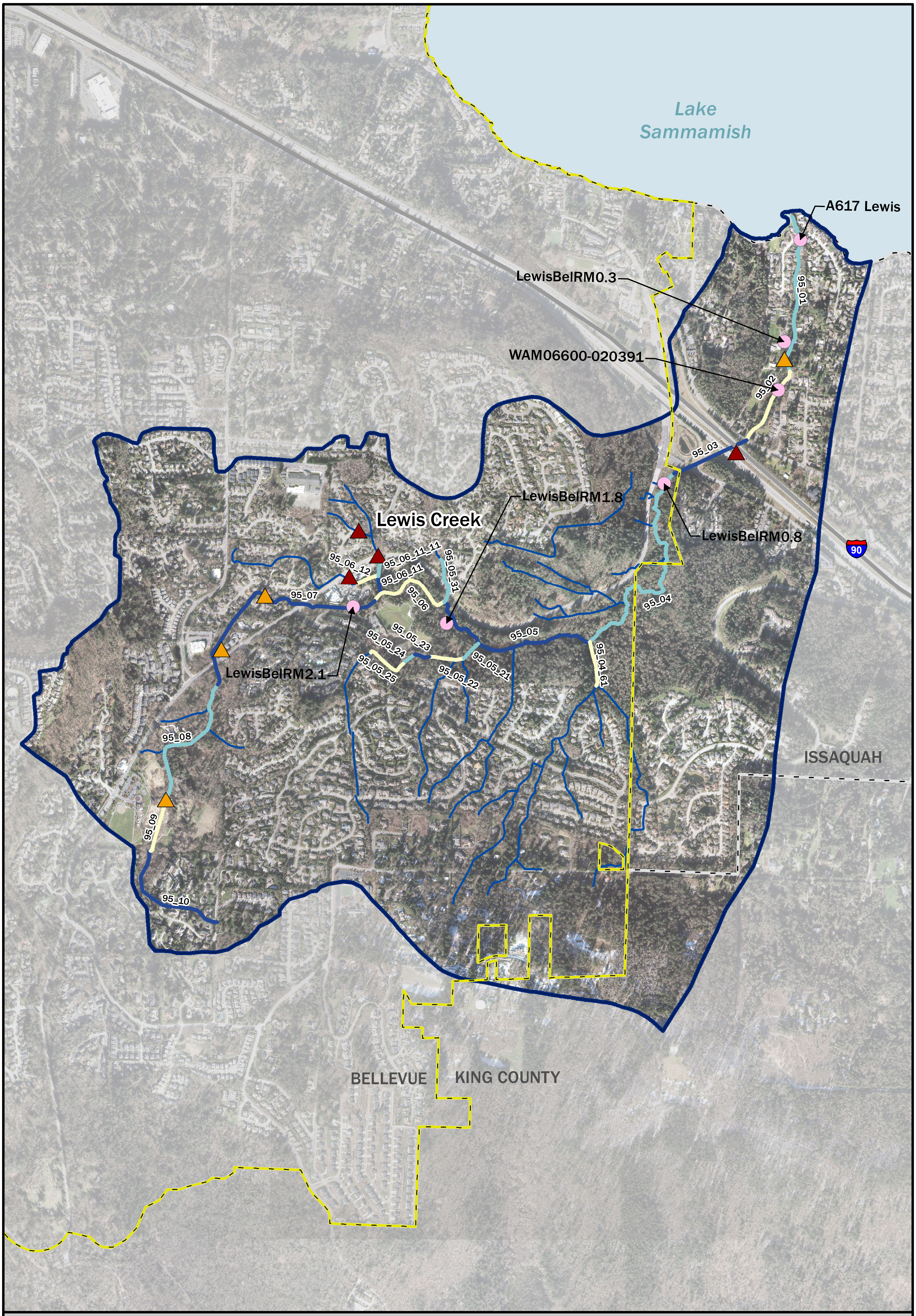
Most fish passage barriers in the Lake Sammamish Watershed are associated with built infrastructure. WDFW has formally documented 8 partial barriers and 30 complete barriers within streams throughout the watershed, although a complete inventory of all culverts and other potential barriers has not been conducted (WDFW 2021c). The culverts beneath I-90 are barriers to migratory and resident fish within many stream systems in the watershed (Lewis Creek, Vasa Creek, Tributary 0160 and Tributary 0162). The Lewis Creek I-90 culvert is scheduled to be replaced with bridges by WSDOT beginning in 2024, which will restore fish passage to migratory species (including Chinook, Coho, and Sockeye salmon) as well as kokanee and steelhead (Bellevue 2022). Of the remaining documented barriers, 14 are listed as being owned by the City and are primarily culverts at road crossings, although weirs and flow control structures also constitute barriers to fish passage. The formally documented fish passage barriers are summarized by subbasin/area in Table 16 and shown in Figures 39 through 42.

More detailed information about fish habitat and passage barriers for each subbasin in the Lake Sammamish Watershed can be found in Appendix B.

Table 16. Partial and Complete Fish Passage Barriers Documented by WDFW

Stream	Barrier Extent		Total Number of Barriers Documented by WDFW
	Partial Fish Passage Barrier	Complete Fish Passage Barrier	
Lewis Creek	4	4	8
Vasa Creek	3	20	23
Ardmore/Idylwood Subbasin (Idylwood Creek)	0	0	0
Wilkins Creek Subbasin Tributaries	0	0	0
North Sammamish Area Tributaries	0	0	0
Phantom Creek Subbasin Tributaries	0	0	0
South Sammamish Area Tributaries	1	6	7
City portion of the Lake Sammamish Watershed, Total	8	30	38

Source: WDFW 2021c



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (City of Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Highway (City of Bellevue 2020)
- Stream (City of Bellevue 2020)
- B-IBI Sample Location (Puget Sound Benthos Database 2021)

Fish Passage Barrier (WDFW 2020)

- Partial Fish Passage Barrier
- Total Fish Passage Barrier

Approximate Stream Reaches

- 95_07, 95_03, 95_05_23, 95_10, 95_06_11, 95_05
- 95_05_25, 95_04_61, 95_09, 95_06_12, 95_05_22, 95_06, 95_02
- 95_05_24, 95_08, 95_05_21, 95_05_31, 95_04, 95_06_11_11, 95_01

Note: Washington Department of Fish and Wildlife (WDFW), Benthic Index of Biotic Integrity (B-IBI), Open Streams Condition Assessment Database (OSCA). Fish Passage Barrier WDFW retrieved Feb. 24, 2021.

Figure 39. Lewis Creek Subbasin Fish Passage Barriers and B-IBI sampling locations.

N

0 550 1,100 2,200 Feet

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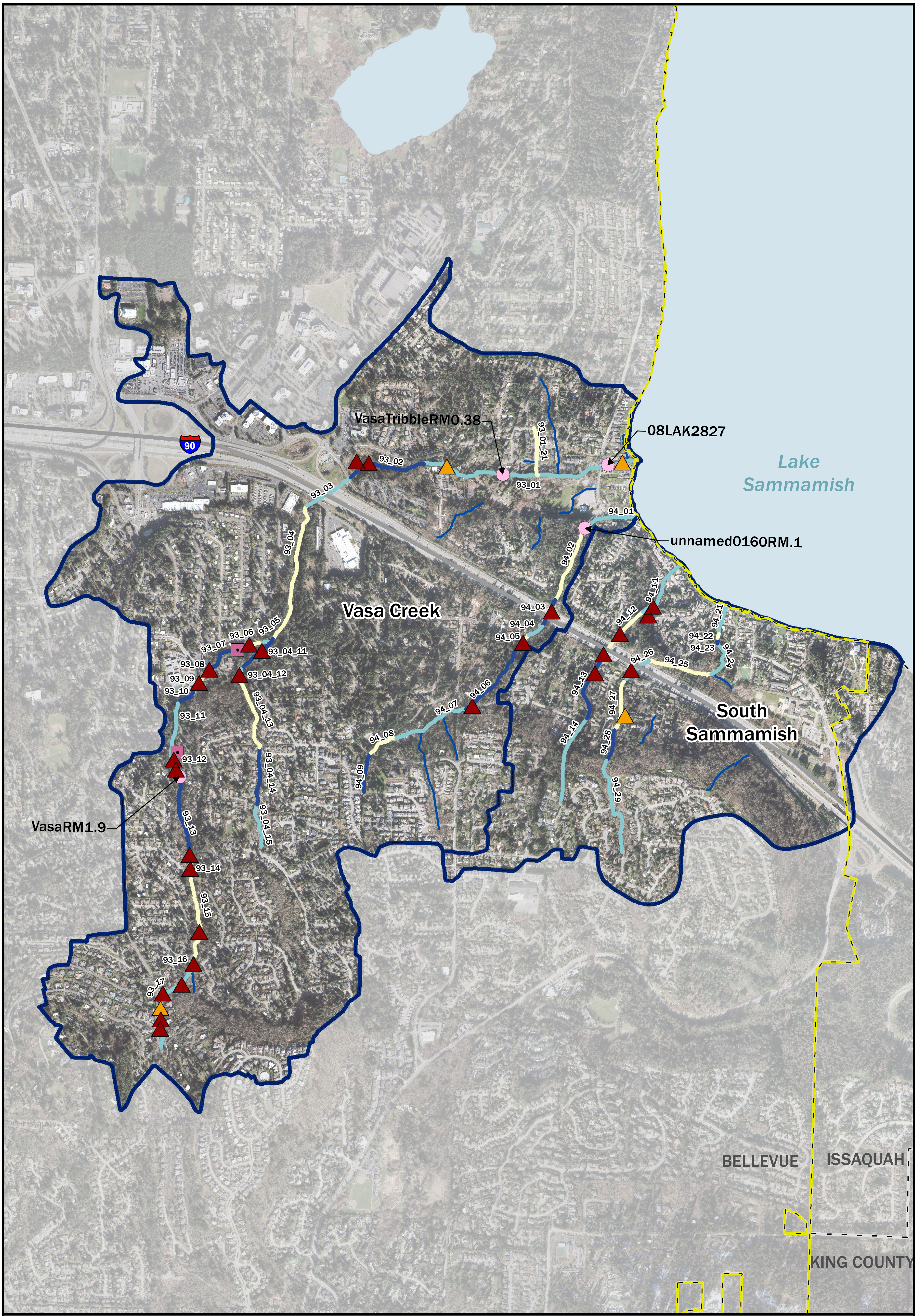


Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (City of Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Highway (City of Bellevue 2020)
- Stream (City of Bellevue 2020)
- B-IBI Sample Location (Puget Sound Benthos Database 2021)
- OSCA observed knotweed location (City of Bellevue 2020)

Fish Passage Barrier (WDFW 2020)

- Partial Fish Passage Barrier
- Total Fish Passage Barrier

Approximate Stream Reaches

- 93_10, 94_09, 93_13, 94_28, 93_04_11, 94_03, 94_13, 93_07, 94_06, 93_04_14, 94_26, 93_02, 93_16, 94_23
- 94_12, 93_04_13, 94_02, 94_05, 93_01_21, 93_04, 93_12, 93_06, 94_08, 94_22, 93_15, 93_09, 94_27, 94_25
- 93_11, 94_21, 94_11, 94_26, 94_07, 93_17, 93_04_15, 93_14, 94_24, 93_04_12, 94_01, 93_08, 93_05, 94_29, 93_01, 94_14, 93_03, 94_04

Note: Washington Department of Fish and Wildlife (WDFW), Benthic Index of Biotic Integrity (B-IBI), Open Streams Condition Assessment Database (OSCA). Fish Passage Barrier WDFW retrieved Feb. 24, 2021.

Figure 40. Vasa Creek Subbasin and South Sammamish Area Fish Passage Barriers and B-IBI sampling locations.

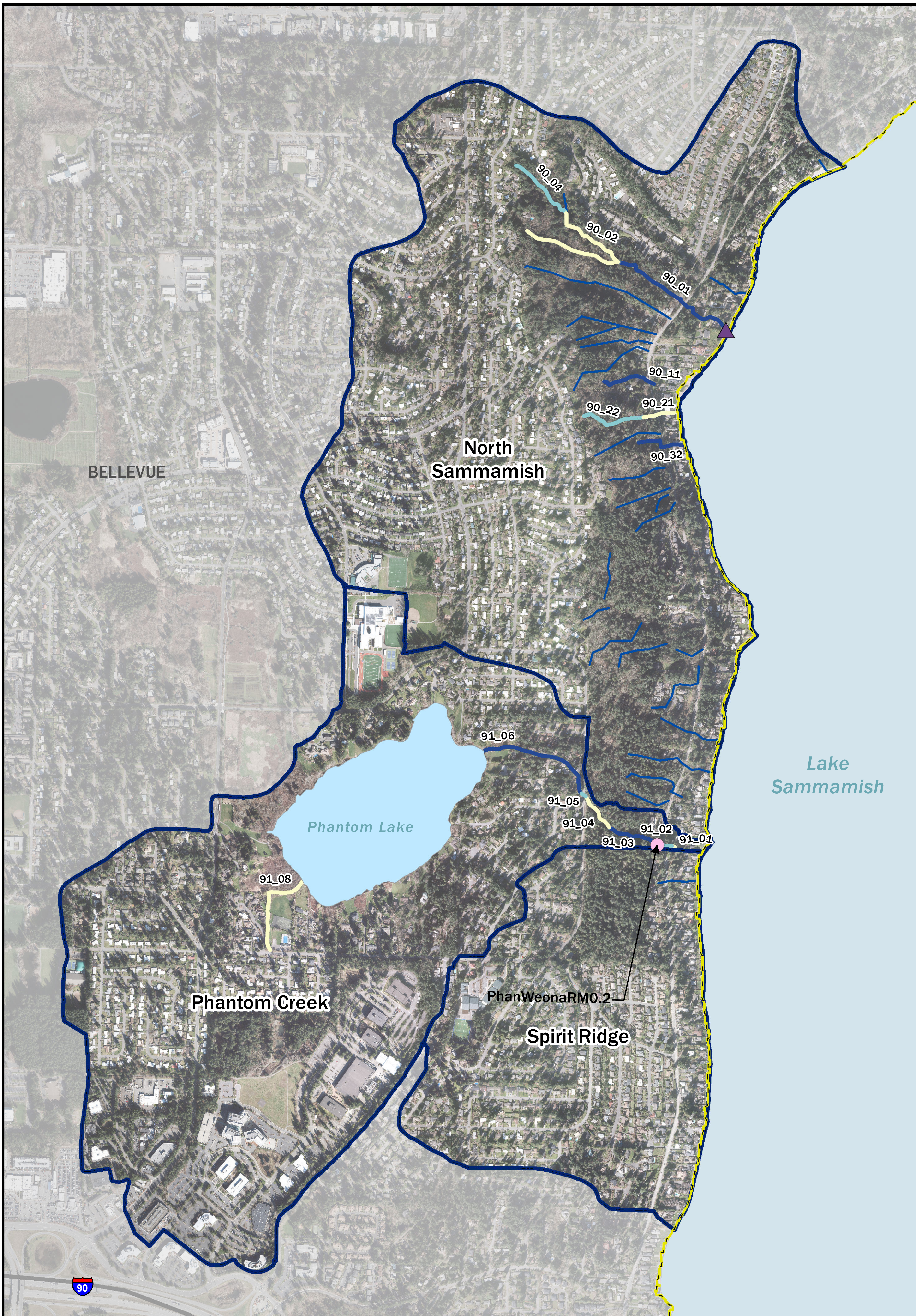
N

0 650 1,300 2,600 Feet

Jacobs

HERRERA

K:\Projects\Y2019\19-07173-001\Project\Report\LakeSammamish\LakeSammamish_StreamCondition_Vasa_SSam.mxd



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (City of Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Highway (City of Bellevue 2020)
- Stream (City of Bellevue 2020)
- B-IBI Sample Location (Puget Sound Benthos Database 2021)

Fish Passage Barrier (WDFW 2020)

- Unknown Percent Passage Barrier

Approximate Stream Reaches

- 90_32, 91_03, 90_11, 91_06, 90_01
- 91_01, 90_21, 91_04, 91_08, 90_02
- 91_02, 91_05, 90_04, 90_22

Note: Washington Department of Fish and Wildlife (WDFW), Benthic Index of Biotic Integrity (B-IBI), Open Streams Condition Assessment Database (OSCA). Fish Passage Barrier WDFW retrieved Feb. 24, 2021.

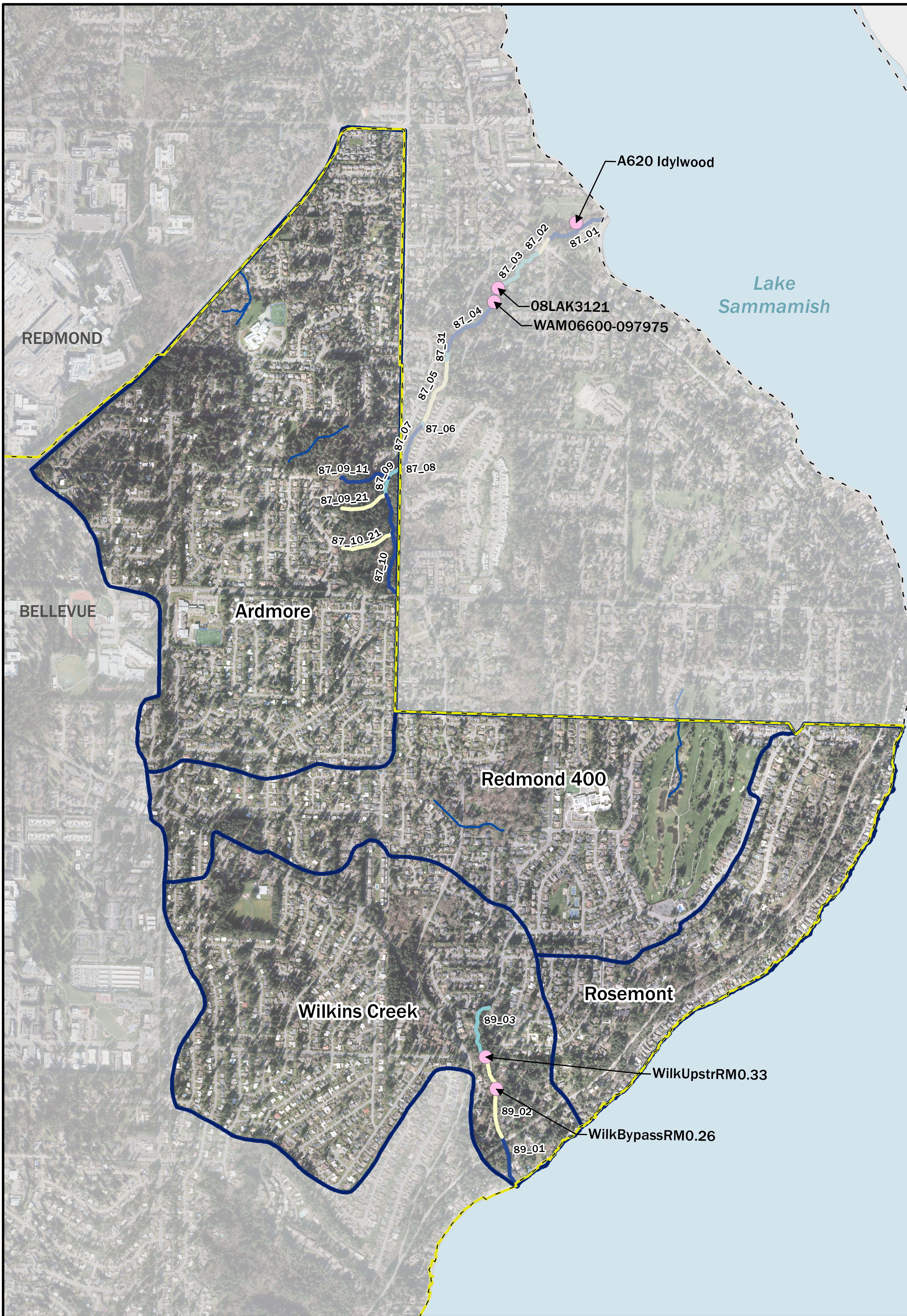
Figure 41. North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area Fish Passage Barriers and B-IBI sampling

N

0 500 1,000 2,000 Feet

Jacobs

Herrera



Legend

- Subbasin (City of Bellevue 2020)
- Bellevue City Limit (City of Bellevue 2020)
- Other Jurisdictions (King County 2020)
- Stream (City of Bellevue 2020)
- B-IBI Sample Location (Puget Sound Benthos Database 2021)

Approximate Stream Reaches

- 87_10, 87_01, 87_04, 87_09_11, 89_01, 87_07
- 87_02, 89_02, 87_10_21, 87_08, 87_09_21, 87_05
- 87_31, 87_06, 89_03, 87_09, 87_03

Note: Washington Department of Fish and Wildlife (WDFW), Benthic Index of Biotic Integrity (B-IBI), Open Streams Condition Assessment Database (OSCA). Fish Passage Barrier WDFW retrieved Feb. 24, 2021.

Figure 42. Ardmore Area/Idylwood Creek Subbasin, Rosemont Area, Redmond 400 Area, and Wilkins Creek Subbasin Fish Passage Barriers and B-IBI sampling locations.

0 500 1,000 2,000 Feet

N

Jacobs

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2.3.6 Aquatic Species

The Lake Sammamish Watershed subbasins include multiple areas that are designated as a priority aquatic and terrestrial habitat by the Washington State Department of Fish and Wildlife (WDFW 2021c). Weowna Park (which extends throughout the North Sammamish Area, Phantom Creek Subbasin, and Spirit Ridge Area) and Lakemont Community Park and Open Space (within Lewis Creek Subbasin) are designated as priority terrestrial habitat. Lewis Creek, Vasa Creek, Phantom Creek, and Phantom Lake are designated as priority aquatic habitat for various salmonid species (described in further within **Section 2.3.6.1**).

Aquatic species within the Lake Sammamish Watershed are described herein under separate subsections for fish species, invasive species, and benthic macroinvertebrates.

2.3.6.1 Fish Species

The Lake Sammamish Watershed is important for salmonids, as it has historically provided extensive spawning and rearing habitat for a larger number of anadromous and migratory salmonids and other fish species. Priority fish species within the Lake Sammamish Watershed, as designated by WDFW, include Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*Oncorhynchus kisutch)*, Sockeye Salmon (*Oncorhynchus nerka)*, and resident Cutthroat Trout (*Oncorhynchus clarkii*). Chinook Salmon, Coho Salmon, and kokanee (lake-dwelling *Oncorhynchus nerka*) are City of Bellevue Species of Local Importance, per Bellevue Land Use Code 20.25H.150A. Additionally, Chinook Salmon are a listed Federally Endangered Species. Lake Sammamish kokanee have been the topic of significant study and investment, a recent partnership between the Cities of Bellevue, Issaquah, Redmond and Sammamish, the Snoqualmie Tribe, and King County was formed to help recover kokanee.

The topographic nature of the Lake Sammamish Watershed limits fish use, and overall (likely due to property access and topography) there is limited fish use data for the tributaries within watershed. In many of the subbasins/areas, salmonid species do not go farther upstream than the confluence of Lake Sammamish and its tributaries. However, in three subbasins and areas (i.e., Lewis Creek Subbasin, Vasa Creek Subbasin, and the South Sammamish Area), salmonids are present upstream of Lake Sammamish. Lewis Creek and Vasa Creek are the best studied streams in terms of fish use within the Lake Sammamish Watershed.

WDFW indicates that portions of Lewis Creek serve as occurrence/migration priority aquatic habitat for Chinook Salmon, Coho Salmon, Sockeye Salmon, winter steelhead, kokanee, and resident Coastal Cutthroat Trout (WDFW 2021c). Table 17 summarizes the estimates of kokanee returns to Lewis Creek. King County Salmon Watcher Program survey efforts undertaken between 1996 and 2015 made observations of Coho Salmon, Sockeye Salmon, kokanee, and a few Chum Salmon within Lewis Creek (King County 2016a). The Watershed Company conducted monitoring and electrofishing annually within Lewis Creek (from the stream's origin to outlet at Lake Sammamish) for a 10-year span sometime between 1980 and 2000, as a City of Bellevue condition for a Cougar Mountain development permit. This monitoring revealed that during this time period, many large Cutthroat Trout and tailed frogs were observed in Lewis Creek (B. Way, personal communication). Migratory fish use is blocked due to a fish-impassable culvert located beneath I-90. Currently within Lewis Creek upstream of I-90, Lewis Creek supports Cutthroat Trout along the mainstem until approximately Lakemont Blvd and Village Park Drive SE, where habitat is insufficient for fish use (Bellevue 2010). Based on City led electrofishing and salmon spawning surveys efforts in 2012, Lewis Creek supports a low level of native species diversity, as native Cutthroat Trout were the only species observed yet several age classes were represented, indicating stream stability (Hart Crowser 2012).

Table 17. Estimated Lewis Creek kokanee Returns by Year

Year	Lewis Creek kokanee return estimate (number of fish)
1996-1997	441
1997-1998	2
1998-1999	89
1999-2000	329
2000-2001	311
2001-2002	990
2002-2003	1985
2003-2004	4951
2004-2005	583
2005-2006	281
2006-2007	471
2007-2008	86
2008-2009	42
2009-2010	673
2010-2011	4
2011-2012	536
2012-2013	6495
2013-2014	47
2014-2015	290
2015-2016	2436
2016-2017	13
2017-2018	7
2018-2019	27
2019-2020	88
2020-2021	26
2021-2022	958

Source: Jim Bower, Fish Ecologist with Water and Land Resources Division of the King County Department of Natural Resources and Parks

Within Vasa Creek, WDFW indicates that some areas may serve as occurrence/migration priority aquatic habitat for resident Coastal Cutthroat Trout, kokanee, Sockeye Salmon, and Coho Salmon. WDFW also shows that portions of Vasa Creek serve as breeding priority aquatic habitat for Coho Salmon (WDFW 2021c). Based on City led electrofishing efforts in 2014, Vasa Creek supports a low level of native species diversity, as native cutthroat were the only species observed (Hart Crowser 2014). Downstream of I-90, occasional Cutthroat Trout have been observed in Vasa Creek (Tetra Tech 2014b).

In the lesser tributaries to Lake Sammamish, "very rare" observations of Sockeye Salmon have been made from 1996 to 2015 by King County's Salmon Watcher Program (King County 2016d) within portions of Idylwood Creek outside of City boundaries within the City of Redmond. Historical information indicates that the downstream portion of Phantom Creek may have been inhabited by Coho and Sockeye salmon (Williams et al. 1975). The upstream segment of Phantom Creek is considered to have fish use due to its association with Phantom Lake (which contains warm-water fish species, including bass (family Centrarchidae)) (Bellevue 2010). WDFW indicates that portions of Phantom Creek may have documented occurrence of resident Chinook Salmon and Coastal Cutthroat Trout(WDFW 2021c), though the City of Bellevue has no documented occurrences. Within the South Sammamish Area, Lake Sammamish Tributary 0160, resident Cutthroat Trout were observed in 1999 (Bellevue 2010). As the Redmond 400 Area, Rosemont Area, and Spirit Ridge Area do not contain perennial open streams, these areas do not support fish use. The Wilkins Creek Subbasin and North Sammamish Area also do not support fish use (see Section 2.3.5.6).

Information on priority fish species documented within the City of Bellevue portion of the Lake Sammamish Watershed is provided below.

Chinook Salmon (*Oncorhynchus tshawytscha*)

The Puget Sound Chinook Salmon Evolutionarily Significant Unit (ESU) has been listed as threatened by the National Marine Fisheries Service (NMFS) under the ESA. Chinook Salmon within the Lake Washington basin are composed of fall-run Chinook Salmon and the population present within Lake Sammamish Watershed is the Sammamish population (as opposed to the Cedar River population). Migration of adults occurs from June through September, with spawning occurring between August and November (Kerwin 2001). Peak Chinook Salmon spawning occurs between September and November (Kerwin 2001). Northwest Indian Fisheries Committee (NWIFC) and WDFW data indicates documented presence of Chinook Salmon in Lewis Creek and Phantom Creek and indicates that Vasa Creek and Idylwood Creek are gradient accessible to Chinook Salmon (NWIFC n.d.).

Sockeye Salmon (*Oncorhynchus nerka*)

Sockeye Salmon that use the tributaries of the Lake Sammamish Watershed are part of the Baker River ESU but are not ESA-listed by NMFS. There are two populations of Sockeye Salmon within the Lake Washington basin, those that spawn in the Sammamish River, and those that spawn in tributaries to the Sammamish River (which represents the larger of the two populations). In addition to the Sammamish and Cedar River populations of Sockeye Salmon, a hatchery program in the Cedar River releases hatchery fry into the Cedar River.

Most adult Sockeye returning to the Greater Lake Washington Watershed (which includes the Lake Sammamish Watershed, Cedar River and its tributaries, May Creek, Coal Creek, Mercer Island, Mercer Slough, Kelsey Creek, Fairweather Creek, Yarrow Creek, Juanita Creek, Forbes Creek, Lyon Creek, McAleer Creek, Thornton Creek, Ravenna Creek, and Lake Washington) are predominantly natural-origin fish from the Cedar River, with adult hatchery-origin Cedar River fish in second greatest abundance, while the

Sammamish River tributary natural-origin fish represent a distant third in terms of abundance. WDFW has identified the Sammamish stock of Sockeye Salmon as "depressed" (Tetra Tech/KCM *et al*. 2006). Per WDFW, the downstream reaches of Vasa Creek closest to the Lake Sammamish contain Sockeye Salmon (Downen 2000). NWFIC and WDFW data indicates documented presence of Sockeye Salmon in Lewis Creek and Vasa Creek and indicates that Idylwood Creek and Phantom Creek are gradient accessible to Sockeye Salmon (NWIFC n.d.).

Kokanee, a lake-bound form of Sockeye Salmon, are a native species to Lake Sammamish and Lake Washington watersheds, having once populated Lake Sammamish and many of its tributaries with tens of thousands of fish. However, since 2016, the number of returning kokanee adults spawners has dipped below 300 fish. Today, the primary range of kokanee has been reduced to Lake Sammamish and three of its tributaries (i.e., Lewis Creek, Ebright Creek, and Pine Creek) (King County 2021). There has been a severe decline in the number of returning adult kokanee within the Greater Lake Sammamish Watershed (both within the City and outside). With a population verging on extinction, the number of returning adult kokanee spawners has been reduced to less 300 fish since 2016 (Lake Sammamish Kokanee Work Group n.d.).

Factors affecting the decline of the Lake Sammamish kokanee population include habitat loss and degradation, increased development (which has affected the hydrology and water quality in the watershed), blocked upstream passage by artificial barriers and low flows, trapping programs in the 1960s through 1970s, disease, shifts in zooplankton densities and composition within Lake Washington and Lake Sammamish, and possibly increased predation by introduced and native fishes as a result of habitat changes (WAFWO n.d., King County 2000). The City is one of many stakeholders involved in an interlocal agreement to restore kokanee and prevent their extinction within the Lake Sammamish Watershed. Together the Kokanee Work Group has undertaken efforts to assess fish habitat in lower Vasa and Lewis creeks (downstream of I-90) to understand the capacity of the stream to support kokanee spawning. These findings indicate that Vasa Creek should be considered potential kokanee spawning habitat based on channel dimensions and sediment composition (Tetra Tech 2014b). NWFIC and WDFW data indicates documented presence of kokanee within Lewis Creek and Vasa Creek (NWIFC n.d.).

Coho Salmon (*Oncorhynchus kisutch*)

Coho Salmon found in the Lake Sammamish Watershed are part of the Puget Sound/Strait of Georgia ESU and are listed as a "Species of Concern" under the Endangered Species Act by NMFS. WDFW has identified Coho Salmon in the Lake Sammamish Watershed as part of the Lake Washington/Sammamish population, which is listed as "depressed" (Tetra Tech/KCM *et al*. 2006, R2 Resources Consultants 2016). Throughout the watershed, Coho Salmon migration and spawning timing occurs later than Chinook and Sockeye salmon, with adults migrating into Lewis Creek and Vasa Creek around mid-October and spawning between mid-November and early-December (WDFW 2018). Compared to other salmonids in these creeks, Coho Salmon possess the advantage of migrating into the system in mid to late October, when stream flows are higher, enabling them to bypass physical barriers more easily (WDFW 2018).

Per NWIFC and WDFW data, Coho Salmon have a documented presence within Vasa Creek, which is supported by observations made during the Vasa Creek Fish Habitat Assessment undertaken by the City (NWIFC, n.d., Tetra Tech 2014b). NWFIC and WDFW data also indicates documented presence of Coho Salmon in Lewis Creek and indicates that Vasa Creek and Idylwood Creek are gradient accessible to Coho Salmon (NWIFC n.d.).

Winter steelhead (*Oncorhynchus mykiss*)

Winter-run steelhead that use the Lake Sammamish Watershed are part of the Puget Sound ESU and were ESA-listed as threatened by NMFS in 2007. WDFW identified steelhead in the watershed as members of the Lake Washington stock, which is listed as “critical” (Tetra Tech/KCM et al. 2006). The Cedar/Sammamish Watershed in which the Lake Sammamish Watershed is located has been categorized as “depressed” in terms of its winter steelhead population. Winter-run steelhead enter the Lake Washington basin in December and historically spawn within the City from late March through early June (Bellevue 2010). Per NWIFC and WDFW data, winter steelhead have a documented presence within Lewis Creek and this resource indicates that Vasa Creek, Idylwood Creek, and Phantom Creek are gradient accessible to winter steelhead (NWIFC n.d.).

Cutthroat Trout (*Oncorhynchus clarkia*)

Cutthroat Trout found in the Lake Sammamish Watershed are part of the Puget Sound ESU and are not an ESA-listed species under NMFS. NWIFC and WDFW data indicates a documented presence of Cutthroat Trout within Lewis Creek, Vasa Creek, and Phantom Creek. Based on City electrofishing surveys, only Cutthroat Trout were captured in Lewis and Vasa creeks (Hart Crowser 2012 and 2014).

2.3.6.2 Invasive aquatic species

Invasive aquatic species are those that have been introduced to an environment outside of their native range. Some invasive aquatic species can cause environmental and economic harm, while the impact of other invasive aquatic species is lesser known (WDFW 2021a). Documented occurrences of invasive aquatic species within the City of Bellevue waters include the New Zealand Mudsnail (NZMS; *Potamopyrgus antipodarum*) and Chinese Mystery Snail (CMS; *Cipangopaludina chinesis*). Though these species have not yet been documented within the Lake Sammamish Watershed, they are described in further detail because their spread is both possible and preventable within the watershed. Other detrimental invasive species that could arrive at any time within City waters include Zebra Mussels (*Dreissena polymorpha*) and the African Clawed Frog (*Xenopus laevis*).

New Zealand Mudsnail (*Potamopyrgus antipodarum*)

According to City data, no New Zealand Mudsnail (NZMS) infestations have not been observed within the Lake Sammamish Watershed as of February 2020 (Bellevue 2021b). However, due to the life history of NZMS, infestation is a real threat to Lake Sammamish tributaries. As such, further information on NZMS and infestation preventative measures are described below.

NZMS reproduce rapidly by cloning, and in the process, crowd out and outcompete native invertebrates for food and habitat. In doing so, NZMS reduce native invertebrates that fish and other aquatic species feed on. While fish can consume NZMS, they are not an effective food source in comparison to other food sources (such as terrestrial and aquatic insects, fish, amphipods, crustaceans, and other invertebrates) due to their low nutritional value. In fact, NZMS can pass through the digestive tract of a fish without injury (WDFW 2021c).

Once NZMS have infested an ecosystem, there is no effective method to remove them. Prevention will help mitigate the damaging impact of NZMS on not yet infested streams. Preventative action includes keeping pets out of infested streams and lakes, scrubbing debris/mud off any materials that have come in contact with streams, lakes or mud, and draining stream or lake water collected in gear or equipment before leaving a site (Bellevue 2021). Through prevention, we can work together to mitigate the spread and harmful effects of the NZMS within watersheds throughout the City, including the Lake Sammamish Watershed.

Chinese Mystery Snails (*Cipangopaludina chinesis*)

Chinese Mystery Snails (CMS) are a relatively large snail species which are commonly used in aquariums (USFWS 2011). It is likely that Chinese Mystery Snails were introduced to Washington State waters through the illegal release of aquarium pets (ANSC 2007). CMS can reach high densities, compete with native invertebrates for food and habitat resources, host parasites and carry diseases known to infect humans, clog water intake pipes, and interact with other invasives to negatively impact native species (USFWS 2018).

There are no known CMS infestations in the Lake Sammamish Watershed. However, as this species presents a looming threat to other waterbodies in the City, prevention includes refraining from releasing aquarium waters and specimens into the wild, and care should be taken to prevent the spread of CMS through cleaning, draining, and drying boats and equipment between water bodies.

2.3.6.3 Benthic Macroinvertebrates

Benthic macroinvertebrates are aquatic animals without backbones that are visible to the naked eye, including insects, crustacea, worms, snails, and clams, that spend all or most of their lives living in or on the bottom of the streambed (King County 2002). Benthic macroinvertebrates are monitored because they are good indicators of the biological health of stream systems and play a crucial role in the stream ecosystem (Karr and Chu 1999). Since they complete most or all of their life cycle in the aquatic environment and are relatively sedentary, benthic communities are reflective of the local sediment, water quality, hydrologic and habitat conditions (Booth *et al.* 2001). Hence, monitoring of macroinvertebrate populations provides a relatively inexpensive and powerful tool to assess short and long-term effects from the primary stressors of stream health identified in Figure 2.

Benthic index of biotic integrity (B-IBI) scores provide a measure of stream health that is derived from samples of benthic macroinvertebrates that are collected from the streambed. B-IBI scores are computed on a scale that ranges from 0 to 100 to indicate relative stream health as follows: 80 to 100 for “excellent”, 60 to 79 for “good”, 40 to 59 for “fair”, 20 to 39 for “poor”, and 0 to 20 for “very poor.” In a study of streams in the Puget Sound lowlands, May *et al.* (1997) showed B-IBI scores declined rapidly in early stages of watershed urbanization such that high B-IBI scores (greater than 60) were observed only at low levels of imperviousness (less than 5 to 10 percent). One drawback of the B-IBI is it does not identify the specific stressor responsible for the decline in stream health. Typically, a more detailed evaluation of the macroinvertebrate community assemblage or supplemental data collection for other chemical and/or physical parameters is required to make such inferences.

From 1998 to 2021, within the Lake Sammamish Watershed, macroinvertebrate samples were collected from 5 locations within Lewis Creek, 2 locations within Vasa Creek, 1 location in Phantom Creek, 2 locations within Wilkins Creek, and 8 locations within Idylwood Creek. The greatest amount of macroinvertebrate sampling data is available for Lewis Creek and Idylwood Creek within the Lake Sammamish Watershed. Appendix C summarizes the available data from each sample by site and subbasin. The most expansive range of B-IBI monitoring data is available for Lewis Creek and Idylwood Creek within the Ardmore Area/Idylwood Creek Subbasin (see Table 18).

B-IBI scores from sites located with Lewis Creek, Phantom Creek, Wilkins Creek, and Idylwood Creek were aggregated over the respective sampling periods to assess stream health based on relatively recent macroinvertebrate sampling. As shown in Table 18, data indicates stream health in the Lake Sammamish Watershed based on biological condition ranges from “very poor” within Idylwood Creek and Wilkins Creek to “poor” within Lewis Creek, Vasa Creek, and Phantom Creek.

Table 18. Median B-IBI Scores in the City of Bellevue portion of the Lake Sammamish Watershed

Surface Water	Sampling Time Period	B-IBI Median Score (n=number of samples)	B-IBI Rating
Lewis Creek	1998 – 2021	39.1 (n=30)	Poor
Vasa Creek	2011 – 2012, 2021	31.1 (n=3)	Poor
Idylwood Creek	2001 – 2020	10.8 (n=48)	Very Poor
Wilkins Creek	2010	11.95 (n=2)	Very Poor
Phantom Creek	2010 – 2011	25.4 (n=2)	Poor

Data Source: Lake Sammamish Watershed Benthic index of Biotic Integrity Scores (included as Appendix C)

In connection with Ecology's Storm Action Monitoring program, data for computing B-IBI scores were collected from 104 sites in streams located in the Puget Lowland ecoregion in the summer of 2015; 45 of these sites were located outside the urban growth area (UGA) in more rural settings while 59 of these sites were located within the UGA in more urban settings. These data provide a good frame of reference for comparing the scores from the Lake Sammamish Watershed to scores from other streams in the region. As reported by DeGasperi *et al.*, the B-IBI scores for streams within the UGA showed a greater proportion of stream length in poor condition (82 percent) compared to streams outside of the UGA (30 percent) (DeGasperi *et al.* 2018). Median B-IBI scores for streams within and outside the UGA were 38.6 and 72.7, respectively. This data suggests that stream health in the Lake Sammamish Watershed is degraded, as the median B-IBI scores range from 10.8 to 39.1 within the reaches sampled, relative to comparable streams located within the UGA from this study.

3. Limiting Factors

The information presented in the previous sections was evaluated to identify potential factors limiting stream health in the Lake Sammamish Watershed and discussed with City staff during a working session on November 17th, 2021. The goal of the working session was to obtain input on potential limiting factors from City staff in departments overseeing resource management in the Lake Sammamish Watershed and possessing institutional knowledge that is directly relevant to this question. The evaluation of potential limiting factors specifically focused on the "sources of stressor" elements from the conceptual model that describes the primary effects of urban runoff on stream health (Figure 43).

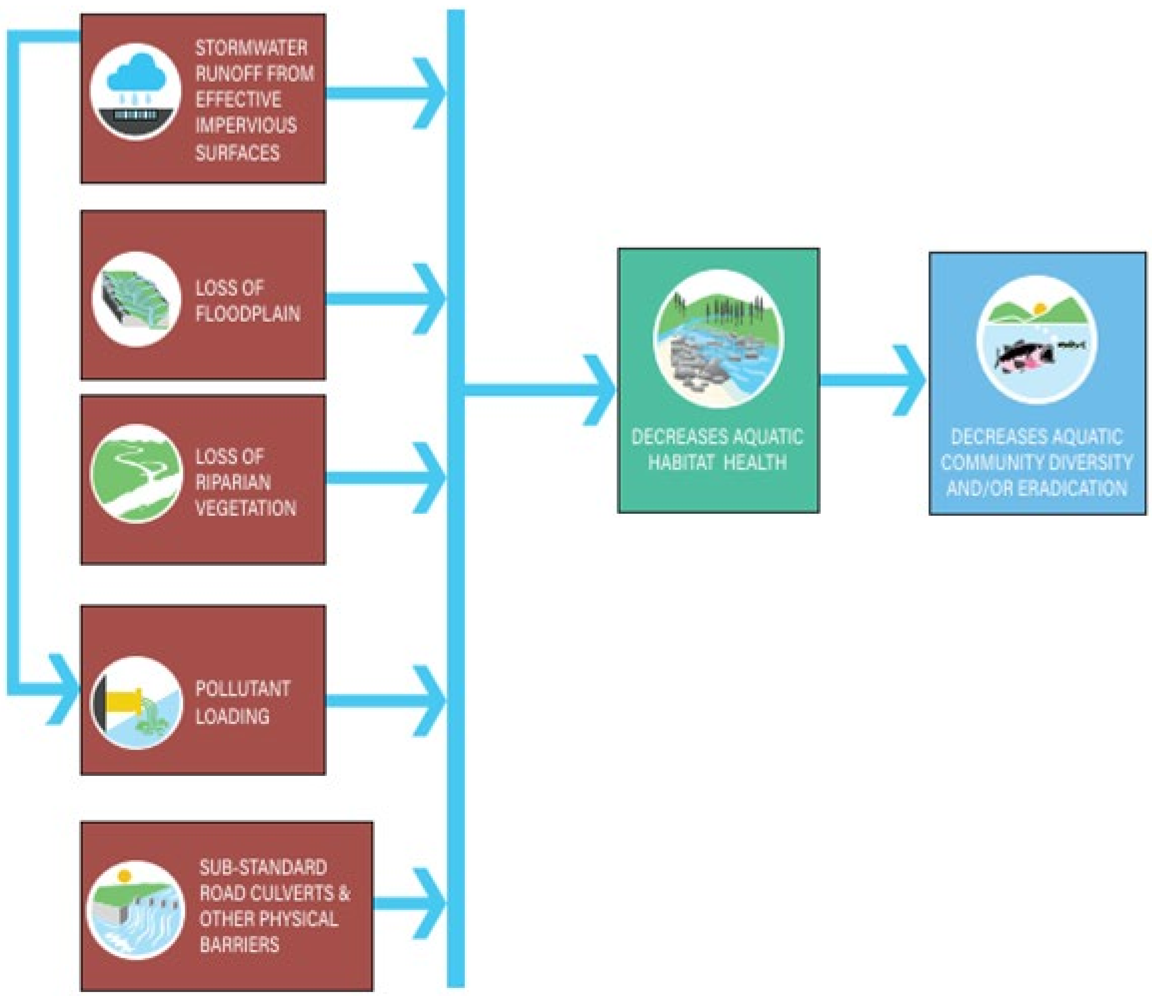

Figure 43. Source of Stressor Elements from the Conceptual Model.

These limiting factors discussions for the Lake Sammamish Watershed must also acknowledge that the Watershed is unique among City watersheds because, unlike all the other areas in the City, it drains to Lake Sammamish. Each of the individual subbasins and areas within the City's portion of the Lake Sammamish Watershed each has its own unique set of characteristics and therefore its own unique limiting factors. As expected for an urbanized watershed, each subbasin and area in the City's portion of the Lake Sammamish Watershed demonstrates symptoms of each limiting factor. The goal of this section is to identify and document the limiting factors that are most important for that subbasin or area. In future phases of the

WMP, these limiting factors will be used to develop investments to promote ecological recovery and/or prevent continued degradation specific to each subbasin's unique needs.

Table 19 summarizes the limiting factors for each of the subbasins and areas in the City's portion of the Lake Sammamish Watershed. The rationale behind what's shown in Table 19 is provided in the narrative after Table 19.

Table 19. Limiting Factors by Subbasin / Area

	Limiting Factors			
Subbasin or Area	**Stormwater Runoff from Effective Impervious Surfaces**	**Loss of Floodplain and Riparian Function**	**Pollutant Loading**	**Road Culverts and Other Physical Barriers**
Lewis Creek Subbasin	●		○	●
Vasa Creek Subbasin	●		●	●
Ardmore Area/ Idylwood Creek Subbasin	●		○	
Redmond 400 Area	●	○		
Rosemont Area	●		○	
Wilkins Creek Subbasin	●		○	
North Sammamish Area	●			
Phantom Creek Subbasin	●		●	
Spirit Ridge Area	●			
South Sammamish Area	●		●	○

● =Identified as primary Limiting Factor(s) applicable across entire subbasin
○ =Identified as secondary Limiting Factor(s) (evidence points to specific location(s) in the subbasin where this limiting factor is driving existing conditions)

Note that no OSCA efforts were conducted in the Redmond 400 Area, the Rosemont Area, the North Sammamish Area, or the Spirit Ridge Area, as these areas do not have year-round creeks. The limiting factors characterization in this section is based on the information provided in this assessment report, particularly land cover and land use information, data from the OSCA surveys, and WDFW fish passage inventories . If information was limited for a particular subbasin or area, limiting factors of stormwater runoff (due to impervious surface) and pollutant loading were selected, with individual characteristics in each subbasin or area determining if these limiting factors are primary or secondary in each subbasin or area.

The evidence supporting the limiting factor designations for each subbasin is provided here, in decreasing order of importance for each subbasin:

Lewis Creek Subbasin

- Stormwater Runoff from Impervious Surfaces (evidence in support: While approximately 30% impervious (which is the 3rd lowest in the City), steep slopes yield high velocities moving through the creek; evidence of channel scour in lower reaches)
- Road Culverts and Other Physical Barriers (evidence in support: I-90 crossing is a full barrier to fish passage; several other barriers starting approximately 2,000 linear feet upstream from creek mouth)
- Pollutant Loading – Secondary (evidence in support: though unlikely that septic systems are present, residential land use tends to contribute pesticides and other pollutants)

Vasa Creek Subbasin

- Stormwater Runoff from Impervious Surfaces (evidence in support: more than 30% impervious with steep slopes leads to high velocities moving through the creek; evidence of channel scour throughout creek channel)
- Road Culverts and Other Physical Barriers (evidence in support: numerous blockages to fish passage, including I-90 crossing)
- Pollutant Loading (evidence in support: septic systems present in upper subbasin area; poor BIBI scores; residential land use tends to contribute pesticides and other pollutants; highway and other major roads in this Subbasin)

Ardmore Area/Idylwood Creek Subbasin

- Stormwater Runoff from Impervious Surfaces (evidence in support: high percent impervious with steep slopes leads to high velocities moving through the creek; extensive channel incision and scour)
- Pollutant Loading – Secondary (evidence in support: BIBI scores downstream are very poor)

Redmond 400 Area

- Stormwater Runoff from Impervious Surfaces (evidence in support: based on land use and land cover, including a golf course, stormwater runoff is problematic)
- Loss of Floodplain and Riparian Vegetation – Secondary (evidence in support: very little canopy cover; minimal or no buffer)

Rosemont Area

- Stormwater Runoff from Impervious Surfaces (evidence in support: based on land use and land cover, stormwater runoff is problematic)
- Pollutant Loading – Secondary (evidence in support: residential land)

Wilkins Creek Subbasin

- Stormwater Runoff from Impervious Surfaces (evidence in support: high percent impervious with steep slopes leads to high velocities moving through the creek)
- Pollutant Loading – Secondary (evidence in support: very flashy system, so stormwater from roads is going straight into the streams)

North Sammamish Area

- Stormwater Runoff from Impervious Surfaces (evidence in support: based on land use and land cover with residential land use upstream of steep ravines, stormwater runoff is problematic)

Phantom Creek Subbasin

- Stormwater Runoff from Impervious Surfaces (evidence in support: steep slopes in lower reaches; high degree of impervious surface clustered near the 'headwaters')
- Pollutant Loading (evidence in support: high degree of office/industrial land use; Phantom Lake has history of water quality issues; potential for septic systems to be in use in this Subbasin)

Spirit Ridge Area

- Stormwater Runoff from Impervious Surfaces (evidence in support: based on land use and land cover with residential land use upstream of steep ravines, stormwater runoff is problematic)

South Sammamish Area

- Stormwater Runoff from Impervious Surfaces (evidence in support: while this Area has the lowest impervious surface percentage in the City's portion of the Lake Sammamish watershed, this system is very flashy and steep and therefore are issues with erosion and scour)
- Pollutant Loading (evidence in support: While upper portion is in residential land use, downstream end contains I-90 and major roads, which are a presumed source of pollutants)
- Road Culverts and Other Physical Barriers - Secondary (evidence in support: Blockages to fish passage exist throughout, though secondary instead of primary because the creek doesn't provide good fish habitat so even if barriers were removed, minimal benefit provided)

This ordering of limiting factors is generally consistent with the hierarchical model of stream functions that was described previously by Herrera (2013). This approach builds on the knowledge that efforts to improve physical habitat quality will be substantially more difficult if conducted in highly impacted watersheds with altered sediment budgets and a flashy hydrologic regime (Roni *et al.* 2002). Stream channel rehabilitation is most effective in watersheds that have a natural hydrograph and minimal sediment loading (Suren and McMurtrie 2005).

Figure 44 presents a Stream Functions Pyramid model prepared by Harman (2009) which, along with the hierarchical model of stream functions, suggests improved stream health (located at the top of the pyramid) is most effectively attained by first addressing stressors at the lower levels of the pyramid. The intention of the pyramid is to show the dominant cause and effect relationships. In general, biodiversity is dependent on habitat structure and quality, which are dictated by the lower levels of the pyramid beginning with hydrologic conditions.

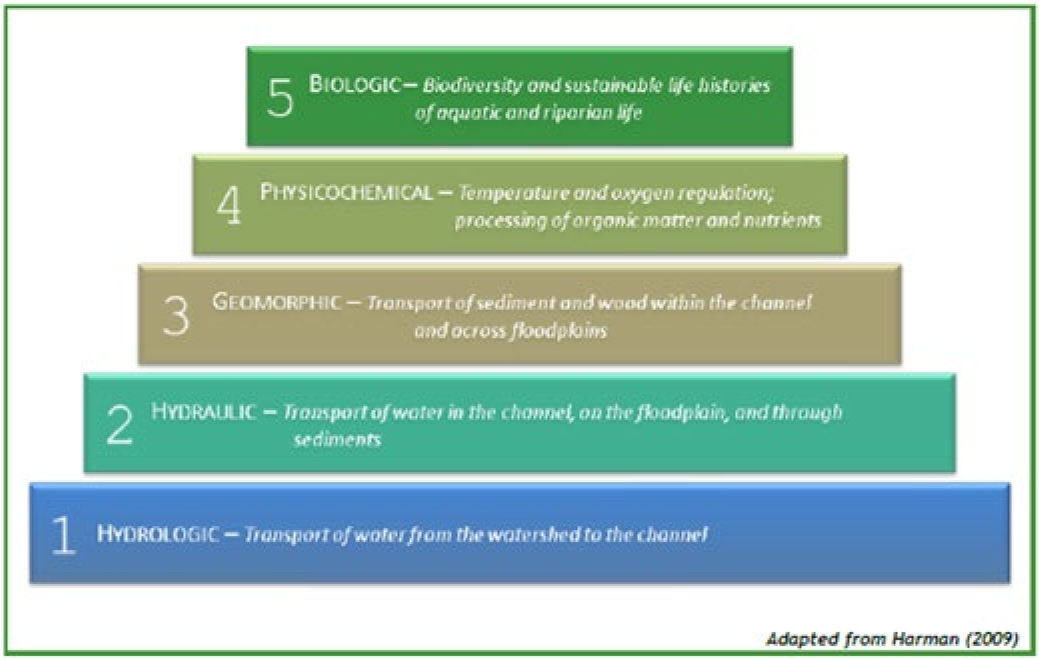

Figure 44. Stream Functions Pyramid.

4. Past and Present Investments

The City has implemented a number of investments to address stream health in the City's portion of the Lake Sammamish Watershed. Table 20 outlines location-specific past and present investments that have been made by the City (or else by King County, before areas were annexed into the City) in the City's portion of the Lake Sammamish Watershed. Note that regional facilities and high-flow bypass facilities described earlier in this AR are not included in this list of investments.

In addition to those location-specific investments described in Table 20, the City has also invested in the following programmatic activities within the Lake Sammamish Watershed:

- Information collection, studies, and environmental monitoring
- Maintenance activities – including conveyance system cleaning and inspection and vegetation maintenance/removal and management of beaver activities
- Education (including natural yard care and invasive species control) and Public Engagement

Table 20. Past and Present Investments in Stream Health in the City of Bellevue Portion of the Lake Sammamish Watershed

Lake Sammamish Watershed Subbasin or Area	Description of Investment(s) by the City
Lewis Creek Subbasin	• Stormwater Pond by I-90 (WSDOT ROW) • Improvements (including low-impact development) turning a former farm into a park • Lakemont Park (replaced culvert crossings under Lakemont Blvd.; sediment detention pond in left-bank tributary) • Sediment pond built to manage new development
Vasa Creek Subbasin	• Culvert replacement under West Lake Sammamish Parkway (near SE 34th Street) • Improvements upstream from pump station (by King County as mitigation) • High flow bypass (installed by King County previous to incorporation) to reduce flooding • 2014 Vasa Creek Basin Study – geology, re-mapping of floodplain, slope stability • Emergency culvert replacement at 2442 West Lake Sammamish Parkway SE • Emergency culvert repair at SE Newport Way, including HDPE slip-lining • HDPE slip-lining of culvert
Ardmore Area/ Idylwood Creek Subbasin	• City identifying and pursing alternatives to address erosion and sedimentation issues in Idylwood Creek and adjacent to Ardmore Park • Various investments by City of Redmond including stream restoration in lower reaches and sediment catchment facilities, also high-flow bypass facility just downstream of Ardmore Park (built by the City of Redmond)
Redmond 400 Area	• No investments for stream health
Rosemont Area	• No investments for stream health
Wilkins Creek Subbasin	• High-flow bypass and treatment wetland at NE 8th Street & Northup Way (constructed in 1998, modified in early 2000s
North Sammamish Area	• Sediment catchment ponds (installed by King County previous to incorporation) to catch sediment caused by erosion (project currently underway to address issues)
Phantom Creek Subbasin	• Phantom Lake Restoration project in late 1980s, including weir (which is now on private property) • Parks Department developing former airfield as open space, using on-site stormwater treatment and low-impact development
Spirit Ridge Area	• No investments for stream health
South Sammamish Area	• HDPE slip-lining of culvert on Tributary 0161 at SE 41st Street just downstream of I-90

5. Potential Opportunities

Table 21 presents instream opportunities for improving the stream health in the City's portion of the Lake Sammamish Watershed based on observations made during the OSCA field work and/or by previous studies conducted by the City. These opportunities will be moved forward into the Watershed Improvement Plans (WIPs) where they will be used to help identify potential investments for stream health improvement.

While the City has invested in some stream restoration and instream maintenance activities within the subbasins and areas of the Lake Sammamish Watershed, the City has not performed many upland projects to reduce stormwater runoff or provide water quality treatment. The Lakemont Facility is the exception. Upland investments might include retrofits of existing stormwater facilities (including high-flow bypasses or regional facilities) or installation of new stormwater facilities aimed at flow control and/or water quality. These upstream investments are especially important for reducing high-velocity flows that cause erosion in the steep stream reaches in this Watershed. Both instream and upland investments will be explored in the forthcoming WIPs to address limiting factors of the Lake Sammamish Watershed identified in this AR.

Table 21. Instream Opportunities for Improving Stream Health in the City of Bellevue's Portion of the Lake Sammamish Watershed

Lake Sammamish Watershed Subbasin or Area	Reach	Instream Opportunity
Watershed-wide (all Subbasins)	--	Prevent and/or manage aquatic invasive and vegetation species, both present and new/emerging (knotweed, New Zealand Mudsnails, Zebra Mussels, Asian Clawed Frog and other new/emerging invasive species)
Watershed-wide (all Subbasins)	--	Improve fish passage at known barriers and restore natural stream processes
Watershed-wide (all Subbasins)	--	Provide programs that foster good stewardship in both the residential and business communities, with a focus on owners of private property adjacent to streams
Watershed-wide (all Subbasins)	--	Introduce new City and community policies and programs to address impacts of human activity (human activities include pet waste, discarded needles, litter, illegal dumping, and other pollutants)
Watershed-wide (all Subbasins)	--	Address streambed and streambank stability, place LWM, and restore riparian vegetation (needed throughout the City's portion of the Lake Sammamish Watershed)
Lewis Creek Subbasin	Reaches 4, 5, and Tributary 0162K Reach 1	Installation of LWM to provide instream structure and stabilization and allow natural stream processes to reconnect the floodplain
Lewis Creek Subbasin	I-90 crossing	Replacement of barriers with fish-passable structures (currently in design, construction anticipated in 2024 or later (by WSDOT))
Vasa Creek Subbasin	Tributary 0160	Explore opportunities to daylight and restore fish passage and connection of this stream to Lake Sammamish
Vasa Creek Subbasin	Lower mainstem reaches downstream of I-90	Identify and implement fish barrier corrections in lower Vasa Creek downstream of I-90; removal of channel armoring and enhancement of riparian vegetation to provide shade, pool habitat and LWM
Vasa Creek Subbasin	I-90 crossing	Replacement of barriers with fish-passable structures (by WSDOT)
Vasa Creek Subbasin	Reaches upstream of I-90	Address barriers to fish passage in these upstream reaches (recognizing that downstream barriers should be addressed first to allow fish to access this area

Lake Sammamish Watershed Subbasin or Area	Reach	Instream Opportunity
Vasa Creek Subbasin	West Lake Sammamish Parkway crossing	Address 6-ft concrete box culvert that does not meet fish passage criteria
Lesser Tributaries to Lake Sammamish	--	Reconnect and enhance creek mouths to restore habitat connectivity and juvenile rearing habitat (see Appendix B of the Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conversation Plan 10-year Update (WRIA 8 2017))
Wilkins Creek Subbasin	Reaches 2 and 3	Removal (or improvement) of high-flow bypass to address sediment accumulation that forces low flows into the piped system
South Sammamish Area	Tributaries 0162 and 0161	Address fish passage barriers, recognizing fish passage removal would need to be paired with stream restoration to maximize benefit

6. Data Gaps

Missing or incomplete information that were not available to inform this Lake Sammamish Watershed AR or future phases of WMP development are as follows:

- Water level and streamflow information is not available for most streams (with Vasa Creek and Lewis Creek the only streams within the City tributary to Lake Sammamish with stream flow information available), preventing hydrological comparisons to measure improvements and/or degradation in those systems
- Stream water temperature data to assess water quality impacts of loss of riparian corridor width, changes to canopy cover, or warm runoff from impervious surfaces.
- Water Quality Index information is limited to only Lewis Creek and Idylwood Creek; Sampling conducted by King County to obtain data for computing WQI scores has not explicitly targeted storm events. Therefore, the scores may underestimate the true level of impairment from parameters that are commonly associated with stormwater runoff
- Resident fish population and health information is not available for several subbasins and areas
- Macroinvertebrate data is unavailable for several subbasins and areas
- Review of all privately and publicly-owned stormwater facilities to characterize currently-provided effectiveness against designed effectiveness
- While locations of septic systems can be identified based on the lack of sewer conveyance infrastructure and King County and/or Washington State Department of Health records, a data gap exists in determining which of those existing septic systems are malfunctioning and causing groundwater quality issues

The City is currently developing an Environmental Monitoring Program Implementation Plan aimed at obtaining robust data to evaluate biological, chemical, physical, hydrological, and invasive species indicators of stream health. These data will inform status-and-trends, cause-and-effect relationships, management decisions, and progress towards achieving watershed and stream health goals within the framework of the WMP. Addressing data gaps, especially those in water quality and stream flow listed above, will be a key part of this Environmental Monitoring Program.

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Appendix A
Data Sources and Methods Used to Summarize Geospatial Watershed Attributes

Appendix A. Lake Sammamish Watershed Assessment Report: Data Sources and Methods Used to Summarize Geospatial Watershed Attributes

1.1 Introduction

This appendix to the Lake Sammamish Watershed Assessment Report (AR) describes the spatial data sources and calculation methods employed to generate figures referenced in the main text of the document. Spatial data was predominantly sourced from the City of Bellevue; additional spatial data sources are also listed at the end of this appendix. Calculations were generally derived by intersecting spatial data within specific boundaries (Lake Sammamish Watershed subbasins and areas, City of Bellevue city limits, Greater Kelsey Creek Watershed). Additional analysis methods are described in detail below. The presentation of this information is organized under the major section titles and figure/table names (and numbers) from the main text, with a final table that contains all of the referenced data sources.

1.2 Watershed Characteristics

1.2.1 Geology (Table 1; Figures 9-12) and Soils (Table 2; Figures 13-16)

Geology and soil data were intersected within the City of Bellevue and subbasin boundaries, only area falling in the City of Bellevue limits was counted towards the total area. For geology, each Geologic Type total area was calculated using USGS geology layers. For soil, each Hydrologic Soil Group total area was calculated by intersecting soil types with subbasin boundaries.

1.2.2 Surface Water Features (Table 3; Figures 4-7)

Wetland area within each subbaasin was calculated by merging King County Sensitive Ordinance Wetlands and NWI Wetlands (2020) data and intersecting wetland boundaries with subbasin boundaries and the City of Bellevue Boundary. Subbasin area falling outside of the City of Bellevue limits was excluded, as were wetlands falling outside of City limits.

1.3 Built Infrastructure

1.3.1 Landcover/Tree Canopy (Tables 4, 6, B-4 to B-8; Figures 18-21)

Landcover analysis was performed using a raster mosaic of the 2017 and 2013 Landcover. These data were provided by the City of Bellevue in Tag Image File Format (TIF) files. The more recent 2017 Landcover only contained data from within the City of Bellevue city limits. Due to this consideration, the more recent 2017 Landcover classifications were used as the default in the landcover analyses. To represent areas in the watershed and subbasins not covered by the 2017 Landcover, the 2013 Landcover classifications were paired to match the 2017 Landcover classifications as follows:

2013 Deciduous classification = 2017 Tree Canopy classification

2013 Evergreen classification = 2017 Tree Canopy classification

2013 Non-Woody classification = 2017 Non-Canopy Vegetation classification

Land cover layers were intersected with the subbasin boundaries in order to calculate the total area of each land cover type within each subbasin. Land cover areas were further clipped to the City of Bellevue extent in order to exclude area falling outside the City of Bellevue from analysis and reporting.

1.3.2 Land Use (Table 5; Figures 22-25)

Initial land use analysis was conducted by merging existing Land Use datasets from the City of Redmond, the City of Bellevue, the City of Kirkland, and King County. To account for detailed land use classifications and naming convention variation across three different datasets, a broad standardized land use classification was created. Each dataset specific, unique land use classification was grouped under a broad, standardized land classification.

Following this initial broad classification, highway polygons were manually extracted from the 2013 City of Bellevue impervious surface polygon dataset and intersected with the broad land use classifications in order to separately identify highway cover within subbasins.

The total area for each land classification was then calculated for all subbasin boundaries and overall watershed extents (clipped to the extent of the City of Bellevue boundary).

1.3.3 Change in Tree Canopy and Impervious Surfaces (Table 6)

Land use change data was downloaded from WDFW's High Resolution Change Detection website and then intersected with subbasin boundaries. The data were then exported to R to calculate the percent change in tree canopy and impervious surfaces for each subbasin and the watershed as a whole.

1.3.4 Percent Stream Channel Piped (Table 7)

The percent of the stream channel that is piped was computed by exporting the stream layer data to R. The SDPIPE field was used to identify stream segments that are piped and the proportion was calculated using the shape length. Segments outside the City or those with an empty SDPIPE field were omitted.

1.3.5 Regional Stormwater Detention Facilities (Table 8; Figure 26)

The Regional Stormwater Detention Facilities data was gathered using the City of Bellevue Storm Inlets layer with focused FACILITYID definition query.

1.3.6 Age of Development Ratings (Table 9; Figures 27-30)

To evaluate the adequacy of stormwater management in the Lake Sammamish Watershed, the age of development was used to classify specific areas into one of five categories that indicate when requirements for improved stormwater management infrastructure became effective. The age of development was determined using the existing attributes in the Parcel Time of Development and Stormwater Standards layer (YearBuiltRes) for the City of Bellevue.

1.4 Natural Systems

1.4.1 Stream Flow and Hydrologic Metric Scores (Table 10, 11)

Stream flow data was gathered from the King County Hydrologic Information Center and analyzed in excel.

1.4.2 Category 5 Waters (Tables 12)

Information on Category 5 waters was gathered from the Washington Department of Ecology's 303(d) list (2014).

1.4.3 Riparian Impervious Surface Cover and Riparian Tree Canopy Cover (Tables 14, B-4 to B-8)

To calculate the riparian impervious surface cover, a 100 ft buffer was created around the stream line by SegmentID (reach number) with capped, not rounded, ends. This buffer was then intersected with the land cover layer. The results were exported to R to calculate the percent riparian impervious surface cover for each reach and the subbasin as a whole.

1.4.4 Subbasin Fish Passage Barriers and B-IBI Sample Locations (Tables 16, 18; Figures 39-42)

BIBI Location data was downloaded from the Puget Sound Stream website and intersected with subbasin boundaries. Fish Passage Barrier data was downloaded from the WDFW SalmonScape website and intersected with subbasin boundaries.

1.4.5 Stream Gradient (Tables B-4 to B-8)

The stream gradient was calculated as follows:

- Use Dissolve tool to group stream segments by SegmentID (reach number)

- Use Feature Vertices to Points tool to create points at each end of each reach

- Use Extract Values to Points tool to get the obtain the elevation at the end of each reach

- Export data to R. Compute stream gradient as the difference between the maximum and minimum elevation divided by the stream length.

1.5 Data Sources Table

See Table on next page.

Table A-1 GIS Data Sources used in Preparation of the Lake Sammamish Watershed Assessment Report

Figure / Table subject	Figure number(s)	Table number(s)	Source Data	Source	Year accessed	Notes
All	All	All	Watershed boundaries	City of Bellevue	2020	
			Subbasin Boundaries (Carta.UTIL.SD_Basin)	City of Bellevue		
			Bellevue City Limit (CITYBDY)	City of Bellevue		City of Bellevue boundary isolated from 2020 CITYBDY polygons
			Highways (lines) (SR500KLRSLinesSPS)	WSDOT		
			Streams (Utilities.UTIL.envStreams)	City of Bellevue		
Vicinity map; Surface water features and monitoring sites; Fish passage barriers and B-IBI sampling locations	3-7, 39-42	--	GeoTIFF aerial orthophotos (2020)	City of Bellevue	2020	
Surface water features and monitoring sites	4-8	--	FEMA 100 year floodplain	FEMA	2020	
		3	King County Sensitive Area Ordinance Wetlands	King County		Wetland area within each subbaasin calculated by merging King County Sensitive Ordinance Wetlands and NWI Wetlands (2020) and intersecting wetland boundaries with subbasin boundaries and the City of Bellevue Boundary. Subbasin area falling outside of the City of Bellevue limits was excluded, as were wetlands faling outside of City limits.
		3	NWI Wetlands	US FWS National Wetlands Inventory		
Geology	9-12	1	Surface geology, 1:100,000	USGS, Washington Division of Geology and Earth Resources (accessed 2020); Citation: Yount, James (1993). Geologic map of surficial deposits in the Seattle 30' x 60' quadrangle, Washington. Open File Report 93-233. USGS.	2020	USGS geology layers (100k) were intersected with City of Bellevue and subbasin boundaries in order to calculate the total area of each geology type within each subbasin. Only area falling within the City of Bellevue limits was included in calculations
Soils	13-16	2	Soil hydrologic groups	City of Bellevue WAR	2020	Soil types were intersected with City of Bellevue and subbasin boundaries in order to calculate the total area of each soil type within each subbasin. Only area falling within the City of Bellevue limits was included in calculations.
Topography	17	--	Contours (Contour50Ft_2016)	City of Bellevue	2020	
Land Cover/Tree Canopy	21-25	4, 6, B-4 to B-8	2017 Land Cover tif (Rasta.ENVIRO.TreeCanopyComposite_2016)	City of Bellevue	2020	Landcover analysis was performed using a raster mosaic of the 2017 and 2013 Landcover. These data were provided by the City of Bellevue in Tag Image File Format (TIF) files. The more recent 2017 Landcover only contained data from within the City of Bellevue city limits. Due to this consideration, the more recent 2017 Landcover classifications were used as the default in the landcover analyses. To represent areas in the watershed and subbasins not covered by the 2017 Landcover, the 2013 Landcover classifications were paired to match the 2017 Landcover classifications as follows: 2013 Deciduous classification = 2017 Tree Canopy classification 2013 Evergreen classification = 2017 Tree Canopy classification 2013 Non-Woody classification = 2017 Non-Canopy Vegetation classification Land cover layers were intersected with the subbasin boundaries in order to calculate the total area of each land cover type within each subbasin. Land cover areas were further clipped to the City of Bellevue extent in order to exclude area falling outside the City of Bellevue from analysis and reporting.
			2013 Land Cover tif (Rasta.ENVIRO.Bellevue_CompositeClass_2014)			
Land Use	22-25	5	Land Use Designations (Comp Plan)	City of Bellevue	2020	Initial land use analysis was conducted by merging existing Land Use datasets from the City of Redmond, the City of Bellevue, the City of Kirkland, and King County. To account for detailed land use classifications and naming convention variation across three different datasets, a broad standardized land use classification was created. Each dataset specific, unique land use classification was grouped under a broad, standardized land classification. Following this initial broad classification, highway polygons were manually extracted from the 2013 City of Bellevue impervious surface polygon dataset and intersected with the broad land use classifications in order to separately identify highway cover within subbasins. The total area for each land classification was then calculated for all subbasin boundaries and overall watershed extents (clipped to the extent of the City of Bellevue boundary).
			Comprehensive Land Use	City of Redmond	2021	
			Comprehensive Plan https://maps.kirklandwa.gov/Html5Viewer/	City of Kirkland	2021	
			2013 Impervious surface polygons (Carta.ITD.ImperviousSurface_2013)	City of Bellevue	2021	
			Land Use Comprehensive Plan	King County	2020	
Age of Development Ratings	27-30	9	Age of Development (V:\UtilitiesDeptGIS\ArcGIS\Watershed Planning Team\Environmental Monitoring\Habitat Assessment\SHP\Parcel_AgeofDevelopment_inBasins.shp)	City of Bellevue	2020	To evaluate the adequacy of stormwater management in the Coal Creek Watershed, the age of development was used to classify specific areas into one of five categories that indicate when requirements for improved stormwater management infrastructure became effective (Table 5). The age of development was determined using the existing attributes in the Parcel Time of Development and Stormwater Standards layer (YearBuiltRes) for the City of Bellevue.
Regional Stormwater Detention Facilities	26	8	Stormwater bypass structures	City of Bellevue	2020	City of Bellevue Storm Inlets with focused FACILITYID definition query.
			Regional stormwater detention facilities (Carta.UTIL.SD_Sites)	City of Bellevue	2020	
Subbasin Fish Passage Barriers and B-IBI Sample Locations	39-42	16	Fish Passage Barriers	WDFW	2020	
		18	B-IBI Locations	Puget Sound Stream Benthos	2021	BIBI Location data was downloaded from the Puget Sound Stream website and intersected with subbasin boundaries. Fish Passage Barrier data was downloaded from the WDFW SalmonScape website and intersected with subbasin boundaries.
		--	OSCA observed knotweed locations (Utilities.UTIL.envKnotweed)	City of Bellevue	2020	
Change in tree canopy and impervious surfaces	--	6	High Resolution Change Detection	WDFW	2020	Land use change data was downloaded from WDFW's High Resolution Change Detection website and then intersected with subbasin boundaries. The data were then exported to R to calculate the percent change in tree canopy and impervious surfaces for each subbasin and the watershed as a whole.
Percent stream channel piped	--	7	Streams (Utilities.UTIL.envStreams)	City of Bellevue	2021	The percent of the stream channel that is piped was computed by exporting the stream layer data to R. The SDPIPE field was used to identify stream segments that are piped and the proportion was calculated using the shape length. Segments outside the City or those with an empty SDPIPE field were omitted.
Stream gradient	--	B-4 to B-8	Digital elevation model (Rasta.TERRAIN.DEMBareEarth_2015)	City of Bellevue	2021	The stream gradient was calculated as follows: - Use Dissolve tool to group stream segments by SegmentID (reach number) - Use Feature Vertices to Points tool to create points at each end of each reach - Use Extract Values to Points tool to get the obtain the elevation at the end of each reach - Export data to R. Compute stream gradient as the difference between the maximum and minimum elevation divided by the stream length.
Riparian tree canopy cover	--	B-4 to B-8; 14	2017 Land Cover tif (Rasta.ENVIRO.TreeCanopyComposite_2016)	City of Bellevue	2021	To calculate the riparian tree canopy cover, a 100 ft buffer was created around the stream line by SegmentID (reach number) with capped, not rounded, ends. This buffer was then intersected with the land cover layer. The results were exported to R to calculate the percent riparian tree canopy cover for each reach and the subbasin as a whole.
Riparian impervious surface cover	--	B-4 to B-8; 14	2017 land cover (Carta.ITD.ImperviousSurface_2013)	City of Bellevue	2021	To calculate the riparian impervious surface cover, a 100 ft buffer was created around the stream line by SegmentID (reach number) with capped, not rounded, ends. This buffer was then intersected with the land cover layer. The results were exported to R to calculate the percent riparian impervious surface cover for each reach and the subbasin as a whole.
Stream flow and hydrologic metric scores	--	10,11	King County stream flow gauge data (Hydrologic information center)	King County	2020	
Category 5 waters	--	12	303(d) list (2014)	Washington Department of Ecology	2020	
Fish species	--	17		King County	2021	

1.6 Geospatial Data Sources

Bower, James, Fish Ecologist with Water and Land Resources Division, King County Department of Natural Resources and Parks. Personal communication: email to Amy Carlson, Jacobs, January 12, 2022.

City of Bellevue. 2013. Bellevue_2013_landcover_101214Proj_NAD83_2011.tif. Provided to Herrera by City of Bellevue, June, 2020.

City of Bellevue. 2017. Bellevue_LC6Class_2017_ClassField.tif. Provided to Herrera by City of Bellevue, June, 2020.

Bellevue. 2021. Open Streams Condition Assessment Database. Provided to Herrera by City of Bellevue Utilities, September, 2021.

Bellevue. 2020. As Built Storm Database. Provided to Herrera by City of Bellevue Utilities, May, 2020.

Bellevue. 2020. Parcel Time of Development and Stormwater Standards layer. Provided to Herrera by City of Bellevue, August, 2020.

City of Bellevue, 2020. GIS Data Portal. Available at https://bellevuewa.gov/city-government/departments/ITD/services/maps/g-i-s-data-portal.

King County, 2020. King County GIS Open Data Portal. Available at https://gis-kingcounty.opendata.arcgis.com/.

King County, 2020. King County Pictometry Basemap Aerial 2019. Available at https://gismaps.kingcounty.gov/arcgis/rest/services/BaseMaps/KingCo_Aerial_2019/MapServer.

OCM Partners. 2020. 2016 - 2017 PSLC Lidar DEM: King County, WA, https://www.fisheries.noaa.gov/inport/item/53392.

USGS, 2020. Washington Division of Geology and Earth Resources, 2016, Surface geology, 1:100,000--GIS data, November 2016: Washington Division of Geology and Earth Resources Digital Data Series DS-18, version 3.1, previously released June 2010.

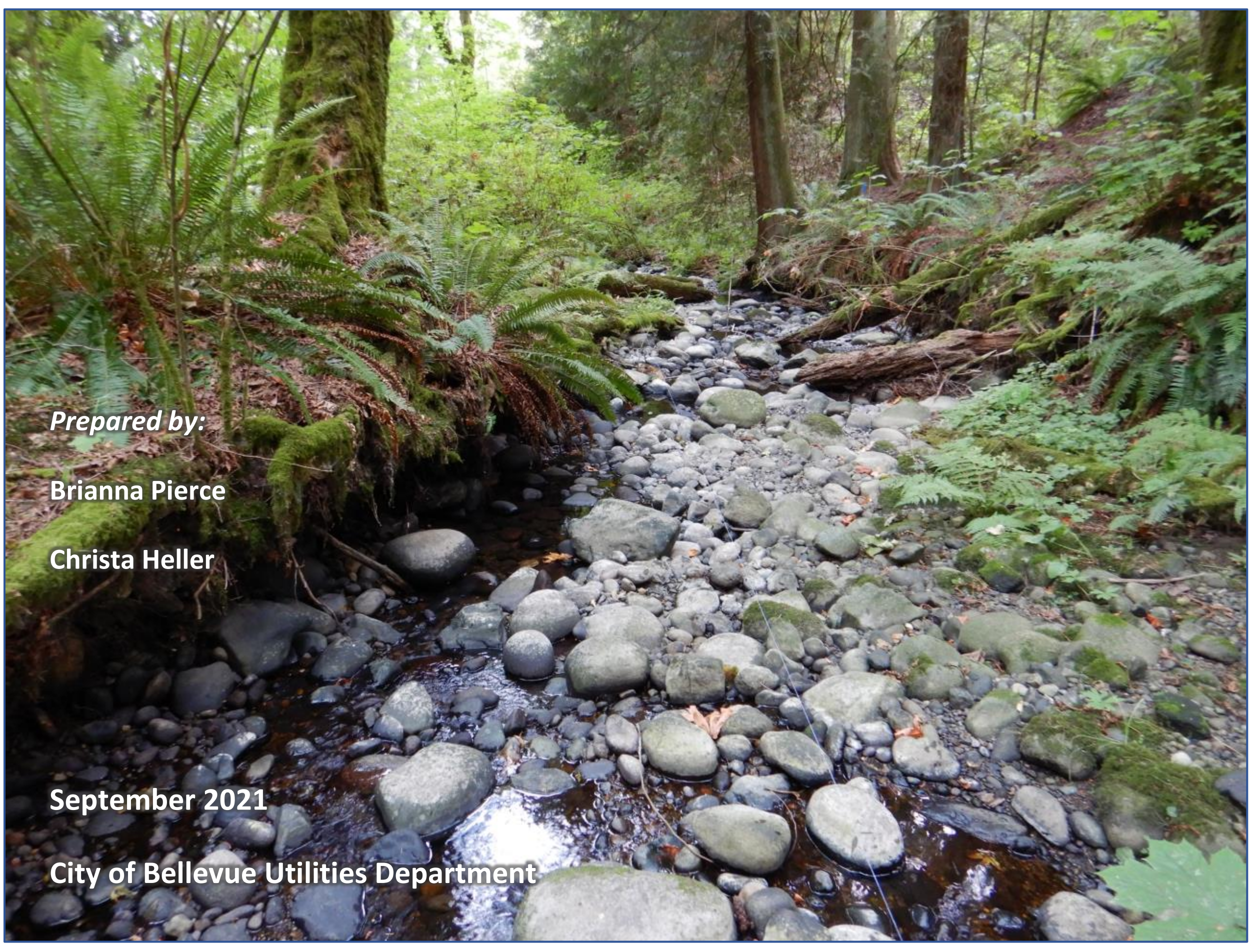
WDFW. 2020. Salmonscape fish distribution. Washington State Department of Fish and Wildlife. Online mapping accessed in summer, 2020 at: http://apps.wdfw.wa.gov/salmonscape/.

Appendix B
Open Streams Condition Assessment Subbasin Summaries for the Lake Sammamish Watershed

Appendix B

Open Streams Condition Assessment Subbasin Summaries

for the Tributaries to Lake Sammamish



Prepared by:

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September 2021

City of Bellevue Utilities Department

Table of Contents

B.1 Introduction

The Open Streams Condition Assessment (OSCA) is a strategic initiative from the City of Bellevue's Storm and Surface Water System Plan (Bellevue 2015). OSCA surveys took place during low-flow conditions between 2018 and 2020. The purpose of the surveys was to establish a baseline and document current conditions and challenges facing Bellevue's streams. This information can then be used to inform and prioritize infrastructure enhancements and habitat restoration activities to promote stream health and the functioning of the City's storm and surface water systems. This appendix summarizes data and qualitative observations gathered during OSCA surveys for six subbasins in the Lake Sammamish Watershed.

B.2 Methods

B.2.1 Rationale for Protocol and Metric Selection

The US Forest Service Region 6 Level II Stream Inventory Protocol Version 2.12 (USFS 2012) was selected due to its rapid, repeatable, and unbiased design. Its watershed approach to habitat assessment allows a comprehensive baseline dataset to be established that will help the Utilities Department define and prioritize its role as a steward of Bellevue streams. Results from this comprehensive survey will help fill data gaps and identify project sites for capital improvement, fish habitat enhancement, and mitigation projects and opportunities. The USFS 2012 protocol does not collect physical habitat metrics for wetland reaches.

Physical habitat metrics in this study were selected based on their biological importance to stream health and/or their role as indicators of stream degradation.

- *Channel dimensions:* Altered hydrology can impact the stream size and channel dimensions, often resulting in wider, more incised channels (Chin 2006). Streams in healthy, "properly functioning" condition are expected to have a bankfull width to depth ratio of less than 10 (NOAA 1996). Conversely, channel modifications such as bank armoring can reduce the channel width. Additionally, urban streams tend to have less flow, and therefore shallower water depths, during the dry summer months. This can create low flow barriers for migratory fishes. Migrating adult trout require a minimum depth of 0.4 ft and Chinook salmon require at least 0.8 ft (Thompson 1972).
- *Pools:* Pools provide a velocity and thermal refuge as well as a refuge when steam flows decrease and water depths elsewhere in the channel become too low. For salmon, pools provide beneficial foraging habitat for juveniles (Naman *et al.* 2018) and resting areas for adults migrating to the spawning grounds. Pool frequency and volume is positively correlated to salmon production (Nickelson *et al.* 1979). Therefore, pool frequency, expressed as either pools per unit length or channel widths per pool, is a useful indicator of stream health (NOAA 1996). Pool depth is also an important metric. The residual pool depth is defined as the pool depth if stream flow was reduced to zero (i.e. maximum pool depth minus the pool tailout depth). The residual pool depth necessary for resident adult trout is one foot (Behnke 1992) and salmon are

generally considered to require a residual pool depth of three or more feet (Marcotte 1984 as cited in CDFG 1998, NOAA 1996).

- *Habitat composition:* Streams impacted by urbanization tend to have reduced habitat complexity, longer habitat units, and a higher percentage of glide habitats (Riley *et al.* 2005). Channel modifications such as weirs, culverts, failed bank armoring, or sediment detention ponds can also alter the habitat composition of a stream. Having a mixture of both fast- and slow-water habitat increases the diversity of stream-dwelling organisms, and juvenile salmonid productivity is highest when there is a roughly equal proportion of riffle and pool habitat area (Naman *et al.* 2018).
- *Large woody material:* Large woody material (LWM) increases habitat complexity by aiding pool formation and providing cover, facilitates trapping and sorting of sediments, and attenuates flow velocities (Bisson *et al.* 1987). Salmonid abundance is positively correlated with LWM abundance (Hicks *et al.* 1991) and dwindling levels of LWM from land use practices have been implicated in the decline of salmon populations. Studies that have determined the LWM abundance in relatively unimpacted streams (e.g. Fox and Bolton 2007) provide a useful reference benchmark for comparing LWM abundance. Such studies often present both the abundance and volume of wood present. However, since secondary growth, urban riparian areas cannot be expected to contain the large, old growth trees present at reference sites, the present study will only compare wood abundance.
- *Substrate:* Substrate size is highly influential to stream biota, determining the algal and macroinvertebrate communities and structuring the food web. Substrate size also determines the available fish spawning habitat. Salmonids require gravel to cobble-sized substrate for spawning, and a high percentage of fine sediment can trap or suffocate the eggs and juveniles of gravel-spawning fish (Bjornn and Reiser 1991).
- *Erosion:* Erosion is a natural process; however, altered hydrology and reduced riparian vegetation in urban areas frequently contribute to increased bank instability (May *et al.* 1998). Therefore, the percent of banks experiencing erosion can be a useful indicator of degradation but should be interpreted while considering the stream's position and function in the watershed.
- *Bank armoring:* Channel hardening results in altered habitat composition, flow, erosion, and sediment deposition (Stein *et al.* 2012), frequently disconnecting the stream from its floodplain. The percent of stream banks that are armored strongly correlates with urban impact. However, the type of armoring can strongly influence its impact on the stream. Bioengineering, or "soft" armoring, that uses rounded boulders, rootwads, and logs can provide bank stabilization while mimicking and facilitating natural stream processes. Therefore, this study presents both the total percent armored banks and the percent bioengineered banks.

B.2.2 Physical Habitat Assessment

Minor modifications were made to the Forest Service (USFS 2012) protocol. Instead of estimating widths and depths and developing statistically valid correction factors for each observer on each stream, actual measurements were collected at representative locations along each habitat unit using a laser range finder, measuring tape and/or stadia rod. A minimum of two thalweg depths, representative and maximum, were collected per habitat unit. The thalweg length of every habitat unit was measured using a hip chain or measuring tape. Habitat units were categorized as a pool, riffle, glide, step pool, side channel, pond, or tributary. Other habitat features such as chutes, falls, beaver dams, or seeps/springs were noted. Streambed substrate was visually estimated for fast water units (i.e. riffles and glides) as fines, gravel, cobble, boulder, and bedrock (or hardpan). Floodprone widths, bankfull depths, and Wolman pebble counts were not collected as part of this assessment.

Three levels of assessment were established to efficiently survey the basin to the greatest extent possible. **Table B-1** details the decision matrix and level of effort associated with the three assessment levels. Level 1 inventory methods were utilized in the mainstem and significant fish bearing streams, whereas Level 2 or 3 inventory methods were used to evaluate the condition and health of steep tributaries and headwater portions throughout the basin.

Geomorphic stream reaches within the jurisdictional boundaries of Bellevue were delineated and verified as part of this stream habitat assessment. It is assumed that these same reaches will be used in future assessments to maintain consistency for their evaluation over time. All surveys took place during low or base stream flows.

Table B-1. Decision matrix for determining the level of assessment.

Assessment	Scale	Fish Use *	Summary
Level 1	Habitat Unit	F/PF	Full inventory at the habitat unit level for habitat and substrate composition; unit length, width, depth; bank instability/armoring; LWM; photo documentation; and reference points (including channel profile data).
Level 2	Reach	F/PF/NF	Simplified inventory at the reach scale. Includes quantification of LWM, armoring, bank instability with data for pool and side channel habitat types and basic channel profile data. Photo documentation and documentation of tributaries and off-channel areas.
Level 3	Reach to Basin	Primarily NF	Consists primarily of spot checks with alerts, photo documentation, and general qualitative observations.

* Fish use categories relate to water type classifications where “F/PF” denotes a stream used by fish or has the potential to support fish populations and has perennial flow; “F/PF/NF” denotes a stream that may be used by fish, but that may have reaches above a natural barrier, may be intermittent, or not have flowing water all year; “NF” denotes a stream that is not used by fish and that does not have perennial flow.

B.2.2.1 Large Woody Material

Pieces of large woody material (LWM) were categorized by length, diameter, and position within the stream channel based on protocols for Wadeable Streams of Western Washington (Ecology 2009). Wood counts by size class were converted to volume using the formula established by Robison (1998). Wood smaller than the minimum length and diameter thresholds in **Table B-2** were not counted but may have contributed to the creation of log jams with small woody material. All LWM were noted as naturally recruited or human-placed. Human-placed logs were further identified as being anchored or unanchored. Log jams were also noted, and for Level 1 surveys, the habitat type in which the wood was located was also recorded, but those data are not included in this report.

Table B-2. Size categories for large woody material.

Length	Diameter
Short (6-16 feet)	Thin (4-12 inches)
Medium (16-50 feet)	Medium (12-24 inches)
Long (>50 feet)	Wide (>24inches)

B.2.2.2 Riparian and Streambank Condition

Riparian vegetation was not quantitatively assessed during the stream habitat surveys but was generally characterized using Geographic Information System (GIS) aerial imagery and field verified at the reach scale. Stands of Japanese knotweed (knotweed) were mapped and measured as a lineal metric and density described as low (less than 10 square feet), medium (10-500 square feet), or high (greater than 500 square feet).

Streambank erosion and armoring were each mapped and measured as a linear metric and described as low (less than 5 feet), medium (5-10 feet) or high (greater than 10 feet). Undercut banks were noted and measured; a representative measurement was recorded for each incidence of erosion or scour, and the maximum was noted if it was substantially greater than the representative value. Bank armoring material was documented and specified as riprap, rocks, metal, concrete, gabion baskets, logs, rootwads, bioengineering, etc.

Anthropogenic features such as culverts, bridges, weirs, outfalls, and litter were also documented when observed but are generally not included in this report.

B.2.2.3 Fish Habitat and Passage Barriers

Fish presence was documented by species, when possible, and abundance was estimated as low, medium, or high. Field protocols for this habitat assessment did not include a formal fish survey nor a fish passage barrier assessment, although locations of potential barriers, type and material of barrier, jump heights, and photos were collected. This information will aid further investigations through Bellevue’s Fish Passage Improvement Program.

B.2.3 Stream Reach Attributes

In addition to the physical stream habitat data collected during the OSCA surveys, this report also presents a table for each subbasin with metrics that describe stream attributes at the reach level. These attributes include sediment dynamics, channel type, stream gradient, drainage area, riparian canopy cover, riparian impervious surfaces cover, and reach length. Appendix A of this report provides greater detail on the methods and data sources used for the numerical calculations.

A brief description of each attribute is as follows:

- *Sediment dynamics*: Describes the relationship between sediment supply and transport capacity as described by Montgomery and Buffington (1998). Stream reaches are designated as source, transport, or response reaches. Channel modifications may alter the sediment dynamics of the reach. In such cases, the sediment dynamics classification is given the “forced” modifier. For example, piped conveyances are considered “forced transport” reaches.

- *Channel type*: Classification given to each stream reach based on its bedform characteristics. These classifications are based on those established by Montgomery and Buffington (1998). However, due to the topography and highly modified environment throughout the City, additional channel types are defined as necessary. When a stream reach exhibits a different channel type than expected given the topography and hydrology, the classification is given the "forced" modifier. Channel types may be forced by an abundance of LWM, beaver dams, weirs, artificially confined streambanks, etc.
- *Stream gradient*: The overall gradient or percent slope of the stream reach.
- *Drainage area*: The total land area that drains into each stream reach.
- *Riparian canopy cover*: Proportion of the area within 100 ft of the stream that is covered by tree canopy.
- *Riparian impervious surfaces*: Proportion of the area within 100 ft of the stream that is covered by impervious surfaces.
- *Reach length*: Total length of each stream reach, derived from GIS stream stationing.

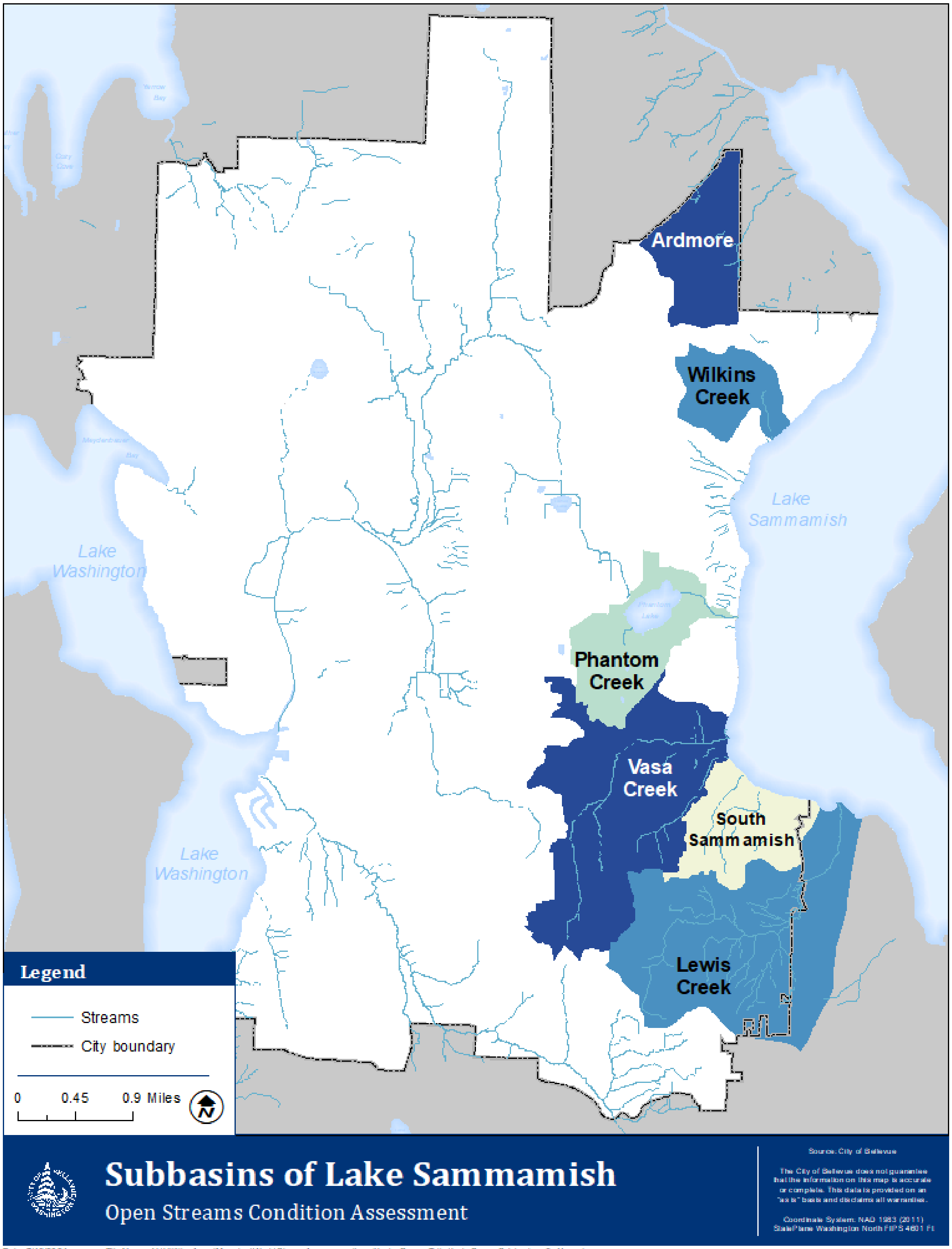
B.3 Summary of Results

The Lake Sammamish Watershed within the City of Bellevue consists of ten subbasins. The subbasins are generally high gradient and only five of these subbasins contain potentially fish-bearing streams with year-round streamflow (**Map B-1**). These five subbasins, as well as one subbasin containing a non-fish-bearing stream, were surveyed as part of the City of Bellevue's Open Streams Condition Assessment (OSCA). Furthermore, several of the "subbasins" in this watershed are not true subbasins in that the land that they encompass drains to more than one stream and are thus generally referred to as "areas" instead of subbasins. Included in this report are the Ardmore Area, Vasa Creek Area, and the South Sammamish Area.

Subbasins of the Lake Sammamish Watershed are generally characterized by moderately high gradient streams confined by ravines. In fact, the six OSCA-surveyed subbasins with the highest stream gradient in the City belong to the Lake Sammamish Watershed. The steep terrain associated with these tributaries has prevented development near the stream channel. Consequently, they have greater canopy cover and less impervious surface within 100 ft of the stream as compared to other streams in the City.

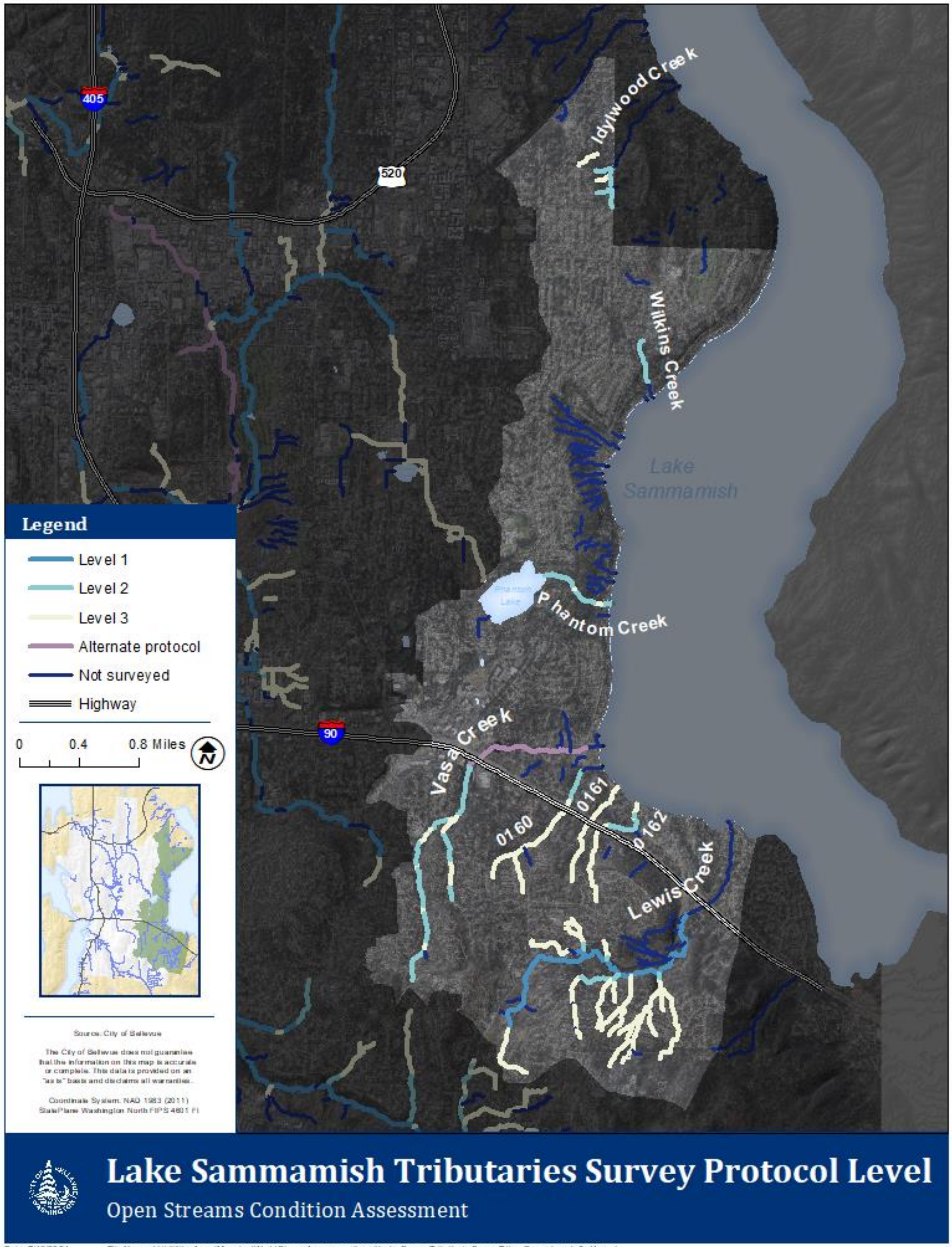
Lewis Creek is the largest subbasin and was surveyed in the fall of 2018 and spring of 2019. The remaining subbasins were surveyed in the spring and summer of 2020, except for lower Vasa Creek downstream of Interstate 90 (I-90) which was surveyed under a different protocol in 2014 (Tetra Tech 2014). **Map B-2** and **Table B-3** present the surveyed streams within the Lake Sammamish Watershed and the survey level used for each. Stream reaches surveyed under a Level 3 assessment protocol are not presented in this report. Hereafter, the phrase "surveyed reaches" will apply to stream reaches assessed under a Level 1 or Level 2 protocol.

In the City of Bellevue's storm drainage basin delineation, Sammamish Tributary 0160 is included within the Vasa Creek Area. This is likely because the high-flow bypass that splits off of Vasa Creek just downstream of the I-90 culverts connects to the piped portion of Tributary 0160 before discharging into Lake Sammamish. Some maps inaccurately show Tributary 0160 as a tributary of Vasa Creek. However, field surveys dating back as far as 1912 indicate this is a separate drainage with an independent outlet into Lake Sammamish (Rollins 1912). For the purposes of this report, Tributary 0160 will be grouped with Sammamish Tributary 0162 in the South Sammamish Area due to similar stream characteristics and geomorphology, but maps will remain consistent with the City’s current subbasin delineation.



Date: 7/16/2021 File Name: V:\UtilitiesAssetMapping\Work\StreamAssessment\mxd\Lake Samm Tribs\LakeSammSubbasins_8x11.mxd

Map B-1. The six subbasins surveyed in the Lake Sammamish Watershed.



Map B-2. Map showing the survey protocol level used for the tributaries to Lake Sammamish.

Table B-3. List of inventoried City of Bellevue streams, including Bellevue Stream Segment number and Water Resource Inventory Area (WRIA) number, organized from north to south and downstream to upstream.

Bellevue Subbasin	Stream Name	WRIA #	Stream Reach	Bellevue Segment ID	Assessment Level
Ardmore Area	Idylwood Creek	08.0143	Reach 9	87_09	2
			Reach 10	87_10	2
	North tributary to Idylwood Creek	-	Reach 1	87_09_11	2
	Middle tributary to Idylwood Creek	-	Reach 1	87_09_21	3
	South tributary to Idylwood Creek	-	Reach 1	87_10_21	2
Wilkins Creek Subbasin	Wilkins Creek	08.0151	Reach 2	89_02	2
			Reach 3	89_03	2
Phantom Creek Subbasin	Phantom Creek	08.0154	Reach 1	91_01	2
			Reach 3	91_03	2
			Reach 4	91_04	2
			Reach 6	91_06	2
Vasa Creek Area	Vasa Creek	08.0156	Reach 1	93_01	*
			Reach 2	93_02	*
			Reach 3	93_03	*
			Reach 4	93_04	2
			Reach 5	93_05	2
			Reach 7	93_07	2
			Reach 9	93_09	2
			Reach 11	93_11	2
			Reach 13	93_13	2
			Reach 15	93_15	2
			Reach 17	93_17	2
	Unnamed Tributary to Vasa Creek	-	Reach 1	93_01_21	*
	East Tributary to Vasa Creek		Reach 3	93_04_13	2
		08.0159	Reach 5	93_04_15	2
South Sammamish Area	Tributary 0160	08.0160	Reach 2	94_02	2
	Tributary 0162	08.0161	Reach 2	94_22	2
			Reach 4	94_24	2
			Reach 5	94_25	2
Lewis Creek Subbasin	Lewis Creek	08.0162	Reach 4	95_04	1
			Reach 5	95_05	1
			Reach 6	95_06	1
			Reach 7	95_07	1
			Reach 8	95_08	1
	Lewis Creek Tributary 0162D	-	Reach 1	95_04_61	2

Lewis Creek Tributary 0162B		Reach 1	95_05_21	2
	-	Reach 2	95_05_22	2
		Reach 3	95_05_23	2
		Reach 4	95_05_24	2
		Reach 5	95_05_25	2
Unnamed Tributary to Lewis Creek Reach 5	-	Reach 1	95_05_31	2
Lewis Creek Tributary 0162K	-	Reach 1	95_06_11	1
		Reach 2	95_06_12	1
Tributary to Tributary 0162K	-	Reach 1	95_06_11_11	2

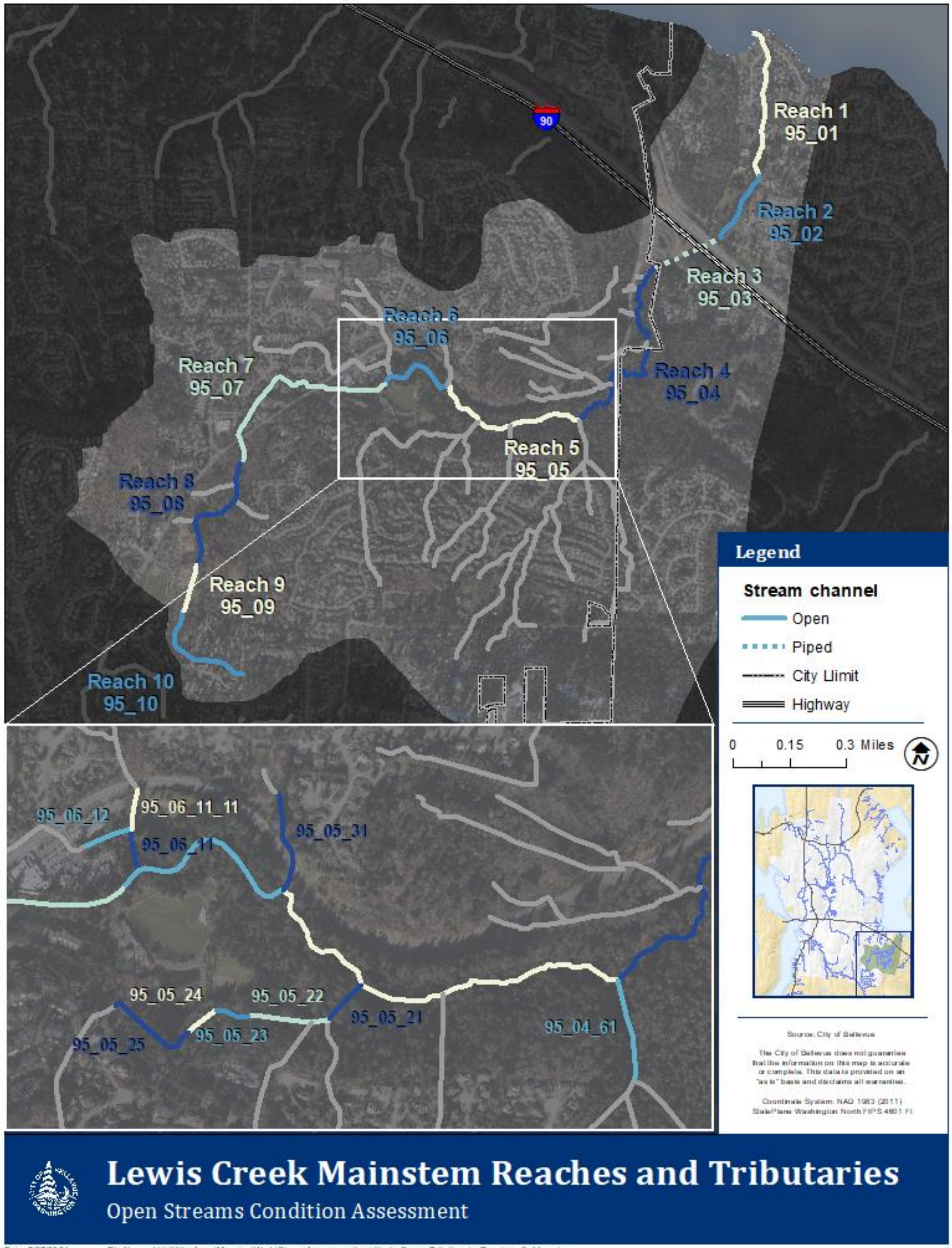
* Lower Vasa Creek was surveyed under a different protocol (Tetra Tech 2014).

B.3.1 LEWIS CREEK SUBBASIN

The Lewis Creek Subbasin, located in southeastern Bellevue, encompasses 1,424 acres in the Cougar Mountain/Lakemont neighborhood and drains into the southwestern end of Lake Sammamish. Approximately 70% of the subbasin is within the City of Bellevue while much of the remainder, including the mouth of Lewis Creek, is in the City of Issaquah, and approximately 5% is in unincorporated King County. Land use is primarily residential although parks and open space account for nearly 20% of the subbasin. Elevation ranges from 31 ft to 1,423 ft. Overall, the subbasin has 10.0 miles of open stream channel and 23.5 miles of storm drainage pipes (Bellevue 2017).

The Lewis Creek Subbasin has numerous second, third, and forth order tributaries that feed into the mainstem of Lewis Creek (**Map B-3**). The present-day headwaters to Lewis Creek lie within the residential areas south of Lewis Creek Park. Within the park is a wetland area that has likely formed due to altered hydrology associated with an old road that is now a park trail. The outlet of this wetland forms the mainstem of Lewis Creek. The stream flows out of the park through a culvert under Lakemont Boulevard and passes through a residential area before crossing back under Lakemont Boulevard and into the Lakemont Community Park and Open Space. For the next 1.5 miles, the stream passes through protected greenspace and confluences with multiple tributaries (including Tributaries 0162B, 0162D, and 0162K) while paralleling Lakemont Boulevard until it reaches SE Newport Way. From here, Lewis Creek crosses into the City of Issaquah where it is piped under SE Newport Way and I-90 and then passes through residential properties before its outlet into Lake Sammamish.

The Lakemont Stormwater Filtration and Detention Facility has a large influence on this subbasin. Built around 1990 to mitigate the impacts of residential development, the facility collects runoff from a large area of the subbasin. The runoff is passed through a sand filter which includes steel wool to remove phosphates, before discharging into the stream at the upstream end of Reach 6. This has the effect of removing many pollutants from the runoff as well as attenuating peak flows. Accordingly, the Lewis Creek Subbasin has one of the lowest densities of outfalls to the steam channel (4.6 per mile) observed during OSCA surveys compared to other subbasins in the City. During the summer low flow period, the volume of water observed discharging from this facility appears to be equal to or greater than the streamflow coming from upstream (Reach 7).



Map B-3. Stream reaches of the mainstem and surveyed tributaries of Lewis Creek.

B.3.1.1 Channel Morphology and Riparian Corridor

The Lewis Creek Subbasin is one of the higher gradient fish-bearing stream systems in the City of Bellevue. The average gradient for surveyed reaches in the subbasin is 7.5% (**Table B-4** and **Table B-5**), which is lower than that found in the other subbasins of the Lake Sammamish Watershed, but much higher than average for streams across the City. The stream channel usually takes on a plane-bed or cascade morphology with a small headwater wetland on the mainstem of Lewis Creek that is likely resultant from relic land use activities that have created a minor impoundment. Approximately 6.8% of the stream length within City limits is enclosed in the storm drainage network, which is a much lower than average proportion for subbasins in the City.

The Lewis Creek Subbasin stream corridor has mostly retained a healthy riparian zone. Land use in the subbasin is primarily residential and the mainstem passes through two large greenspaces: the Lakemont Community Park and Open Space and Lewis Creek Park. This has helped to maintain the relatively good riparian canopy cover and low proportion of impervious surfaces within the 100 ft riparian buffer (**Table B-4** and **Table B-5**). Across all surveyed reaches, the Lewis Creek Subbasin has 77% riparian canopy cover and 9% riparian impervious surfaces, which is about average for the Lake Sammamish Watershed but much better than average for subbasins across the City. The canopy generally consists of mixed conifers, alder, and big leaf maple with an understory of vine maple, salmonberry, devils club, and ferns. Invasive plant species, predominantly Himalayan blackberry, are intermittently prevalent although this is much less of an issue for the Lewis Creek Subbasin as compared to others in the City.

Streams in the Lewis Creek Subbasin tend to be broad and shallow although the floodplain is somewhat confined by steep banks and the mainstem retains greater channel depth than the tributaries. Across all reaches surveyed under a Level 1 protocol, the median wetted and bankfull widths are 7.0 ft and 13.6 ft, respectively. This yields a bankfull to wetted width ratio of 1.9 indicating that this is the least confined subbasin in the City. The stream generally widens and deepens as you proceed downstream (**Figure B-1** and **Figure B-2**). The median representative and maximum thalweg depths are 0.4 ft and 0.7 ft, respectively.

Table B-4. Lewis Creek mainstem reach attributes.

	Reach 1*	Reach 2*	Reach 3*	Reach 4	Reach 5
Reach Segment ID	95_01	95_02	95_03	95_04	95_05
River Mile Boundaries	0.00 – 0.28	0.28 – 0.61	0.61 – 0.79	0.79 – 1.42	1.42 – 1.87
Sediment Dynamics	Response	Response	Forced transport	Transport/ Response	Transport
Channel Type	Plane-bed	Plane-bed	Piped conveyance	Cascade/ Plane-bed	Cascade
Stream Gradient (%)	3.5	3.5	3.7	5.0	8.2
Riparian Canopy Cover (%)	-	-	-	89	89
Riparian Impervious Surface Cover (%)	20	12	39	3	1
Reach Length (ft)	1,500	1,700	950	3,350	2,350
	Reach 6	**Reach 7**	**Reach 8**	**Reach 9**	**Reach 10**
Reach Segment ID	95_06	95_07	95_08	95_09	95_10
River Mile Boundaries	1.87 – 2.09	2.09 – 2.64	2.64 – 3.01	3.01 – 3.14	3.14 – 3.45
Sediment Dynamics	Transport	Response	Response	-	Source
Channel Type	Cascade	Plane-bed	Plane-bed	Wetland	Colluvial
Stream Gradient (%)	6.6	4.1	4.4	0.2	8.7
Riparian Canopy Cover (%)	84	57	68	23	60
Riparian Impervious Surface Cover (%)	1	26	2	3	14
Reach Length (ft)	1,200	2,900	1,950	700	1,600

* Reaches 1-3 are outside the City of Bellevue.

Table B-5. Reach attributes for the Lewis Creek tributaries.

	Lewis Creek Tributary 0162B				
Reach Segment ID	95_05_21	95_05_22	95_05_23	95_05_24	95_05_25
River Mile Boundaries	0.00 – 0.05	0.05 – 0.13	0.13 – 0.17	0.17 – 0.20	0.20 – 0.30
Sediment Dynamics	Transport	Transport	Response	Transport	Transport
Channel Type	Cascade	Cascade	Plane-bed	Cascade	Cascade
Stream Gradient (%)	29.8	17.7	6.5	13.4	7.1
Riparian Canopy Cover (%)	100	96	89	74	86
Riparian Impervious Surface Cover (%)	0	0	8	11	3
Reach Length (ft)	250	450	200	150	550
	Lewis Creek Tributary 0162D	**Unnamed Tributary**	**Lewis Creek Tributary 0162K**		**Unnamed Tributary to Tributary 0162K**
Reach Segment ID	95_04_61	95_05_31	95_06_11	95_06_12	95_06_11_11
River Mile Boundaries	0.00 – 0.30	0.00 – 0.11	0.00 – 0.04	0.04 – 0.10	0.00 – 0.04
Sediment Dynamics	Transport	Transport	Transport	Response/ Transport	Response
Channel Type	Cascade	Cascade	Cascade	Forced step pool	Plane-bed
Stream Gradient (%)	26	14.4	3.9*	9.6*	1.8
Riparian Canopy Cover (%)	89	52	74	57	53
Riparian Impervious Surface Cover (%)	0	26	<1	25	12
Reach Length (ft)	175	579	230	292	222

* Value calculated manually from the digital elevation model because the GIS-computed value was clearly incorrect due to an inaccurate stream centerline.

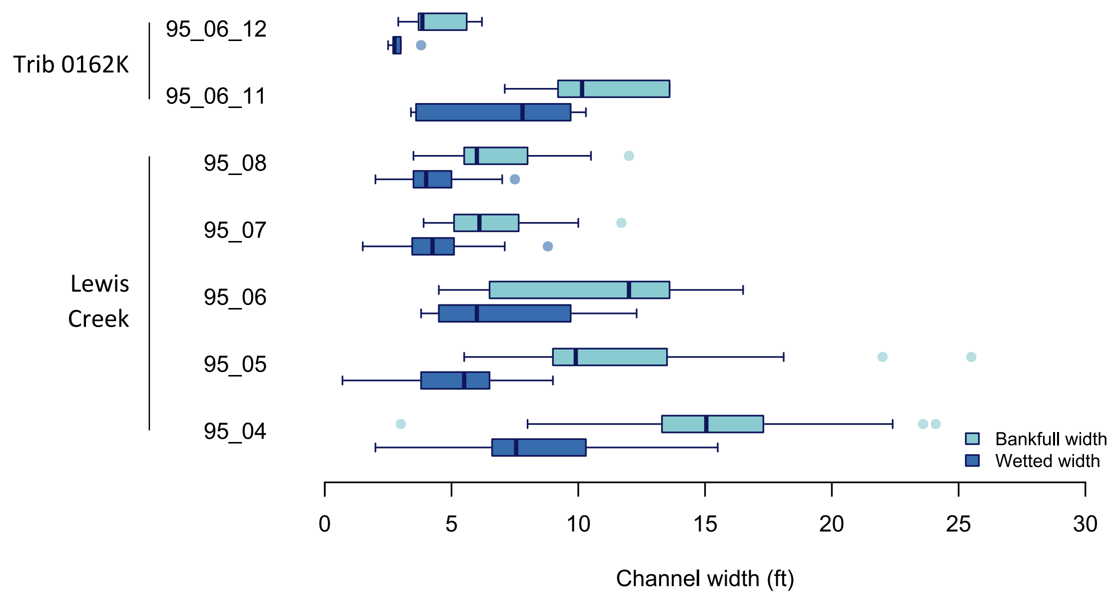


Figure B-1. Boxplot of the wetted and bankfull channel widths for stream reaches in the Lewis Creek Subbasin that were surveyed under a Level 1 protocol.

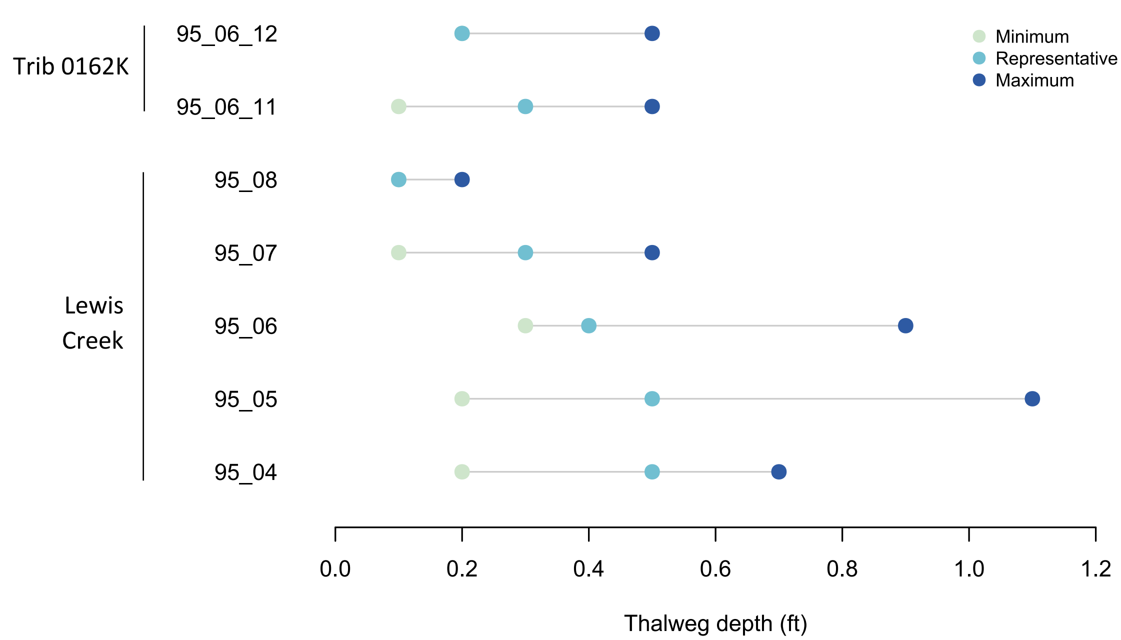


Figure B-2. Dumbbell plot of wetted stream depths for stream reaches in the Lewis Creek Subbasin surveyed under a Level 1 protocol. Points represent the median value for the minimum, representative, and maximum depth for each reach.

B.3.1.2 Habitat Unit Composition and Off-Channel Habitat

The Lewis Creek Subbasin is strongly dominated by riffle habitat. The survey protocol we used does not differentiate between riffle and cascade habitat, though much of the habitat documented as riffles would also be considered cascade habitat. For the stream reaches surveyed under a Level 1 protocol, riffle habitat accounts for 83% of the stream area and 79% of the stream length (**Figure B-3** and **Figure B-4**). Glide habitat accounts for 10% of the stream area and is most abundant in the upper reaches of Lewis Creek. In the rest of the City, glide habitat is generally associated with low-gradient reaches. However, the large boulders present in Lewis Creek create short glides between cascades.

True pool habitat is minimal in the Lewis Creek Subbasin. Across all surveyed reaches, pools, as defined by our survey protocol, account for only 2% of the stream area. This yields a riffle to pool ratio of 37.5 and an overall pool frequency of 6 pools per mile or approximately 61 channel widths per pool. This is the second lowest pool frequency in the Lake Sammamish Watershed, third lowest in the City of Bellevue, and far below the ideal pool frequency of around 80 pools per mile expected in healthy, “properly functioning” streams (NOAA 1996). When present, pools are generally not very deep, and at the time of the survey, no pool in the subbasin exceeded 2 ft maximum depth. The median residual pool depth is 1.2 ft (**Figure B-5**), which is about average for both the watershed and the City. However, these metrics do not fully capture the habitat present in the mainstem of Lewis Creek. There are numerous pocket pools (often over 1 ft in depth) in the cascade portions of the stream which provide deep water and velocity refugia but do not qualify as pool habitat by our protocol. Nevertheless, these pocket pools provide similar ecological functions as larger pools and are essential habitat to the numerous fish observed in the stream.

Despite its steeper than average gradient, Lewis Creek has some potential for off-channel habitat. Unlike all other streams in the City of Bellevue, the mainstem of Lewis Creek has consistent side channel habitat which accounts for 4% of the stream area and 8% of the stream length. Reaches 4 and 5, in particular, have an intermittent floodplain bench and an intact riparian buffer than can support natural channel migration.

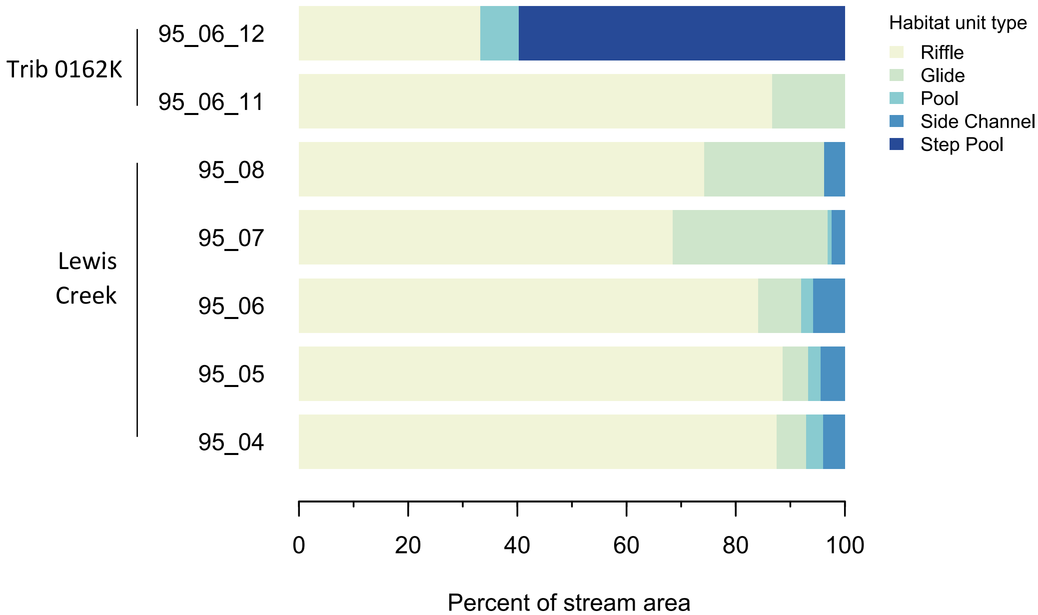


Figure B-3. Habitat unit composition (by percent area) for the Lewis Creek Subbasin stream reaches surveyed under a Level 1 protocol.

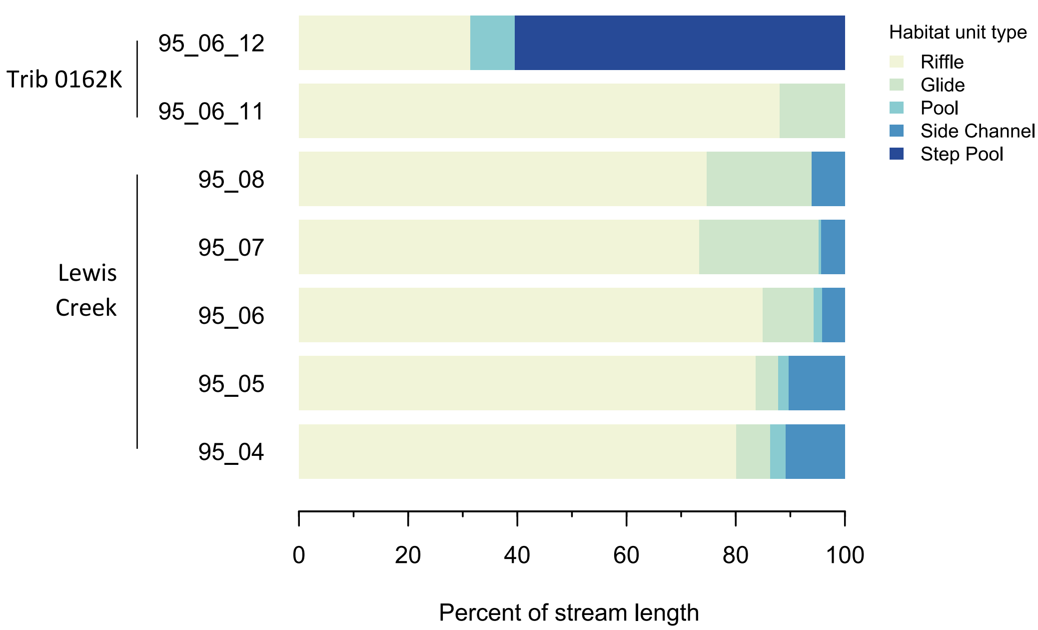


Figure B-4. Habitat unit composition (by percent length) for the Lewis Creek Subbasin stream reaches surveyed under a Level 1 protocol.

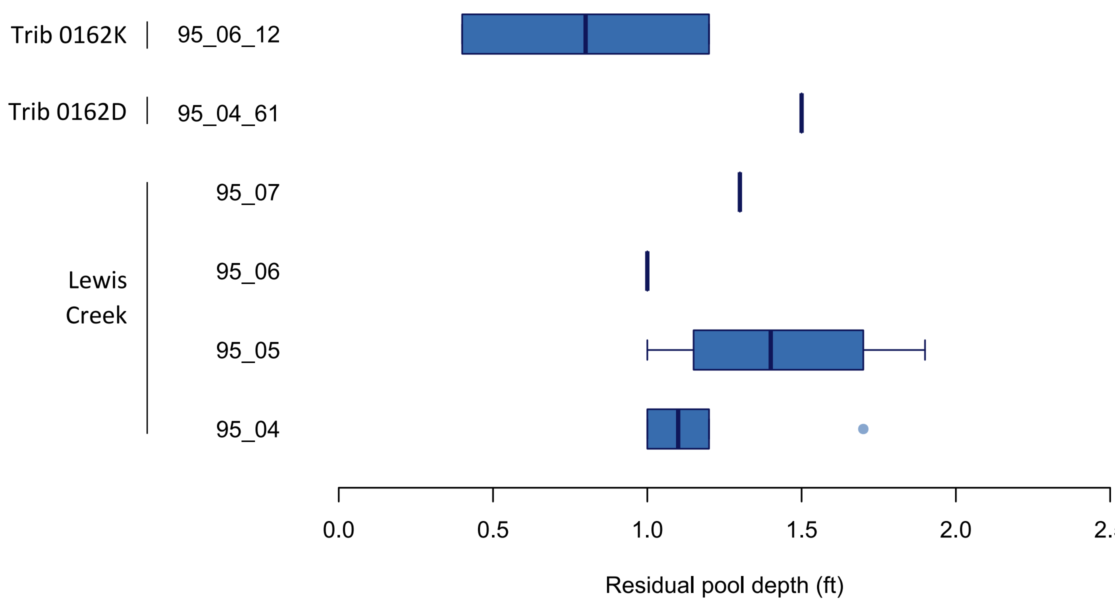


Figure B-5. Boxplot of residual pool depths observed in Lewis Creek Subbasin stream reaches. Reaches are omitted if they did not contain pool habitat.

B.3.1.3 Large Woody Material

The Lewis Creek Subbasin has moderately good levels of large woody material (LWM) for an urban stream. The overall wood density for surveyed reaches is 325 pieces per mile (20 pieces per 100 m) which is about average for the Lake Sammamish Watershed but higher than average for subbasins across the City. Although better than in most urban streams, this wood frequency is still below the 25th percentile observed in similarly sized reference streams (Fox and Bolton 2007) and thus considered a "poor" level of LWM. Wood abundance varies dramatically among stream reaches in the subbasin (**Figure B-6)**. More than one-third of all stream reaches have wood levels that exceed the reference median wood frequency, but wood is quite sparse in Lewis mainstem Reaches 7 and 8 and the upper portion of Tributary 0162B. Low LWM frequency is generally associated with residential land use.

The healthy, intact riparian areas found throughout much of the subbasin help maintain LWM levels. Nearly all the LWM observed during surveys was presumed to be of natural origin; only one piece had been placed. The riparian canopy, consisting of mixed conifers, alder, and big leaf maple, provides opportunities for natural LWM recruitment. Somewhat unique to this subbasin is the size of the wood that is present. More than half of all recorded LWM is greater than 1 ft in diameter, indicative of the more mature riparian vegetation found in this subbasin. This is beneficial, as larger wood will persist longer and is better at withstanding high flows, retaining substrate, and forming habitat complexity. LWM seems to be particularly important in pool formation in the Lewis Creek mainstem and Tributary 0162K. Although pool habitat only comprises 2% of the stream area, 45% of all documented wood was associated with pools.

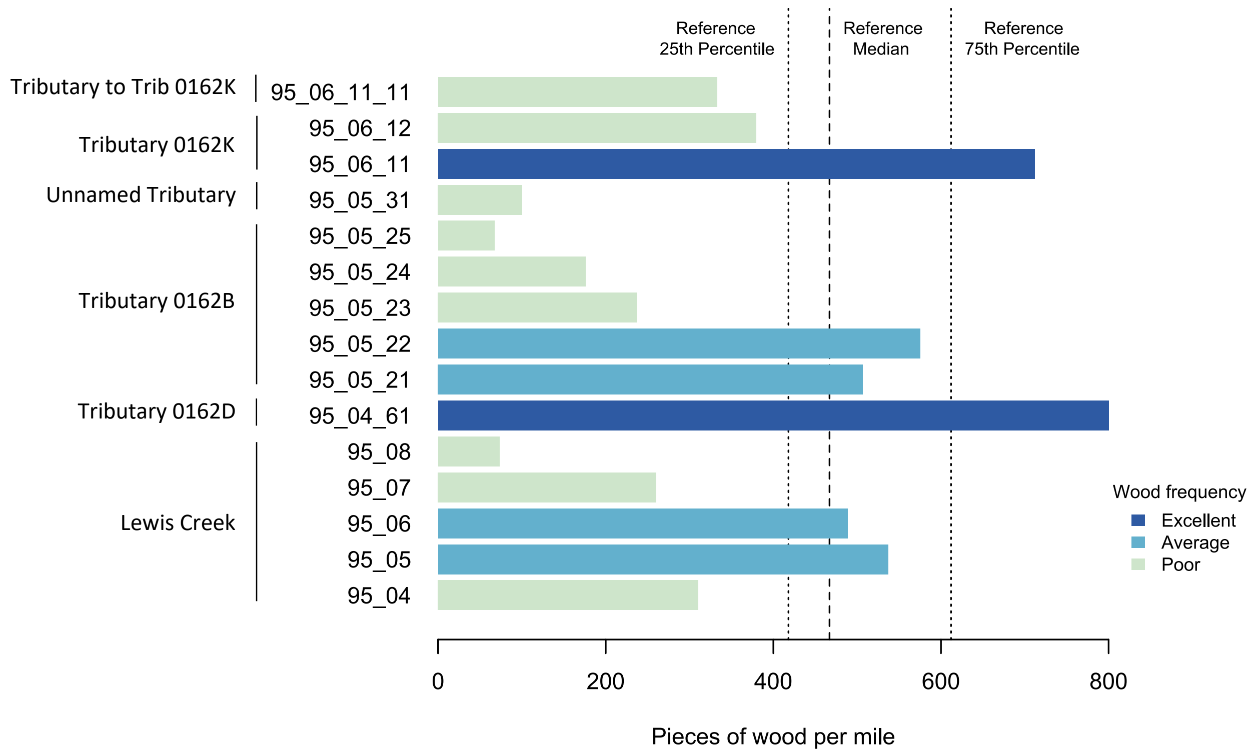


Figure B-6. Large woody material frequency in Lewis Creek Subbasin stream reaches compared to reference levels (Fox and Bolton 2007).

B.3.1.4 Streambed Substrate

The Lewis Creek Subbasin has some of the coarsest substrate observed in the City of Bellevue. Across all riffle habitats in reaches surveyed under a Level 1 protocol, the substrate is composed of cobble (33%), gravel (24%), boulders (22%), fines (17%), and exposed glacial till (3%; **Figure B-7**). This is the lowest percent fines of any subbasin in the City. Exposed hardpan glacial till is intermittently present throughout the subbasin and is more prevalent in Lewis mainstem Reach 5 and Tributary 0162K Reach 2 where it influences the channel morphology, creating cascades and pocket pools.

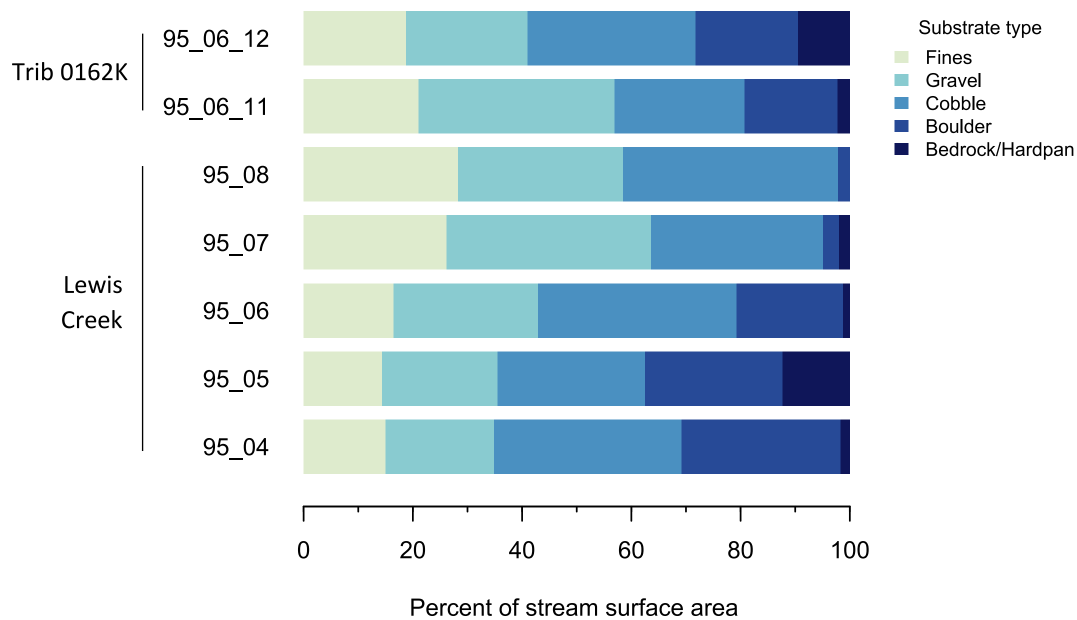


Figure B-7. Substrate composition of riffle habitat in stream reaches of the Lewis Creek Subbasin surveyed under a Level 1 protocol, determined by visual estimation.

B.3.1.5 Streambank Conditions

The Lewis Creek Subbasin has the least streambank armoring observed in the City of Bellevue. Across all surveyed reaches, only 2% of the streambanks are armored. Nearly two-thirds of the surveyed reaches have no armoring at all. When present, the proportion of the streambank that is armored varies considerably by reach (**Figure B-8**) and is most frequently associated with residential land use. All of the armoring in the subbasin is traditional or "hard" armoring, predominantly large angular rock or pieces of concrete.

Streambank erosion is fairly low in the Lewis Creek Subbasin. Across all surveyed reaches, 5% of the streambank is undercut and 10% of the streambank is eroding which is the lowest percentage in the Lake Sammamish Watershed and lower than average for subbasins across the City. There are numerous areas, particularly in the mainstem of Lewis Creek, where the streambanks are stable but undercut, providing beneficial habitat and shading. Both erosion and undercutting vary considerably among stream reaches (**Figure B-9** and **Figure B-10**). Although most of the erosion in the subbasin is low (< 5 ft in height), there is evidence of mass wasting events in Lewis Creek mainstem Reaches 4 through 6 and Tributary 0162D Reach 1. Additionally, there is localized streambed scour and head cutting in Tributary 0162K Reach 1 that has resulted in a 4 ft hydraulic drop and is likely associated with a stormwater outfall. The Lakemont Stormwater Filtration and Retention Facility has likely had a large beneficial impact in mitigating erosive stream flows throughout much of the subbasin. Even so, there is intermittent evidence of channel incision resulting from high flows in Reaches 4 and 5 downstream of the facility which could gradually disconnect the stream from its floodplain.

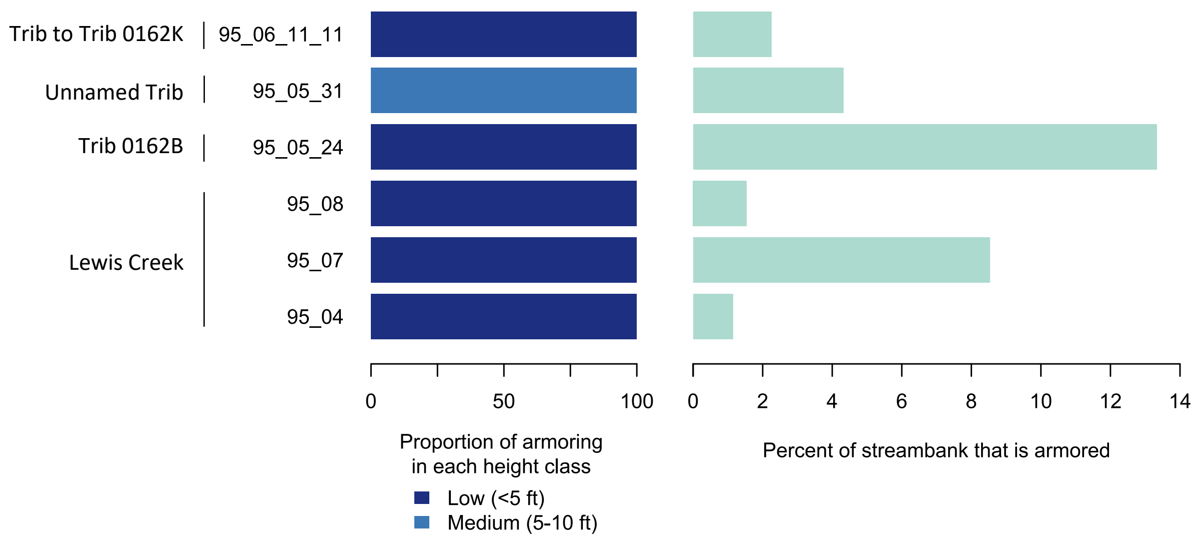


Figure B-8. Multi-panel bar graph showing the height and proportion of armoring in each surveyed stream reach in the Lewis Creek Subbasin. Omitted reaches had no armoring.

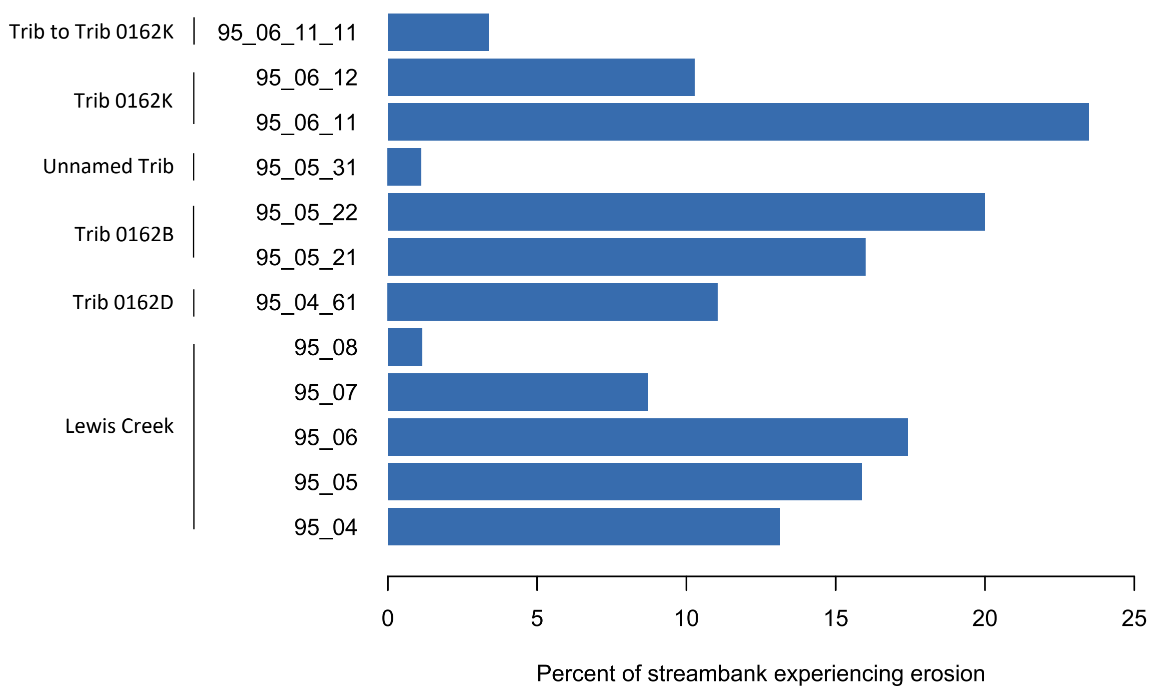


Figure B-9. Percent of each surveyed reach in the Lewis Creek Subbasin that is experiencing erosion. Omitted reaches had no erosion.

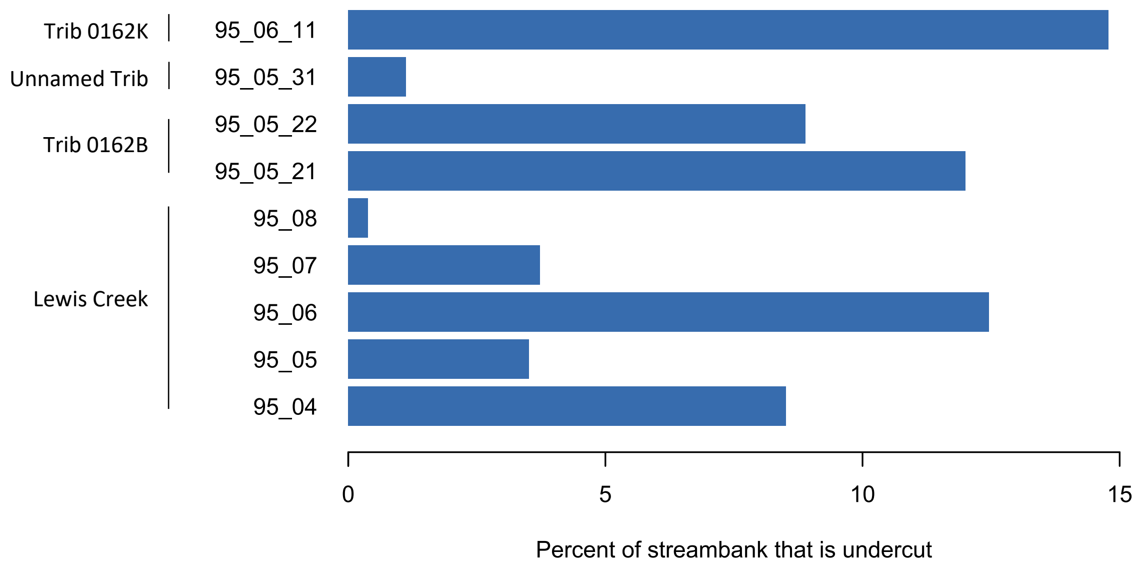


Figure B-10. Percent of each surveyed reach in the Lewis Creek Subbasin with undercut streambanks. Omitted reaches had no undercut banks.

B.3.1.6 Fish Habitat and Passage Barriers

All surveyed stream reaches in the Lewis Creek Subbasin are fish-bearing or potentially fish-bearing except for Lewis Creek Tributary 0162D which is listed as a non-fish bearing, stream with year-round flow (Bellevue 2010). However, during the OSCA surveys, fish were only documented in the mainstem of Lewis Creek. Fish were most abundant in Reaches 4 and 5 and sporadically present in Reaches 6 and 7. All observed fish were Cutthroat Trout and were generally juveniles, although a couple of larger (6-7 in) Cutthroat Trout were also observed.

Channel complexity and instream cover as well as healthy riparian vegetation contribute to the good fish habitat found in Lewis Creek. Although pool habitat, as defined by our protocol, is lacking, there are numerous pocket pools found in riffle and cascade habitat, and fish were abundant in these areas. Additionally, undercut banks, large woody material, and overhanging vegetation provide shade and cover and increase the abundance of prey items available in the stream.

The streambed substrate in Lewis Creek provides good spawning habitat for resident trout as well as migratory salmonids. The low proportion of fines in the streambed substrate is ideal for gravel-spawning fishes. Although the stream gradient and large substrate size found in the mainstem of Lewis Creek is at the upper threshold preferred by Coho Salmon, there is still intermittently available quality spawning habitat for this species as well as for kokanee. Additionally, this stream could provide good habitat for steelhead.

Fish passage barriers in the Lewis Creek Subbasin have not been formally assessed by WDFW since 2000. Assuming barriers have remained the same since then, the mainstem of Lewis Creek has four partial barriers (three within the City of Bellevue) and one complete barrier. Only one of the partial barriers is owned by the City (a culvert in Lewis Creek Park at the downstream end of Reach 9). The complete barrier is the I-90 culvert which is scheduled to be replaced with bridges and a restored channel by WSDOT beginning around 2024. This will restore access to the subbasin for migratory species that have been seen in Lewis Creek downstream of I-90 including Coho, Sockeye, and Chinook salmon as well as kokanee and steelhead (Kerwin 2001). During the OSCA surveys, a bedrock chute was observed in the upper portion of Reach 7 and is presumed a natural barrier to migratory fish into the stream reaches upstream of Lakemont Blvd. Additionally, the box culvert under Lakemont Blvd in upper Reach 7 had no surface water connection during the OSCA survey and is assumed to be a summer low flow barrier.

In addition to the barriers on the mainstem, there are two complete barriers at the upstream ends of the surveyed portions of Lewis Creek Tributary 0162K and its unnamed tributary where they pass under Lakemont Blvd SE. Both barriers are owned by the City. The channels upstream are considered potentially fish bearing.

B.3.1.7 Opportunities

Lewis Creek is one of the healthiest streams in the City of Bellevue, yet there are still opportunities to protect and restore the stream. Installation of LWM, particularly in Lewis mainstem Reaches 4 and 5 and Tributary 0162K Reach 1, would provide instream structure and stabilization and would allow natural stream processes to reconnect the floodplain. Additionally, the stream would benefit from riparian enhancement to remove non-native vegetation, facilitate future forest succession, and thereby ensure the potential for natural LWM recruitment into the future. Private landowner educational outreach and incentive programs are also recommended because the most degraded sections of stream in the subbasin are on private residential properties.

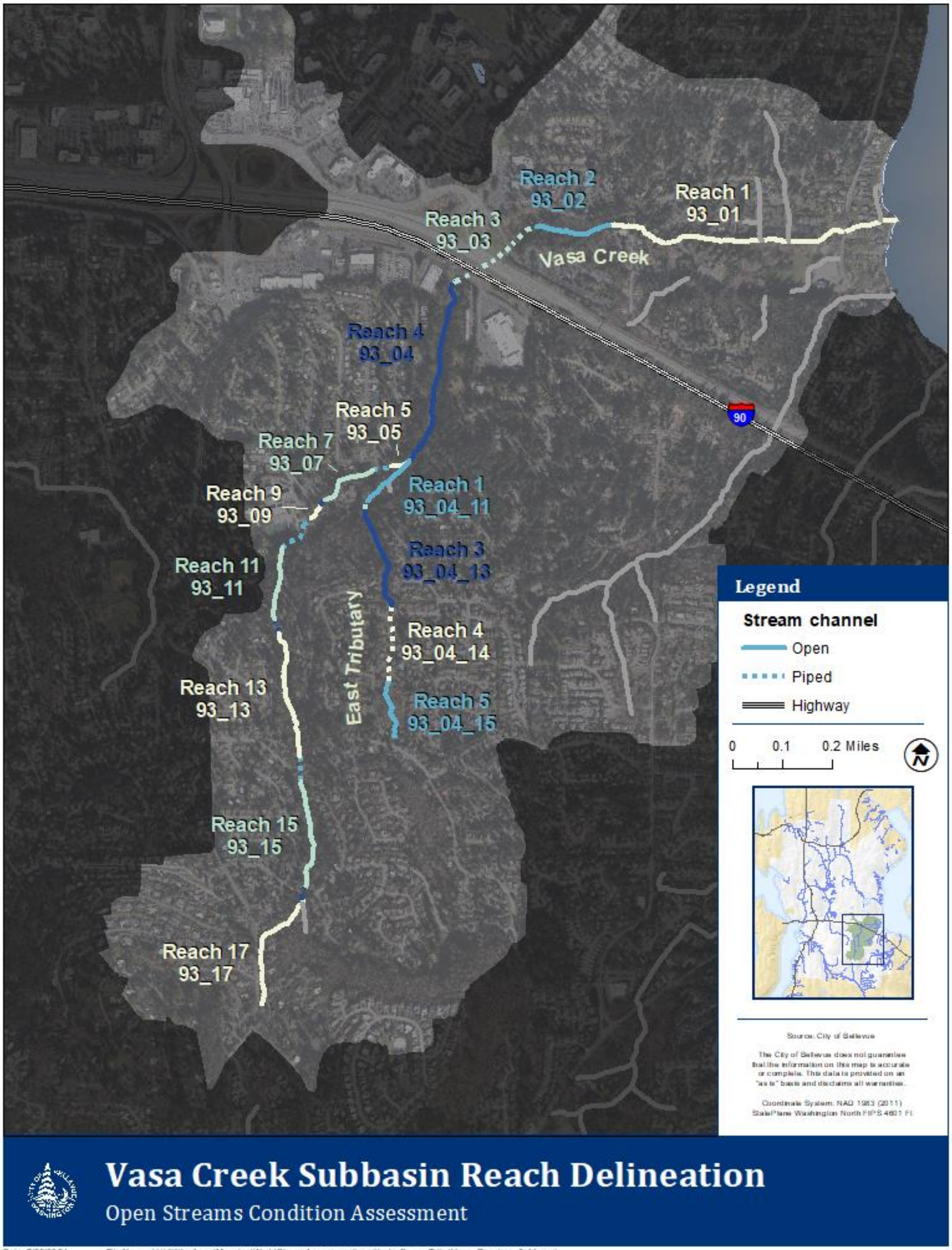
The upcoming removal of the I-90 culverts provides an opportunity to study the effectiveness of fish passage barrier correction and stream enhancements. The OSCA surveys have documented that there is quality habitat for migratory fishes upstream of this barrier. If fish passage is currently a limiting factor in this system, we would expect to see migratory fishes naturally recruit into Reach 4 and potentially further upstream once the barrier is removed. Thus, we are ideally situated to evaluate the effectiveness of barrier correction and stream restoration activities on stream biota broadly and migratory salmonids in particular. Such an effectiveness study provides an opportunity to partner with tribal, governmental, and independent conservation groups on this regionally important topic.

B.3.2 Vasa Creek Subbasin

Located in southeast Bellevue, the Vasa Creek Subbasin encompasses 1,268 acres and drains into the southwestern end of Lake Sammamish. Land use is primarily residential although public right of way, including the I-90 corridor, accounts for over 21% of the land area. Parks and open space comprise only 2.3% of the subbasin. Elevation ranges from 31 ft to 1,196 ft. Overall, the subbasin has 4.7 miles of open stream channel and 30.1 miles of storm drainage pipes (Bellevue 2017).

Vasa Creek (also known as Squibbs Creek) passes through the Cougar Mountain/Lakemont, Eastgate/Factoria, and West Lake Sammamish neighborhoods. The present-day headwaters of the subbasin are a small wetland located near Saddleback Park, which forms the divide between the Vasa and Coal Creek subbasins. As it flows downstream, the creek passes through a small ravine in the narrow Whispering Heights Open Space and Horizon Heights Open Space before being piped under much of the Eastgate Elementary School property (Reach 10). This area has been subject to flooding during severe rain events. Downstream of SE Newport Way, the channel meanders through residential properties before confluencing with its largest tributary (known as the East Tributary) and entering a larger ravine area. At the downstream end of this ravine, the channel splits and braids through a fluvial depositional area before emptying into an instream stormwater and sediment detention pond maintained by WSDOT. From there, the channel is piped under I-90 (Reach 3) and stream flow is split between a high-flow bypass that is piped to Lake Sammamish while the remaining instream flow then proceeds through residential areas with a relatively low gradient before emptying into Lake Sammamish.

The portion of Vasa Creek downstream of I-90 (Reaches 1 and 2; **Map B-4**), was surveyed under a different protocol (Tetra Tech 2014) in 2014. The rest of Vasa Creek and the East Tributary were surveyed as part of the OSCA effort in 2020 using a Level 2 protocol. Where possible, this report incorporates data from the previous survey to provide a more complete overview of the subbasin. For a more in-depth assessment of Reaches 1 and 2, see the Tetra Tech (2014) report.



Map B-4. Stream reaches for Vasa Creek and the East Tributary.

B.3.2.1 Channel Morphology and Riparian Corridor

The steep terrain and ravines surrounding much of the Vasa Creek stream corridor strongly impacts the channel morphology. Overall, the stream gradient is 7.3%, which is lower than average for streams in the Lake Sammamish Watershed but approximately twice the average gradient for streams throughout the City. The channel morphology is primarily composed of cascade channel types with generally high sediment transport and plane-bed channel types where the response to sediment deposition is evident (**Table B-6**). Numerous grade control structures have been installed throughout the mainstem of Vasa Creek. While stabilizing the streambed, these structures are also posing substantial barriers to fish movement and migration. Additionally, 19.6% of the stream channel within the subbasin (excluding Tributary 0160) is piped, the most notable sections of which include the I-90 culverts (Reach 3), the piped stream conveyance under the Eastgate Elementary School (Reach 10), and the upper portion of the East Tributary (East Tributary Reach 4).

Riparian vegetation and canopy cover varies by stream reach, with residential areas generally having less canopy cover (**Table B-6** and **Table B-7**). Across all surveyed reaches, the impervious surface cover within the 100 ft stream buffer is 16%, which is average for the City but ties with the Phantom Creek Subbasin for having the worst percent riparian imperviousness in the Lake Sammamish Watershed. Likewise, the average canopy cover for the subbasin is 61%, which is about average for subbasins in the City but low compared to other subbasins in the watershed. Riparian canopy cover generally consists of big leaf maple interspersed with alder, cedar, and Douglas fir. Frequent invasive plant species include Himalayan blackberry and English ivy.

Vasa Creek is smaller than Lewis Creek but larger than the other tributaries to Lake Sammamish. Downstream of I-90, the wetted and bankfull widths average about 4.6 ft and 7.2 ft, respectively. Upstream of I-90, stream cross-sectional profile data collected at one to three representative locations per stream reach reveal that the average wetted width is around 6 ft and the bankfull width is around 8.8 ft. Overall, the bankfull width to wetted width ratio is around 1.5, which is less confined than average for subbasins in the City. Although wetted depths were not taken as part of the Level 2 OSCA surveys, bankfull depths were taken at the stream profiles and average 0.7 ft upstream of I-90 compared to 1.0 ft downstream of I-90, indicating that the channel is generally pretty shallow.

Table B-6. Reach attributes for Vasa Creek.

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6
Reach Segment ID	93_01	93_02	93_03	93_04	93_05	93_06
River Mile Boundaries	0.00 – 0.63	0.63 – 0.79	0.79 – 0.98	0.98 – 1.37	1.37 – 1.42	1.42 – 1.46
Sediment Dynamics	Response	Response	Forced transport	Response	Transport	Forced transport
Channel Type	Forced pool-riffle*/ Plane-bed	Plane-bed	Piped conveyance	Plane-bed	Cascade	Piped conveyance
Stream Gradient (%)	3.6	6.4	9.0	3.1	6.6	14.1
Riparian Canopy Cover (%)	43	81	-	72	71	-
Riparian Impervious Surface Cover (%)	25	3	51	<1	5	37
Reach Length (ft)	3,300	850	1,050	2,050	225	225

	Reach 7	Reach 8	Reach 9	Reach 10	Reach 11	Reach 12
Reach Segment ID	93_07	93_08	93_09	93_10	93_11	93_12
River Mile Boundaries	1.46 – 1.58	1.58 – 1.60	1.60 – 1.63	1.63 – 1.71	1.71 – 1.87	1.87 – 1.89
Sediment Dynamics	Response	Forced transport	Response	Forced transport	Response/ Transport†	Forced transport
Channel Type	Plane-bed	Piped conveyance	Plane-bed	Piped conveyance	Plane-bed/ Bedrock†	Piped conveyance
Stream Gradient (%)	4.9	0.2	5.7	6.8	7.0	8.2
Riparian Canopy Cover (%)	62	-	60	-	74	-
Riparian Impervious Surface Cover (%)	24	46	24	45	9	30
Reach Length (ft)	650	75	175	450	800	150

	Reach 13	Reach 14	Reach 15	Reach 16	Reach 17
Reach Segment ID	93_13	93_14	93_15	93_16	93_17
River Mile Boundaries	1.89 – 2.16	2.16 – 2.21	2.21 – 2.44	2.44 – 2.46	2.46 – 2.72
Sediment Dynamics	Response/ Transport	Forced transport	Response/ Transport	Forced transport	Source/Response
Channel Type	Forced plane-bed/Cascade‡	Piped conveyance	Forced plane-bed/Cascade‡	Piped conveyance	Colluvial/ Plane-bed
Stream Gradient (%)	7.6	8.5	9.4	9.2	10.9
Riparian Canopy Cover (%)	85	-	76	-	50
Riparian Impervious Surface Cover (%)	4	18	10	48	24
Reach Length (ft)	1,400	250	1,225	125	1,350

* Pool abundance in this reach is strongly increased by the presence of log and rock weirs, most of which are not of natural origin.
† The downstream portion of this reach is plane-bed with notable sediment accumulation, but upstream the channel is scoured to hardpan.
‡ Grade-control structures and debris jams force the channel to adopt a plane-bed morphology interspersed with short cascades.

Table B-7. Reach attributes for the primary tributaries to Vasa Creek.

	Unnamed Tributary	East Tributary				
Reach Segment ID	93_01_21	93_04_11	93_04_12	93_04_13	93_04_14	93_04_15
River Mile Boundaries	0.00 – 0.12	0.00 – 0.12	0.12 – 0.14	0.14 – 0.35	0.35 – 0.51	0.51 – 0.63
Sediment Dynamics	Unknown	Unknown	Forced transport	Transport/ Source	Forced transport	Source
Channel Type	Unknown	Unknown	Piped conveyance	Bedrock/ Cascade	Piped conveyance	Plane-bed
Stream Gradient (%)	4.9	8.7	16.0*	19.7*	9.4	3.9
Riparian Canopy Cover (%)	33	72	-	74	-	79
Riparian Impervious Surface Cover (%)	29	8	51	11	56	10
Reach Length (ft)	630	650	100	1,100	850	650

* Value calculated manually from the digital elevation model because the GIS-computed value was clearly incorrect due to an inaccurate stream centerline.

B.3.2.2 Habitat Unit Composition and Off-Channel Habitat

The Vasa Creek Subbasin is strongly dominated by riffle habitat. Downstream of I-90, 83% of the stream length is riffle habitat. Habitat units were not delineated upstream of I-90, but from qualitative estimation, riffle habitat is equivalent to or greater in proportion than that observed downstream. Pools, when present, are often associated with physical channel alterations including weirs and culverts, although naturally formed pools are also present.

Upstream of I-90, there is an average of 18 pools per mile or approximately 33 bankfull channel widths per pool. This pool frequency is about average for subbasins in the City though less than ideal for salmonid habitat. Downstream of I-90, Tetra Tech (2014) documented approximately 102 pools per mile. However, due to differences in pool classification methods used in the two surveys, it is difficult to draw comparisons. For the OSCA-surveyed pools, the median residual depth is 1.0 ft with a maximum observed depth of 2.2 ft (**Figure B-11**). This is shallower than average for pools found throughout the City but approximately average for the watershed.

Off-channel habitat, and the potential for off-channel habitat, is virtually nonexistent in the Vasa Creek Subbasin. Much of the stream corridor lies within ravines with little associated floodplain, and the few areas without steep streambanks are restricted by private residential land use. The only portion of the stream that provides an opportunity for channel migration and off-channel habitat formation is the lower portion of mainstem Reach 4. Here, the ravine widens into a small valley floor and the channel splits into two channels that run along each bank and many small, seasonal, and highly transitory channels braid back and forth through this fluvial deposition area. However, previous reports (Britton 2013) indicate that flow may go subsurface through this area during the summer low flow period. Flow was still present at the time of the OSCA surveys in early-June of 2020.

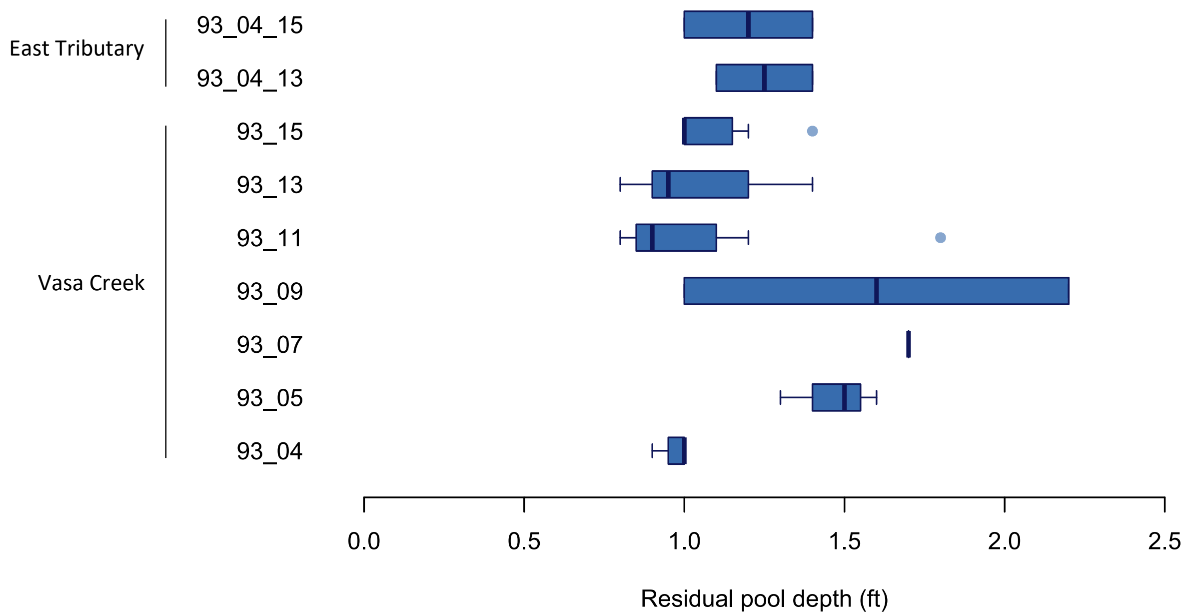


Figure B-11. Boxplot of residual pool depths in OSCA-surveyed stream reaches of the Vasa Creek Subbasin. Mainstem Reach 17 is omitted as no pools were observed at the time of the survey.

B.3.2.3 Large Woody Material

Large woody material (LWM) frequency in the Vasa Creek subbasin is good compared to other urban subbasins in the City of Bellevue but falls well below reference conditions. Only two mainstem reaches and one tributary reach have LWM frequencies comparable to that found in unaltered reference streams (Fox and Bolton 2007; **Figure B-12**). In the OSCA-surveyed reaches upstream of I-90, the overall wood frequency is 356 pieces per mile (22 pieces per 100 m). Although this frequency of LWM is considered poor compared to reference conditions, this is the third highest abundance of LWM found in the City of Bellevue (following Coal Creek and Newport Creek subbasins).

Consistent with observations from the rest of the Lake Sammamish Watershed, the wood in the Vasa Creek Subbasin is generally larger than that found in the other subbasins in the City. In fact, the Vasa Creek Subbasin has the greatest volume of wood per mile found in the City (9,624 ft^3 per mile). Although this volume is still very far below reference conditions, it is indicative of the relatively more mature riparian canopy found in this subbasin and watershed.

All observed LWM is presumed to be of natural origin and the generally intact riparian canopy provides opportunity for future natural recruitment. This is evidenced in the East Tributary Reach 3 where the exceptionally high frequency of LWM is due to several recently downed trees from a storm event. The reaches with the least LWM (mainstem Reaches 1, 9, and 17) also have the lowest riparian canopy cover (**Table B-6**) and greatest impact from residential land use. LWM is important in this system for retaining streambed substrate and creating habitat complexity. Numerous pools in this subbasin are the result of

LWM trapping sediment and smaller debris and creating a small hydraulic drop with a plunge pool below.

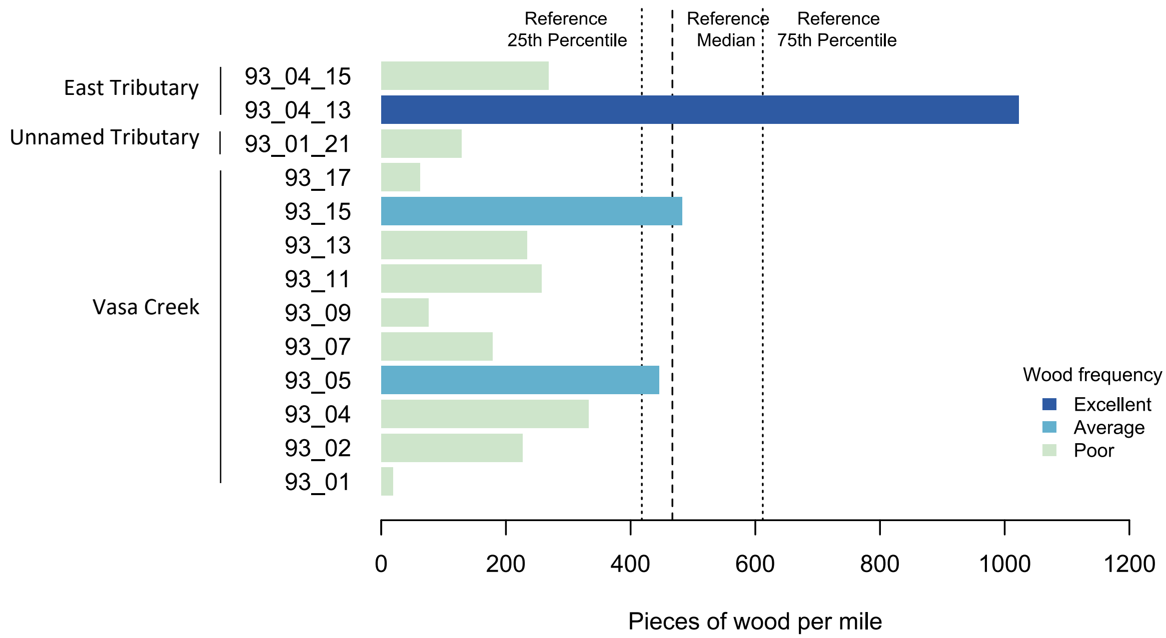


Figure B-12. Large woody material frequency in surveyed reaches of the Vasa Creek Subbasin compared to reference levels (Fox and Bolton 2007). Note: Reaches 93_01, 93_02, and 93_01_21 were surveyed under a different protocol (Tetra Tech 2014) which included wood greater than 4 inches in diameter as opposed to the 6 inch minimum used in the OSCA surveys but did not count wood that was on the bank or spanning the channel.

B.3.2.4 Streambed Substrate

Streambed substrate is highly variable in the Vasa Creek Subbasin. Downstream of I-90, the dominant substrate type is fine gravel. Coarser substrate, when present, is frequently from streambank armoring or large angular rock placed as weirs for grade control. Upstream of I-90, the substrate is dominated by gravels (**Figure B-13**) and the proportion of fines is generally lower than that seen in other subbasins in the City.

There are multiple areas throughout the subbasin where the streambed is scoured down to hardpan glacial till. This is particularly notable in mainstem Reach 11 and in the East Tributary Reach 3 where a hardpan "waterslide" extends for more than 50 ft. This reach, which receives flashy stream flows from the piped reach upstream, is sediment starved and substrate transport is very high causing gravels and cobbles to accumulate and partially block the upstream side of the culvert under SE Newport Way.

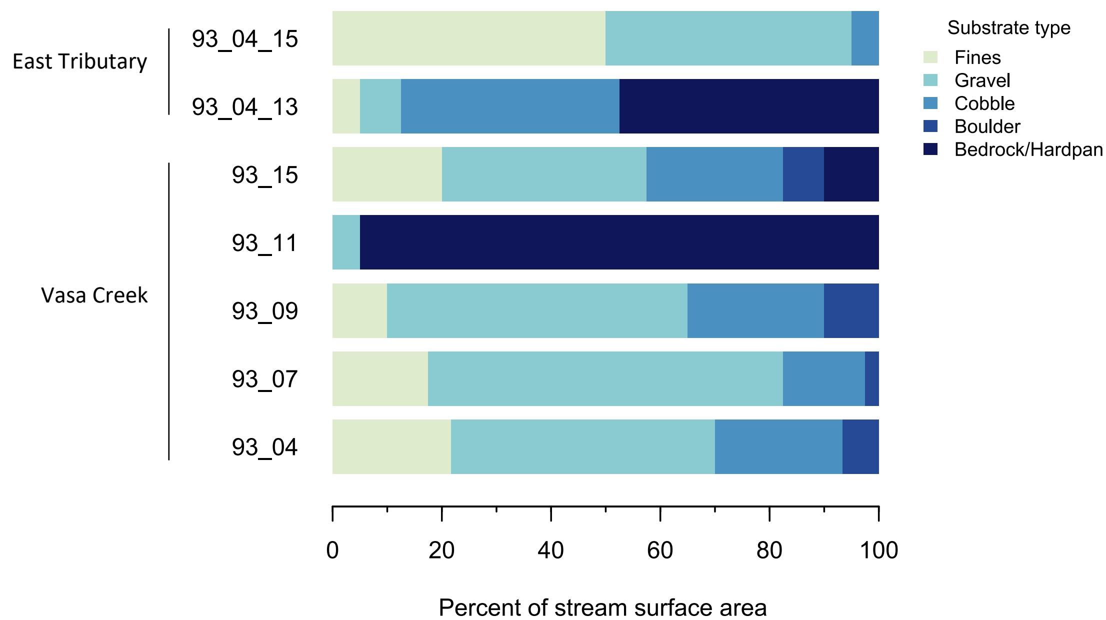


Figure B-13. Substrate composition of riffle habitat in the Vasa Creek Subbasin, determined by visual estimation at representative stream cross-sectional profiles. Profiles were not taken in Reach 5 or 17.

B.3.2.5 Streambank Conditions

Streambank armoring is intermittently prevalent in the Vasa Creek Subbasin. Although streambank armoring varies greatly by stream reach (**Figure B-14**), across all OSCA-surveyed reaches 8% of the channel is armored, which is about average for subbasins across the City. In general, each instance of armoring is relatively short, rarely extending more than 50 ft. Much of the streambank armoring is traditional, "hard" armoring, but 21% of all armoring (accounting for 2% of the streambank) is bioengineering. This bioengineering is associated with wood and rock weirs and consists of logs, rootwads, and large boulders placed along the streambank in the Horizon Heights Open Space. Although most armoring is less than 5 ft in height (**Figure B-14**), the Vasa Creek Subbasin generally has a higher proportion of streambank armoring that is greater than 5 ft in height compared to other subbasins in the City.

Streambank erosion is patchy in the Vasa Creek Subbasin upstream of I-90 and ranges from low scour and channel incision to large areas of mass wasting. Across all OSCA-surveyed reaches, 14% of the streambank is eroding and 6% of the streambank is undercut (**Figure B-15** and **Figure B-16**) which is about average for subbasins in the City of Bellevue. However, like other tributaries to Lake Sammamish, the Vasa Creek Subbasin is experiencing some larger-scale erosion issues than many other streams in the City. More than a fifth of all erosion (3% of the streambank) is greater than 10 ft in height. This is the third highest percent of the streambank with erosion in the high category, behind the Ardmore Area and the Phantom Creek Subbasin. Several areas have experienced mass wasting events, particularly in the upper portion of Reach 4 and in Reach 5 around the confluence with the East Tributary.

Although streambank armoring and erosion are present downstream of I-90, they were not quantified during the previous survey (Tetra Tech 2014).

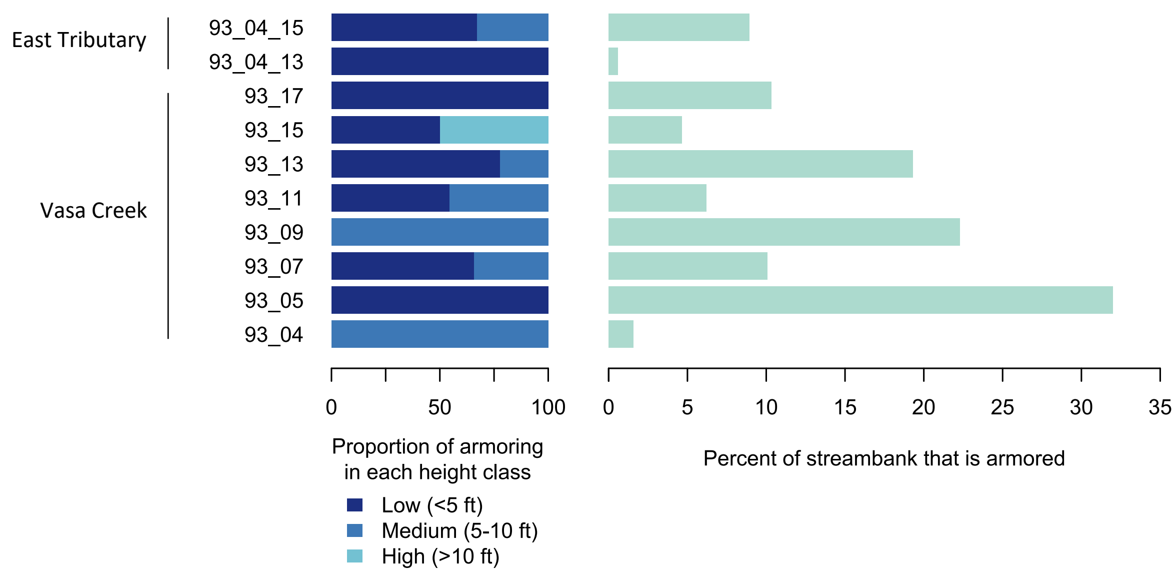


Figure B-14. Multi-panel bar graph showing the percent of each OSCA-surveyed stream reach in the Vasa Creek Subbasin that is armored as well as the proportion of armoring in each armoring height class.

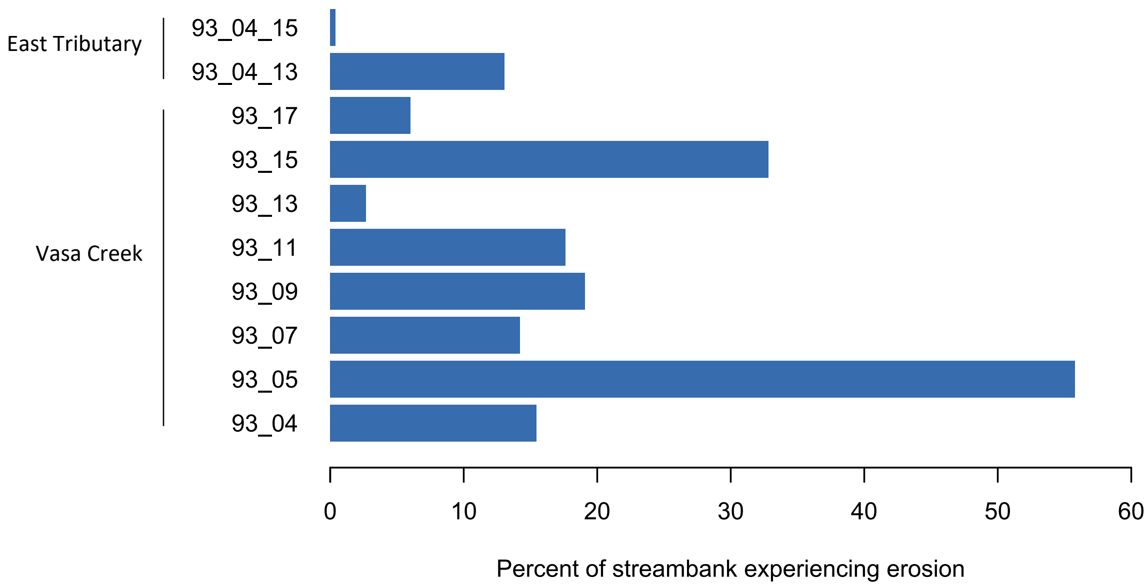


Figure B-15. Percent of each OSCA-surveyed stream reach in the Vasa Creek Subbasin that is experiencing erosion.

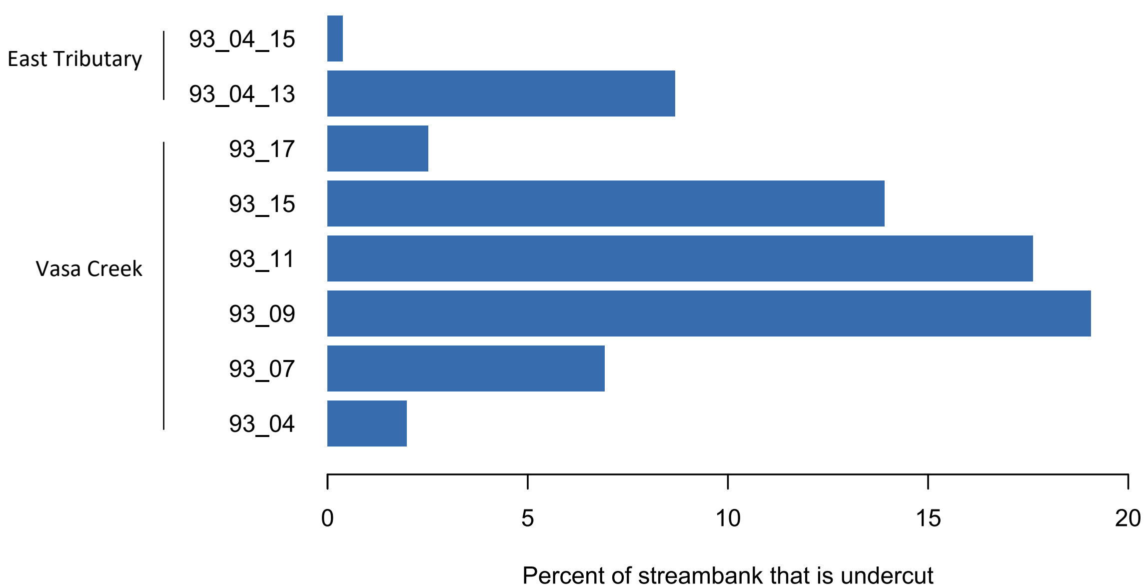


Figure B-16. Percent of each OSCA-surveyed stream reach in the Vasa Creek Subbasin that has undercut streambanks. Mainstem Reaches 5 and 13 are omitted as they did not have undercut banks.

B.3.2.6 Fish Habitat and Passage Barriers

Historically, Vasa Creek supported spawning kokanee and juvenile Coho Salmon in addition to resident Cutthroat Trout (Kerwin 2001). Unfortunately, this stream no longer provides quality fish habitat. No fish were observed upstream of I-90 during the OSCA surveys. Small resident Cutthroat Trout were documented by Tetra Tech (2014) downstream of I-90. The scarcity of fish in this system is likely due to the lack of habitat complexity, flashy stream flows, and potential water quality impacts from urbanization.

Additionally, there are numerous barriers that impede fish passage. In fact, the mainstem of Vasa Creek has the highest density of fish passage barriers in the City. WDFW has formally documented three partial barriers and fourteen complete barriers in the mainstem and two complete barriers in the East Tributary. Additionally, there are numerous inweirs in the mainstem of Vasa Creek both upstream and downstream of I-90 that have not been formally assessed as barriers but likely pose a substantial impediment to fish passage.

B.3.2.7 Opportunities

The most notable challenges in Vasa Creek are flashy stream flows, streambed and streambank instability, and fish passage barriers. Projects targeting these issues should be prioritized over stream habitat enhancement for the portion of Vasa Creek upstream of I-90. Projects focusing on upland detention of stormwater runoff would greatly benefit this system by minimizing the flashy and highly erosion stream flows and reducing flooding risk. Streambed and streambank stability projects should include increasing channel complexity with large woody material and boulders to attenuate stream flow and help retain streambed substrate and could be done in conjunction with fish barrier correction projects. Additionally, although the riparian canopy cover is generally good and mostly consists of native plants, there are areas where invasive plants are prevalent and canopy cover is sparse. In these areas, riparian enhancements would be beneficial, aiding bank stability as well as providing a source for the future recruitment of LWM.

Fish barrier correction opportunities in lower Vasa Creek downstream of I-90 should be explored and prioritized to restore kokanee and Coho Salmon spawning opportunities and rearing opportunities for all salmonids. Lower Vasa Creek has been strongly influenced by residential land use. The channel is generally confined and armored with limited fish cover, pool habitat, or LWM (Tetra Tech 2014). Because much of lower Vasa Creek passes through private properties, projects in this area include opportunities for public-private partnerships in addition to land acquisition and redevelopment opportunities

Vasa Creek and West Lake Sammamish Parkway – The City owns a 6-ft concrete box culvert under West Lake Sammamish Parkway that does not meet current fish passage criteria. Streambed aggradation has resulted in gravel and cobble filling the culvert until there is less than 1.5 ft of vertical clearance between the roof of the culvert and the water surface at summer low flow. This substantially reduces the culvert capacity and could be a flooding concern at high flows. It is recommended that the culvert be replaced with a bridge or stream simulation culvert to allow for sediment and woody debris transport. Downstream of the culvert, the stream passes through private property and lacks habitat complexity.

This project could be an opportunity for a public/private partnership with a multifaceted objective of fish passage, flood control, and habitat enhancement.

B.3.3 The Lesser Tributaries to Lake Sammamish

In addition to Lewis Creek and Vasa Creek, there are five other tributaries to Lake Sammamish that were surveyed during the OSCA effort in 2020. These include Idylwood Creek (in the Ardmore Area), Wilkins Creek, Phantom Creek, and two unnamed tributaries in the South Sammamish Area designated as Sammamish Tributary 0160 and 0162 (**Map B-5**).

The Ardmore Area is located in the Northeast Bellevue neighborhood. It is not a true subbasin, but rather an approximately 600-acre area with multiple small drainages, which pass into the City of Redmond before their outlet into Lake Sammamish. The largest drainage in the subbasin is Idylwood Creek with its upper-most reaches and tributaries located in Bellevue's Ardmore Park. Land use within the portion of the subbasin that is within Bellevue city limits is primarily residential. Subbasin elevation within Bellevue city limits ranges from 123 to 443 ft. The subbasin includes 2.0 miles of open stream channel (including streams outside of Bellevue) and 12.9 miles of storm drainage pipes within the City. Less than 2% of the stream conveyance within City limits is confined within storm drainage pipes.

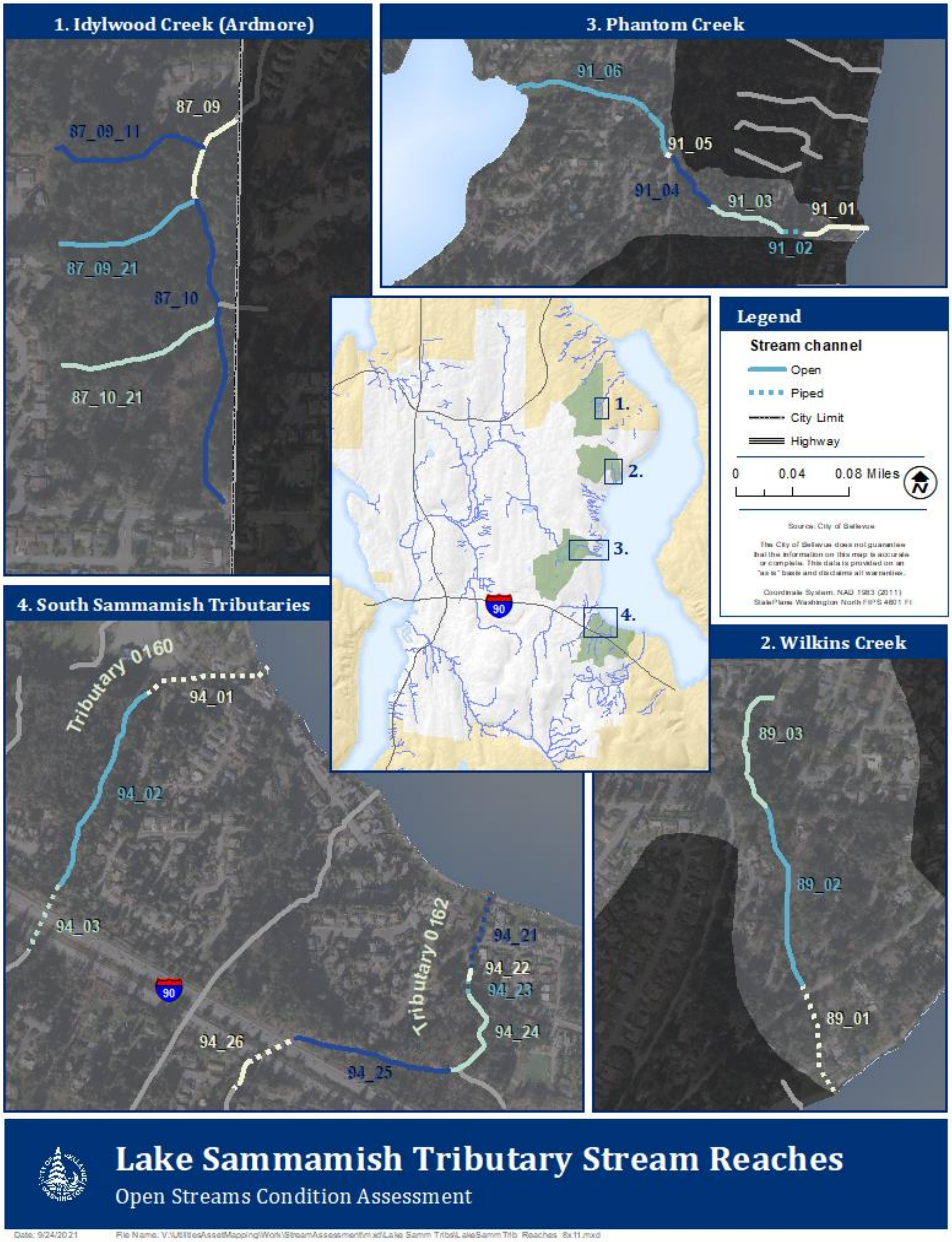
The Wilkins Creek Subbasin includes 305 acres and spans the Northeast Bellevue and West Lake Sammamish neighborhoods. Land use is predominantly residential. Elevation ranges from 31 ft to 446 ft. This small subbasin includes 8.3 miles of storm drainage pipes and only 0.3 miles of open channel. More than a quarter (27%) of the Wilkins Creek channel is piped, encompassing the downstream-most reach between West Lake Sammamish Parkway and the stream's outlet at Lake Sammamish. The stream is not fish bearing but was surveyed due to its importance for stormwater conveyance and the presence of a high-flow bypass and numerous weirs.

The Phantom Creek Subbasin is predominantly in the West Lake Sammamish neighborhood with its upland areas extending into the Lake Hills and Eastgate/Factoria neighborhoods. The 530-acre subbasin ranges in elevation from 31 ft to 426 ft. Land use is predominantly residential, although commercial and office land use account for over a fifth of the subbasin, which is greater than that seen in the other subbasins in the watershed. The subbasin contains 7.6 miles of storm drainage pipes and 0.7 miles of open channel. Approximately 7.4% of the primary stream channel is piped, which is well below average for subbasins in the City and is primarily resultant from road culverts.

Phantom Creek (historically also called Weowna Creek) forms the outlet of Phantom Lake and drains into Lake Sammamish. This is a man-made stream with a unique history. Phantom Lake was historically part of the headwaters to the mainstem of Kelsey Creek. In the late 19th century, farmer Henry Thode dug a new outlet to Phantom Lake to lower the water level and drain surrounding wetlands so that they could be used for agriculture. This diverted flow east to Lake Sammamish and created an impressive canyon through which Phantom Creek now flows (WSSA 2010). Erosion in this canyon, located in Weowna Park, and the resultant sedimentation and nutrient loading in Lake Sammamish, prompted an extensive stream restoration and stabilization project in the 1990s that included the creation of two waterfalls.

The South Sammamish Area is located in southeast Bellevue between the Vasa Creek and Lewis Creek Subbasins in the West Lake Sammamish and Cougar Mountain/Lakemont neighborhoods. Land use in the subbasin is primarily residential, although a larger than average portion of the subbasin is public right of way due to I-90 which cuts through the subbasin. Elevation ranges from 31 ft to 733 ft. This approximately 400-acre area encompasses two small, fish-bearing drainages, Sammamish Tributary

0161 and Sammamish Tributary 0162. As mentioned previously, Sammamish Tributary 0160, which is also fish-bearing, is a part of the Vasa Creek Area but will be discussed in this section. Only the portions of Tributaries 0160 and 0162 downstream of I-90 were surveyed. Overall, the subbasin (excluding Tributary 0160) includes 8.3 miles of storm drainage pipes and 1.8 miles of open stream channel. Each tributary is piped at its downstream end before discharging into Lake Sammamish. This, in addition to the I-90 culverts, results in approximately 22% of the primary stream channels (including Tributary 0160) being piped.



Map B-5. Stream reaches for the lesser tributaries to Lake Sammamish.

B.3.3.1 Channel Morphology and Riparian Corridor

The lesser tributaries to Lake Sammamish are typified by high-gradient and well-vegetated ravines. The channel morphologies vary from plane-bed to cascade to bedrock and generally have a high sediment transport capacity (**Table B-8**). For each subbasin, the average stream gradient of surveyed reaches ranges from 7.4% (Phantom Creek) to 10% (South Sammamish Area), which is much higher than average for streams across the City.

Because they tend to be in ravines, the lesser tributaries to Lake Sammamish have generally maintained a vegetated riparian buffer with minimal development directly adjacent to the stream channel. Across all surveyed reaches, the average proportion of tree cover within the 100 ft riparian buffer ranges from 61% (Phantom Creek) to 85% (Ardmore and South Sammamish Areas) which is average to much higher than average for subbasins in the City. Riparian impervious surface cover for the same reaches ranges from 3% (Ardmore Area) to 16% (Phantom Creek), which is, respectively, much lower than average to average for the City. The uppermost and lowermost portions of Phantom Creek (Reaches 1 and 6) have the least canopy cover and greatest impervious surface cover. Through these reaches, the stream is lower gradient without steep banks and passes through many residential properties.

Riparian vegetation in the lesser Lake Sammamish Tributaries is varied, but predominantly consists of a canopy of Douglas fir, western red cedar, and big leaf maple with an understory of vine maple, salmonberry, and sword fern. Himalayan blackberry and English ivy are intermittently abundant invasive plants and can be quite dense when present.

The lesser tributaries to Lake Sammamish are smaller than most other fish-bearing streams throughout the City. Stream cross-sectional profile data collected at one to three representative locations per stream reach reveal that the average wetted width is around 4 to 5 ft and the bankfull width is around 7 to 7.5 ft. Wilkins Creek and Phantom Creek are generally narrower than the other tributaries, averaging 3.5 ft wetted width and 7 ft bankfull width. The South Sammamish Tributaries (0160 and 0162) generally have the widest wetted widths (averaging 5.5 ft), while Idylwood Creek and its tributaries have substantially wider bankfull widths (averaging 11 ft) compared to the other tributaries. Wetted depths were not taken as a part of these stream profiles, but average maximum bankfull depths range from 0.5 ft (the South Sammamish Tributaries) to 1.1 ft (Ardmore Area) indicating that these are rather shallow streams.

Table B-8. Reach attributes for the lesser tributaries to Lake Sammamish.

	Idylwood Creek (Ardmore)		North Tributary to Idylwood	Middle Tributary to Idylwood	South Tributary to Idylwood
Reach Segment ID	87_09	87_10	87_09_11	87_09_21	87_10_21
River Mile Boundaries	0.79 – 0.85	0.85 – 1.08	0.00 – 0.11	0.00 – 0.11	0.00 – 0.12
Sediment Dynamics	Response	Transport	Source	Source	Transport
Channel Type	Plane-bed	Bedrock/ Step-pool	Colluvial	Colluvial	Bedrock/ Cascade
Stream Gradient (%)	3.2	8.4	16.9	21.0	12.3
Riparian Canopy Cover (%)	84	89	69	91	95
Riparian Impervious Surface Cover (%)	4	<1	8	<1	0
Reach Length (ft)	325	1,200	600	550	615

	Phantom Creek					
Reach Segment ID	91_01	91_02	91_03	91_04	91_05	91_06
River Mile Boundaries	0.00 – 0.09	0.09 – 0.11	0.11 – 0.22	0.22 – 0.31	0.31 – 0.32	0.32 – 0.57
Sediment Dynamics	Response	Forced transport	Transport	Transport/ Response[*]	Forced transport	Source
Channel Type	Plane-bed	Piped conveyance	Cascade	Cascade/Forced step-pool[*]	Piped conveyance	Plane-bed
Stream Gradient (%)	6.4	16.7	17.4	16.5	7.5	0.3
Riparian Canopy Cover (%)	37	-	92	74	-	50
Riparian Impervious Surface Cover (%)	22	27	<1	5	42	24
Reach Length (ft)	490	80	610	440	70	1,310

	Wilkins Creek			Sammamish Tributary 0160	
Reach Segment ID	89_01	89_02	89_03	94_01	94_02
River Mile Boundaries	0.00 – 0.11	0.11 – 0.30	0.30 – 0.43	0.00 – 0.14	0.14 – 0.36
Sediment Dynamics	Forced transport	Response[†]	Response	Forced transport	Transport
Channel Type	Piped conveyance	Forced plane-bed[†]	Plane-bed	Piped conveyance	Cascade/Bedrock
Stream Gradient (%)	13.6	9.4	9.2	7.3	8.8
Riparian Canopy Cover (%)	-	70	71	-	84
Riparian Impervious Surface Cover (%)	23	9	9	35	2
Reach Length (ft)	600	970	690	751	1196

	Sammamish Tributary 0162				
Reach Segment ID	94_21	94_22	94_23	94_24	94_25
River Mile Boundaries	0.00 – 0.08	0.08 – 0.09	0.09 – 0.11	0.11 – 0.22	0.22 – 0.39
Sediment Dynamics	Forced transport	Response	Forced transport	Response/ Transport[‡]	Transport
Channel Type	Piped conveyance	Plane-bed	Piped conveyance	Plane-bed/ Cascade[‡]	Cascade
Stream Gradient (%)	8.9	4.8	4.1	7.2	13.9
Riparian Canopy Cover (%)	-	37	-	90	87
Riparian Impervious Surface Cover (%)	40	31	38	5	10
Reach Length (ft)	420	65	90	585	890

[*] Weirs in the upper portion of the reach force the channel into a step-pool morphology and retain sediment.

[†] Numerous weirs force the channel to assume a stepped plane-bed morphology (flow is insufficient to form step pools). Considering the gradient, the channel would likely be a cascade if unaltered.

‡ This stream reach has been modified and the channel is lined with quarry spalls. It is unclear what the channel type and sediment dynamics would be in the absence of alteration.

B.3.3.2 Habitat Unit Composition and Off-Channel Habitat

Due to their higher gradient, the lesser tributaries to Lake Sammamish are dominated by riffle habitat, and pool habitat, when present, is most frequently a plunge pool associated with a hydraulic drop or a pocket pool scoured into hardpan. Phantom Creek and Wilkins Creek have very low pool frequency with 2 and 6 pools per mile, respectively, and several reaches in those streams have no pool habitat at all. The surveyed reaches of the South Sammamish Tributaries average 19 pools per mile, which is about average for streams in the City of Bellevue, though far less than ideal for fish habitat. Ardmore Area has the greatest pool density, averaging 58 pools per mile. The vast majority of pools in the Ardmore Area are pocket pools in hardpan glacial till, which accounts for both their frequency and shallow depth.

Overall, pools in the lesser tributaries to Lake Sammamish tend to be very small (**Figure B-17**). The median residual depth ranges from 0.6 ft (Ardmore Area) to 1.1 ft (Wilkins Creek and the South Sammamish Tributaries). Only one pool was observed to have a depth greater than 2 ft, and this was a plunge pool in Idylwood Creek with a maximum depth of 3.2 ft.

There is virtually no off-channel habitat in the lesser tributaries to Lake Sammamish. The streams are generally confined within ravines for much of their length. The only opportunity for off-channel habitat would be in the lower-gradient, downstream reaches just before they outlet into Lake Sammamish. However, these reaches are either constrained by development, as is the case in Phantom Creek, or they are piped, as in Wilkins Creek and Tributaries 0160 and 0162.

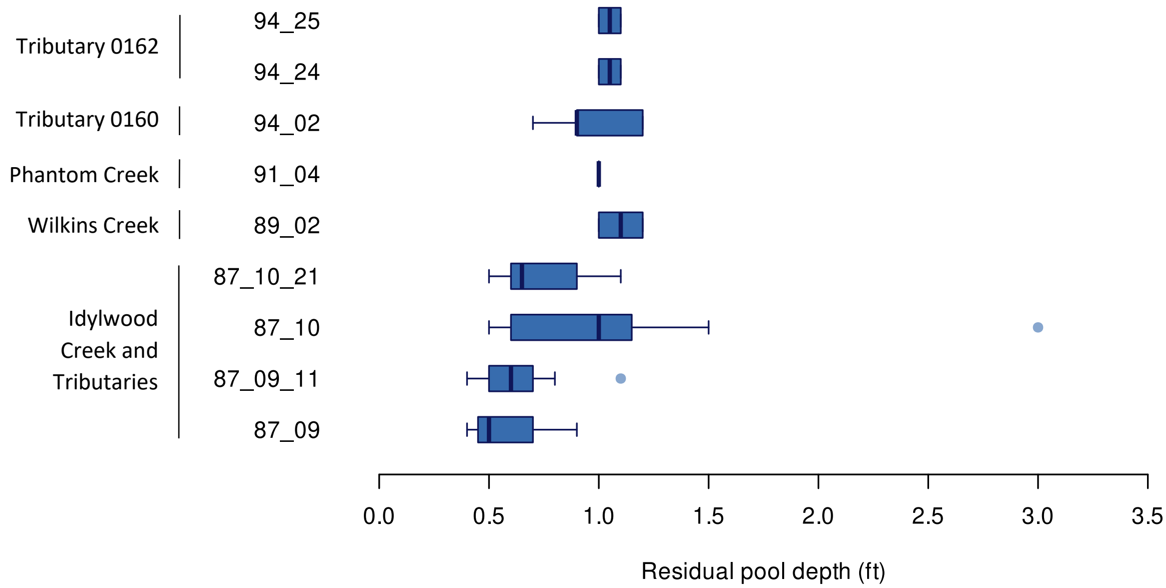


Figure B-17. Boxplot of residual pool depths observed in the lesser tributaries to Lake Sammamish. Omitted reaches had no pools at the time of the survey.

B.3.3.3 Large Woody Material

Despite having a generally intact riparian corridor, the lesser tributaries to Lake Sammamish have moderately low levels of large woody material (LWM). The frequency of LWM ranges from 95 pieces per mile (6 pieces per 100 m) in Wilkins Creek to 309 pieces per mile (19 pieces per 100 m) in the South Sammamish Tributaries, which is below reference levels for similarly sized streams in Western Washington (**Figure B-18**). Only three stream reaches, two in the Ardmore Area and one in the South Sammamish Area, have LWM levels comparable to reference conditions. These reaches with high levels of LWM are within City-owned parcels; LWM is much more sparce in reaches with high residential land use. Nearly all of the LWM in the lesser tributaries to Lake Sammamish are of natural origin, and the intact riparian corridors offer opportunities for further natural recruitment.

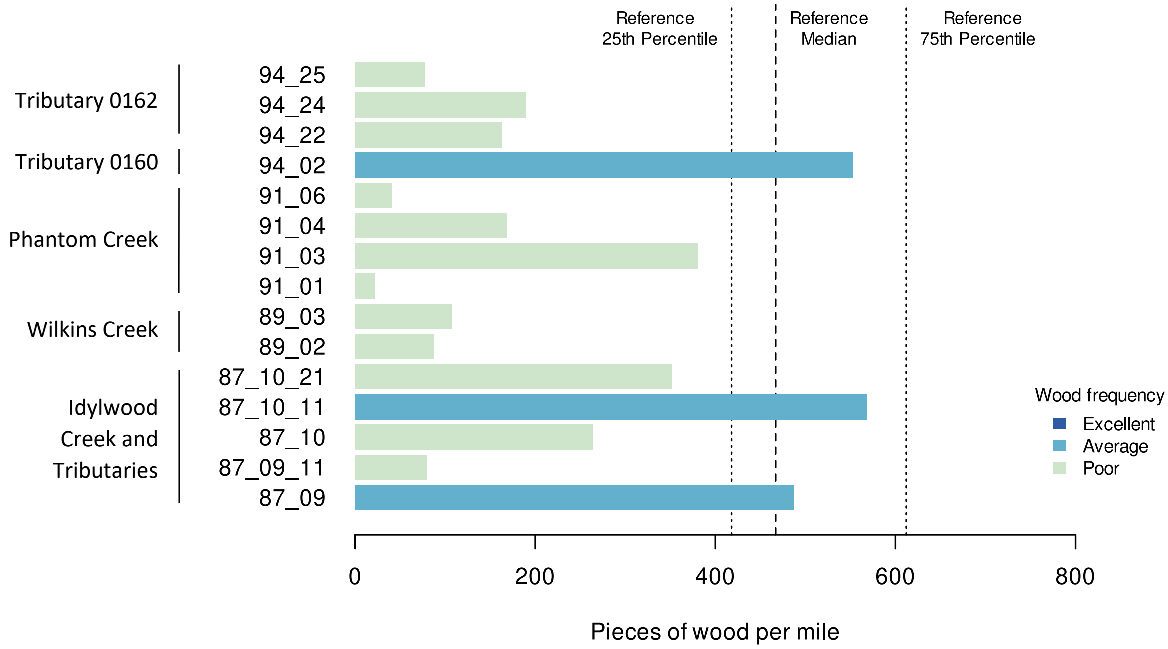


Figure B-18. Large woody material frequency in stream reaches of the lesser tributaries to Lake Sammamish compared to reference levels (Fox and Bolton 2007).

B.3.3.4 Streambed Substrate

Streambed substrate is varied in the lesser tributaries to Lake Sammamish (**Figure B-19**). Because these streams were surveyed under a Level 2 protocol, substrate composition was identified from stream cross-sectional profile data collected at one to three representative locations per stream reach. Although highly variable, the percent of fines in the substrate tends to be inversely proportional to the stream gradient (**Table B-8**), with the lowest gradient reach (Phantom Creek Reach 6) having the highest proportion of fines. It should be noted that the substrate composition presented here is likely slightly biased towards smaller substrate size classes as the profiles were taken in riffle habitat and would've avoided boulder cascades where possible. The proportion of exposed hardpan is also likely underestimated due to the small sample size. Hardpan is an influential feature in many of the stream reaches in the Ardmore Area and is also present to a much more limited extent in Phantom Creek and both South Sammamish Tributaries but not in Wilkins Creek.

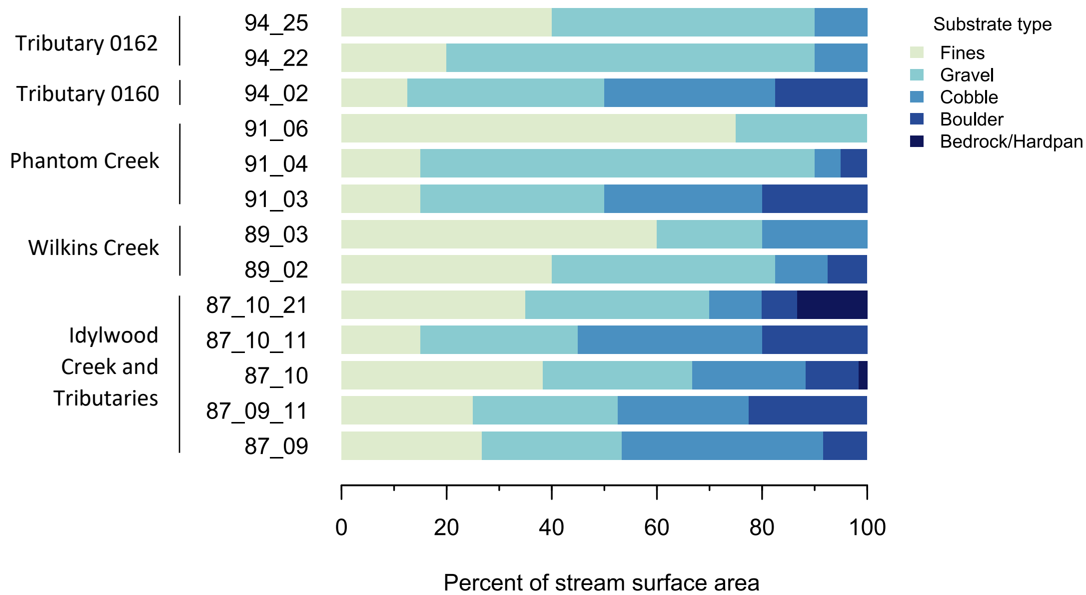


Figure B-19. Substrate composition in riffle habitats of the lesser tributaries to Lake Sammamish, determined by visual estimation at representative cross-sectional profiles.

B.3.3.5 Streambank Conditions

The extent of streambank armoring is highly variable in the lesser tributaries to Lake Sammamish. The Ardmore Area has some of the least armoring observed in the City with only 2% of its streambanks being armored. Wilkins Creek is slightly better than average for the City with 7% armored streambanks, while Phantom Creek and the South Sammamish Area have a much greater than average proportion of armored streambanks at 17% and 18%, respectively. However, the extent of streambank armoring varies considerably by stream reach (**Figure B-20**) and is generally greatest in residential areas. Nearly all the armoring present in these subbasins is less than 5 ft in height and primarily consists of large angular rock or chunks of concrete.

Like armoring, streambank erosion is highly variable in the lesser tributaries to Lake Sammamish, ranging by stream reach from 0% to 33% (**Figure B-21**). Most of the subbasins have erosion on the order of 11% to 12% of the streambank which is comparable to the average seen throughout the City. However, the Ardmore Area has substantially greater erosion with 21% of the streambanks showing active erosion. Likewise, undercutting (**Figure B-22**) ranges from 2% (Phantom Creek) to 7% (South Sammamish Area), which is lower than average for the City, but the Ardmore Area has 14% undercut banks, which is the third highest percent seen in the City. Undercutting in this subbasin is primarily associated with large erosion events resulting in overhanging escarpments and unstable banks as opposed to low and stable toe scour. Across all subbasins, the vertical extent of the erosion is generally greater than that seen in the rest of the City (**Figure B-23**). These tributaries tend to be incised into steep ravines such that scour from high flows can create larger bank instability.

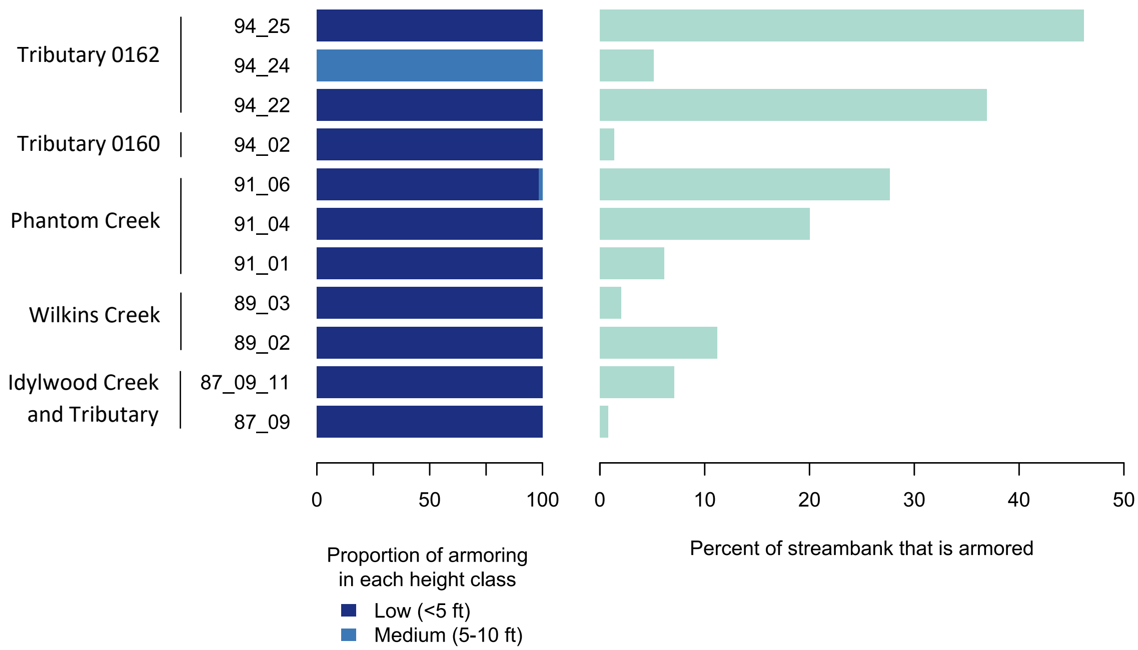


Figure B-20. Multi-panel bar graph showing the percent of the streambank that is armored as well as the proportion of armoring in each armoring height class for each surveyed reach in the lesser tributaries to Lake Sammamish. Omitted reaches have no streambank armoring.

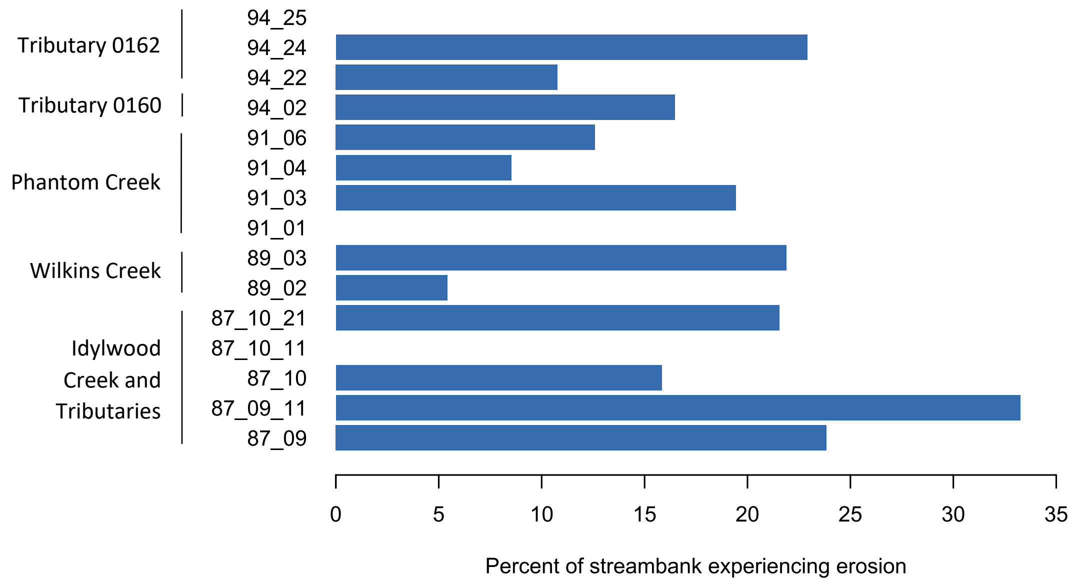


Figure B-21. Percent of each stream reach that is experiencing erosion in the lesser tributaries to Lake Sammamish.

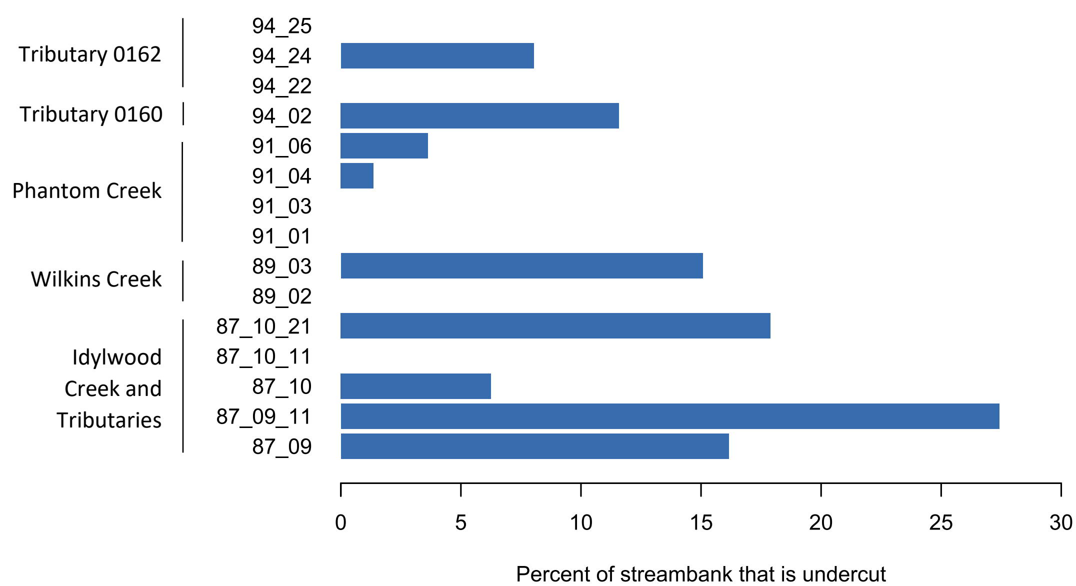


Figure B-22. Percent of each stream reach that has undercut banks in the lesser tributaries to Lake Sammamish.

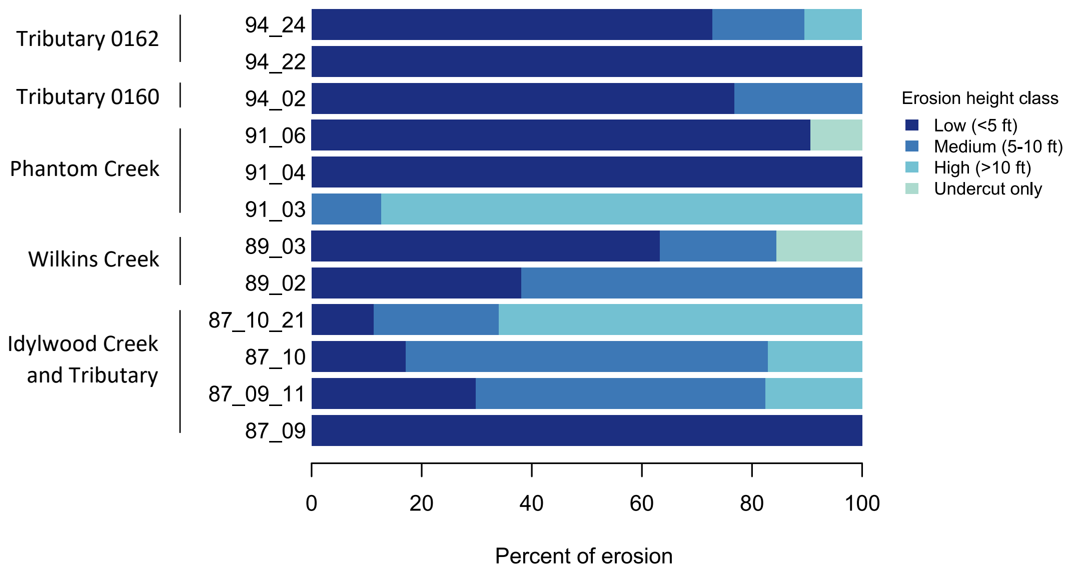


Figure B-23. Proportional bar chart showing the percent of erosion falling into each height class.

B.3.3.6 Fish Habitat and Passage Barriers

Each of the Type F (fish-bearing) streams in the tributaries to Lake Sammamish could conceivably host resident trout and sculpin, and even kokanee, steelhead, and Coho Salmon. However, only two fish were observed during the OSCA surveys: a 5-in Cutthroat Trout in a small pocket pool in Idylwood Creek and an unknown fish at the outlet to Phantom Lake. A lack of pool habitat, coupled with flashy stream flow, is likely a limiting factor for sustaining healthy fish populations in these streams. Given the stream gradients, large woody material is likely necessary for the formation and maintenance of pool habitat in these streams. Low stream flow during the summer months also potentially limits fish success in these streams.

There are multiple obstacles to fish movement and migration in the lesser tributaries to Lake Sammamish. In Idylwood Creek, there are two complete barriers and one partial barrier (WDFW 2021), all of which are located beyond Bellevue city limits downstream of the surveyed reaches. Although Phantom Creek has not been formally assessed for fish passage, the OSCA surveys noted that the culvert under West Lake Sammamish Parkway SE is likely a complete barrier and there are several privately-owned driveway culverts that may impede fish passage. Additionally, there are at least two waterfalls in Weowna Park that are complete barriers. There are four documented complete fish passage barriers in Tributary 0160 (WDFW 2021). Three of those barriers are owned by the City, including the downstream-most reach that is piped to the outlet at Lake Sammamish. This effectively blocks the entire stream from migratory fish use. Tributary 0162 has one complete barrier at I-90 and one partial barrier further upstream (WDFW 2021). Neither are owned by the City. During the summer low-flow period, all of the lesser tributaries become very shallow which potentially creates low-flow barriers and restricts fish habitat to pools and deeper portions of the channel.

B.3.3.7 Opportunities

Opportunities to improve stream health along the lesser tributaries to Lake Sammamish may require public-private partnerships or land acquisition. Projects in the lesser tributaries should focus on stormwater conveyance and streambed and streambank stability. Upland stormwater detention as well as instream placement of large woody material and riparian enhancements could benefit these streams. Opportunities to *Reconnect and Enhance Creek Mouths* should be considered for the lesser tributaries to restore habitat connectivity and juvenile rearing habitat for Lake Sammamish fish populations. This recovery strategy was identified in the *Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan 10-Year Update (Appendix B)* and will benefit lake rearing Chinook Salmon and juvenile salmonid migration (WRIA 8 2017). Fish passage improvements, specifically culvert replacements, should include design considerations for passing LWM and sediment in these dynamic, high transport systems. Additionally, opportunities for removing or improving conditions around the high flow bypass in Wilkins Creek between Reaches 2 and 3 should be evaluated. At the time of the OSCA surveys, sediment accumulation around the bypass was diverting base stream flows into the piped network. During the summer low flow period, Wilkins Creek will occasionally run dry, and it is highly likely that the high-flow bypass has increased the frequency and duration of these dry periods thereby altering the hydrology and reducing the aquatic habitat downstream.

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Appendix C
Lake Sammamish Watershed Benthic Index of Biotic Integrity Scores

Subbasin	Agency	Project	Site Code	Latitude	Longitude	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Lewis Creek (Lake Sammamish)	City of Bellevue	Macroinvertebrates	LewisBelowLakemont_21	47.558	-122.113																												57.1
Lewis Creek (Lake Sammamish)	City of Bellevue	Macroinvertebrates	LewisBelRM0.3	47.567	-122.093												43.7	37.5	22.4				26.7										
Lewis Creek (Lake Sammamish)	City of Bellevue	Macroinvertebrates	LewisBelRM0.8	47.562	-122.099					37.9			18.7	42.5	43.5		47.4	36.9	35.7			13.2		38.1		39.5			41.2				28.5
Lewis Creek (Lake Sammamish)	City of Bellevue	Macroinvertebrates	LewisBelRM1.8	47.557	-122.11										60.0		59.7		38.7				61.1					40.7					
Lewis Creek (Lake Sammamish)	City of Bellevue	Macroinvertebrates	LewisBelRM2.1	47.5575	-122.115																				56.4						63.6		61.5
Phantom Creek	City of Bellevue	Macroinvertebrates	PhanWeonaRM0.2	47.5925	-122.112																	30.3	20.5										
Vasa Creek	City of Bellevue	Macroinvertebrates	VasaRM1.9	47.566	-122.137																			33.1									13.3
Vasa Creek	City of Bellevue	Macroinvertebrates	VasaTribbleRM0.38	47.578	-122.119																		31.1										
Wilkins Creek	City of Bellevue	Macroinvertebrates	WilkBypassRM0.26	47.6158	-122.106																	10.9											
Wilkins Creek	City of Bellevue	Macroinvertebrates	WilkUpstrRM0.33	47.6168	-122.106																												
unnamed 0160	City of Bellevue	Macroinvertebrates	unnamed0160RM.1	47.576	-122.114																					42.6							
Lewis Creek (Lake Sammamish)	King County - DNRP	KC Historical	A617 Lewis	47.5705	-122.092								27.3																				
Lewis Creek (Lake Sammamish)	King County - DNRP	WRIA08_WS_Survey	WAM06600-020391	47.5653	-122.093																	14.1		32.3	41.5								
Idylwood Creek	King County - DNRP	Ambient Monitoring	08LAK3121	47.6411	-122.107									1.7	5.9		9.1	8.8	1.5	5.3	20.3	6.6	12.3	15.7	23.6	7.1	12.8	13.2	16.6	16.4	23.4	11.9	
Idylwood Creek	King County - DNRP	KC Historical	A620 Idylwood	47.6432	-122.103								9.0																				
Idylwood Creek	City of Redmond	City of Redmond Annu	IDCR1230	47.6425	-122.105																			10.1									
	City of Redmond	Annual Benthos Moni	IdylRed168	47.6432	-122.102											11.8				10.5	14.5	12	2.7	3.7	11.1	5.4	0.9	13.8	0	8.6	10	8.2	11.1
Idylwood Creek	City of Redmond	Annual Benthic Monit	IdylRed168	47.6432	-122.102										10																		
Idylwood Creek	City of Redmond	Annual Benthic Monit	IdylRed169	47.6427	-122.104										2.8	13.9																	
Idylwood Creek	City of Redmond	Annual Benthic Monit	IdylRed170	47.6422	-122.105									13.9	17.4	25.1																	
Idylwood Creek	City of Redmond	Annual Benthic Monit	IdylRed171	47.6353	-122.111									13.7	7.8	12.3																	
Idylwood Creek	King County - DNRP	WRIA08_WS_Survey	WAM06600-097975	47.6406	-122.107																	10.4	9.3	14.5	22.5								