SAMMAMISH RIVER CORRIDOR ACTION PLAN

FINAL REPORT

September 2002

US Army Corps of Engineers
Seattle District

King County
Department of Natural Resources and Parks
Water and Land Resources Division

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EXECUTIVE SUMMARY

The Sammamish River Corridor—defined in this Action Plan as the historic floodplain of the river, including tributary confluence areas—has great potential to support native fish, birds and other wildlife, and to serve the surrounding human community, much better than it currently does. Over the past century and longer, major alterations to the river corridor were made with little thought to the resulting ecological harm. This plan acknowledges that while it is virtually impossible to re-create historic conditions; it nevertheless identifies a set of actions that could significantly benefit native fish, birds and other wildlife. To help governments and others meet legal requirements based on listings under the Endangered Species Act, the plan focuses especially on the Sammamish River's role as a necessary migratory corridor for anadromous salmon in the Sammamish Watershed. Implementation of the plan, however, would benefit more than just salmon and a wide range of other wildlife; it would also enhance the river corridor's ability to serve as a place of pleasure and refuge for the surrounding human community.

The Action Plan views the Sammamish River Corridor's most important ecological role as a link between other habitats. It is primarily a link between Lakes Washington and Sammamish, but it also links major tributaries and upland habitats with each other and with the lakes. Many species other than salmon use the river as a critical migratory corridor. The fundamental goal of the Action Plan is to make the Sammamish River Corridor a strong link, rather than a weak one, in this larger ecosystem. To meet this goal, the plan recommends the following programmatic strategy:

- *Restore riparian areas throughout the river corridor* to provide shade, cover and enhanced habitat for all native fish and wildlife;
- *Create and enhance pools in the river channel* to provide cool-water refuge and cover, particularly for migrating adult salmon;
- *Explore engineered solutions to cool the river upstream of the Bear Creek confluence* to reduce thermal stress for migrating adult salmon where it is greatest;
- *Protect all major tributaries to the river*, particularly Bear Creek, as sources of cool water for the river and as habitat for other life stages of fish and wildlife using the river; and
- *Systematically apply adaptive management across jurisdictions*, monitoring projects closely compared both to each other and to baseline conditions, to identify features of greatest value to include in future projects.

This overarching strategy and more specific recommendations are discussed in detail in Chapters 3 through 5 ("Strategic Approach for Restoration," "Restoration Action Plan," and "Research, Monitoring and Adaptive Management"). This Action Plan recommends both programmatic (corridor-wide) and site-specific studies and projects for implementation. Programmatic recommendations are rated as either “core” recommendations that directly implement the above strategy and address the most critical problems in the corridor, or “non-core” recommendations which address important large scale issues, but do not immediately address the most critical problems in the corridor. Site-specific recommendations are rated as high, medium, or low priority based on their ability to address the critical problems in the corridor and other factors of decline for salmon and wildlife. A number of additional studies are also recommended, primarily to address continuing questions on where additional water temperature reductions could be gained in the tributaries and through use or supplementation of groundwater. Finally, this plan recommends an extensive monitoring and adaptive management program to be used during and after implementation of recommendations to determine effects on salmon populations and benefits to the overall recovery of salmon in the greater Lake Washington watershed.

Implementation of all recommendations in this Action Plan (including research and monitoring) would cost an estimated $55 million (not accounting for inflation), over the next ten or more years. It would require coordinated action by local governments in the river corridor—King County, Redmond, Woodinville, Bothell, and Kenmore—together with state and federal agencies and multiple other stakeholders, including private property owners along the river and volunteers from the community. Implementation of the plan will likely be linked to other initiatives and processes, including:

- Regional efforts to respond to the listing of Puget Sound chinook salmon under the Endangered Species Act (which include development of a long-term salmon conservation plan for the Greater Lake Washington watershed [WRIA-8]).
- The Corps of Engineers' Ecosystem Restoration Study for the Greater Lake Washington watershed, which will identify priority habitat restoration projects to be constructed by the Corps under local sponsorship.
- Proposed major regional infrastructure improvements in the vicinity of the Sammamish River, such as the widening of I-405 and construction of a regional wastewater treatment plant in the vicinity of the Sammamish Corridor, which will likely require millions of dollars of environmental mitigation.
- Department of Ecology (Ecology) efforts associated with Water Cleanup Plans (or TMDLs) for waterbodies in the Sammamish River Corridor not meeting state water quality standards.
- Future improvements to the park and trail system along the river, including a pedestrian and equestrian trail King County plans opposite the existing Sammamish River Trail.
- King County's development of capacity to produce and provide reclaimed water in the Sammamish River Corridor for non-potable uses.
- Other actions along the river by individual governments, such as future stages of Redmond's RiverWalk project.
- Actions by private developers, such as shoreline improvements planned as part of the LakePointe project in Kenmore.

Implementation of this plan, in combination with other restoration and conservation actions being considered in the greater Lake Washington Watershed, should help ensure the Sammamish River Corridor continues to support naturally-spawning salmon populations at equal or greater levels and distribution as exist today, even as the region's human population grows. Under the plan, the Sammamish River would be cooler in the summer and provide higher quality cool water refuge for migrating adult salmon. Juvenile salmon would find far more preferred habitat for rearing and predator avoidance. As restored riparian areas mature, willows near the river would grow to heights of 20 to 30 feet, while Douglas fir and other trees on the banks would reach 100 feet and higher, providing shade, cover and other crucial habitat features. Birds and wildlife in the river corridor could utilize a significantly enhanced riparian corridor for migration, nesting, and feeding. In short, the Sammamish River Corridor would be a strong link in its larger ecosystem, to the lasting benefit of the fish and wildlife populations, as well as the surrounding human community.

If the plan were not fully implemented, the opportunity to create this strong link and provide habitat diversity would be lost. Clearly, the “core” and high priority projects are the most important to address the high water temperatures and provide a suitable migratory corridor for salmonids. However, if only these projects are implemented, numerous areas will still have poor habitat quality and continued degradation within the corridor will occur. The complete Action Plan addresses all of the known and probable limiting factors to fish survival and ensures that the regulatory environment in the corridor is consistent and addresses the causes of habitat degradation. Additionally, the recommended studies will ensure that further opportunities for habitat improvements are identified and evaluated for feasibility of implementation (e.g. the use of reclaimed water and groundwater for controlling high water temperatures).

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INTRODUCTION

PURPOSE AND NEED FOR ACTION PLAN

The Sammamish River Corridor is a special place—dramatically changed from its historic condition, yet still performing important ecological functions while serving as a source of pleasure and refuge for the surrounding human community. The goal of this Sammamish River Corridor Action Plan (Action Plan) is to guide the conservation and enhancement of natural resources in the river corridor for at least the next five to ten years, with a particular focus on enhancing habitat and habitat-forming processes that would contribute to salmon recovery in the greater Lake Washington Watershed (Water Resource Inventory Area [WRIA] 8). This Action Plan was sponsored by King County and the U.S. Army Corps of Engineers (Corps of Engineers), and written in collaboration with the cities of Redmond, Woodinville, Bothell, and Kenmore as one piece of the region's response to current and potential future listings under the Endangered Species Act (ESA). It strives to recommend habitat improvements for salmon, birds, and other wildlife that are compatible with existing human uses of the river corridor, including recreation, agriculture, and urban development.

The Action Plan will be used for multiple purposes by many different parties as described below:

- Local governments across the greater Lake Washington Watershed will use the Action Plan to help identify and prioritize actions in the Sammamish River and sidewall tributaries as part of the regional response to the endangered species listing for salmon.
- The Corps of Engineers will use it to identify and prioritize actions it implements as part of its Ecosystem Restoration Study in the Lake Washington watershed.
- Local governments within the river corridor--King County, Redmond, Woodinville, Bothell, and Kenmore—will use it to identify and prioritize actions they undertake to enhance habitat and natural resources.
- Those same local and regional jurisdictions and state and federal regulatory agencies may use the Action Plan to identify effective mitigation for other actions in the river corridor that may adversely affect habitat, such as road widening, new development, or recreational uses of the river (i.e. personal watercraft).
- Ecology may use the data and/or actions emanating from the Action Plan for Water Cleanup Planning (or TMDL) efforts in the corridor.
- The King County Park System will use it as guidance for future improvements to its extensive park and trail system along the river.
- The King County Wastewater Treatment Division will use it to help guide development of reclaimed water projects in the river corridor.

By 2005, the Action Plan may in part be superseded by a comprehensive plan the region is developing to support salmon recovery and ecological health across the entire Greater Lake Washington Watershed. However, the Action Plan is intended to provide the initial suite of projects and research recommended for the Sammamish Corridor within the larger watershed plan. All recommendations in this plan will be subject to future adaptive management, to be modified or even rejected as new and better information on habitat use and other parameters becomes available.

As previously discussed, many agencies and other interested parties within the greater Lake Washington Watershed are currently developing a comprehensive plan for recovery of chinook and other salmon species in response to the listing of Puget Sound chinook salmon as a threatened species under the ESA. A multijurisdictional WRIA 8 recovery planning process is proceeding with the following steps: (1) Reconnaissance Assessment that summarizes existing information on salmon population/distribution and habitat conditions in the basin (Kerwin, 2001); (2) Near Term Action Agenda to recommend near-term projects, policies, research, and programs to conserve and recover salmonids in the watershed (WRIA 8 Steering Committee, draft 2002); (3) Strategic Assessment that will collect data where important gaps in knowledge have been identified in step 1; and (currently being developed, see below) (4) the final Watershed Conservation Plan for long-term salmon conservation and recovery (target date summer 2005).

As part of the technical strategic assessment the WRIA 8 Technical Committee will consider action alternatives developed as a result of this plan. The strategic assessment for WRIA 8 is currently in development. The WRIA 8 Strategic Assessment can be defined as the tools and assessment methods that will provide the scientific basis for development of the WRIA 8 Salmonid Habitat Conservation Plan. The Strategic Assessment will develop testable hypotheses that will allow the WRIA 8 Technical Committee to design research, strategies, and action alternatives toward development of the habitat conservation plan. This Action Plan will provide a valuable resource of information, data, and basis for development of conservation actions.

STUDY AREA

This report is focused on the Sammamish River Corridor, herein defined as the river from Lake Sammamish to Lake Washington, the valley floor, the lower extent of small sidewall tributaries that primarily exist in the valley floor (approximately 1,000 feet [or 300 meters]), and the confluences of major and minor tributaries to the river. Major tributary conditions will be discussed as they relate to the Sammamish River Corridor and its habitats.

The greater Lake Washington Watershed encompasses two major river systems, the Cedar and Sammamish Rivers, as well as Lakes Sammamish, Washington, and Union and numerous tributaries to each of the above water bodies. The Sammamish River begins at the outlet of Lake Sammamish, approximately 12 linear miles (19.2 km) northeast of downtown Seattle, Washington. The Sammamish River flows in a north and then westerly direction for approximately 14 miles (~22 km) to the confluence at the north end of Lake Washington. Several tributaries enter the Sammamish River including Bear, Little Bear, North, and Swamp Creeks and several smaller named and unnamed creeks (see Figure 1). The Sammamish River provides a migration corridor for both fish and wildlife species between Lakes Washington and Sammamish. The Sammamish River is the second largest tributary to Lake Washington (after the Cedar River) and contributes approximately 30 percent of the flow into the lake. The Sammamish River is fed by outflow from Lake Sammamish and tributary flows from lowland streams. Human-caused changes over the past century have dramatically changed the hydrologic regime and channel alignments within the watershed. The Lake Washington watershed is also the most populated watershed in the State of Washington.

To determine what type of habitat restoration actions would be most appropriate and effective in this system, a review of both historic and current watershed conditions and limiting factors was undertaken. Although habitat for both fish and wildlife species is assessed in this report, the motivation for most restoration planning in the watershed is salmon recovery. Therefore, aquatic habitat is generally discussed in greater detail than terrestrial habitat. However, a well functioning ecosystem that includes both aquatic and terrestrial habitats is critical to the recovery of salmonid species and their long-term viability. This report summarizes the available information on historic conditions, human-caused changes to the watershed, existing ecological conditions, and limiting factors to salmon production, and identifies and evaluates potential restoration and conservation actions for both fish and wildlife species.

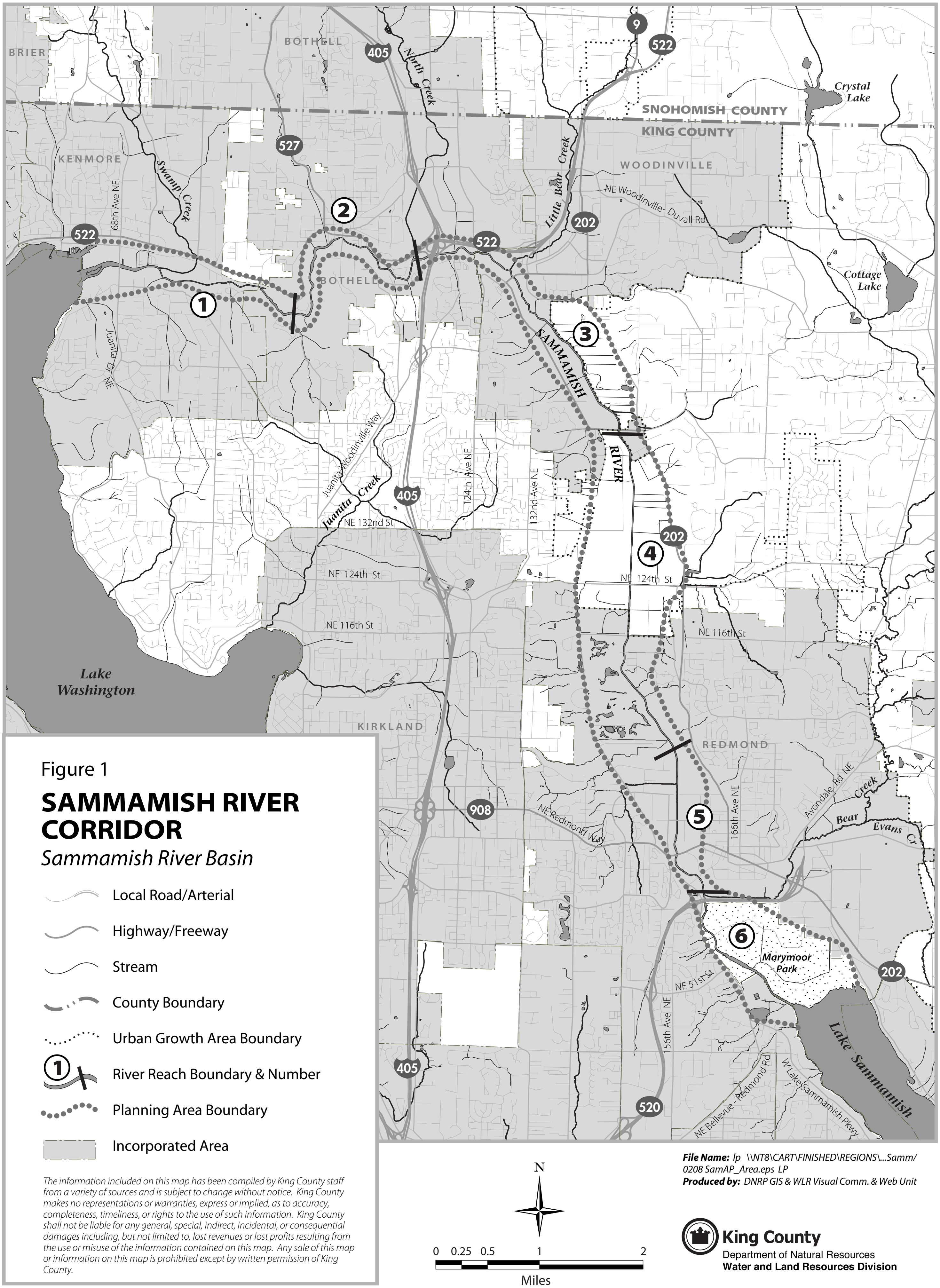

Figure 1

SAMMAMISH RIVER CORRIDOR

Sammamish River Basin

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CHAPTER 1. HISTORIC CONDITIONS IN THE SAMMAMISH WATERSHED

In order to identify the most appropriate and effective restoration measures for use within the Sammamish River Corridor, it is instructive to review historic watershed conditions, as well as anthropogenic changes that have occurred over the past 120 years. This assessment summarizes available information from 1859 through approximately the 1960s, when the last of the major changes occurred to the river (not including continued urban development). Information for conditions prior to European settlement is available from only a few sources (primarily the General Land Surveys of 1859 and histories of the Sammamish Valley such as Stickney & McDonald 1977).

Historically the Sammamish River Corridor was a place of vast wetlands, numerous meandering and braided channels, and old growth forest. The frequent flooding made it seasonally habitable, during the dry season. The extremely complex system of emergent, shrub, and forested wetlands, and multiple channels provided significant rearing opportunities for salmon species, and ideal habitat for large and small mammals and birds. It is unlikely, however; that extensive spawning areas were present in the river due to its flow characteristics and gradient but all other aquatic and floodplain habitat types (such as side channels, pools, emergent, shrub and forested wetlands,) were present in abundance. Significant human-induced changes have been incurred in the Sammamish River Corridor since Europeans began to settle in the area in the 1880s. Lake Washington was lowered nine feet and Lake Sammamish by six feet when the Hiram Chittenden Locks (hereafter referred to as the locks) were built; the vast forested areas of the valley and surrounding hillsides were logged; the river was confined to one channel, wetlands were drained for agriculture; and in the 1960s the river was further constrained for flood and now has uniform aquatic habitat and essentially no riparian area. Details are provided below.

FLOODPLAIN AND RIPARIAN VEGETATION

The Sammamish River Corridor is approximately 12 miles (19.2 km) in length and the floodplain varies in width from nearly one mile (1.6 km) in the upper two-thirds to approximately 1,000 feet (303 m) wide near Bothell (see Figure 1). Prior to European settlement, the Sammamish River floodplain was primarily wetland, (General Land Survey Office 1859; General Land Office 1884; USGS 1897) and heavily vegetated with a diverse mix of plant communities (see Figure 2). Communities likely included emergent, shrub, and forested wetland, and riparian and upland forest, although wetland habitat likely dominated most of the valley floor (as evidenced in GLSO 1859). Common plant species noted anecdotally by early settlers included cranberry (possibly *Viburnum edule*), wild crabapple (*Malus fusca*), hazelnut (*Corylus cornuta*), nettle (*Urtica dioica*), marshgrass (possibly *Carex* species), cattail (*Typha latifolia*), cedar (*Thuja plicata*), alder (*Alnus rubra*), fir (*Pseudotsuga menziesii*), hemlock (*Tsuga heterophylla*), and several species of willow *(Salix* sp.) (Washington Native Plant Society [WNPS] 1994; Stickney and McDonald 1977; Johnston and Johnston 1976). Photographs from the turn of the century show massive old growth cedar, Douglas fir, hemlock, and numerous cottonwood (*Populus balsamifera*), willow, and alder (Stickney and McDonald 1977; McDonald 1976).

It is likely that several types of natural, low-elevation wetland communities (as identified in Kunze, 1994) were present in the Sammamish River Corridor because of its low gradient, frequently flooded nature, including variations of the following: (1) sphagnum bog, shrub-dominated (still present adjacent to tributary streams and on Sammamish plateau, may not have been present in the Sammamish Corridor itself); (2) minerotrophic[1] permanently flooded (oxbows, behind beaver dams, etc); (3) minerotrophic seasonally

[1] Minerotrophic wetlands have inflows of moderate quantities of nutrients and minerals from mineral-rich groundwater, natural streams, and/or rainfall.

flooded, herb-dominated; (4) minerotrophic seasonally flooded, shrub-dominated; and (5) minerotrophic seasonally flooded, tree-dominated. Typical dominant species assemblages in each community are shown in Appendix A. It is likely that all but the sphagnum bog, shrub-dominated wetland types were very common in the Sammamish Valley historically.

Typical wetland community plant species are listed below as derived from the Washington Native Plant Society's (WNPS 1994) list of plants collected in the Puget Sound area in the 1850s and Kunze (1994). Emergent wetlands likely contained several species of sedge that are typically found in undisturbed native wetlands in western Washington, including *Carex aquatilis*, *C. cusickii*, *C. obnupta*, *C. lenticularis*, and *C. stipata;* rush species such as *Juncus effusus, J. acuminatus, J. ensifolius,* and *J. mertensianus;* and other emergent wetland species such as *Alisma plantago-aquatica, Eleocharis palustris; Scirpus acutus, S. microcarpus; Polygonum amphibium* and *Typha latifolia*. Shrub wetland and riparian areas likely included such species as spirea (*Spirea douglasii),* vine maple *(Acer circinatum),* red-osier dogwood (*Cornus sericea),* red alder, salmonberry (*Rubus spectabilis),* twinberry (*Lonicera involucrata),* willow *(Salix lasiandra, Salix scouleriana),* Labrador tea (*Rhododendron groenlandicum),* and bog laurel (*Kalmia polifolia)*. Forested wetland and riparian areas likely included such species as red alder, cottonwood, Oregon ash (*Fraxinus latifolia),* red cedar, western hemlock, big-leaf maple (*Acer macrophyllum),* Douglas fir, snowberry (*Symphoricarpos albus),* red elderberry *(Sambucus racemosa),* impatiens *(Impatiens noli-tangere),* and skunk cabbage (*Lysichiton americanum)*.

The floodplain contained numerous channels, sloughs, and oxbows from the highly braided river channel, and the entire valley flooded almost yearly. Navigation reports from the late 1800s indicate it was very difficult to discern the main river channel from the numerous blind channels within the valley floor. Large woody debris (LWD) was also very abundant and a hazard to navigation as recently as the early 1960s (Stickney & McDonald 1977; various newspaper articles). Since the river had limited transport capacity, it is likely that wood from tree fall adjacent to the river and wood transported down the tributaries accumulated in large quantities in the mainstem. Large jams may have formed at, or immediately downstream of the tributary mouths.

HYDROLOGY

The Sammamish River and Lakes Washington and Sammamish, occupy glacially scoured troughs from the most recent glaciation (~10,000 years before present). The Sammamish River flows primarily northward from Lake Sammamish for approximately ten miles and then turns westward for another four miles starting near Woodinville. The North Creek Valley that continues as a northern extension of the Sammamish River Corridor historically contained an extensive wetland area (General Land Office 1859 and 1897; Stickney & McDonald 1977) and likely is the location of the anecdotal "third lake" that may have existed in the valley. The City of Bothell has recent soil information that shows extensive layers of diatomaceous earth in the vicinity of North Creek, which is typically derived from diatom deposition in a lake or marine environment (B. Blackburn, City of Bothell, pers. comm. 2001).

Historically, the Sammamish River was the primary tributary to Lake Washington, and the level of Lake Washington fluctuated annually by several feet (from elevation 18 to 27 feet [5.4 to 8.2 m] [National Geodetic Vertical Datum 1929]; Ajwani 1956). Historically the median lake level was about 8 to 9 feet (~2.5 m) higher than its current mean elevation (historical mean elevation of about 22 feet [6.7 m]; current mean elevation of about 14 feet [4.2 m]). The Sammamish River Corridor ranges in elevation from 20 feet (6 m) at Kenmore to about 28 feet (8.5 m) at Marymoor Park, suggesting that the lower half of the corridor was on average flooded to a depth of 2 feet (0.6 m). During high water conditions, the entire valley floor was flooded. Stickney and McDonald (1977) point out that during foggy weather or wintertime, riverboat operators could not find the river channel amongst the numerous flooded channels that existed and would typically tie up to a snag and wait for better visibility. Water levels in Lake Sammamish were also directly tied to the level of Lake Washington and fell significantly when Lake Washington dropped below 20 feet in elevation (6 m). The river gradient was even less than it is today due to the approximate 30-mile (48 km) length of the main channel and less elevation difference between Lakes Washington and Sammamish (Chrzastowski 1981).

Lake Sammamish has likely always had warm epilimnetic (surface) water temperatures during the summer months primarily associated with thermal stratification of the shallow lake and the hydraulic retention time of the lake. The outflow temperature from the lake to the Sammamish River would have been elevated as a result of these conditions, similar to the existing situation. J.G. Cooper (WNPS 1994) describes the rivers of western Washington in the 1850s as typically having low temperatures (<52°F [11° C]) throughout the summer and uniformly very clear water, except those fed by glacial meltwater. He does not specifically refer to the Lake Washington watershed, however, other than describing the Black River as an area of significant wetlands. However, since the Sammamish River is fed by lake outflow it was not likely to have ever had low temperatures like other river systems. Since no data are available, we can only speculate on what temperatures in the Sammamish River may have been. We do know that the Sammamish River Corridor had very dense forest and shrub vegetation in the floodplain and riparian areas which would have shaded most of the river (particularly because of the numerous small braided channels that could be completely shaded more easily than the existing wide single channel), thus providing some measure of cooling and preventing additional heating. Additionally, there were likely numerous groundwater inflows associated with the vast wetland complex in the corridor, as well as typically higher flows in the tributaries (prior to impervious surfaces and more rapid runoff) that would have provided much more significant cooling than current conditions provide. Also prior to initiation of water withdrawals from the river there may have been higher flows in both the tributaries and the mainstem, which would have been less susceptible to heating (it takes more heating to increase the temperature of a larger volume of water).

Historically, Bear Creek entered the Sammamish River very near the outlet of Lake Sammamish (in Marymoor Park), approximately 0.7 miles (1.1 km) upstream of its existing outlet. Therefore, the length of the reach over which river temperatures were similar to lake surface temperatures would have been much shorter. The inflow from Bear Creek would likely have been at least as cool if not cooler than today. Therefore, a temperature decrease below the confluence of Bear Creek of a few to several degrees centigrade would be expected depending on flow. The historical temperature of the river below Bear Creek would depend on a number of factors that include residence time in the river, the amount, type, and distribution of streamside vegetation, and the historical flow regime and temperature of other tributary and groundwater inputs. Although it is likely mainstem river temperature was generally much lower that it is today, we cannot be certain it was not similar to the current conditions (depending on the above factors, see Chapter 2 for current conditions). What can be said with some certainty, however, is that the historical river channel and associated network of wetlands, tributaries and side channels provided a greater variety of temperature conditions (especially cool water refuges) than at present. In addition, due to the old growth forest characteristics of the watershed, the tributaries would have likely experienced cooler temperatures.

HABITAT CHARACTERISTICS

Habitat for salmon and other native fish species in the Sammamish River was likely diverse prior to European settlement. Stickney and McDonald (1977) mention the presence of numerous logs and LWD jams in the river that impeded navigation, in addition to the presence of numerous side channels and oxbows off the main channel. The LWD likely caused formation of numerous deep pools that served as refuge and habitat for rearing. The dense and diverse vegetation communities would have further provided opportunity for juvenile fish rearing and refuge in the slow-moving river. It is unlikely, however, the mainstem provided significant habitat for spawning (such as the Cedar River) due to the very low gradient. It is likely however that the mainstem river supported some smaller areas suitable for spawning, particularly at tributary mouths where gravel may have deposited or where groundwater upwelling may have occurred. Also, the connection with two major lakes and several significant tributaries provided an additional array of habitat types for salmon to utilize. Coho, steelhead, sockeye, and cutthroat seek out and utilize side sloughs and channels, tributaries, and spring-fed seeps for rearing (Kerwin 2001). The river may have been the primary rearing area utilized by chinook, coho, steelhead, and cutthroat in the Sammamish watershed due to the complex cover and numerous sloughs, side channels and wetlands, whereas the lakes are typically primary rearing areas for sockeye and kokanee. Cutthroat trout use a wide variety of habitats including lakes and small and large streams or rivers and likely utilized the mainstem Sammamish River extensively. It is unknown, however, if bull trout historically present in the watershed were anadromous. If so, they may have primarily been present in Bear and Issaquah Creeks (coldest water temperatures) and migrated through the Sammamish River. They prefer highly complex habitat with extensive cover (USFWS 1999), which would have been present throughout the mainstem.

Tributaries historically provided spawning and rearing habitat for chinook, coho, steelhead, and cutthroat and bull trout. Bear, Swamp, and North Creeks all contained significant wetland areas (based on historic maps and aerial photos such as GLSO 1859) that would have provided a diversity of habitats, as well as serving to maintain fairly constant year-round flow conditions. All of the tributaries to the river are lowland stream systems that would not have experienced the typical hydrologic extremes of spring snowmelt runoff or winter rain-on-snow flooding. Issaquah Creek, which is a tributary to Lake Sammamish, is the only sub-basin originating in the Cascades, but still has generally lowland stream flow characteristics because its headwaters are at approximately 2000 ft (600 m), which is below the usual snow-pack elevation.

The mosaic of wetland, riparian, and upland habitat in the Sammamish Valley would have also provided a diversity of habitat for numerous waterfowl and birds, as well as small and large mammals, amphibians, and reptiles. Habitat would have varied from open water and ponded wetlands to saturated wetlands, riparian, and upland forests. Early accounts indicate the valley was primarily forested swampland (Stickney & McDonald 1977). As evidenced by photos of logging during the early 1900s (Stickney & McDonald 1977), most coniferous forested areas were likely in old growth conditions, which would have provided suitable habitat for species now rare or extinct in the lowlands, including bat, cougar, grizzly bear, gray wolf, marbled murrelet, fisher, and others.

As previously indicated, there are no historic water quality data available other than anecdotal accounts from other watersheds (WNPS 1994). Historically, there was likely great variability in water temperatures throughout the corridor (very cool in the tributaries [<60°F or 15.5°C] and numerous cool water refuges in spite of the likely elevated Lake Sammamish surface temperatures). Otherwise, water quality is presumed to have been of good quality to support all native fish and wildlife species.

DESCRIPTION OF FISH SPECIES AND POPULATIONS

Prior to significant human-induced changes in the watershed, Lake Washington had its outflow through the Black River and into the Green/Duwamish watershed. An initial cut to connect Lake Washington to Lake Union was made near Montlake as early as 1886 (Ajwani 1956) for log transport purposes; it is unlikely however, that anadromous fish were able to use this access to the lake. The Washington Conservation Commission (Kerwin 2001) recently prepared the best reconstruction of historic fish species present in the watershed. Fall chinook, coho, sockeye, kokanee, steelhead, cutthroat trout, and bull trout are likely the only salmon species that were historically present in the Sammamish subwatershed, although spring chinook, pink, and chum salmon were likely present in the Cedar River and may have entered Lake Washington. Other species such as white sturgeon, mountain whitefish, northern pike minnow, suckers, peamouth, sculpins, sticklebacks, and lamprey were likely present as well. Early reports of fish in the watershed indicate kokanee were abundant, and significant quantities of eggs were taken from Lake Washington/Lake Sammamish kokanee to stock other watersheds in the state (Kerwin, 2001). Stickney and McDonald (1977) indicate fish (not identified) were abundant in Squak Slough (former name of Sammamish River) and Lake Sammamish and were a primary food source for Native Americans, which is also reiterated by Buerge (1984), that the kokanee fishery was tremendous and tribes from around Puget Sound came to fish during the spawning runs. Actual population sizes of the various salmonid species are not known, but were likely quite significant, as there were several native villages around Lake Washington and at the mouth of the Sammamish River that extensively utilized the various fish species (Buerge, 1984). Kokanee egg take data from the turn of the century (Kerwin 2001) indicate there were many tens of thousands of kokanee at that time.

Fish species in the Sammamish sub-watershed (Lake Sammamish and Sammamish River and tributaries) would have likely evolved to tolerate cool water temperatures and to use a variety of habitats including wetlands, sloughs, floodplains, and channels similarly to fish in other western Washington systems. Lowland- and wetland-dominated systems can be very productive for coho and steelhead and cutthroat trout. Chinook were not likely abundant in the Sammamish sub-watershed due to lack of a large river system with extensive spawning areas and the presence of two relatively large lakes that are typically not preferred rearing areas for chinook (Healey 1991). However, populations that did occur had excellent rearing opportunities in the Sammamish River Corridor.

Freshwater mussels (presumed to be the western pearlshell [*Margaritifera falcata*]) still occur in Bear Creek (Fevold & Vanderhoof 2002) and it is likely several native species of freshwater mussels and clams were historically present in the Sammamish River Corridor in the shallow ponds and side channels of the floodplain (such as Oregon floater and other species). Freshwater mussels are considered indicative of high quality stream habitat because they require clean gravel and sand and for part of their life history they are parasitic on salmonid species (Fevold & Vanderhoof 2002).

There is no data available on the historic aquatic invertebrate populations, but the highly diverse wetland, river, slough complex would likely have supported abundant populations of both terrestrial and aquatic insects and other invertebrates. There was a diversity of substrate type and extensive overhanging and emergent vegetation. The corridor would likely have produced abundant food sources for all salmonid species and other resident fish.

WILDLIFE

There is very little information on historic wildlife populations in the Sammamish River Corridor. Based on the previous discussion that the valley was a mosaic of old-growth forested swamps, emergent and scrub-shrub wetlands and adjacent old-growth fir and hemlock uplands, all native wildlife species that utilize these lowland habitat types would have likely been present. Marshes and riparian areas would have provided additional habitat for migratory birds, and proximity to lakes would have further attracted waterfowl. Table 1, below, lists many of the wildlife species that may have historically been present in the Sammamish River Corridor. This list is derived from a review of native wildlife species distribution and habitat requirements and judgment of wildlife biologists (Corkran & Thoms 1996; Csuti, *et al* 1997; Kruckeberg 1991; Maser 1998; National Geographic Society 1985; K. Brunner, ACOE, pers. comm. 2001)

Table 1. Wildlife species that may have historically (pre-European settlement) been present in the Sammamish River corridor (Not intended to be entirely inclusive)		
Mammals	Western pond turtle	**Birds (cont.)**
Grizzly bear	Various snakes	Merlin
Black bear	**Birds**	Peregrine falcon
Cougar	Pied-billed grebe	Ruffed grouse
Elk	Great blue heron	Band-tailed pigeon
Black-tailed Deer	Tundra swan	Owls (great-horned, spotted, screech, pygmy, saw-whet)
Gray wolf	Canada geese	Rufous hummingbird
Coyote	Mallard	Belted kingfisher
Mink	Teal (green-winged, blue, cinnamon)	Northern flicker
Fisher	American wigeon	Woodpecker (downy, hairy, pileated)
Long-tailed weasel	Northern pintail	Flycatcher (olive-sided, Hammond's, willow, Pacific-slope)
Porcupine	Ruddy duck	Western wood pewee
Beaver	Wood duck	Swallows (tree, violet-green, barn, cliff, northern rough-winged)
Mountain beaver	Lesser scaup	Purple martin
River otter	Barrow's goldeneye	Steller’s jay
Muskrat	Common goldeneye	Magpie, crow, raven
Bobcat	Bufflehead	Chickadee (black-capped, mountain, chestnut-backed)
Raccoon	Mergansers (common, hooded)	Bushtit
Red squirrel	Virginia rail	Wren (house, winter, Bewick's, marsh)
Western cottontail rabbit	Sora	Kinglet (golden-crowned, ruby-crowned)
Bats	American coot	Thrush (Swainson's, hermit, varied)
Voles	Long-billed curlew	American robin
Shrews	Greater yellowlegs	Cedar waxwing
Amphibians/Reptiles	Snipe	Vireos (Cassin’s, red-eyed, Hutton’s, warbling)
Northwestern salamander	Gulls (Bonaparte’s, ring-billed, mew, herring, CA, glaucous, Thayer’s, western)	Warblers (orange-crowned, yellow, yellow-rumped, Townsend's, Wilson's, MacGillivray’s, black-throated gray, Nashville)
Long-toed salamander	Marbled murrelet	Common yellowthroat
Roughskin newt	Golden eagle	Yellow-breasted chat
Pacific giant salamander	Bald eagle	Black-headed grosbeak
Ensatina	Northern harrier	Lazuli bunting
Van Dyke's salamander	Sharp-shinned hawk	Spotted towhee
Western redback salamander	Cooper's hawk	Sparrow (savannah, song, golden-crowned, white-crowned, fox, Lincoln’s, vesper)

Table 1. (Continued)		
Western toad	Northern goshawk	Red-winged blackbird
Pacific treefrog	Red-tailed hawk	Western tanager
Red-legged frog	Osprey	Finches (American, pine siskin, red crossbill, purple)
Spotted frog	American kestrel	

NATIVE AMERICAN PRESENCE AND USE OF THE SAMMAMISH RIVER CORRIDOR

All information in this section is summarized from Buerge (1984) and Stickney and McDonald (1977*)*. The Lake Washington basin was highly productive of fish, birds, mammals, and a variety of edible plants and several native winter villages were located along the Lake Washington lakeshore and adjacent to tributaries including the Sammamish River. There was also extensive native use of Lake Sammamish. A village was located at the mouth of Sammamish River and was known to be occupied by the “willow people” as described by early European settlers. There are also extensive archaeological sites in and adjacent to Marymoor Park at the upper end of the river. The native tribe around Lake Sammamish was generally known to the settlers as the Squak people (the Sammamish River was called Squak Slough). It is unknown, however, if winter villages were present in the Sammamish valley because of the frequent flooding that occurred. It is likely there were summer camps and other uses by native Americans because of the extensive fish runs that used the corridor. There could have been more extensive use of the corridor by tribal populations than was noted by early settlers because many native peoples are believed to have been decimated by smallpox and other diseases as a result of early trappers and explorers (Hudson Bay Company, etc.), prior to most settlement.

HUMAN-INDUCED CHANGES TO THE RIVER AND BROADER WATERSHED

From the time the first European settlers began moving into the Sammamish Valley to the present day, significant changes have occurred to the system’s hydrology, floodplain, and aquatic and terrestrial habitats. The first settlers moved into the valley in the 1870s (Stickney and McDonald, 1977) and almost immediately began clearing the upland forest for both timber and farmland. The Sammamish River was a major route for transporting logs down to Kenmore and across Lake Washington. The heaviest logging activity occurred from the 1880s through about 1900. In photos around 1903 (Stickney and McDonald, 1977), the valley and surrounding hillsides are nearly devoid of trees.

Following the logging boom, more and more settlers moved into the valley for farming and other ventures. As early as 1892 (King County Testimony and Petitions 10/12/1895; 9/26/1892; 3/20/1895; 8/20/1892; 9/21/1892; 1/11/911), the settlers were trying to form a drainage district and straighten and deepen the river channel to its approximate existing alignment (see Figure 2). Landowners downstream of Hollywood were opposed to initiation of the drainage district because they would be taxed and thought deepening the river would not solve their continuing flooding problems due to backwater conditions from Lake Washington. These landowners advocated lowering Lake Washington as a better alternative. When plans for building the Lake Washington Ship Canal were initiated in 1910 by the Corps of Engineers, King County, and the City of Seattle, there was an initial plan to appropriate $25,000 for deepening the Sammamish River to coincide with the lake lowering (Stickney and McDonald 1977). The deepening plan did not come to fruition, however, and a drainage district was formed in 1911 (King County 1911). Residents considered the debris jams and sand and gravel bars within the river as unreasonable restrictions on navigation and other uses and subsequently began the process of widening and "brush" removal.

The locks and Lake Washington Ship Canal were completed in 1917, and Lake Washington was slowly lowered about 9 feet (2.7 m) over the construction period, with a subsequent drop in Lake Sammamish elevation of approximately 6 feet (1.8 m). Ajwani (1956) states that following the lowering of the lake, the

Sammamish River had a stronger current, and many areas of the valley floor that were formerly submerged or otherwise wet were drained and placed under cultivation. The drainage districts continued to implement incremental straightening and deepening projects throughout the Redmond to Woodinville reach, primarily in the early 1920s. By 1938 (USACE map 1938), the river essentially existed in its current alignment, and the majority of the floodplain was under agricultural production; however, portions of the old channel alignment still existed as shrub wetland habitat (King County aerial photos ~1940). The river was also dredged sometime before 1950 (Ajwani 1956) to provide navigation for small boats. It is unclear who conducted the dredging (possibly the drainage district or King County). Ajwani (1956) considered the dredging to have destroyed habitat for trout and salmon, which included spawning habitat in several areas of the river, with the higher gradient from the lowered lake level.

In spite of these significant alterations, the Sammamish floodplain still experienced a high groundwater table and frequent flooding that impeded early season crops and made much of the floodplain undesirable for residential or commercial development. In the 1950's King County requested that the Corps investigate a flood control project to prevent spring flooding of croplands (USACE, 1962). The Corps undertook a feasibility study that recommended deepening of the river to facilitate drainage and to contain flows up to a 40-year event after March 1.[2] The Corps completed this project in 1964, which deepened the river by approximately 5 to 10 feet and also included minor straightening near North Creek (for Highway 522 construction) and elimination of a couple of meanders upstream of Woodinville. A levee was also constructed along lower North Creek. The dredged material was typically sidecast to fill in low spots (probable wetlands) and form short berms along the banks, providing additional flood protection that exceeded the design event in some areas. During construction, essentially all riparian vegetation was removed, and the design standard was for a grass-lined channel, which King County is obligated to maintain. This was the final major alteration to the river channel, to date. There is no levee system along the Sammamish River, but rather areas of sidecast material from the channel improvement project that filled in low elevation floodplain areas. Rock bank protection was also placed as part of the Corps/King County project to protect bridges and some banks, in approximately 50% of the channel.

Following completion of the Corps/King County flood control project, the floodplain gradually began to transition from agricultural use to residential, commercial, and industrial uses. A significant proportion of the former floodplain is now developed (estimated at ~45%; not including agriculture or park lands). Based on the comprehensive plans of King and Snohomish Counties and associated cities approximately 57% of the overall Sammamish watershed is planned for urban growth (King County Office of Regional Policy and Planning 2001; Snohomish County Department of Planning and Development Services 2000). The Swamp and North Creeks sub-basins are almost entirely planned for urban growth (Swamp Creek 100% and North Creek 99%). Much less of the Bear and Little Bear Creeks sub-basins are planned for urban growth--only 20% and 28%, respectively. Continued development will restrict restoration options in the future and could reduce existing high quality habitats without specific public acquisition or restoration actions.

In summary, the Sammamish River Corridor has undergone dramatic alterations since settlement began in the 1870s. Alterations include major hydrologic changes (lake lowering and channel deepening); urban, industrial, and agricultural development in the river corridor and surrounding watershed; timber harvest; stocking of non-native fish species; construction of in-channel structures such as weirs; channel realignment; and filling of remnant oxbows and floodplain areas. These alterations have eliminated most floodplain and wetland habitat in the corridor and seriously degraded riparian and in-stream habitat for fish and wildlife. The following chapter describes these existing conditions in more detail.

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[2] The significance of the 40 year design event for flows after March 1st, is that the project was never designed to control winter flooding, only to facilitate crop growing in the springtime. Some flood control benefits have accrued to floodplain landowners over the years, particularly because portions of the channel may provide slightly higher protection than was originally designed (L. Smith & J. Lencioni, Corps of Engineers, pers. comm. 1999).

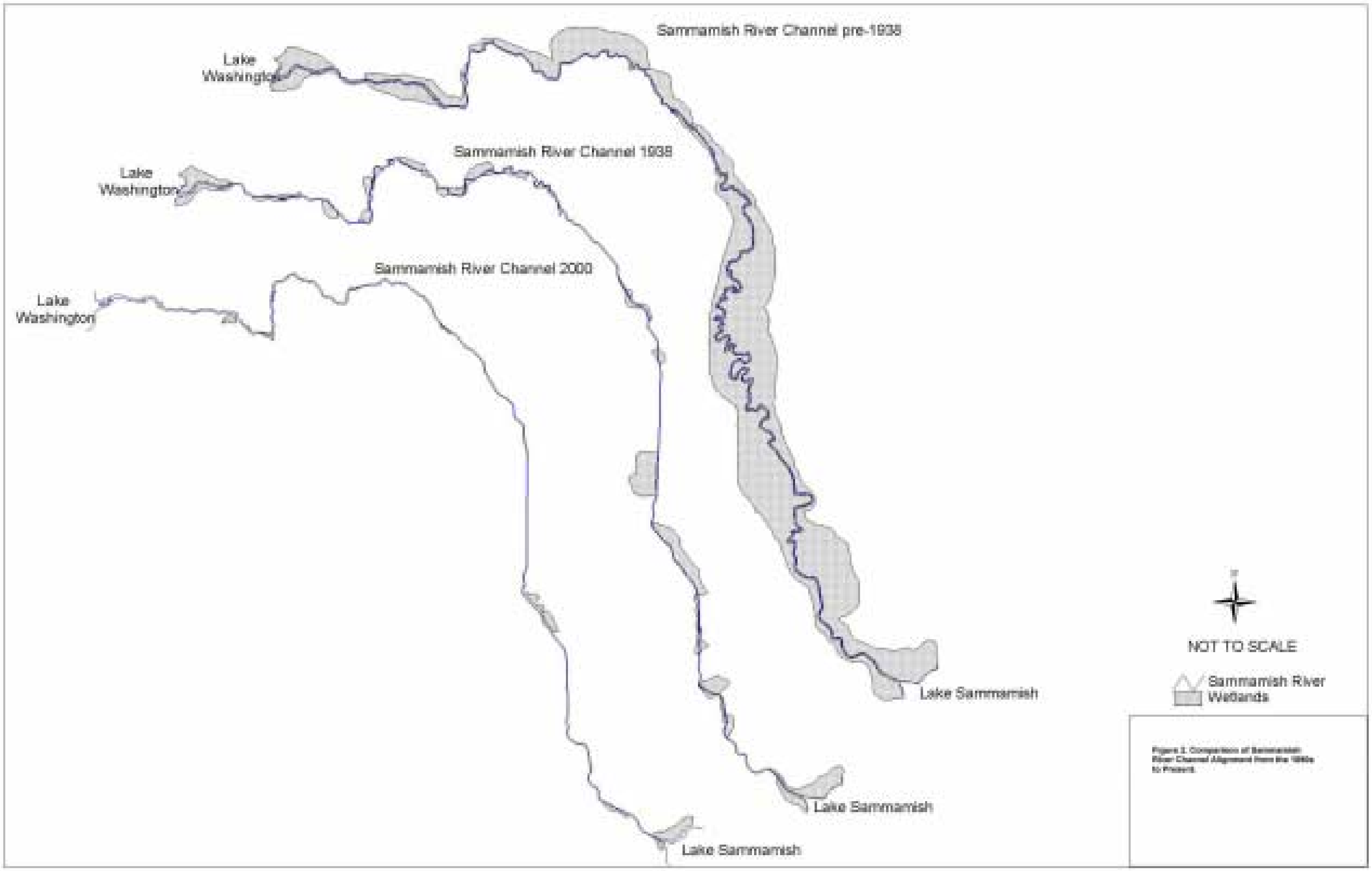

Figure 2. Comparison of Historic Channel Alignment with Existing Channel Alignment

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CHAPTER 2. EXISTING CONDITIONS IN THE SAMMAMISH RIVER CORRIDOR

As a result of historical and recent events, current conditions in the Sammamish River Corridor are severely degraded and have resulted in a decline in many fish and wildlife populations. Aquatic habitat area has been reduced by more than half (as estimated by the change in river length; originally ~30 miles, now less than 14 miles in length), and the remaining channel was designed to have a uniform width and gradient (eliminated pools and riffles). Native plant communities are rare in the corridor and are completely changed from the historic forested swamp conditions. Typically, the only native fish species doing well in the river are often adaptable to altered conditions, such as cutthroat trout. However, it appears no native fish species have yet become extinct in the Sammamish sub-watershed (although there may have been a spring chinook stock in the subwatershed which no longer exists), although many wildlife species have been extirpated[3]. Alterations have caused adverse impacts on native salmon populations in particular. A total of seven salmon species are known to be present in the north Lake Washington watershed, and of those, two are listed as threatened (chinook, bull trout), one has been petitioned for listing as endangered (kokanee), three are considered depressed by WDFW (coho [listed as a candidate species under ESA], steelhead, and sockeye), and one has unknown status although it is considered “not warranted” for listing under the ESA (coastal cutthroat) (NOAA 2000; USFWS 2000; WDF 1993; Kerwin 2001).

Of particular importance to native fish and wildlife species, natural watershed processes have been disrupted. Watershed processes naturally create and rework habitat features over time and historically exerted natural selection forces on the fish and wildlife populations in the watershed. Watershed processes crucial to proper ecological functioning include the following: (1) routing and delivery of water, sediment, and LWD; (2) cycling of nutrients and carbon; and (3) heat balancing (Gersib, *et al*. 2001).

As previously discussed, routing and delivery of water has been significantly altered in the Greater Lake Washington Watershed by the lowering of Lake Washington, the deepening of the river channel, water withdrawals, and a significant increase in impervious surface area, which increases peak flow and decreases base flow. The Sammamish River likely never transported a significant quantity of coarse sediment, but the channel deepening and armoring has eliminated native substrate and reduced bank sediment sources. Fine sediment deposition has increased in tributary streams and their deltas. LWD is currently almost non-existent in the river due to removal before and during the deepening project, in addition to a lack of riparian trees for recruitment along the mainstem and in the tributaries. The riparian area is not forested and is now dominated by non-native grasses and shrubs (or development), and channelization has eliminated erosion and meandering processes necessary to recruit what little adjacent wood does exist. Stormwater runoff is delivered directly to the river in a number of locations, causing increased levels of nutrients and other pollutants (particularly bacteria and other contaminants). In addition, few wetlands exist within the valley to retain contaminants. The heat balance throughout the river has been significantly altered from natural conditions as a result of reduced base flow, increased groundwater withdrawal, and lack of a functional riparian area. In short, all watershed processes have been degraded to a greater or lesser extent in the Sammamish River Corridor. Degradation of natural processes has a profound influence on the quantity and quality of aquatic and terrestrial habitats as described below.

FLOODPLAIN AND RIPARIAN VEGETATION

Riparian vegetation has been removed or altered over a significant portion of the corridor, and in many areas revegetation is constrained by urban development, developed parks and golf courses, or agriculture (Jeanes

[3] Pink and chum salmon likely historically occurred in the Cedar River, but no longer occur likely as a result of the diversion of the Cedar River into Lake Washington.

and Hilgert 1999). Generally, the vegetated riparian area along the river is less than 50 feet (15 m) wide with very few trees. In many areas, vegetation is nonexistent, having been replaced by parking lots, agricultural fields, and paved trails. In areas where vegetation is present, it is primarily comprised of non-native species. Jeanes and Hilgert's (1999) habitat survey shows reed canary grass and Himalayan blackberry dominate the plant community in most reaches, although overall percent cover was not determined (see reach maps, Figures 5-11). Riparian vegetation loss leads to several problems in a stream system, including elevated water temperatures, increased bank erosion, decreased LWD recruitment, decreased insect and detrital inputs, and decreased instream cover. A loss of riparian cover may lead to decreased fish survival and production, since terrestrial insects that colonize riparian vegetation can comprise a significant portion of the fish diet (Higgs, *et al* 1995). Direct shading of the river can, in some cases, reduce water temperature and prevent temperature increases associated with solar radiation. However, in the case of the Sammamish that is now a single, much wider channel, riparian shading can generally only provide slight cooling because the wide width of the river prevents complete shading and the volume of water is quite large (the historic channel was composed of narrower braided channels). Of equal importance is loss of wetland habitat in the floodplain, which has likely resulted in reduced groundwater recharge, and subsequent loss of discharge to the river. Groundwater withdrawals in the floodplain may also have reduced groundwater discharge to the river (King County is currently studying this issue).

As a result of the deepening project, the Sammamish River floodplain has been significantly diminished in many areas. While reduced flooding results in less damage to human structures and activities, it also significantly reduces wetland habitat, groundwater recharge, LWD recruitment, and creation of new aquatic and floodplain habitat. Most of the valley floor is now devoted to agricultural and urban land uses (including golf courses and maintained playing fields). These areas provide only minimal wildlife habitat. A few small native plant communities remain (although non-native species are rapidly encroaching): in Marymoor Park, across from the Willows Run Golf Course, at Blythe Park, at Swamp Creek, and at the island at the mouth of the river. A few newly restored or revegetated areas also exist in Redmond, Woodinville, and at the confluence with North Creek. However, these natural or semi-natural areas comprise less than 10% of the former floodplain area. Essentially no off-channel habitat exists since completion of the deepening project, and the river has very little capability to form these habitats due to its gradient, the deepened channel, and bank armoring. All former oxbows and sloughs are either cut off by elevation or have been filled in. Some wetland habitat still exists, primarily in Kenmore, Woodinville and Marymoor Park, but most wetlands are not connected to the river except during floods above the design flow (40 year spring flood). Most of the existing wetland areas contain the following plant communities: emergent or scrub-shrub with willow, spirea, and reed canary grass as common dominant species (Shannon & Wilson 2001). It appears that only about 150 acres [60 hectares] of wetland remain in the corridor (since many parts of the historic valley were wetland, the historic acreage was likely more than 3000 acres [1200 hectares]).

HYDROLOGY

The current configuration of the straightened channel was designed to convey a 40-year spring flood event (after March 1, approximately a 10-year annual event, ~2,200 cfs) and has further shortened the channel length to approximately 13.7 miles. Sources vary regarding the actual length of the channel. Depending on where the end points are designated, the length ranges from 12.8 to 15.3 miles (Jeanes and Hilgert 1999; King County SWMD 1993; Kerwin 2001; PNWRBC 1969). For the purpose of this report, we will consider the length of the river to be 13.7 miles (21.9 km) based on measurements on USGS topo maps from the western tip of the island at the mouth (Lake Washington) to 3,000 feet (909 m) upstream of the weir (Lake Sammamish). Extreme flows (100-year low and high flows) in the Sammamish River range from approximately 10 cfs (at the weir) to more than 4,000 cfs (at Woodinville). Frequent summer low flow conditions are approximately 30 to 40 cfs (at the weir), and winter high flows (2-yr event) are approximately 1,500 cfs (at Woodinville). (All flow data is from ACOE frequency data, from staff and flow gage records at the weir and Woodinville). Of particular note is that many of the lowest flows on record have occurred since 1985. This is likely due to a combination of factors including reduced low flow associated with development impacts and increased surface and groundwater withdrawals, and possibly some lesser effects from decadal climate oscillations in the eastern Pacific Ocean and global climate change. Lower summer base flow creates an opportunity for increased heating (temperature increases) of the river due to a lower volume of water. A number of entities have water rights to withdraw groundwater or surface water for residential, agricultural, and municipal and industrial uses. These water right holders include several water purveyors, Marymoor Park, farmers, golf courses and others.

As previously discussed, the channel was deepened and widened for the express purpose of preventing spring flooding and high water table conditions on agricultural lands in the floodplain. The channel deepening reduced the frequency of overbank flow, lowered the groundwater table, and disconnected off-channel habitat from the river. Natural off-channel habitat has essentially been eliminated. Furthermore, although a few channels are connected to the river, they are primarily irrigation ditches. The channel-deepening project excavated beneath the alluvial sediments into lower soil layers of glacial outwash and glacial till (King County Memo, 1964). Following the deepening, several adjacent landowners complained their wells had gone dry or were nearly dry (King County Memo, 1964). This would be expected if the original groundwater table was in direct connection with the river and was lowered by 5 to 10 feet. Subsequent investigations indicated the groundwater table *was* lower than the river elevation in some areas (King County Memo, 1964; Metropolitan Engineers, 1972), possibly due to seasonal withdrawal of groundwater for irrigation. The Corps also noted that the groundwater table was lower than the elevation of Bear Creek in geotechnical investigations in 1996 near Bear Creek in Redmond (Corps geotechnical data, 1996).

The backwater condition that occurs due to the seasonal fluctuation of Lake Washington water levels has also been significantly changed. Historically, water levels of Lakes Washington and Sammamish would have been lowest in late summer resulting in the lowest influence of Lake Washington backwater conditions during this period. The Lake Washington water level is currently regulated by the Corps to provide some flood control benefit, as well as water supply for navigation and fish passage at the locks. The Lake elevation is strictly controlled with an average 2-foot (0.6 m) fluctuation over the year. Lake Washington is maintained at its lower level (13 feet NGVD) during the winter months (November through March) and raised to the higher level (15 feet NGVD) during spring to provide sufficient water throughout the typically dry summer season. In very dry years, the lake elevation may be drawn down to low water (13 feet NGVD) conditions by August or September. This reverse high summer and low winter elevation changes the natural flow dynamics in the Sammamish River. The high summer lake elevation causes backwater conditions in the Sammamish River up to approximately RM 3 (4.8 km). The backwater condition significantly slows river velocity (Jeanes & Hilgert [1999] measured average velocity below RM 3 at 0.2 fps or less) and may contribute to elevated temperature as a result of solar heating. However, even the lowest historical Lake Washington water levels were typically higher than current lake levels (see page 6). This would have caused a backwater effect even during the summer months, although the channel was far more braided and shaded by mature trees.

AQUATIC HABITAT

An aquatic habitat survey was recently conducted by R2 Resource Consultants (Jeanes & Hilgert 1999) to define and quantify the aquatic habitats present in the mainstem Sammamish River. The methodology used for this survey was the Timber-Fish-Wildlife Ambient Monitoring Program (Northwest Indian Fisheries Commission 1994), which has been used on many streams and rivers in Washington. The mainstem Sammamish River between Lakes Sammamish and Washington is comprised of 98% glide habitat (Jeanes and Hilgert 1999). Riffles make up 1.4% of habitat and only two pools that meet the Timber-Fish-Wildlife criteria[4] (1994) were identified (0.4%) on the mainstem. Riffles and pools provide rearing habitat and appropriate prey organisms for some juvenile salmon (coho, steelhead). The lack of these habitats has further reduced the value of the mainstem for juvenile salmon. Velocity in the river typically averages less than 0.5 feet per second (0.15 meters per second) in this glide-dominated system.

Another recent study, using ultrasonic telemetry to determine adult chinook migration timing and behavior identified and mapped a total of 29 "pools" in the Sammamish River (Fresh *et al* 1999) that were utilized by adult salmon for holding on at least one occasion. These "pools" were not identified using any standardized methodology, but are based on visual observation that they are deeper than adjacent channel areas. Overall, pools are necessary for juvenile rearing and refuge and as adult holding areas for upstream migration. Fresh *et al*. (1999) reported that tagged adult chinook moving through the Sammamish River during the warm 1998 summer/fall season were only detected in pools or other deep areas or near overhanging vegetation[5]. Residence time for chinook in a single pool was as long as 24 days. It is likely they were holding in the relatively deeper water because of slightly cooler water temperatures (water quality measurements as part of the study in 1998 indicated that temperatures were up to 3.6 F [2° C] cooler at the bottom of "pools" than at the surface of the river) and/or a preference for cover from predators (depth can serve as cover in some situations and coho and other salmon have been observed migrating quickly through riffles and holding in deep pools both for resting and cover [Sandercock 1991]). In the cooler year of 1999, tagged chinook also remained in pools for up to several days (data not fully analyzed yet). Total average time spent in the river for tagged chinook was approximately 9 days in 1998 versus 7 days in 1999, possibly indicating they spend less time in the river or "pools" when temperatures are cooler, although not enough statistical analysis has been conducted to show this difference is statistically observable (K. Fresh, WDFW, pers. comm. 2001). Even under the most optimistic estimate, less than 5% of habitat in the river consists of pools. Sufficient cool water pool habitat is critical for adult migration and thermoregulation.

To adequately provide refuge and holding habitat in the river, pools should be of depth and area sufficient to provide low-velocity resting habitat for one or many adult salmon in each pool. More than 30% of the pool bottom should be obscured due to surface turbulence, turbidity, or presence of logs, boulders, or overhanging vegetation (Raleigh *et al* 1986). Although velocity in the Sammamish River is typically not high enough to deplete an adult salmon's energy reserves, the high water temperatures result in a greater need for rest and thermoregulation. To provide adequate habitat for adult migration and juvenile rearing, the Sammamish River should have pools with greater than 1.5 ft (0.4 m) residual depth (based on TFW criteria, will vary from 5 to 12 ft [1.5 - 3.6 m] total depth at low flows depending on where located in the river) and in total comprise an area between 40% to 60% of the total surface area of the river (Raleigh, *et al*. 1986). NMFS criteria (NMFS 1996) in their Matrix of Pathways and Indicators for holding pools are greater than 3.3 feet (1 meter) in depth with good cover and cool water.

In many of the reaches characterized by Jeanes and Hilgert (1999), the dominant substrate was silt and clay. Typically, reaches were dominated by 70 to 90% silt and clay, but were mixed with 10 to 30% sand, large gravel, or all sizes of cobble. Only one 150-foot (45 m) reach was dominated by gravel, and only 9% of reaches contained any gravel substrate at all. Under existing conditions, only a couple of small areas in the river are suitable for salmon spawning (less than 15,000 ft^2 [1400 m^2] total area; under ½% of the river substrate area*)*. Salmon species prefer to spawn in relatively silt-free, gravel-rubble areas, with substrate

[4] According to the TFW criteria, for a river with a bankful width greater than 20 m, a pool must have a minimum surface area of 5 m^2 and a minimum residual pool depth of 0.4 meters to be considered a pool. Only two pools were identified that met these criteria.

[5] 1998 is considered the warmest year on record world-wide by the Intergovernmental Panel on Climate Change (2001) since recording began in 1861. King County data also supports that 1998 was a warmer than average year (D. Houck, pers. comm.).

sizes between 0.3 and 15 cm (Raleigh, *et al*. 1986; Bjornn & Reiser 1991). While conducting the habitat assessment of the mainstem Sammamish River, Jeanes and Hilgert (1999) observed kokanee spawning in three small riffles (Little Bear Creek mouth, Tributary 101 mouth and Leary Way bridge) that do have suitable gravel. In 2000, some coho were also observed spawning in the transition zone just downstream of the weir (E. Jeanes, R2, pers. comm. 2001) Salmon may spawn in glides if they are of suitable velocity and contain appropriate substrate, although it has not been observed in the Sammamish River. Overall, while spawning habitat should not be a priority for restoration because it is not likely to persist in the low velocity river, existing areas of spawning should be protected *(i.e*. at tributary mouths).

Substrate plays a significant role in foodweb production and food availability in the stream. Areas dominated by silt and clay substrate do not support a wide variety of readily accessible, preferred juvenile salmon prey items, primarily larval and adult insects (Healey 1991; Sandercock 1991). Preferred aquatic prey organisms (*e.g.*, chironomids, ephemeropterans, crustaceans; from Higgs *et al* 1995) for salmon species typically occur in gravel and cobble substrates or from overhanging vegetation.

Shallow sloping banks and shallow water are often preferred rearing areas for fry and small juvenile salmon (Peters 1999). R2 Resource Consultant staff recently observed that the areas in the river primarily utilized by sockeye and coho fry were shallow bank areas where banks or levees had been set back (E. Jeanes, R2, pers. comm. 2001). Overhanging vegetation also plays a significant role in providing prey items for salmon species. Many juvenile salmon use terrestrial insects as a major food source. In general, very minimal overhanging vegetation exists along the river (except blackberries). Blackberries do provide some insect input, although species diversity and abundance is not known.

A total of 92 pieces of LWD were observed in the Sammamish River, however; only ten are considered “large logs” as defined in TFW (NWIFC 1994) as having a diameter greater than 20 inches (50 cm) (Jeanes and Hilgert 1999), and only seven pieces would meet NMFS LWD criteria (1996) as being greater than 24 inches (60 cm) in diameter. In general, the size requirement is based on the fact that in most large rivers only "large" logs can typically be sustained because of their size and mass. Most of these larger pieces are associated with recent restoration efforts. Only one of the 92 pieces identified was providing a pool forming function (in the transition zone). Overall, there is a significant lack of wood, and wood-created habitat, in the Sammamish River. The average number of LWD per mile averaged less than 7; NMFS criterion (1996) is for greater than 80 pieces of LDW per mile that meets the 24-inch criterion. As previously discussed, the river has been subject to LWD removal for the past 100 years to both aid navigation and aesthetics. LWD provides many essential functions for habitat formation including scour and trapping of sediment; formation of side channels, riffles and pools necessary for cover and resting areas for fish; trapping of detritus and nutrients; and decomposition and food web support (Maser & Trappe 1984).

A study recently completed by R2 Resource Consultants (Jeanes & Hilgert 2001) evaluated juvenile salmon use of various habitats in the Sammamish River. Jeanes & Hilgert (2001) found that the limited available LWD cover and scour habitat did not seem to be used significantly by juvenile salmon and instead found most juvenile salmon were observed in shallow water areas (shallow sloping banks), where the river bank had been set back. Some juvenile salmon were also observed in shallow bank habitats with LWD, and at sites with steeper banks and LWD; however, their numbers were lower than sites with shallow water and no wood. It is possible that the cover and low-velocity habitat typically provided by LWD in other northwest river systems is not a significant habitat element in such a low-gradient, low-velocity river as the Sammamish, and it functions more like LWD in lakes. Adult salmon have primarily used pools and other deeper areas for holding during upstream migration. Although there is some evidence that they utilized overhanging vegetation and other cover to a lesser extent (R. Tabor & D. Houck, pers. comm. 2001).

WATER QUALITY

In general, water quality in the Sammamish River is poor. Although the Sammamish River is officially classified as a Class AA stream (WAC 173-201), for some parameters, it does not even meet Class C water quality standards set by the state of Washington. Water temperatures as high as 80°F (27°C) have been measured in late July in the Sammamish River (Martz, *et al* 1999). This is well above the lethal limit for salmon, and well above the Class AA standards (currently at 60°F [15.5°C][6], which is considered the upper end of optimal or natural temperature for salmon species). Three areas of the mainstem river are 303(d) listed for temperature (See Table 2 below) (WDOE 1998). The NMFS temperature guideline (NMFS 1996) for properly functioning conditions for salmon is 50-57°F (10-14°C). Additional 303 (d) listings are in effect for pH, dissolved oxygen, and fecal coliform. Each of the listings falls within one of three areas, including Kenmore, Bothell, and Redmond. The lower reaches of Swamp, North and Bear Creek are also 303(d) listed for fecal coliform. King County is currently in the process of conducting an assessment of sediment and water quality in the Sammamish River to determine the presence and distribution of chemical contaminants (i.e., pesticides, metals and organic compounds). The study included collection of water and sediment samples for analysis of chemistry (sediment and water), toxicity (water) and benthic community structure (sediment). Analysis of these data is not yet complete, however, preliminary water quality results indicate bacteria are present at concentrations exceeding state water quality standards (confirms 303(d) listings previously discussed), aluminum concentrations exceed the EPA chronic water quality criteria in some locations. Concentrations of organic compounds and nutrients in water samples were not present at elevated levels. Toxicity was observed in four water samples, although the specific cause is unknown. Sediment samples contained slightly elevated levels of arsenic, chromium and nickel; however, these levels may be associated with background soil concentrations. Sediment PAHs were also slightly elevated in some locations. The data analysis is currently being conducted, but it appears that the known pollutants such as bacteria are still a concern. More evaluation on the potential cause of the observed toxicity is warranted. Because these samples were taken during base flow conditions, there were not elevated turbidity levels. High turbidity levels have been anecdotally observed during winter storm flows, but no single source has been identified. Elevated turbidity may be a result of several sources including stormwater runoff from streets and urban areas, runoff from agricultural fields or parks, resuspension of the fine silty sediments in the river and other sources. In general, based on the current 303(d) listings, water quality conditions are clearly impaired in the corridor.

Table 2. Locations of 303(d) listings within the mainstem Sammamish River

Location	303(d) Listings
Within Kenmore just upstream of outlet into Lake Washington	Temperature and Fecal Coliform
Within Bothell between 100th Ave N.E. and I-405	Temperature, Fecal Coliform, and Dissolved Oxygen
Within Redmond between Lake Sammamish and Hwy 908	Temperature, Fecal Coliform, and pH

Daily high temperatures in the upper Sammamish River frequently exceed 68°F (20°C) and on some occasions have exceeded 80°F (26.6°C) (Corps unpublished temperature data from 1998 and 1999, see Figure 3 for summer temperatures at several points in the river). Temperatures between Lake Sammamish and above the mouth of Big Bear Creek are typically the highest in the river because the tributaries provide

[6] Ecology is in the process of revising their temperature standards; proposed revisions are available at http://www.ecy.wa.gov/programs/wq/swqs/index.html.

some cooling of the mainstem, thus moderating temperature further downstream. The surface water outflow from Lake Sammamish is the warmest water in the system.

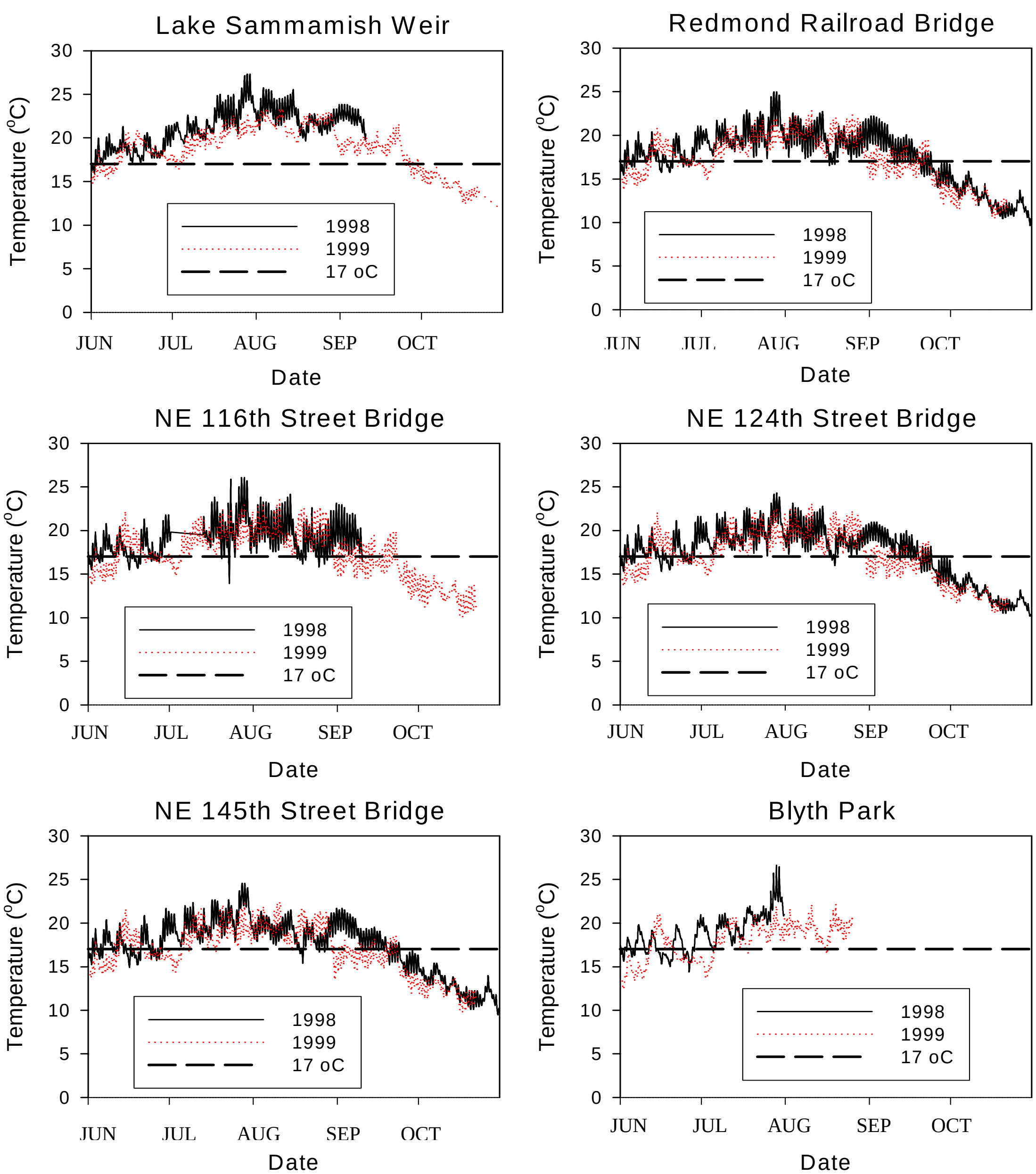

Figure 3. Temperature data from USACE compared to the 17°C fish stress temperature used in temperature modeling. See Appendix B.

Elevated temperature is likely the most significant limiting factor to salmon species in the Sammamish River because it is well within the range of causing adverse physiological and behavioral effects, and frequently in the lethal range. High temperatures in the Sammamish River can affect the reproductive health and survival of all adult salmon entering the Sammamish Watershed and potentially affect smoltification, smolt migration, and habitat suitability for juvenile rearing. Adult chinook and sockeye salmon are the primary species and age group likely to be adversely affected by elevated water temperatures (Martz, *et al*. 1999). This is because adults of these species enter the basin in August and September when temperature is typically highest. This migration pattern coincides with temperatures that have both lethal and sub-lethal effects, including death, disorientation, egg retention, production of abnormal embryos or alevins, high fry or alevin mortality, increased vulnerability to disease of adults and offspring, and other physiological problems (Berman & Quinn 1991 and 1989). Temperatures above 70°F (21°C) equal or exceed lethal temperatures for chinook (McCullough 1999). Sockeye may be able to tolerate slightly higher temperatures than chinook, but geometric mean survival times for adult sockeye is only 1,000 minutes at 75°F (24°C) and 100 minutes at 79°F (26°C) (Servizi and Jensen 1977, cited in McCullough 1999). Berman (1991) experimentally held Columbia River spring chinook at 66°F (19°C) for 1.5 months, and all perished of columnaris infections, while fish held at lower temperatures (the "control" fish in the study) experienced no mortality. High temperature can also cause a migration barrier, where fish refuse to move upstream into the higher temperatures (as appeared to occur at the locks in 1998; Fresh, *et al* 1999), and delays as few as 3-4 days have possibly caused pre-spawning mortality (Andrew and Geen 1960 cited in McCullough 1999). This delay also increases susceptibility to disease and reduces egg viability when spawning grounds are finally reached (McCullough 1999; Berman 1991). See Table 3 for a list of salmonid species and their temperature requirements.

Fecundity and survival data for chinook returning to the Issaquah Hatchery from 1995 to 1998 show no trends (Martz, *et al* 1999). There is high variability between fish, generally within the normal range. No information on egg viability or deformities was available.

Juvenile salmon may also experience high temperatures in the Sammamish River during June and July (Corps unpublished temp data from 1998-1999 and Jeanes & Hilgert 2001; see Figure 4 for timing of juvenile salmon use of the river). Juvenile salmon mortality can result from exposure to elevated temperature, inadequate feeding (higher metabolism, reduced feeding), and increased disease incidence. Smoltification is also affected by temperature and can either occur too early when temperatures are higher (and juveniles are smaller) or be incomplete leading to reduced survival when fish reach saltwater (McCullough, 1999) or even cause desmoltification.

Tracking of adult chinook in 1998 and 1999 indicates that during migration adult salmon utilize every available deeper spot in the Sammamish River, likely in an attempt to find cooler water temperatures and/or cover. One mechanism that salmon use to cope with elevated temperature is to reduce activity and hold in cooler pools (Berman & Quinn, 1991). Also, many fish were observed to migrate primarily at night, likely because river temperature drops each night as ambient air temperature cools (although predator avoidance could also be a factor). In the warmest reach of the river, upstream of Bear Creek, the adult chinook migrated only at night (Fresh, *et al*, 1999). Spawning data is not conclusive, but fish returning to the Issaquah Hatchery or Issaquah Creek may spawn in Bear Creek or other tributaries when temperatures upstream of Bear Creek are too high.

Table 3. Salmonid species and temperature requirements			
Information from (Bell 1991; Kraemer 1994; USFWS 1998; McCullough 1999)			
Species	**Lethal Limit**	**Upper Optimal Limit**	**Present in River July through October?**
Chinook	77°F (25°C)	58°F (14°C)	Adults – yes Juveniles - yes
Coho	78°F (25.5°C)	69°F (20.5°C)	Adults – yes Juveniles - unknown
Sockeye	76°F (24.4°C)	58°F (14°C)	Adults – yes Juveniles – no
Steelhead	75°F (23.9°C)	58°F (14°C)	Adults – no Juveniles – unknown
Cutthroat	73°F (22.8°C)	55°F (12.8°C)	Adults – yes Juveniles – yes
Bull trout		58°F (14°C)	Unknown

WATER QUANTITY

As previously discussed, construction of the Lake Washington Ship Canal and locks dropped the surface elevation of Lakes Washington and Sammamish by 9 and 6 feet, respectively. Water levels in the Sammamish River also decreased, lowering the base flow as a result of reduced floodplain and groundwater connections. The flood control channelization project further disconnected and drained the floodplain, likely causing additional loss of groundwater flow into the river as a result of reduced floodplain storage. It is estimated that summer base flow in the Sammamish River upstream of Little Bear Creek has been reduced by approximately 16 cfs (WRIA-8 Technical Subcommittee 2001), primarily from water management and withdrawals. This is an estimated 29% reduction in historic base flows upstream of Little Bear Creek, with approximately a 21% reduction downstream of Little Bear Creek (lesser reduction in the lower river is primarily due to the importation of water (municipal water supply) from the Cedar River and other basins; [WRIA-8 Technical Subcommittee 2001]). Impervious surface area has increased in the Sammamish floodplain as well, further contributing to a decline in groundwater recharge and reduced low flow conditions. Water withdrawals for domestic and agricultural uses may have reduced water volume in the river resulting in greater heating of the smaller volume of water (Jain, *et al* 2000). It is unknown however, if groundwater withdrawal for domestic and agricultural use directly translates into reduced groundwater inflow to the river. King County is currently investigating the potential volume and quality of groundwater flow into the river. This information will be useful in determining potential options to increase groundwater flow.

DESCRIPTION OF FISH POPULATIONS

Six species of salmon are known to currently be present in the overall Sammamish River watershed[7]: (i.e., chinook, coho, and sockeye salmon, kokanee, and steelhead and cutthroat trout). The presence of bull trout has not been confirmed, but will still be discussed in this section. Chum salmon occasionally stray into the watershed, but are not known to be a sustaining population. All information provided below is summarized from Kerwin (2001) and Washington Department of Fish and Wildlife (WDF, *et al* 1992 and www.wa.gov/wdfw/ which provides summaries of stock conditions*)* unless otherwise noted. This section is not intended to be a definitive description of the various populations, but a summary from the most recent compilations of existing data. Stocks of the various species are described as defined by WDFW and the Muckleshoot Indian Tribe, and Evolutionarily Significant Units (ESUs) are described as defined by the National Marine Fisheries Service (NMFS). Stock and ESU designations are not necessarily the same for each species or between species. A stock is considered a discrete breeding population which can occupy a specific lake or stream or a combination of lakes and/or streams but do not interbreed with another stock spawning in a different place, or in the same place at a different season (WDF 1993). An ESU is defined as a distinct population of fish that does not interbreed with other populations, hence a species (NMFS 1997). There may be several stocks of one species within a given watershed (i.e. North Lake Washington tributaries, Cedar River) based on their run timing or lack of interbreeding. An ESU typically encompasses a species from several watersheds that have similar run timing and the potential to stray between watersheds and interbreed (i.e. Puget Sound).

Chinook

Kerwin (2001) has identified two stocks of chinook salmon that are present in the Sammamish River watershed: (1) North Lake Washington tributaries stock, that may be native, although it has likely been influenced by Issaquah Hatchery strays, and (2) Issaquah Creek stock considered non-native (derived from the Issaquah Hatchery; ancestry from several south Puget Sound basins). Both stocks are summer/fall runs and adults enter the Lake Washington basin from June through November. Spawning occurs from September through October and fry typically emerge from redds from January through March. For most ocean-type chinook such as the majority of Lake Washington basin chinook, juveniles may rear in tributary streams, larger rivers, lakes, or estuaries for one to six months before migrating into estuarine areas. Peak smolt outmigration typically occurs at the locks from June through August, but smaller numbers outmigrate from February through September (see Figure 3 for timing in the Sammamish River). There may be a small number of stream-type chinook present in the watershed, which rear for approximately one year in freshwater prior to outmigrating. Natural spawning takes place in Bear and Cottage Lake Creeks and in Issaquah Creek, and smaller numbers of chinook spawn in Little Bear, North, and Swamp Creeks. The North Lake Washington tributaries stock has declined severely in the past several years and is part of the Puget Sound Evolutionarily Significant Unit (ESU) listed as threatened; fish returning to the Issaquah Creek Hatchery are currently not listed with the Puget Sound ESU, but all naturally spawning chinook in Issaquah Creek are part of the ESU. Between 1983 and 1987, escapement to Bear Creek averaged 300 individuals. Between 1992-1997, that number declined to less than 100 for each year; however, more detailed surveys conducted in 1998 and 1999 estimated escapement at 401 and 733 fish, respectively (Carrasco *et al* 2001 and Mavros *et al* 2001). Jeanes and Hilgert (1999) observed a few chinook in a riffle of the Sammamish River near Lake Sammamish during their habitat surveys. However, chinook are generally not expected to spawn in the Sammamish River.

[7] Includes the Sammamish River and all its tributaries, including tributaries to Lake Sammamish.

Coho

The coho salmon that occur in Lake Washington and the Sammamish tributaries are considered as a single stock, which is a mixed stock of native and hatchery derived fish. A significant proportion of this stock returns to Issaquah Hatchery. This stock is listed as depressed by WDFW (WDF, *et al* 1992), and is part of the Puget Sound/Strait of Georgia ESU, which is a candidate for listing under the ESA. Adult coho enter the locks from August to December. Spawning typically occurs in tributaries in November and December, although some spawning occurs as early as October. Fry emerge from redds from March through June and juveniles typically rear in freshwater for one year. Juveniles utilize the tributaries, mainstem river (limited use, Jeanes and Hilgert 2001), and Lakes Sammamish, Washington and Union for rearing. In general, freshwater habitat that is more structurally complex with dense LWD, pools, and other cover typically supports the most coho juveniles (Sandercock 1991). Smolts typically outmigrate through the locks in May as yearlings (see Figure 3 for timing in Sammamish River). Escapement since 1989 has been very low (less than 5,000). Coho are not known to spawn in the Sammamish River and surveys are not conducted along the mainstem (although some spawning activity was observed by E. Jeanes in 2000, downstream of the weir [E. Jeanes, R2, pers. comm. 2001]), however, coho are known to spawn in Issaquah, Bear, and Little Bear Creeks.

Sockeye

One stock of sockeye salmon occurs in both Lake Washington and Sammamish River tributaries. This stock is of unknown or mixed origin. A significant number of sockeye fry hatchery releases occurred throughout the greater Lake Washington watershed up until at least 1954, although there are also reports of sockeye and/or kokanee present in the system dating back to the turn of the century. Adults typically enter the Lake Washington basin from June through November. Spawning typically occurs in Bear, Cottage Lake, and Issaquah Creeks and in smaller numbers in Little Bear, Swamp, and North Creeks, and several Lake Washington tributaries, from September through December or January. Sockeye are not known to spawn in the Sammamish River. In the tributaries, fry emerge from redds from February through May and migrate down to Lake Washington or Lake Sammamish to rear for approximately one year. A smaller number of sockeye fry rear for one to two months in tributaries on their way down to the lakes (fry capture data from mouth of Bear Creek and lower Cedar River, D. Seiler, WDFW, pers. comm. 1999). Smolts migrate out through the locks in May and June (see Figure 3 for timing in the Sammamish River). This stock is listed as depressed by the SaSSI (WDF 1992), but is not listed under ESA. Escapement for this stock was lowest in 1989, 1995 and 1999 when fewer than 5,000 individuals were recorded in the Sammamish tributaries and highest in 1996 with greater than 70,000 individuals (primarily in Bear and Cottage Lake Creeks).

Kokanee

Kokanee salmon are a freshwater form (non-anadromous) of sockeye salmon. They rear in lakes and spawn in tributary streams. At least two stocks of kokanee have been identified in the greater Lake Washington Basin: (1) early run Issaquah Creek; and (2) a late run population found in the East Lake Sammamish tributaries of Ebright, Laughing Jacobs, and Lewis Creeks (Kerwin 2001). Though many kokanee of Lake Whatcom origin were outplanted throughout the Lake Washington basin over the years, genetic sampling suggests that those fish have not survived (S. Brewer, King County, pers. comm. 2002). Genetic sampling of the Issaquah Creek, East Lake Sammamish tributaries and Bear and Cottage Lake Creeks has occurred and the two above stocks have been identified as distinct populations (S. Brewer, King County, pers. comm. 2002). Kokanee from Bear and Cottage Lake Creeks are not distinguishable from the sockeye populations in these creeks. None of the fish sampled are similar to the Lake Whatcom stock. Kokanee have been observed spawning within the Sammamish River in at least three locations[8] in early October 1999 (Jeanes and Hilgert

[8] Kokanee were observed spawning at the Little Bear Creek outlet, Tributary 101 outlet and at the Leary Way bridge in Redmond in small numbers (range 5 to 20 redds).

1999). Several kokanee were observed attempting to ascend over a large cottonwood log in lower Bear Creek in early September 1998 (Martz, M. observation of 6-10 kokanee 1998). Kokanee from the Sammamish River have not been genetically evaluated and their origin and distinctness as kokanee is yet to be determined.

Early run adults in Issaquah Creek spawn in August and September. Fish found in tributaries to the Sammamish River were noted to spawn during the fall months of September, October, and November, whereas the late run to Lake Sammamish tributaries spawns from late October through December or January. The early run to Issaquah Creek is considered native (Ostergaard, *et al* 1995). The kokanee found in the Sammamish River tributaries may also be native, but more sampling needs to occur to determine if they are residualized sockeye. It is not known whether juvenile kokanee utilize the Sammamish River.

Kokanee stocks have declined dramatically in the past 20 years. The early run Issaquah Creek kokanee have been petitioned for listing as endangered and are designated in critical condition (WDF, *et al* 1992). Further surveys and genetic sampling throughout the greater Lake Washington basin, including the Sammamish River, will be necessary to determine the presence and status of kokanee.

Steelhead Trout

Steelhead trout throughout the greater Lake Washington basin are considered one stock. This stock is considered native and is listed as depressed by WDFW (WDF, *et al* 1992). This stock has declined to fewer than 1000 adults since 1986, likely a result of a number of factors including sea lion predation at the locks and loss of spawning and rearing habitat. A small broodstock supplementation program was initiated in 1994, however escapement has not significantly improved and no broodstock have been collected in the last few years. Adults typically enter the locks from December through March and spawn in all accessible tributaries from March to June (no spawning is known to occur in the Sammamish River). Juveniles rear in freshwater from one to three years and then outmigrate as smolts from May through July. Most of the returning fish typically return to the Cedar River; very few, if any, have returned to Sammamish River tributaries in recent years. Fewer than 10 individuals were observed in the Sammamish tributaries in 2000, the lowest escapement year ever (S. Foley, WDFW, pers. comm. 2001).

Cutthroat Trout

Cutthroat trout have a diversity of life history strategies from anadromous (sea-run) to adfluvial to resident. Very little information on cutthroat trout exists for the Lake Washington basin, particularly the anadromous form. A sizable adfluvial population is known to exist in Lake Washington with resident fish also observed in most tributaries, including the Sammamish River. Stock status for coastal cutthroat trout is unknown due to lack of information. The Puget Sound ESU of cutthroat trout are not currently listed under ESA, and are considered "not warranted" for listing by NMFS and the USFWS (http://www.nwr.noaa.gov/1salmon/salmesa/cuttpug.htm). Adfluvial and resident adults spawn in tributaries and rivers in April and May, and anadromous fish spawn in December/January, previously coinciding with the steelhead migration and spawning (S. Foley, WDFW, pers. comm. 2001). Juveniles may spend several years in freshwater before outmigrating. Escapement values are unknown at this time.

Bull Trout

Western Washington bull trout are listed as a threatened species under ESA (USFWS 1999). The USFWS considers all bull trout that occur in coastal Washington and Puget Sound drainages as a distinct population segment (DPS). The stock status for bull trout in the Lake Washington Basin is largely unknown, and information on their abundance is extremely limited. Studies are currently underway by King County and other agencies to determine if any bull trout remain in the Lake Washington basin. It is known that a self-sustaining, adfluvial population occurs above Chester Morse dam in the upper Cedar River (WDFW 1998). A few stray individuals have been observed in scattered locations in the Lake Washington watershed

(WDFW 1998 cites B. Fuerstenberg observation in Issaquah Creek in 1993, M. Martz person observation in 1998 in the Cedar River), but no pairs or redds have been observed. Bull trout prefer very cold headwater streams (temperatures generally less than 55° F [13° C]) and utilize boulder step pool habitat. Spawning typically occurs in late summer and fall (late August through November) in areas of cobble and gravel substrate with overhead cover. Wall-base side channels are often suitable for spawning as well. Fry emerge in April and May and rear in amongst LWD, cobbles, and boulders. Juveniles and adults also utilize pool habitat extensively (summarized from Kraemer 1994). It is possible the headwaters of Issaquah and Bear Creeks could provide suitable habitat for bull trout. However, due to the elevated water temperatures in the Sammamish River it would be unlikely that bull trout are present in the corridor.

Other Fish Species

Many other fish species are known to be present in the Sammamish River and its tributaries including native species such as longfin smelt, northern pike minnow, peamouth chub, three-spine stickleback, largescale sucker, longnose dace, brook lamprey, and several species of sculpin, and non-native species such as yellow perch, smallmouth bass, largemouth bass, brown bullhead, warmouth, pumpkinseed sunfish, tench, and carp (Wydoski & Whitney 1979; E. Warner, MIT, pers. comm.1999). Predation by non-native fish species on salmon fry and juveniles may be a significant issue in the Sammamish River, although limited sampling has occurred to verify this theory. The river currently provides excellent habitat for warm water species as a result of the elevated temperatures (water temperatures around 80°F are optimal for largemouth bass; Wydoski and Whitney 1979). There is also likely some longfin smelt spawning habitat in the lower reaches of the river near Kenmore.

WILDLIFE

Many bird, mammal, reptile, and amphibian species are present in the Sammamish River Corridor, although many species that historically utilized the old growth forest and extensive wetlands no longer occur in the watershed. Mammals present today include those species that have adapted to human development such as deer, beaver, mountain beaver, nutria, raccoon, opossum, skunk, river otter, coyote, rabbits, shrews, mice, and voles. Bears are occasionally observed in the upper end of the Bear Creek sub-basin (R. Heller, pers. comm. 1996). State and federally listed mammals or species of concern that may occur in the watershed include western pocket gopher and gray-tailed vole. Species of local importance in King County include marten, mink, Columbian black-tailed deer, elk and mountain goat. These species are most likely to be present east of the Sammamish River Corridor in the Cascade Mountains (King County 2002).

Although many bird species utilize the river and lakes, riparian area, and particularly the wetland areas of Marymoor Park, the available habitat is fairly degraded and could be much improved, particularly the riparian areas. Species that utilize the corridor include those listed in Table 4.

Several bird species are listed on the federal or state endangered species lists and King County has designated several species as species of local importance. Listed species or species of local importance that may occur in the corridor include red-tailed hawk, osprey, great blue heron, band-tailed pigeon, harlequin duck, northern goshawk, merlin, peregrine falcon, Vaux's swift, pileated woodpecker, olive-sided flycatcher and purple martin (King County 2002). With the exception of Marymoor Park, the riparian forested and shrub habitats that many migratory bird species use are significantly lacking in the Sammamish River Corridor. Following shoreline revegetation in Marymoor Park in 1998 as part of the Corps weir replacement project, Swainson's thrush was observed using the newly created shrub habitat (Tweeters 1999).

Western pond turtles, a state endangered and federal species of concern, may be present in the Sammamish River Corridor, although none have been recently observed in the watershed, they are believed to have been present historically. Western pond turtles would likely benefit from restoration efforts if combined with a reintroduction effort. Their habitat and survival is reduced due to lack of basking logs or boulders, human disturbance, and lack of suitable nesting and wintering sites. Pond turtles typically prefer un-vegetated, south-facing clay slopes to dig nests in and require forested uplands with a dense layer of leaves and other organic material for wintering habitat (Holland 1994). Western toad is a state and federal species of concern that may occur in the Sammamish Corridor. They prefer forested or meadow habitats with brush or LWD for cover. Red-legged frogs are another species of concern that may have been eliminated from the Sammamish River Corridor. Bullfrogs and predatory fish such as bass that occur in the Sammamish River often prey on red-legged frogs, further reducing survival or frequently causing local extinctions (probably extinct along the Sammamish River). Red-legged frogs require seasonally inundated wetlands for egg laying and prefer a dense riparian zone for cover and foraging (Corkran and Thoms 1996). Northern leopard frogs and Oregon spotted frogs are both state endangered and federal species of concern that are believed to have been extirpated from the Puget lowlands due to the presence of bass and bullfrogs and loss of habitat. They prefer slow moving streams and seasonal ponds and wetlands, which would have historically been present in the Sammamish River Corridor.

Table 4. Bird species that currently are present in the Sammamish River Corridor.		
(All bird information from the King County wildlife program data and Friends of Marymoor Park list at ***www.scn.org/fomp/birdlist.htm****)*		
pied-billed grebe	Western grebe	double-crested cormorant
great blue heron	green heron	Canada geese
wood duck	gadwall	mallard
northern shoveler	green-winged teal	canvasback
ring-necked duck	greater scaup	lesser scaup
bufflehead	common goldeneye	hooded merganser
common merganser	osprey	bald eagle
sharp-shinned hawk	Cooper’s hawk	red-tailed hawk
Virginia rail	American coot	killdeer
spotted sandpiper	mew gull	ring-billed gull
California gull	glaucous-winged gull	rock dove
band-tailed pigeon	Vaux’s swift	rufous hummingbird
belted kingfisher	downy woodpecker	northern flicker
western wood-pewee	willow flycatcher	warbling vireo
red-eyed vireo	Steller’s jay	American crow
tree swallow	violet-green swallow	cliff swallow
barn swallow	black-capped chickadee	bushtit
Bewick’s wren	winter wren	marsh wren
golden-crowned kinglet	ruby-crowned kinglet	Swainson’s thrush
American robin	European starling	cedar waxwing
yellow warbler	yellow-rumped warbler	common yellowthroat
spotted towhee	savannah sparrow	fox sparrow
song sparrow	white-crowned sparrow	dark-eyed junco
black-headed grosbeak	red-winged blackbird	house finch
pine siskin	American goldfinch	house sparrow

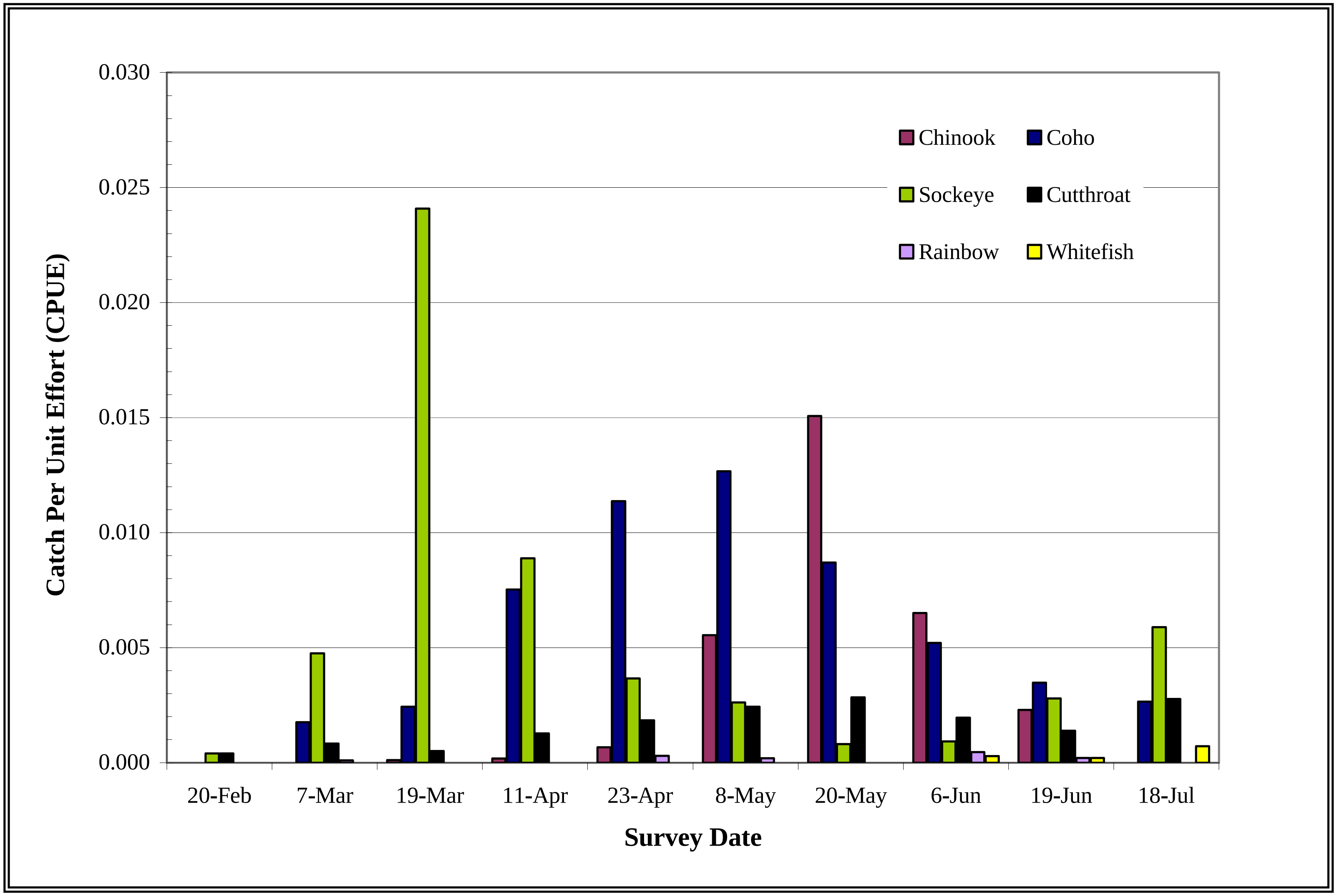

Figure 4. Catch per unit effort indices by species for survey sites located in the Sammamish River, Washington, 2001.

(from Jeanes and Hilgert, 2001)

TRIBUTARY CONDITIONS

Tributaries entering the Sammamish River also affect the river's ability to provide fish and wildlife habitat. A number of recent habitat surveys have been conducted in the watershed including surveys of the major tributaries (Fevold *et al* 2001), Bear Creek (King County, not published), and the minor tributaries (Jeanes and Hilgert 1999; and Jones and Stokes for the Corps of Engineers, not published). Fevold *et al* (2001) reported that, in general, ecological conditions in Little Bear, North and Swamp Creeks were slightly better than the mainstem, but are still relatively degraded. Kerwin (2001) notes a number of issues in the major tributaries including fish passage barriers in Bear, Little Bear, and North Creeks; degraded riparian conditions in Little Bear and North Creeks; altered hydrology or flows in Bear, Little Bear, North, and Swamp Creeks; 303(d) listings for Bear, Little Bear, North, and Swamp Creeks and degraded channel complexity and altered sediment transport processes in Bear, Little Bear, and North Creeks. Typically, all of these tributaries are lacking sufficient LWD and have reduced recruitment capability due to lack of conifers in the riparian area. Residential and commercial development have reduced riparian buffer widths and resulted in significant bank armoring along most of the tributaries to the Sammamish River. Runoff associated with urban, agricultural, and forestry activities has elevated fine sediment loads in the tributaries.

The tributaries provide fair to good quality spawning and rearing habitat for salmonid species. Bear and Cottage Lake Creeks are considered Regionally Significant Resource Areas (King County 1990) because of their support of several salmonid populations[9]. The Bear Creek system also supports other aquatic resources such as freshwater mussels and freshwater sponges (Kerwin 2001). Bear and Cottage Lake Creeks are primarily groundwater fed and provide a significant cooling effect on the Sammamish River (typical summer temps in lower Bear Creek are about 10°F (5.5°C) cooler than the mainstem river and can lower temperatures in the river by as much as 2-3°C; Corps data from 1998 and 1999; [McIntosh and Faux 2001]). Little Bear, North, and Swamp Creeks also provide inputs of cooler water to the river, although not as significant as that provided by Bear Creek. The tributary mouths may be important holding areas for adult salmon and rearing areas for juvenile salmon. The tributary mouths also provide some spawning habitat for kokanee and other species (E. Jeanes, R2, pers. comm. 2001) because they are the only areas of gravel in the mainstem.

Jeanes and Hilgert (1999) conducted a habitat survey of the lower 1,650 feet (500 m) of four unnamed tributaries (WRIA 0090, 0095, 0101, and 0104) that converge with the mainstem river upstream of Woodinville. Habitat quality and quantity in these small tributaries was frequently as poor as that observed on the mainstem; habitat was uniform with minimal cover. No pool habitat was present in any of the tributaries; all areas were dominated by shallow riffle habitat. During the survey (October 1999), these tributaries had flow well below 1 cfs and no water was flowing in Tributary 0090 because it was temporarily diverted around a construction site. Willow and alder were the dominant species in some areas along Tributaries 0090, 0101, and 0104, although reed canary grass dominated other areas. Tributary 0095 was dominated by reed canary grass or sod (from adjacent turf farm) as riparian vegetation. Fish passage to Tributaries 0090, 0095, and 0101 appears limited to high-flow events because of perched culverts at the confluence with the Sammamish River.

Overall, some minor tributaries contribute cooler water, and may even lower mainstem temperatures, at least in localized areas (Fresh, *et al*. 1999, McIntosh and Faux 2001), whereas irrigation return or tributaries that function as agricultural ditches may contribute warmer water to the Sammamish River during the summertime. At this time, there are limited data available regarding temperature conditions in the minor tributaries.

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[9] Regionally Significant Resource Areas do not have any specific regulatory protection, but do receive recognition by the County and other local governments as resources which should be protected.

RECREATION FEATURES OF THE CORRIDOR

Many aspects of the Sammamish River Corridor make it a desirable place for recreation. The Sammamish River Trail runs along the north and east banks of the river. The Sammamish River Trail is a former railroad line that was developed into a trail in the mid to late 1970s. The trail parallels the river for about 10 miles starting in Kenmore and ending in Marymoor Park in Redmond. The west bank also has recreational capabilities along most of the corridor, although it is currently unpaved and will likely remain unpaved. Many access points along the river include city and King County owned parks which provide many opportunities to access the corridor for trail and river activities.

The trail offers a variety of uses including bicycling, walking, rollerblading and more. Trail users average approximately 1700 a day. The primary users of the trail are bicyclists (approximately 1200 of the 1700 users per day). The remainder is comprised of walkers, joggers, equestrians, and skaters. Sixty-two percent of these users are recreational and thirty-two percent use the trail for commuting (Moritz 2000). Other activities include bird watching, dog walking, picnicking, and par course use.

The river also offers a variety of recreational activities. The waterway is used by watercraft such as canoes, kayaks, motorboats, and jet-skis. A public boat launch is available at Kenmore Park. An active user of the waterway is the Sammamish Rowing Association located at the upper end of the river in Marymoor Park. Game fishing in the river includes trout, panfish and crawfish. There is likely opportunity to fish for largemouth and smallmouth bass, crappie and other non-native species. The Sammamish River is closed to fishing from June 1 through August 31 every year. Trout fishing is catch and release only and statewide rules apply. Salmon and steelhead fishing is not permitted in the river.

Additional recreational assets along the river corridor include access to athletic fields, golf courses, the wineries and brewery in Woodinville and several city and county parks. King County’s Marymoor Park is a regional park with a remote-controlled airfield, climbing wall, sports fields, tennis courts, off-leash dog area, and hiking trails. Most public parks along the corridor are wheelchair accessible and provide restroom and garbage facilities.

SAMMAMISH RIVER REACH DESCRIPTIONS.

The following provides a description of habitat conditions for individual reaches of the Sammamish River. The reaches were designated for this Action Plan based on land use and width of the floodplain. A total of six reaches are delineated. Descriptions presented below detail the primary land uses, instream and terrestrial habitats, tributaries, wetlands, and key restoration opportunities within each reach. Wetland information comes from the National Wetland Inventory, King County Wetland Inventory and a functional assessment of several wetlands in the corridor prepared by Shannon & Wilson (2001) for King County; descriptions of adjacent land uses come from aerial photos from 2000 (obtained from the Corps) and zoning maps from the cities; and aquatic habitat information come from Jeanes and Hilgert (1999). Restoration opportunities identified in this chapter are described in greater detail in Chapter 4.

See Figures 9 through 14 for maps of each reach. Existing riparian coverage is shown on the map with the following codes:

- Coniferous forested – dominated by native coniferous trees
- Deciduous forested – dominated by native deciduous trees
- Scrub/shrub – Dominated by a mix of native shrubs
- Non-native – 50-85% dominated by non-native shrubs and herbs
- Non-native extreme – more than 80% dominated by non-native shrubs and herbs

Reach 1 (RM 0 to 2.5)

This reach begins at the Lake Washington boundary and ends at the 96th Avenue bridge and is located within the cities of Kenmore and Bothell. The end of this reach is in the middle of Wayne Golf Course, therefore, golf course issues are described for both this reach and reach 2. Land use is primarily residential (~70%). In the near future a former industrial site, located on the north bank at the mouth (LakePointe site), is expected to undergo a cleanup of hydrocarbons and other pollutants, and conversion to commercial and residential use. The remainder of the area within this reach is comprised of parks, undeveloped land, and two golf courses. There are limited areas of forested floodplain, and the vegetated riparian area is typically less than 50 feet (15 m) wide with sparse tree presence. The lower 3,000 feet of the reach contains a greater density of trees and a wider riparian area; however, the remainder of the reach is bordered directly by residential, golf course, or former agricultural land (at Swamp Creek, King County property). Cottonwoods and Douglas fir are present near the lake, but the riparian area within this reach is primarily dominated by blackberry and reed canary grass. Some red alder and willow are also present. The aquatic habitat is 100% glide, with no pools or riffles. Two deeper areas used by adult salmon for holding are present in this reach, at approximately RM 0.8 and 2.3 (D. Houck, King County, pers. comm. 2001). These deeper sites were not identified as pools by Jeanes and Hilgert (1999) because they do not meet the Timber-Fish-Wildlife (NWIFC 1994) criteria for residual pool depths[10]; however, they are slightly deeper than the average channel depth in this reach (R. Tabor, USFWS, pers. comm. 2001). Swamp Creek enters at RM 0.87 and contributes flow that is slightly cooler than the mainstem in both the summer and winter (McIntosh and Faux 1999; USACE unpublished gage data, 1998 and 1999), and adult salmon have been observed holding in a deeper area a short distance downstream of the mouth. Two small tributaries (0057C and 0057D) enter this reach on the left bank at RMs 0.8 and 1.4, from the residential neighborhoods of Kenmore. It is not known if these are perennial streams. Backwater from Lake Washington is present year-round throughout this reach and typically occurs as a warmer surface layer during the summer and fall months (see DeGaspari 2001 in Appendix B). This causes surface temperature in the river to be elevated relative to reaches 2 and 3 (McIntosh and Faux 1999; temperatures on the order of 20-24°C). The temperature in the backwater area is stratified and fish could migrate in deeper water through this reach, but more information is needed to understand the specific temperature dynamics in this reach.

The area adjacent to the mouth of the Sammamish River contains an approximately 20-acre area of semi-permanently flooded or saturated emergent wetland. Another wetland complex of approximately 70 acres, primarily under King County Parks ownership, exists adjacent to Swamp Creek. This wetland consists of a large area of seasonally saturated scrub-shrub habitat with smaller areas of seasonally flooded emergent and forested wetlands. This area represents a significant restoration opportunity, including the potential to reconnect the wetlands to Swamp Creek for more frequent inundation of the floodplain; remove exotic species, which now dominate the site; and revegetate the wetland and riparian area along both Swamp Creek and the mainstem. Wetlands also exist at Kenmore Park and across the river from Swamp Creek. Another key restoration opportunity would be to revegetate the riparian area along both Wayne and Inglewood golf courses. The City of Bothell has an open-space easement with Wayne golf course, so riparian restoration is likely a feasible option at this location.

The primary limiting factors for salmonids in this reach of the river are lack of channel complexity and cover, loss of wetlands, and limited riparian area. Historically, this reach had significant wetland areas and therefore, would be an appropriate location to initiate restoration of wetland habitat. The wetland areas would have provided an excellent rearing area for salmon fry and juveniles prior to entering the deeper waters of Lake Washington. Temperature, while elevated in this reach, is stratified in the Lake Washington backwater and the existing data does not show whether there is cooler water near the bottom of this reach. The Inglewood Golf Course management has undertaken some restoration actions on their property and is willing to implement more restoration features.

[10] For a channel with a bankfull width greater than 20 meters [66 feet], the minimum residual pool depth is 0.4 meters [1.3 feet] and the minimum surface area is 5 m2 [55 ft2].

Reach 2 (RM 2.5 to 4.5)

This reach extends from the 96th Avenue Bridge in Bothell to the North Creek confluence. Adjacent land uses include the upper portion of Wayne golf course, several parks, downtown Bothell, and residential development. The left bank of the river in this reach is mostly undeveloped. This area includes less impervious surface area within 200 feet (61 m) of the river channel compared to Reaches 1, 3, and 5. This reach of the river is the most constrained in a narrow floodplain. In Blyth Park, the riparian area is generally forested with a mix of conifer and deciduous trees (Douglas fir, maple, cottonwood, alder). This reach has the most natural and mature riparian vegetation of any reach, although there are still many areas dominated by reed canary grass, blackberry, or impervious surface. The riparian width in this reach ranges widely from 0 to over 200 feet (0 to 61 m). The aquatic habitat is 100% glide with no pool or riffle habitat. However, there are six deeper areas (as previously defined) in this reach that could be used by adult fish for holding at approximately RM 2.55, 2.7, 2.8, 3.2, 3.5, and 3.9 (D. Houck, unpublished map; in 1998 tagged adult chinook were observed holding at RMs 2.7, 3.5 and 3.9; Fresh *et al*. 1999). All of these deeper areas are associated with the outside of meander bends and are likely areas of bank scour. Horse Creek enters this reach from the right bank in Bothell, and three unnamed tributaries enter this reach (0066, 0068, and 0069) from the left bank, at about RM 2.6, 2.7, and 4.2. Several pipes or open culverts that carry groundwater flow enter the river off of Norway Hill. Lake Washington backwater does influence this reach, although to a lesser extent than in reach 1.

There are two major wetland areas in this reach: (1) along the left bank from 102nd Avenue to Blythe Park and (2) along the left bank adjacent to Bothell Landing Park. Along the left bank there are two former side channels and associated seasonally flooded or saturated wetlands of approximately 10 to 15 acres. On the right bank just downstream of Bothell Landing Park, there is a small pond and associated wetland with an outflow connection to the river. North Creek is the upstream boundary of this reach and does provide some slightly cooler water to the main channel. North Creek currently flows along the far western edge of its natural floodplain and is further constrained by the I-405 and Highway 522 interchange. Backwater from the river extends up the lower few hundred feet of North Creek; possibly reducing any influence its cooler water may have on the river.

Key restoration opportunities in this reach include riparian enhancement along the Sammamish River Trail and reconnection of former side channels and floodplain areas on the left bank near 102nd Avenue. Another restoration opportunity would be to reconnect the river with the pond/wetland and small outflow on the right bank adjacent to Bothell Landing Park. Also, it is possible the groundwater flow from Norway Hill could potentially be used to provide cool water refuge for fish. Tributary 0066 drains a fairly large sub-basin (several hundred acres), and the lower end of the tributary could be enhanced for rearing habitat and to provide a cool water refuge at the confluence. The confluence of North Creek could also be improved to provide wetlands and a cooler water refuge for fish.

The primary limiting factors for salmonids in this reach include lack of channel complexity, cover, and floodplain connectivity and limited riparian area. Even though it still exceeds state standards (typically 20-22°C, see Figure 6), this reach has the lowest temperatures of any reach., Deep pools do not exist in this reach, but the numerous meanders provide opportunities to create scour pools using LWD and other features. The primary limiting factors for wildlife are a lack of a migratory corridor (highly fragmented) and lack of riparian area.

Reach 3 (RM 4.5 to 7.5)

This reach extends from the North Creek confluence up to the 145th Street Bridge. Adjacent land uses are dominated by the City of Woodinville and the I-405 and Hwy 522 interchange. In the lower half of the reach, land use is primarily urban and residential, opening up to agricultural on the right bank in the upper half of the reach. Because much of the floodplain is developed to within 100 feet (30 m) of the river's edge (particularly on the left bank), this reach includes significant areas of impervious surface adjacent to the channel, which reduces restoration opportunities in this area. The riparian vegetation is dominated by blackberry and reed canary grass; together these two species make up 50 to 90% of the vegetation cover throughout the reach. Trees are very rare and willows occur in only a few locations. Several tributaries enter the river in this reach, including Little Bear, Woodin (0087), and Gold (0088) Creeks, Tributary 0090, and several ditches. Each of the tributaries contributes cooler water to the mainstem during the summer months (McIntosh and Faux 1999). While Little Bear Creek is cooler than the mainstem in the winter, Gold Creek has warmer winter waters that may be a result of groundwater flow. During low flow conditions, Little Bear Creek also contributes a significant cooling effect downstream for up to 825 feet (250 m) (McIntosh & Faux 1999).

Instream habitat includes a single 150-foot (45 m) riffle downstream of Little Bear Creek, and the remainder of the habitat in this reach is glide. The riffle represents approximately 1% of the entire reach length. Kokanee were observed spawning in this riffle during 1999 surveys (Jeanes and Hilgert 1999). Five deeper areas that do not qualify as pools based on the Timber-Fish-Wildlife (TFW) methodology were identified by Fresh *et al* (1999). These areas may provide adult salmon holding habitat at approximately RM 5.6, 6.0, 6.1, 7.1, and 7.5. Only one of these areas was observed to contain tagged chinook in 1998 (R. Tabor, pers. comm. June 2001). Most of these areas are also associated with bridges or the outside of meander bends. These potential holding areas are widely spaced apart, (typically more than 1/2 mile [2640 feet]), likely as a result of the straight channel that exists in this reach. NMFS pool frequency criterion (NMFS 1996) considers 23-26 pools per mile properly functioning conditions (pools approximately every 200 feet).

This reach has a greatest number of wetlands. Wetlands may be present in the former North Creek floodplain (south of Highway 522) and are present adjacent to Tributaries 0087 and 0088, at the Red Hook brewery, and in the mixed-use industrial/commercial lands adjacent to Highway 202. Total acreage of known wetlands is about 50 acres (20 hectares). Other agricultural lands in this reach could potentially contain wetlands, but have not been identified as such. The identified wetlands are seasonally or temporarily flooded or saturated emergent with some scrub/shrub areas (primarily willow or spirea). Wetlands have been restored recently just upstream of the confluence of North Creek and the Sammamish River. Undeveloped lands primarily only exist adjacent to the I-405/522 interchange, along the Sammamish River Trail, and on the agricultural lands. Some restoration was implemented along Gold Creek a few years ago, but there may be additional restoration opportunities in this area.

Key restoration opportunities in this reach include restoration of floodplain interaction and wetland creation in the I-405/522 interchange area, riparian revegetation along the Sammamish River Trail corridor, and restoration of small tributaries to provide wetland and riparian vegetation and create cool-water refuge for fish.

The most obvious limiting factor for salmon species in this river reach is elevated temperature because this reach is far more complex with more forested riparian area than other reaches. However, limiting factors still include lack of channel complexity, cover, and floodplain connectivity and narrow riparian area. Lack of adult cool water holding habitat in this reach is also a significant limiting factor. Wildlife habitat is also extremely poor and limited by the poor riparian corridor and urban development.

Reach 4 (RM 7.5 to 11)

Reach 4 extends from the 145th Street Bridge to the upstream end of the Willows Run Golf Course. Adjacent land uses are agriculture and playfields with a few houses and other structures. Riparian vegetation is overwhelmingly dominated by blackberry and reed canary grass with essentially no trees within the riparian area. Continued heating occurs in this reach in spite of the cooling effects of Bear Creek inflow upstream in Reach 5 due to the almost complete lack of shading and the north-south orientation of the river. Several minor tributaries may contribute cool water in this reach, however, as temperature in this part of the reach is 1 or 2°C lower than that observed at the Little Bear Creek confluence (McIntosh and Faux 1999). The Sammamish River Trail runs parallel with the channel throughout the reach. A 25- to 50-foot (7.5 to 15

m) strip of grass and shrubs (primarily blackberries) are present on either side of the river for the entire reach. A short 100-foot (30 m) riffle is present at the upstream boundary of this reach, and kokanee have been observed spawning here (Jeanes and Hilgert 1999). Seven deeper areas that do not qualify as pools based on the TFW methodology were identified in this reach at approximately RM 9.0, 9.1, 9.7, 9.8, 9.9, 10.3, and 10.7. This reach has only minimal impervious surface area, so there are opportunities to restore oxbows and old channel areas. Several unnamed tributaries (0091, 0095, 0099, 0100, 0101, 0102, 0104) and ditches enter the river in this reach. During the summer months, tributaries 0095 and 0102 were both found to contribute cooler water to the river (McIntosh and Faux 1999). Other than Lake Sammamish outflow, this reach contributes the most heating to the river. Several wetlands are identified on the NWI website (see references), primarily of seasonally inundated emergent habitat, but are currently farmed.

Key restoration opportunities in this reach include revegetation of the riparian area between the trail and river, or perhaps relocation of the trail away from the river to allow for a larger buffer. Although it will likely not be possible to move more than a few sections of trail further from the river. In this reach the river is also severely lacking in aquatic habitat complexity in the form of LWD, pools, and other cover. Also, this reach is the most channelized and straightened and would benefit from some channel remeandering. Wetlands in this reach could be restored for groundwater recharge or wildlife habitat as feasible with the agricultural and other development constraints.

The primary limiting factors for salmon in this reach are elevated water temperature, lack of channel complexity and floodplain connectivity and essentially no riparian area. This reach has undergone the most radical change from historic conditions. Historically, numerous meanders were present in this reach, and it is now virtually straight.

Reach 5 (RM 11 to 12.5)

This reach extends from the downstream end of the Willows Run Golf Course to the Bear Creek confluence. Adjacent land uses are predominantly urban, commercial, and residential. Only the narrow corridor along the Sammamish River Trail (both banks) and near the Bear Creek confluence is undeveloped. The City of Redmond has undertaken several restoration projects associated with their RiverWalk plan that have included riparian revegetation and instream habitat features; however, the riparian area in this reach is still dominated by grasses until the recently planted trees and shrubs begin to mature. One 50-foot (15 m) pool is located just downstream of the Bear Creek confluence and one 50-foot (15 m) riffle were identified in 1999 (Jeanes and Hilgert 1999). Recent restoration associated with RiverWalk appears to have created some additional riffle and pool habitat associated with placement of gravel and LWD. In addition, six deeper areas were identified for potential adult salmon holding in this reach, most of which are associated with bridge piers and outer meander bend scour. These deeper areas are located at approximately RM 11.3, 11.7, 11.8, 11.9, 12.1, 12.3, and 12.5. Peters Creek and Bear Creek enter this reach of the river, both of which provide cooler water in the summer, particularly Bear Creek, which typically provides the river with a volume of water equal to the volume that flows from Lake Sammamish. This reach, like Reach 3, is highly developed adjacent to the river.

Wetlands present in this reach include a pond and associated wetland on the Willows Run Golf Course (approximately 3 acres [1.2 hectares]) and there is potential that wetlands exist across the river in an area of a former meander. Other currently farmed areas may also contain wetlands, although it is not known at this time.

Key restoration opportunities for this reach include creation of cool water refuge for salmon at the Bear Creek confluence and at Peters Creek. Restoration of the lower Bear Creek floodplain is also very important to create additional adult holding habitat and a diversity of habitat types in an urbanized area. Redmond's RiverWalk project has provided some additional aquatic habitat; however, already completed sections and future planned sections should be evaluated to determine if more or different aquatic habitat features could be added. There is at least one remnant oxbow or meander in this reach (on the right bank across from Willows Run) that could be reconnected to the river.

The primary limiting factors for salmon species in this reach of the river are elevated temperature and lack of a riparian area. Lack of floodplain connectivity and lack of cover are also limiting factors. Wildlife habitat is negligible in this reach, primarily due to the high level of human disturbance and habitat fragmentation. Wildlife habitat could be improved by restoring wetland habitat and the riparian area.

Reach 6 (RM 12.5 to 13.6)

This reach extends from the Bear Creek confluence to Lake Sammamish. Adjacent land use is almost entirely Marymoor Park, although residential areas are located just out of the floodplain on the left bank. West Lake Sammamish Parkway also borders the river for a portion of this reach. The vegetation in the riparian area is composed primarily of willow although the lower third of the reach is dominated by blackberry and reed canary grass. Instream habitat includes 22% riffles, 3% pools, and 75% glide habitat. This reach of the river provides the best existing physical habitat; however, elevated temperature is the most severe in this reach as a result of the warm Lake Sammamish outflow. The relatively long riffle (>1000 feet [303 m]) in the transition zone[11] is bordered on both banks by 60% willow and provides some of the only canopy cover along the entire mainstem. However, the riparian width here is still only 25 to 50 feet (7.5 to 15 m) wide for much of the reach, although the very upper end of the reach has a riparian area greater than 100 feet (30 m) wide. Coho and kokanee have been observed spawning in the transition area, although the substrate is primarily composed of quarry spalls. Jeanes and Hilgert (1999) also observed chinook and coho there, although not spawning, in 1999. Two unnamed tributaries enter this reach (0141 and 0142). Temperature in this reach can exceed 79°F (26°C) for brief periods in the summer and is typically above 73°F (23°C) (Corps unpublished data 1998 and 1999 used in the model in Appendix B). Historically, this entire reach was likely part of Lake Sammamish prior to construction of the locks. Where the lake meets the river, a significant amount of wetland area is still present on both riverbanks. Emergent, forested, and scrub-shrub wetlands provide a mosaic of habitats within the open space.

Key restoration opportunities in this reach include temperature reduction through modification of the Lake Sammamish outflow, riparian revegetation, reconnection of an old meander adjacent to the transition zone, and creation of cool water refuge by utilizing groundwater sources in the reach. Any mitigation that may be planned for this area should consider the key restoration needs and opportunities mentioned above.

The primary limiting factor for salmon in this reach is elevated temperature, more than in any other reach. Other than water temperature, habitat is actually of moderate quality in this reach. Wildlife habitat is also in fairly good condition, but is limited by lack of sufficient migration corridors and potential effects of park uses such as the dog leash-free area, which may limit wildlife usage. Currently, the dog access locations along the river are fenced off during the salmon migration season, although there is limited evidence to show if dog presence inhibits fish migration upstream of the weir.

CONTINUED DEVELOPMENT

In 2000, the Sammamish River watershed population was approximately 410,000. King County estimates the population will grow to approximately 500,000 by 2010 and 580,000 by 2020, using growth projections from the Puget Sound Regional Council (C. Gaolach, King County, pers. comm. 2001). A majority of this increase is projected to occur in the Swamp and North Creek basins, which are almost entirely within the urban growth boundaries of King and Snohomish counties. Additional population growth will place further

[11] The transition zone is located downstream of the weir and was designed for the Corps/King County flood control project to be a transition between Lake Sammamish and the regular river channel. It is wider than all other areas of the river and is lined with quarry spalls to reduce erosion of the bed.

pressures on the already degraded Sammamish River Corridor. Additional forested areas may be cleared for housing and other development that could reduce buffers on streams and wetlands and development will increase impervious areas (which will increase winter runoff and reduce groundwater recharge). There will be an increased demand for water supply, which may be primarily provided from other subwatersheds (i.e. Cedar River, Tolt River), although proposals to utilize Lake Washington water as a potential drinking water source have been discussed. Overall, it will be important to minimize the degradation that could continue to occur as a result of population growth; otherwise, any restoration actions may just maintain existing conditions without effective improvements to the ecosystem.

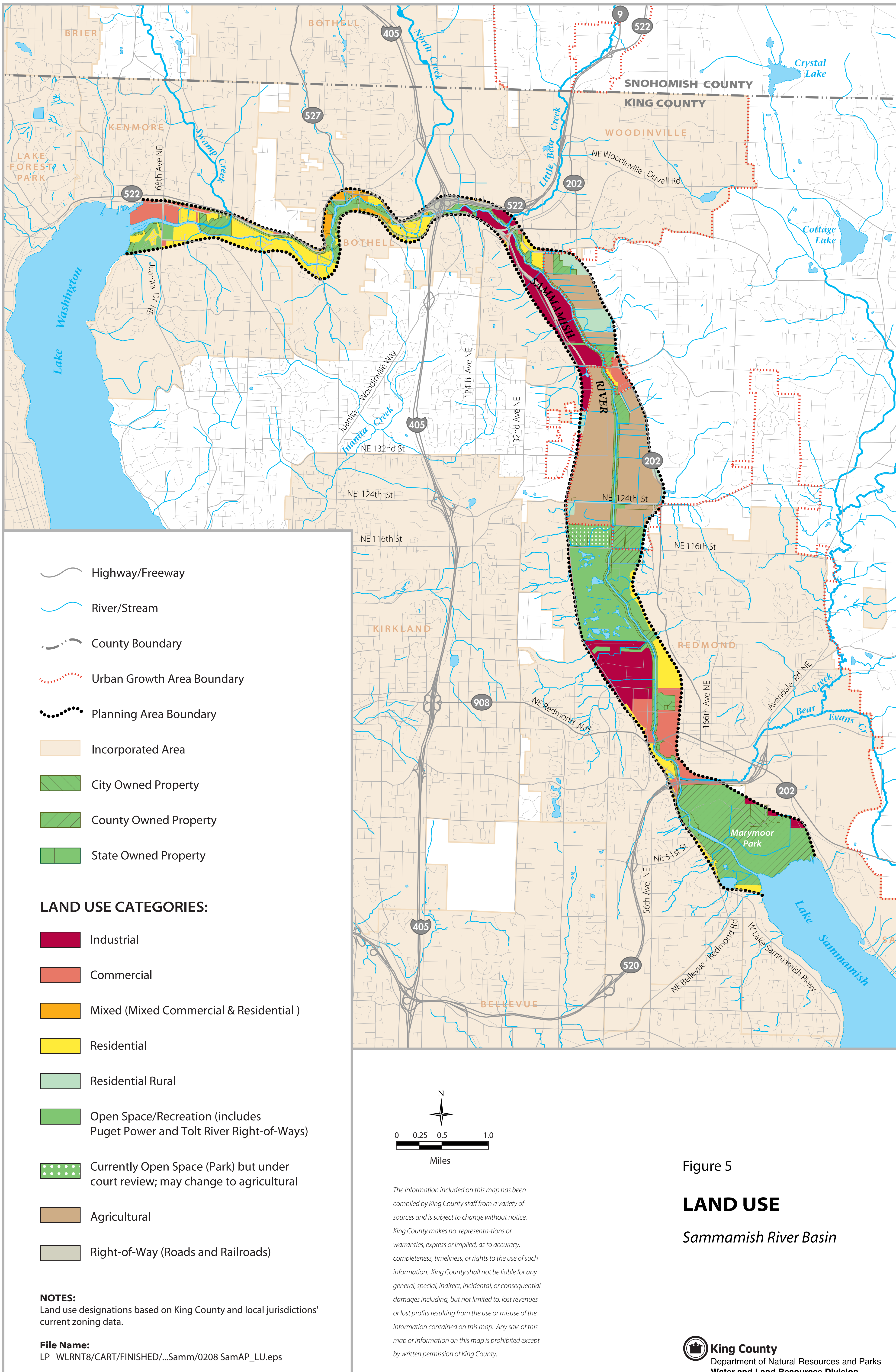

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Figure 5

LAND USE

Sammamish River Basin

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

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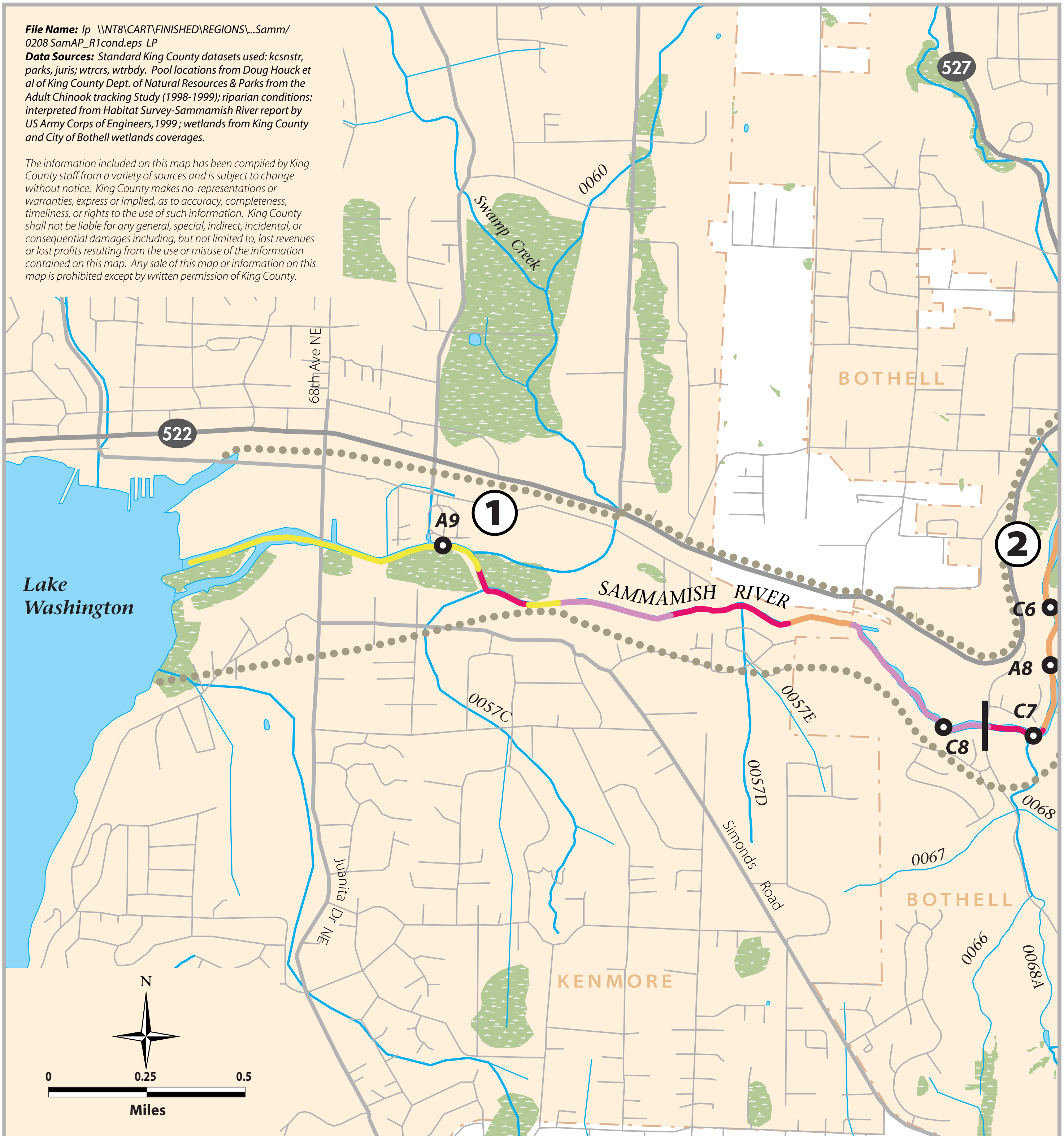

Figure 6

REACH 1 Existing Conditions

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

1 River Reach Number
River and Reach Boundary
Road
River/Stream
Planning Area Boundary
Wetland
Incorporated Area

A7 Pool Location & Number

RIPARIAN CONDITIONS
Forested Coniferous
Forested Deciduous
Non-native
Non-native Extreme
Scrub/Shrub

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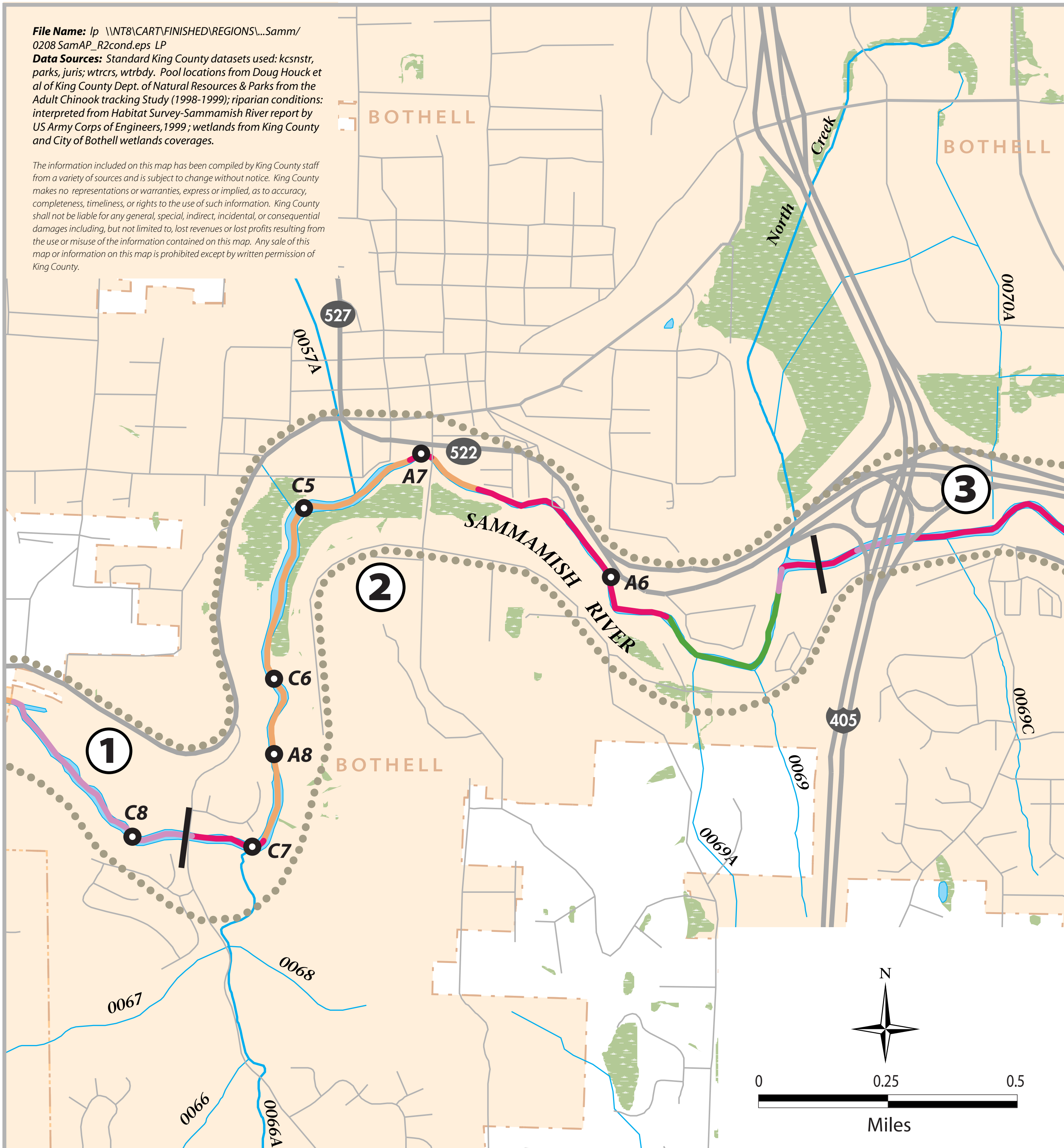

Figure 7

REACH 2
Existing Conditions

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

1 River Reach Number
River and Reach Boundary
Road
River/Stream
Planning Area Boundary
Wetland (from City of Bothell)
Incorporated Area

A7 Pool Location & Number

RIPARIAN CONDITIONS
- Forested Coniferous
- Forested Deciduous
- Non-native
- Non-native Extreme
- Scrub/Shrub

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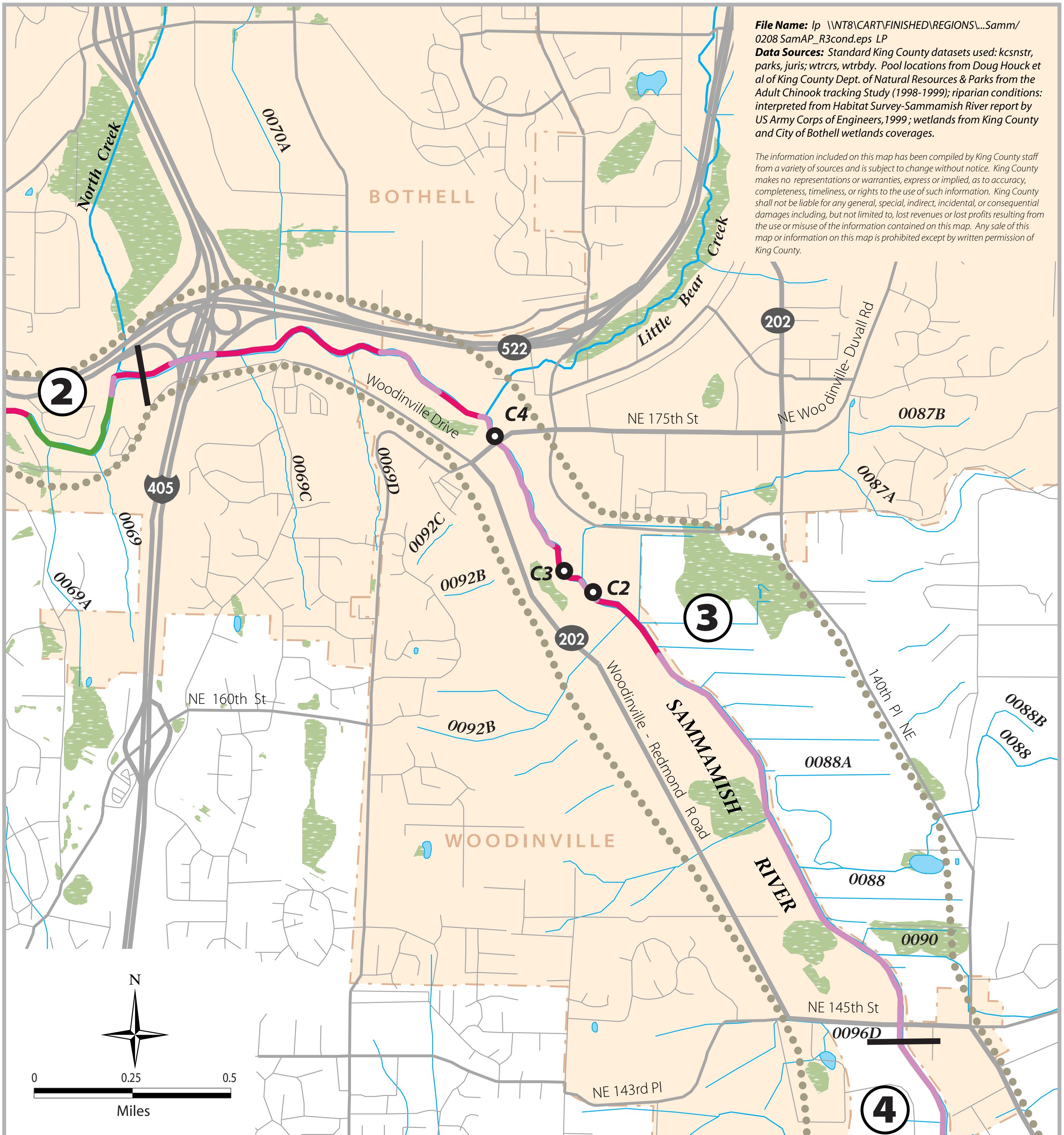

Figure 8

REACH 3
Existing Conditions

Sammamish River Corridor

1	River Reach Number
	River and Reach Boundary
	Road
	River/Stream
	Planning Area Boundary
	Wetland (from City of Bothell)
	Incorporated Area
A7	Pool Location & Number

RIPARIAN CONDITIONS

- Forested Coniferous
- Forested Deciduous
- Non-native
- Non-native Extreme
- Scrub/Shrub

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

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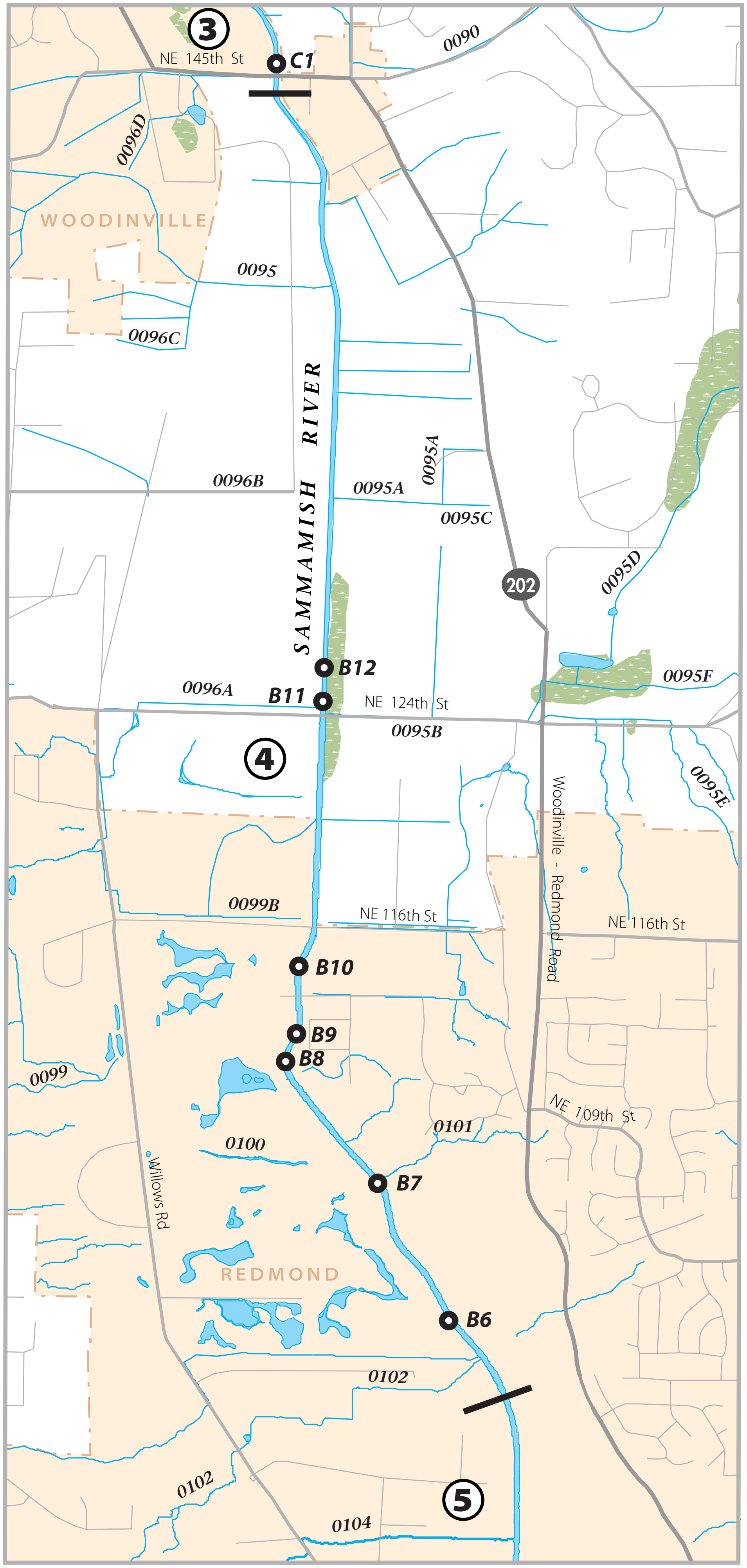

Figure 9

REACH 4
Existing Conditions

Sammamish River Corridor

- River Reach Number
- River and Reach Boundary
- Road
- River/Stream
- Planning Area Boundary
- Wetland (from City of Bothell)
- Incorporated Area
- Pool Location & Number

RIPARIAN CONDITIONS

- Forested Coniferous
- Forested Deciduous
- Non-native
- Non-native Extreme
- Scrub/Shrub

N

0 0.25 0.5

Miles

File Name: *lp \\NT8\CART\FINISHED\REGIONS\...Samm/ 0208 SamAP_R4cond.eps LP*

Data Sources: *Standard King County datasets used: kcsnstr, parks, juris; wtrcrs, wtrbdy. Pool locations from Doug Houck et al of King County Dept. of Natural Resources & Parks from the Adult Chinook tracking Study (1998-1999); riparian conditions: interpreted from Habitat Survey-Sammamish River report by US Army Corps of Engineers,1999 ; wetlands from King County and City of Bothell wetlands coverages.*

King County
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Water and Land Resources Division
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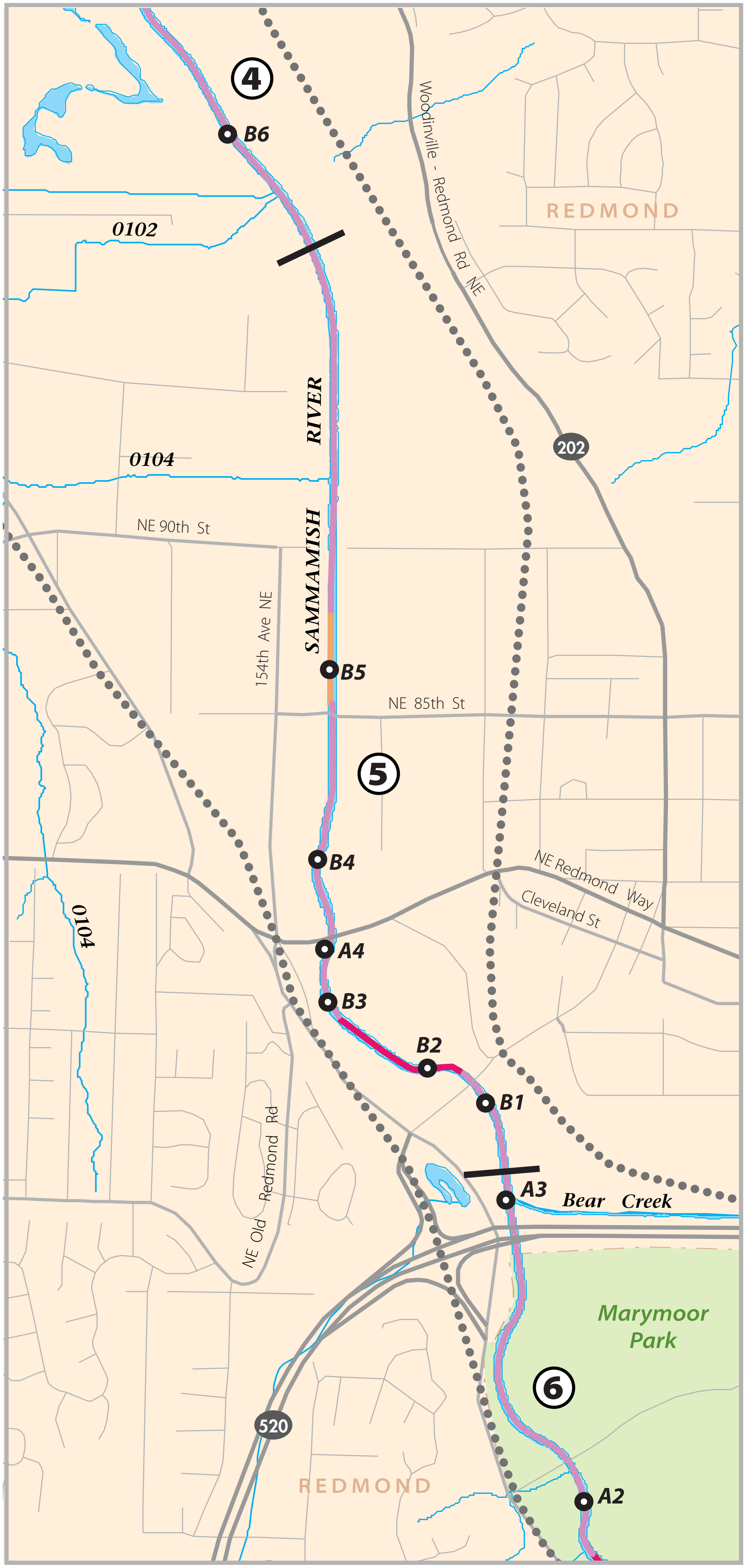
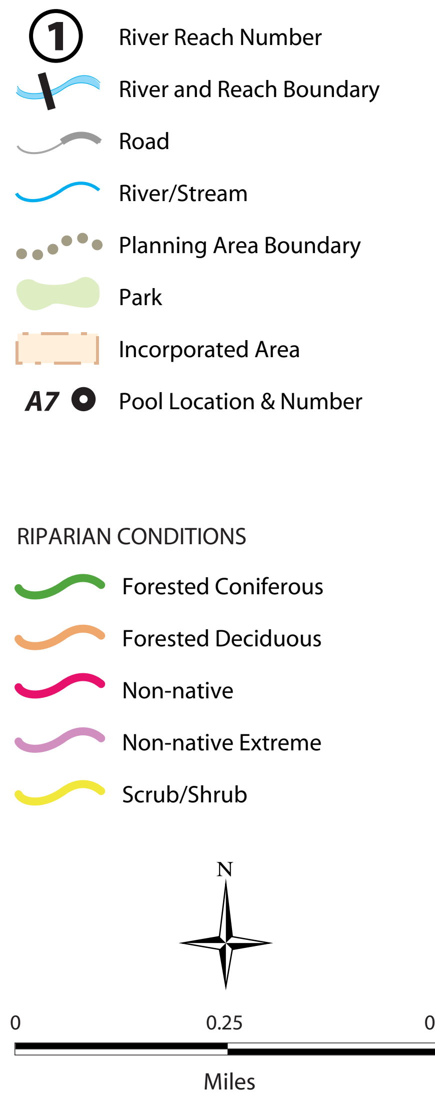


Figure 10

REACH 5
Existing Conditions

Sammamish River Corridor



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Data Sources: *Standard King County datasets used: kcsnstr, parks, juris; wtrcrs, wtrbdy. Pool locations from Doug Houck et al of King County Dept. of Natural Resources & Parks from the Adult Chinook tracking Study (1998-1999); riparian conditions: interpreted from Habitat Survey-Sammamish River report by US Army Corps of Engineers,1999 ; wetlands from King County and City of Bothell wetlands coverages.*

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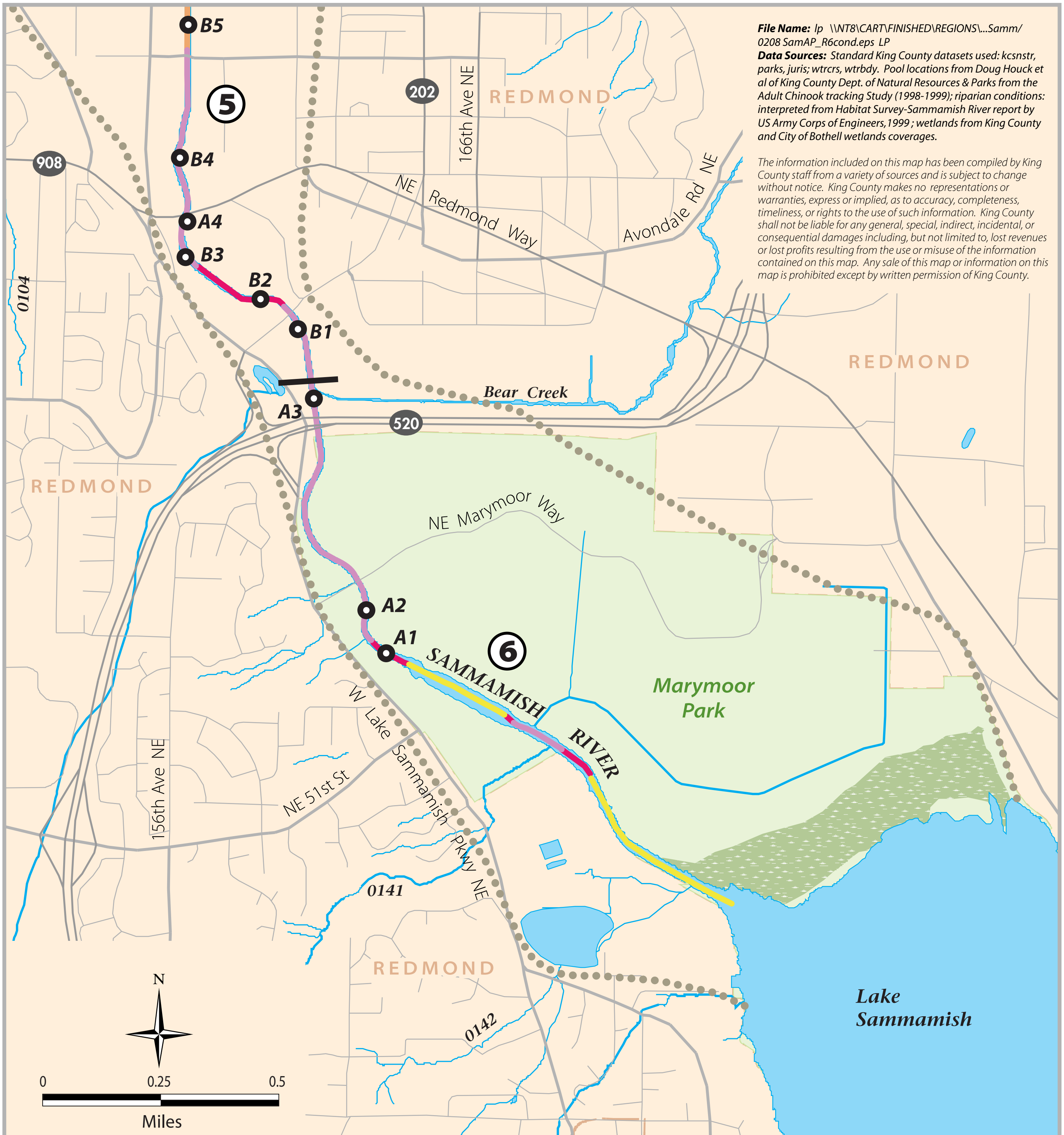

Figure 11

REACH 6
Existing Conditions

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

1 River Reach Number
River and Reach Boundary
Road
River/Stream
Planning Area Boundary
Park
Wetland

A7 Pool Location & Number
Incorporated Area

RIPARIAN CONDITIONS
Forested Coniferous
Forested Deciduous
Non-native
Non-native Extreme
Scrub/Shrub

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CHAPTER 3. STRATEGIC APPROACH FOR RESTORATION

The change from historic to existing conditions in the Sammamish River Corridor discussed in the previous two chapters describe a system with very significant constraints on the ecological functions the area can be expected to provide. Prior to the lowering the level of Lake Washington and channelization and dredging of the river, the Sammamish River Corridor was a vast wetland complex, which is almost entirely gone today. The Seattle metropolitan area now exists within and surrounding the changed corridor. The historic conditions cannot be re-established. However, the Sammamish River Corridor still performs important ecological functions, especially as a migratory link between other habitats. Most obviously, it is a link between Lake Washington and Lake Sammamish, but it also links numerous tributaries and upland habitats with each other and with the lakes. Many species in addition to salmon use it as a critical migratory corridor. The fundamental goal of the Action Plan is to make the Sammamish River Corridor a strong link, rather than a weak one, in this larger ecosystem.

The Action Plan recommends the following overarching strategy to meet this goal with the following key elements:

- *Restore riparian areas throughout the river corridor* by regrading the river's banks and planting them with native vegetation to provide shade, cover and enhanced habitat and habitat-forming processes for all native fish and wildlife.
- *Create and enhance pools in the river channel* to provide cool-water refuge and cover, particularly for migrating adult salmon; design the pools to be sustained over time by the river's hydraulics.
- *Explore engineered solutions to cool the river upstream of Bear Creek* where thermal stress for migrating adult salmon is greatest.
- *Protect all major tributaries to the river*, particularly Bear Creek, as sources of cool water for the river and as habitat for other life stages of fish and wildlife using the river.
- *Apply adaptive management systematically across jurisdictions*, monitor projects closely and compare them to each other and to baseline conditions, to identify features of greatest value to include in future projects as progress is made toward river-wide restoration.

These strategies serve multiple purposes. However, a driving concern of the Action Plan is to reduce the stress of high summer water temperature on migrating salmon. The temperature modeling conducted by King County is included as Appendix B and describes a detailed review of some of the potential options available to address this concern. Its findings provide an important foundation for the strategies discussed in this chapter. Additionally, there are other problems in the corridor that should continue to be addressed, but are generally given lower priority than the above listed strategy. They are briefly described at the end of this chapter.

RESTORE RIPARIAN AREAS THROUGHOUT THE SAMMAMISH RIVER CORRIDOR

Healthy riparian areas could provide crucial shade to reduce solar heating of the Sammamish River. Improvements to riparian areas are also fundamental to maximizing the river's capacity to serve as a migratory corridor for birds and other wildlife. As discussed in Chapter 2, riparian areas in the Sammamish River Corridor are currently in extremely poor condition. The river is completely cut off from its former oxbows and side channels and has only a few connections with riparian wetlands, primarily in Reaches 1, 3 and 6. Only a few locations along the river have native or even partly native plant communities. Dredging for flood control in the 1960s was either the direct cause, or indirectly supported other actions that seriously aggravated most of these conditions. The maintenance standards of the Corps, which have required minimizing woody vegetation to maintain the river's flood conveyance capacity, have resulted in continuing degraded conditions. In recent years, the Corps has re-evaluated some of these requirements, partly in response to changes in environmental regulations, including the listing of Puget Sound chinook salmon under the Endangered Species Act. Maintaining flood conveyance and a healthy riparian area are not mutually exclusive. Sloping back the river's banks prior to revegetation improves riparian habitat value for both fish and wildlife and increases channel conveyance. Perhaps the greatest advantage for restoration of the Sammamish River is that approximately 70 percent (length) of the riparian area on both banks is publicly owned.. The public owns or has conservation easements on at least one bank of an additional 20 percent of the river. Given this extraordinary degree of public ownership in a heavily urbanized area and the critical role that the riparian area plays for all fish and wildlife species in the Sammamish River Corridor, this Action Plan proposes to make improvement of riparian areas the major element of the strategic approach for restoration.

In the last decade, more than 20 projects have included replanting portions of the banks of the Sammamish River through the initiative of local governments, the Corps and literally thousands of volunteers. The Action Plan recommends a dramatic expansion of this work, applying a number of important lessons learned, including:

- In all cases, except where the county sewer line prohibits, the river's banks should be regraded to significantly decrease slope[12] before additional planting efforts occur. This should frequently include creation of flood benches set at or below the ordinary high water mark of the river. The benches should extend into the river's existing channel, constricting low flows while still providing an increase in total flood conveyance capacity. Juvenile salmon in the river have shown a preference for shallow water habitat and for cover that increases their safety from potential predators (Jeanes and Hilgert 2001). Flatter slopes and flood benches also provide more suitable conditions for native riparian and wetland plants to establish themselves. Significant slope regrading increases the likelihood that root systems of non-native species currently established on the river's banks would be removed, reducing their ability to compete with new plantings. Poor soil conditions should be improved throughout the planting areas, not just in the planting holes prepared for individual plants.
- Colonizing species (such as red alder, willow, redstem dogwood, and black cottonwood) should be the first species planted because they create a shade canopy relatively quickly and are effective competitors against undesirable invasive species, such as reed canary grass and blackberry . Survival rates for Douglas fir, vine maple, Sitka spruce, Nootka rose, salmonberry, Oregon grape, and ocean spray have been greater than 80 percent at past plantings along the Sammamish River. The goal should be to eventually establish a mixed conifer/deciduous forested zone (i.e. red cedar, cottonwood, Oregon ash). Conifers should dominate near the tops of banks—their greater height will provide maximum shade even with more gently sloped banks; they can better compete with blackberry (which are dormant less of the year than deciduous trees) along the vulnerable edges of the riparian corridor; and tend to cause fewer safety problems for users of the Sammamish River Trail. Willows on flood benches not only can grow quickly to provide significant shade, but also over time, can provide smaller woody debris that juvenile salmon appear to find attractive in the Sammamish River (E. Jeanes, R2, pers. comm. 2001). Migrating adult salmon have also been found to hold in area of the Sammamish River where willows provide cover.

[12] The existing slope of the banks varies from 1.5H:1V to 3H:1V, as designed for the 1964 channel improvements. However, the slope below the ordinary water line is often even steeper as a result of bank scour. This existing slope provides minimal habitat for juvenile salmon and minimizes the area which could be revegetated with riparian species. Sloping the banks back to a minimum of 3:1 (and up to 7:1 where there is room), including below the water level would provide additional fish habitat and a better riparian buffer.

- Aggressive maintenance for a minimum of three to five years after planting, particularly removal of invasive species and irrigation, is necessary for plants to thrive and should be included in all project budgets.
- Volunteers can be very helpful with major planting projects, as well as ongoing maintenance of planting sites. However, qualified technical experts should supervise volunteer planting projects to ensure appropriate plantings are conducted. Volunteers involved with ongoing maintenance can provide helpful advice for future plantings, in addition to serving as important public advocates for the river. Effective volunteers require coordination and appropriate training and tools—they are not free. Volunteers alone are not sufficient for the enormous task of replanting riparian areas along the entire river, and would not be appropriate in large-scale sites or where other activities such as grading are occurring. Construction crews and landscapers with adequate equipment are necessary in many cases to accomplish the scale of restoration envisioned in this plan.

In general, replanting efforts in the upper reaches of the river would likely provide the greatest benefit to salmon. In regard to shade, this is true both because the upper river reaches tends to be warmest (and therefore in most need of shade) and also because the benefits of shade are cumulative. As such, the further upstream shade is provided, the greater length of river is benefited. Jeanes and Hilgert (2001) indicate juvenile salmon spend a short period of time (days or at the most a month) in the upper river, after which they appear to migrate fairly quickly to Lake Washington (although this could also be due to a lack of habitat in the lower river). This would also tend to raise the priority of improvements in Reaches 5 and 6, as well as immediately downstream of major tributaries in the other reaches (i.e., Little Bear, North and Swamp Creeks).

In contrast to some suggestions, there does not appear to be an advantage to planting the west bank rather than the east bank of the river to block afternoon sun. Solar radiation heats the water throughout the day. Further, it is unlikely that mature vegetation present in a fairly narrow riparian corridor would reduce localized afternoon air temperature significantly enough to influence river temperature. It could even be argued that planting on the east bank would be preferable, because it would block solar radiation in the morning, and this would potentially help maintain cooler evening temperatures longer into the day. Updates of the model developed by King County to predict river temperature under different conditions may help refine priorities for sequencing riparian improvements. However, the fundamental strategy should be to plant both sides as soon as possible, in conjunction with regrading of riverbanks and the channel improvements discussed below. In addition to increasing shade and habitat for juvenile salmon, riparian improvements throughout the river are important as sources of detritus and insects (supporting the aquatic food web), LWD recruitment for habitat complexity, overhanging vegetation and cover, bank stability, and filtration of pollutants.

Wildlife species will also benefit significantly from restoration of forested riparian areas. Numerous species depend on riparian habitat during key stages of their life history. Native amphibians in particular, use riparian forests and downed logs for cover, foraging and wintering as juveniles and adults, though most return to aquatic habitats to lay their eggs underwater. Many bird species use riparian forests and shrubs, particularly where snags are abundant for nesting, foraging and perching. These include, but are not limited to bald eagle, great blue heron, green heron, osprey, kingfisher, wood duck, willow flycatcher, tree swallow, yellow warbler, and Swainson's thrush. Both small and large mammals and numerous amphibians and birds also use riparian corridors for transit between habitats, making it strategically important to connect restored riparian areas to existing good-quality upland habitats. Relatively large forested wetlands and riparian areas in Marymoor Park are currently isolated from downstream areas. The Bear and Little Bear Creek basins also contain significant high-quality forest habitat that is currently isolated from the Sammamish River. Specific areas to target riparian improvement to benefit wildlife include Reach 6, to connect Lake Sammamish habitat with the Sammamish River and Bear Creek; the confluence areas of major tributaries, to improve connection between upland forest habitat and the Sammamish River; Reach 3, to connect existing wetlands to the river; and throughout Reach 4, where there is currently virtually no cover.

As noted above, one of the greatest assets of the Sammamish River is the degree to which its riparian areas are already in public ownership. King County Parks is by far the largest owner, managing the Sammamish River Trail, an undeveloped trail right-of-way on much of the river's left (west) bank, and numerous adjacent parks and open space lands. A new soft-surface trail, which would serve pedestrians and equestrians, is planned for the undeveloped right-of-way and would reduce conflicts between the growing numbers of users of the existing trail, which has nearly tripled since it opened in the mid-1970s. Design of the new trail has not yet been funded, but its construction would create an excellent opportunity for cost-sharing joint riparian improvements along the upper 11 miles of the river from Marymoor Park to Blyth Park in Bothell. Redmond's RiverWalk provides another excellent opportunity for riparian improvements along the river in the next few years. All riparian planting projects should allow for specific public access locations and viewpoints to encourage community buy-in and direct users to designated access points, rather than causing disturbance of riparian plantings. Chapter 4 identifies additional remaining opportunities for public acquisition of riparian areas along the river.

Privately owned riparian areas along the river should also be improved where feasible. Literature reviews of riparian buffer functions generally recommend that 100 feet is the minimum buffer width to provide a multitude of functions such as sediment retention, pollutant removal, shading, and wildlife habitat (Wenger 1999). Buffers wider than 100 feet would provide for increased functioning; however, due to the level of development currently present in the corridor, a minimum of 100-foot buffers are recommended. As discussed further in Chapter 4, improvements in sensitive area regulations for all jurisdictions should require buffers of at least 100 feet for new development along the Sammamish River and all its perennial tributaries to maintain and restore water quality (temperature) and improve fish and wildlife habitat. These sensitive area regulations should also be re-evaluated to provide incentives for already developed sites with narrower buffers to either move toward this preferred buffer width or at least improve the quality of existing buffers by providing native trees and removing non-native species such as blackberry. Incentives could include tax reductions for implementing native buffers, use of buffer averaging on individual parcels to allow enhancements in buffer quality and width in some areas with reduced width buffers required in other areas, technical assistance or donations of native plants in exchange for specific types of improvements and maintenance of those improvements.

CREATE AND ENHANCE POOLS IN THE RIVER CHANNEL

As discussed in Chapter 2, dredging of the Sammamish River in the 1960s not only severely degraded riparian areas, but also changed the river channel to a generally uniform width and gradient. Maintenance for flood control has prevented development of channel variation that might otherwise have occurred naturally (such as recruitment of LWD). A remarkable 98.2% of the river is glide habitat, 1.4% is riffle and only 0.4% meets TFW criteria for pools (Jeanes and Hilgert 1999). Field tracking of adult chinook salmon migrating through the river in 1998 and 1999, found a clear preference for deeper areas with cover, even if the extra depth was minimal compared to average channel depth (K. Fresh, WDFW, pers. comm. 2001 and D. Houck, King County, pers. comm. 2002). Given the severe shortage of pools, and the clear preference that salmon have shown for deeper areas (for either thermal refuge or cover), creation of more and better pools throughout the river is a high priority of the Action Plan. Strategic considerations for how and where these pools should be created include the following:

- Pools should take advantage of existing sources of cool water wherever possible, including tributaries and groundwater inflows. Locations just downstream of tributary mouths should be a priority, if they can be designed so they do not fill with sediment. Groundwater studies currently being conducted by King County should help identify general areas of groundwater flow into the river; piezometers should be used to identify specific locations and elevations. In the Norway Hill area of Reach 2 and possibly elsewhere, some springwater or groundwater flows are piped directly to the river. New pools could be strategically located to take advantage of these inflows. King County is also investigating methods to reduce infiltration of groundwater into their sewer system.

- New pools and improvements to existing deeper areas should be constructed so they are self-sustained over time by river hydraulics. LWD can be used to create areas of localized scour, to inhibit mixing of cool water input with warmer river, and to provide cover to make pools more attractive to salmon. Most of the existing deeper areas in the river are located on the outside of meander bends, where the river naturally scours the bed and bank. These could be excavated deeper and supported with woody debris.
- New pools should be created in areas where there are currently long gaps between deep areas, including between RM 0.8 and 2.3, RM 3.9 and 5.6, RM 6.1 and 7.1, and RM 7.5 and 9.0. Assuming pools will primarily serve as thermal refuge, they are more important in the upper river, where temperature is generally higher, but given the severe overall shortage of pools, they are needed throughout the river's length.
- Pool improvement should be closely monitored in comparison to each other, as well as to baseline conditions and to unimproved deeper areas, to see what features appear to provide the most benefit for adaptive use in future projects.
- We do not recommend adding gravel to pool locations and other channel improvements, particularly if it will not be kept scoured clean by flow. It could be used in areas such as immediately downstream of tributaries, where it would naturally tend to accumulate, or experimentally to create pool tailouts and riffles (primarily in the upper river).

As discussed above, when riparian areas are regraded, existing slopes can be extended into the river to constrict the low-flow channel. Benches should be set at or below the ordinary high water mark so there is substantial shallow habitat for juvenile salmon use during their migration to Lake Washington. Jeanes and Hilgert (2001) found juvenile salmon utilizing this habitat resulting from bank regrading more extensively than other sites in the river (see Figure 12). Though this sampling also suggests this habitat type may be more important in the upper river, where salmon from Bear Creek and Lake Sammamish appear to be acclimating to the river, these results may also be due to a lack of this habitat type downstream. Shallow habitat should be created in specific locations throughout the river and monitored to see which features and locations provide the greatest benefits. As an example, based on the observations of Jeanes and Hilgert (2001), it appears LWD plays a much less important role in creating habitat for juvenile salmon in the Sammamish River than it tends to elsewhere, probably due to the river's much slower current (see Figures 13 and 14 for differences between shallow water zones with and without LWD). This does not mean LWD should not be used in projects on the Sammamish River, but it may be more effective if used in smaller quantities and in different ways than is typically optimal elsewhere. For example, more small woody debris (less than 12 inches in diameter and branches) could be utilized to increase cover density for small fish and reduce use of this habitat by larger potential predators. Woody debris is also particularly beneficial for amphibians and reptiles.

As discussed in Chapters 1 and 2, the length of the Sammamish River has been dramatically decreased from its historic condition, particularly through Reach 4, where it once meandered across the mile-wide Sammamish Valley. Though some have called for restoration of the old river channel or re-creation of meanders that at least attempt to emulate historic conditions wherever possible, the Action Plan does not recommend meanders of this scale. The historic river formed under watershed hydrologic conditions that had significantly higher surface water elevations throughout the corridor (because Lake Washington was 9 feet higher). Development in the corridor and watershed over the past century, particularly in its historic floodplain, has permanently altered much of the former hydrologic regime. The current channel also ranges from two to fifteen feet deeper than it did historically. It would be impossible to recreate the river's historic meanders, even if its channel was shifted to the few remaining meander locations. Under current conditions, adding large meanders to the river might further slow the river's flow, resulting in increased heating from solar radiation, although riparian restoration would tend to reduce this problem.

Redmond's RiverWalk has introduced small meanders of approximately one channel width to a portion of Reach 5, upstream of the NE 90th Street Bridge. Though limited surveys of juvenile salmon (Jeanes and Hilgert 2001) found greater use of this site than control sites with no restoration, they did not find greater use than other shallow habitats that have been created along the river. RiverWalk's meanders have created more complexity within the channel and are beginning to form small riffles and pools. Over time, they should hydraulically help sustain some deeper areas that were created by the project, which have not yet been monitored for their use by migrating adult salmon. Movement of the river channel is expensive and may not be possible on the side of the river where King County's sewer line is located (primarily the east bank). Additional small meanders may be feasible and valuable, particularly to sustain pools. As riparian areas are regraded and channel improvements are made, new habitats should be monitored for use by juvenile and adult salmon and other wildlife to determine if there is sufficient benefit from addition of small meanders to justify their cost.

Changes to the morphology of the river channel will alter its conveyance capacity, as will regrading and re-vegetation of riparian areas. Given that the Action Plan recommends these changes along the entire river, conveyance capacity could be altered enough with implementation of this plan to affect water surface elevation from current conditions along portions of the river. This is an important design consideration for all future improvements to the river. We therefore recommend that King County and the Corps of Engineers update the existing hydraulic model (HEC-2 Sammamish River Backwater Model) to incorporate projected changes to the river's conveyance capacity associated with implementation of the Action Plan. Work on the updated model should be coordinated with other hydrologic models that King County is currently developing for the entire greater Lake Washington watershed.

EXPLORE ENGINEERED SOLUTIONS TO COOL THE RIVER UPSTREAM OF BEAR CREEK

Extensive temperature modeling conducted by King County (included as Appendix B, but not discussed in detail here) has shown that while riparian revegetation will help to cool the Sammamish River, it will have most benefit to the lower river because of the cumulative benefit that shading provides over the length of the river. Shading has very little effect on Reaches 5 and 6 because of the very warm outflow from Lake Sammamish, but as shading occurs over the length of the river, moving downstream, the cumulative effect of reduced heating and some cooling provides significant cooling to the lower river. Table 5 shows the percent change in the average daily degree-days of thermal stress[13] for salmon for various restoration options.

[13] The index of thermal stress used in this modeling effort is described in more detail in Appendix B. In general, the index measures temperatures above 17°C which was used as a temperature above which salmon would experience stress or physiological problems. Although there are many studies which show some stress for salmonids at temperatures above 15°C, we used 17°C as the threshold where there would almost certainly be physiological stress or behavior modifications, particularly to populations that may be adapted to somewhat warmer temperatures that occurred naturally in the river.

Table 5. Summary of percent (%) change of average temperature stress for selected restoration options compared to the existing conditions.

(Adapted from Table 7 in Appendix B, does not include all alternatives modeled, please refer to Appendix B for detailed description of alternatives). Negative numbers indicate a decrease in temperature stress and positive numbers indicate an increase in temperature stress.

Alternative	Reach 6	Reach 5	Reach 4	Reach 3	Reach 2	Reach 1
Existing Condition (assumed 5 cfs surface withdrawals and 5 cfs groundwater withdrawals for modeling purposes; not based on actual data)	0	0	0	0	0	0
50% Shade	-0.9	-7.1	-41.6	-65.7	-84.1	-46.9
25% Shade	-0.4	-3.6	-21.6	-35.9	-51.6	-20.0
Eliminate Assumed Surface and Groundwater Withdrawals	-1.6	-5.4	-13.9	-17.1	+6.6	+5.0
Groundwater Augmentation (15 cfs @ 13° C)	-5.1	-16.2	-39.3	-45.6	-16.4	+4.6
Bear Creek Flow Restoration (5 cfs)	-0.1	-12.5	-6.4	-6.5	+6.2	+2.8
Lost Shading in Bear Creek Which Increases Water Temp by 2° C	0	+13.9	+8.9	+7.4	+4.3	+0.5
Combine Eliminate Withdrawals with Groundwater Augmentation (above)	-6.6	-20.8	-46.5	-54.9	-27.4	+7.5
Combine Eliminate Withdrawals with Groundwater Augmentation and Bear Creek Flow Restoration	-6.7	-29.8	-47.9	-56.9	-31.8	+9.0
Hypolimnetic Withdrawal (20 cfs)	-96.5	-92.8	-79.8	-76.1	-55.6	-11.3

The hypolimnetic withdrawal alternative is an option that would withdraw cool water from the hypolimnion[14] of Lake Sammamish and discharge it near the weir where it would be mixed with Lake Sammamish outflow to significantly reduce temperature of the river at its upper end. As shown by the model results in Table 5, this alternative could significantly reduce water temperatures in Reach 6, upstream of Bear Creek, where thermal stress for salmon is greatest. Historically, Bear Creek's confluence was approximately 0.7 miles (1.1 km) closer to Lake Sammamish, providing a cool water input. The other alternatives that were modeled can generally provide only minimal benefit in Reach 6. It is important to note, however, that without increased riparian shade, cooler inflow in Reach 6 would tend to heat up as the water moved downstream. Riparian improvements are important to address temperature conditions in the Sammamish River regardless of whether the outflow of Lake Sammamish can be cooled.

[14] During the summer months the lake is thermally stratified, with a layer of warm water at the surface (epilimnion) and a layer of cool water at the bottom (hypolimnion). Between the two is the metalimnion, a transition layer between the two. For modeling purposes, it was assumed that hypolimnetic water would vary in temperature based on monitoring data from King County.

The use of hypolimnetic withdrawal as a method for reducing temperature would be a highly engineered solution to the temperature problems in Reaches 5 and 6. Such a strategy has a variety of practical obstacles and potential ecological risks. It would require laying a pipe up to two miles in length to reach water at a depth below the lake's thermocline, where temperature is significantly cooler than surface waters. It would be necessary to design the intake structure to avoid causing localized problems for kokanee and other fish in Lake Sammamish. Removal of cold water from the lake could possibly alter the temperature stratification regime in the lake, and potentially cause adverse effects to the aquatic food web. Dissolved oxygen levels are typically very low (~1-3 mg/L) at this depth, therefore, aeration may be necessary before or during discharge. Phosphorus levels, in contrast, tend to be higher in the hypolimnion, which suggests this strategy could potentially lead to an increase in phosphorus loading to the river and Lake Washington; these conditions could possibly result in increased productivity and excess production of algae. This could, in turn, potentially result in lower dissolved oxygen levels in the river, as the algae die and consumes oxygen through decay. Clearly, more evaluation of these issues is required to better understand the feasibility of implementing such an option for reducing temperature in the Sammamish River. However, it would likely only need to be operated during the warmest months (August and September), so operation costs would be fairly low.

Another potential engineered solution is the use of cooling tower technology, which uses evaporation to cool water prior to discharge. Cooling towers use evaporative cooling to reduce the temperature of water prior to discharge. Cooling towers could be located adjacent to the river, near the intake and discharge points, eliminating the need for a long pipe to withdraw lake water. Similar to the hypolimnetic withdrawal, it would only be necessary to operate the cooling tower(s) during the time of year when cooler water would provide a benefit to migrating adult salmon--typically August and September. Ambient air temperature and humidity level however, limit the degree of cooling that can be accomplished with this process; cooling towers may be of limited benefit when air and water temperatures are highest (in the summertime).

These potential engineered options to address the temperature problem in the upper river should be investigated in greater detail prior to making a decision on whether such a solution is feasible from both an environmental and economic standpoint. However, because engineered solutions appear to be the only options for significant temperature reduction in the upper river a feasibility evaluation of these options is a high priority.

PROTECT ALL MAJOR TRIBUTARIES TO THE RIVER: BEAR, LITTLE BEAR, SWAMP AND NORTH CREEKS

The major tributaries to the river (Bear, Little Bear, Swamp, and North Creeks) provide significant cooling inflows to the river and have helped maintain the ecological functions that still remain. The confluences of these tributaries with the mainstem river are also significant nodes of fish and wildlife usage. The tributaries also provide significant spawning and rearing habitat for salmon species and are the destination for many fish that use the corridor. As shown in Table 5 even minor changes in flow volume and water temperature in Bear Creek can have fairly significant effects on water temperature in the upper river. One scenario analyzed in the model indicates that an increase of approximately 5 cfs in Bear Creek's summer base flow could significantly reduce thermal stress for salmon in the river--particularly in Reach 5, immediately downstream of Bear Creek's confluence with the river. The City of Redmond; the water districts of Olympic View, Northeast Sammamish, and Union Hill; and the Sahalee and Bear Creek Golf Courses withdraw the largest water volumes from the Bear Creek basin. Based on 1994 withdrawals, a 30 percent reduction in summer irrigation (assuming no change in year-round baseflow withdrawals) by these users could potentially increase flow in Bear Creek up to 2 cfs (D. Hartley, King County, pers. comm. 2001). Water conservation and/or replacement/augmentation of irrigation withdrawals with reclaimed wastewater in the Bear Creek basin could potentially increase flow by several cfs. Compared to historical conditions, Little Bear, Swamp, and North Creeks currently experience higher base flow conditions because of the use of imported water (from Cedar and Tolt basins) for irrigation of lawns and gardens (WRIA-8 Technical Subcommittee 2001).

However, there are still ground and surface water withdrawals from these sub-basins, which could be replaced with other water sources such as reclaimed wastewater to help protect and maintain sufficient flow volumes in these tributaries.

Groundwater recharge has been reduced in all of these sub-basins due to development and increase of impervious surface area. Base flows in Bear Creek are approximately 39% less than historic base flow conditions; approximately 26% of this change is associated with water withdrawal and 13% from loss of groundwater recharge due to increasing impervious surface area (WRIA-8 Technical Subcommittee 2001). In the Swamp and North Creek sub-basins, it is likely that a more significant loss associated with decreased groundwater recharge has occurred. We recommend water conservation measures, replacement/augmentation of irrigation withdrawals with reclaimed wastewater, and investigation of sites that may be suitable for groundwater recharge (either from floodplain reconnection or percolation of stormwater runoff) in all of the major tributary sub-basins.

Another scenario analyzed in the model evaluated the potential effects of increasing the temperature of Bear Creek inflow by 2° C[15]. An increase in Bear Creek inflow temperature would have a significant effect on mainstem river temperature, particularly in Reach 5. Similar effects could be expected for the other tributaries if riparian shading is reduced. It is therefore critical to maintain cool tributary temperatures by maintaining riparian cover in these sub-basins. Swamp Creek is highly urbanized, and as such, there may be areas of the mainstem river that experience significant heating. It may, however, be possible to decrease the level of heating (for example, if a reach was highly confined between developed areas and devoid of riparian vegetation and lined with rock or similar engineered erosion control features collect and retain heat some simple riparian revegetation or removal of rock could have a significant impact on temperature reduction). We recommend evaluation of the temperature regime in these four tributaries to determine if additional restoration efforts to improve and maintain riparian shading would be effective in further reducing temperatures.

Lastly, the confluence areas for all these tributaries are important habitat for fish and wildlife. The deltas at Bear and Little Bear Creeks have formed small riffles, which are used for spawning by kokanee or residualized sockeye. Additionally, these are natural areas for accumulation of LWD and small woody debris. They are also important holding areas for adult fish migrating upstream because of their cool water inflow. In addition, they also provide an important connection for wildlife between the Sammamish River and upland forest areas and wetlands in the sub-basins.

The confluence areas could be enhanced in a variety of ways, including creation of pools and LWD jams to allow a thermal refuge and reduce the immediate mixing of cool inflow water with warmer Sammamish River water. LWD jams could promote formation and maintenance of scour pools and further create channel diversity through sediment deposition in riffles and bars. To maintain the cooling effects of the tributaries, it is important to provide shading along the river downstream of the confluences.

APPLY MONITORING AND ADAPTIVE MANAGEMENT SYSTEMATICALLY ACROSS JURISDICTIONS

Even though the region has considerable experience with implementation of riparian improvements, this and other strategies recommended in the Action Plan should be pursued with a research and adaptive management approach. In recent years, a few studies have been conducted on adult chinook migration and juvenile use of various habitats (Fresh *et al* 1999; Jeanes and Hilgert 2001), however, there are still many unknowns regarding the most effective ways to improve aquatic habitat for all salmon species in the corridor. Historic conditions are only a minimal guide for habitat improvements in the river corridor, given

[15] An increase of 2° C was selected for modeling purposes assuming that is a reasonable increase in water temperature from decreased shading along a significant stretch of the creek. Not based on any water quality sampling data.

how severely it has been altered, and the inability to restore many of the processes that historically formed and sustained its ecological integrity. The fact that past alterations have severely degraded riparian and in-channel conditions in ways that are relatively uniform across the river's length can be seen as an opportunity for a restoration program. The entire river corridor cannot be restored all at once. As restoration projects are implemented in different areas, they can be treated to some extent as "experiments" and monitored to determine which methods are most effective and whether certain methods are more effective in some places than others.

The adaptive management approach as envisioned in this plan (see Chapter 5 for more detailed discussion), would not necessarily be directly tied to individual project sites, but should be incorporated into a larger river wide focus. Funds from individual projects should be allocated for this larger monitoring program. This will allow much more information to be gathered than could be reasonably funded by an individual project and will also provide for population-level monitoring throughout the corridor that would not likely be detectable at a single site.

LOWER PRIORITY PROBLEMS

There are a number of other problems in the watershed that need to be addressed in order for the Corridor to function to its maximum capacity and sustain habitats over time. However, in general they are of lower priority in this strategic approach because they are not the major factors for decline for either fish or wildlife species in the Corridor. The following provides an over view of some of these problems.

Fish Passage Barriers

There are numerous fish passage barriers present in the corridor, primarily located on minor tributaries, either at their confluence with the Sammamish River or further upstream. Although many of these minor tributaries are also degraded, these barriers prevent fish from accessing potential spawning and rearing areas. Removal of fish passage barriers can be implemented relatively quickly as a relatively low-cost way to dramatically increase fish habitat. Removal of fish passage barriers will not solve the most urgent problems in the corridor, but should be considered a "medium" priority to provide a well-connected corridor. There have been some surveys of fish passage barriers conducted by various entities, however, a consistent methodology has not been used throughout the region. We recommend a survey with consistent methods be conducted throughout the corridor that can be used to prioritize barrier removal (see Chapter 5).

Water Quality (Other than Temperature)

In addition to the temperature issues and strategies discussed previously, there are other known water quality problems in the Sammamish River that may adversely affect fish, wildlife, and human use of the corridor. As previously indicated, the Sammamish River is on the 303(d) list for elevated fecal coliform bacteria levels, low dissolved oxygen, and pH. These issues will likely be partially addressed through the riparian restoration strategy and other engineered solutions for decreasing water temperature (particularly dissolved oxygen levels which are directly related to temperature) previously discussed. Currently, the source of fecal coliform bacteria is not known: possible sources include pet waste, waterfowl waste, or other animal waste. There is little opportunity for leaking septic systems to be a source of bacteria, as most of the watershed is connected to the wastewater system. Buffering runoff with riparian areas and wetlands is a potential option for reducing bacterial contamination. Best management practices can be implemented to reduce pet waste and other domestic animal waste, such as buffers along seasonal ditches and other locations of runoff, frequent removal of waste, and public education. Nuisance waterfowl populations can be reduced by increasing riparian vegetation along the river corridor and active programs to discourage geese and other resident waterfowl (egg addling, etc.).

An additional known, but not well studied, water quality problem is elevated turbidity levels following storms, and deposition of fine sediment in the tributary streams. Fine sediment is likely derived from stormwater runoff from roads, parking lots, and cleared areas including agricultural areas and construction sites. This problem will need to be addressed by improved erosion control practices and long-term monitoring and evaluation of turbidity levels and erosion control measures. In some cases, it may be most beneficial to tight-line stormwater runoff around construction sites to decrease turbidity. .

Toxicity was observed in some samples collected in fall 2001 for King County's assessment of sediment and water quality in the Sammamish River. The cause of this observed toxicity has not been identified. More study of this potential cause of toxicity and an evaluation of whether agricultural infiltration basins (wetlands) could reduce this problem are warranted.

Water Quantity

Low flow conditions in the river are primarily a concern for upstream adult salmon migration and effects on water temperature. However, low flows could also concentrate pollutants that are discharged. Summer and late fall low flows are decreased from historic conditions. This overall decrease is suspected to have occurred as a result of increased ground and surface water withdrawals and runoff from impervious or less pervious surfaces that reduces groundwater recharge. Of particular strategic interest, is the opportunity to increase groundwater recharge through creation or restoration of wetlands and use of reclaimed wastewater for percolation through wetlands into the groundwater table. Existing wetlands in the floodplain could be reconnected to the river to allow seasonal inundation and groundwater recharge. Areas with suitably permeable soils should be identified where percolation ponds could be installed to allow percolation of reclaimed wastewater. Much more information is required before any of these proposals could be implemented; see Chapter 5 for recommended studies evaluating groundwater.

Floodplain Habitat

Very little of the historic floodplain has the capacity to serve its historic functions. Lacustrine wetlands where the river connects with Lakes Sammamish and Washington still perform many important ecological functions, including habitat for wildlife, nutrient and sediment retention, and flood storage. These areas should be protected and enhanced with native vegetation. Reconnection of existing floodplain wetlands should also be pursued, particularly to benefit wildlife habitat and groundwater recharge. Care should be taken; however, not to enhance habitat that non-native predators of juvenile salmon and native amphibians would use (such as bullfrogs, bass and other species). Predators often prefer year-round warmwater ponds and sloughs, whereas seasonally inundated floodplains provide more natural habitat for native species. In the Agricultural Production District, one or more palustrine wetlands that are currently farmed or otherwise degraded could be restored with the potential to utilize portions of the sites as nurseries for producing a stock of native wetland plants to maintain viable farming activities and possibly support further wetland restoration projects in the basin.

Overall, the strategic approach outlined in this chapter will address the worst problems in the Sammamish River Corridor: elevated water temperature and lack of aquatic and riparian habitat diversity. By rectifying these problems, the Sammamish River Corridor can begin to function again as a healthy migratory corridor for both fish and wildlife species. While we recognize the corridor will not be fully restored, it will however, be dramatically improved over existing conditions and serve as a strong link between habitats in the larger watershed. Then, as the most severe problems are addressed, other issues that are also contributing to the decline of fish and wildlife populations can be addressed. The next chapter will describe specific project and study recommendations to implement this strategic approach.

Figure 12. Catch per unit effort indices with standard deviation for setback levee test (shaded) and control (clear) survey sites in the Sammamish River, Washington, 2001.

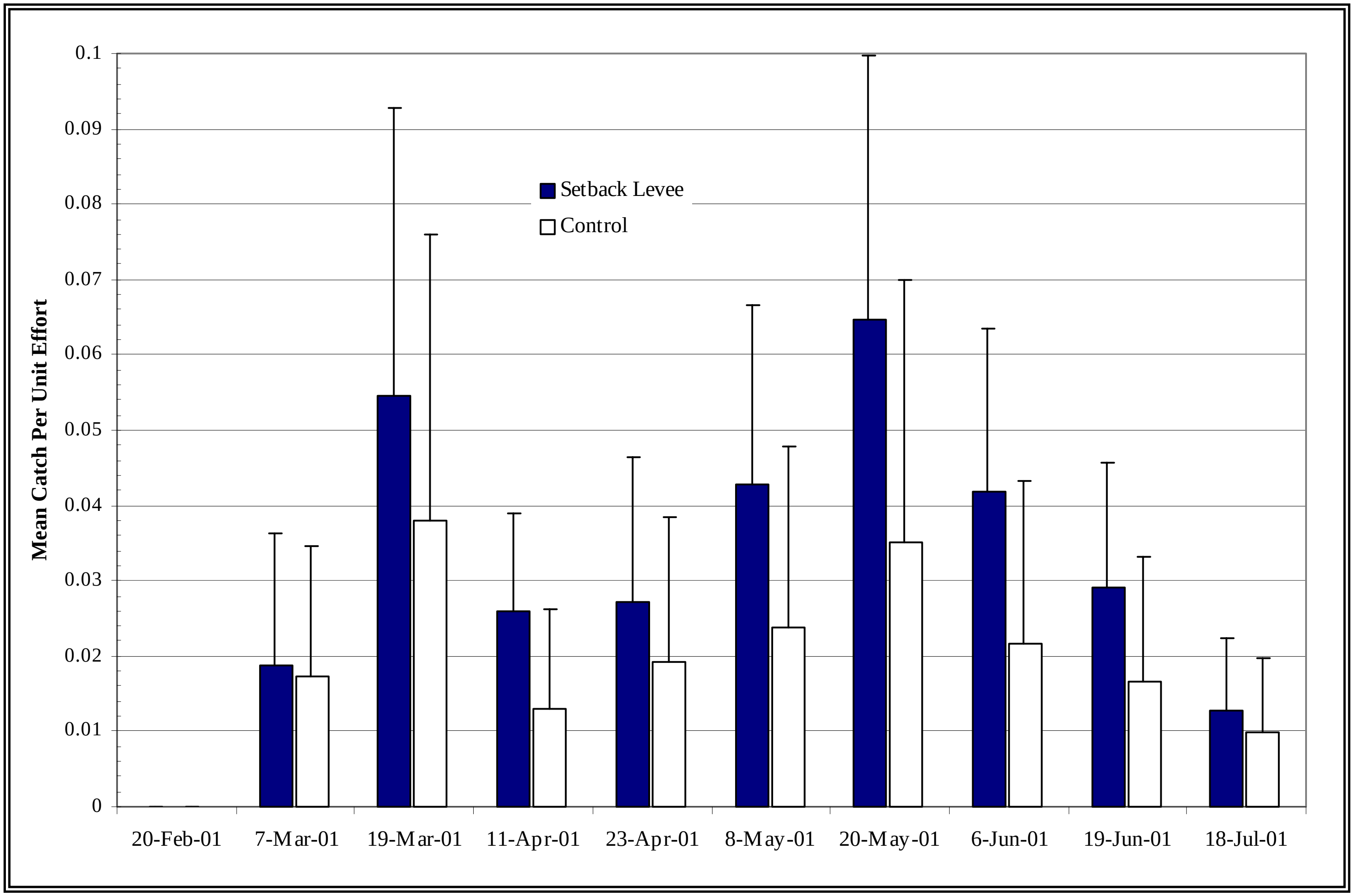


Figure 13. Catch per unit effort indices for large woody debris test (shaded) and control (clear) survey sites in the Sammamish River, Washington, 2001.

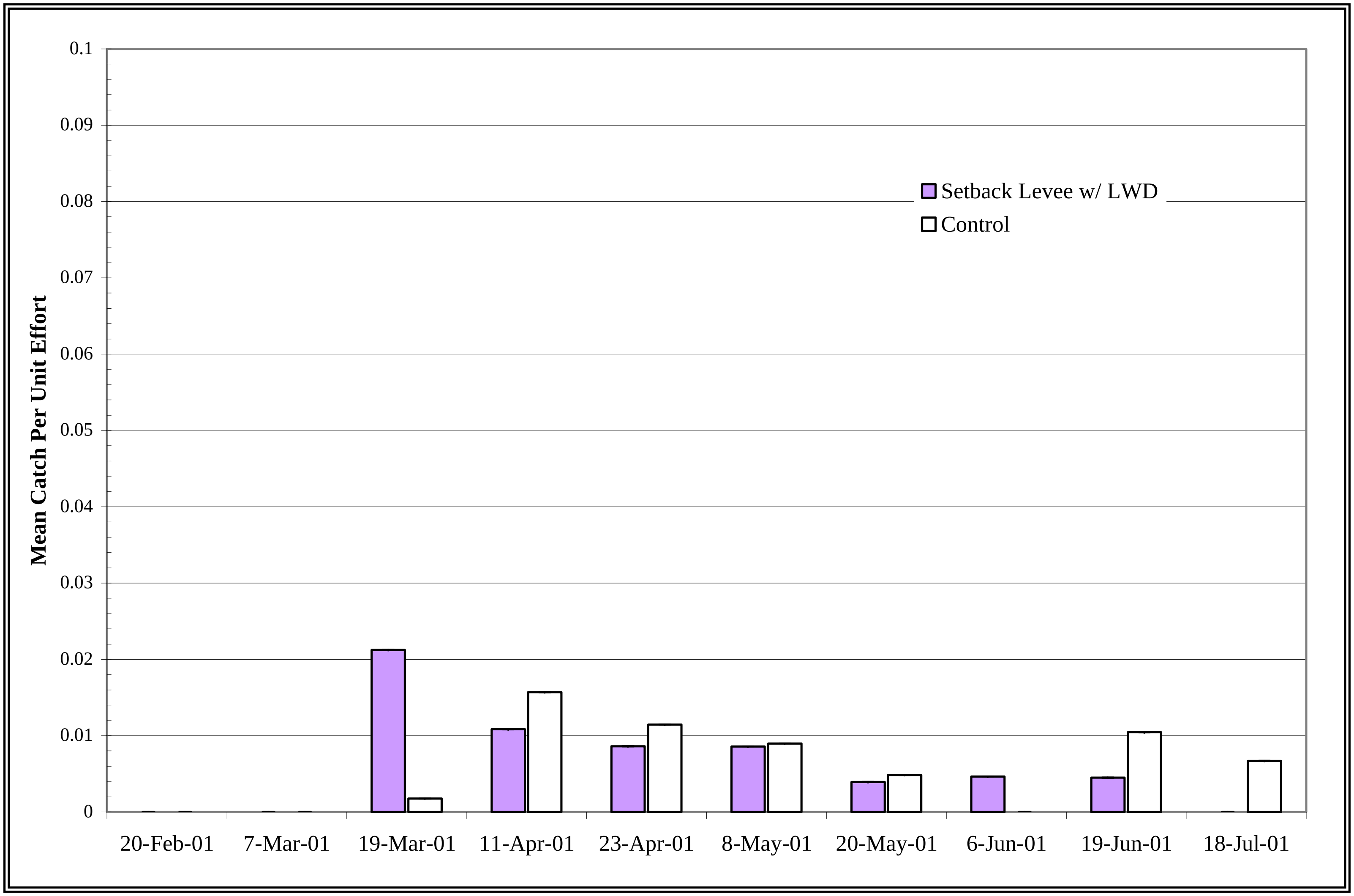
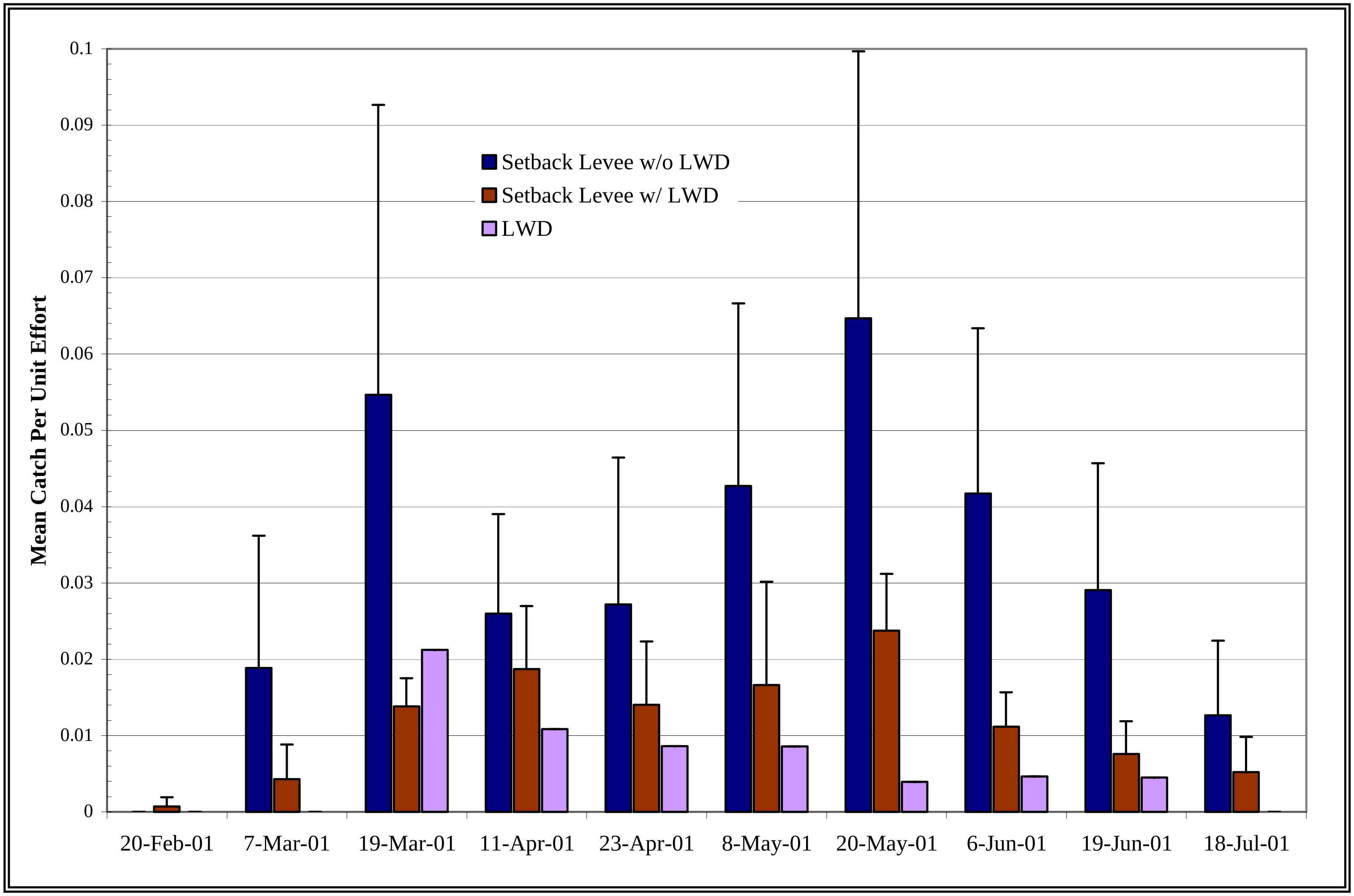


Figure 14. Catch per unit effort indices for setback levees, setback levees containing large woody debris, and large woody debris survey sites in the Sammamish River, Washington, 2001.

From Jeanes and Hilgert, 2001.



CHAPTER 4. RESTORATION ACTION PLAN

In order to actually implement the strategic approach described above in Chapter 3, this chapter presents programmatic and site-specific project recommendations to restore the Sammamish River Corridor to a much better functioning ecosystem that has suitable conditions and habitats for a variety of fish and wildlife species. The strategic approach identified the most critical elements necessary to achieve the goals of a healthy migratory corridor for fish and wildlife, in addition to contributing to the overall recovery of salmon in the greater Lake Washington watershed. Those critical elements are embodied as the first six programmatic action alternatives identified below and comprise the "*core*" recommendations for this Action Plan. These recommendations ***must*** be implemented in order to address the most critical problems in the corridor. Implementation of many of these recommendations will likely require participation of several jurisdictions in the corridor. Additional "*non-core*" programmatic recommendations along with site-specific project recommendations are then presented that will further implement the strategic approach and rectify several sources of degradation in the corridor to achieve an overall well-connected corridor with key habitats for both fish and wildlife. A summary of the programmatic recommendations is presented in Table 6.

The site-specific actions are prioritized according to their ability to both implement the key strategies and address lower priority problems in the Corridor. A prioritized list of recommendations is shown in Tables 7 and 8 at the end of this chapter. Implementation of the recommended Action Plan will dramatically improve the habitat values, water quality conditions, and character of the Sammamish River Corridor and allow it to maintain these functions over the long term.

PROGRAMMATIC RECOMMENDATIONS.

Table 6. Summary of Core and Non-Core Programmatic Recommendations

Programmatic Recommendation	**Designation**
P1. Restore riparian areas throughout the entire Sammamish River Corridor	**Core**
P2. Create and enhance pools in the river channel	**Core**
P3. Protect and improve buffers along the river, tributaries and wetlands	**Core**
P4. Explore engineered solutions to cool the river upstream of Bear Creek (Reach 6)	**Core**
P5. Increase water conservation in the Sammamish Watershed (Particularly the Bear Creek Basin)	**Core**
P6. Acquisition of existing high-value habitats or areas with high likelihood of restoration success	**Core**
P7. Reduce unauthorized water withdrawals	**Core**
P8. Construct demonstration reclaimed water production facility	Non-Core
P9. Tightline stormwater above landslide hazards and steep slopes	Non-Core
P10. Education and incentive program for landowners along the Corridor	Non-Core

P1. Core Recommendation: Restore Riparian Areas Throughout The Entire Sammamish River Corridor.

This is the most important alternative to address temperature problems and provide significant habitat improvements for salmon and wildlife. This alternative includes bank sloping to create shallow water habitat; removal of non-native invasive plant species; and riparian revegetation with native trees, shrubs and herbaceous species. This alternative will be primarily focused on areas that are currently publicly owned, which is approximately 70% of the length of the corridor on both banks, and an additional 20% on the right bank only.

The width of public ownership available for buffer restoration (above OHWM) varies from approximately 25 feet to over 100 feet (7.5 to 30 m). However, a minimum average width of 100 feet (30 m) is recommended for revegetation to provide a variety of buffer functions. Wherever wider buffers can be achieved, they should be in order to provide a more fully functional buffer. This large-scale project cannot be accomplished within a single year (or even two or three years) and will need to be phased over several years, perhaps over a ten-year schedule. It may be most feasible to implement riparian revegetation as trail modifications or maintenance occurs (particularly where it may be opportune to move the trail somewhat further from the river or as the equestrian trail is constructed on the west bank), or in conjunction with larger floodplain projects to minimize mobilization costs. High-priority locations to begin riparian restoration for each reach are identified in the site-specific recommendations section later in this chapter.

The Sammamish River Trail will continue to be located somewhere within the restored riparian buffer. Other activities such as the placement of stormwater detention or percolation ponds should generally not occur within the buffer because they would reduce shading and cause a "break" in the corridor (any large scale facility). However, in areas where streams or ditches enter the river via culverts and other structures, it would be beneficial to daylight the stream or create a wetland at the mouth of the ditch which will both improve fish passage and create wetland habitat.

These publicly owned lands provide a unique opportunity to create wildlife habitat features along with riparian restoration. Specific elements should include placement of aquatic and terrestrial LWD[16], grading to create microtopographic features[17], revegetation with native fruiting shrubs, and inclusion of snags for cavity nesting and foraging bird species.

The placement of LWD along the shoreline may not provide significant salmon habitat benefits, at least for chinook salmon, based on Jeanes and Hilgert (2001) work (refer to Figures 13 and 14). However, LWD should be used experimentally in this large-scale riparian restoration to determine what functions it may provide and whether LWD is more useful in some reaches than others. This experimental LWD study is described further in Chapter 5.

P2. Core Recommendation: Create and Enhance Pools in the River Channel.

Adult salmon frequently migrate through the river during the warmest period of the year (i.e., late summer and early fall). In order to conserve energy, avoid predators (i.e., birds, mammals and humans), avoid warm water and hold until temperature conditions improve[18], adult salmon typically use pools for refuge during their upstream migration to reach spawning areas. Currently, only two areas in the entire river actually meet

[16] LWD in uplands or wetlands provides cover and wintering habitat for native amphibians and reptiles.

[17] Microtopographic relief provides wintering habitat for native amphibians and reptiles during high water periods.

[18] Water temperatures fluctuate daily, but depending on air temperatures may remain elevated for several days at a time.

TFW criteria for depth and cover to be classified as a pool. An additional 27 somewhat deeper than average channel depth areas were identified during field tracking of adult chinook in 1998 and 1999. This small number of pools, and the large distance between them, means that a limited number of salmon can use the pools at any particular time forcing some fish into warmer waters outside of the pools, and fish must sometimes migrate up to a mile between pools. Historically, prior to dredging, it appears that pools were located approximately every 100 to 200 feet (30 to 60 m) in the river (USACE 1962). Pools should be created within the channel profile, and when possible, should be located to take advantage of cool water from tributaries and groundwater inflows. Further, these pools should be designed either with engineered features (i.e. log jams) or placed in specific locations (outside of meander bends or adjacent to bridge piers) that will provide natural scour over time to prevent sediment deposition. Cool water sources include all of the major and most of the minor tributaries, plus groundwater sources.

Pool creation should also include cover features such as LWD or overhanging vegetation. Depth is another form of cover (obscures visual observation of fish). LWD may help sustain pools over time by creating scour. Overhanging vegetation can be provided by constructing pools in connection with riparian restoration efforts described above in recommendation P1 or as part of riparian restoration at specific sites chosen for pool creation. Pools are usually not naturally formed adjacent to shallow bank zones, so bank sloping may not be necessary at pool locations.

This large-scale project should be implemented over several years because, even with more detailed design work and monitoring, it cannot be assumed that all pools will persist and function over time. A few pools in several locations should be initially constructed, focused in the upper river where temperature refuge is most critically needed. These constructed pools should then be monitored for temperature stratification, sediment deposition or scour, and fish use over one to three years. Subsequently, adaptive management should be applied in the design of additional pools depending on the information gained from monitoring.

P3. Core Recommendation: Protect and Improve Buffers Along the River, Tributaries, and Wetlands.

The cities and King County should use their sensitive area protection authority (under the Shoreline Management Act and Growth Management Act) to protect and improve the quality and size of buffers to the Sammamish River, its tributaries and their associated wetlands, consistent with the rights of private property owners. Where existing development or lot sizes has reduced the potential size of buffers, emphasis should be placed on improving the quality of degraded riparian areas through incentives, such as tax reduction programs and conservation easements, as well as conditions placed on future development. To the extent possible, improvements should promote the riparian restoration strategy described in Chapter 3. Literature reviews of riparian buffer functions (R2 Resource Consultants 2001; Wenger 1999) recommend minimum 100-foot buffers to provide multiple functions (e.g., sediment retention, pollutant retention, shading, wildlife habitat). Wider buffers are better, particularly on salmon bearing streams, or where adjoining land uses create a moderate to high risk of environmental risk (pollutant spills, etc.). In the Sammamish River Corridor, wider buffers should be sought for significant habitat nodes, such as tributary mouths, to promote shade and possible localized reductions in air temperatures that could help cool the river. All perennial streams should have 100-foot buffer recommendations and intermittent streams should have 50-foot buffers to prevent degradation from erosion or pollutants.

P4. Core Recommendation: Explore Engineered Solutions to Cool the River Upstream of Bear Creek (Reach 6).

Reach 6 of the river has the most severe temperature problems because of the very warm surface water outflow from Lake Sammamish. Riparian revegetation will have minimal effect on temperature in this reach or in Reach 5. While there may be potential for increased groundwater recharge in Marymoor Park, it would not likely significantly influence the temperature of warm surface water outflow from the lake. We recommend that King County and the Corps immediately undertake a feasibility study of both hypolimnetic withdrawal and cooling tower technology, and possibly construct a demonstration project. More detailed evaluation of these technologies will allow comparison of costs, potential environmental impacts, and potential benefits. Benefits should not only be quantified in terms of temperature, but also into predicted biological effects to better translate temperature reductions into benefits to fish. Other solutions may be developed during these studies that could prove more effective.

P5. Core Recommendation: Increase Water Conservation in the Sammamish Watershed (particularly the Bear Creek Basin).

Improved water conservation in the Sammamish Watershed could help increase and maintain summer base flow conditions and reduce summer water temperature in the Sammamish River. Reduction of either groundwater or surface water withdrawals (or both) could be effective. Conservation efforts that lead to reduced groundwater withdrawal in the Bear Creek basin are particularly important, since the Bear Creek confluence is in the vicinity of where the river experiences its warmest temperatures. The model results described in detail in Appendix B suggest that an increase of approximately 5 cfs in Bear Creek summer flow could significantly reduce thermal stress for salmon in the mainstem river—particularly in Reach 5 immediately downstream of Bear Creek's confluence with the river. The City of Redmond; the water districts of Olympic View, Northeast Sammamish and Union Hill; and the Sahalee and Bear Creek golf courses withdraw the largest volume of water from the Bear Creek basin. King County Parks withdraws water for Marymoor Park and other parks along the mainstem. Modern water supply systems have highly efficient transport of water, however, some water purveyors may find that reduction of leaks in their piping system conserves significant quantities of water. Implementation of a conservation-based rate structure could further increase conservation of water for some utilities. Some utilities already have implemented a conservation-based rate structure and have realized some significant reductions in water use. It is recommended that athletic fields be converted to an alternate type of turf (i.e. “sports turf”) that either does not require irrigation or significantly reduced irrigation. Little Bear, North and Swamp Creeks appear to contribute more flow to the river during low-flow periods than occurred historically (WRIA-8 Technical Subcommittee 2001) as a result of importation of water from outside the basin. However, it is still of critical importance to protect and maintain low flow conditions in these basins because runoff of irrigation water is not nearly as beneficial (and often at higher temperatures) as the natural inflow of groundwater and surface water. Groundwater withdrawals in the valley floor may reduce groundwater inflows or small tributary flows which may also be important for cool water refuges.

P6. Core Recommendation: Acquisition of Existing High-Value Habitats or Areas with High Likelihood of Restoration Success.

In many cases, riparian restoration and other habitat restoration projects in the Sammamish River Corridor will be limited to publicly owned lands because of other land use priorities for private landowners. In order to maximize restoration potential within the corridor, existing high quality habitats or other areas with a high potential for restoration success should be acquired by public entities to ensure they will be protected or restored. In many areas, publicly owned lands along the river are very narrow and this limits the area available for riparian restoration recommended in recommendation P1. Acquisition of a wider easement or fee title should be investigated in these areas (particularly in Reaches 4 and 5) to ensure a minimum 100-foot (30 m) buffer can be established along most of the river. A few vacant parcels exist along the river, such as the former meander across the river from Willows Run Golf Course, and currently face development pressure. These areas have good potential for restoration success and should be acquired to provide future wetland restoration or groundwater recharge sites. Another high quality area is the Cold Creek headwater area (tributary to Bear Creek) that provides a year-round source of cool water and helps maintain cool temperatures in Bear Creek. A large parcel along Bear Creek near the Evans Creek confluence is an ideal location for floodplain and riparian restoration that could also provide significant shading benefits. This parcel is being evaluated for its potential as a mitigation bank. However, whether restoration is accomplished for mitigation purposes or as part of this plan, this should be a high priority for acquisition. It is very critical that these areas do not experience further habitat degradation while restoration projects are being implemented and maturing.

P7. Core Recommendation: Reduce Unauthorized Water Withdrawals.

Based on field observations (by King County staff and other agencies), there appear to be a significant number of unauthorized water withdrawals that likely have an adverse effect on base flow and temperature in the Sammamish River and its tributaries. These include:

- Withdrawals covered by state water right permits, but which are currently un-metered and may exceed their authorized withdrawal volumes.
- Un-permitted withdrawals for which potentially invalid claims have been filed.
- Un-permitted withdrawals for which no claims have been filed.
- Wells that are exempt from requirements for water rights because they withdraw less than 5,000 gallons-per-day, but which may be in violation of other requirements listed below.

The most significant of these un-authorized withdrawals for the river's ecology are those in direct hydraulic continuity with either the river or Bear Creek (the latter for reasons discussed in Recommendation P5). Ecology is taking steps to ensure water right holders install flowmeters (particularly for the largest water withdrawals in the Greater Lake Washington watershed by the end of 2002). Ecology will require meter-monitoring reports to ensure users do not exceed authorized volumes. The sooner that these data are available, the sooner the efficacy and urgency of using reclaimed water to augment or replace existing water withdrawals can be evaluated. We encourage Ecology to prioritize the Sammamish Valley and Bear Creek for metering.

Because legal adjudication of water right claims could take many years, we do not recommend it as a priority at this time. Highest priority, however, should be placed on enforcement against illegal withdrawals. If base flow continues to be a significant problem after metering and enforcement have occurred, then adjudication of claims should be undertaken.

Unauthorized withdrawals identified (or suspected) by state or local field personnel should be reported to Ecology as quickly as possible. Exempt wells cannot be used for commercial nurseries or other non-domestic purposes, or to irrigate more than a total of 1/2-acre across the one or more homes they may serve. Current surface withdrawals should be reviewed both for water rights and for appropriate fish screens. Ecology has jurisdiction over water rights and we do not recommend that other local governments attempt to exert jurisdiction over water rights..

P8. Construct Demonstration Reclaimed Water Production Facility.

By 2004, King County plans to construct a pilot reclaimed water production facility in the Sammamish Valley, which would treat wastewater to Class A standards for non-potable uses. It would serve as a demonstration project for potential expanded use of reclaimed water in the valley and elsewhere in the region. The highest initial priority for the facility would be to replace current surface and groundwater withdrawals from wells believed to be in hydraulic continuity with the river. In the future, reclaimed water could potentially be used to augment groundwater flow to the river if supported by studies discussed in Chapter 5. Based on the model results discussed in Appendix B, a combination of strategies using reclaimed water (including replacement of existing withdrawals and large-scale augmentation of groundwater flow) could potentially reduce thermal stress on salmon in the Sammamish River. King County's initial demonstration facility is expected to produce approximately 3 million gallons per day (about 4.5 cfs in river flow, assuming complete hydraulic continuity between the withdrawals it would replace and the river). It should be designed for future expansion, since the potential uses and demand for reclaimed water in the Sammamish River Corridor are likely far greater than simply replacing existing withdrawals.

P9. Tightline Stormwater Above Landslide Hazards and Steep Slopes.

Large new developments that drain to landslide hazard areas or steep slopes should be required to discharge stormwater into tightlines to provide conveyance beyond the hazard area and to minimize discharge of fine sediments into the Sammamish River and its tributaries. This requirement could be waived if stormwater is discharged to stable drainages, such as road ditches or constructed stormwater conveyance systems. It could also be waived for small residential developments that have less than 10,000 square feet of new impervious surface area and can effectively disperse flows.

P10. Education and Incentive Program for Property Owners Along the Sammamish River Corridor.

Toxicity has been observed in water samples collected from the Sammamish River (King County unpublished data, 2000-2001). It is suspected that pesticides may be the cause of the observed toxicity; however, agricultural users are only one potential source of pesticides. There are a variety of other land uses in the basin that can result in pesticide runoff (i.e., residential use and golf courses). This recommendation would develop an education and, as feasible, an incentive program to reduce pesticide and herbicide use and associated runoff. Methods to reduce runoff include stream and wetland buffers, created wetlands for water quality enhancement, and improved irrigation practices (avoid flood irrigation and excessive sprinkler watering). Discharge of potential contaminants can also be decreased by reduced application of pesticides/herbicides and use of organic or biological (predator insects, etc.) alternatives. This program should be targeted at farmers and commercial, industrial, and residential landowners. The incentive approach could include reduced-cost organic/biological alternatives; reduced-cost native plants for buffer plantings; reduced-cost drip irrigation equipment or irrigation timers/meters, etc. A variety of Best Management Practices may also be suitable to reduce runoff and reduce pesticide/herbicide use (such as spot application of chemicals rather than large-scale application). Replacement of existing golf course or athletic fields with “sports turf” could also minimize pesticide and fertilizer use

The Core programmatic recommendations presented above **must** be implemented to achieve a functioning river corridor and implement the overall strategic approach. Non-core programmatic recommendations are of lower priority because implementation requires significantly more study or time for implementation, or they address less critical problems. However, this does not mean to suggest that non-core ecological integrity of the corridor will be missed and degradation will continue to occur. The next section describes more localized projects that can be implemented by single jurisdictions or otherwise relatively quickly.

SITE-SPECIFIC HABITAT RECOMMENDATIONS, BY REACH

The following section provides a description of specific locations to implement the programmatic recommendations of riparian restoration and pool creation are described for each reach.. Additionally, numbered site-specific project recommendations are included, by reach.

Reach 1

Riparian Restoration in Reach 1 as Part of P1

Several opportunistic locations (either publicly owned or known landowner willingness) exist for riparian restoration in this reach, including Inglewood Golf Course, WDFW boat ramp at Juanita Bridge, Kenmore Park, and the lower half of Wayne Golf Course. However, none of these sites are designated as "high priority" because shading has a greater cumulative temperature benefits when implemented first in the upper half of the river. Riparian restoration in this reach will however, significantly improve wildlife habitat, provide a shallow water migration corridor for juvenile salmon and contribute LWD over the long term. Riparian restoration in this reach should be considered medium priority and implemented as funds are available.

Pool Locations in Reach 1 as Part of P2

Currently, only two somewhat deeper areas exist in this reach. This reach is dominated by backwater from Lake Washington, so thermal refuge may not be as important for migrating salmon because the water column is stratified in this area (i.e., cooler water at the bottom). However, sufficient cover is important for migrating adult salmon. Additionally, the small tributaries that enter this reach may provide a source of cool water for pools if created. The mouths of these small tributaries are moderate priorities for pool creation (at approximately RMs 1.0 and 1.8). Additional lower priority pools could be constructed to provide more frequent holding areas for adult salmon, potentially on the outside of meander bends at approximately RMs 1.5, 1.9, and 2.0. Medium and low priority pools should only be constructed after those identified as high priority have been constructed and subsequently monitored for at least two years to determine if they persist (don’t fill in with sediment), provide cooler water habitat, and are actually used by adult or juvenile salmon.

Other Project Recommendations for Reach 1

1-1. *Sammamish River Mouth Wetland Restoration*. Historically, this area was a vast wetland. Currently, only a minimal area of wetland remains and is highly disturbed. The mouth of the Sammamish River could serve as an important rearing and refuge habitat for juvenile salmon as they enter Lake Washington, particularly for sockeye fry, which have been observed using shallow water and wetland habitat adjacent to the Cedar River mouth. This project would include restoration on King County property, including the island at the mouth of the river. This area is primarily wetland, with a small riparian area. It will first be necessary to remove non-native species (i.e. Himalayan blackberries, purple loosestrife) and revegetate the riparian area up to a 100-foot width with native shrubs and trees, especially including willow, alder, cedar and spruce. Emergent and shrub wetland species that could be planted in the wetland area and toe of slope include species such as *Spirea douglasii*, *Scirpus acutus,* and *Carex aquatilis*. A mixed LWD and small woody debris jam should be placed on the upstream end of the island. This project should be monitored extensively for fish use, particularly for use of the woody debris jam to determine if it provides habitat for native or non-native fish.

1-2. *LakePointe Property Riparian and Aquatic Restoration.* The LakePointe project is a proposal for a mixed-use development to be built on approximately 45 acres (18 hectares) on Lake Washington at the Sammamish River mouth (right bank). The project contemplates including approximately 650,000 square feet of commercial space and 1,200 residential units. King County approved the Master Plan and Shoreline Permit for the project just prior to the City of Kenmore’s incorporation. Upon incorporation, jurisdiction over the project transferred from King County to the City. In August 2001, a consent decree was signed with the State Ecology resolving site clean-up issues for the hydrocarbons and other pollutants present on the site. Preliminary plans were developed to restore and enhance habitat along the Sammamish River and Lake Washington shorelines as part of the Commercial Site Development and Shoreline Permits issued by King County. Detailed plans will be developed as part of the site’s construction permit applications and reviewed by the City of Kenmore for consistency with the previously issued permits. While not required as part of the previously issued permits, it is desirable that this shoreline restoration be consistent with this report’s recommendations for other riparian restoration projects. Some of the desired restoration elements are: decrease bank slope on the Sammamish River shoreline to 3:1 or less; revegetate a minimum 100 foot wide (30m) riparian area on the river bank with native trees and shrubs, especially including willow, alder, cedar and spruce; place gravel substrate at the toe of the slope on the Lake Washington shoreline to provide shallow water habitat; and provide a shallow-water, emergent wetland area along the toe of slope on the Sammamish River shoreline (emergent species to include *Scirpus acutus, Carex obnupta, etc*.)

1-3. *Swamp Creek Regional Park Wetland and Stream Restoration*. Currently, King County is developing plans for restoration of a portion of Swamp Creek and its floodplain downstream of 175th Street. Historically Swamp Creek had a large wetland area within its floodplain. Similar to the Sammamish River, it also likely contained a significant quantity of LWD that created pools, provided overhead cover for fish, and caused meandering of the creek channel. Currently, the creek is confined to a narrow, and relatively straight channel. Wetlands are present in the floodplain, but are not well connected to the creek and fill has been placed in many areas. Restoration element recommendations include: removal of fill material; removal of non-native vegetation (e.g., reed canary grass, Himalayan blackberries); re-meander Swamp Creek across its floodplain; excavate connections and create a diversity of wetland elevations in the floodplain; revegetate the entire site with native trees, shrubs and emergent species; place LWD in jams in the lower creek. Educational trails and signage would provide a good recreational element. It is further recommended that the adjacent parcel to the east that is also undeveloped be acquired and included in the overall plan.

1-4. *Wetland and Riparian Restoration at Wildcliff Shores Property Across River from Swamp Creek.* Directly across the river from the Swamp Creek confluence is a large, relatively undeveloped area, currently in private ownership. This area is also of flat topography and much of the site is wetland. It was formerly farmed, and is currently minimally vegetated with native trees and shrubs and appears to have been recently used for unofficial recreation (trails, biking, etc.). This project would include removal of non-native plant species; excavation to seasonally connect the wetlands to the Sammamish River; sloping of banks; revegetation of the parcel with native trees and shrubs; and placement of terrestrial LWD and snags for wildlife habitat.

Reach 2

Riparian Restoration in Reach 2 as Part of P1

Several opportunistic locations (either publicly owned or known landowner willingness) exist for riparian restoration in this reach, including Blyth Park and King County trail land. Multipurpose projects at the side channel at 102nd Ave and at I-405 are discussed below. None of these locations are classified as "high priority" because shading has greater cumulative temperature benefits when implemented first in the upper half of the river, however, increased vegetation will provide other significant benefits to the corridor and should be considered medium priority. Riparian restoration at the mouth of North Creek should be considered a high priority to provide enhanced habitat at an important tributary junction and connect restored habitat upstream on North Creek to the Sammamish River.

Pools in Reach 2 as Part of P2

This reach has a greater frequency of deeper areas per mile than all other reaches. However, it still contains only six such areas. This reach receives significant groundwater flow from Norway Hill that could potentially be utilized to create cool water refuge pools. No specific locations are yet identified, but the groundwater seep area extends from approximately RM 3 to 4.5. Four small tributaries also enter this reach at approximately RMs 2.6 (Wayne Golf Course), 3.4, 4.2, and 4.3. These cool water pools should all be considered high priority, because of the known groundwater seeps and tributaries. As a pilot project, it would be beneficial to construct a couple of pools in this reach and then monitor temperature, sediment deposition and other factors before constructing additional pools throughout this reach.

Other Project Recommendations for Reach 2

2-1. *Improve Tributary 0068 Confluence and Upstream Reaches*. Tributary 0068 enters the river through the Wayne Golf Course. It is a fairly extensive system arising on Norway Hill, which includes tributaries 0067 and 0066, and likely has extensive groundwater inputs. This system should be both protected and enhanced by restoring a riparian area and allowing the channel to meander and a natural delta to form at the mouth if enough coarse sediment is coming out of the system. It is unknown if there are any fish passage barriers, however, this should be investigated (see Chapter 5). Other restoration elements include removal of non-native vegetation and placement of LWD in the creek channel[19]. This tributary may provide a significant migration corridor for wildlife from the forested uplands down to the river.

2-2. *Wetland Restoration on Right Bank in Bothell*. Two undeveloped parcels located on the right bank downstream of the 102nd Avenue bridge were previously classified as wetland (NWI 1982). A portion of both properties could be restored to seasonally inundated wetlands with small channels connecting them to the river. Restoration elements could include removal of non-native vegetation; creation of wetlands and channels; riparian and wetland revegetation with native trees, shrubs and emergents; placement of LWD in wetlands, channels and river shoreline; and placement of snags and upland topographic features for enhancement of wildlife habitat.

2-3. *Side Channel Restoration Near 102nd Avenue*. This property is owned by King County and remnants of former wetlands and channel meanders exist both upstream and downstream of the 102nd Avenue bridge on the left bank. In conjunction with riparian restoration, a side channel could be restored in this area, along with seasonally inundated wetlands. Restoration elements could include removal of non-native vegetation; removal of fill material; excavation of connections to the side channel and wetlands; riparian and wetland revegetation with native trees, shrubs and emergents; and placement of LWD in side channel, wetlands, and river shoreline. Constraints on restoration will be the bridge abutments.

2-4. *Investigate Restoration Opportunities at Minor Tributaries (Tribs 0057A, 0069).* The small tributaries entering this reach should be investigated for habitat preservation and enhancement opportunities. Some restoration has already been done at Horse Creek (0057), but additional measures may be warranted to create a cool-water refuge. There may also be fish passage barriers in these tributaries.

Reach 3

Riparian Restoration in Reach 3 as Part of P1

Riparian restoration adjacent to and downstream of the Little Bear Creek confluence should be considered a very high priority. Little Bear Creek is a significant cool water source for the river, which should be maintained with shading along the Sammamish River downstream of the confluence. The right bank of the corridor in this reach is owned by King County, and should also be considered high priority because there is currently very little riparian vegetation in this reach.

Pools in Reach 3 as Part of P2

This reach has five deeper areas that are widely spaced apart (up to a mile between some areas). These areas are associated with bridge piers or the outside of meander bends. Several small tributaries enter this reach and would be prime locations for pools, including at approximately RMs 4.7, 4.9, 6.3, 6.9, 7.0, and 7.4. The Little Bear and Gold Creek confluences should be considered the highest priority for pool creation in this reach. A particularly long stretch without pools exists between RMs 6.1 and 7.1, and the Gold Creek confluence is within this area. There may also be opportunities in this reach to use existing groundwater wells that are no longer in use as a source of cool water that could be diverted into a created pool.

[19] For this project and several other site-specific projects, we recommend the placement of LWD in the tributary streams where it should function to provide cover and form pools. This is in contrast to the recommendations for the mainstem Sammamish River, which propose to place LWD only experimentally because evidence suggests that it does not function the same way in the larger river as in the small tributaries.

Other Project Recommendations for Reach 3

3-1. *Restore Wetlands and Riparian Area Adjacent to I-405/Highway 522 Interchange*. Land on the right bank owned by the Washington State Department of Transportation (WSDOT) adjacent to the I-405/Highway 522 interchange could be restored. The King County trail parallels this bank Currently, the bank slope is steep and rarely overtops; the riparian area is limited. Restoration elements could include creation of wetlands and small channels to connect the wetlands to North Creek and the Sammamish River; removal of non-native vegetation; and revegetation of riparian and wetland areas with native trees, shrubs and emergent species. Revegetation will be constrained by the highway bridges that will shade the site, but shade-tolerant shrubs and herbs could be planted in these areas. Another constraint will be the need to prevent undermining of any bridge structures and requirements for highway maintenance access roads.

3-2. *Side Channel and Wetland Restoration on East Bank.* There are remnants of a former river meander and wetland area near Gold Creek that could be restored; and portions of the site could be used as a demonstration nursery for wetland plants in order to provide agricultural income for the property owner. If the property can be acquired for restoration, features could include removal of non-native vegetation; creation of a side channel and wetlands; revegetation of riparian and wetland areas with native trees, shrubs and emergent plants; and placement of terrestrial LWD and microtopographic variation for wildlife habitat. .

3-3. *Investigate Restoration Opportunities at Minor Tributaries (Gold, Woodin and Derby Creeks)*. Three small tributaries, Gold, Woodin, and Derby Creeks, enter the River on the right bank, upstream of Little Bear Creek. The very lower reaches of both Gold and Woodin Creeks have been restored by King County (primarily for fish passage), but there may be additional opportunity for both habitat preservation and enhancement, particularly within Gold Creek Park. There may be additional fish passage barriers that need removal in these systems. All of these tributaries contribute cool water to the river during much of the year; this function should be maintained.

Reach 4

Riparian Restoration in Reach 4 as Part of P1

This reach has virtually no existing native riparian vegetation, other than the few small areas that have recently been restored. However, both sides of the river are owned by King County. Of high priority in this reach would be riparian restoration in areas adjacent to existing or proposed creation of pools, such as upstream and downstream of 124th Street and along the stretch between Tributary 0101 and 0098 (RM 10 - 10.5). There are several wider areas (Sammamish River Regional Park) in this reach where riparian restoration could extend beyond 100 feet; these areas should be high priority for restoration. Additionally, this reach would be ideal to experiment with placement of LWD and small woody debris along the shallow banks and monitoring to determine if fish are using such habitat features in this reach.

Pools in Reach 4 as Part of P2

A two-mile long stretch with only two deeper areas exists between 145th and 116th Streets (deeper areas are only a foot or so deeper than the main channel). A limited number of small tributaries enter this reach; however two of them may provide a source of cool water at approximately RM 8 and 9. Additionally, pools should be created further upstream at the mouths of Tributaries 0101 and 0098. There may be a potential to utilize existing groundwater wells currently not in use as a source of cool water that could be diverted to created pools. Additionally, this reach would be ideal to experiment with using LWD to create and maintain scour pools.

Other Project Recommendations for Reach 4

4-1. *Restore Small Meanders in Reach 4*. Reach 4 is the most straightened reach of the river and as such does not naturally form pools and other habitat features. If it is feasible and compatible with the Farmland Preservation Program (FPP), restoration of small meanders should be considered in this reach (similar to the scale of the meanders within Redmond's RiverWalk). This project could be done in conjunction with recommendations P1 and P2, to restore riparian vegetation and pools to Reach 4 where they are critically needed. These small meanders will not significantly increase river length and may allow for natural maintenance of pools, and also create a diversity of velocities in the reach.

4-2. *Minor Tributary Restoration*. A habitat survey of the lower 1,650 feet (500 m) of Tributaries 0095 and 0101 was conducted in 1999 (Jeanes and Hilgert 1999). Tributary 0095 flows in an agricultural ditch and has a perched culvert during low to moderate flow conditions. Tributary 0101 has moderate canopy cover and some medium sized LWD. All of the small tributaries in Reach 4 could contribute cool water to the river, which is very important in this reach where significant heating occurs. Restoration of the riparian areas would help maintain cooler temperatures; placement of LWD would provide additional aquatic habitat diversity. On the tributaries with impassable culverts, the culverts should be replaced with a culvert at an appropriate elevation or an open channel. Mitigation is planned for the lower end of Tributary 0095 as part of a King County Roads project, however, additional restoration measures should also be investigated.

4-3. *Wetland and Side Channel Restoration on Right Bank Across from Willows Run Golf Course*. A large parcel(s) (about 80 acres) exists on the right bank across from Willows Run Golf Course. This parcel may be slated for development in the near future. It is the site of former channel meander and may still contain wetlands. It is recommended that a side channel and floodplain wetland habitat be restored to at least a portion of the site. Restoration elements could include removal of non-native vegetation, excavation of side channel and wetlands, revegetation of riparian and wetland areas with native trees, shrubs and emergent plants, and placement of LWD in restored or created side channel, wetlands and at river confluences. A significant constraint on this site is the location of the King County sewer line under the trail, which will make construction of an open channel for reconnection more difficult; a culvert connection may be the best option.

4-4. *Riparian and Wetland Restoration in Willows Run Golf Course*. This project was not included in recommendation P1 because it is unknown if the landowner is willing to provide restoration features; however, it is a significant opportunity for riparian restoration, with additional wetland opportunities. There is also the potential to connect some of the ponds/wetlands in the Golf Course to the river channel for groundwater recharge and potential juvenile salmon rearing, although water quality and pesticide/herbicide use by the golf course should be investigated first. These areas could provide fish habitat if they were emergent wetlands rather than ponds, which can experience high temperatures. Currently the golf course has minimal trees or shrubs, but more could be planted in several areas without decreasing playing surface.

Reach 5

Riparian Restoration in Reach 5 as Part of P1

This reach, within the City of Redmond, has already had several riparian restoration projects constructed as part of RiverWalk. There may be opportunities to widen the riparian area in RiverWalk areas. The City of Redmond should continue to complete their RiverWalk plans as a high priority because riparian restoration in these upper reaches likely provides the most cumulative benefit to the river for shading. We also recommend reducing use of boulders and LWD in future sections as there is limited information on their benefit. In addition, this would provide an opportunity to compare sections with LWD and/or boulders to areas without. A particularly important section to restore is adjacent to and downstream of Bear Creek. This should be implemented as a high priority regardless of whether the lower Bear Creek project is implemented in the near future (see below).

Pools in Reach 5 as Part of P2

There are several deeper areas within this reach; however, this is the second most critical reach to provide cool water refuges (after Reach 6). The existing deeper areas should be enhanced by further excavation and provision of cover (they are currently too shallow to be considered pools under the TFW criteria). Also, as the highest priority in this reach, a pool should be created or enhanced (there is an existing deeper area here) at the mouth of Bear Creek with an LWD jam or similar feature to reduce mixing of water and promote scour.

5-1 *Minor Tributaries Restoration*. Some restoration has already occurred on Peters Creek and Tributary 0102 to provide fish passage and increase riparian revegetation. Tributary 0104 would benefit from similar restoration, particularly fish passage improvements.

5-2 *Lower Bear Creek Floodplain and Channel Restoration*. The Corps of Engineers and the City of Redmond have developed final designs for remeandering lower Bear Creek with pools and riffles and other aquatic habitat features, floodplain wetlands and extensive riparian revegetation. This project is highly recommended and will provide improved habitat in lower Bear Creek, as well as provide groundwater recharge and help maintain or reduce temperature in Bear Creek. An additional feature that should be added (P2) is to place an LWD jam on the upstream side of the outlet to the river and create a large holding pool. LWD in this instance will be primarily used to reduce immediate mixing of the cooler Bear Creek water with river water and provide scour for a cold-water refuge pool for fish in the upper river. This project will also provide a wildlife corridor to the restored habitat upstream (WSDOT project).

Reach 6

Riparian Restoration in Reach 6 as Part of P1

A number of riparian restoration projects have been implemented in this reach; however it should still be considered a very high priority to complete riparian restoration throughout this corridor between Lake Sammamish and Bear Creek, and because riparian restoration in the upper reaches likely provides the most cumulative benefit to the river. Riparian restoration adjacent to existing pools and areas proposed for pool creation would be the highest priority. The use of LWD may be the most beneficial in this reach because it has a higher gradient than the other reaches .

Pools in Reach 6 as Part of P2

There are only two deeper areas or pools in this reach, and they are critically important due to the elevated temperatures in this reach. This reach should be considered the highest priority for enhancement and pool creation, particularly at small tributary outlets, at the meander bend downstream of the transition zone, and just downstream of the weir. Additional pools should also be created downstream of the Marymoor Park entrance road on the outside of the large meander bend. There is no apparent benefit to providing pools upstream of the weir.

6-1. *Restore Transition Zone*. The transition zone downstream of the weir eliminated a left meander of the river, but remnants of the meander still remain on the left bank as wetlands. Restoration of the left meander as either the main channel or a seasonal channel with wetlands is recommended. Restoration elements could include excavation of new channel, pools, and wetlands; removal of non-native vegetation; placement of gravel substrate in the new channel; and revegetation of riparian and wetland areas with native trees, shrubs, and emergent plants.

PRIORITIZATION OF RECOMMENDED ACTIONS

The programmatic alternatives described in the first part of this chapter are already ranked according to whether they are "core" or "non-core" recommendations. The "core" recommendations significantly contribute to achieving the goal of restoring the Sammamish River Corridor and addressing the critical elevated water temperature and migration problems for salmon and are numerically listed in order of priority. The "core" projects will immediately begin to address the elevated water temperature issue in the system by protecting existing cool water sources, and beginning to restore the riparian area and increasing shading. They will also provide specific aquatic habitat features of value to migrating juvenile and adult salmon and investigate potential solutions to the primary cause of elevated water temperature (i.e., outflow from Lake Sammamish). Recommendations P8 through P10 are considered "non-core" recommendations that will address more difficult and long-term issues associated with possible replacement of water withdrawals with reclaimed water, sediment inputs and education/incentives for landowners. However, they will not immediately provide benefits that address the critical problems.

The site-specific alternatives are further rated below in Table 7 by listing whether they address either the most critical problems and other factors of declined in the watershed such as fish passage, water quality problems (other than temperature), water quantity and base flow issues, habitat complexity, and wildlife habitat features. The rating is qualitative and is intended to only demonstrate a relative scale of benefit.

Table 7. Rating of site-specific recommendations based on ability to address other limiting factors.

Recommendation	Water Temperature	Fish Barriers	Water Quality (not temperature)	Water Quantity	Habitat Complexity	Wildlife Habitat
1-1. Sammamish River Mouth Wetlands					X	X
1-2. LakePointe Property			X		X	
1-3. Swamp Creek Park	X		X	X	X	X
1-4. WildCliff Shores				X	X	X
2-1. Tributary 0068	X	X			X	
2-2. Right Bank in Bothell					X	X
2-3. Side Channel at 102nd Avenue					X	X
3-1. I-405/522 Wetlands				X	X	X
3-2. Side Channel/ Wetland Near Gold Creek				X	X	X
3-3. Minor Tribs, Reach 3	X	X			X	
4-1. Small Meanders in Reach 4					X	
4-2. Minor Tribs, Reach 4	X	X			X	
4-3. Wetlands Across from Willows Run				X	X	X
4-4. Willows Run	X				X	X
5-1. Minor Tribs, Reach 5	X	X			X	
5-2. Lower Bear Creek	X		X	X	X	X
6-1. Transition Zone	X				X	X

The site-specific projects are ranked below by three categories high, medium, and low priority, based on the number of factors they address (Table 7). A relative scale of cost is also provided for each recommendation, based on construction costs of similar types of projects in the basin (the cost estimate provided here does not include real estate or operation and maintenance [O&M] costs). The reader should not consider these estimates to be more accurate than a preliminary conceptual cost. Low cost is less than $100,000; medium cost is $100,000 to $1 million; high cost is $1 million to $5 million; and very high cost is more than $5 million.

High Priority Site-Specific Recommendations

1-3	Swamp Creek Regional Park Wetland and Stream Restoration	***High Cost***
5-2	Lower Bear Creek Floodplain and Channel Restoration	***High Cost***

These two projects contribute significantly to implementation of key strategies in this plan and further address several other limiting factors in the corridor. These two projects will significantly enhance the lower end and confluence area of two major tributaries, providing cool water refuge, and significantly benefit fish and wildlife migration corridors.

Medium Priority Site-Specific Recommendations

1-4	Wildcliff Shores Wetland and Riparian Restoration	***Medium Cost***
2-1	Tributary 0068 Confluence and Upstream Reaches	***Medium Cost***
3-1	I-405/Hwy 522 Interchange Wetland and Riparian Restoration	***Medium Cost***
3-2	Side Channel/Wetland Restoration Near Gold Creek	***Medium Cost***
3-3	Minor Tributaries, Reach 3	***Medium Cost***
4-2	Minor Tributaries, Reach 4	***Medium Cost***
4-3	Wetland Restoration Across from Willows Run	***High Cost***
4-4	Willows Run Riparian and Wetland Restoration	***Low Cost***
5-1	Minor Tributaries, Reach 5	***Medium Cost***
6-1	Transition Zone Channel and Riparian Restoration	***High Cost***

These projects primarily are floodplain wetland or minor tributary enhancements (which includes riparian restoration and removal of fish passage barriers). These projects should be considered important for creating the well-connected river corridor and providing key locations for wildlife habitat. They make minor contributions to the implementation of the key strategies in this plan and provide other important features.

Low Priority Site-Specific Recommendations

1-1	Sammamish River Mouth Wetlands	***Low Cost***
1-2	LakePointe Property Riparian and Shoreline Restoration	***Low Cost (to public)***
2-2	Right Bank Wetland and Riparian Restoration in Bothell	***Medium Cost***
2-3	Side Channel at 102nd Avenue	***Medium Cost***
4-1	Small Meanders in Reach 4	***Medium Cost***

These projects provide minimal contributions to the key strategies in this plan and also only address one or two limiting factors. They do contribute to formation of a well-connected corridor. These projects may be lower priorities for implementation under this Action Plan, but in the case of the LakePointe project, will be required for regulatory purposes. Further, the wetlands at the mouth of the river are important for wildlife habitat and may provide fish habitat. Restoration at this site can be achieved for very low cost and so should be opportunistically implemented if funds are available.

PLAN IMPLEMENTATION

Potential lead implementing agencies for each of the recommendations are identified in the following Tables 8 and 9. The relative scale of cost is reiterated here for future planning purposes. The "core" recommended actions are primarily large-scale, thus requiring significant funds and a long-term commitment to implementation.

Table 8. Core and High-Priority Recommendations

Core Recommendations	Potential Lead Implementing Agency	Relative Scale of Cost
P1. Restore Riparian Areas Throughout The Entire River Corridor	King County/Corps/Cities	Very High ($5-6 mil)
P2. Create and Enhance Pools in the River Channel	King County/Corps/Cities	Very High ($5-6 mil)
P3. Protect and Improve Buffers Along the River, Tributaries and Wetlands	King County/Cities	Low (primarily regulatory)
P4. Explore Engineered Solutions to Cool the River Upstream of Bear Creek (Reach 6)	Corps/King County	High ($1 mil for studies + demo project)
P5. Increased Water Conservation in the Sammamish Watershed	Ecology/Utilities/Water rights holders	Medium ($500K- $1 mil for incentives, etc.)
P6. Acquisition of Existing High-Value Habitats or Areas With High Likelihood of Restoration Success	King County/Cities	High ($10 mil at least)
P7. Reduce Unauthorized Water Withdrawals	Ecology	Medium (primarily enforcement)
High Priority Site-Specific Recommendations		
1-3. Swamp Creek Regional Park Wetland and Stream Restoration	King County/Corps	High ($5 mil)
5-2. Lower Bear Creek Floodplain and Channel Restoration	Corps/City of Redmond	High ($4 mil)

Implementation of these core and high priority projects would cost an estimated $33 million shared between federal, state and local governments over ten years of implementation (not including real estate costs or O&M).

Table 9. Non-Core and Medium to Low Priority Recommendations

Non-Core Recommendations	Potential Lead Implementing Agency	Relative Scale of Cost
P8. Construct Demonstration Reclaimed Water Production Facility	King County	Very High ($10 mil+ *already planning for other reasons*)
P9. Tightline Stormwater Above Landslide Hazards and Steep Slopes	King County/Cities	Low (regulatory)
P10. Education and Incentive Program for Property Owners Along the Sammamish River Corridor	King County/Cities	Medium ($150K/yr)
Medium Priority Site-Specific Recommendations		
1-4. Wildcliff Shores Wetland and Riparian Restoration	City of Kenmore/private landowner(s)	Medium ($200K public)
2-1. Tributary 0068 Confluence and Upstream Reaches	City of Bothell	Medium ($300K)
3-1. 405/Hwy 522 Interchange Wetland and Riparian Restoration	WSDOT/City of Bothell	Medium ($300-500K)
3-2. Side Channel/Wetland Restoration Near Gold Creek	King County	Medium ($500K)
3-3. Minor Tributaries, Reach 3	City of Woodinville	Medium ($500K)
4-2. Minor Tributaries, Reach 4	City of Redmond	Medium ($500K)
4-3. Wetland Restoration Across from Willows Run	City of Redmond	High ($1 mil)
4-4. Willows Run Riparian and Wetland Restoration	City of Redmond/Golf course	Low ($100K public)
5-1. Minor Tributaries, Reach 5	City of Redmond	Medium ($500K)
6-1. Transition Zone Channel and Riparian Restoration	King County/Corps	High ($2 mil)
Low Priority Site-Specific Recommendations		
1-1. Sammamish River Mouth Wetlands	King County	Low ($100K)
1-2. LakePointe Property Riparian and Shoreline Restoration	Private Developer	Low (<$50K public)
2-2. Right Bank Wetland and Riparian Restoration in Bothell	City of Bothell	Medium ($250K)
2-3. Side Channel at 102nd Avenue	King County	Medium ($300-500K)
4-1. Small Meanders in Reach 4	King County	High ($1 mil+)

Implementation of the "non-core" and medium and low priority projects would cost approximately $20 million. However, the most expensive project, the demonstration facility for reclaimed water (P8) is already being pursued by King County as part of their wastewater management planning. The other projects entail approximately $10 million.

Implementation of ***all*** of the above recommendations and the research and monitoring recommendations described below in Chapter 5 would result in a dramatically changed Sammamish River Corridor. Of particular interest to the citizens of the greater Lake Washington watershed will be how this Action Plan will contribute to the recovery of salmon species. Implementation of the above recommendations will significantly contribute to reversing the trend that has caused the corridor to not function properly for salmonids. Water temperature would be reduced throughout the river, although temperatures could still occasionally exceed 64° F (17° C)[20] the stress on salmon species will be dramatically reduced. Runoff of fine sediment and other pollutants would likely be reduced as a result of riparian improvements and regulatory actions. Salmon would be able to freely migrate upstream and downstream to all available spawning and rearing areas as passage barriers are removed. The riparian corridor would provide shade, small and large woody debris to the river, overhanging cover, buffering of surface water runoff, and significantly enhanced wildlife habitat and migration corridors. Pools would be frequent and provide thermal refuge and cover for juvenile and adult salmon. There would be a diversity of aquatic habitat types including pools, riffles, glides, and shallow water bank habitat, with significant cover in the form of LWD, small woody debris, and overhanging vegetation. Remaining floodplain wetlands would seasonally flood and provide groundwater recharge and significant areas of wildlife habitat. The tributaries would be protected and provide high quality spawning and rearing habitats and migration corridors for wildlife. Recreational and educational opportunities would be significantly enhanced and more diverse. The corridor would provide significant ecological functioning and provide the surrounding communities with a healthy and beautiful recreational feature. (See Figures 15 to 21 for with-restoration view of the reaches.)

Implementation of the core and high priority actions is necessary to address the most severe problems in the corridor. Implementing only these actions will reduce water temperature throughout the river, and provide riparian and aquatic habitat benefits. The tributaries would be protected and some would be enhanced. However, a cohesive and well-connected corridor would be lacking, and opportunities would likely be missed to restore wetland habitat and remove fish passage barriers. The Corridor would provide a healthy migration corridor for salmon, and to a lesser extent wildlife, but its functioning would not have been maximized and continued degradation could occur. However, the corridor would be significantly improved.

Overall, it is expected that full implementation of the programmatic and site-specific actions will cost approximately $53 million over the next 10 years (not including real estate costs or O&M).

IMPLEMENTATION AND PERMITTING ISSUES

The recommendations identified in this Action Plan are conceptual in nature. Further design work will be necessary to implement any of these proposed actions. Additional information necessary for design work includes detailed topographic survey information, location of utilities and other constraints, acquisition of real estate interests, hydraulic modeling, floodplain and flood control effects, and permitting.

All restoration actions will require some measure of environmental documentation and permitting. All projects will need to comply with the State Environmental Policy Act (SEPA) and projects with a federal connection will need to comply with the National Environmental Policy Act (NEPA). Projects that occur

[20] 64 F (17 C) was considered in the temperature model (Appendix B) to be the point at which salmon experience significant stress. and NMFS considers temperatures above this to be not properly functioning for salmon migration and rearing (NMFS, 1996).

below the ordinary high water mark (OHWM) will need to comply with Sections 404 and 401 of the Clean Water Act (CWA). Any construction activity over 5 acres in size will need to comply with stormwater regulations under the National Pollutant Discharge Elimination System (NPDES). Actions that modify a waterbody or its banks may need a Hydraulic Project Approval (HPA). All construction actions will need to comply with local (city and/or county) grading and erosion control rules. Expedited permits are available for both Section 404 and the HPA for some restoration activities. The expedited HPA process allows a waiver of local grading permits for qualifying projects. All projects with a federal connection will require consultation under ESA. All projects must also include an appropriate level of cultural resource investigation to ensure that historic or archaeological sites are not damaged or destroyed. There are several known archaeological sites within Marymoor Park and there are likely to be other sites in the corridor.

The Corps of Engineers may undertake a number of these projects with their Lake Washington Basin Ecosystem Restoration Study. Programmatic environmental documents will be prepared for those projects.

Table 10 identifies the permits and compliance requirements that may be applicable to the recommended projects.

Table 10. Potential Permitting Requirements for Recommended Restoration Actions

NEPA	Prepare programmatic or individual EAs or EISs
National Historic Preservation Act	Investigate site for potential historic or cultural features and coordinate with State Historic Preservation Officer and tribes
Clean Water Act	Section 404 permit, Section 401 Water Quality Certification, NPDES construction stormwater, NPDES if point source discharge
Endangered Species Act	Consult as required for federal nexus, ensure no “take” for non-federal projects
Coastal Zone Management Act	Ensure consistency
Executive Orders 11988 (Floodplain Mgmt) and 11990 (Protection of Wetlands)	Ensure consistency with Executive Orders for federal projects
Fish and Wildlife Coordination Act	For Corps projects, must consult with the US Fish & Wildlife Service
State Environmental Policy Act	Prepare appropriate programmatic or individual documents (EIS, EA, or checklist)
Washington Hydraulic Code	HPA
City or County Development and Land Use Regulations and Sensitive Area Ordinances	Grading Permits, Substantial Development Permits, Erosion Control Plans

CHAPTER 5. RESEARCH, MONITORING, AND ADAPTIVE MANAGEMENT

In order to fully implement the key strategies in this plan, determine if some of the longer-term recommendations are feasible, and learn which projects provide significant habitat and water quality benefits, a program of further research and monitoring and adaptive management is proposed. This is a critical element of the strategic approach of the plan. Without further research and monitoring, it will be difficult to determine if any of the projects have achieved their expected benefits, and additional opportunities to further protect and enhance the corridor will be missed. Additionally, we recommend the creation of a central database where data from all further research and monitoring studies can be collected and accessible to interested parties. King County may be the most appropriate agency to maintain this database.

PROPOSED ADDITIONAL STUDIES NEEDED TO FULLY IMPLEMENT THE ACTION PLAN

S-1. *Evaluate Engineered Solutions to Cool the River Upstream of Bear Creek*. This study is recommended as a programmatic action (P4), but should be designed as a study to evaluate the costs and potential effects of both hypolimnetic withdrawal from Lake Sammamish and cooling tower technology and other alternatives that may be identified during the study. Estimated cost $300K (already included as part of P4).

S-2. *Update Flood Conveyance Model*. King County and the Corps of Engineers should update the flood conveyance model based on expected conditions from implementation of this Action Plan. This should occur as soon as possible in order to allow time to correctly design of restoration alternatives to ensure there is no increase in floodwater surface elevations as a result of any of these actions. Estimated cost $100K.

S-3. *Monitor Temperature Regime in Major Tributaries and Determine if Additional Restoration Measures are Warranted to Protect and Enhance Cool Water Inputs to the Sammamish River*. Develop standard protocols for use of continuous recording thermographs and collect temperature data in several locations in Swamp, North, Little Bear, and Bear Creeks to determine if reaches are contributing to increases in water temperature. In areas of measurable heating (e.g., more than 1°C of heating) , document riparian conditions and opportunities for riparian improvements and other features that affect temperature (e.g., riprap, bulkheads, agricultural runoff, etc.). Estimated cost $100K.

S-4. *Collect Additional Temperature Data in the Lower River to Further Calibrate Temperature Model.* Recommend collecting additional data (temperature and water elevations) in Reaches 1 and 2 to better understand how stratification caused by Lake Washington backwater impacts model results. Also conduct further longitudinal temperature monitoring and dye studies to provide travel time estimates. Also, use tributary data collected for S-1, above to allow the model to more accurately predict the effects of various restoration measures on water temperature. Estimated cost $100K.

S-5. *Evaluate Groundwater Inflows at Norway Hill*. Continued development is occurring in the Norway Hill area and may reduce groundwater recharge over time due to increased impervious surface area. A study to determine if groundwater flow into the river is from shallow or deep aquifers should be conducted to determine the potential effects of increased impervious surface area and possible mitigation measures that could be enacted. Estimated cost $100K.

S-6. *Continue Groundwater Studies*. King County has already conducted some initial investigations into presence and quality of groundwater in the corridor. These studies should be continued to determine the location, volume, and water quality condition of the groundwater table, particularly in Reach 3-6.

If any groundwater sources are potentially appropriate to use for diversion into pools, a demonstration project should be implemented and monitored to determine if groundwater will provide sufficient temperature stratification in pools and create a cool-water refuge for salmon. Estimated cost $300K.

S-7. *Investigate Groundwater Recharge Opportunities*. Further research should also be conducted to determine if treated wastewater could be utilized to augment groundwater recharge, and/or opportunities to percolate stormwater runoff to augment groundwater flow, rather than only providing temporary flood storage. As part of recommendation P8, one or two small groundwater recharge wetlands should be constructed and monitored to determine rate and volume of groundwater recharge that is possible in different soil types and the concentration of any pollutants in groundwater flowing from the recharge sites. There may be restrictions on where reclaimed water can be used to recharge groundwater depending on adjacent wells and their uses. Dye testing could also be conducted to determine if groundwater then flows into the Sammamish River or adjacent tributaries. Estimated cost $500K.

S-8. *Identify Wetland Restoration and Enhancement Sites*. Several wetlands exist in Reaches 3 and 4, but are isolated from the river and have very poor habitat (reed canary grass dominated). It is recommended that an investigation of these wetlands be conducted to determine if they are suitable and feasible for reconnection to the river for seasonal inundation to promote groundwater recharge. Restoration elements could include removal of non-native vegetation; excavation of wetlands and channels; riparian and wetland revegetation with native trees, shrubs, and emergents; and placement of LWD in wetlands and river shoreline. Even if it would not be feasible to restore groundwater recharge or provide fish access, these wetlands could provide wildlife habitat. Estimated cost $50K.

S-9. *Identify and Prioritize Removal of Fish Passage Barriers*. The cities and King County have identified fish passage barriers in several tributaries to the Sammamish River, but the data has not been consistent, particularly in the determination of what constitutes a fish passage barrier. It is recommend that a comprehensive survey of the corridor be conducted to identify all fish passage barriers (adult salmonid barriers). Information should be collected on the type and magnitude of barriers and habitat conditions upstream of the barriers. In addition, develop a plan for prioritized removal of barriers based on quality and area of habitat upstream, type of fish expected to use the habitat, and other features. Estimated cost $75K.

S-10. *Review Results of King County Water Quality Study and Conduct Literature Review to Determine if a Demonstration Agricultural Infiltration Basin is Needed or Feasible to Treat Irrigation Return Flows*. Because irrigation return flows may contribute to high water temperatures and export potential contaminants into the river (Wilson, *et al* 2001), an evaluation of King County's recent toxicity data should be conducted to determine if measures to prevent direct runoff should be taken. One option is an agricultural infiltration basin/wetland demonstration project. A literature review of the effectiveness of these wetlands should be first conducted to determine if the pollutants of concern could be removed. If so, a demonstration wetland could be constructed and monitored to further determine its effectiveness for reducing temperature and other pollutants in irrigation return flows. Such a basin/wetland could be constructed at the location of an existing irrigation return flow. Features would include excavation of a wetland large enough to receive the irrigation return flow volume and hold it for a minimum of 24 hours before passive outflow over a sill or similar structure, plantings of dense emergent and shrub wetland vegetation and a riparian forest zone for shading, and removal of non-native species. The project should be designed so that it does not capture and strand fish during high flows. Estimated cost $20K for study, $100K for design of infiltration basin.

S-11. *Water Quality Study*. Some key questions remain about water quality in the river based on the 303(d) listings: the seriousness of both bacteria and turbidity/suspended sediments in the river. It is recommended that a study be conducted to further quantify bacterial concentrations throughout the river and identify potential bacteria sources, such as at Marymoor Park and urban outflows. Also recommend collecting turbidity measurements throughout the year and particularly downstream of urban outfalls to determine frequency, concentrations, and potential sources of fine sediments. Estimated cost $100K.

Implementation of the above studies would cost approximately $1.6 million (not including S-1, which was already included in P4). These studies are very important to understand if any further actions can be undertaken to reduce temperatures in the river, ensure there are no adverse effects on flood control from any proposed restoration actions, and reduce the runoff of potential contaminants into the river.

MONITORING PLAN

Monitoring is necessary to determine if specific restoration objectives are being met for individual and programmatic projects, and if not, to implement adaptive management actions. In particular, for this Action Plan, monitoring is necessary to ensure that early projects implemented under the programmatic recommendations are providing the expected benefits, in addition to providing feedback and additional design information for later projects. To this end, we propose four types of monitoring: (1) construction monitoring; (2) success monitoring at the localized scale; (3) success monitoring at the corridor scale; and (4) monitoring of adaptive management actions. This monitoring plan is intended to be the basis for development of a more detailed monitoring program that must be prepared as the recommended projects are being designed.

Construction Monitoring

Monitoring will be required during the construction phase or phases to ensure that all water quality and other permitting requirements and/or conservation measures are met, and also to ensure the project is built according to design specifications (or if not, there is a documented technical reason for the deviation). This monitoring will occur on a site-specific basis and be funded as part of the overall project construction costs. Specific tasks would likely include turbidity and other water quality measurements (upstream and downstream of project); removal of fish species within the work area; flagging and monitoring of vegetation that will not be removed; oversight by a biologist of all construction activities; and implementation of all erosion control requirements.

Success Monitoring at the Localized Scale

Success monitoring documents whether the project is surviving (e.g., planting project) and functioning (e.g., are pools persisting over time?) as expected. At the localized scale, the growth and survival of plants and stability and persistence of features is of particular interest. At each project location, these types of monitoring efforts would be undertaken for approximately five to ten years following construction. The exact length of required monitoring would be based on the type of project.

Riparian Revegetation

For several years (typically years 1, 2, 5, and 10) after construction, the riparian vegetation plantings should be evaluated for percent cover, canopy cover over the river, and overall percent survival. Percent survival should be greater than 90% in all years. If excessive mortality occurs in year 1 (greater than 20%), additional measures may need to be taken, such as irrigation and replacement plantings. In later years, the project sponsor would be responsible for supplementing the plantings if there are unacceptable levels of mortality. Adaptive management measures may need to be taken to increase survival of plants, such as use of fencing or other measures to prevent beaver predation, planting of more suitable species for a location, etc. Irrigation of plantings should be provided at all projects for one to three years, based on existing experience with riparian plantings. Monitoring should always occur during the July -August timeframe to document the maximum growth of each season.

Stability/Persistence of Aquatic Features

Aquatic features such as shallow banks, pools, and LWD clumps/jams should be monitored to determine if they are persisting over time (e.g., maximum depth, residual depth and surface area) and if hydraulic conditions have been created that affect their function or if additional pools have been created. Cross sections or other representative points in and adjacent to specific restoration projects should be surveyed (years 1, 2, and 3 after construction) to determine if sediment deposition or erosion has occurred, and if so, the cause and magnitude. LWD should be monitored to determine if it has moved or caused any bank erosion.

Success Monitoring at the Corridor Scale

Success monitoring at the corridor scale will enable this Action Plan to be implemented as a series of experiments with adaptive management and design feedback to ensure later projects are as effective as possible. As each project is implemented, its associated effects and benefits will be monitored and compared to other projects in the corridor so that each subsequent project can be designed to function most effectively for its location. For example, because it is currently expected that juvenile salmon use the upper river more than the lower river for rearing habitat, a comparison of fish use of shallow water habitats specifically created in upper and lower reaches of the river can be conducted to determine if future projects in the lower river should include shallow water habitats. This scale of monitoring is particularly necessary to evaluate the programmatic recommendations (riparian restoration and creation of pools) and to determine if water temperature is being reduced. This monitoring program should be funded by all parties to this Action Plan on a proportionate scale to the number and size of projects undertaken by each party. Funds could be allocated as part of the construction budget of each restoration site that would be contributed to the overall program or funded separately as a monitoring program. The following types of studies should be undertaken throughout the corridor.

Adult Fish Use of Pools

Pools created in various parts of the river should be evaluated during the warmest months (July through November) to determine adult salmon use; compare fish use of created pools to existing pools and deeper areas; and evaluate pool temperature and compare tributary confluence pools to groundwater inflow pools and to other pools to determine if cool water refuges were actually created and are functioning.

Juvenile Salmon Use of Various Habitats

Several programmatic features may be used by juvenile salmon for rearing, cover, or refuge including shallow bank habitats, LWD clumps and jams, pools, and overhanging vegetation. Comparisons should be made between fish use of each of these habitat types and between different locations in the river. Additionally some sampling should be conducted in areas of aquatic vegetation (both native and non-native) to determine what fish species are utilizing these habitats. Sampling should be conducted year-round to determine if species that rear in freshwater for extended periods are utilizing these habitats.

Wildlife Use of Various Habitats

Wildlife use of riparian areas, wetlands, side channels, and in-stream locations should be monitored. Bird species counts could be conducted at various seasons (nesting, wintering, etc.) to identify how the riparian zone is improving (conduct in conjunction with Audubon Society and other groups). Particularly, use of LWD and other wildlife features (snags, etc.) should be compared to areas without those features and to different parts of the corridor.

Water Temperatures

Permanent temperature measurement stations should be established to document responses to restoration actions. It will take many years for the riparian restoration to achieve a significant level of shading, but year-to-year variations and other restoration actions can be monitored in the interim. The following features should be monitored extensively for water temperature changes: pools, tributary confluences and mixing; effects of Lake Washington elevations on backwater conditions; groundwater inflows and mixing; cooling tower or other demonstration project; and wetlands and side channels.

Biological Health of the Aquatic System

Baseline, and then follow-up monitoring studies of invertebrate populations should be conducted. Index of Biotic Integrity (IBI) is probably not appropriate in the Sammamish River, but other indices may be used to assess the overall health of the aquatic ecosystem. Samples should be taken adjacent to various types of projects and near tributary confluences, as well as representative samples in various habitat types.

Population and Recovery Estimates

Fry trapping is currently conducted in lower Bear Creek to estimate population size of various salmon stocks in the Bear Creek sub-basin. To determine if recovery is occurring as a result of restoration actions taken in the Sammamish River Corridor and throughout the Greater Lake Washington Watershed, fry trapping and adult spawner surveys need to occur throughout the watershed. It is recommended that population studies be conducted in more detail in the Sammamish River Corridor to include other major tributaries and compare outmigration and survival in the upper versus lower river. This should be integrated with the broader WRIA 8 monitoring currently under development, which will probably be conducted by WDFW and the treaty tribes.

Adaptive Management and Additional Monitoring

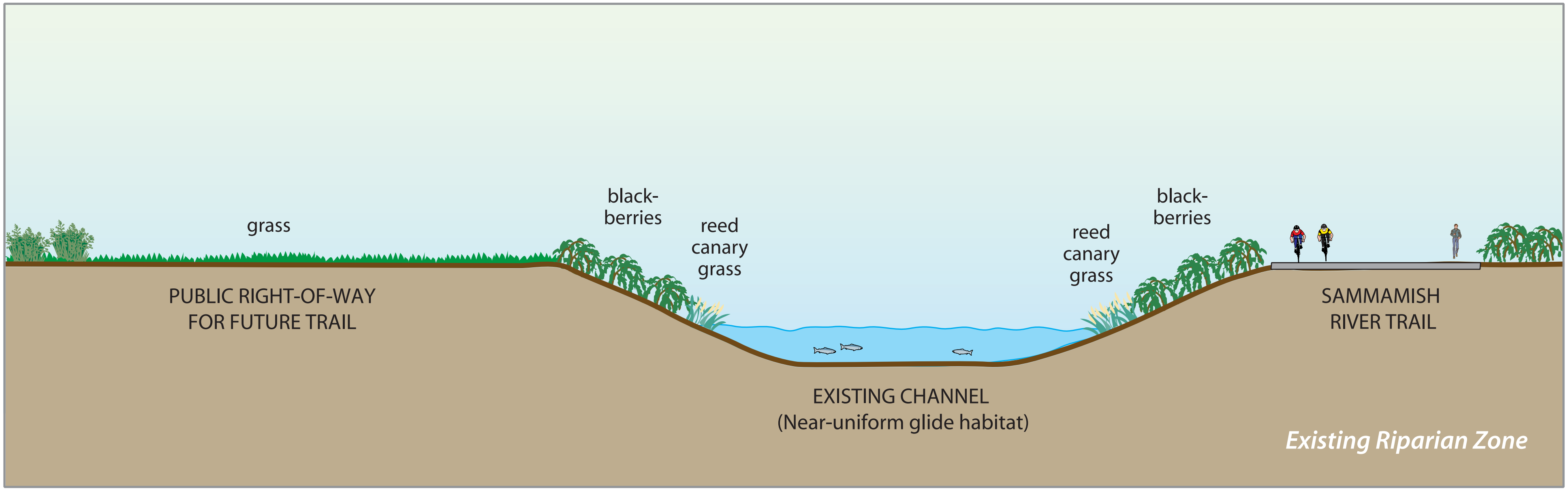
The success monitoring (at both scales) must be used by parties to this Action Plan to undertake adaptive management of existing and future projects to achieve the goals of this plan. To be most effective, an Adaptive Management Team should be formed with representatives from each jurisdiction and interested resource agencies[21], with funding provided from each jurisdiction or agency. This Team will direct and implement the research and monitoring plan and determine if any adaptive management actions are necessary. Decision-making could include one or more of the following response actions:

- No Action
- Further Monitoring (continued years of same studies or propose new studies)
- Maintenance or Modification of Specific Projects or Project Features
- Design Modifications for Future Projects
- Modification of Restoration Strategies

An annual report on the monitoring results should be prepared each year by the entity(ies) conducting the work and submitted to the Adaptive Management Team. The report(s) would summarize monitoring data collected during the previous year and recommendations on any adaptive management measures (either monitoring modifications or actions to modify restoration features). The Adaptive Management Team would use the information in the report(s) to assess progress toward the restoration objectives and identify remedial actions that could be implemented to rectify problems. The Adaptive Management Team would prepare a memo documenting the results of its assessment of the mitigation program that would include recommendations for the following year’s monitoring plan. An annual report on monitoring would continue

[21] A technical representative from the Cities of Kenmore, Bothell, Woodinville, and Redmond; King County; Corps of Engineers, at a minimum should be involved. This team should coordinate with a potential adaptive management team from the broader watershed and also include WDFW, tribal, NMFS and USFWS representatives. Other agencies may be involved as interested.

for an agreed upon period (5, 10, or longer period of years) until the Adaptive Management Team was satisfied with the success of the Action Plan. At this time, we recommend that the Action Team that developed this plan scope out an operating plan for the Adaptive Management Team in conjunction with the WRIA 8 technical committee.



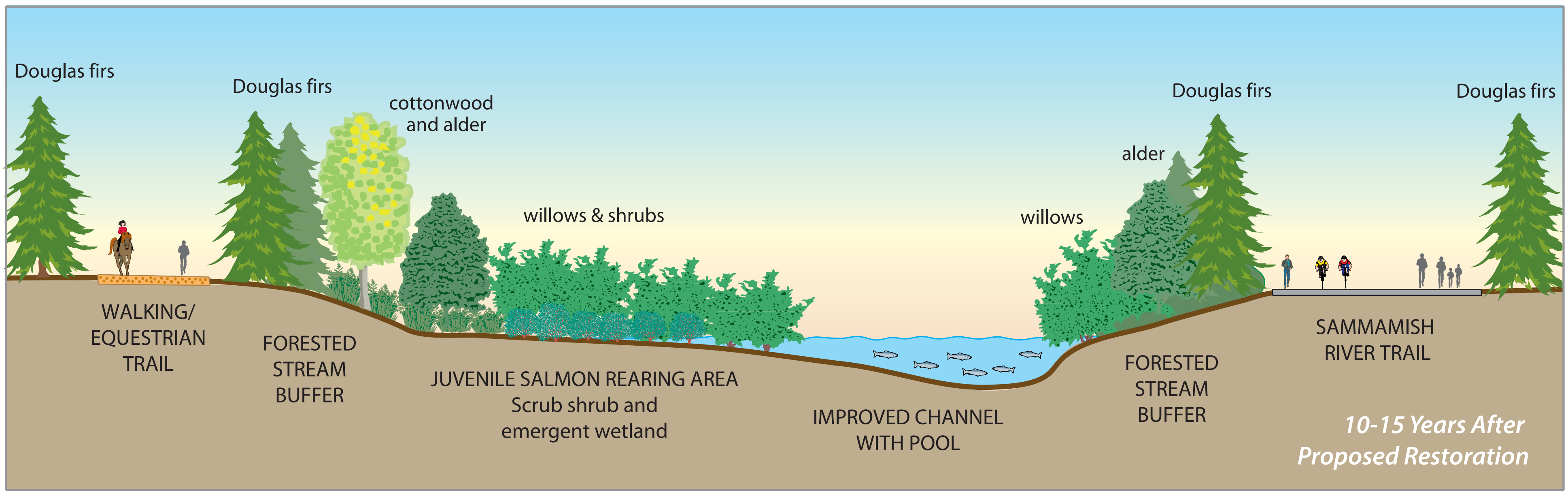


Figure 15

Cross-sections for Existing and Proposed Restored Riparian Zone

Sammamish River Corridor

0 5 10 20 30 Feet

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Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

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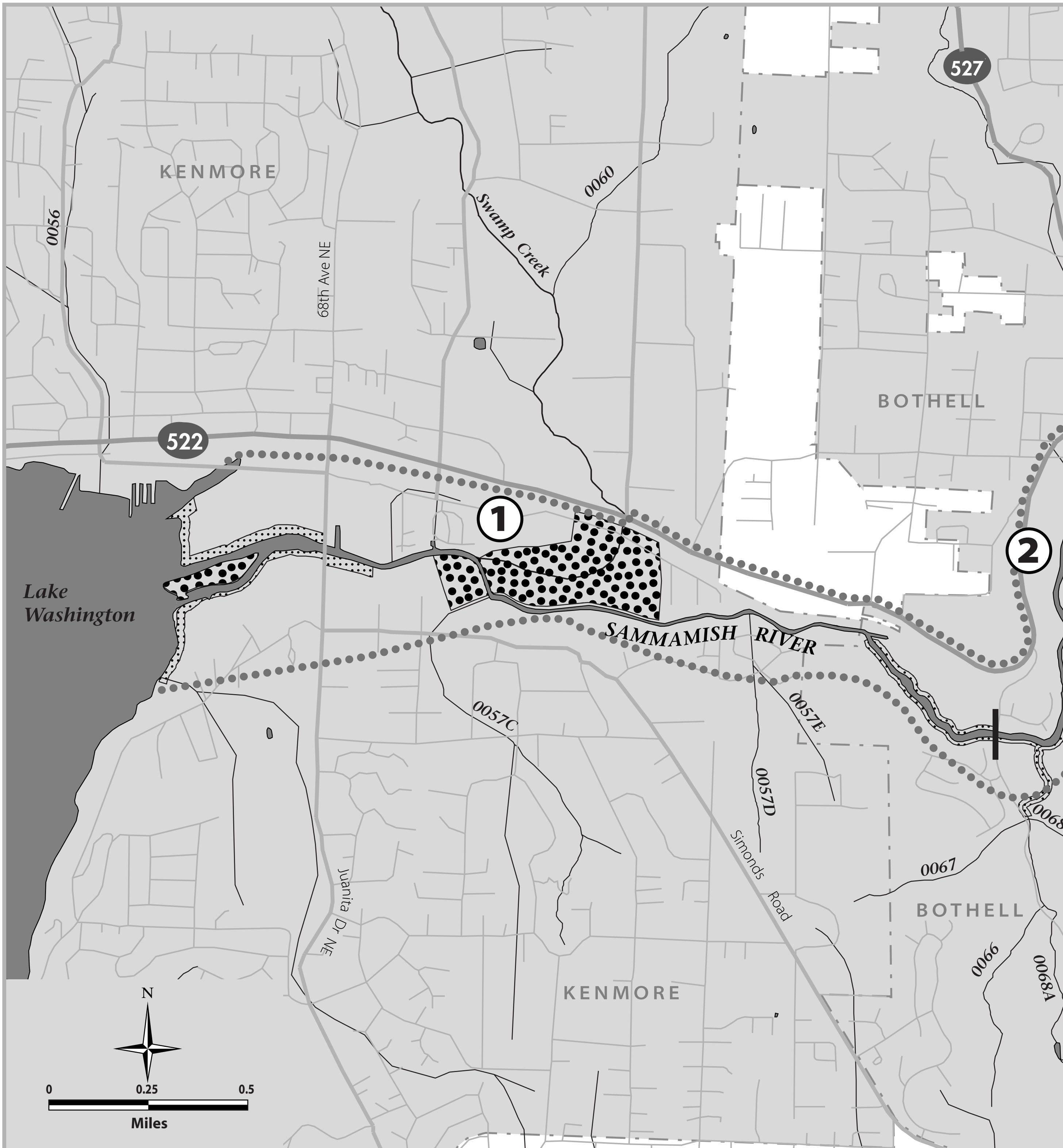

Figure 16

REACH 1 Proposed Restoration Areas

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

1 River Reach Number
River and Reach Boundary
Road
River/Stream
Planning Area Boundary
Incorporated Area
Riparian Restoration Area
Wetland Restoration Area

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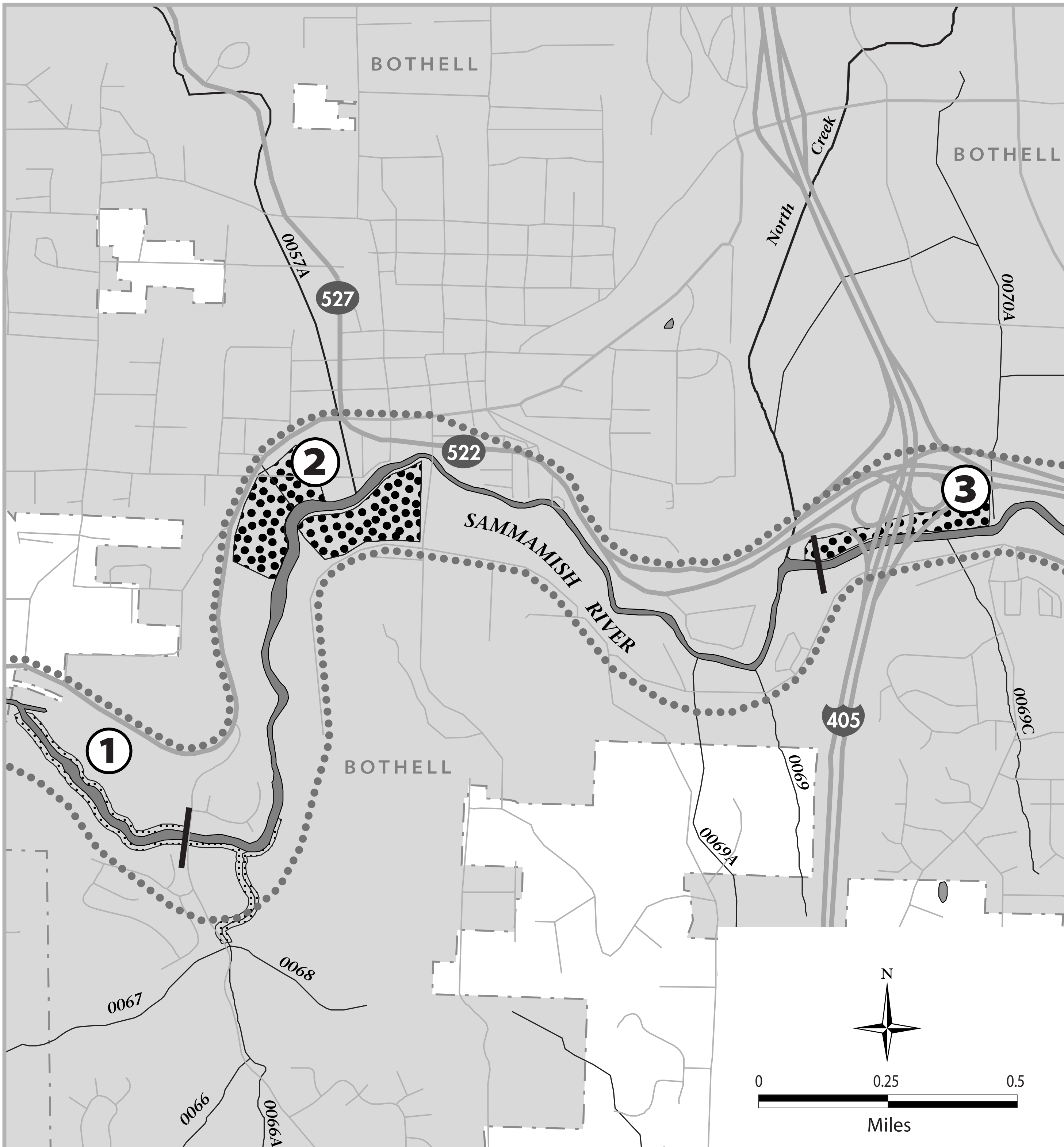

Figure 17

REACH 2 Proposed Restoration Areas

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

- River Reach Number
- River and Reach Boundary
- Road
- River/Stream
- Planning Area Boundary
- Incorporated Area
- Riparian Restoration Area
- Wetland Restoration Area

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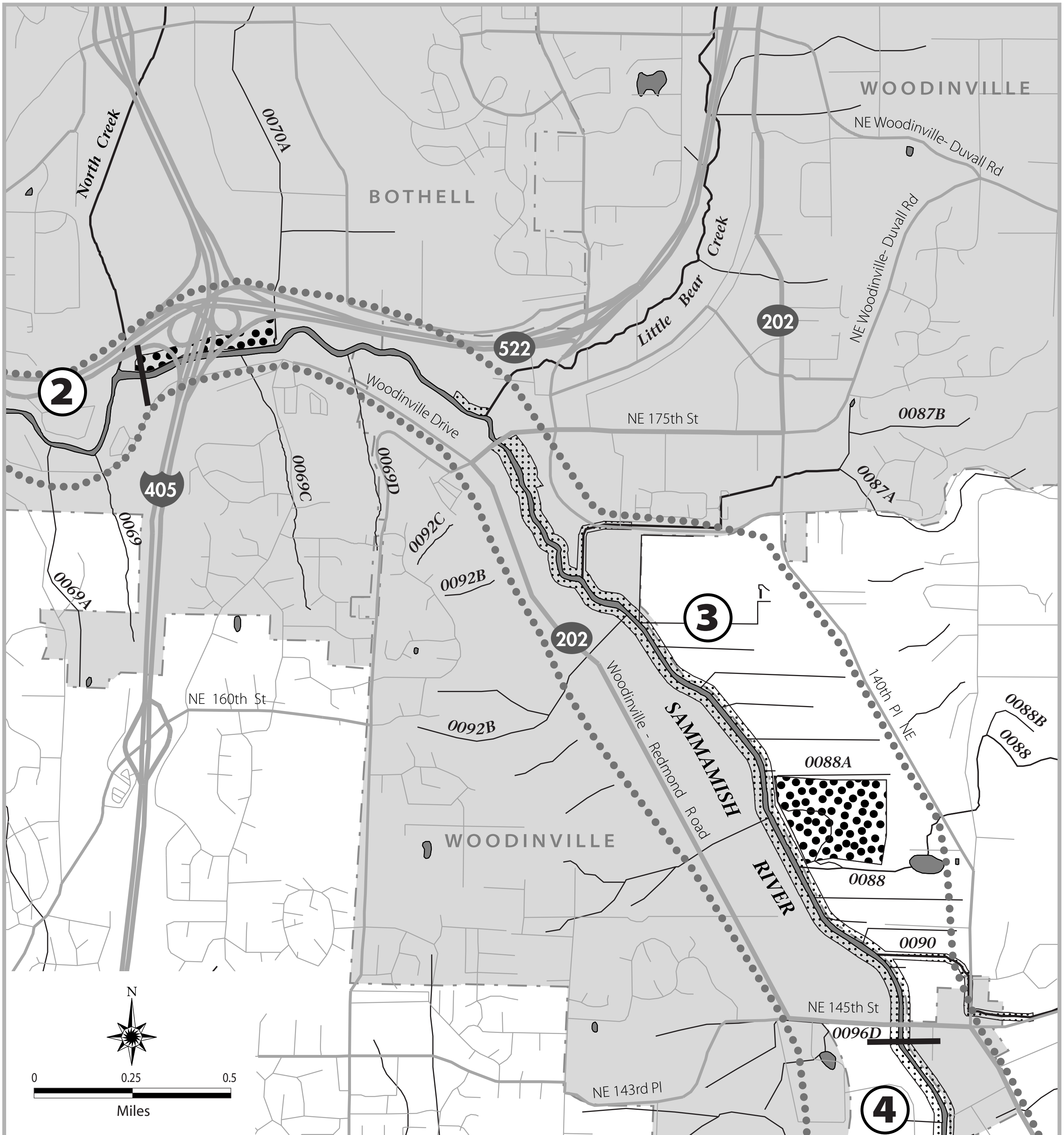

Figure 18

REACH 3 Proposed Restoration Areas

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

1 River Reach Number
River and Reach Boundary
Road
River/Stream
Planning Area Boundary
Incorporated Area
Riparian Restoration Area
Wetland Restoration Area

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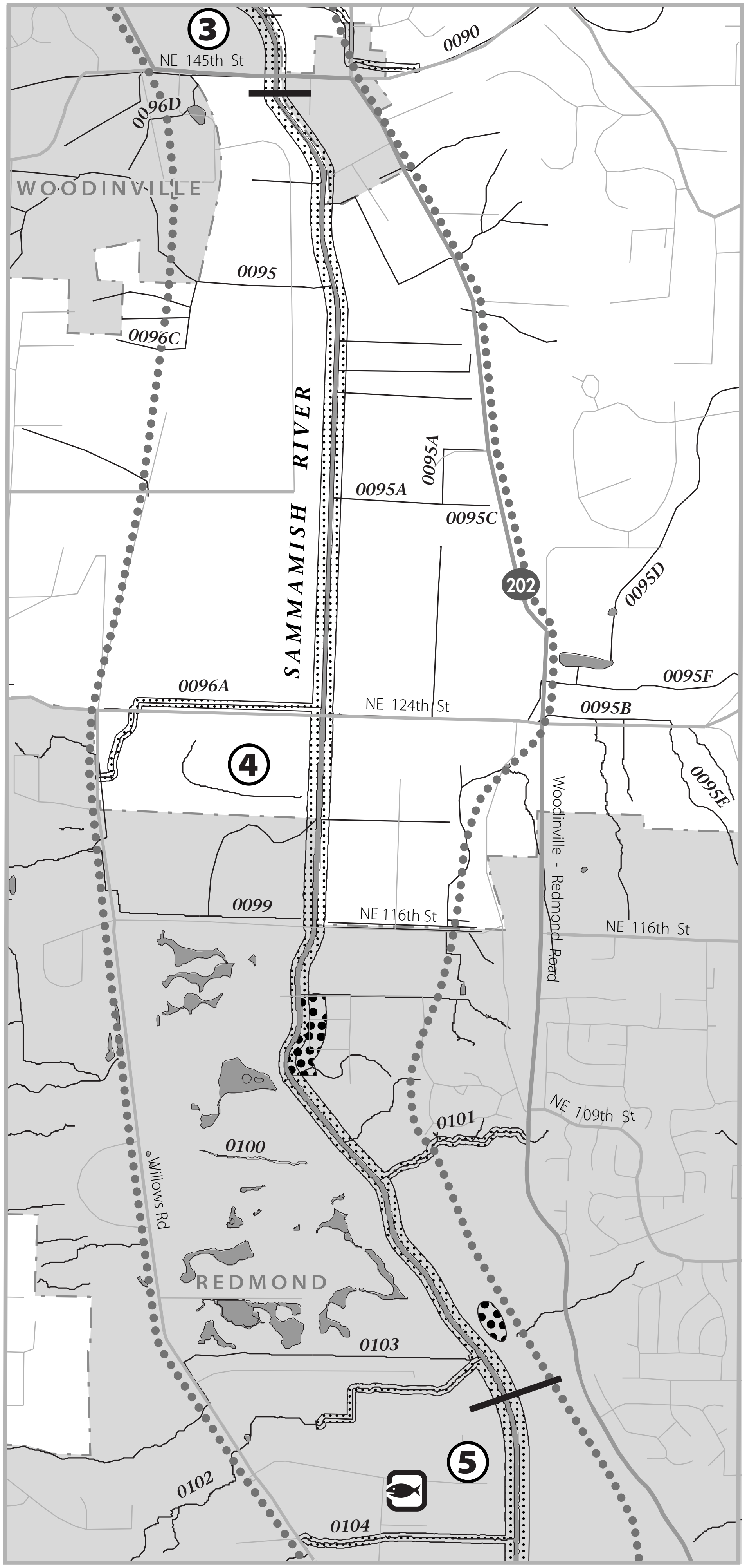

Figure 19

REACH 4 Proposed Restoration Areas

Sammamish River Corridor

Road
Stream
Planning Area Boundary
River and Reach Boundary
River Reach Number
Incorporated Area
Wetland Restoration Area
Riparian Restoration Area
Removal of Fish Barrier

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King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

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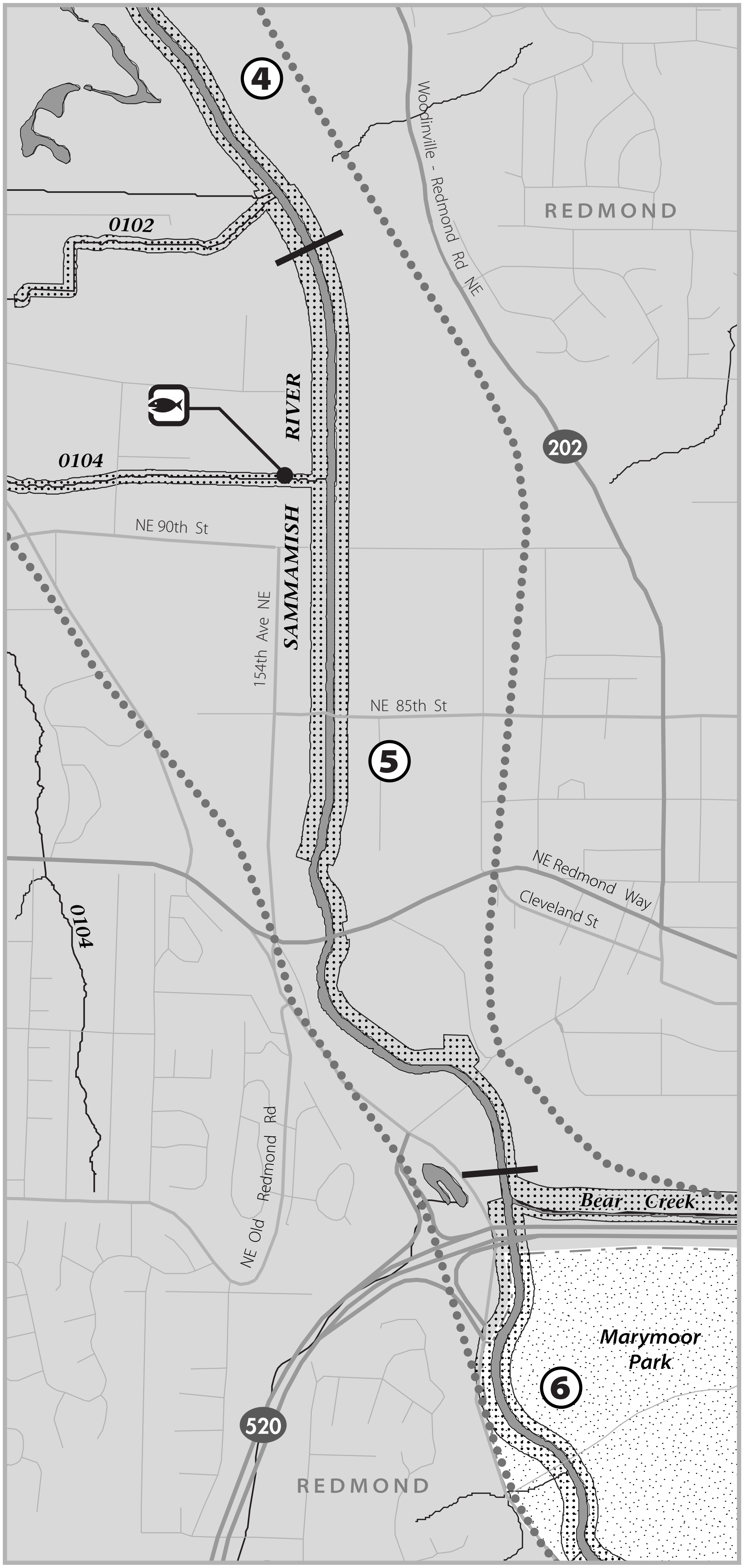

Figure 20

REACH 5 Proposed Restoration Areas

Sammamish River Corridor

Road

Stream

Planning Area Boundary

River and Reach Boundary

River Reach Number

Incorporated Area

Floodplain Restoration Area

Wetland Restoration Area

Riparian Restoration Area

Removal of Fish Barrier

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King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

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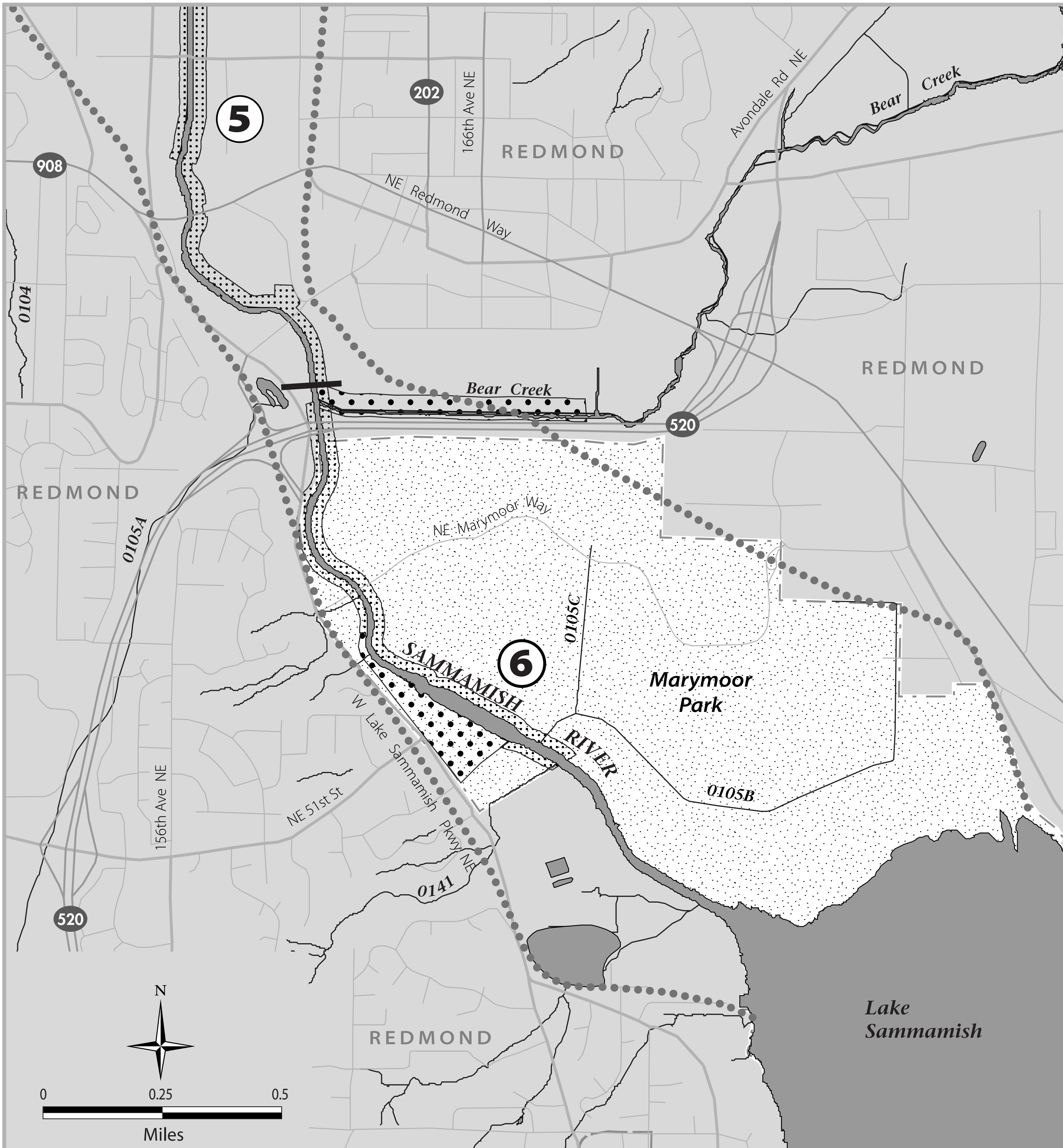

Figure 21

REACH 6 Proposed Restoration Areas

Sammamish River Corridor

King County
Department of Natural Resources and Parks
Water and Land Resources Division
GIS and Visual Communications & Web Unit

1 River Reach Number

River and Reach Boundary

Road

River/Stream

Planning Area Boundary

Incorporated Area

Riparian Restoration Area

Floodplain Restoration Area

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APPENDIX A. PLANT SPECIES IN NATIVE WETLAND PLANT COMMUNITIES

Lowland Western Washington Wetland Plant Community Types (from Kunze 1994)	
Community	**Dominant Species Assemblage**
Sphagnum Bog Shrub Dominated	*Kalmia occidentalis/Sphagnum* spp. variant
	Ledum groenlandicum/Sphagnum spp. variant
	L. *groenlandicum/Gaultheria shallon/Sphagnum* spp. variant
	L. *groenlandicum/Carex rostrata/Sphagnum* spp. variant
Minerotrophic Permanently Flooded	*Brasenia schreberi*
	Hippuris vulgaris
	Juncus balticus
	Nuphar polysepalum
	Potomogeton natans
	Scirpus acutus
	Scirpus subterminalis
	Typha latifolia
Minerotrophic Seasonally Flooded/Saturated Herb Dominated	*Carex obnupta*
	Carex rostrata
	Carex sitchensis
	Dulichium arundinaceum
Minerotrophic Seasonally Flooded/Saturated Shrub Dominated	*Alnus incana*
	Cornus stolonifera/Salix spp/*Spiraea douglasii*
	Myrica gale
	Salix spp.
	Spiraea douglasii
Minerotrophic Seasonally Flooded/Saturated Tree Dominated	*Alnus rubra/Lysichitum americanum*
	A. *rubra/Rubus spectabilis*
	Fraxinus latifolia/Carex obnupta
	F. *latifolia/Symphoricarpos albus*
	Pyrus fusca
	Thuja plicata/Tsuga heterophylla/L. *americanum*

APPENDIX B. REFINEMENT OF THE SAMMAMISH RIVER CE-QUAL-W2 TEMPERATURE MODEL AND APPLICATION TO LONG TERM SIMULATIONS

King County Department of Natural Resources

Technical Memorandum

TO: John Lombard / Director's Office

FROM: Curtis DeGasperi / WTD

DATE: December 21, 2001

SUBJECT: Refinement of the Sammamish River CE-QUAL-W2 Temperature Model and Application to Long Term Simulations

Executive Summary

A temperature model developed by John E. Edinger and Associates, Inc. (JEEAI), for predicting the temperature of the Sammamish River in response to various management scenarios was improved and set up to perform long term simulations of various temperature management scenarios. Model improvements included changes in the model configuration to better simulate the summer increase in water surface temperatures in the downstream river reach and incorporation of additional monitoring data not previously made available to JEEAI. The revised model was applied to improve upon the previous evaluation of management scenarios by:

- Focusing on the time of year when temperatures pose a significant threat to migrating adult salmon (August 1 - October 31), using weather and flow data from 1970-99 to represent a range of conditions experienced during that time of year. Management scenarios were previously evaluated based on a 2-day "worst case" period in July 1998 that is unlikely to occur when salmon are in the river.
- Using an "Index of Thermal Stress" to measure the cumulative effects of high temperatures on salmon, as recommended by biologists. The previous analysis focused on average and maximum temperatures during the "worst case" period.
- Better characterizing actual management scenarios under potential consideration.

This memo documents the latest model configuration/calibration and the results of long-term model simulations of fifteen temperature management scenarios. The memo also identifies further needed improvements in the model configuration, primarily at the downstream boundary. Additional recommendations for monitoring and modeling efforts are also included in this memo.

For brevity, not all of the tables and figures have been included with this memo. References are made in the text to additional tables and figures that are available on request.

Analysis of the different management alternatives results in a few key findings:

- Hypolimnetic withdrawal is the only strategy reviewed that can make large reductions in thermal stress on salmon where it is greatest--at the outlet of Lake Sammamish, where the river is currently fed by the warm upper layer (epilimnion) of the lake. Even the more conservative modeling of this strategy (Alternative 14) resulted in a 66.4% decrease in average thermal stress and a 34.8% decrease in maximum thermal stress at Segment 3 (above Bear Creek), compared to 7.0% and 3.6%, respectively, for the combination of all of the other strategies (Alternative 13).
- Averaged over the entire river, revegetation of riparian areas could significantly reduce thermal stress on salmon as plantings mature, but this benefit is cumulative--the greatest benefits are in the lower river, where thermal stresses are less severe. Still, other than hypolimnetic withdrawal, shade from fully mature riparian vegetation (Alternative 6) is the most effective single strategy reviewed to reduce thermal stress for salmon.
- A combination of strategies using reclaimed water (Alternative 12) could significantly reduce thermal stress on salmon, by roughly the same magnitude as fully mature riparian vegetation. Groundwater augmentation (Alternatives 3-5) could potentially be the most significant strategy, depending on the volume, temperature and location of the enhanced flows entering the river.
- Management actions affecting Bear Creek have significant consequences for thermal stress on salmon in the Sammamish River. Restoration of up to 5 cfs of creek flows (Alternative 8) and protection of riparian shading of the creek (Alternative 9) are particularly important for the portion of the river immediately downstream of the confluence of the creek and river.
- Uncertainty regarding the amount of current surface withdrawals from the river does not create significant uncertainty in evaluating management actions. The estimate of surface withdrawals can be doubled (Alternative 2, compared to Alternative 1) without large changes in predicted temperatures.

Introduction

This document describes the work performed by King County Department of Natural Resources (KCDNR) staff to extend the application of an existing river temperature model developed for the Sammamish River to simulate multiple years. The model has previously served as a management tool to assess the potential of various alternatives to reduce simulated July 27-28, 1998 river temperatures. Lower summer temperatures should provide improved habitat conditions for salmon that migrate through the river to tributary spawning areas. Based on the initial assessment results, a number of recommendations were made by JEEAI (Jain et al. 2000) that included (but are not limited to) the following:

- Change the configuration of the model to reflect two distinct stream reaches: an upper sloping reach and a lower flat-water reach representing the backwater from Lake Washington;
- Perform multi-year simulations of existing conditions and alternative management scenarios

to provide temperature predictions that are more relevant to salmon management and protection.

Background

Listing of Puget Sound chinook under the federal Endangered Species Act (ESA) has triggered an intensive effort to identify causes of salmon population declines and measures that can be taken to maintain or improve existing populations. Observed pre-spawn mortality of adult chinook in the Sammamish River led water quality managers to initiate a temperature monitoring and modeling investigation of the river (Martz et al. 1999). Following the initial investigation, the monitoring program and model were refined, and the model was updated to the latest version by JEEAI (Jain et al. 2000, Buchak et al. 2001). The model is a two-dimensional, laterally averaged, hydrodynamic and water quality model (CE-QUAL-W2 Version 3.0) supported by the U.S. Army Corps of Engineers Waterways Experiment Station (ACOE-WES) (Cole and Wells 2000).

The model was calibrated to 1999 late summer temperature conditions in the Sammamish River and used to evaluate potential temperature management scenarios. Management scenarios included:

- Reduction of surface water withdrawals
- Flow augmentation with cool groundwater released to specific river segments
- Creation of riparian shade
- Replacement of warm water inputs from the surface of Lake Sammamish with cooler bottom water withdrawn from the lake

The assessment of the potential effectiveness of each scenario was based on a comparison of 2-day average, minimum, and maximum temperatures for a relatively extreme 48-hr period — July 27-28, 1998. As pointed out by Jain et al. (2000), the use of a single extreme period (relatively low flow and high temperature) does not provide a realistic distribution of possible management outcomes based on the natural hydrological and meteorological variability of the system.

The modeling results and field data were also compared to the results of a Forward-Looking Infrared (FLIR) study conducted on September 2, 1999 (McIntosh and Faux 1999). The FLIR results provide a thermal image of river surface temperatures. This comparison indicated that although the existing model configuration reproduced the hydraulic backwater from Lake Washington, the model did not allow the development of a warm surface layer in the lower river reach below Blyth Park.

Objectives

The overall objectives of the work described in this report were as follows:

- Continue support of Sammamish River temperature management studies
- Reconfigure the model geometry to reflect at least two distinct stream reaches (a sloping

upper reach and a lower flat-water reach)
- Develop the capability to simulate multi-year time periods
- Re-evaluate selected temperature management scenarios using a multi-year simulation

Specific tasks to meet these objectives were:

1. Reconfigure the model geometry with at least two distinct stream reaches
2. Re-evaluate the model calibration to additional time periods beyond the July-September period used previously if additional data are available
3. Set up the reconfigured model to simulate an extended (multi-year) period of time
4. Run the model to develop a simulation of long term temperature variation under "existing" or "base" conditions
5. Rerun selected temperature management alternatives for the extended time period
6. Statistically summarize the model output in a manner consistent with temperature management guidelines for the protection of cold water fish
7. Compare the summarized modeled alternative results to the "base" condition results
8. Prepare a Technical Memorandum that briefly summarizes the available data and data processing steps, model evaluation/refinement/calibration steps as necessary, and model application results

Approach

The general approach to completing the above tasks included 1) initial model reconfiguration and testing and incorporation of additional data; 2) compilation, processing, and evaluation of data needed to perform long term model simulations; 3) and specification of the method to statistically summarize model output in a manner relevant to the protection of cold water fish. The work performed to complete these tasks is described below.

Model Reconfiguration

JEEAI noted inconsistencies between model-predicted and FLIR-observed surface water temperatures at the downstream end of the Sammamish River on September 2, 1999 (Buchak et al. 2001). JEEAI performed some initial model testing to identify the cause of this inconsistency and recommended that the model configuration be modified to reflect two distinct river reaches with different slopes. Therefore, the model geometry input file provided by JEEAI was modified from the single reach/slope configuration to a two reach configuration with an upstream sloping reach (with the same slope as the original JEEAI geometry) and a second downstream reach with zero slope. Plan and profile views of the revised model geometry are shown in Figures 1 and 2, respectively. The boundary between the two reaches (At segment 34 above Blyth Park) was selected based on the following:

- The JEEAI model configuration did not reproduce the river surface temperatures (measured using FLIR) below Blyth Park in Bothell on September 2, 1999
- Reasonably good model agreement was obtained between hourly river temperatures (measured using continuously recording thermistors) and model output at Blyth Park and at

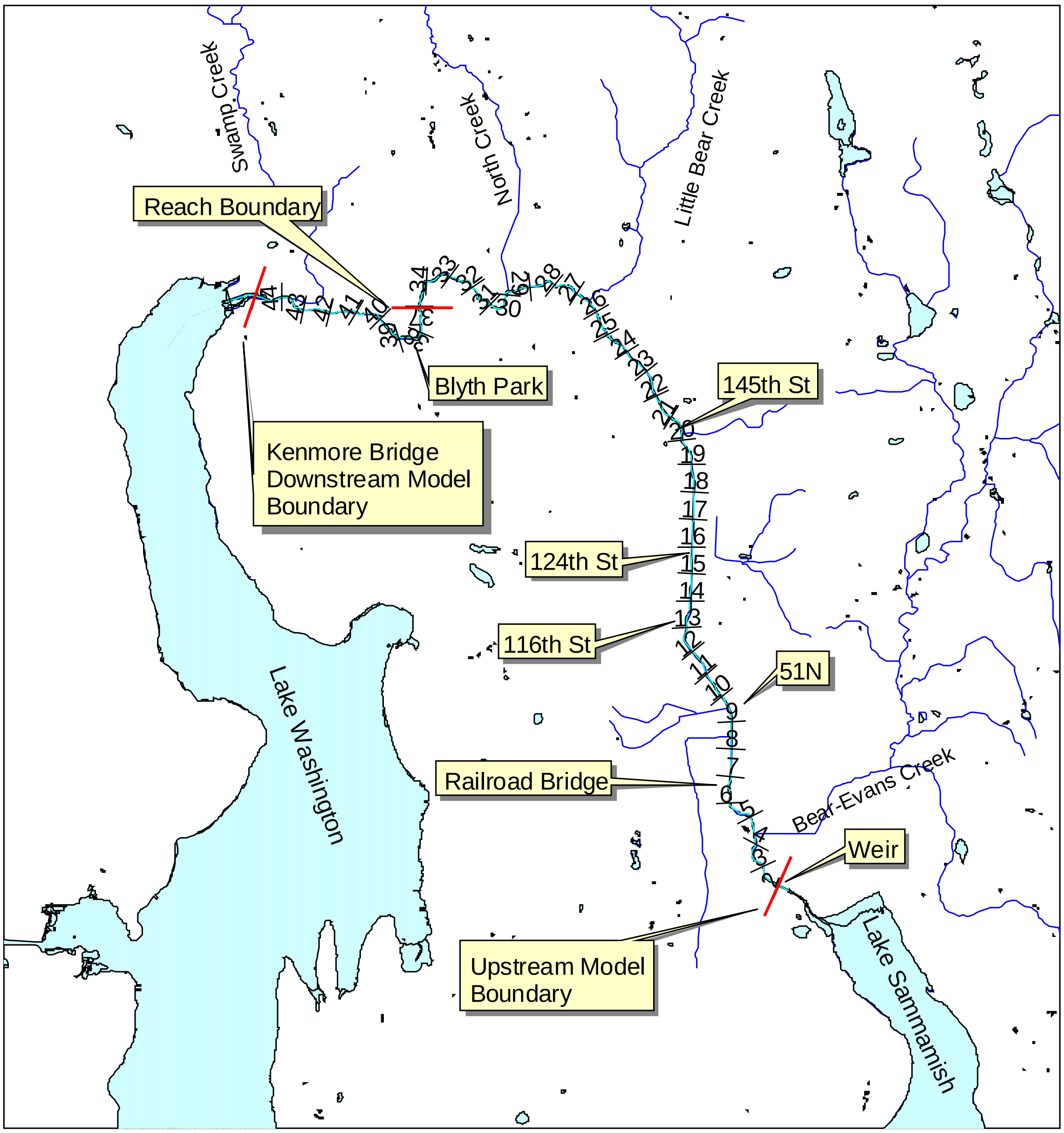


Figure 1. Revised Sammamish River CE-QUAL-W2 Model Geometry - Plan View.

Map produced by staff, Wastewater Treatment Division (WTD), King County Department of Natural Resources. WTD disclaims any warranty for use of this digital product beyond that for which it was designed. Neither this digital product, nor any portion thereof may be reproduced in any form or by any means without the expressed written authorization of WTD. This document includes data copyrighted by the Kroll Map Company and is being used with their permission. Use is restricted.

2000 0 2000 4000 6000 8000 10000 Feet

March 12, 2001

Legend
- Segment Boundaries
- Sammamish River
- Waterbody
- Tributaries

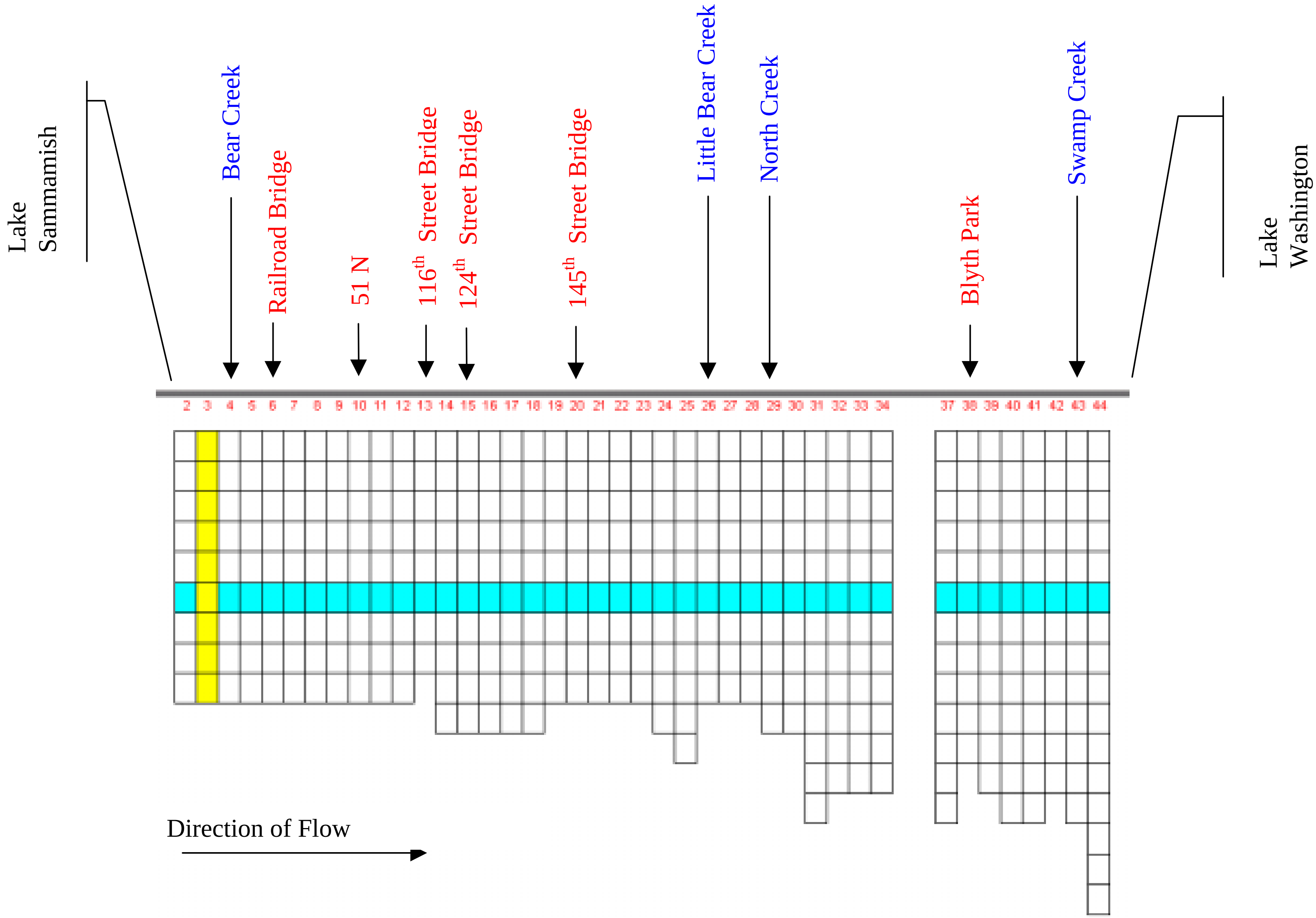


Figure 2. Revised Sammamish River CE-QUAL-W2 Model Geometry – Side View.

- four other locations upstream

In addition to changes in model geometry, the model was also improved through the compilation of additional 1999 data not previously made available to JEEAI. These data included observed tributary flows and temperatures recorded as part of the County's monitoring activities. For example, North Creek tributary flow and temperature was previously based on HSPF model results and the Swamp Creek temperature input was based on the records for Little Bear Creek due to the poor quality of the Swamp Creek temperature record. A table that provides model input source documentation and notes regarding data quality problems and solutions is available upon request. The additional data and supplemental analyses allowed the simulation of the entire 1999 calendar year. However, with the exception of additional hourly monitoring data collected by KCDNR at Station 51N below the Railroad Bridge in Redmond (4/30/99-10/11/99), model re-calibration and testing could not be extended beyond the period June 1 – October 22, 1999. Monthly grab monitoring data from two KCDNR stations [0486 (Marymoor) and 0450 (Kenmore)] and one Washington State Department of Ecology station [080B070 (Bothell)] were also obtained, but were not considered suitable (too infrequent) for use in model calibration.

Testing of the revised model geometry as a single waterbody with two reaches and as two waterbodies lead to the conclusion that the two waterbody setup provides more reliable predictions of river temperatures in the downstream reach boundary with Lake Washington. This conclusion was supported by discussions with Tom Cole (ACOE-WES) and Scott Wells (Portland State University), developers of the version 3.0 CE-QUAL-W2 model code (pers. comm.). The problem with the original single reach and two-reach setup (as a single waterbody) was due to the way the sloping water surface layer thickness is controlled by the model reference surface layer. The reference model surface layer is constant within a waterbody, which resulted in a reference layer that coincided closely with the water surface elevation in the upstream reach, but became progressively further apart as the water surface slope decreased. The two waterbody setup allows the reference surface layer to change between the sloping reach and the flat-water reach, minimizing the surface layer thickness at the downstream head boundary, and providing more realistic downstream conditions for modeling boundary driven hydrodynamics.

Model testing also suggested the need to add at least one additional downstream segment and perform further testing related to the potential need to divide the upstream reach into additional reaches with varying slope (or shorter segments) and test/refine the placement of the boundary between the two waterbodies. Additional revisions to the model geometry and further testing were beyond the resources allocated for the work described in this report. Further refinement of the model geometry, primarily to couple the river model to models of Lake Sammamish and Lake Washington, is recommended prior to performing additional applications

Long Term Model Setup

Once a satisfactory model geometry was identified, available data were compiled, evaluated, and processed to simulate a multi-year period. The length of the long term modeling period selected depended on the availability of hydrological and meteorological data. Model data needs include:

- Meteorological data (air temperature, dew point temperature, wind speed/direction, and cloud cover)
- Upstream flow and temperature at the Lake Sammamish weir
- Tributary flow and temperature (Big Bear, Little Bear, North, and Swamp creeks)
- Distributed tributary inflow (ungaged flow that includes ungaged tributary inputs and net groundwater flow to the river) and temperature
- Lake Washington (Kenmore) water surface elevation and temperature profiles

A table that summarizes long-term model data sources is available upon request.

- ***Meteorological Data***

Jain et al. (2000) provided meteorological data from Sea-Tac Airport for the period 1/1/1991 to 3/31/2000. Additional data available from Sea-Tac Airport were obtained from the National Climatic Data Center through a commercial vendor (EarthInfo, Inc.). The potential availability of meteorological data collected at local high schools as part of the King 5 TV Schoolnet program, and data collected by the University of Washington (UW) Department of Atmospheric Sciences was evaluated through discussion with Mark Albright, Research Meteorologist at UW (pers. comm.) Mark indicated that he routinely downloads and archives the SchoolNet data for use in synoptic evaluations of the Mesoscale Model Version 5 (MM5) climate-forecasting model. He also indicated that the UW also archives their climate records. However, he cautioned that there are data gaps in these records and various data are stored in different files and formats. He indicated that retrieval of the available data in the current archives would require additional time and resources beyond that available for this study.

Additional climate data sources have also been identified [e.g., City of Seattle water supply reservoirs, National Oceanic and Atmospheric Administration (NOAA) at Sand Point, Washington Department of Transportation (WSDOT) floating bridges, KCDNR Remote Underwater Sampling Stations (RUSS)]. The variety of data sources and needs, suggests the need for larger interagency cooperation and coordination to facilitate the storage and exchange of the climate information that is currently collected.

- ***Upstream Flow Boundary Condition***

Lake Sammamish water surface elevation records (Station 12122000) were obtained from the U.S. Geological Survey (1/30/39-1/17/01) and flow was derived from these records using the best available stage-discharge relationships for the appropriate historical time periods (Funke, D., pers. comm.). Further refinement of the current low flow stage-discharge relationship is recommended.

- ***Tributary Flows***

Tributary flows were modeled for the period 10/1/48-12/31/99 using existing County Hydrologic Simulation Program-Fortran (HSPF) watershed models that represent 1990s basin conditions (Hartley, D., pers. comm.). Tributary flows for Swamp, North, and Little Bear creeks were based on the Everett precipitation record and Big Bear Creek flow was modeled using the Everett precipitation record and a multiplier of 1.2. A 1.2 rainfall multiplier was used for the Big Bear basin to account for the generally higher elevations in this basin.

Distributed tributary flow was based on 1.7 times the flow in Little Bear Creek as in the modeling work conducted by JEEAI. The 1.7 multiplier is based on the ratio of the ungaged drainage area along the river to the drainage area of Little Bear Creek. The distributed flow is designed to account for ungaged inputs (net inputs) of surface and groundwater to the river. In lake and reservoir systems that are gaged at the inflow and outflow and also have recorded water surface elevations, it is relatively easy to estimate the contribution (or loss) resulting from ungaged sources of water. In the case of the Sammamish River, flow is measured at the upstream end and on the four major tributaries to the river. No measurements of flow at the downstream end are available (flow gaging at the downstream end is complicated due to the backwater effect from Lake Washington). It is recommended that further investigation of groundwater contributions to the river be conducted. A watershed model of the ungaged area along the river may also be useful in better quantifying the distributed runoff to the river.

- ***Lake Washington Water Surface Elevations***

Lake Washington (Kenmore and Ship Canal) water surface elevations [daily instantaneous value at 8 AM Pacific Standard Time (PST)] were obtained from the Seattle District of the ACOE (Herman, L., pers. comm.). The length of the Kenmore record was approximately 6 years (5/13/95-5/10/01), while the Ship Canal record extended back to 1941 (1/1/41-3/31/01). Comparison of the records from these two locations indicated that the record at the Ship Canal would require some adjustment for systematic seasonal differences between the two observation stations. There appeared to be an upward trend in the annual average and monthly average differences between the two stations from 1995 to 1999 and an upward trend in the Kenmore elevations, suggesting a problem with the Kenmore gage. The Seattle District ACOE did not feel that there were any long term systematic errors in the Kenmore elevation record but did acknowledge that periodic adjustments of as much as 0.2 ft have been made in the past (Herman, L., pers. comm.). Therefore, the monthly average differences between the two stations (1995-1999) were used to synthesize a Kenmore water surface elevation record from the Lake Washington Ship Canal record.

- ***Tributary Temperatures***

The tributary inflow temperatures were derived using the Response Temperature Model as previously applied by JEEAI to estimate the distributed tributary temperature (Jain et al. 2000). The Response Temperature Model is a relatively simplistic water temperature model. The “response temperature” is defined as the temperature a column of fully mixed water would have if surface heat exchange were the only active heat transfer process. The rate of surface heat exchange is computed from water depth, air and dew point temperature, wind speed, cloud cover, solar radiation, and atmospheric pressure. The model also incorporates a simple riparian shading algorithm and the effect of a steady groundwater inflow to allow adjustment of model temperature output to fit an observation time series. In general, the model variables for water depth, percent riparian shade, and fraction of groundwater were adjusted until no further improvement in model fit could be made. A groundwater temperature of 11 ^{o}C was used in the model, which is similar to the long term annual average air temperature recorded at Sea-Tac airport (10.8 ^{o}C for the period 1970-1999).

Available inflow and tributary temperature monitoring data were used to evaluate the reliability of the Response Temperature Model to synthesize the long-term inflow temperature records. It is envisioned that in the future as part of KCDNR's Sammamish-Washington Analysis and Assessment Program (SWAMP), more fully developed tributary basin models will provide predictions of flow and temperature for use as input to the Sammamish River model.

- ***Upstream Boundary Temperatures***

Originally, the long-term temperature of the Sammamish River at the upstream model boundary (Lake Sammamish weir) was to be derived using the Response Temperature Model (KCDNR 2001). However, because the seasonal temperature at the weir is the result of more complex heat exchange processes that take place within Lake Sammamish, the Response Temperature Model could not be calibrated well to the available 1999 weir temperature time series. It was decided a Lake Sammamish temperature model that simulated lake outlet temperatures might better reproduce the observed temperatures at the weir. Using available lake bathymetry data, a model of Lake Sammamish was set up for CE-QUAL-W2. The model consisted of 22 lake segments approximately 500-m long and 38 3-ft thick layers. Four additional shallow segments were added to represent the outlet from the lake to the weir. Inputs to the model included Issaquah Creek flow (USGS Station 12121600), calibrated Response Temperature Model simulation of Issaquah Creek and distributed tributary temperature [calibrated to limited Issaquah Creek data provided by D. Houck (pers. comm.)], distributed tributary inflow based on a flow balance between inflow, outflow, and lake storage, and the Sea-Tac meteorological data. This approach still did not reproduce the 1999 weir temperature time series with a high level of accuracy, but did provide a better fit to observed data during the critical August-October period of interest (see below).

- ***Downstream Temperature Boundary***

Hourly Lake Washington temperature profiles for specifying the downstream boundary were unavailable, with the exception of the records provided by the ACOE for the Kenmore buoy (8/18-12/22/99). The best available temperature profile information consists of monthly grab profile observations recorded at the North End Lake Washington Station (0804) near Kenmore as part of King County's long term lakes monitoring program. Detailed profile information (samples from 1, 4 and 8 m depth) going back to 1996 were used to develop a 4 year downstream stratified boundary temperature time series. This time series was then repeated (beginning with the appropriate year to account for leap years) to generate a long-term downstream temperature boundary condition.

- ***Additional Monitoring Data***

Additional tributary and mainstem (Marymoor only) monitoring data were also obtained from D.

Houck, KCDNR Wastewater Treatment Division (WTD) (pers. comm.). These data are being collected as part of the County's ongoing Habitat Conservation Planning (HCP) activities. However, data collection in the Sammamish River basin did not begin until late 1999. Therefore, these data will be most useful in the setup and testing of the model for the 2000 calendar year.

- ***Selection of Long Term Modeling Period***

Evaluation of the available data and consideration of model run time indicated that the most reasonable period for long-term modeling was 1970-1999 — a 30 year time history. This period was selected as the most representative of current basin flow conditions due to the uncertainty in the weir stage-discharge relationship prior to 1964 (Funke, D., pers. comm.). A 30-year simulation required approximately 14 hours of clock time on a Gateway E-4400 personal computer equipped with a 1 GHz Pentium processor.

Because the HSPF tributary basin flow models do not consider changes in land use or land cover over time, the model is not expected to accurately reproduce the actual 30-year river temperature time history. Instead, the use of the observed 30-year meteorological time history (primarily rainfall and air temperature) is intended to incorporate the natural climatic variability under reasonably current land use conditions in the basin. Incorporation of natural climate variability is expected to improve the confidence in model-predicted comparisons between the existing condition base case and temperature management alternatives.

Analysis of Model Output Relevant to Salmon

In order to provide comparisons among modeling scenarios that were most relevant to the exposure of salmon to heat stress, daily temperature threshold exceedances were combined with the duration of the exceedances to provide an Index of Thermal Stress (ITS). This approach essentially produced degree-day values above a chosen threshold—in this case 17 ^{o}C. As a simple example, a two-hour exceedance at 19 ^{o}C [2/24 x (19-17) = 0.168 degree-days] would count as four times as much thermal stress in this index as a one-hour exceedance at 18 ^{o}C [1/24 x (18-17) = 0.042 degree-days]. The resulting daily degree-day values were then summarized for the period August through October (the relevant chinook and sockeye spawning migration period in the Sammamish River) over each 30-year model run. Summary statistics included the average daily degree-day value (i.e., the sum of each daily-degree value divided by the number of days between August and October during the simulation period [2,760 days]) and the maximum daily degree-day value for the 30-year simulation period (i.e., the worst day during August through October during the simulation period [worst of 2,760 days]).

The threshold of 17 ^{o}C was chosen based on a literature review performed by the Washington Department of Ecology (Hicks 2000). The Ecology report cites 17 ^{o}C as the "Most Recommended Value" to support the summer migrations of chinook and sockeye (Hicks 2000, p. 100), which are the most relevant species and life stage for this analysis in the Sammamish River. This threshold was confirmed for use in the ITS by ecologists working on the river (Lucchetti, G. and Martz, M., pers. comm.).

Evaluation of Model Performance

Model calibration was re-evaluated using the same error statistics computed as part of the previous study (Jain et al. 2000): average hourly bias and hourly root mean square error (RMSE) (see Results section below). Graphical comparison of model output and observed temperatures are also provided in the appendix to this memo. Note that this information provides only a portion of the information needed to establish the acceptance of a model and its applications. The ultimate acceptance of a model requires evaluation of a host of factors and no specific pass/fail criteria exist. In general, model performance was considered adequate for conducting the alternatives analyses described in this report.

In addition to model error statistics, a limited number of model sensitivity analyses were conducted. The sensitivity analyses focused on the uncertainty associated with the downstream Lake Washington water surface elevation and temperature boundary conditions. The results of these analyses are summarized and discussed below.

Description of the CE-QUAL-W2 Model

CE-QUAL-W2 Version 3.0 has been recently released for beta testing and includes a number of improvements over the previous Version 2.0 releases (Cole and Wells 2000). These improvements include:

- Ability to model sloping river reaches
- Ability to model combinations of river, reservoir, and estuarine waterbodies
- Turbulence closure models for each waterbody using eddy-viscosity mixing length models
- Varying vertical grids between waterbodies
- Chezy or Manning’s friction factor
- Reaeration formulae based on riverine or reservoir/lake or estuary character or user-defined formulations
- Evaporation models based on theory or user defined formulations
- Numerical algorithms for pipe, weir, and pump flow within or between waterbodies
- The effect of hydraulic structures on gas transfer and total dissolved gas transport
- Conservation of longitudinal momentum at intersections between main branches and side branches
- The effect of lateral inflows from tributaries or the lateral component of inflows from branch intersections on the vertical eddy viscocity
- Multiple user defined algal groups (up to six)
- Multiple user defined organic matter groups (up to nine)
- A simple routine to reduce segment-specific incident solar radiation to account for the effect of riparian or topographic shading on the heat balance

The latest improvements and proposed model features (see below) make CE-QUAL-W2 well suited for application to temperature problems in the Sammamish River.

Further model enhancements are proposed, although no specific time frame has been identified for addition of the following:

- A dynamic shading model dependent on topographic and vegetative shading for each segment
- Complex sediment diagenesis model to improve the reliability of long term water quality modeling where sediment-water interactions are important
- Incorporation of the water quality and hydrodynamic effect of macrophytes and periphyton
- A k-ϵ turbulence model that will collapse all turbulent eddy viscocity formulations into one
- User-defined number of organic matter fractions, algal groups, or arbitrary constituents as desired

Temperature Management Alternatives

The base case and fifteen management scenarios tested are described below:

Base Case - The Base Case consisted of the latest version of the Sammamish River W2 model that continuously simulates mainstem river water temperatures. The Base Case model also includes a 5 cfs "surface" withdrawal (July-August) from the bottom of river segments 13, 15, and 20 to represent existing point withdrawals. Withdrawals increase linearly from 0 cfs on April 30 to 5 cfs on July 1. Withdrawals decrease linearly from 5 cfs on August 31 to 0 cfs on October 1. Conceptually, it was assumed that the distributed flow in the calibrated model accounts for current groundwater withdrawals and resulting diversion of a portion of the groundwater flow to the river.

Fifteen management scenarios were simulated. These scenarios are described below.

Elimination of Existing Withdrawals

1. **Eliminate Existing Withdrawals vs. Base Case-** Eliminate existing surface withdrawals and introduce a maximum groundwater flow of 5 cfs distributed over model segments 2 - 24 (from Marymoor Park to downtown Woodinville) to simulate groundwater augmentation from terminating existing groundwater withdrawals along this reach of the river. The temperature of the additional groundwater is assumed to be 13 ^{o}C. Groundwater flow will mimic the pattern of the existing surface withdrawals (i.e., ramp up from 0 cfs to 5 cfs during May-June, peak at 5 cfs from July-August, and ramp down to 0 cfs by Oct 1).
2. **Eliminate Existing Withdrawals vs. Doubled Surface Withdrawal** - Evaluate possible effect of underestimating surface withdrawal. Create a revised Base Case with a maximum surface withdrawal of 10 cfs (same ramping pattern as above). Compare this case to the results for Alternative 1 to evaluate the effect of eliminating a larger surface withdrawal along with terminating groundwater withdrawals.

Groundwater Augmentation

3. **Small Groundwater Augmentation-** Simulate the potential effect of augmenting groundwater recharge. Introduce to the base case a steady year-round groundwater flow of 5

cfs distributed over model segments 2 - 24 to simulate additional groundwater recharge along this reach of the river. The temperature of the additional groundwater is assumed to be 13 ^{o}C.

4. **Large Groundwater Augmentation-** Same groundwater recharge case as Scenario 3 but with a steady year-round groundwater flow of 15 cfs distributed over model segments 2 - 24. The temperature of the additional groundwater is assumed to be 13 ^{o}C.
5. **Warmer Groundwater Augmentation** - Same groundwater recharge case Alternative 4, but the temperature of the groundwater inflow to the river was set at 16 ^{o}C (to reflect the possibility that augmented groundwater may not be as cool as existing groundwater).

Riparian Vegetation

6. **50% "Shade" [1]** – 50 percent total reduction in solar radiation, representing mature riparian plantings. This may be an optimistic maximum for shade given the width of the river, its angle to the sun and human uses still anticipated in the buffer area, including the trail (Lombard, J., pers. comm.). Riparian plantings might result in modification of localized climate (e.g., lower air temperature), but for now these effects are not assumed in the model.
7. **25% "Shade" –** 25 percent total reduction in solar radiation, representing mid-stage growth of riparian plantings.

Bear Creek Management

8. **Increased flows from Bear Creek of up to 5 cfs (Bear Creek Restoration)** - Assumes replacing existing withdrawals with other sources, including possible savings from conservation. The additional flow in Big Bear Creek increases linearly from 2.5 cfs beginning in May to a maximum of 5 cfs in July-August and decreases linearly to 2.5 cfs by October 1. The additional 2.5 cfs flow occurs from October 1 through April 30 of the following year.
9. **Increasing temperature of Bear Creek (Lost Bear Creek Shade) –** Increased temperature of Big Bear Creek, resulting from reduced shade as existing riparian areas along the stream are reduced or removed (a management scenario to be avoided, evaluating risk from inadequate protection of vegetation). The synthesized long term Big Bear tributary temperatures were adjusted through the use of the Response Temperature Model and its shading coefficient to produce a maximum difference of 2 ^{o}C during the maximum temperature period in 1999. The model was then run using the modified tributary temperature for this tributary.

Combination of Alternatives

10. **Eliminate withdrawals plus Bear Creek Restoration –** Eliminate existing surface withdrawals as in Alternative 1 and Bear Creek Restoration as above.
11. **Eliminate withdrawals plus large groundwater augmentation** - Eliminate existing surface withdrawals as in Alternative 1 and large (15 cfs at 13 ^{o}C) groundwater augmentation as in Alternative 4 above.

[1] A simplified approach to simulating the effect of riparian shade on incoming solar radiation is currently used in CE-QUAL-W2 version 3.0. The addition of a dynamic shading model is planned for a future release of CE-QUAL-W2.

12. **Eliminate withdrawals, large groundwater augmentation, and Bear Creek restoration -** Eliminate existing surface withdrawals as Alternative 1, large (15 cfs at 13 ^{o}C) groundwater augmentation as in Alternative 4, and Bear Creek restoration as above.
13. **Eliminate withdrawals, large groundwater augmentation, Bear Creek restoration, plus 25 % shade -** Eliminate existing surface withdrawals as Alternative 1, large (15 cfs at 13 ^{o}C) groundwater augmentation as in Alternative 4, Bear Creek restoration and 25 % "shade" as above.

Hypolimnetic Withdrawal

14. **Hypolimnetic Withdrawal from Lake Sammamish Scenario 1 -** Represents construction of a hypolimnetic withdrawal system in Lake Sammamish. The hypolimnetic temperature input is based on available monthly temperature profile monitoring data. Reliable hypolimnetic data for the Mid-Lake Lake Sammamish stations [North (0611) and South (0612)] go back as far as 1994 corresponding to the implementation and use of electronic temperature profiling equipment. Review of the 1999 profile data for the two mid-lake stations indicated that the bottom temperatures became relatively uniform at and below the 15-m depth. Due to the limited length of the available temperature record, a representative 30-year time history was constructed using the 99 percent upper confidence limit of the monthly mean temperatures recorded at 15-m depth at Station 0611 from 1994 to 2000 (Table 1). It was assumed that hypolimnetic temperatures do not fluctuate significantly on an hourly basis (fairly reasonable) and that linear interpolation between monthly values would provide a suitable test of the potential influence of this management scenario on river temperatures. Scenario 1 assumes that 10 cfs of hypolimnetic water are blended with the existing lake weir outlet flow during the critical August-October period. This alternative assumes that no existing flow is diplaced. The temperature of the weir flow decreases and the existing flow is increased by 10 cfs..
15. **Hypolimnetic Withdrawal Scenario 2 –** This scenario assumes that 20 cfs of hypolimnetic water is blended with the existing weir outlet flow to reduce the outlet temperature without any change in the existing flow rate. This scenario is more optimistic (i.e., will result in greater predicted cooling) than the previous scenario due to the higher hypolimnetic withdrawal rate and the greater influence of replacing a portion of the warm outlet flow vs. adding additional cool water to the existing warm outflow.

Selected Locations for Management Evaluation

A total of six model grid locations were selected for purposes of calculating the ITS and comparison of management alternatives. All temperature differences were based on comparison with model predictions from the **bottommost** model layer, assuming that salmon will seek the coolest available water. The model segments selected were as follows:

- Segment 3, upstream of Bear Creek
- Segment 6, downstream of Bear Creek (after inflow has mixed and "reset" river temperature)
- Segment 20, NE 145th Street (north end of Agricultural Production District)
- Segment 25, The segment just above the confluence with Little Bear Creek

- Segment 37, Blyth Park (typically the coolest point of the river in summer)
- Segment 43, Swamp Creek mouth (after river has warmed from lake backwater)

Table 1. Summary Statistics for Lake Sammamish Hypolimnetic Temperatures (°C) at 15 m depth – August-October 1994-2000

	August	September	October
Mean	9.9	9.9	10.7
Standard deviation	0.46	0.65	1.5
n	7	5	6
Minimum	9.4	9.2	9.6
Maximum	10.6	10.8	13.7
95 % UCL	10.3	10.8	12.3
99 % UCL	10.5	11.3	13.2

UCL = Upper Confidence Limit
Statistics derived from monthly temperature profiles measured at the northern Lake Sammamish mid-lake station 0611.

Results

The model prediction errors associated with model reconfiguration and the use of additional/improved data and the results of the temperature management alternative simulations are summarized below.

Model Reconfiguration and Calibration

Changes in the model configuration and input files resulted in a general reduction in average hourly model prediction bias and hourly RMSE, except for the bias of predictions at the 124th Street and 145th Street bridges and RMSE at 145th Street Bridge, which increased (Table 2). Note that the comparison is based on the June-September period selected by JEEAI for calculation of error statistics.

Table 2. Comparison of Hourly Model Error Statistics for the June-September 1999 calibration, °C

	KCDNR (Jun – Sept 99)		JEEAI (Jun – Sept 99)	
Station	**Bias**	**RMSE**	**Bias**	**RMSE**
Railroad Bridge	0.03	0.31	0.17	0.33
Willows Run (51N)	0.07	0.35	-	-
NE 116th Street	-0.02	0.40	-0.20	0.56
NE 124th Street	0.13	0.46	-0.01	0.66
NE 145th Street	0.26	0.59	0.11	0.58
Blyth Park	-0.12	0.50	-0.13	0.61
Overall	0.06	0.43	-0.01	0.56

Notes: Willows Run (51N) temperature record was for the period 4/30/99 to 10/11/99. Problems with the Blyth Park thermistor resulted in a record for the period 6/1/99 to 8/25/99. Willows Run (51N) temperature records were not available to JEEAI for comparison to their model results.

The hourly average bias and hourly RMSE associated with the current model configuration and setup for the 1999 period of record and the critical period for management alternatives evaluation (August-October) are shown in Table 3. Model bias and RMSE for the entire period of record (June-October) was similar to the June-September period, except for the bias of predictions at the 124th Street and 145th Street bridges, which decreased. The bias and RMSE associated with the August-October period was generally higher, except for the bias of predictions at the 124th Street and 145th Street bridges. Plots of the hourly observed and model-predicted 1999 August-October temperatures at the six observation locations are provided in Appendix Figures A1 through A6. Figures that show the model fit to the entire period for which data are available and summary tables of the model setup and model coefficients are available upon request.

Table 3. Model Error Statistics for the Entire 1999 calibration, °C

	Jun - Oct 1999		Aug – Oct 1999	
Station	**Bias**	**RMSE**	**Bias**	**RMSE**
Railroad Bridge	-0.02	0.32	-0.06	0.36
Willows Run (51N)	0.02	0.33	0.02	0.39
NE 116th Street	-0.08	0.43	-0.15	0.48
NE 124th Street	0.06	0.48	0.00	0.53
NE 145th Street	0.17	0.58	0.09	0.59
Blyth Park	-0.12	0.50	-0.18	0.56
Overall	0.01	0.44	-0.05	0.48

Notes: Willows Run (51N) temperature record was for the period 4/30/99 to 10/11/99. Problems with the Blyth Park thermistor resulted in a record for the period 6/1/99 to 8/25/99.

The model reconfiguration also improved the match of model-predicted to observed surface water temperatures recorded during the September 2, 1999 FLIR study[2] (Figure 3). The FLIR study provided the most recent data indicating that summer surface water temperatures in the lower river increase downstream of North Creek. This phenomenon was also observed during a two-year study of the Sammamish River conducted in the late 1960s (Dalseg and Hansen 1969). Figure 3 shows the initial JEEAI model result based on the addition of two downstream model segments to the original 43 segment single reach (slope = 0.0000687 m/m) geometry and the result of widening and deepening the downstream model reaches (Buchak et al. 2001). Figure 3 also shows the result of dividing the original geometry into two waterbodies separated below segment 34 upstream of Blyth Park.

Note that the figure displays the FLIR-observed surface temperatures (at approximately 14:30 Pacific Standard Time [PST]), output from the model surface layer at the same time, and the temperature observations taken below the water surface at six locations along the river at 14:00, 15:00 and 16:00 PST. Field observations indicate that the river above Little Bear Creek is

2 The Excel spreadsheet supplied with the Watershed Sciences, LLC report (McIntosh and Faux 1999) indicates that the FLIR survey was conducted between 22:22 to 22:40 Greenwich Mean Time (GMT). Since GMT is 8 hours ahead of PST, the correct period for comparison of model results is 14:22 to 14:40 PST (or approximately 14:30 PST).

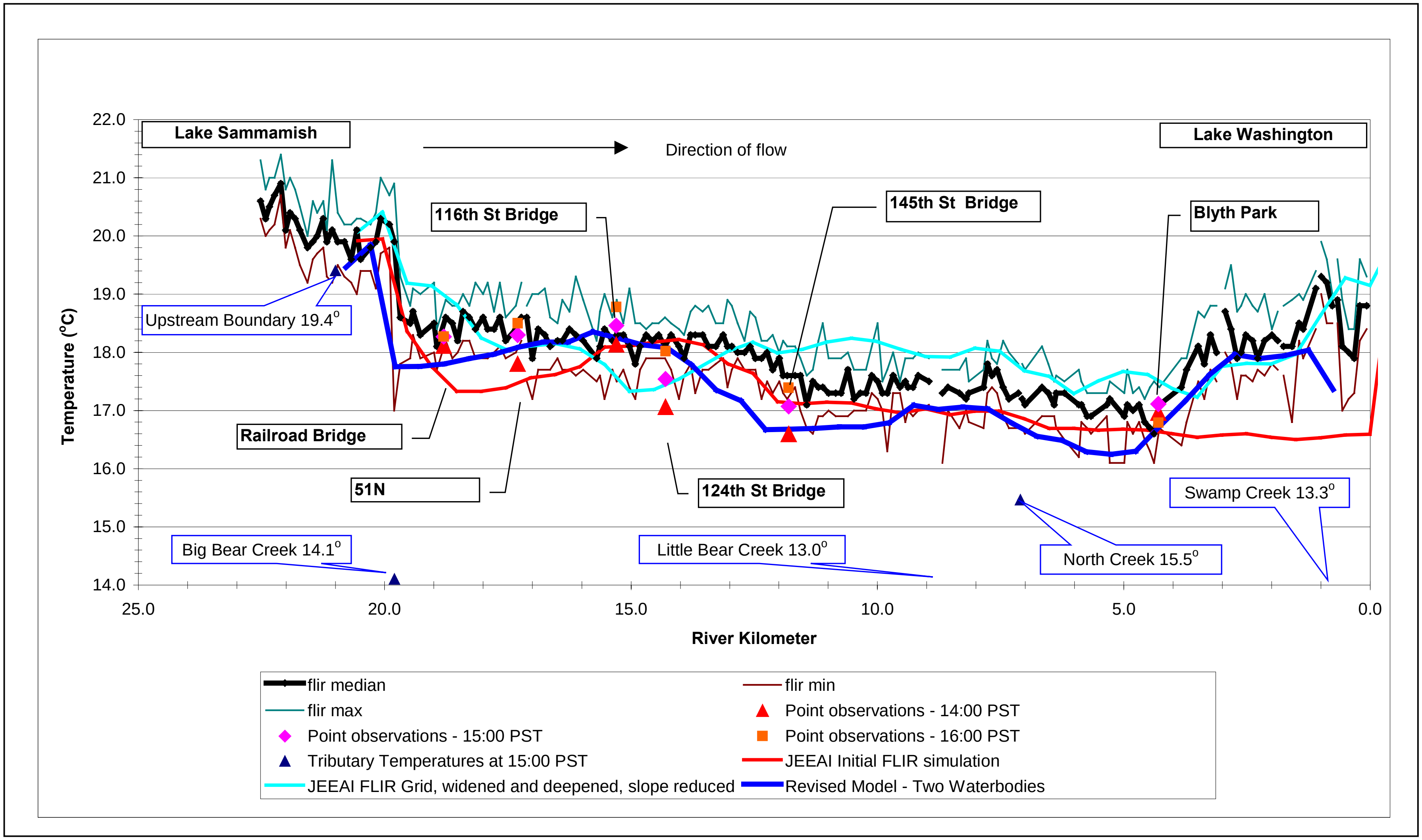


Figure 3. Comparison of Revised Model and JEEAI Model Simulations to the September 2, 1999 Forward-Looking Infrared (FLIR) Data. [Note: FLIR minimum, maximum, and median temperatures represent 10 sample points taken longitudinally along the center of the stream channel from every 4th color coded thermal image derived from the raw thermal images. Point observations and tributary temperatures based on sensors placed below the water surface at the identified locations.]

relatively unstratified (Houck, D., pers. comm.). Therefore, the FLIR observations in the upper river reaches represent the mixed river temperatures. However, the model predicts that the river becomes thermally stratified downstream of North Creek as the river deepens and slows due to the backwater effect of Lake Washington. The deepening and slowing of the river allows for greater solar heating of surface waters and development of thermal stratification. A recent field study (August 30, 2001) confirmed the warming of surface waters downstream of North Creek and the occurrence of thermal stratification in the downstream reach of the lower river.

Although the model currently reproduces the general surface warming and development of stratification in the downstream river reach, sufficient data have not yet been collected that would allow further calibration and testing of the model in this reach. The interactions of tributary and main stem flow and temperature with the backwater effect of Lake Washington are complex. Therefore, the model predictions in this reach, particularly for segments 37 and 43 considered in the evaluation of the temperature management alternatives, should be viewed with caution. Collection of additional temperature data suitable for calibration of the model to the stratified temperature conditions in the lower river is recommended.

Model Sensitivity Analyses

Limited model sensitivity analyses were conducted to evaluate the potential effect of 1) systematic error in the downstream water surface elevations recorded by the Corps of Engineers at Kenmore and 2) the effect of using continuous vs. monthly temperature profile data for the downstream boundary condition.

- ***Kenmore Water Surface Elevation***

To evaluate the potential effect of systematic error in the Kenmore water surface elevation, two additional model runs were conducted by increasing and decreasing the water surface elevation by 0.1 m (0.3 ft). These model runs indicated that river temperatures as far upstream as Blyth Park can be affected as much as 0.5 ^{o}C by a 0.1 m change in the downstream elevation boundary condition (figure available upon request). Therefore, it is recommended that the uncertainty in the Kenmore water surface elevation be evaluated as part of further model refinement.

- ***Downstream Temperature Profiles***

To evaluate the potential effect of using monthly vs. continuous temperature profile data at the downstream boundary, one additional model run was conducted using only monthly temperature profile data (North End Lake Washington Station 0804) as the downstream temperature boundary condition. Comparison with the model predictions based on the Corps of Engineers 1999 continuous temperature data indicated that model temperature predictions at the most downstream model segment were relatively sensitive to the downstream temperature boundary condition (maximum difference of 1.2 ^{o}C at 4 m depth). However, the predicted temperatures at Blyth Park did not differ by more than 0.01 ^{o}C (figure available upon request). Therefore, the use of monthly grab temperature profile data from the North End Lake Washington Station 0804 appears reasonable for the evaluation of temperatures at or above Blyth Park.

Synthesis of Temperatures for Long Term Simulations

A table that summarizes the final calibration values used in the Response Temperature Model to synthesize long term tributary temperatures is available upon request. The average hourly bias and hourly RMSE associated with the synthesis of weir and tributary temperatures for the 1999 period of record and the critical period for management alternatives evaluation (August-October) are shown in Table 4. Plots of the hourly observed and model-predicted 1999 temperatures are available upon request.

Table 4. Temperature Synthesis Model Calibration Error Statistics, °C

	Annual 1999		Aug - Oct 1999	
Boundary Condition	**Bias**	**RMSE**	**Bias**	**RMSE**
Upstream Boundary (weir) – CE-QUAL-W2	-0.68	1.01	-0.63	0.86
Upstream Boundary (weir) – Response Model	-0.27	1.09	-0.67	1.21
Big Bear Creek	0.01	0.84	0.20	1.04
Little Bear Creek	0.04	0.75	0.29	0.82
North Creek	-0.31	1.08	-0.01	0.91
Swamp Creek	0.20	0.80	0.10	0.96

Notes: The weir temperature record was for the period 4/30/99 to 10/22/99. The weir temperature synthesis generated by the CE-QUAL-W2 model was used in the long term simulation of the Base Case. The remaining tributary temperatures were synthesized using the Response Temperature Model.

Average hourly Response Temperature Model tributary temperature prediction bias ranged from -0.28 to 0.05 and the hourly RMSE ranged from 0.76 to 1.00. Bias and RMSE for the August-October period was higher for Big Bear and Little Bear Creeks and lower for North Creek. Bias was lower and RMSE higher for Swamp Creek. The Response Temperature Models evidenced an overall positive prediction bias for Big Bear, Little Bear, and Swamp Creeks and a very slight negative bias for North Creek.

Temperatures that were predicted for the weir using the Response Temperature Model indicated a relatively higher bias and RMSE, likely due to the more complex processes that control the outlet temperature from Lake Sammamish. The average hourly Response Temperature Model bias on an annual basis for the weir was lower than for the outlet prediction from the Lake Sammamish CE-QUAL-W2 model. However, bias and RMSE for the August-October CE-QUAL-W2 modeling period was lower than that of the Response Temperature Model and qualitative comparison (figure available upon request) indicated that the CE-QUAL-W2 model has less negative bias at the end of the critical period in October.

In general, the potential negative bias in the synthetic long term weir temperature record should not affect relative comparisons between Base Case and temperature management alternatives as long as the management alternative does not involve manipulation of the weir temperature. This condition holds true for all but the hypolimnetic withdrawal alternatives analyzed. In the hypolimnetic withdrawal scenarios, the potential average bias of approximately –0.5 °C in the synthetic weir temperature is likely balanced somewhat by the selection of the 99 percent upper confidence limit of recorded hypolimnetic temperatures for the long term hypolimnetic withdrawal temperature input (see Table 1).

Synthesis of Tributary Flows for Long Term Simulations

Existing County watershed hydrologic models (HSPF) were used to synthesize the long-term time history of tributary flows. The average hourly bias and hourly RMSE associated with the HSPF models for the 1999 calendar year and the August through October period are shown in Table 5. Plots of the hourly observed and model-predicted 1999 tributary flows are available upon request.

Table 5. HSPF Model Error Statistics, cfs

	Annual 1999		Aug - Oct 1999	
Tributary	**Bias**	**RMSE**	**Bias**	**RMSE**
Big Bear Creek (02A at Union Hill Rd)	27	55	9	12
Little Bear Creek (30A at Highway 202)	1	23	2	9
North Creek (Snohomish Co. gage)	15	47	4	13
Swamp Creek (56B at 73rd Ave)	2	35	-5	11

Temperature Management Alternatives

The results of the Base Case and temperature management alternatives are summarized in Table 6. The summary table shows the average daily degree-day for the August-October period for 1970-1999 for the selected grid locations and the maximum daily degree-day for the same period. Table 7 provides the percent change in the average and maximum degree-day for each alternative in comparison to the Base Case, except for Alternative 2. Alternative 2 (maximum 10 cfs surface withdrawal) is a sensitivity test for the assumed rate of existing withdrawals. Therefore, Alternative 2 is most appropriately compared to Alternative 1 (elimination of existing withdrawals).

- ***Note on Interpretation of Management Alternative Results***

Though it is useful to understand the mathematical basis for the numbers in Table 6 shown for the Base Case and fifteen management alternatives (see example calculations for a hypothetical location and day in Figure 4), it is more important to understand the numbers in the context of the effects of thermal stress on salmon3.

3 The reader should be cautioned that the long-term model results are based on synthetic tributary flow and temperature data. Therefore, the results are not intended to accurately represent temperature condtions in a particular year. The results are intended to capture the response of a number of temperature management alternatives under a wide variety of hydrologic and climatic conditions relative to the base case. Nonetheless, the Base Case results do provide a good indication of the magnitude and temporal variation of thermal stress.

Numbers shown as "Average" are averaged across a three month period (August to October) for 30 years. As an example, the daily average Index of Thermal Stress at Segment 3 (just below the weir) during August-October for the 30-year simulation period (and the overall average daily value) is shown in the top panel of Figure 5. Actual temperatures at segment 3 typically rise and fall as much as 2 ^{o}C over 24 hours, are greater than 17 ^{o}C over a 24-hr period in much of August, and typicallydecline from August to October.. The index number of 1.35 for the Base Case average at segment 3 (above Bear Creek), then, does not signify that 18.35 ^{o}C (1.35 above the 17 ^{o}C threshold) would be a typical temperature at segment 3 over the 30-year record of flow and weather conditions for August through October.. In the afternoon, segment 3 would typically be much warmer than 18.35 ^{o}C in August and much of September.

A 1.35 average index of thermal stress is a very high number, given the amount of time it implies adult salmon in that part of the river would endure temperatures that can be expected to do them physical harm—if not killing them outright, then increasing their susceptibility to disease and reducing the number and viability of their eggs for spawning. Even the 0.101 average index of thermal stress for the Base Case at Segment 37 is a cause of concern, recognizing that afternoon temperatures in August must typically be well above 17 ^{o}C to produce that average over the entire time period. Numbers shown as "Maximum" represent the single day with the highest index of thermal stress over the entire 30-year record (see bottom panel of Figure 5). Even they, however, represent the integrated temperature exceedances over a 24-hour period. Water temperatures were not typically 24.02 ^{o}C (7.02 above the 17 ^{o}C threshold) on the "Maximum" day for the Base Case at Segment 3—they were considerably higher than 24.02 ^{o}C in the late afternoon, and less than 24.02 ^{o}C in the early morning. Such temperatures can be lethal for salmon, especially if the days that follow are similar.

- ***Discussion of Results***

Note that in the management alternatives that reduce thermal stress in the upper river reaches, the average and maximum daily-degree day was almost always predicted to increase (i.e., increase stress) at segment 43. This was particularly true for the alternatives that resulted in an increase in flow in addition to a reduction in upstream river temperatures. In fewer cases where thermal stress was predicted to decrease in upstream reaches, the thermal stress was also predicted to increase at segment 37. As noted above, the thermal dynamics of the lower river reach is a complex interaction of main stem and tributary flow with the backwater produced by Lake Washington. Because the model has not been adequately calibrated to conditions in this reach, the predictions for segments 37 and 43 should be viewed with caution. Considering that the Base Case stress levels are lowest in this reach of the river (and that the absolute increases are relatively small [maximum difference of 0.003 and 0.20 for the average and maximum daily degree-day, respectively]), the direction and uncertainty of these predictions does not compromise the significance of the results reported for the upper river reaches.

Table 6. Summary of Average and Maximum Index of Thermal Stress (Daily Degree Day) for the Period August-October 1970-1999 as Predicted by the Sammamish River CE-QUAL-W2 Model.

	Segment 03		Segment 06		Segment 20		Segment 25		Segment 37		Segment 43		Average (n=6)	
Case	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Maximum
Base Case (5 cfs surface/5 cfs gw withdrawals)	1.35	7.02	0.691	5.56	0.611	5.78	0.405	4.99	0.101	2.65	0.028	1.96	0.53	4.66
Eliminate Withdrawals														
1) Elim. With. (No surface withdrawal/5 cfs gw return)	1.32	6.95	0.654	5.42	0.525	5.37	0.335	4.14	0.108	2.52	0.030	2.01	0.50	4.40
2) Mod. Base Case (10 cfs surface/5 cfs gw withdrawal)	1.35	7.02	0.691	5.56	0.605	5.76	0.404	5.22	0.088	2.63	0.027	1.92	0.53	4.68
Groundwater Augmentation														
3) 5 cfs 13 ^{o}C	1.32	6.95	0.651	5.42	0.514	5.34	0.329	4.24	0.099	2.50	0.029	1.99	0.49	4.41
4) 15 cfs 13 ^{o}C	1.28	6.84	0.579	5.14	0.370	4.60	0.220	3.58	0.085	2.54	0.030	2.05	0.43	4.13
5) 15 cfs 16 ^{o}C	1.31	6.89	0.635	5.27	0.497	4.99	0.316	3.94	0.108	2.66	0.031	2.04	0.48	4.30
Riparian Vegetation														
6) 50% "Shade"	1.33	7.00	0.642	5.40	0.357	4.97	0.139	3.05	0.016	1.33	0.015	2.01	0.42	3.96
7) 25% "Shade"	1.34	7.01	0.666	5.48	0.479	5.39	0.259	4.00	0.049	2.07	0.023	2.00	0.47	4.33
Bear Creek Management														
8) 5 cfs Flow Restoration	1.34	7.01	0.605	5.37	0.571	5.69	0.378	4.69	0.108	2.61	0.029	1.98	0.51	4.56
9) Effect of Lost Shade	1.35	7.02	0.787	5.81	0.665	5.98	0.434	5.13	0.106	2.73	0.028	1.96	0.56	4.77
Combined Alternatives														
10) Elim. With. / Bear Ck. Rest.	1.32	6.95	0.574	5.24	0.497	5.30	0.317	4.09	0.108	2.68	0.030	2.02	0.47	4.38
11) Elim. With. / Large GW Aug.	1.26	6.78	0.547	5.01	0.327	4.30	0.183	3.30	0.074	2.44	0.030	2.12	0.40	3.99
12) Alternative 11/Bear Ck. Rest.	1.26	6.78	0.485	4.87	0.318	4.29	0.174	3.23	0.069	2.38	0.031	2.15	0.39	3.95
13) Alternative 12 / 25% "Shade"	1.25	6.77	0.465	4.80	0.232	3.96	0.103	2.56	0.026	1.62	0.024	2.16	0.35	3.64
Hypolimnetic Withdrawal														
14) 10 cfs Added to Outlet	0.453	4.58	0.302	4.05	0.381	4.75	0.263	3.81	0.090	2.48	0.029	2.02	0.25	3.61
15) 20 cfs Blended w/ Outlet	0.047	3.31	0.050	3.07	0.124	3.51	0.097	3.13	0.045	2.02	0.025	1.99	0.06	2.84

Notes:

Daily Degree-Days based on product of daily duration and magnitude of temperature exceedances greater than 17 ^{o}C. Temperature statistics derived from model output from the bottom active cell of the referenced model segments.

Table 7. Summary of Percent Change Relative to the Base Case in the Average and Maximum Index of Thermal Stress (Daily Degree Day) for the Period August-October 1970-1999 as Predicted by the Sammamish River CE-QUAL-W2 Model.

	Segment 03		Segment 06		Segment 20		Segment 25		Segment 37		Segment 43		Average (n=6)	
Case	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Max.	Average	Maximum
Withdrawal Sensitivity Analysis														
2) Mod. Base Case (10 cfs withdrawal) [1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1) Elim. With. (No surface withdrawal/5 cfs gw return)	- 1.6	- 1.0	- 5.4	- 2.6	- 13.2	- 6.8	- 17.0	- 20.6	+ 22.1	- 4.0	+ 8.9	+ 4.4	-5.8	-6.0
Alternatives Comparisons to Base Case														
Base Case (5 cfs surface/5 cfs gw withdrawals)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eliminate Withdrawals														
1) Elim. With. (No surface withdrawal/5 cfs groundwater return)	- 1.6	- 1.0	- 5.4	- 2.6	- 13.9	- 7.1	- 17.1	- 17.0	+ 6.6	- 4.8	+ 5.0	+ 2.2	-6.4	-5.6
Groundwater Augmentation														
3) 5 cfs 13 oC	- 1.8	- 1.0	- 5.7	- 2.5	- 15.9	- 7.5	- 18.6	- 15.1	- 1.9	- 5.8	+ 1.9	+ 1.6	-7.5	-5.4
4) 15 cfs 13 oC	- 5.1	- 2.6	- 16.2	- 7.5	- 39.3	- 20.4	- 45.6	- 28.2	- 16.4	- 4.0	+ 4.6	+ 4.7	-19.5	-11.4
5) 15 cfs 16 oC	- 2.9	- 2.0	- 8.1	- 5.1	- 18.6	- 13.7	- 21.8	- 21.1	+ 6.9	+ 0.3	+ 7.8	+ 3.8	-9.0	-7.8
Riparian Vegetation														
6) 50% "Shade"	- 0.9	- 0.3	- 7.1	- 2.8	- 41.6	- 14.0	- 65.7	- 39.0	- 84.1	- 49.8	- 46.9	+ 2.2	-21.4	-15.0
7) 25% "Shade"	- 0.4	- 0.1	- 3.6	- 1.4	- 21.6	- 6.6	- 35.9	- 19.9	- 51.6	- 22.0	- 20.0	+ 2.0	-11.5	-7.2
Bear Creek Management														
8) 5 cfs Flow Restoration	- 0.1	- 0.2	- 12.5	- 3.4	- 6.4	- 1.5	- 6.5	- 6.1	+ 6.2	- 1.6	+ 2.8	+ 1.0	-4.6	-2.2
9) Effect of Lost Shade	0.0	0.0	+ 13.9	+ 4.6	+ 8.9	+ 3.5	+ 7.4	+ 2.7	+ 4.3	+ 3.1	+ 0.5	- 0.1	+ 5.8	+ 2.4
Combined Alternatives														
10) Elim. With. / Bear Ck. Rest.	- 1.7	- 1.0	- 16.9	- 5.8	- 18.7	- 8.2	- 21.7	- 18.0	+ 6.9	+ 1.0	+ 7.3	+ 3.0	-10.5	-6.0
11) Elim. With. / Large GW Aug.	- 6.6	- 3.4	- 20.8	- 9.9	- 46.5	- 25.5	- 54.9	- 33.8	- 27.4	- 8.0	+ 7.5	+ 7.8	-24.0	-14.3
12) Alternative 11/Bear Ck. Rest.	- 6.7	- 3.4	- 29.8	- 12.4	- 47.9	- 25.8	- 56.9	- 35.2	- 31.8	- 10.2	+ 9.0	+ 9.4	-26.7	-15.2
13) Alternative 12 / 25% "Shade"	- 7.0	- 3.6	- 32.7	- 13.6	- 62.1	- 31.5	- 74.6	- 48.7	- 74.2	- 38.7	- 14.7	+ 10.0	-34.0	-21.8
Hypolimnetic Withdrawal														
14) 10 cfs Added to Outlet	- 66.4	- 34.8	- 56.4	- 27.1	- 37.5	- 17.8	- 34.9	- 23.6	- 11.1	- 6.6	+ 2.9	+ 3.1	-52.3	-22.4
15) 20 cfs Blended w/ Outlet	- 96.5	- 52.9	- 92.8	- 44.8	- 79.8	- 39.2	- 76.1	- 37.2	- 55.6	- 23.7	- 11.3	+ 1.6	-87.8	-39.1

[1] The 10 cfs surface withdrawal case was designed to evaluate the effect of possibly underestimating existing surface withdrawals. The increased withdrawal case is a revised base case with a maximum surface withdrawal of 10 cfs (with the same ramping pattern as the Base Case). This case is most appropriately compared to the Withdrawal Elimination Alternative 1 to evaluate the effect of eliminating a larger surface withdrawal along with terminating groundwater withdrawals.

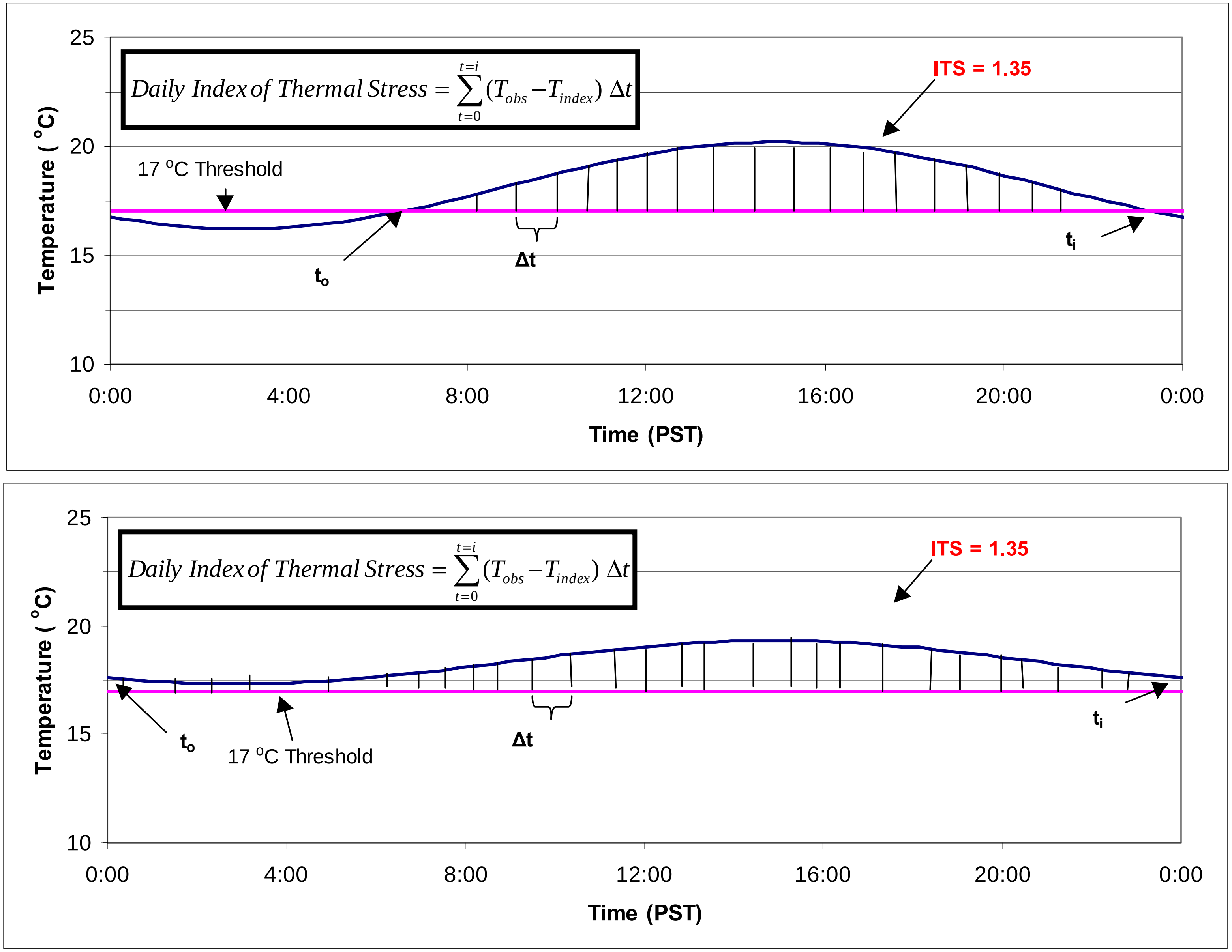
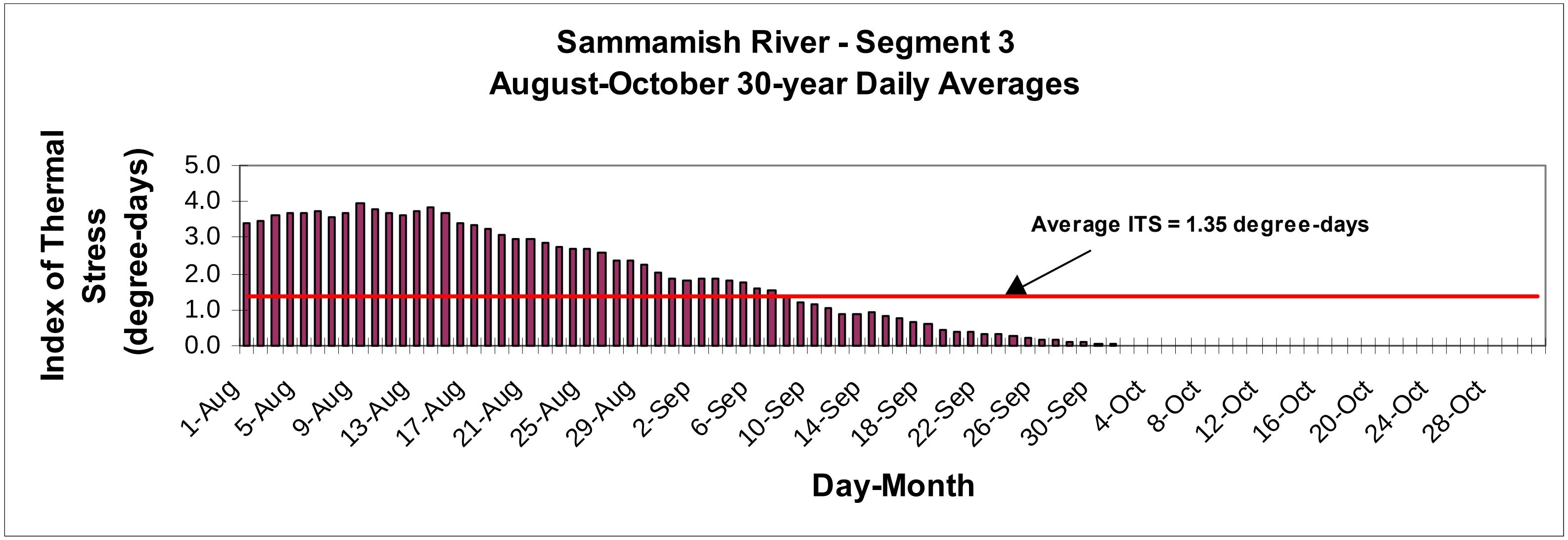


Figure 4. Example Calculations of an Index of Thermal Stress Equal to 1.35 Degree-Days. [Note: The top figure shows a diurnal temperature fluctuation of 4 °C (average =18.2 °C) and the bottom figure shows a fluctuation of 2 °C (average =18.3 °C). The actual model calculations were conducted at intervals of 15-seconds or less.]



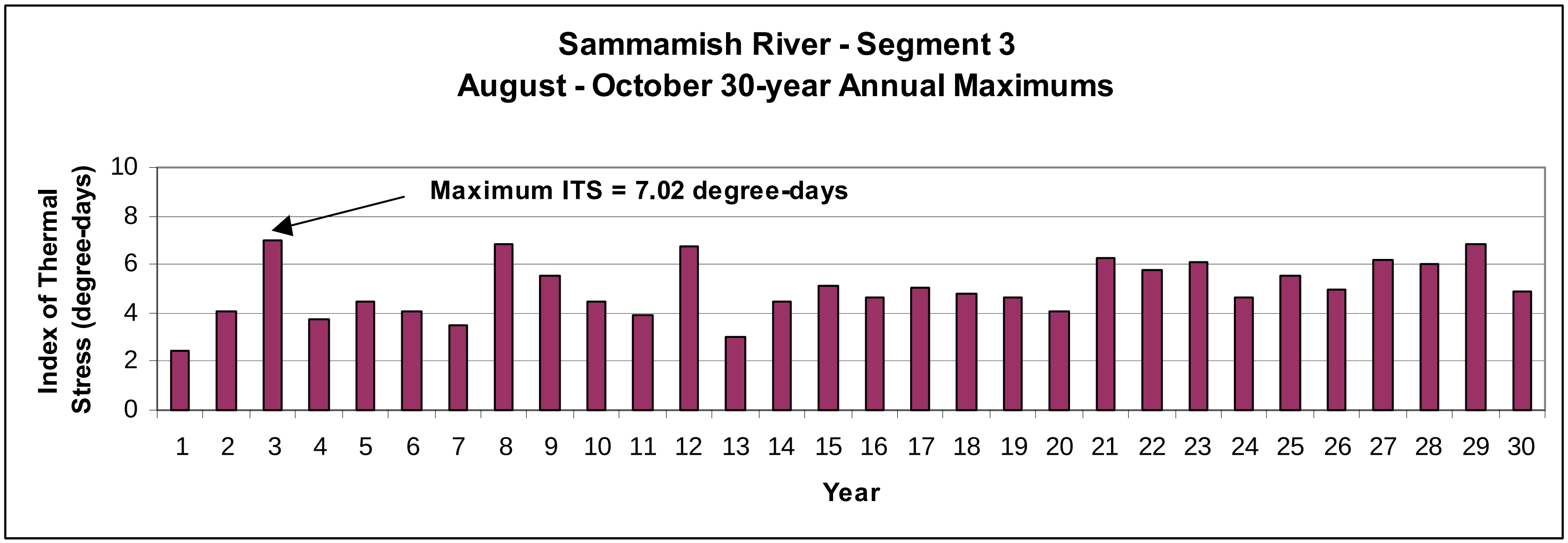


Figure 5. Summary of Daily Average and Annual Maximum (August-October) Index of Thermal Stress at Segment 3 over 30-year Simulation Period for the Base Case.

***Base Case*:** The Base Case results indicate that the greatest thermal stress for salmonid migration occurs in the vicinity of the upstream boundary. Thermal stress then decreases as a function of downstream distance. The average daily degree-day declines from 1.35 at model segment 3 to less than 0.03 at the most downstream evaluation segment 43. The maximum daily degree-day declines from 7.02 to 1.96 at the same locations.

***Sensitivity to Existing Withdrawal Estimate*:** Changing the maximum Base Case withdrawal from 5 to 10 cfs has little or no measurable effect at the most upstream locations (segments 3, 6, and 20), but does slightly increase the maximum daily degree-days at segment 25 (increase of 4.6 %) (see Table 6). The average daily degree-days actually decreases at segments 37 and 43 (12.9 and 3.5 %, respectively) relative to the Base Case, due to the increased influence of cool tributary inputs from Little Bear and North Creeks as a result of reduced upstream flow (i.e., the effect of greater upstream withdrawals). Comparison of the percent change in the Index of Thermal Stress between the Base Case and Alternative 1 and Alternative 2 (revised base case) and Alternative 1 (see Table 7), indicates that the expected change in thermal stress is generally very similar. However, there is a greater predicted increase in the average daily degree day at Segment 37 (+22.1 vs. +6.6 percent) when elimination of withdrawals (Alternative 1) is compared to a 10 cfs maximum withdrawal base case (Alternative 2). Again, this difference is due to the interaction of upstream withdrawals with the influence of cooling derived from the inputs of downstream tributaries.

Because the evaluation of management alternatives is based on the relative difference between the Base Case and alternatives model runs, the small differences between the 5 and 10 cfs model runs in the lower river model reaches should not raise too great a concern over the uncertainty of existing withdrawals. The results also indicate that the uncertainty in existing withdrawals is of relatively small consequence for the prediction of upstream reach temperatures.

***Eliminate Existing Withdrawals*:** Eliminating existing withdrawals is predicted to increasingly reduce thermal stress beginning at the head of the river as the cumulative effect of cool groundwater return distributed over segments 2-24 reduces river temperatures. The largest reduction in thermal stress is predicted to occur just below the region of enhanced groundwater inflow at segment 25— a 17.1 and 17.0 % decrease in the average and maximum daily degree-day, respectively.

***Groundwater Augmentation*:** The direct augmentation of groundwater flow to the river over the same reach also provided a cumulative benefit beginning at the head of the river. The greatest overall reduction in thermal stress was predicted for augmentation with 15 cfs of groundwater at a temperature of 13 ^{o}C. The largest reduction in thermal stress for this alternative is predicted to occur just below the region of augmented groundwater inflow at segment 25— a 45.6 and 28.2 % decrease in the average and maximum daily degree-day, respectively.

***Riparian Vegetation*:** The “Shade” alternatives also produced a gradually increasing benefit beginning with small reductions in thermal stress at Segment 3 and increasingly larger reductions downstream. The greatest overall reduction in thermal stress occurred in downstream reaches 20 to 43 due to the cumulative effect of shade on downstream temperatures. The largest overall reduction in thermal stress is predicted to occur at Segment 37 – a 84.1 and 51.6 % decrease in the average daily degree-day for the 50 and 25 % "Shade" alternatives, respectively.

***Bear Creek Management*:** Reducing existing withdrawals in the Big Bear-Evans Creek basin, is predicted to result in a significant reduction in thermal stress just below the creek confluence with the Sammamish River— a 12.5 and 3.4 % decrease in the average and maximum daily degree-day at segment 6. However, the relative benefit appears to diminish considerably downstream.

The evaluation of the potential negative effect of reducing existing riparian shade in Big Bear Creek indicates that increasing daily maximum Bear Creek temperatures by as much as 2 ^{o}C would increase thermal stress below Bear Creek as far downstream as segment 37. The largest increase in thermal stress would occur immediately downstream of the confluence with the Sammamish River — a 13.9 and 4.6 % increase in the average and maximum daily degree-day at segment 6.

***Combined Alternatives*:**

Possible combinations of the above alternatives were also evaluated (i.e., Alternatives 10 through 13 described above). Generally, the greater the number of combined alternatives, the greater the predicted decrease in thermal stress, although combinations that included alterations in flow resulted in small increases in predicted thermal stress in the downstream reach associated with segment 43.

***Hypolimnetic Withdrawal*:**

Because the temperature of the Lake Sammamish hypolimnion at 15 m is almost always below 14 ^{o}C, the effect of these management alternatives appear to have the potential to greatly reduce thermal stress in the uppermost reaches of the Sammamish River (see Table 7). These alternatives also showed similar or less potential to reduce thermal stress at locations downstream of segment 6. The hypolimnetic withdrawal scenarios also showed the greatest potential river-wide reduction in thermal stress. An average reduction of 52.3 percent in the average daily degree-day was predicted for the most conservative hypolimnetic withdrawal scenario (Hypolimnetic Withdrawal Alternative 14 - addition of 10 cfs of cool hypolimnetic water to the existing river inflow).

Regardless of potential uncertainties in the analysis of the hypolimnetic withdrawal alternatives (see discussion on page 20 of this memo), the relatively significant reduction in thermal stress in the upper river reaches can not be dismissed.

***Summary of Results*:** Of the positive individual Sammamish River management alternatives evaluated (not including hypolimnetic withdrawal), the 50 % "Shade" alternative appears to provide the greatest overall reduction in thermal stress in downstream segments 20 to 43 (41.4 to

84.1 % reduction in average degree-days) due to the cumulative effect of segment shading on stream temperatures. However, the greatest benefit from shade occurs in the lower river reaches where the thermal stress is lower. Alternative 4 (groundwater augmentation of 15 cfs at 13 ^{o}C) provided the greatest overall reduction in thermal stress in upstream segmentss 3 and 6, including the greatest reduction in maximum degree-days at segment 20 (20.4 %). Overall, these two alternatives (i.e., shade and groundwater augmentation) provided very similar average benefits river-wide based on the average change in thermal stress at the six model segment evaluation locations; -19.5 and –21.4 percent in the average daily degree-day for Alternative 4 (large groundwater augmentation) and 50% “Shade”, respectively (see Table 7). The combination of withdrawal elimination, large groundwater augmentation, Bear Creek restoration and 25% “Shade” resulted in the greatest overall reduction in river-wide average stress (-34.0 percent in the average daily degree-day).

The effect of reducing existing withdrawals in the Big Bear-Evans Creek basin, also results in a significant reduction in thermal stress just below the creek confluence with the Sammamish River— a 12.5 and 3.4 % decrease in the average and maximum daily degree-days at segment 6. However, the benefit appears to diminish considerably downstream.

Hypolimnetic withdrawal provides the greatest benefit where it is needed most, in the upstream reach that receives the warm surface water outflow from Lake Sammamish. The less conservative strategy of adding 10 cfs of cool hypolimnetic water to the existing lake outflow is predicted to reduce the average and maximum thermal stress at Segment 3 by 66.4 and 34.8 %, respectively. The next greatest benefit at Segment 3 was achieved by the combination of all alternatives, including 25% “Shade” (Alternative 13) – a reduction of 7.0 and 3.6 % in the average and maximum thermal stress.

Recommendations

As a result of the knowledge base and experience gained from the refinement and application of the Sammamish River temperature model a number of recommendations for further model improvement can be made. Because the Sammamish River temperature model will also be incorporated into the SWAMP to link water quality models of Lakes Sammamish and Washington, further changes and additions to the model are also necessary. These changes primarily involve modification of the model geometry to facilitate linkages to the upstream and downstream lake models and development of the eutrophication, indicator bacteria, and toxics modeling components of the model.

Suggested field monitoring activities that would provide information to further improve and refine the temperature model include:

- Collection of additional downstream temperature profiles for further refinement and calibration of model predictions in the downstream river reach and improve our understanding of the stratified flow regime in the lower river
- Monitoring and evaluation of stratified temperature conditions in the lower river reach below

North Creek during critical conditions to provide data suitable for evaluation of the model predicted stratification in this reach.

- Establishment of mainstem continuous temperature monitoring stations for further calibration and refinement of model predictions
- Longitudinal synoptic temperature monitoring to further refine and calibrate model predictions over the entire river reach during critical conditions
- Groundwater studies to better estimate the spatial and temporal contributions of flow to the river including estimates of groundwater quantity and temperature.
- Additional low flow measurements at the weir to improve the low flow stage-discharge relationship
- Synoptic longitudinal observations of river water surface elevations during various flow regimes for model calibration and refinement
- Dye transport studies to provide travel time estimates for further model calibration

Suggested field monitoring activities that would provide information for the development of the Sammamish River eutrophication model include:

- Establishment of mainstem monitoring locations for water quality model calibration
- Periodic continuous measurements of dissolved oxygen and pH at representative mainstem locations to establish typical patterns of diurnal variation in these parameters.
- Addition of total organic carbon (TOC), dissolved organic carbon (DOC), and chlorophyll a to the County's existing routine tributary and Sammamish River mainstem monitoring program
- Evaluation of aquatic plant coverage and biomass and its potential influence on river water quality

Other recommendation include:

- Development of watershed models capable of accurately simulating tributary temperature and water quality inputs for the Sammamish River model, including distributed (ungaged) tributary inputs
- Further development of a Lake Sammamish water quality model to provide improved upstream boundary conditions to the Sammamish River model
- Further evaluation/correction/refinement of the Kenmore water surface elevations used for model calibration
- Develop interagency coordination and funding to compile, manage, and store a variety of climate data collected by various agencies and institutions in the region to facilitate the access and use of local climate information
- Develop and implement standardized procedures for the use of continuously recording thermistors to collect temperature data

The last recommendation should provide greater assurance that measured temperatures are representative of the actual well-mixed temperatures at each sampling location recorded with a documented time standard [e.g., Pacific Standard Time (PST)].

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Martz, Merri. May 4, 2001. E-mail to J. Lombard, KCDNR-Director's Office. Senior Biologist, Tetra Tech, Inc., Portland, OR.

Wells, Scott. May 9, 2001. E-mail to C. DeGasperi, ., KCDNR-WTD. Professor of Civil Engineering, Portland State University, Portland, OR.

APPENDIX A

FIGURES

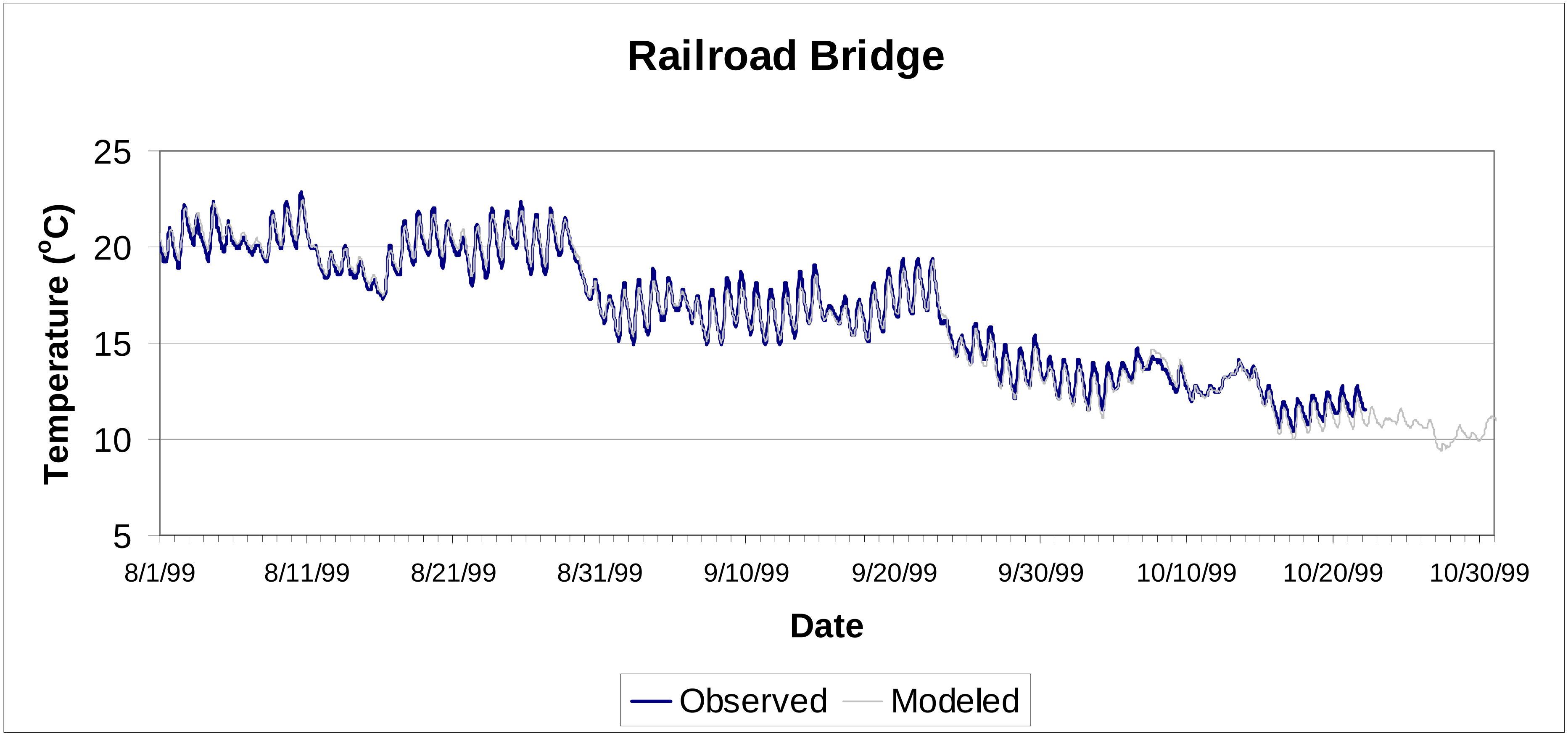

Figure A1. Model-predicted and observed temperatures at the Railroad Bridge – August - October 1999. Station location shown in Figure 1.

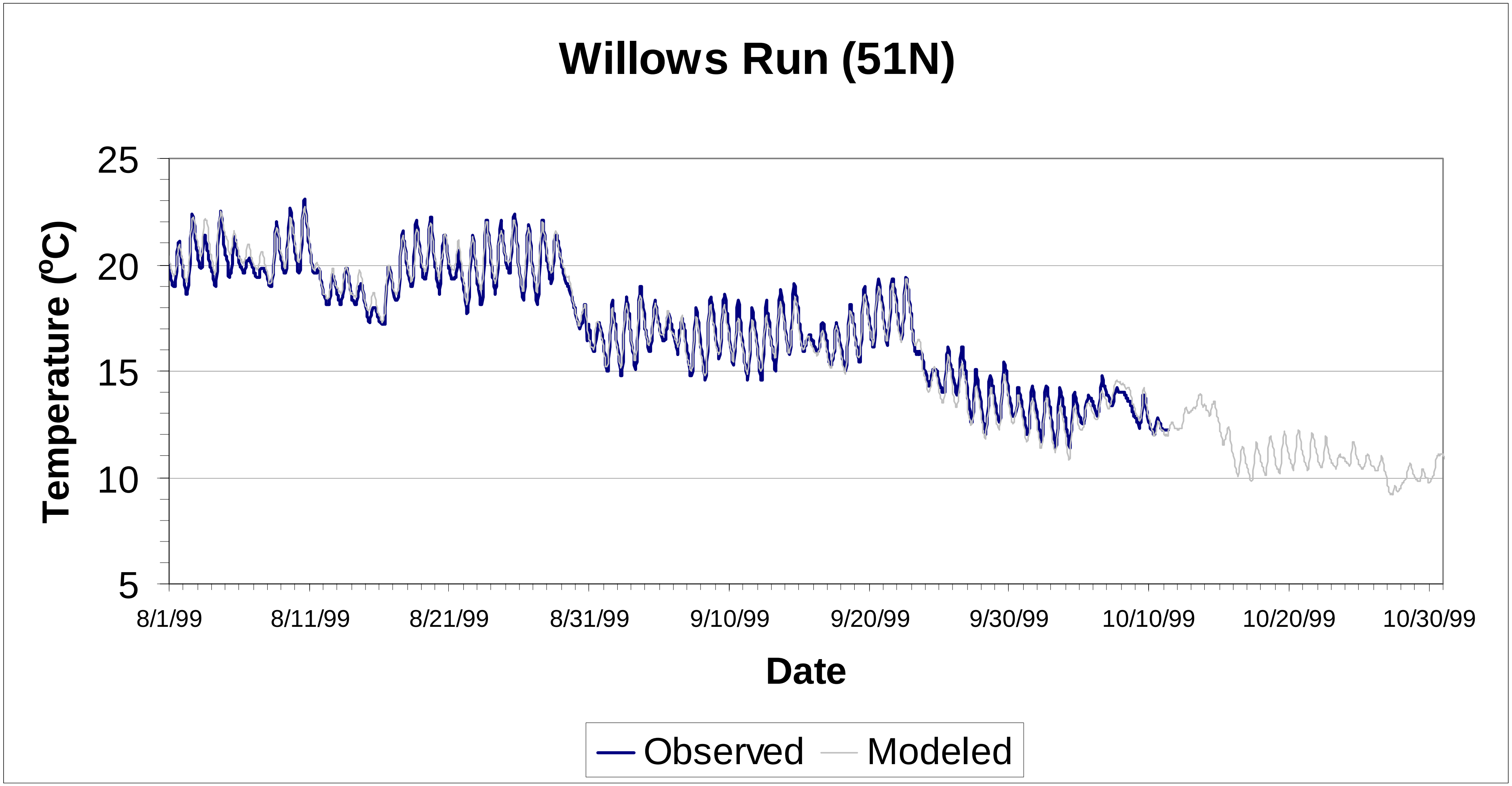

Figure A2. Model-predicted and observed temperatures at Willows Run (51N) – August - October 1999. Station location shown in Figure 1.

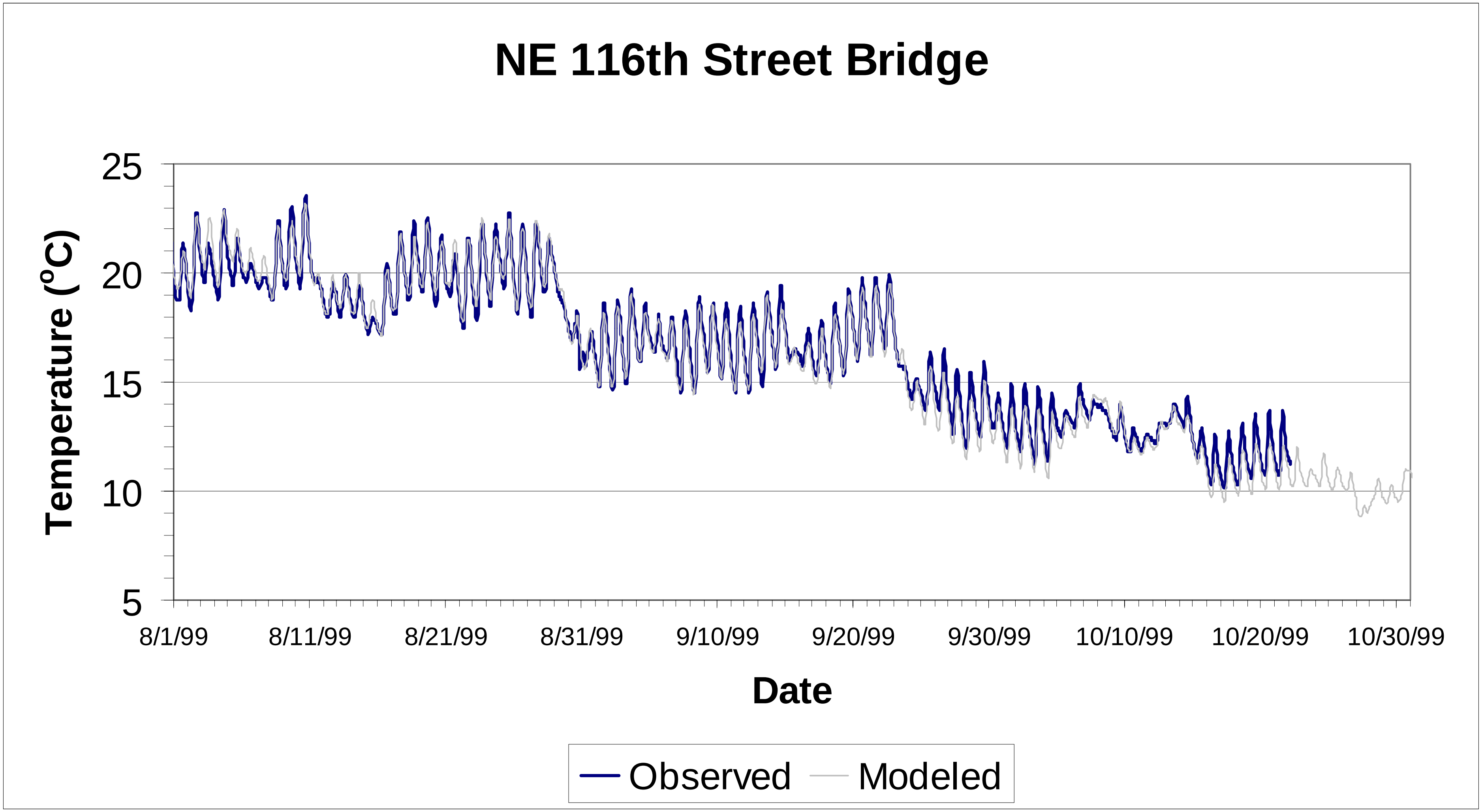

Figure A3. Model-predicted and observed temperatures at NE 116th St Bridge– August - October 1999. Station location shown in Figure 1.

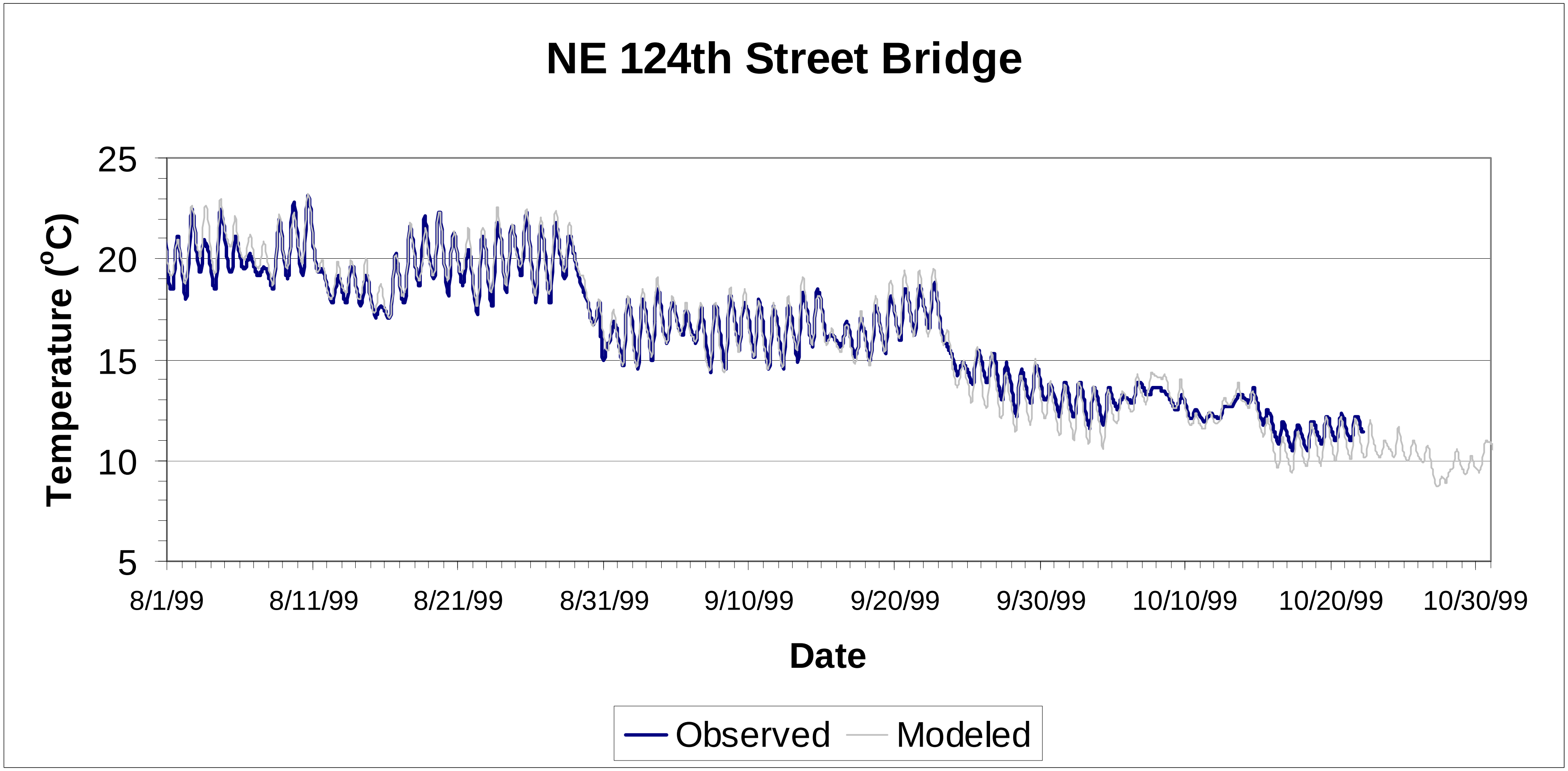

Figure A4. Model-predicted and observed temperatures at NE 124th St Bridge– August - October 1999. Station location shown in Figure 1.

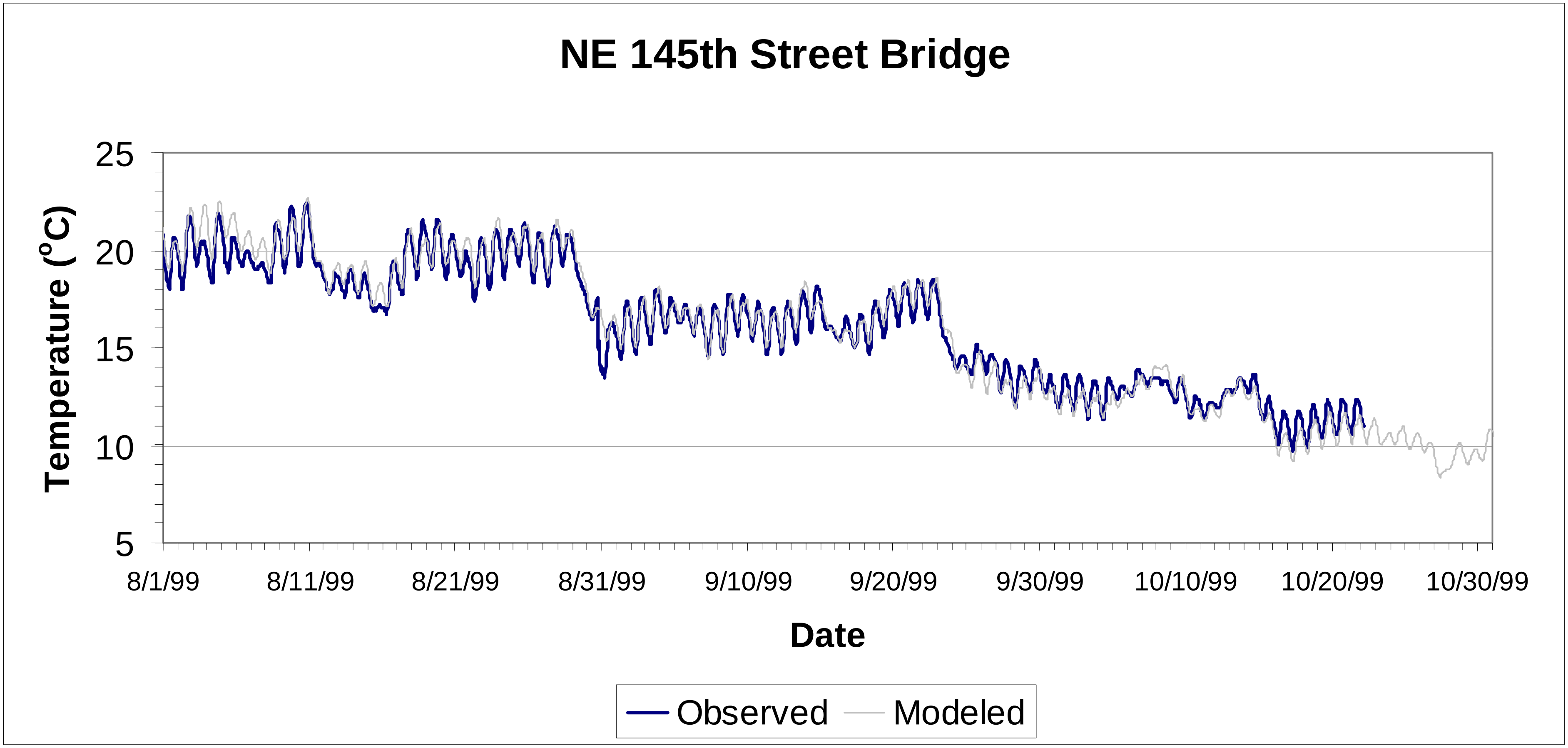

Figure A5. Model-predicted and observed temperatures at NE 145th St Bridge– August - October 1999. Station location shown in Figure 1.

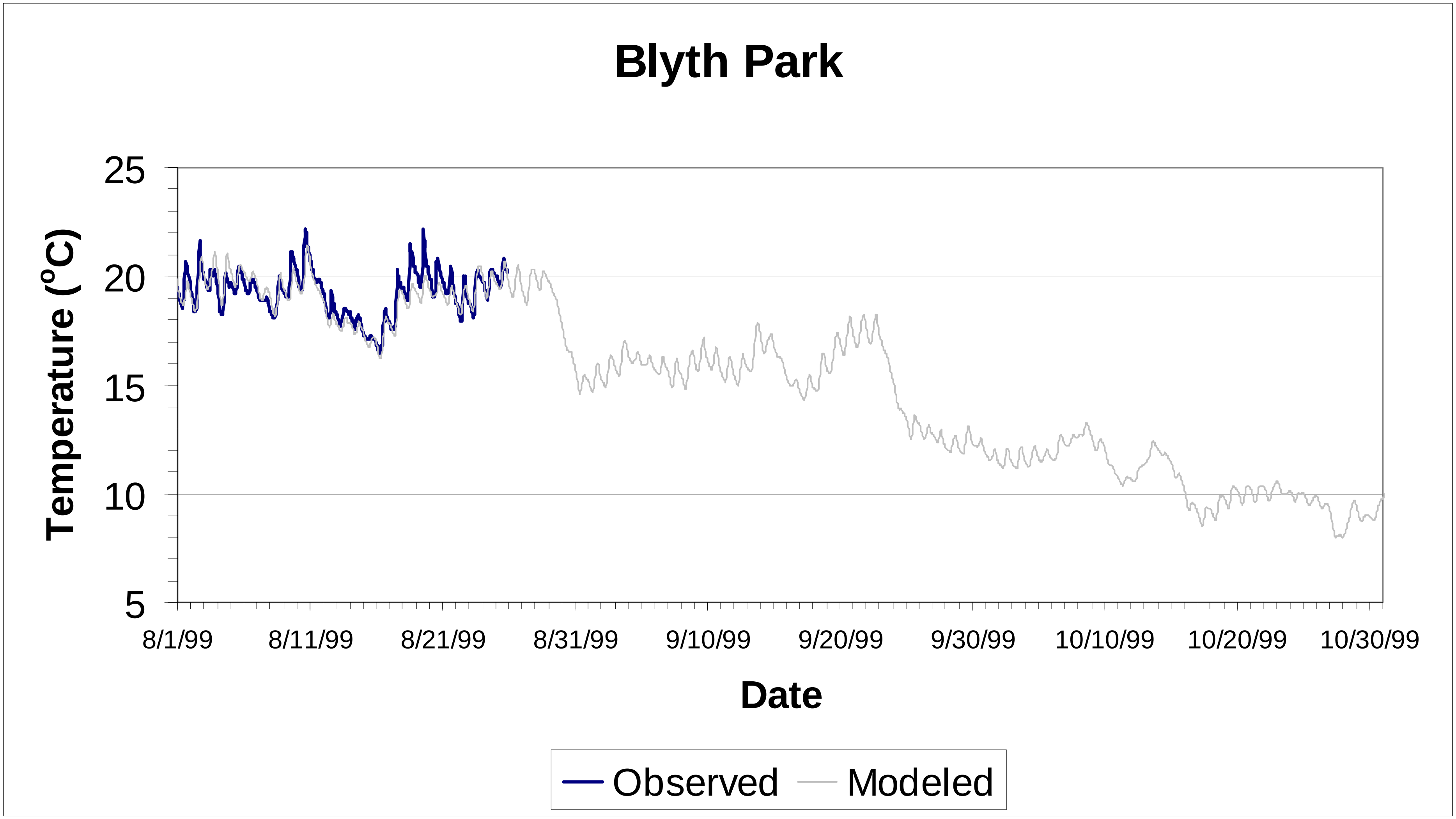

Figure A6. Model-predicted and observed temperatures at Blyth Park – August - October 1999. Station location shown in Figure 1.

APPENDIX C. SUMMARY OF COMMENTS RECEIVED AND RESPONSES FROM DRAFT REPORT

The draft report was provided to a number of agencies and some interested citizens for their review. The following agencies or individuals provided written comments or questions:

- Washington Department of Natural Resources
- Washington Department of Ecology
- King County Department of Natural Resources
- King County Wastewater Division
- King County Parks
- City of Bothell
- City of Kenmore
- City of Redmond
- City of Woodinville
- Muckleshoot Indian Tribe
- Steward and Associates
- NE Sammamish Sewer and Water District
- Michael Hobbs, Citizen
- Geoff Clayton, Citizen

The comments can be summarized under the major types of comments identified below:

Water Rights

1. Affected water purveyors should have a chance to review the document.
2. Water conservation is recommended as a core recommendation, but some water purveyors already have implemented water conservation strategies. It may be difficult to achieve additional conservation.
3. No data is presented that indicates water withdrawals in the Evans Creek basin causes harmful conditions to fish.
4. WA Department of Ecology has jurisdiction over water rights, so local governments do not really have authority to make decisions concerning water withdrawals.
5. Enforcement actions against illegal water withdrawals should be a high priority recommendation of this plan.

Response: The final document will be made available to interested parties, including water purveyors in the corridor. We recognize that some water purveyors have made significant efforts in water conservation, but water conservation is still very important for other water users including agricultural users, golf courses, and parks. Water conservation remains an important recommendation of this plan, particularly in the context of the opportunity to replace existing withdrawals with reclaimed water. Evans Creek is not discussed in this plan because it is outside of the defined river corridor. However, it is important to protect the existing cool water inputs from the Bear Creek system which includes Evans Creek. Some modifications have been made throughout the report to clarify that Ecology is the agency with jurisdiction over water rights. The local governments have no intention of trying to exert authority over water withdrawals. Enforcement actions against illegal water users has been made a core recommendation.

Fish Species and Populations

1. Please cite original publications for information included in this report for fish species and populations rather than recent compilations.
2. Please provide more information regarding escapement and population sizes for several salmonid species.
3. Please provide more recent and detailed information on spawning timing and distribution for several species, fecundity and egg mortality at Issaquah hatchery, etc.
4. Please provide clarification of the kokanee genetic studies.
5. Please provide more information on predation on salmonids in the corridor.
6. Please provide information on the effect of non-native aquatic plants on salmon use and survival.
7. Please provide information on benthic invertebrate communities, including mussels.

Response: The summary of fish species and populations in this plan is not intended to be the definitive statement on the numbers, distribution, etc. in the watershed. We relied on recent compilations of information provided by the Greater Lake Washington Technical Committee and Washington Conservation Commission for the most up to date information available. More details are available in the documents being produced by the WRIA 8 technical committees. Fish species information is provided as background in this document. The document has been revised to clarify most of the issues above where information was available. There is no information available on the effects of non-native aquatic plants and the data available on predation in the corridor is limited to a few locations (i.e. in Bear Creek) and does not provide enough information to be useful for the mainstem river.

Wildlife

1. Please revise the historic and existing conditions chapters to reflect bird species that were most likely to have been in the corridor and have been observed recently. Many of the county species of concern do not occur in the corridor.
2. Stress the importance of riparian and wetland restoration to wildlife species.

Response: Chapters 1 and 2 of the document have been revised per specific comments received on bird and wildlife species. The benefits to wildlife have been added to recommendations on riparian and wetland restoration.

Water Quality

1. The temperature model was not provided for review prior to the development of this plan.
2. Please provide data or citation to demonstrate that 1998 was an unusually warm year and that temperature is the most important limiting factor to salmon in the corridor.
3. Is the dog-leash free area a significant source of bacteria to the river?
4. Turbidity is not mentioned as a major problem. Is it?
5. What other water quality problems exist besides temperature?
6. Is 17°C an appropriate temperature to use in the model to determine stress? NMFS and state water quality standards use lower temperatures.

Response: The temperature model was initially developed by the Corps of Engineersand its consultants starting in 1998. The most recent refinement of the model is summarized in Appendix B of this document. It was developed concurrently with the plan and used to define the relative scale of effect of doing various restoration measures. Specific review of the model is ongoing and an additional study is recommended to provide more data to calibrate the modeling. 17°C was used in the model as the temperature above which stress was almost certain to occur to salmon. Citations have been provided for various water quality information, and the document has been clarified to indicate that temperature is a key limiting factor, but not the only one. No information is available on bacteria from the dog leash-free area. No specific study has evaluated turbidity in the river, but it is recommended as a further study.

Water Quantity

1. Water withdrawals may be affecting natural processes as well as temperatures, base flows, etc.
2. Provide additional information on ditches that convey water to the river.

Response: The document has been clarified to note that water withdrawals may be affecting a number of things in the corridor.

Riparian Buffers

1. NMFS and other agencies may be requiring more than 100-foot buffers on salmon-bearing streams. Please cite other requirements and if 100-foot buffers will be able to provide appropriate functions.
2. What activities should be allowed within the riparian buffer corridor?
3. Cottonwoods are a concern for public safety and the damage their roots can cause to the trail system.
4. Coniferous forest should be the ultimate goal of riparian restoration.
5. Discuss moving the trail further away from the river to maximize the buffer width.
6. Clarify buffer width recommendations.

Response: The buffer recommendation has been clarified and some discussion of appropriate activities within the buffer provided. Although Ecology and other entities are currently revising their buffer standards, the best literature reviews indicate that a minimum 100-foot buffer on perennial streams is appropriate, although wider buffers are better. Text has been clarified that cottonwoods are a public safety concern and plantings include native coniferous tree species. The idea of moving the trail has been mentioned for some reaches to maximize buffer width.

Monitoring and Adaptive Management

1. Identify who the members of the adaptive management team are.
2. Monitoring data should be collected into a central database.
3. Additional monitoring should be added including benthic invertebrates, pool formation, water quality.

Response: The text has been clarified to discuss a tentative membership of the adaptive management team and recommend a centralized database for future studies. Additional studies have been recommended in the monitoring section.

General

1. Provide more maps for historic condition, 303(d) listed reaches, etc.
2. A number of editorial comments were received.
3. Provide more discussion on what will happen if the plan is not implemented fully
4. How does this plan relate to the WRIA 8 efforts and other salmon recovery planning efforts.
5. Clarify what the cost estimates include.
6. Separate out cost estimates for core and high priority projects versus non-core and medium/low priority projects.
7. Comments on implementing entities for various projects.
8. Clarify what designation of regionally significant areas means.

Response: A map of the historic alignment of the river versus current conditions has been provided. The document has been revised per a number of editorial comments. Text has been added to discuss plan implementation and how the plan will be used by the WRIA 8 committees. Cost estimates have been revised and clarified. The recommendation of designating the corridor as a regionally significant area has been deleted because it does not appear that such a designation provides any additional protection to the corridor.

This document is available in alternative formats for individuals with disabilities upon request by calling the Water and Land Resources Division of the King County Department of Natural Resources at 206-296-6519 or TTY Relay at 1-800-833-6388.

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