Section 1. Semi-Quantitative Analysis of Human Actions Affecting Flow Regime

1.1 Introduction

The scope of work for the pilot project involves a focused study of two discrete subbasins in the Stillaguamish Water Resource Inventory Area, WRIA 5. The two subbasins being studied are Pilchuck Creek and the adjacent Church Creek basins, both located in the western portion of WRIA 5. Figure 1-1 shows the location of these basins. The subbasins were chosen in part because they illustrate management actions that affect flow regime that are or will be fairly common throughout Puget Sound drainages. These management actions include land use and land cover change, surface or groundwater water withdrawal and consumption, water diversion, and storm water management. Additionally, the two selected subbasins represent contrasting basin scales, topographic characters, patterns of salmonid usage, and potentials for future land use intensity that are also considered to be representative of many other Puget Sound basins. Church Creek is a small (3rd order at 1:24,000 map scale) stream with generally mild topography and rain-dominated hydrology. In its natural condition the stream is highly favorable for by coho, but not much used by Chinook salmon. It straddles the I-5 corridor and is relatively vulnerable to urbanization. Pilchuck Creek is a larger stream (4th order at 1:24,000 map scale), includes steeper topography and higher elevations with rain-on-snow hydrology. Pilchuck Creek provides Chinook salmon habitat along its mainstem. Forestry is the dominant land use under current and planned future conditions, making the Pilchuck Creek basin relatively less vulnerable to urbanization. Both of these stream types and basin characteristics are common in the Puget Sound basin.

Pilchuck Creek is a major tributary to the Stillaguamish River, draining approximately 76 square miles, and is used by all anadromous salmonids including Chinook salmon. Preliminary review during scope preparation for this project suggested that the primary human impact on Pilchuck Creek's hydrology was water withdrawals by the Tatoosh Water Company, with land use activities playing a secondary role. Subsequent review and analysis showed that the potential impact of Tatoosh's withdrawals would be largely confined to a tributary of Pilchuck Creek, and that effects on the mainstem would be minor.

Church Creek is a smaller but still significant tributary to the Stillaguamish River, draining approximately 11 square miles. It is used by coho salmon, sea-run cutthroat, and chum salmon. Preliminary review during scope preparation indicated that the primary human impact on Church Creek's hydrology would likely result from current land use and planned urbanization associated with the Stanwood Urban Growth Area. Subsequently, it was found that municipal water extraction from wells immediately adjacent to the creek were likely to be reducing summer base flows. The scope called for coho to be the focal species of ecosystem effects in this urbanizing basin.

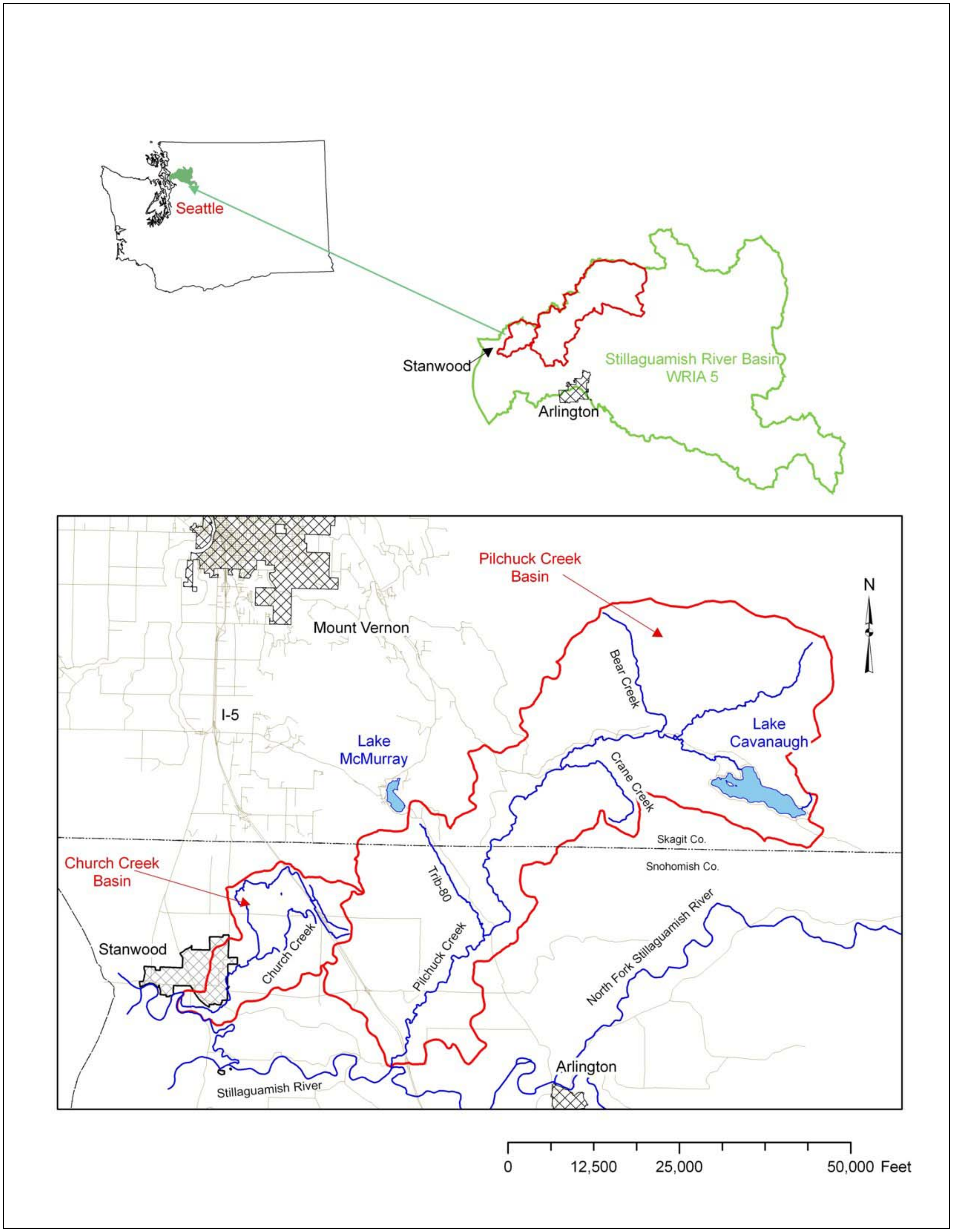

Figure 1-1 Location Map

1.2 Overview of Historical Development Actions

The history of the city of Stanwood, located at the lower end of the Church Creek basin, provides a view of the social history of the overall study area. The following summary is excerpted from the website[1] for the Everett-based Daily Herald Company newspaper.

Welcome to Stanwood

Bridging the gap between Camano Island and north Snohomish County is the town of Stanwood.

Situated on the banks of the Stillaguamish River, Stanwood was first settled as a trading post in 1866 and was a bustling port where loggers brought their product down to Puget Sound for export, while tall ships unloaded supplies for the mountain mining and logging communities.

Farmers moved into the region to provide hay for the many animals essential to the logging industry, and found the topsoil rich and fertile. Dairy farmers arrived soon after, and have ever since had a strong presence in Stanwood.

Railroads arrived in the early 1900s, and a large depot was built east of town. A new settlement, East Stanwood, sprang up, and the two communities maintained a bitter rivalry until 1960, when they finally united.

Today, Stanwood is a quaint mix of farming village and bedroom community. Downtown supports art galleries that showcase Northwest and tribal artists. Church Creek Park on the east side of town is a great picnic spot on warm summer days.

Stanwood holds its annual May Fest the first weekend of that month and hosts the Stanwood-Camano Fair in early August.

Stanwood Facts

Population:	3,923 (2000 census)
Area:	approximately 2.75 square miles
Mayor:	Matthew J. McCune
First settled:	1866
Incorporated:	1903
Median household income:	$44,512 Source: 2000 U.S. Census
Major local employers:	Twin City Foods, Stanwood School District

[1] http://www.heraldnet.com/guide/stanwood/

The **Stillaguamish Technical Advisory Group (STAG, 2000) developed an assessment of human impacts on Chinook populations in the Stillaguamish Basin. The following excerpts from their report** were selected to highlight activities with potential impacts on streamflow regime:

> *Prior to European settlement, many Native American tribes utilized the Stillaguamish Valley; particularly from Barlow Pass down to the river's mouth near Stanwood. Europeans first settled in the lower basin in the early 1860s and began diking and draining the floodplain for agricultural purposes shortly thereafter. Removal of log jams allowed areas upriver to be cleared and settled, facilitating access to the upper reaches and giving rise to several small towns.*
>
> *Logging began in the lower river as early as 1863 and was hastened by the establishment of timber mills near Florence and Silvana. As upriver navigation and access improved, logging became more widespread, reaching into the upper river and its tributaries. By the turn of the century, nearly all of the floodplain land on the mainstem had been cleared of trees and converted to agricultural lands. Accompanying this was the large scale conversion of tidal-influenced salt marsh habitat to agricultural lands through diking, ditching, and filling*
>
> *Historically, forest and agricultural land management practices have been the primary source of most habitat loss in the Stillaguamish Watershed. However, the conversion of existing forest and agricultural lands to rural residential uses has also been identified as a leading cause of declining salmon stocks in the watershed. Impervious surface, created by such development, impairs habitat function by reducing the area available for infiltration and increasing surface runoff. Development activities in urbanizing areas also frequently result in stream channelization and bank hardening, further impairing habitat function and hydrology.*
>
> *From 1870 to 1910, riparian logging had removed most, if not all, large conifers on the mainstem, lower South Fork, and North Fork up to Rollins Creek. A decade later, riparian forests in nearly all of Church Creek, much of Pilchuck Creek, lower portions of the North Fork Tributaries, and the South Fork Valley up to Granite Falls had been logged. Much of this land was converted to agricultural and urban uses, and consequently little replanting occurred.*
>
> *At the turn of the century, deciduous trees dominated the floodplain accounting for 63% of individual tree species; primarily red alder, black cottonwood, and big leaf maple. In the uplands, 79% of the forest was dominated by coniferous species, primarily western hemlock, Douglas fir, Pacific silver fir, and western red cedar. Currently, 52% of the riparian areas in the Stillaguamish Watershed are dominated by hardwoods, small conifers, or no trees at all.*
>
> *Flood control activities dominated from 1930 to present and precipitated the loss of more than one-third of the channel area from 1933 through 1991. Channelization, bank protection, levee and dike construction, railroad grade*

construction, and channel filling shorten and narrow channels within the floodplain. These alterations increase water velocity and, for the same discharge, may lead to increased flooding.

1.3 Quantified Assessment of Land Use Changes

1.3.1 General

Pilchuck Creek is the larger of the study basins with a drainage area of approximately seventy-six square miles. The headwaters begin in Skagit County at an elevation of approximately 3500' and flow to the Stillaguamish River. There are four significant tributaries in the basin: Trib-80, Bear Creek, Crane Creek and Lake Creek. Lake Creek drains an 844 acre recreation lake called Lake Cavanaugh. The lake is located in the headwaters and is surrounded by a number of small homes and cabins. With a predominantly steep mountainous character, the basin is currently only sparsely populated with most of the area held by commercial timber companies. Basin soils are dominated by loams founded on glacial till.

Church Creek, a relatively small basin at 11.4 square miles, is located immediately west of Pilchuck Creek and discharges near the mouth of the Stillaguamish. This lowland stream is dominated by accelerating urbanization in its lower, westernmost subbasins within and near the City of Stanwood, and rural and suburban residential development in the remainder of the basin. This development has resulted in both the loss of forest cover and now the conversion of pastures and other rural land to residential uses. The only tributary of Church Creek is Freedom Creek, which crosses under and is directly impacted by Interstate-5. While most of Church Creek is located on a till geology, the lowest portion of the basin is located on the Stillaguamish valley floor which is dominated by alluvium.

For the purpose of this analysis the Church Creek basin was divided into six subbasins and the Pilchuck Creek basin into sixteen subbasins. The subbasin divisions range from one to ten square miles. See Figure 1-2 for more detail.

1.3.2 Current Land Use

An assessment of current land use conditions was performed for the study area using a land-cover classification based on a 2001 LANDSAT-TM scene shown in Figure 1-3. The purpose of this assessment was to determine the character and spatial distribution land cover change in the study basins- information that is both informative in its own right and as a necessary step in modeling changes in stream flow regime. Each 30-meter pixel in the scene is classified with one of eleven land-cover categories (Purser et. al, 2003). The dataset includes the following ten land-cover classes and one unknown class: Mature evergreen forest, Medium evergreen forest, Deciduous stands, Shrub / small trees, Grass, Bare ground, Medium density development, High density development, Alpine rock / talus slope, Open water, and Unknown (shadow / cloud). An assessment of current land use in the watershed was made by refining the current land-cover data using its underlying zoning. Note that for purposes of this study, forest areas include not only mature forest cover (both evergreen and deciduous), but also areas of shrubs, bare ground, and grass as estimated from the LANDSAT image analysis. These areas in most cases may be attributed to forest harvest operations and in most subbasins amount to 30% to 40% of areas zoned for forestry. Similarly, areas zoned agriculture were assigned an agricultural land use in the current conditions land use. This was done because the agricultural areas are limited and the most significant area in ‘Church-1’ was poorly classified by the LANDSAT dataset. All areas included in the open water and wetlands datasets were applied to the current conditions dataset regardless of the LANDSAT derived classification.

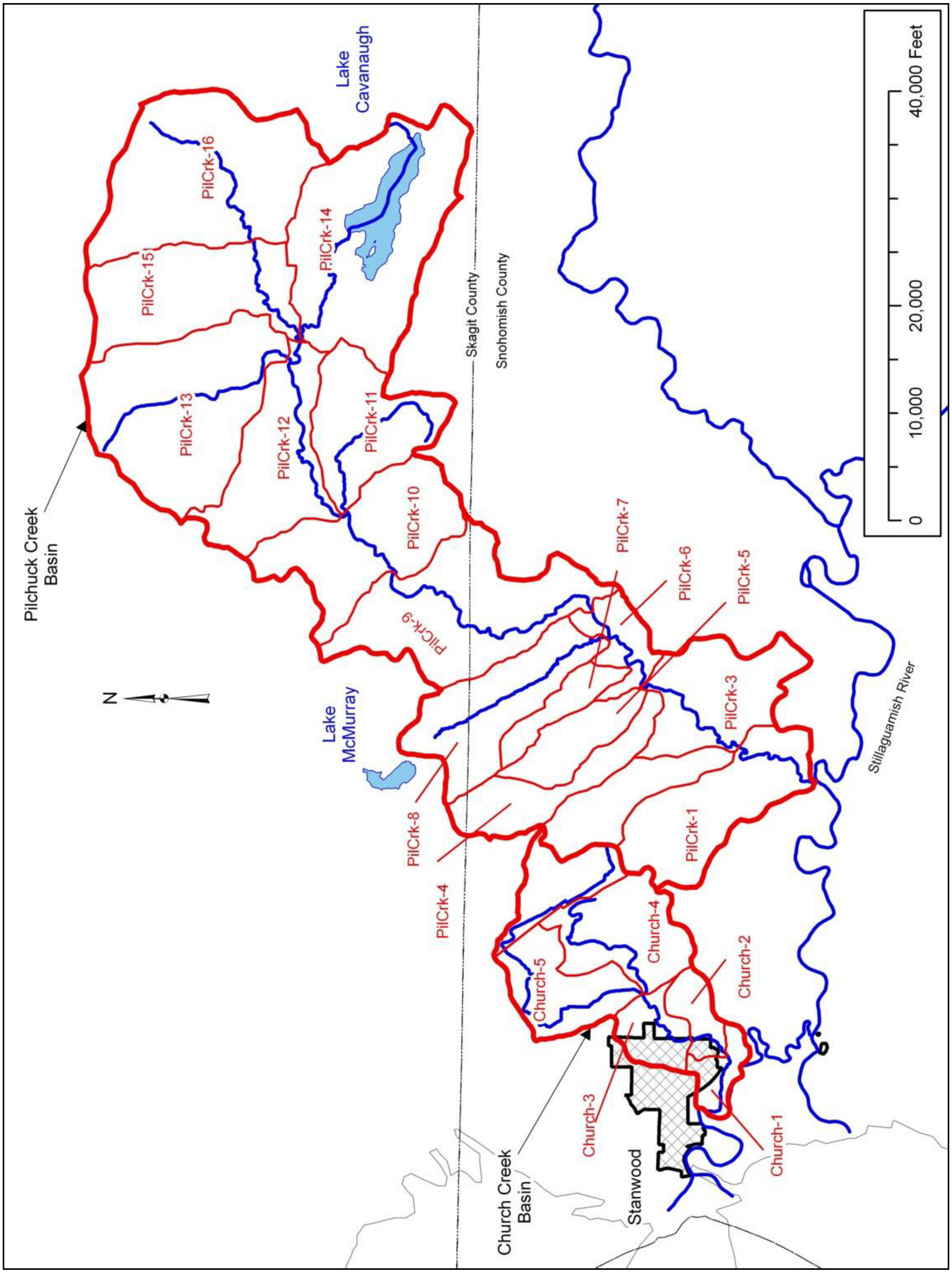

Figure 1-2 Land Use Assessment Subbasins

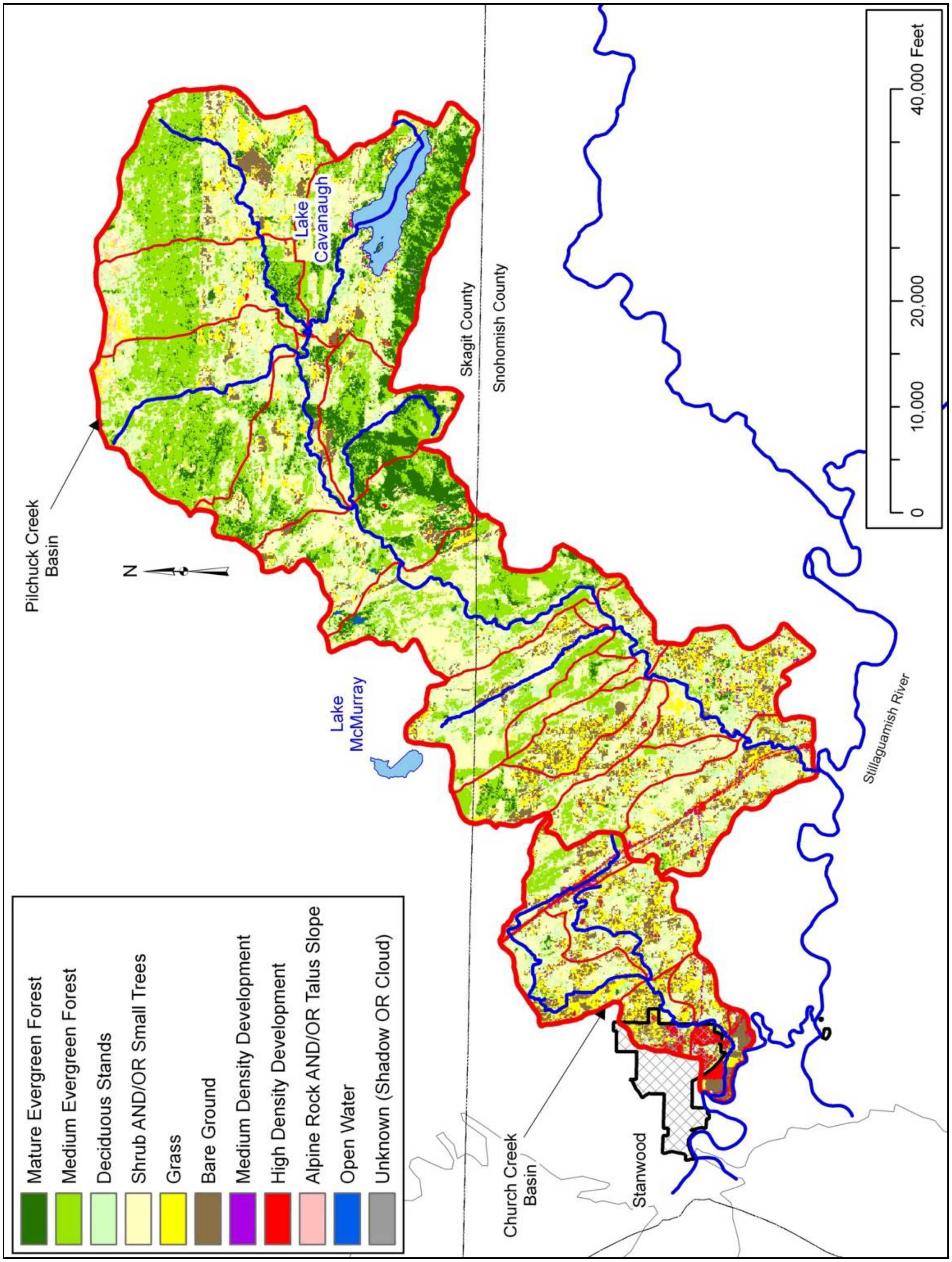

Figure 1-3 Current Land Use derived from LANDSAT 2001 Classification

Table 1-1. Current Land Use derived from LANDSAT 2001 Classification

	Area (Square Miles)	Forest[2]	Agric-ulture[3]	Pasture / Other Perv[4]	Grass/ Urban[5]	Open Water	Wet-land	EIA[1]	TIA[1]
Church-1	0.9	2.6%	64.2%	10.1%	9.4%	0.4%	4.8%	8.4%	10.5%
Church-2	1.0	10.2%	0.0%	48.9%	21.4%	0.0%	9.0%	10.5%	13.1%
Church-3	1.4	5.3%	0.0%	41.7%	28.8%	0.2%	17.5%	6.6%	8.2%
Church-4	3.4	17.1%	0.0%	59.9%	12.4%	0.8%	8.6%	1.3%	1.6%
Church-5	2.8	16.9%	0.0%	55.4%	10.6%	1.3%	15.0%	0.8%	1.1%
Church-6	1.9	49.1%	0.0%	33.3%	9.9%	0.6%	2.1%	4.9%	6.1%
Church Sub-Total	11.4	19.2%	5.3%	47.2%	14.1%	0.7%	9.8%	3.8%	4.8%
PilCrk-1	4.8	23.3%	1.6%	53.3%	11.3%	2.0%	4.5%	4.0%	7.2%
PilCrk-2	2.5	42.6%	0.0%	50.0%	6.0%	0.4%	0.5%	0.5%	0.7%
PilCrk-3	4.1	23.8%	0.0%	52.8%	12.7%	2.8%	6.5%	1.3%	1.7%
PilCrk-4	2.6	46.4%	0.0%	45.8%	6.5%	0.0%	0.9%	0.5%	0.6%
PilCrk-5	1.9	38.3%	0.0%	45.2%	12.3%	0.9%	2.9%	0.4%	0.5%
PilCrk-6	1.5	69.1%	0.0%	23.3%	3.5%	3.1%	0.5%	0.5%	0.6%
PilCrk-7	1.2	93.5%	0.0%	4.5%	0.2%	1.5%	0.4%	0.0%	0.0%
PilCrk-8	4.4	77.2%	0.0%	17.8%	2.5%	0.5%	1.9%	0.1%	0.2%
PilCrk-9	7.1	91.9%	0.0%	4.0%	0.4%	2.4%	1.3%	0.1%	0.1%
PilCrk-10	5.6	95.1%	0.0%	0.0%	0.2%	1.9%	2.4%	0.3%	0.4%
PilCrk-11	4.1	99.3%	0.0%	0.0%	0.1%	0.3%	0.3%	0.1%	0.1%
PilCrk-12	4.7	99.2%	0.0%	0.0%	0.2%	0.3%	0.1%	0.2%	0.2%
PilCrk-13	8.2	98.7%	0.0%	0.0%	0.0%	0.6%	0.6%	0.0%	0.0%
PilCrk-14	9.3	78.5%	0.0%	3.3%	0.8%	15.2%	1.5%	0.5%	0.6%
PilCrk-15	5.4	99.1%	0.0%	0.0%	0.1%	0.1%	0.5%	0.2%	0.2%
PilCrk-16	8.6	98.1%	0.0%	0.0%	0.2%	0.5%	1.0%	0.2%	0.2%
Pilchuck Sub-Total	76.1	79.5%	0.1%	12.9%	2.5%	2.8%	1.6%	0.5%	0.8%
Grand Total	87.5	71.6%	0.8%	17.4%	4.0%	2.5%	2.7%	1.0%	1.3%

1. TIA is total impervious area. This represents the percentage of an area of a land use type that does not infiltrate rainfall or snowmelt water. Roads, sidewalks, parking lots, and roofs all contribute to TIA. EIA or Effective Impervious Area represents that portion of TIA from which runoff is conveyed directly and in a concentrated manner to an improved conveyance system or stream channel with limited opportunity for infiltration to groundwater. EIA summed with other land-covers, excluding TIA, yields 100% of the land area. TIA is calculated 90% 'High Density Development' + 45% 'Medium Density Development' + '1.3% Agricultural Lands'. EIA is calculated 72% 'High Density Development' + 36% 'Medium Density Development' + '1% Agricultural Lands'
2. 'Forest' includes LANDSAT classes 'Deciduous stands', 'Mature evergreen forest', 'Medium evergreen forest' and 'Bare ground' 'Grass' and 'Shrub / small trees' that are located in areas zoned for commercial forestry.
3. 'Agriculture' includes all areas zoned for agriculture. Note that this was done following orthophoto inspection that deemed the classifications in the agriculture zones of Church-1 to be inaccurate.
4. 'Pasture / other pervious' includes LANDSAT classes 'Bare ground', 'Shrub / small tree' and ½ of areas in the 'Grass' class that are located in areas zoned for Low Density Residential (LDR) following Table 1-2.
5. 'Grass/Urban' includes 'Medium Density Development' and 'High Density Development' areas not included as EIA (see note 5), ½ of areas in the 'Grass' class that are located in areas zoned for Low Density Residential (LDR) following Table 1-2, and the remaining 'Grass' areas not in an LDR, AG or Forest Zones.
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The Church Creek basin has lost the majority of its historical forested land cover. Only one of the six subbasins retains more than 20 percent forest cover and nearly all of the forests in the other subbasins are deciduous stands. The basin is dominated by low density development with small pastures, sparse tree cover and has an average effective impervious area (EIA) of less than 4 percent. The highest density development in the basin has occurred in subbasins 'Church-1' and 'Church-2' with EIA percentages of 8.4 and 10.5 respectively. More than 60 percent of 'Church-1' occupies the Stillaguamish mainstem valley floor which is nearly all agricultural. After pasture and forest, the third most dominant land cover in the basin is wetlands which take up nearly 10 percent of the basin on average and as much as 17.5 percent of 'Church-3'.

Unlike Church Creek, the Pilchuck Creek basin is predominantly in commercial forestry with minimal land area developed for residential or commercial use. Currently, 80 percent of the overall basin is forested. The most developed subbasins ('Pilcrk-1' through 'Pilcrk-5') range from 20 and 50 percent forest cover, while the remaining eleven subbasins range in forest cover between 69 and 99 percent.

Land cover change and especially the conversion of forest cover to effective impervious surfaces is known to have a strong influence on the storm runoff as well as impacts on base flow and water quality. Typical ratios of peak annual flow quantiles for different land covers to forest cover peak flows in the Puget Sound Basin are as follows:

Factors of Increase in Peak Flow Quantiles Compared to Forested Cover

	2-year	10-year	100-year
Forest	1.0	1.0	1.0
Pasture, Shrub	1.4	1.7	1.8
Suburban Landscape, grass	3.6	4.0	3.3
Impervious	19.2	12.3	6.5

As shown, typical peak annual runoff rates from impervious surfaces are in the range of 5 to 20 depending on the frequency of the event. Similarly, though less dramatically, peak runoff from suburban landscaping is 3-4 greater than forest cover. These changes in peak discharge per unit area demonstrate that relatively small amounts of impervious cover within a basin can cause a marked increase in peak stream flow if the impervious area runoff is concentrated and delivered rapidly (i.e. it is effective impervious area) to the stream channel. Stormwater detention ponds can suppress these increases in peak runoff; however, the vintage and character of most of the effective impervious area currently within the pilot basins suggests that there is an insignificant amount of detention storage currently in operation. Similarly, runoff from impervious surfaces, especially highly trafficked roadways, is known to deliver runoff with higher pollutant loadings and higher temperature to receiving streams. The total amount of effective impervious area (3.8%), suburban grass (14%) and agriculture and pasture land (53%) in Church Creek suggest that 2-year peak annual flows may have increased as much as 100% compared to pristine, forested land cover conditions, although the actual rate of increase is probably less because peak runoff from different areas of a basin typically arrive at a basin outlet at different times and tend not to be linearly additive. Increases in peak flows in the lower mainstem of Pilchuck Creek are expected to be less than half the increases expected for Church Creek. Reductions in summer base flow associated with loss of groundwater recharge are also a possible outcome of conversions for forest cover to impervious and developed pervious cover, but the loss may be counterbalanced to some degree by reduced evapo-transpiration.

1.3.3 Future Land Use

To develop a scenario that would allow consideration of the hydrologic impacts of potential future development, an estimation of build-out conditions was made from zoning and comprehensive plan data. This future land use dataset was assembled from Snohomish County comprehensive plan and zoning data, the Skagit County comprehensive plan, the City of Stanwood comprehensive plan and zoning data, Snohomish County wetlands, open water and parks inventories, and the National Wetlands Inventory (NWI). Currently undeveloped areas designated as wetlands by County and NWI coverages were excluded from future development regardless of any underlying zoning. Other types of critical areas that might exclude future land uses were assumed to be too small in extent to be considered in determining future land cover in the pilot basins. The planning designations for these areas were aggregated to a set of hydrologically meaningful land-cover categories based on build-out conditions (Table 1-2). In unincorporated Snohomish County and the City of Stanwood the comprehensive plan and zoning datasets designate dissimilar levels of future development with neither being consistently higher than the other; in these areas the most developed condition at any location was applied to the future land use dataset. Figure 1-4 shows the land use zoning for the study basins. A tabulation of the future land cover categories for each of the study area subbasins is presented in Table 1-3.

Under future buildout conditions, the Church Creek basin is expected to lose approximately two thirds of its current 19% forest cover while more than doubling its total and effective impervious area. The major driver of these land cover changes is low-density residential land development, and secondarily commercial and other residential development in or near the City of Stanwood. Low-density residential development shifts the land cover from a forest / pasture dominated ground cover to an urban grass / pasture ground cover with EIA increasing to over 10 percent. The only significant forest preserved in the basin is associated with a few ultra low-density / forest zones in ‘Church-6’; this brings the basin average down to 6.5 percent. The agricultural land use designation in the Stillaguamish mainstem valley floor is preserved as agriculture in the future scenario.

Industrial forest land use designations preserve most of the Pilchuck Creek basin as forest in the future conditions scenario with a relatively minor increase in residential development in the lower subbasins. Forest cover only decreases 6 percent to 73.7 percent as a result of forest lost in the lowest five subbasins to low residential development. The development in the lower subbasins also reduces pasture to 10 percent and increases urban grass. EIA is still only 1.9 percent in the future conditions scenario.

Table 1-2
Zoning/Comprehensive Plan Aggregated Zoning Categories and Land-cover

Aggregated Land Use Category based on PSRC Zoning	Land-cover Percentages							
	Forest	Agri-culture	Pasture	Grass (Urban)	EIA[1]	TIA[1]	Wet-land	Open Water
Lakes / Open Water (OW)	0	0	0	0	0	0	0	100
Designated Wetlands (WET)	0	0	0	0	0	0	100	0
Industrial Forest (IND FOR): Roaded timber production areas	99.5	0	0	0	0.5	1	0	0
Open Grass (OG): Parks and recreational space	0	0	0	100	0	0	0	0
Mineral Resource Lands: Quarries and mines (MRL)	0	0	0	50	50	50	0	0
Agricultural lands (AG)	0	99	0	0	1	1.3	0	0
Low Density Residential – Forestry (LDR-F): < 1 d.u. per 20 acres[2]	96	0	0	0	4	6	0	0
Low Density Residential (LDR): < 1 d.u. per acre	0	0	48	48	4	10	0	0
Medium Density Residential (MDR): 1-3 d.u. per acre	0	0	0	86	14	25	0	0
High Density Residential (HDR): 4-7 d.u. per acre	0	0	0	64	36	49	0	0
Multi-Family Residential (MF): >7 d.u. per acre	0	0	0	52	48	60	0	0
Commercial (COM): commercial, industrial, airport, and transportation corridors	0	0	0	14	86	90	0	0

[2] The LDR-F category was created for a few portions of the study area that are zoned as forestry but they have 1 dwelling unit per 20 acres designated in the Comprehensive Plan.

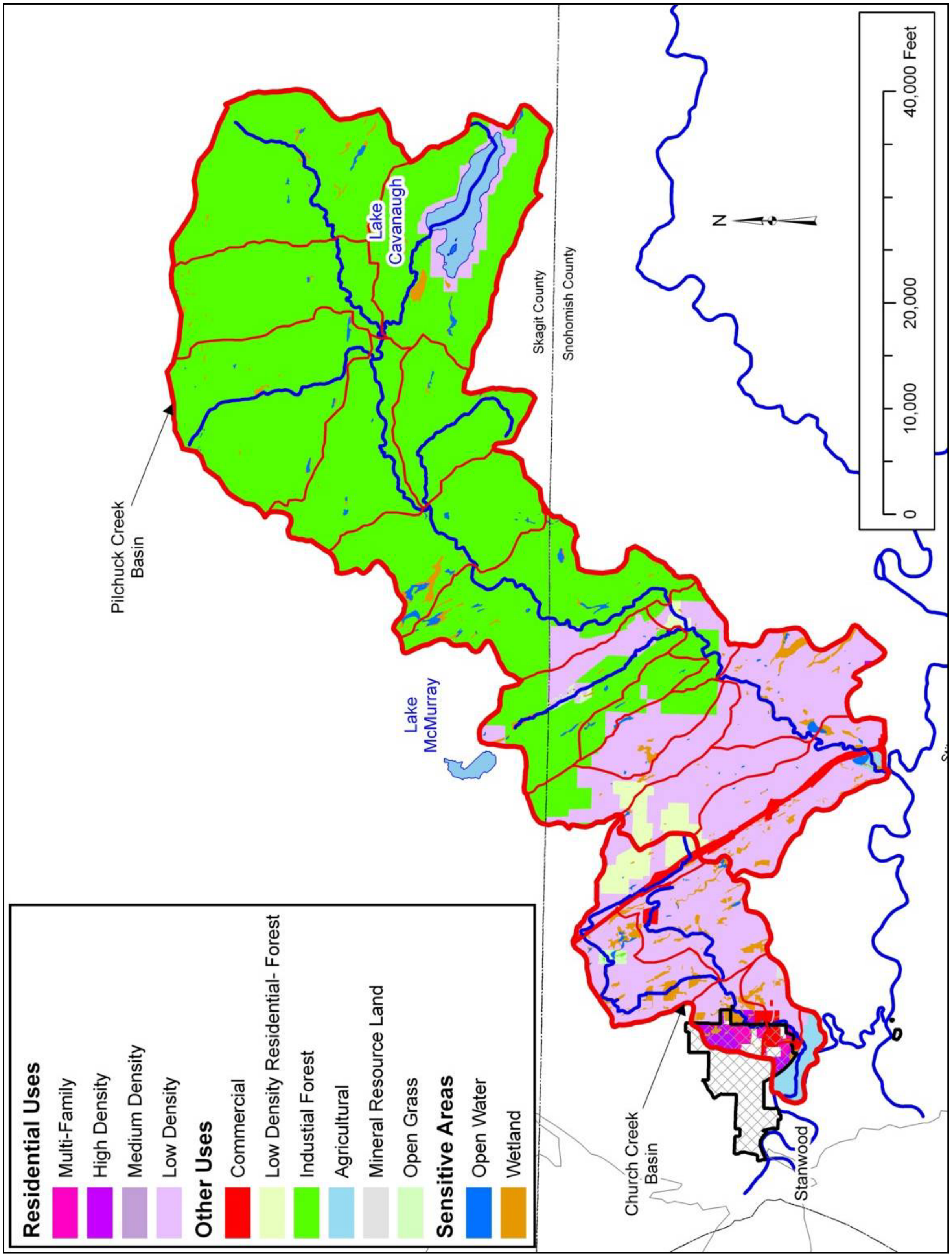

Figure 1-4 Land Use Zoning (Future Land Cover)

Table 1-3
Future land cover classifications for each of the 22 study area subbasins

SubBasin Name	Area (Miles^2)	Forest	Agri-culture	Pasture	Grass	Open Water	Wetlnd	EIA	TIA
Church-1	0.9	0.0%	64.2%	2.6%	16.0%	0.4%	4.8%	12.0%	15.1%
Church-2	1.0	0.0%	0.0%	32.1%	39.4%	0.0%	9.0%	19.4%	24.7%
Church-3	1.4	0.0%	0.0%	17.3%	45.5%	0.2%	17.5%	19.6%	27.1%
Church-4	3.4	0.0%	0.0%	42.0%	42.5%	0.8%	8.6%	6.2%	11.6%
Church-5	2.8	0.4%	0.0%	37.7%	41.6%	1.3%	15.0%	4.1%	8.8%
Church-6	1.9	38.4%	0.0%	20.6%	22.6%	0.6%	2.1%	15.6%	19.6%
Church Creek Sub-Total	11.4	6.5%	5.2%	30.4%	36.9%	0.7%	9.8%	10.5%	15.6%
PilCrk-1	4.8	0.9%	1.6%	38.2%	39.8%	2.0%	4.5%	12.9%	18.2%
PilCrk-2	2.5	23.1%	0.0%	36.0%	36.0%	0.4%	0.5%	4.0%	9.0%
PilCrk-3	4.1	0.0%	0.0%	43.4%	43.6%	2.8%	6.5%	3.7%	9.2%
PilCrk-4	2.6	35.2%	0.0%	30.5%	30.5%	0.1%	0.9%	3.0%	7.1%
PilCrk-5	1.9	26.6%	0.0%	33.3%	33.3%	0.9%	2.9%	2.9%	7.2%
PilCrk-6	1.5	59.5%	0.0%	17.4%	17.4%	3.1%	0.5%	2.1%	4.7%
PilCrk-7	1.2	85.4%	0.0%	5.9%	5.9%	1.5%	0.4%	0.9%	2.1%
PilCrk-8	4.4	69.0%	0.0%	12.7%	14.6%	0.5%	1.9%	1.4%	3.4%
PilCrk-9	7.1	89.5%	0.0%	3.1%	3.1%	2.3%	1.3%	0.7%	1.5%
PilCrk-10	5.6	95.1%	0.0%	0.0%	0.0%	1.9%	2.5%	0.5%	1.0%
PilCrk-11	4.1	98.9%	0.0%	0.0%	0.0%	0.3%	0.3%	0.5%	1.0%
PilCrk-12	4.7	99.1%	0.0%	0.0%	0.0%	0.3%	0.1%	0.5%	1.0%
PilCrk-13	8.2	98.2%	0.0%	0.0%	0.0%	0.6%	0.6%	0.5%	1.0%
PilCrk-14	9.3	73.0%	0.0%	4.8%	4.8%	15.1%	1.5%	0.8%	1.7%
PilCrk-15	5.4	98.9%	0.0%	0.0%	0.0%	0.1%	0.5%	0.5%	1.0%
PilCrk-16	8.6	98.0%	0.0%	0.0%	0.0%	0.5%	1.0%	0.5%	1.0%
Pilchuck Creek Sub-Total	76.1	73.7%	0.1%	9.8%	10.1%	2.8%	1.6%	1.9%	3.5%
Grand Total	87.6	64.9%	0.8%	12.5%	13.6%	2.5%	2.7%	3.0%	5.1%

1.4 Quantified Assessment of Current Water Withdrawals

1.4.1 Overview

Several sources of data were used to identify existing wells and diversions which are currently in use. Primary data sources were the Washington State Department of Health (WSDOH) records on Public Water Supply Systems and Department of Ecology records on water rights claims and certificates, and on well drilling activity. There are no significant water supply or flood control reservoirs, or high flow bypasses for purpose of flood management in either pilot basin so the analysis does not consider effects related to such activities. A similar analysis in another basin may need to include analysis of these activities and their effects on flow regime.

In this discussion, the terms "Group A" and "Group B" systems, and also "exempt wells" are frequently used and deserve explanation. Group A and Group B are identifiers used by the Department of Health to classify and regulate Public Water Supply systems. Group A systems are public water supply systems with 15 or more service connections, plus some transitory and non-community systems[2]. Group B systems are public water supply systems with from 2 to 14 connections. The term "exempt well" is an identifier used by the Department of Ecology to identify relatively small wells that are allowed to withdraw groundwater without a permit issued by Ecology. Exempt wells are sometimes associated with small subdivision (up to six dwellings) water supplies which would in turn be regulated by the WSDOH as Group B Public Water Supply Systems. However, this is just one of the four classes of water permit exemptions which include: 1) stock watering; 2) watering of lawn or non-commercial garden areas not to exceed 1/2 acre in size; 3) domestic uses not exceeding 5,000 gallons a day; and industrial purposes not exceeding 5,000 gallons per day.

1.4.2 Public Water Supply Systems

A total of 17 public water supply systems are active in the study basins; seven in the Church Creek Basin and ten in the Pilchuck Creek Basin. Table 1-4 identifies these systems and provides population and service connection data for each system as reported by WSDOH. Figure 1-5 shows locations of all public water supply sources and also the service areas for the two Group A community systems: the Stanwood Water Department in the Church Creek Basin and the Tatoosh Water Company in the Pilchuck Creek Basin. Note that the Stanwood service area is much larger than the Church Creek pilot study area and that the WSDOH data are for the entire service area.

Table 1-4
Public Water Supply Systems Active in the Study Basins

Basin	System Name	Type	Service Area (WSDOH data)	
			Population	Connections
Church	Stanwood Water Dept	Group A – Community	4375	1830
Church	Stanwood Kingdom Hall	Group A – Transient	0	1
Church	Noah Animal Shelter	Group A – Transient	0	4
Church	Westhaver, Frank Water Co	Group B	12	5
Church	Caughlin S	Group B	5	0

[2] See Washington Administrative Code chapter 246-290-020 for a full definition of Group A & B systems.

Basin	System Name	Type	Service Area (WSDOH data)	
			Population	Connections
Church	Glacier Moldings Ltd	Group B	1	1
Church	Freeborne Fire Station	Group B	0	1
Pilchuck	Tatoosh Water Company	Group A – Community	223	103
Pilchuck	Camp Brotherhood Inc	Group A – Transient	13	14
Pilchuck	Stanwood Deli And Gas	Group A – Transient	0	2
Pilchuck	Sno Pud 1 - 212 Market & Deli	Group A – Transient	0	1
Pilchuck	246th Street Well	Group B	20	0
Pilchuck	Stang S Water System	Group B	14	4
Pilchuck	Bryant Mobile Park	Group B	11	5
Pilchuck	Jacobs Well #2 Water System	Group B	7	0
Pilchuck	National Food Corporation	Group B	4	1
Pilchuck	Lake Cavanaugh Fire Dist No 7	Group B	0	1

An assessment was made of the two Group A community systems – Stanwood Water Department and the Tatoosh Water Company – which account for the majority of public water supply in each of the study basins. The two issues of particular interest for each system were: 1) the actual current rates of water withdrawal from sources in the study basins; and 2) the extent to which those withdrawals are in hydraulic continuity with surface water in the study basins and would result in reduced streamflows. Data for the city of Stanwood was obtained primarily from the city's Comprehensive Water System Plan dated July 2001, with some supplemental information obtained verbally from city public works staff. Data for the Tatoosh Water Company was from area hydrogeology reports provided by the company and by verbal reports from the company of current water use.

City of Stanwood Water System

The city of Stanwood provides water service to approximately 1,830 customer accounts throughout its water service area boundary which extends beyond both the study basins and the City's corporate limits. Annual consumption in 1999 was just over 248 million gallons, which translates to a mean annual discharge of 1.18 cfs. Commercial users account for 51% of total system demand with single-family and multi-family customers accounting for 41% and 8% of demand respectively. The largest individual customer, Twin City Foods, had an annual demand in 1999 of 39.65 million gallons which represents 14% of total system use. The water system has experienced a trend of decreasing system-wide demand since 1992, possibly due to implementation of water conservation practices and new buildings with more efficient plumbing.

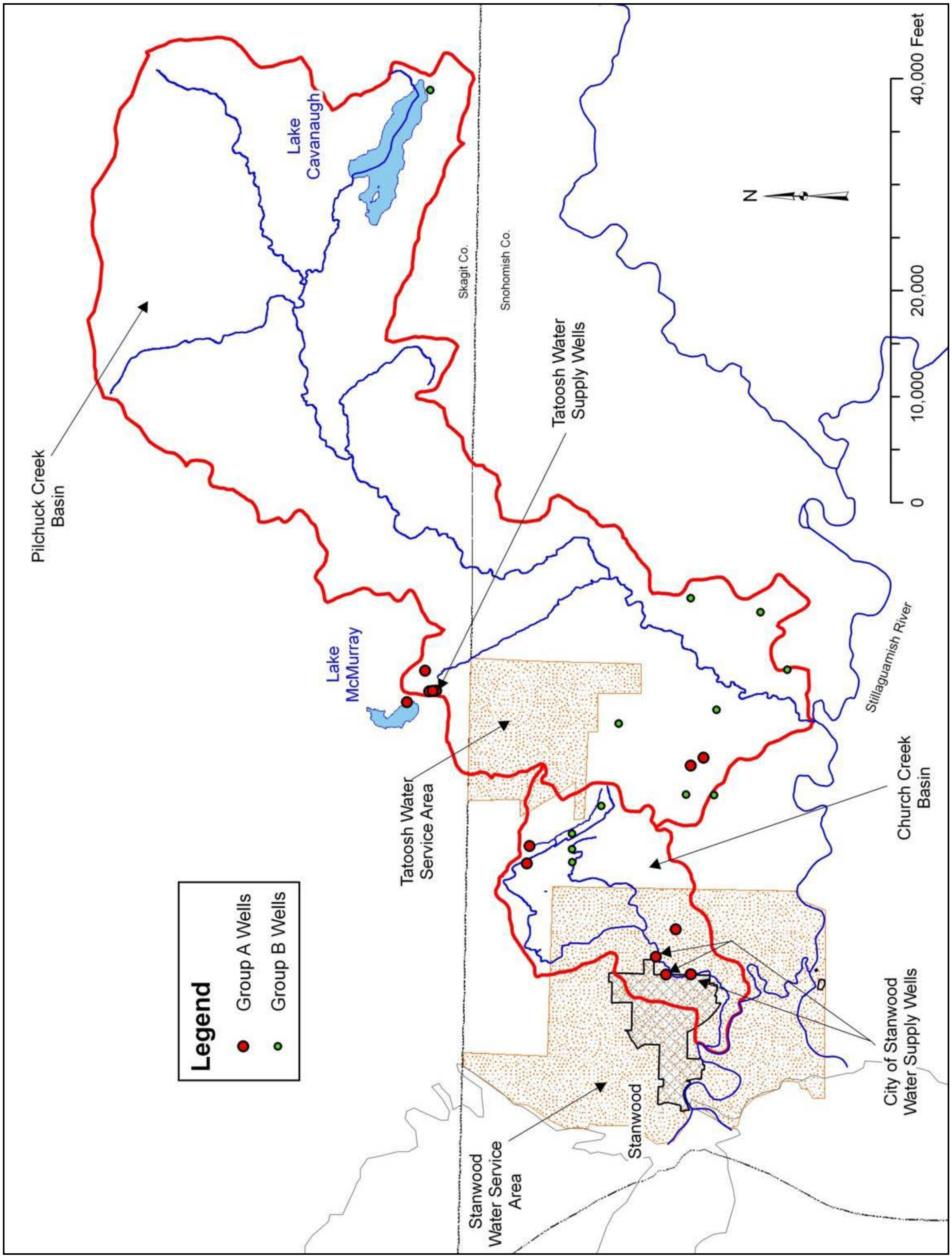

Figure 1-5 Public Water Supply System Wells and Service Areas

The city of Stanwood's water supply is currently obtained from three groundwater wells, all located within the Church Creek basin, and one groundwater spring source (Hatt Slough Springs) located approximately two miles south of the study basin.

The following text from the Water Supply Plan describes the area geology.

> *The Stanwood water system is located in the Puget Sound Lowland in an area with a complex geological history. The site conditions at the four production wells (three currently operational) are caused by at least two glaciations separated by nonglacial and interglacial periods. Vashon glacial till, a dense mixture of sand, gravel, silt and clay, exists to a depth of 50 to 70 feet below the ground surface at all of the City's wells. Below the glacial till is a layer of Vashon advance outwash approximately 60 to 80 feet thick composed of sandy and silty gravel. Fure Well and Hatt Slough Springs appear to withdraw partially from this formation. Pre-Fraser glacial sediments beneath the advance outwash are 50 to 90 feet thick and consist of sand with lenses of hard silt and gravel. Fure Well appears to also withdraw water partially from this formation. The next underlying layer is the pre-Frasier non-glacial deposits composed of fine sand with lenses of silt and clay. The non-glacial deposits are at least 250 feet deep. Fure Well appears to withdraw partially from this formation while Bryant Wells, Still Well (abandoned) and the City's future source of supply, the Cedarhome Well, appear to withdraw completely from these sediments.*

A review of hydrogeological data including logs for the City's wells obtained from Department of Ecology's database as well as USGS reports related to groundwater resources in the vicinity of the Stanwood wells suggest that Stanwood's Bryant and Fure wells receive water from the Church Creek Basin and are likely to be in hydraulic continuity with the creek.

The most productive City well is Bryant Well #1. This well is 250 feet deep, as noted by the City's Comprehensive Plan, but the screened portion begins at a depth of 50 feet. This effectively causes the well to have effects similar to a shallow well. The average pumping rate at Bryant Well #1 in 1999 was 265 gallons per minute (gpm) or 0.6 cfs.(Comprehensive Water Plan). This represents 72% of groundwater volume that was extracted by the City's wells in 1999. The nearby Fure Well accounted for an additional 90 gpm (0.2 cfs and 24%). The Comprehensive Water Plan indicates that the Fure Well is screened from a depth of 145 feet to 150 feet; however, the Department of Ecology well log appears to record a screened interval from a depth of 50 to 150 feet.

Table 1-5 summarizes historic water levels measured in deeper wells in the vicinity of the City of Stanwood's well field. These data show that the aquifers used for water supply wells were initially confined aquifers. For example, the depth to water at Bryant Well #1 (the first well listed in Table 1-5) was apparently 40 feet in 1948. This corresponds to an elevation of +20 feet, which is approximately 10 feet above the top of the aquifer. Water levels in other wells listed in Table 1-5 also show confined conditions. The water level elevation for the Bryant Well #1 listed in the Water Comprehensive Plan is –22.5 feet. This water level, which apparently was measured in or around 1999, corresponds to unconfined conditions and may be the result of groundwater extraction at the Bryant well field.

Under confined conditions, a reduction in hydraulic head or water level due to groundwater extraction will cause leakage from overlying layers. The magnitude of this leakage will be proportional to the magnitude of the head reduction as long as the aquifer remains confined. Once a portion of the aquifer becomes unconfined, the leakage at those unconfined locations will continue but the leakage will no longer be proportional to the water level in the pumped aquifer.

Impacts of groundwater extraction on stream flow were considered in the modeling study by Morgan and Jones (USGS, 1999). This study focused specifically on effects of wells on discharge to streams and springs in small basins typical of the Puget Sound lowland. The study considered an aquifer system similar to the system that apparently exists in the Church Creek basin. The modeling results showed that under steady-state conditions, wells in a confined aquifer similar to the Q_{va} aquifer in the Church Creek basin cause local reductions in discharge to adjacent streams that equal approximately 2/3 of the extraction rate. Placing the wells deeper in the system did not significantly change these effects.

Although caution should be used in generalizing these results and applying them to other systems, the underlying physics and hydraulics are transferable. The aquifer systems in the Puget Sound region are leaky systems. Wells in these systems induce leakage and reduce discharge to stream flow. The leakage and flow reductions are largest in the immediate vicinity of the well and wells in close proximity to streams are more likely to impact stream flow than wells that are most distant from streams. Recent analytical tools and field work further demonstrate that wells tend to have a more local effect than was perhaps previously appreciated (Hunt et al, 2001; Hunt, 2003; Nyholm et al, 2003; Sophocleous et al., 1995).

Significant time and effort that is well beyond the scope of this study would be required to develop quantitative and defensible estimates of the precise spatial distribution of discharge reductions due to the Stanwood's Bryant and Fure wells within Church Creek basin. In the absence of these more detailed studies, an ecologically conservative assumption is taken that pumping from these wells reduces base flow in Church Creek by an amount that is approximately equal to 2/3 of the average annual pumping rate and that these effects are distributed for 2 miles upstream of Bryant Well #1. In reality the exact spatial distribution of these effects on upstream locations is a difficult question to answer without developing a relatively sophisticated numerical groundwater model; however, the proposed assumptions are considered reasonable and conservative given currently available information.

In addition to the Bryant and Fure Wells, Stanwood operates three groundwater wells that draw water from the East Stanwood Aquifer. Our assumption is that this is a deep regional aquifer system without direct hydraulic continuity to the streamflow in Church Creek.

Table 1-5

Section	Qtr/Qtr	Surf. elevation	Well depth	Screen depth	Water depth	Static Water elevation	Date measured	Source
29	**NW/NE**	**61**	**250**	**50 to 250**	**40**	**+20**	**1/1948**	**Well log[a]**
					83.5	–22.5[b]	n.a.	City Water Comp. Plan
29	NE/NE	130	132	n.a.	44.6	+87.4	1/12/93	Thomas et al.
29	SE/NE	100	94	n.a.	77.8	+22.2	1/12/93	Thomas et al.
20	SE/NE	135	235	215 to 235	90	+45	1955	Well log (Sill well?)
20	NW/SE	105	150	50 to 150	50	+50	1949	Well log (Fure well?)
20	SE/NE	150[c]	495	381 to 476	130	+20	5/30/1995	Well Log (Cedarhome well?)
20	NE/SW	80	249	n.a.	18.6	+61.4	3/4/1949	Newcomb[d]
20	NW/SW	175	245		80	+95	1944	Newcomb[e]

[a] Well log for the Bryant Well #1 reports clay from depth of 0 to 50 feet and gravel from depth 50 to 250 feet)
[b] Drawdown during pumping is reported as 5 feet (City's Comprehensive Water System Plan)
[c] Estimated from topographic map
[d] Listed as Stanwood Water Co. well. It Fits as Bryant #1 in terms of depth and date, but the location is off. Depth to gravel listed as . 80 feet, aquifer is described as confined aquifer and 90 feet thick.
[e] Listed as East Stanwood School District No. 317

Tatoosh Water Company Water System

The Tatoosh Water Company provides water service to approximately 103 customer accounts located mostly in the Pilchuck Creek basin. Annual withdrawals are typically in the range of 20 to 25 million gallons (MG); the higher value translates to a mean flow of 0.106 cfs. Demands during the months of November through March are typically about 1.5 MG (.076 cfs) and reflect domestic use without irrigation. The largest monthly demands on the system occurred in July and August 2004 at 3.1 and 4.5 MG respectively. The larger of these monthly demands is equivalent to a flow rate of 0.229 cfs. The Tatoosh Water Company holds water rights certificates issued in 1971 which authorize a total annual withdrawal of 2419 acre-feet (3.34 cfs) and withdrawal at a maximum pumping rate of 1550 gpm (3.45 cfs).

The water supply for Tatoosh Water Company is from wells drawing from an aquifer discussed in groundwater reports for the Lake McMurray area. Lake McMurray is located in the Skagit River watershed; surface flows from the lake discharge eventually to the Skagit River. Available groundwater reports for the area by two different authors provide information on the available yield from this aquifer and pumping effects on surface water levels and streamflows. These reports are discussed below.

The earliest reports on ground-water investigations in the Lake McMurray area consist of two letters dated July 25, 1970 and February 3, 1972 by Consulting Geologist Richard J. Rongey. In summary, these reports identified spring flows in the Pilchuck Creek basin that were considered to originate from an aquifer beneath Lake McMurray. The study made five spot measurements of the spring flows during the period of November 1971 to February 1972 and estimated the mean annual flow to be approximately 3.0 cfs and to represent conditions in "normal" years.

The study concluded that the aquifer could produce a safe yield of 1660 acre feet (equivalent to 2.3 cfs) and expressed concern that existing appropriations (including the current Tatoosh water rights certificates) already totaled more than 2300 acre-feet (3.2 cfs) and might result in an overdraft.

A more recent report titled "Ground Water Development Feasibility Study; Lake McMurray Area; Snohomish/Skagit Counties, Washington" was prepared June 7, 1983 by Hart Crowser & Associates for Snohomish County Public Utility District No. 1. That report included a finding that ground water production (in the aquifer with the wells used by Tatoosh Water Company and an additional well used by Camp Brotherhood) in the order of 3,000 gpm (6.68 cfs) should not have a significant effect on Lake McMurray. The report also stated that the central valley stream (WRIA 05.0080 tributary to Pilchuck Creek) "may be partially derived from discharge of ground water" and that "impacts on the stream should be further evaluated if ground water development is undertaken."

Our interpretation of the available information is that the water withdrawals by Tatoosh Water Company are from an aquifer which is apparently in hydraulic continuity with surface flows that are tributary to Pilchuck Creek, and that at certain magnitudes these withdrawals will likely result in reduced streamflows.

Other Public Water Supply Systems

Withdrawal data are not published for the other public water supply systems noted in Table 1-4. For purposes of this analysis, it was assumed that all of the systems withdraw from sources which are in hydraulic continuity with surface flows. The amounts of withdrawals were estimated as 350 gallons per day per connection; this use rate is considered by Ecology to be the average measure of beneficial water use for residence and business connections. Also following Ecology guidelines[3], the consumptive fraction of the withdrawal, taking recharge into account, is estimated as 175 gpd for residences and businesses not served by sewer or approximately 50% of the withdrawal. While these unit withdrawal amounts may not be directly applicable to each individual system in the study area, they do provide a reasonable basis for an order-of-magnitude assessment of cumulative effects.

In the Church Creek study basin, the other public water systems (excluding Stanwood) supply approximately 13 connections. The combined annual water demand from these systems, at 350 gpd, is estimated to be 1.67 MG annually or 0.007 cfs.

In the Pilchuck Creek study basin, the other public water systems (excluding Tatoosh) supply approximately 33 connections. The combined annual water demand from these systems, at 350 gpd, is estimated to be 4.2 MG annually or 0.018 cfs.

1.4.3 Self-Supplied Domestic Withdrawals

Self-supplied domestic uses are generally associated with exempt wells for which no water use permit is required by the Department of Ecology. However, exempt wells with more than one service connection are regulated by the Department of Health as Group B water supply systems.

[3] December 17, 2004 DRAFT of Chapter 173-505 WAC; INSTREAM RESOURCES PROTECTION AND WATER RESOURCES PROGRAM; Stillaguamish River Basin; Water Resources Inventory Area (WRIA) 5.

This section presents an evaluation of withdrawals and consumption from self-supplied domestic use for single-connection systems.

Initially, the number of single-connection, exempt wells in use in Church and Pilchuck Creek basins were estimated from Department of Ecology (DOE) records. First, these records were used to determine the average rate of single-connection, exempt, well construction in each basin over a recent 10 year period. Assuming an average life span of each well as 20 years, the number of single-connection, exempt wells in the basin was estimated as 240 and 540 wells in Church and Pilchuck Creek basins, respectively. These totals exceeded the total number of claims on file with Ecology- 190 and 428 respectively for each basin. This was initially thought to represent the upper limit of the number of exempt wells that could exist within the pilot basins.

Ecology has two databases associated with water wells. The first is the Notice of Intent to Construct a Water Well (NIT, started in 1993) and the second is the Water Well Reports. The NIT database has data on the use of the well, either single domestic, group domestic, or other. The Water Well Reports database started in 1972, but was only populated with water well reports systematically since 1975. In general it took several years for the well drilling community to do water well reports and submit them. In both databases, the well locational data is, at best, the ¼ of the ¼ of the ¼, of the Section, within a Township and Range.

The Water Well Report database was screened for all records that fall within WRIA 5. Ecology correlated those screened records (post 1993) with a notice of intent from the NIT database. Records that had both a water well report and a notice of intent were reviewed to exclude records for group domestic use leaving the single domestic water wells. The remaining records were processed to determine the post-1993 rate of exempt well construction in each of the study basins. It could not be determined from the available data which of the wells are "new" systems and which were constructed to replace older, failing systems. Results are summarized in Table 1-6.

Table 1-6
Exempt Well Construction in the Church and Pilchuck Creek Basins

Year	Church Ck Basin	Pilchuck Ck Basin
1994	15	36
1995	16	36
1996	12	35
1997	11	25
1998	14	23
1999	7	21
2000	15	24
2001	10	27
2002	11	26
2003	7	33
2004	14	30
Average	12.0	28.7

As shown in Table 1-6, the rates of exempt well construction in the two study basins are reasonably constant over the past 10 years. Assuming for discussion that the average current rates are representative of a longer period, and that wells have an average lifespan of 20 years before retirement or replacement, the current number of active exempt wells can be estimated as the rate of construction times the lifespan. By this approach, it is estimated that there are approximately 240 active exempt wells in the Church Creek basin and 574 active exempt wells in the Pilchuck Creek basin. These values, however, seem high given the earlier assumption that the numbers of water rights claims on file with Ecology might set an upper bound to the number of active exempt wells.

Subsequently, this approach to estimating the number of single-connection, exempt wells was checked using census data and GIS processing, (see Section 3 of this report for further details). Both total population and number of housing units were determined in each study basin. From these totals, the population and service connections supplied by the regulated public water systems (Group A and Group B) were deducted to yield the approximate population and housing units served by unregulated wells. Based on this method, the number of households served by unregulated wells was found to be 498 households for Church Creek and 1315 for Pilchuck Creek, more than double the number of claims on file or the number estimated above from well construction data. These results suggest that the number of claims on file with DOE greatly underestimate the number of wells in actual use within the basin. Also, there seems to be a reasonably high likelihood that a considerable number of wells have been constructed in recent years without being documented by NITs or Water Well Reports.

For analysis purposes, we assumed that the number of exempt wells is equal to the higher numbers suggested by census data.

In the Church Creek study basin, exempt wells are estimated to supply approximately 498 connections. The combined annual water demand from these systems, at 350 gpd, is estimated to be 62.9 MG annually or 0.27cfs. The consumptive annual use after return flow, at 175 gpd, is estimated to be 12 MG or 0.13 cfs.

In the Pilchuck Creek study basin, exempt wells are estimated to supply approximately 1315 connections. The combined annual water demand from these systems, at 350 gpd, is estimated to be 169 MG annually or 0.71 cfs. The consumptive annual use after return flow, at 175 gpd, is estimated to be 83 MG or 0.37 cfs.

1.4.4 Other Water Uses

The Department of Ecology water rights records provide a comprehensive dataset of unverified claims and certificates of potential legal use. Many of those claimed and certificated sources may presently be inactive or underutilized. The water rights records are insufficient to identify active sources and current water usage. Despite this limitation, they are best data available to assess industrial, irrigation, mining, and other withdrawals not regulated as public water supply systems.

The water rights certificates for the study area were processed to eliminate identifiable Group A and B public water supply systems. Figure 1-6 shows the locations of the remaining certificated uses, and Table 1-7 summarizes the number of certificates and the authorized withdrawals. Most of the certificates in the Pilchuck Creek Basin area are for relatively small quantities of water, including 38 of the 39 certificates which identify Lake Cavanaugh as the water source. Irrigation and stock watering are the uses which are associated with the largest withdrawals.

Table 1-7
Summary of Water Rights Certificates Excluding Public Water Supplies

	Church Creek Basin	Pilchuck Creek Basin
Number of Surface Water Certificates	3	50
Number of Ground Water Certificates	4	5
Total Number of Certificates	7	55
Number of Large Use Certificates (with > 2 ac-ft annual withdrawal or irrigation of > 1 acre)	5	6
Number of Small Use Certificates	2	49
Total Annual Withdrawal Volume, acre-feet	143	224
Total Max Surface Withdrawal Rate, cfs	0.45	1.85
Total Max Well Withdrawal Rate, gpm	481	230
Total Irrigable Land, acres	94	91
Total Annual Withdrawal Volume, cfs	0.20	0.31
Total Max (Sfc + Well) Withdrawal Rate in cfs	1.52	2.36

Note that the water rights certificates are paper rights which set an upper limit on the amount of legally authorized withdrawals and which may significantly overstate actual current use. If it should become important to other aspects of this study, additional work would be required to determine the current status of these potential uses.

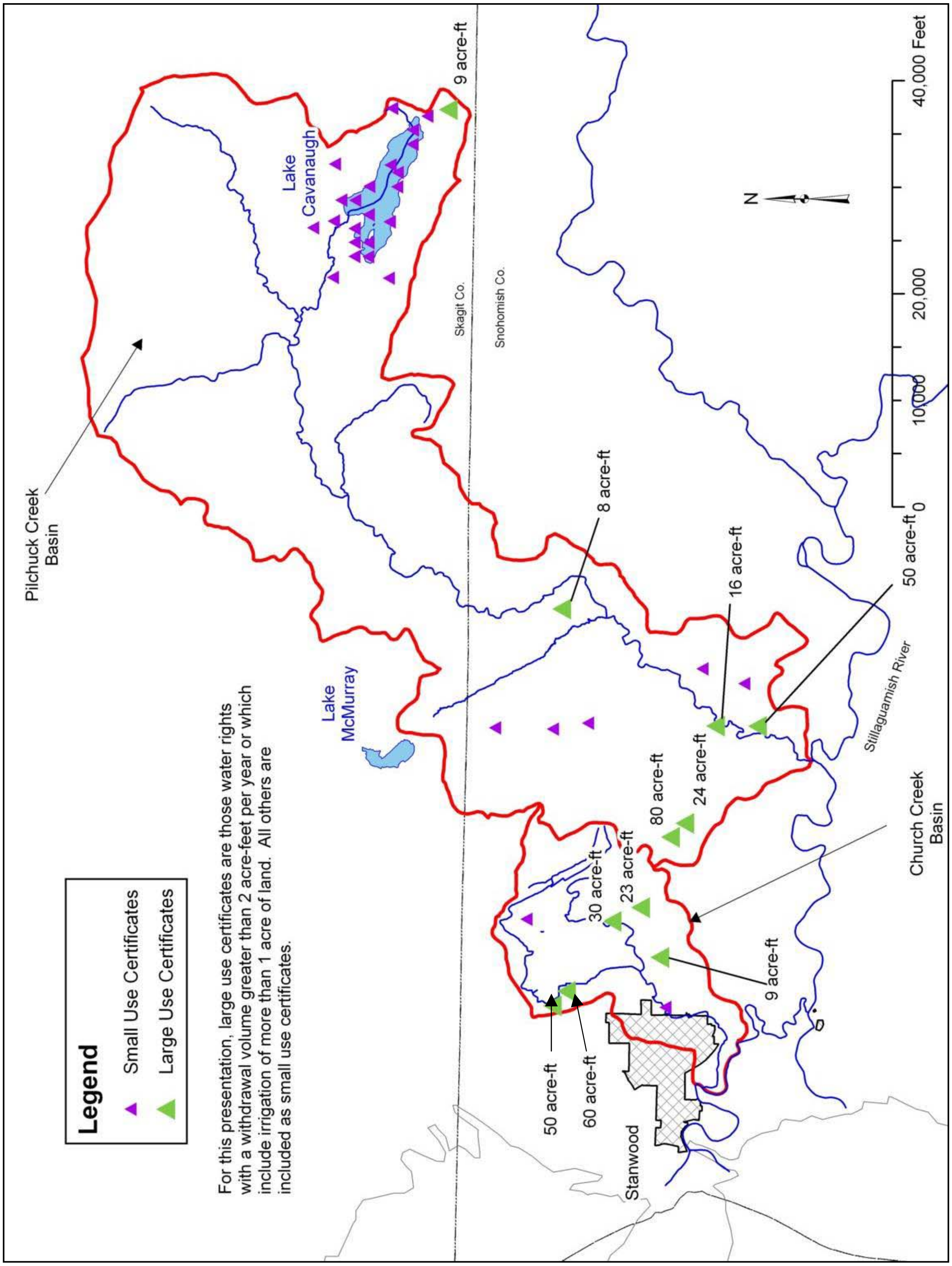

Figure 1-6 Certificated Water Uses Not for Public Water Supply

1.5 Instream Flow Regulations

As of February 2005, draft instream flow regulations had been proposed for the Stillaguamish Watershed but had not yet been adopted. The regulations propose the simultaneous adoption of instream flows and of water reservations which will be exempt from being interruptible due to instream flow conditions.

Table 1-8 presents the minimum instream flows proposed for Church and Pilchuck Creeks which are listed in the December 17, 2004 draft of Chapter 173-505 WAC.

Table 1-8
Proposed Instream Flows for Church and Pilchuck Creeks
(flows in cubic feet per second)

Month	Day	RM 2.1	RM 3.4	RM 11.7
		Church Ck	Pilchuck Ck	Pilchuck Ck
Jan.	1-31	24	130	98
Feb.	1-29	24	170	98
Mar.	1-15	43	180	98
Mar.	16-31	43	180	98
Apr.	1-30	43	180	98
May	1-31	43	180	98
Jun.	1-15	28	180	98
Jun.	16-31	28	170	98
Jul.	1-31	28	170	98
Aug.	1-31	10	170	98
Sep.	1-30	10	170	98
Oct.	1-31	24	170	98
Nov.	1-15	24	170	98
Nov.	16-30	24	130	98
Dec.	1-31	24	130	98

The proposal will create reservations of water for additional new domestic water uses, targeting permit-exempt wells in particular, which will not be subject to the instream flows. The draft rule does not specify allotments for Church and Pilchuck Creeks, but rather includes these in a management area which encompasses all of the lower Stillaguamish River, and its tributaries, downstream of the North Fork Stillaguamish River at RM 6.5 and the South Fork Stillaguamish River at RM 24.4. The draft rule proposes a water use reservation totaling 5 cfs for the entire lower management area which includes Church and Pilchuck Creeks. A separate reservation of 0.1 cfs for stock watering is proposed which would be allocated over the entire Stillaguamish River basin.

The draft rule proposes that Church Creek be closed to future water appropriations other than can be accommodated under the water reservations. For Pilchuck Creek, the rule identifies that up to 50 cfs water will be available during the winter period October 16 through May 31 each year for new appropriations which would be junior to the instream flows and hence interruptible if the instream flows are not met. During the summer period June 1 through October 15 each year, Pilchuck Creek would be closed to future water appropriations other than can be accommodated under the water reservations.

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Section 2. Review of Hypothesized Flow Change Mechanisms that Affect Salmon Populations in Church Creek and Pilchuck Basins

2.1 Introduction

In July 2005, WRIAs across the Central Puget Sound Evolutionarily Significant Unit (ESU) submitted draft salmon conservation and recovery plans to further the formal process of environmental and fish population analysis and planning for the recovery of Endangered Species Act-listed Chinook salmon populations and the conservation (i.e., prevention of loss of viability) of other salmon populations in the ESU. Many, if not all, of these draft plans indicate that peak flows and/or low flows affected by human land use and water management activities are, or may be under possible future conditions, factors in the status of the populations. These plans offer strategic restoration and protection actions that are intended to address these factors. This project will augment the analysis done to date and will help improve the certainty that these actions will be successful. In particular this analysis will help determine population parameters of the focal species, coho salmon and Chinook salmon under four scenarios to ascertain the proportional effect of flow-related changes on these populations. Chinook salmon were selected as one of the focal species for this study because of its Endangered status under the ESA and because of the regional effort to restore Chinook habitat and populations in the Puget Sound ESU. While Puget Sound coho are not currently listed, they have been designated a “candidate species of concern” because of the health of Puget Sound/Strait of Georgia ESU. In view of the possibility that Puget Sound/Strait of Georgia coho may be listed under the ESA in the future and the relatively high potential sensitivity of smaller stream systems preferred by coho to human management activities, coho were selected as a second focal species for this study.

The delivery and routing of water, and its streamflow constituents, wood and sediment, is the major driver in the formation and maintenance of physical habitat for spawning and rearing, water quality, food supplies, and survival of salmon of all life stages. These factors are mediated by watershed forest cover, riparian vegetation, wetlands, and disturbance wrought by humans. In watersheds already disturbed by humans, natural disturbances such as flooding or drought can have effects far beyond those that might be expected in an undisturbed watershed.

This section provides a review of the literature on the ecological effects associated with changes in streamflow and stormflow magnitude, timing, duration, and flashiness; a review of hydrologic indicators of changes in the natural flow regime; and from this a prioritized list of flow parameters and impact mechanisms relevant to the pilot basins. Further, data and other information on the habitat conditions in the pilot basins and population characteristics of the focal species, coho salmon and Chinook salmon, are presented. Finally, reach-specific hypotheses will be developed relating flow changes associated with land use and water withdrawals to potential, current, and future effects on the focal species.

2.2 Literature Review on Linkage between Flow Regime and Ecological Effects

In an oft cited paper entitled “The Natural Flow Regime”, Poff, et al. (1997) connected the health of native riverine biological communities to natural river flow regimes that could be broadly characterized by their flow magnitude, frequency, duration, timing, and rate of change. Through an extensive review of case studies available in the literature, they showed that deviations from natural flow regime attributes such as magnitude, frequency, duration, timing, and rate of change could have negative effects on native riverine biota. Examples of these biological-flow linkages included:

- washout or stranding of aquatic and riparian species (peak flow increases),
- invasion by exotic species, cutting off of water and nutrients to floodplains,
- vegetation encroachment and narrowing of channels (flow stabilization),
- disruption of fish migration and spawning (loss of natural freshets or imposition of out-of-season peaks),
- loss of riparian plant cover and species diversity (prolonged low flows), and
- failure of seedling establishment (rapid change in river stage and accelerated flood recession).

Spence, et al. (1996) recognized the importance of understanding the linkage of hydrology to habitat for purposes of developing ecosystem-based salmon conservation plans. They recognized the role of large, infrequent floods in reshaping stream channels, recruiting woody debris, eroding and depositing sediment, and noted both the short-term *destruction* of salmonid habitat and long-term *rejuvenation* of habitat caused by such events. More frequent floods were cited as moving and reorienting woody debris, cleaning spawning gravels, wetting floodplains, and recharging valley aquifers that provide base flows in drier periods and serve as the supply source for wells. Low flow extremes were cited as causing constriction of habitat, thermal stress on fish, as well as migration disruption. On the positive side, the authors noted that extreme lows allow some colonization of channel areas by riparian vegetation that can serve to dissipate hydraulic energy and add habitat complexity when flows increase.

Spence, et al. (1996) cite flow-altering activities, exclusive of dams, that are significant considerations in salmon conservation. These include change in water yield (or mean annual flow), peak flow increase, increase or decrease in summer base flows, and altered timing of seasonal flows. These changes may result from forest practices, including harvest, and road construction and maintenance; agriculture; rural residential development; or urbanization. In cleared forest areas, peak flows are considered to be increased as a result of increased snow accumulation and higher melt rates in rain-on-snow zones (DNR, 1995). Spence, et al. list a panoply of negative effects on salmon habitat associated with these flow changes including decreases in both the amount and quality of habitat, scouring of spawning gravel, change in substrate size, dewatering of stream reaches, and interruption of migration by thermal barriers or deposition of sediment.

Reduced flows, especially seasonal low flows, are associated with direct reduction in fish habitat or stress on particular species and life stages as a result of reduction of wetted area, depth, and velocity. Reduced flows has been the dominant, if not exclusive, concern of instream flow setting to date. Historically, the setting of instream flows has focused on establishing minimum seasonal flows and not on maintenance of the multiple ecological functions provided by a natural flow regime that are critical to native species (Poff, et al., 1996; Instream Flow Council, 2002) including salmon.

The effects of urbanization on flow regime are well documented and have been recently reviewed in the context of Puget Lowland streams by Booth, Hartley, and Jackson (2002) and include many, if not all, of the changes noted by Spence, et al. (1996) as being significant for salmon as well as several noted by Poff, et al. (1997) and Richter, et al. (1996, 1997, 1998) as being significant for general ecosystem health. According to the authors, peak flow frequency, duration, hydrograph flashiness, seasonal hydrograph patterns, and summer base flow can all be markedly changed by urbanization; however, the most consistently observed effects have been dramatic increases in peak annual flood frequency, high flow durations, and hydrograph kurtosis (flashiness). All of these have direct effects on salmonids as well as dramatic affects on sediment transport, deposition, and geomorphic stability.

2.2.1 Indicators of Hydrologic Alteration (IHA) and Range of Variability Approach (RVA), and Normative Flow

Richter, et al. (1996) presented a method for statistically quantifying flow regime and flow regime change using long term mean daily stream flow data that pre-date and post-date flow-altering management action(s) such as dam construction. The "Indicators of Hydrologic Alteration" (IHA) include 32 biologically meaningful flow parameters associated with the basic categories discussed by Poff, et al. (1997): magnitude, frequency, duration, timing, and rate of change. The authors propose that flow regime alteration assessment be based on an examination of the shifts in both means and standard deviations of the suite of flow parameters. This recognizes the importance of the range of interannual variability of flow characteristics as well as average increases or decreases between the natural and managed flow conditions. While the selection of IHA parameters is designed to predict direct effects on aquatic and riparian plant and animal communities, the suite of parameters is also suitable as an indicator of fluvial geomorphic change associated with flow such as sediment regime and substrate size distribution, wood recruitment, habitat structure, channel cross-section, and planform properties.

IHA and its associated methodology, the Range of Variability Approach (Richter, et al., 1997), have been applied primarily in flow regime negotiations and management of rivers that are regulated by dams operated for hydropower, water supply, and/or navigation. For these purposes, the inclusion of 32 parameters may be viewed as thorough because reservoirs and dams that actively control flow have the potential to decouple flow characteristics that would otherwise be correlated such as 1-day versus 3-day annual maximum discharges. For creeks such as those in this pilot study that are impacted by basin land cover change, direct alteration of land drainage by ditching and roads, transformation of riparian buffers, stream channel modifications, and water withdrawals, 32 IHA parameters are excessive in number. In addition they may not characterize all the flow changes that most affect the key salmonid population viability parameters – diversity, productivity, capacity, and abundance – defined by NMFS (McElhany et al., 2000).

Similarly, IHA and RVA, as tools to design stream systems that act more in line with the natural flow regime described by Poff, et al., must be applied cautiously where hydraulic, sediment, and geomorphic conditions have been altered by human engineering (revetments and levees) or where these conditions have changed in response to basin land cover/land use change through channel incision, migration, sedimentation, or planform shifts. The most favorable habitat conditions for salmonids are produced by the interaction of natural flow regimes with natural channel, floodplain, and riparian conditions, and the restoration of one of these elements may not result in the expected response if the others are not in balance with it. This broader view of the role of instream flows or flow regime perceives hydrology as a component of riverine ecosystems linked with four other components: biology, geomorphology, water quality, and connectivity (Instream Flow Council, 2002).

The King County Normative Flow project (http://dnr.metrokc.gov/wlr/basins/flows/; Cassin, in press) developed a literature-derived list of potentially significant flow regime metrics; screened the list for ecological relevance, sensitivity to urban effects, and completeness in representing a range of flow-relevant flow characteristics; reviewed biological data sets and prioritized biological metrics; and performed correlation studies between selected biologic and hydrologic metrics.

The initial list of hydrologic parameters considered by King County included nearly 300 flow regime metrics, many of which are either the same or variants of the Indicators of Hydrologic Alteration (IHA) and Range of Variability Approach (RVA) (Richter, et al., 1996, 1997, 1998). In addition to IHA-RVA based parameters, several other parameters were considered including Tqmean, a measure of stream flashiness (Konrad, 2000); Q2/Qf10 (Booth and Jackson, 1997), a measure of change in peak annual flood frequency; variability of mean daily flow as measured by standard deviation and coefficient of variation, and several others reviewed by Booth et al. (2001).

Of the 300 original metrics, 30 were selected for correlation analysis with biologic metrics. Selected biologic metrics included Benthic Index of Biological Integrity (BIBI) and its component metrics plus some non-BIBI metrics available from invertebrate sampling. Of the 30, correlation with biologic metric values or categories of sites defined by biologic condition suggested 19 that are more strongly correlated with biologic condition as indicated by invertebrate population data (Table 2-1). Of these 19 parameters, three are related to base or low flow conditions, and 16 are related to storm conditions. The three base flow conditions cover flow characteristics related to frequency, duration, and seasonal timing, but not magnitude or rate of change. The storm parameters include 2 representing storm durations, 6 representing intra-annual storm flow frequency, 2 representing annual storm flow magnitude, 2 representing storm flow timing (initiation in the fall and length of storm season), and 2 representing rate of change, as well as 2 additional parameters reflecting combinations of the other parameter types. Of the 19, only the Q2/Qf10 and Relative Stream Power are intrinsically scaled to pristine flow regime conditions.

Table 2-1. Hydrologic parameters strongly correlated with biological metrics (Cassin, in press)

KC Parameter #	KC Descriptor	Hydrograph Category	Parameter Type
34	Low Pulse Duration	Base Flow	Duration
33	Low Pulse Count	Base Flow	Frequency
27	Date of Annual Minimum	Base Flow	Timing
41	High Pulse Duration	Storm Flow	Duration
87	Runoff Event Duration - Mean	Storm Flow	Duration
55	T-Qmean Annual	Storm Flow	Frequency, flashiness
52	Fall Count (0.1 Rule)	Storm Flow	Frequency
40	High Pulse Count	Storm Flow	Frequency
53	Rise Count (0.1 Rule)	Storm Flow	Frequency
91	Flow Reversals	Storm Flow	Frequency
86	Runoff Event Count	Storm Flow	Frequency
79	Stream Power - Relative to Baseline	Storm Flow	Integrated (F,D,M) relative to baseline
56	R-B Index	Storm Flow	Flashiness

60	DAY-Q MAX/MEAN	Storm Flow	Magnitude
80	Q2:Q10	Storm Flow	Magnitude compared to baseline
50	Fall Rate	Storm Flow	Rate of Change
51	Rise Rate	Storm Flow	Rate of Change
81	Onset of Fall Flows (1)	Storm Flow	Timing
48	High Pulse Date Range	Storm Flow	Timing, storm season length

In analyzing correlations with biologic parameters, the King County project faced several challenges including the shear number of possible parameters that describe hydrologic regime and changes to hydrologic regime, cross-correlations among the parameters, and confounding effects of non-hydrologic factors on biological metric values. Additionally, significant changes in BIBI or other biological metrics will not occur as a result of some types of hydromodification that may significantly affect the salmonid populations.

One example of this is withdrawal of water during the low flow period upstream of a monitoring site. While significant amounts of physical habitat at the margins of stream may be lost as a result of flow reductions, thalweg conditions that affect BIBI scores may not be affected if a site is well shaded and the loss of flow does not impact aspects of water quality such as mid-stream temperature. This has been noted in Rock Creek near Maple Valley in King County where BIBI scores have been consistently some of the highest of any Puget Sound Lowland stream. Withdrawals of water in the summer and early fall have reduced base flow by more than 50% for many years. BIBI monitoring of the creek began many years after these withdrawals were initiated and scores have been consistently high. It is not known whether restoring flows to their natural levels would raise these scores even higher but it seems that a dramatic increase would be unlikely.

2.2.2 Flow-related attributes in Ecosystem Diagnosis and Treatment (EDT) model

In contrast to either IHA comprehensive parameter set or King County's prioritized set, Ecosystem Diagnosis and Treatment (EDT) modeling utilizes only six, direct hydrologic variables (Lestelle et al, 2004; Table 2-2). One of these six, HydroRegimeNatural, is used to characterize the natural flow regime based on climate, geology, and geography; it represents a static parameter that does not change with management scenarios unless global issues like human-induced climate change are considered. A second variable, HydroRegimeReg is used by EDT to describe the level of seasonal flow pattern alteration in a stream reach caused by dam and reservoir operations that change the shape of the annual hydrograph. There are no significant dam/reservoir operations in the pilot study basins. Thus, for purposes of this study, human actions affect only four of the EDT variables that characterize hydrologic regime, provided the term "hydrologic regime" is interpreted narrowly as pertaining only to the spatial and temporal distribution of total discharges in the stream network under study. As the preceding text indicates this narrow interpretation of flow regime has implications for the relationship of this analysis and ecosystem-based salmon recovery.

Table 2-2
Level 2 Attributes (inputs) Directly Related to Streamflow in EDT

EDT Level 2 Input	Definition	Flow Regime Component Characterized	Aspect of Component Characterized
FlowLow	%Change in average daily low flow over low flow season (45-60 days) compared to natural	Base Flow	Magnitude
FlowIntraAnn	%Change in TQmean from pristine	Storm Flow	Frequency, flashiness
FlowHigh	% Change in Q2yr compared to natural	Storm Flow	Magnitude
FlowDielVar	Average intra-day variation in flow during storm season (max-min)[1]	Storm Flow	Rate of Change
HydroRegimeNatural	Characterization of natural flow regime as groundwater, rain, snow, glacial-dominated etc. Not a hydrologic change indicator.	Annual Hydrograph	Patternl
HydroRegimeReg	Hydromodification indicator for dam-regulated rivers	Annual Hydrograph	Patternl

[1]Redefined for project based on guidelines provided by EDT handbook. According to handbook, Rating =0 for TIA < 10%, 1 for TIA between 10 and 25%, 2 for TIA between 25 and 40%, 3 for TIA between 40 and 50%, 4 for >50% EIA assuming no detention. Values of the average of max-min for high flow season (November – March) to be calibrated from HSPF models based on regional parameters and till soils.

Besides the much smaller number of hydrologic parameters employed by EDT, there are additional differences and similarities with King County's prioritized list of parameters that are worth noting. For base flow, EDT employs a single parameter that characterizes the *change in magnitude* of base flow during the annual low flow period compared to pristine conditions. In contrast, King County's base flow parameter set includes separate parameters for frequency, timing, and duration, but does not include magnitude. For storm flows, EDT employs three parameters characterizing intra-annual storm frequency (or flashiness), intra-day average rates of hydrograph change, and peak annual magnitude. Of these, FlwIntraAnn representing frequency can be based on TQmean, consistent with King County's prioritization. There is also close similarity between FlwHigh and Q2:Qf10 except that the EDT parameter represents the ratio of scenario 2-year peak to pristine 2-year peak rather than pristine 10-year peak. FlowDielVar is defined differently than any of King County's rate of change parameters, but as implemented in this project, it will capture very similar intra-day flow fluctuations similar to either rise or fall rates. EDT does not directly capture changes in seasonal timing or include integrated variables characterizing flow duration, energy or stream power; however, to some degree these parameters may correlate strongly with the three other metrics of storm flow condition used by EDT.

HydroRegimeReg represents an auxiliary parameter for broad brush changes to annual hydrographs on streams with significant amounts of regulation by dams. In sum, EDT uses many fewer parameters than have been identified by King County, and while it avoids some of the obvious duplication represented by the County's list of 19, it does not explicitly represent changes in peak or low flow timing or the length of the storm flow season. HydroRegimeReg might be used for purposes of representing these timing shifts, but its EDT definition suggests that this would be a stretch.

2.2.3 Summary of Parameters Hypothesized to Indicate a Flow-biology relationships

King County narrowed the universe of hydrologic parameters suggested by Richter et al. and others from several hundred down to 19 for Puget Sound Lowland Streams experiencing urbanization. Nineteen (19) parameters are probably not required to represent current land use and water management effects in the study pilot basins. EDT includes 4 hydrologic change parameters that measure urbanization and water management effects, of which three are related to storm flows and one is related to summer and fall base flows. The 4 direct hydrologic attributes in EDT FlwHigh, FlwLow, FlwIntraAnn, and FlwDielVar are estimated directly from long term, simulated, hourly discharge and flow stage data produced by the HSPF hydrologic model. The development of the model, model outputs, and their translation into EDT model inputs are described in Sections 3 and 4 of this report.

2.3 Background on Focal Species Populations and Habitat Conditions in the Pilot basins

2.3.1 Church Creek population and habitat

Figure 2-1 shows the spatial extent of anadromous fish usage in Church Creek and Pilchuck Creek basins. This figure is based on Pess, et al., 1999 and field verified by Snohomish County staff.

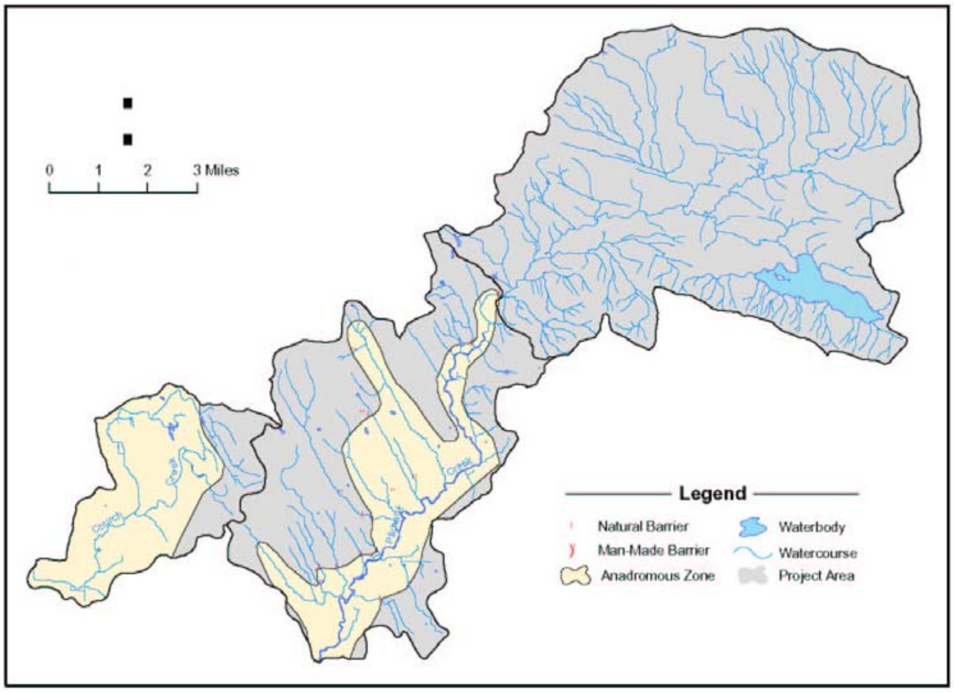

Figure 2- 1: Study Area Anadromous limits, after Pess, et al. 1999

Church Creek is currently used by coho salmon as well as other salmonid species excluding Chinook salmon. The basin includes 19 miles of anadromous fish habitat (Pess, et al., 1999). Lowermost Church Creek, locally called Jorgenson Slough, is a highly modified (ditched, straightened, and bermed) channel that empties into the Old Stillaguamish Channel near Stanwood. The Old Stillaguamish Channel was formerly the mainstem channel of the Stillaguamish River prior to the early 1900's when locals blasted a large log jam of several thousand pieces from what is now called Hat Slough. Hat Slough is now the main exit of the Stillaguamish River to Port Susan. Historical Stillaguamish Chinook salmon populations were comprised of more than 40,000 returning adult fish (SIRC, *in press,*2005). The millions of smolts outmigrating would be members of many more life history trajectories than are currently used by the average of 1300 returning adults escaping to spawn in the North Fork and South Fork (STAG, 2000). Thus it is possible and even likely that lower Church Creek (i.e., Jorgenson Slough) was formerly used by juvenile Chinook salmon for feeding and smoltification prior to the radical modification of the channel, installation of a tidegate at the mouth of Jorgenson Slough, and the current drastically reduced abundance.

The coho salmon that currently use Church Creek spawn throughout the middle and upper sections from October through January having migrated upstream from saltwater generally starting in July (WCC, 1999). Beginning in 2003 the Stillaguamish Tribe has surveyed two index spawning reaches in Church Creek for coho salmon and chum salmon (Tables 2-3a and 2-3b). Index reach 1 is from RM 1.5-2.0 (from behind Haggen Food Market upstream to the Fish Ladder); index reach 2 is from the fish ladder to Woodland Road (RM 2.0-2.5). Typically, most of the coho salmon spawn above the Fish Ladder. Chum salmon do not make it that far up, possibly being impeded by the structure of the existing fish ladder.

Table 2-3a
Results of Church Creek Index Spawning Reach Surveys: 2003-4.
(Personal Communication, Jody Brown, Stillaguamish Tribe, 2005)

2003-2004					
Church Creek					
WRIA 05-0019					
Index 1		**COHO**			
RM 1.5-2.0					
	Live	Dead	Redd	% seen	comments
11/17/2003	14	0	4	60	
12/10/2003	0	6	0	60	
1/6/2004	0	0	0	60	
Index 2					
RM 2.0-2.5					
11/17/2003	13	0	7	50	
12/10/2003	8	9	3	70	
1/6/2004	0	0	0	60	
Index 1		**CHUM**			
RM 1.5-2.0					
	Live	Dead	Redd	% seen	comments
10/30/2003	0	0	0	90	20,30
11/17/2003	0	0	0	60	
11/25/2003	2	0	0	30	
12/10/2003	0	0	0	60	
1/6/2004	0	0	0	60	
Index 2					
RM 2.0-2.5					
10/30/2003	0	0	0	50	
11/17/2003	0	0	0	50	
11/25/2003	0	0	0	30	
12/10/2003	0	0	0	70	
1/6/2004	0	0	0	60	

Specific conditions for spawning include pools to hold and rest in on their migration; adequate flows for migration, aeration of and removal of wastes from the redds; cold water temperatures; and the availability of gravel in a particular size range in which to construct their redds (Spence, et al., 1996; Groot and Margolis, 1991). Incubation occurs through the winter. Juveniles rear for about 1½ years in low energy environments including channel margins, pools, beaver ponds, and other connected wetlands, where cover (for shade and protection from predators) and food are available. Complex habitat that includes large woody debris and rootwads provides cover, reduced competition and an environment productive of preferred food sources and contributes to the formation of pools.

Table 2-3b
Results of Church Creek Index Spawning Reach Surveys: 2004-5.
(Personal Communication, Jody Brown, Stillaguamish Tribe, 2005)

2004-2005				
Church Creek				
WRIA 05-0019				
Index 1		**COHO**		
RM 1.5-2.0				
	Live	Dead	Redd	% seen
11/11/2004	2	0	1	50
12/2/2004	36	15	17	30
Index 2				
RM 2.0-2.5				
11/11/2004	25	0	13	50
12/2/2004	115	25	50	60
Index 1		**CHUM**		
RM 1.5-2.0				
11/11/2004	0	0	0	50
12/2/2004	3	0	1	30
Index 2				
RM 2.0-2.5				
11/11/2004	0	0	0	50
12/2/2004	0	0	0	60
Below Index 1*	Chum			
12/3/2004	16	0	5	
	Coho			
12/3/2004	6	4	2	
* From Railroad Grade to RM 1.5				

Habitat conditions in Church Creek were recently investigated by Pess, et al. (1999) and Snohomish County SWM (2003). The Pess, et al. survey focused on habitat loss in a comparative study similar to that of Beechie, et al. (1994). Current and historic freshwater rearing habitats for coho salmon were quantified for the entire Stillaguamish Basin and the causes of losses were interpreted from broad land use patterns. Loss of beaver ponds (90% lost), side-channel sloughs (59% lost), and distributary sloughs (81% lost) were highly significant. Side-channel sloughs are found in the mainstem reaches and in larger tributaries; distributary sloughs are found in the estuary. Beaver ponds were formerly found throughout the watershed, but are now relatively rare. The dramatic loss of beaver pond habitat has likely had a significant effect on streamflow, baseflow, duration and timing of stormflow delivery, and groundwater recharge in the Church Creek subbasin, in addition to a significant effect on coho populations in Church Creek, Pilchuck Creek, and the Stillaguamish watershed as a whole.

Pess et al assert that "[t]he vast majority of lost juvenile coho summer and winter rearing capacity is due to the draining and filling of beaver ponds and other wetland areas." This would definitely apply in Church Creek. The drastic reduction in pond habitat available for both summer and winter rearing has caused tributary habitat such as that found in Church Creek to take an increasingly important role in coho salmon production basin-wide. Habitat degradation (defined in Pess, et al. as loss of large woody debris due to forest harvest and land use conversion) and fish passage-blocking culverts were the other leading causes of habitat loss in tributaries such as Church Creek noted by the authors. Losses in smolt production capacity throughout the Stillaguamish totaled about 1,000,000 during summer and 2,000,000 during winter. The loss of ponds was responsible for 30% and 80%, respectively, of the lost coho salmon smolt production capacity. Finally, it was reported that in 71 of 72 Stillaguamish basin streams, rearing habitat, either summer or winter, is limiting coho salmon production, not spawning habitat. Changes in physical habitat characteristics documented in Pess, et al. (1999) include a decrease in pool area percentage and a drastic loss of large woody debris in areas where agriculture dominates.

Church Creek itself was field surveyed in 1995 between RM 3.0 and 3.6. It was found to be about 10 feet wide at bankfull, to have a gradient of less than 0.01%, and to have 53% pool area; 40% of the pools being formed by woody debris. The frequency of woody debris was reported to be 15.5 pieces per 100 meters. This is equivalent to 1.55 pieces/channel width and would indicate some recovery of woody debris frequency with the onset of rural residential development as noted by Pess, et al. (1999).

Snohomish County SWM (2003) reported the results of a physical habitat field survey conducted in the low flow period in 2002 in portions of Church Creek that included pool frequency, percent pool area, large and total woody debris frequency, percent bank instability, percent hydromodifications (bank hardening with revetment, dikes, levees, bulkheads, etc.), and the percent of fine sediments (< 6.3 mm diameter) in spawnable substrate that has the potential to suffocate eggs or entomb juveniles. Nearly four kilometers of Rosgen (1996) C channel (out of 15.3 kilometers of C channel total) and 0.3 kilometers of A channel (out a total of 0.7 kilometers) were surveyed. Seven kilometers of highly modified channel, including Jorgenson Slough and ditches in the middle and upper parts of Church Creek were not surveyed.

Pool area comprised 41.4% of Rosgen C channels (meandering, unconfined, 0-2% gradient reaches; Rosgen, 1996) measured and 57.5% of the relatively short reach of Rosgen A channel (0.7 kilometers at 4-10% gradient in the gorge upstream from the Stillaguamish River floodplain). Pool frequency was reported to be 0.19 pools/channel width and 0.18 pools/channel width in the A and C channels respectively. Woody debris frequency of a size similar to that measured by Pess, et al. (1999) was found to be 4 pieces per 100 meters in the A channel reach and 3.3 pieces per 100 meters in the C channel reaches surveyed. This is notably less than the frequency found by Pess et al. 7 years earlier. It is likely that the entire length of the reach surveyed by Pess, et al. (1999) was within the C channel reach surveyed by Snohomish County SWM in 2002.

Other habitat characteristics of note found by the Snohomish County survey include low percentages of bank instability and hydromodification of the channel, and medium to high amounts of fine sediments (less than 6.3 mm diameter) in spawnable gravel. Jorgenson Slough was not surveyed in either effort but would have extremely low gradient, percent pool area, and woody debris frequency and very high bank instability and hydromodification. Collins and Sheikh (2003) show this area to historically have been a riverine-tidal freshwater marsh that is seasonally inundated. Wetlands of all types may or may not have channels running through them. The fact that there is an upstream source of water (Church Creek) ensures that this marsh had stream characteristics as well.

2.3.2 Pilchuck Creek populations

Pilchuck Creek is used by both focal species, coho salmon and Chinook salmon. The population and life history characteristics of coho salmon using Pilchuck Creek are similar to those using Church Creek. Coho salmon in Pilchuck Creek are able to exploit habitat in tributaries that Chinook salmon do not use, including Trib 80 for which there is physical habitat data from Pess, et al. (1999).

Summer-fall Chinook salmon use only the mainstem of Pilchuck Creek up to a natural falls barrier at river mile 9.4 for spawning; some freshwater rearing may occur in tributaries. Washington Department of Fish and Wildlife (WDFW) surveys for spawning Chinook salmon from the mouth of Pilchuck Creek up to Hwy 9 bridge (RM 5.6). Typically there has only been about 1 fish per mile. The highest count in the record was in 1969 where 53 fish were observed, or 9.5 fish per mile. Chinook salmon utilize the lower 9.4 miles of Pilchuck Creek, their migration halted by a natural falls barrier.

Adult Chinook salmon typically enter freshwater beginning in June, spawning taking place from August through October. After incubation, juveniles emerge from the gravel in mid- to late-winter. Various life-history strategies are employed by Chinook salmon within two broad categories, “stream-type” and “ocean-type.” Stream-type fish typically make their way downstream from their natal redd using channel margins, side-channels, and pools with a preference for complex habitat that includes woody debris. They overwinter in freshwater seeking refuge from high energy flows and feeding. They enter the estuary in their second year to feed and smoltify, often at an advantage over other smolts due to the increased size resultant from the year of freshwater rearing. Chinook salmon then enter saltwater and grow to adults before returning to spawn at age 3-7 years.

Ocean-type Chinook salmon emerge from the gravel, migrate downstream while trying to feed and maintain cover from predation, and reach the estuary between late spring and late summer of their first year. They then feed and smoltify, leaving the freshwater with the fall freshets. From smolt trap data it is thought that, currently, all but about 5% of Stillaguamish Chinook salmon are ocean-type fish. Historically, it is likely that more life history trajectories existed that would have taken full advantage of the freshwater resources (STAG, 2000). This possibly would have included a higher percentage of stream-type fish (e.g., spring Chinook salmon) that would spawn in headwater streams and rear in-river for a year, using side-channels, pools, and edge habitat.

2.3.3 Pilchuck Creek Habitat

Pess, et al. (1999) calculated 44 miles of potential anadromous fish habitat in the lower Pilchuck Creek subbasin. This would include 9.4 miles of mainstem Pilchuck Creek and habitat in eight or more tributaries. The lower part of the Pilchuck Creek basin, including mainstem and tributary habitat, has been affected to a somewhat lesser degree than in Church Creek by historical land use and habitat loss. Large areas of the lower Pilchuck and its tributaries, however, were converted early in its development history to agriculture. This led to the removal of forested and scrub-shrub wetlands as they were drained and converted to cropland and pasture. Creeks were straightened, snagged, and bermed.

The industrialization of agricultural practices and globalization of agricultural markets that accelerated in pace after World War II, plus the extra cost and level of subsidy involved in maintaining farming in wetlands, led to the gradual abandonment of farms and the ecological succession of creek- and wetland-adjacent pastures and cropland into their current "feral," reed canarygrass wetland state, bereft of the complex and diverse habitat known to not only provide high quality conditions for the rearing of coho salmon, but, in a paradigm being slowly accepted by some biologists, potentially contributing to the productive rearing of juvenile Chinook salmon.

Although much drainage of wetlands and destruction of beaver habitat have occurred in the lower Pilchuck concurrent with conversion of the historical forest to Douglas-fir plantations, the style of private forestry practiced has since been more conducive to hydrologic stabilization, albeit in a slightly different regime.

Pess et al. (1999) surveyed three reaches of Trib 80, a left bank tributary used by coho salmon and located approximately at RM 5.8 on Pilchuck Creek. The total length surveyed was about 1.2 miles. The stream is approximately 10 feet wide throughout this length and ranges in gradient from a little over 4% in the lowermost surveyed reach (RM 0.2 to 0.5) to about 0.05% in the uppermost surveyed reach (RM 2.7 to 3.6). Percent pool area ranged from 45% in the upper reach to 57% in the lower reach. Woody debris frequency was 9 pieces/100 meters throughout the surveyed reaches (about 0.9 pieces per channel width). The mean piece size was notably small at 0.22 meters diameter (about 8 inches) and 2.1 meters long (less than 7 feet).

The 9.4 miles that the Chinook salmon are known to spawn in have been characterized in EDT using three reaches. The habitat types in these reaches were determined using best professional judgment in the 2004 modeling of Chinook salmon in the Stillaguamish in preparation for running recovery scenarios (SIRC, 2004). This EDT modeling for Chinook will be updated and broadened to include coho salmon in this study.

2.4 Land Use and Water Management Links to Flow and Focal Species Habitat – Hypotheses

This section discusses the hypothetical nexus between land use change and water management, flow regime change, and impact on the focal species in both pilot basins. The nexus is conceived of as cascade of influence as in Figure 2-2.

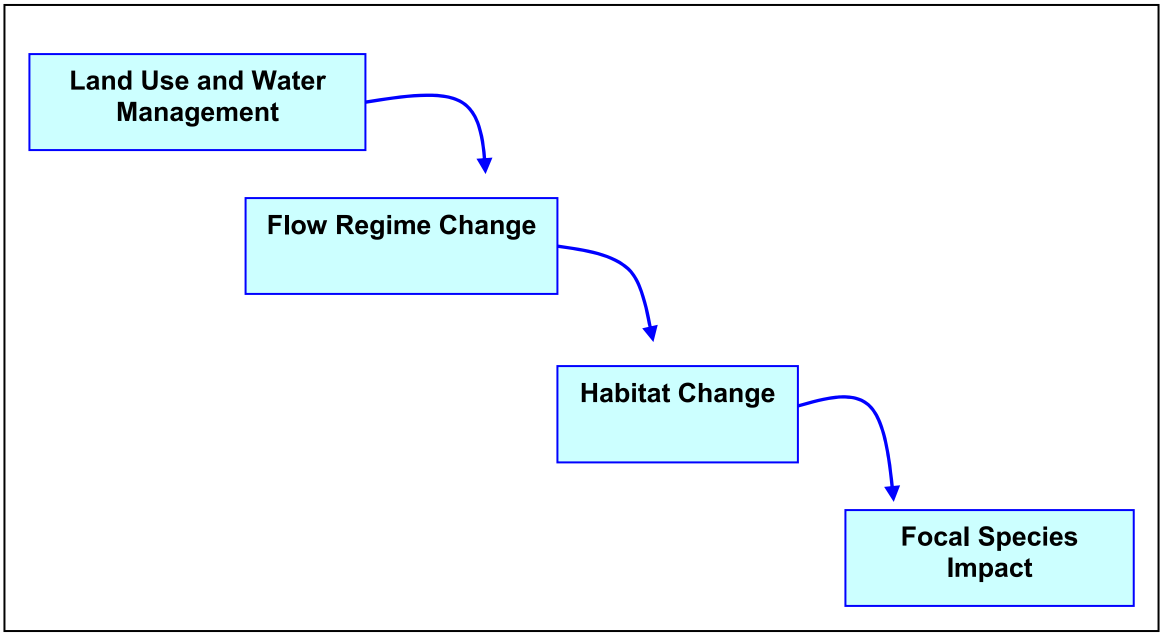

Figure 2- 2: Cascade of Influence

Table 2-4 summarizes different types of management actions that were considered to be operative within the pilot basins after initial review of the available data and information. The tabulation is followed by a more specific discussion of how these linkages were likely to play out in each of the study basins. Subsequent modeling and analysis for this project (see Sections 3-6 of this report) tend to support a majority of these hypotheses.

Table 2-4. Land Use, Flow Regime, Focal Species Habitat, and Population Changes

Actions Affecting Flows[4]	**Flow Regime Changes**	**Effects on Focal Species Habitat**	**Effects on Focal Species Populations**	**Areas Most Affected**
Forest Removal and road construction	Reduced infiltration, increased concentration of flow, increased magnitude of stormflow, decreased duration of stormflow, more rapid time to concentration, increased velocity of streamflow, increased erosion and transport of large woody debris from the system.	Removal of riparian vegetation has specific localized affects on large woody debris delivery, bank erosion, delivery of fine sediments that have the potential to intrude redds and suffocate eggs or entomb juveniles. Reduced shading and increased stream temperature if riparian forest removed.	Simplification of habitat, increased sediment delivery affects both spawning and rearing habitat; high sediment concentrations can cause feeding problems for salmonids; higher stream flow velocities have potential to scour redds; higher velocities of streamflow imperils juveniles in search of low-energy environment to feed and avoid predators. Higher temperatures may impede migration and reduce fecundity.	Entire Church Creek subbasin dramatically affected; lower riparian area is currently least affected. Lowermost Pilchuck Creek and lower tributaries most severely affected. Upper subbasin is managed for long-term supply of timber by local owners.
Agricultural Development	Continued prevention of forest regrowth magnifies above flow regime affects; regular soil disturbance increases potential for soil erosion orders of magnitude greater than undisturbed forest.	Agricultural development in estuary and lower river has greatest effect on Chinook salmon; Pess et al., (1999) found large woody debris frequencies the lowest of any land use in agriculture land use areas; habitat simplification follows. Reduced shading and increased stream temperature if riparian forest removed.	Water quality effects of conventional agriculture that uses pesticides and fertilizers can have direct toxic effects on fish; high sediment concentrations can cause feeding problems for salmonids; combined with simplified habitat, poor spawning and rearing success results. Higher temperatures may impede migration and reduce fecundity.	Entire Church Creek subbasin has been affected. Much previous agricultural land use is converting to rural residential. Lower Pilchuck Creek subbasin, including mainstem and tributaries, is affected in lower few miles.
Rural Residential Development	Extensive roading, vegetation removal, and impervious area have effects on magnitude, duration and timing of stormflow.	Change in stormflow patterns plus removal of riparian vegetation destabilizes banks, increases sediment delivery and increased temperature, and leads to habitat simplification.	Can maintain sub-populations of salmonids, that are not viable in and of themselves, at low levels as a result of mixed levels of habitat quality. Higher temperatures may impede migration, deplete oxygen and reduce fecundity.	Most of Church Creek subbasin, including Freedom Creek, has been and will continue to be affected by this land use/cover. Lower Pilchuck Creek subbasin, including mainstem and tributaries, are affected; Upper Pilchuck Creek subbasin has minor amounts of this land use/cover type.

[4] The management of dams and reservoirs for flood management were not considered in this analysis as this is not a factor in the pilot study basins.

Land Use/Cover Changes	Flow Regime Changes	Effects on Focal Species Habitat	Effects on Focal Species Populations	Areas Most Affected
Channel modifications (ditching, straightening, revetment, dikes, levees, cutting off meanders, installing tidegates)	Channel straightening and cutting of meanders increases the energy gradient and velocity of streamflow leading to increased bed and/or bank erosion; ditching, dikes and levees are designed to contain the streamflow within assigned channel leading to similar effects (more rapid delivery of stormflow of greater magnitude).	Dramatically reduces habitat diversity; cuts off access to low-energy rearing habitat; removes and prevents regrowth of riparian vegetation, reduces cover, shade and food sources; increased energy can lead to scouring of redds.	Reduced low-energy rearing habitat availability; increased juvenile mortality due to increased competition, scouring of eggs in redds.	Freedom Creek and parts of upper Church Creek are affected by this practice. Lower Pilchuck Creek and some lower tributaries are affected by this practice
Floodplain modification (filling ponds, cutting off side-channels)	Reduces floodplain storage and aquifer recharge, increases flood height and stormflow velocity.	Reduces habitat diversity; cuts off access to low-energy rearing habitat.	Reduces low-energy rearing habitat availability; increases juvenile mortality due to increased competition.	Freedom Creek and parts of upper Church Creek are affected by this practice. Lower Pilchuck Creek and some lower tributaries are affected by this practice.
Urban Development	Medium to high levels of impervious area yield increased magnitude and more rapid delivery of stormflow, reduces duration (i.e., increases flashiness); generally coincident with channel and floodplain modifications, forest removal and extensive roading so would include flow regime changes resultant from those land use/cover changes.	Little area available for juvenile protection from high-energy flows; extremely poor water quality and food production; spawning habitat reduced or lost by stormflow gravel scour, channels excavated to maintain conveyance; in extreme cases habitat is lost altogether as it is replaced by detention ponds and conveyance pipes.	As channels are scoured to bedrock by increased energy of stormflow spawning habitat is reduced and lost; high energy stormflow and small to non-existent riparian buffer areas greatly reduce large woody debris that greatly reduces habitat diversity and opportunities for juvenile rearing.	Southwestern Church Creek subbasin affected by this land use/cover type. Upper most Freedom Creek and Church Creek affected by I-5 “urban” development. Lowermost Pilchuck Creek and lower right bank tributaries affected by I-5 “urban” development.
Surface Water Withdrawals for Irrigation or Other Uses	Instantaneous reduction in flow downstream of points of diversion, increased frequency and intensity of low flow extremes.	Loss of flow depth and wetted area, increase in water temperature; reduced capacity to create habitat structure and maintain habitat quantity	Possible desiccation of redds, reduced rearing habitat, migration barriers, reduced reproductive success.	Most of Church Creek and lower Pilchuck Creek; if current certificates actively utilized affected area would increase.
Groundwater Withdrawals for Irrigation or	More gradual reduction in base flows in areas with surface continuity	Loss of flow depth and wetted area, increase in water temperature; reduced capacity to create habitat	Possible desiccation of redds, reduced rearing habitat, migration barriers, reduced reproductive success.	Most of Church Creek, Tributary 80 of Pilchuck Creek and lower mainstem Pilchuck Creek; if

Domestic Use		structure and maintain habitat quantity.		current certificates actively utilized area affected would increase.

2.4.1 Church Creek Basin-Land Use Change Effects on Flow Regime

Conversion of forest areas to pastures and impervious surfaces has significantly affected flow regime in Church Creek and will continue to significantly alter future flows under current land use trends.

Clearing of trees and other riparian cover, more rapid drainage from pasture ditching and roads, together with declines in beaver populations and removal of beaver dams, has probably reduced storm flow attenuation and promoted channel incision in Church Creek basin.

In addition to changes in runoff to the Church Creek stream reaches, it is likely that woody debris and beaver dams have been removed from stream channels in order to improve drainage of riparian pastures. This has increased stream flow velocity. Direct clearing of stream side trees and other riparian cover, more rapid drainage from pasture ditching and roads, together with declines in beaver populations and removal of beaver dams and logjams, has probably reduced storm flow attenuation, promoted channel incision, and reduced pool habitat**.**

General basin land cover change, direct manipulation of stream channels, and land drainage has probably also reduced the opportunity for recharge of shallow groundwater resulting in stream base flow reductions. Lower base flows during summer and early fall coupled with reduced riparian vegetation have increased stream temperatures.

Development allowed under the current (1995) Snohomish County Comprehensive Plan future land use designations in the non-UGA portion of Church Creek watershed is primarily rural residential development that will more than double impervious area, reduce the already small amount of basin forest cover, and increase the rapidity of storm runoff and cause other flow regime changes.

2.4.2 Church Creek Basin-Land Use Induced Flow Effects on Habitat and Focal Species

The focal species in the Church Creek basin is coho salmon. Coho salmon habitat has been degraded by increases in the magnitude and frequency of peak discharges with associated increases in stress velocities and scouring of spawning gravels.

Pool habitat favored by coho for rearing has been reduced by increased peak discharges and removal of beaver dams and debris jams, and lack of recruitable wood caused by clearing of riparian vegetation to allow animal and human access to streams.

Base flow reduction increases the occurrence of sub-optimal and lethal stream temperatures caused by lack of riparian shading.

Coho habitat degradation caused by flow impacts related to land used change is general throughout the Church Creek Basin but probably most pronounced in low gradient valley areas where pastures and residential landscaping abut the stream.

2.4.3 Church Creek Basin-Water Management Effects on Flow Regime

Under current conditions, water withdrawals for public water systems in Church Creek basins have not been of sufficient magnitude to have any significant affect on flow regime. At the current time, the net amount and effect of irrigation from private wells and surface diversions is not known. The maximum rate of ground and surface water withdrawal allowed by water rights in Church Creek (1.52 cfs) would certainly have a pronounced impact on stream base flows; even the 0.45 cfs maximum surface diversion would be significant for such a small stream basin.

Current or future use of relatively large (in proportion to size of the basin and streams) water rights on both branches of Church Creek has the potential to greatly reduce summer base flows if irrigation rights are currently active or could become active in the future.

2.4.4 Church Creek Basin-Water Management Induced Flow Effects on Habitat and Focal Species

The current assumption is that these effects are small and that, for the most part, irrigation rights are not actively exercised in the basin. Still, added to loss of base flow associated with land cover and channel changes, any additional withdrawal of water during low flow seasons and dry years is likely to harm coho habitat by reducing flow depth and raising stream temperatures.

2.4.5 Pilchuck Creek Basin-Land Use Change Effects on Flow Regime

Pilchuck Creek has been affected mainly by forestry in the middle and upper Pilchuck Creek basin (subbasins 6 -16, figure 1-3, Section 1) and by historical conversion to agricultural land and current conversion to rural, residential land cover in the lower subbasins (Pilcrk-1 through Plicrk-5).

Moderate increases to peak runoff and stream flow in forestry areas arising from three sources are assumed. In expected order of importance they include increased melt water from clearcut or immature forest areas, increased effective drainage density caused by the forest road system, increased effective impervious area associated with compacted forest road surfaces.

In the lowermost part of the basin (subbasins Pilcrk-1 through Pilcrk-8; Figure 1-2), current and future land cover resembles middle and upper Church Creek, albeit at a somewhat less intense current level. Consequently the entire panoply of flow changes noted above for Church Creek probably also apply there currently, and are likely to increase more dramatically there as existing forest cover is permanently converted to rural residential use and land cover. While acreage throughout the Pilchuck subbasins (both Upper Pilchuck and Lower Pilchuck) is in tree farm status, this land is not "protected" or pristine. It is regularly harvested, the forest is kept in a juvenile state, it is roaded and thus natural ecosystem processes are not at work. Finally, adjacent commercial and rural residential uses increase the risk of nearer term conversion to "transition" designation and perhaps, eventually, rural residential and/or commercial use.

2.4.6 Pilchuck Creek Basin-Land Use Induced Flow Effects on Habitat and Focal Species

Peak flow increases on the mainstem associated with forest clearing and forest roads are likely, but of unknown magnitude and significance with respect to Chinook and coho habitat quality. Any effect of peak flow increases on both salmon species has been aggravated by removal of wood from the channel to increase conveyance during flood flows.

Flow increases on tributaries in Pilchuck subbasins 1-5 have likely been more dramatic and have degraded coho habitat through increased flow velocity, loss of pool habitat, and increased frequency of redd scour. These have likely been affected by clearing of riparian forest and removal of woody debris from channels to improve drainage.

2.4.7 Pilchuck Creek Basin-Water Management Effects on Flow Regime

Currently, flow regime is not significantly affected on either the mainstem or tributaries by water withdrawals from public water sources; however, the potential for diversions under private certificates to significantly reduce mainstem flow during dry years is extreme. USGS records on Pilchuck Creek indicate that during a 10% drought year, the August monthly average flow near Bryant (draining approximately 68% of the entire basin area) was only 3.0 cfs while the typical August flow (median) at this site is 17.6 cfs. If all certificated water rights holders drew their maximum during a drought, creek flow could be easily be reduced by 50% or more. This underscores the need to determine the current and potential future level of activity associated with these water rights.

Similarly, Tatoosh Water Company, located in the headwaters of Tributary 80 in subbasin 8 currently pumps at a maximum rate (.23 cfs) that is less than 10% of their maximum allowable rate and produces an annual volume of water for its customers that is only 3% (.106 cfs annualized) of the amount under its water right. While under current practice, production has a minor impact on base flows in Tributary 80 and has negligible impact on Pilchuck Creek, future permitted increases in Tatoosh's production could significantly reduce base flows in Tributary 80 and cause a proportionately lower impact to the mainstem.

2.4.8 Pilchuck Creek Basin-Water Management Induced Flow Effects on Habitat and Focal Species

Public water systems and private exempt wells currently have minor impact on focal salmon species, but this may change in the future if production is expanded to the limits specified in the water rights certificates. The effect of such an expansion would most likely be located on Tributary 80 (stream draining Pilchuck subbasin 8) and on the mainstem of Pilchuck Creek downstream of Tributary 80. The effect of these flow reductions would be reduced refuge for fish during droughts and increased incidences of suboptimal or lethal temperature conditions.

Surface and groundwater withdrawals under privately held certificates for irrigation or other purposes represent a wild card impact for base flows. If currently active, these withdrawals may be significantly reducing habitat quantity and quality during low flow seasons and years. Based on the location of these sources, their current or potential future impacts would be concentrated along the mainstem of lower Pilchuck Creek and in subbasin 1.

Section 3. Hydrologic Modeling, Flow Parameter Extraction, and Analysis

3.1 Introduction

This section summarizes the development of a precipitation-runoff and stream water temperature model for the two pilot basins and discusses how it has been used to simulate continuous, long term flow hydrographs from which selected parameters have been extracted for comparison of four scenarios reflecting a range of basin conditions. The results of the hydrologic analysis are summarized for the 19 reaches identified as potential salmon habitat to be modeled with EDT (Ecosystem Diagnosis and Treatment) and habitat index methods.

HSPF (Bicknell et al., 2004) represents a watershed as a series of subbasins linked by a flow routing network consisting of channels and storages (reservoirs, ponds, lakes). Subbasins consist of hydrologic response units (HRUs) representing different combinations of attributes including soil, landcover, and sometimes also slope and elevation classes indicative of varying temperature and precipitation conditions. Acreages of these HRUs are determined by overlaying maps or GIS layers representing each of these attributes.

HSPF was selected as the model to synthesize flow regimes because it and its derivative models have been used widely and successfully to represent precipitation runoff behavior of streams in the Puget Sound basin by federal, state, and local agencies including the USGS, FEMA, Washington Department of Ecology, Snohomish County, King County, Thurston County, City of Bellevue and City of Seattle to name a few. Since the 1980s, this model has proven itself capable of synthesizing continuous stream flow based on precipitation data and has been a preferred hydrologic analysis tool for watershed, stormwater, and floodplain studies in natural, suburban, and urban basins.

3.2 Scenario Development

To capture the hydrologic effects of basin land cover change associated with historic and potential future land development in the pilot basins, four scenarios were developed for representation by the hydrologic and ecological models. In each of these scenarios, riparian vegetation, distribution of habitat types, and wood loading were assumed to be in their approximate, historic, pristine state. This assumption was made in order investigate the impact of land cover change (exclusive of riparian areas) and the associated shifts in runoff and stream flow on flow regime and salmon populations. However, while the study did not directly explore the a range of riparian, wood, and habitat structure conditions, the importance of these factors is certainly acknowledged and in fact was underscored by the study's salmon population modeling results as discussed in Section 5.

3.2.1 Natural or "Template" Conditions

Natural or "Template" conditions represents a pristine condition in which basin area is made up exclusively of mature forest cover and currently mapped wetlands and there is effectively zero consumptive water use by humans. As in all the scenarios, channels and riparian areas are assumed to be in their historic, pristine state with regard to riparian vegetation and wood debris loading. Scenarios 2-4 below represent increasing levels of urban and rural land development and consumptive water use.

3.2.2 Scenario 2: "Current" Land Use, No Stormwater Detention

The current conditions land cover/land use scenario was developed using a land-cover classification based on a 2001 LANDSAT-TM scene shown in Figure 3-1. Each 30-meter pixel in the scene is classified with one of eleven land-cover categories (Purser et. al, 2003). The dataset includes the following ten land-cover classes and one unknown class: Mature evergreen forest, Medium evergreen forest, Deciduous stands, Shrub / small trees, Grass, Bare ground, Medium density development, High density development, Alpine rock / talus slope, Open water, and Unknown (shadow / cloud). An assessment of current land use in the watershed was made by refining the current land-cover data using its underlying zoning, wetlands and open water datasets. Areas classified by LANDSAT-TM as 'Grass' were modeled as urban grass if they are located in areas zoned for residential or commercial and modeled as pasture if they were zoned for agriculture or forestry. Areas classified as 'Bare ground', 'Shrub / small trees', or 'Alpine rock / talus slope' were modeled as pasture regardless of their underlying zoning. With the exception of Cavanaugh and Summer Lakes, all areas either classified by LANDSAT-TM or by the open water GIS dataset were modeled as wetlands. All areas included in the open water and wetlands datasets were applied to the current conditions dataset regardless of the LANDSAT derived classification. Areas classified by the LANDSAT-TM scene as Medium and High Density Development are specified (Purser et. al, 2003) to have EIA (Effective Impervious Area) percentages of 36 and 72 respectively. In addition to these EIA areas, a roads dataset was also buffered and modeled as 100 percent EIA. A tabulation of the EIA properties is presented later with the HSPF model discussion in Table 3-9.

The Church Creek basin has lost the majority of its historical forested land cover. Only one of the six subbasins retains more than 20 percent forest cover, and nearly all of the forest in the other subbasins is deciduous stands. The basin is dominated by low density development with small pastures, sparse tree cover and has an average effective impervious area (EIA) of less than 4 percent. The highest density development in the basin has occurred in subbasins 'Church-1' and 'Church-2' with EIA percentages of 8.4 and 10.5 respectively. More than 60 percent of 'Church-1' occupies the Stillaguamish valley floor which is nearly all agricultural. After pasture and forest, the third most dominant land cover in the basin is wetlands, which take up nearly 10 percent of the basin on average and as much as 17.5 percent of 'Church-3'.

Unlike Church Creek, the Pilchuck Creek basin is predominantly in commercial forestry with minimal land area developed for residential or commercial use. Currently, 80 percent of the overall basin is forested. The most developed subbasins ('Pilcrk-1' through 'Pilcrk-5') range from 20 and 50 percent forest cover, while the remaining eleven subbasins range in forest cover between 69 and 99 percent.

This scenario assumes no any stormwater detention facilities. This is not expected to cause a significant discrepancy between simulated stream flow and stream flow that has occurred in recent years in either pilot basin. In the case of Pilchuck Creek basin, development to date has been almost exclusively rural in character. Rural development has typically not exceeded thresholds that would require installation of detention ponds. Also, much of the development occurred prior to requirements for onsite stormwater facilities of any consequence. Church

Creek includes a higher percentage of urban development than Pilchuck Creek, but because of the older age-distribution of the development and the minimal volumes of detention required by stormwater regulations until very recent years, the total volume of facilities is expected to be small and have little net hydrologic impact on Church Creek flows.

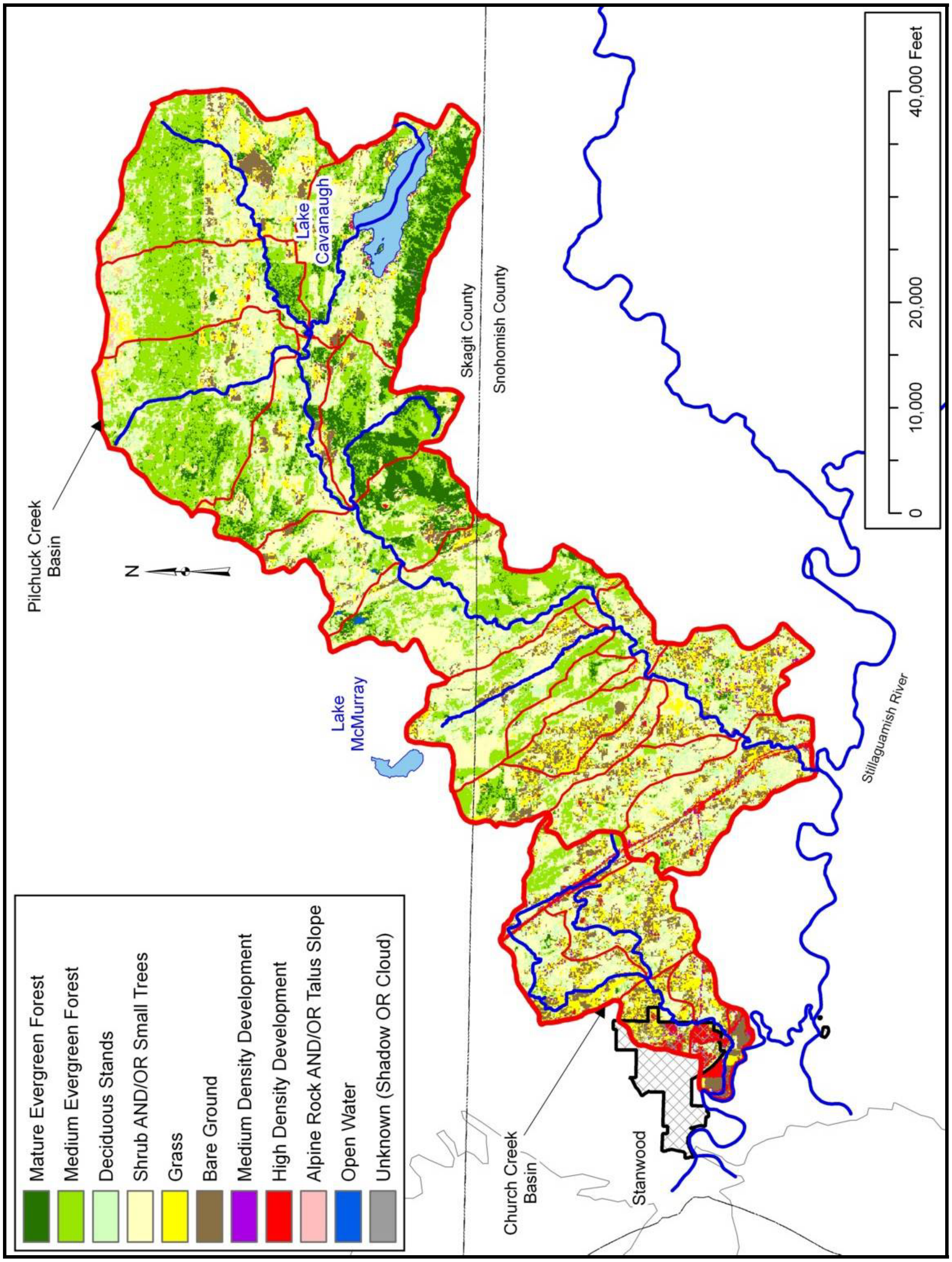

Figure 3-1: Current Land Use derived from LANDSAT 2001 Classification

3.2.3 Future Scenarios

Two future land use and population scenarios are modeled in addition to template (pristine watershed conditions) and current conditions. One future scenario – scenario 3 or "Future 1" – is the typical buildout scenario. Scenario 4 is the same as Future 1 in areas zoned for forest and agricultural use as well as urban areas; however, a distinctly different approach has been taken in currently planned rural (LDR) areas along the I-5 corridor and between the corridor and the present City of Stanwood. As shown in Figure 3-2, this area includes all Church Creek subbasins as well as the lowest Pilchuck Creek subbasin (PilCrk-1).

Scenario 3: "Future 1" (Buildout to Comprehensive Plan, no stormwater detention)

Future development, land use, land cover, and population have been based on land uses designated by current comprehensive plans and GMA boundaries within the pilot basins. This future land use dataset was assembled from Snohomish County comprehensive plan and zoning data, the Skagit County comprehensive plan, the City of Stanwood comprehensive plan and zoning data, Snohomish County wetlands, open water and parks inventories, and the National Wetlands Inventory (NWI). This is similar to the future conditions characterization outlined in Section 1 and is presented in Table 3-1 and Figure 3-2 below. The landcover assessment from Section 1 was expanded here to implement a general assumption of "no reverse" development. This means that impervious area and urbanization indicated by analysis of 2001 LANDSAT data as described in Section 1 represent minimum levels of future development at any given location within the two pilot basins. This includes an assumption that future percentages of hydrologic immaturity (clearcuts and immature forest cover areas) in forest use zones will be assumed valid under future1 conditions.

Scenario 4: "Future 2" (Buildout with Hypothetical, Additional Highly Urbanized Area)

Future 2 is distinct from Future 1 in that current GMA boundaries are assumed to be substantially expanded, allowing urban development to extend from the City of Stanwood east to the I-5 corridor. While development densities in the area have varied in the past and are perhaps tending to get denser, we selected the highly urbanized Thornton Creek basin within Seattle as an example of a builtout, mixed urban land use basin that is dominated by single family residential use. Although this basin is densely developed, it includes considerable amounts of open space including a golf course and riparian park land. Thirty-one percent of Thornton Creek basin is effective impervious area (EIA) and average housing density is 4.3 DU/Acre. Because the study area is located much further from the regional urban core (downtown Seattle), we assumed that the Future 2 expanded urban area that includes all of Church Creek basin and the Pilchuck-1 subbasin would have 70% of population and household density currently seen in Thornton Creek or 22% EIA and 3 DU/Acre. To achieve this in Future 2, Church Creek and Pilchuck-1 subbasins have been allocated 846 and 293 acres of EIA in their currently designated LDR areas. This results in EIA percentages of 19 and 13, respectively, in these areas.

Stormwater Mitigation Assumptions for Future 1 and Future 2

No stormwater mitigation is assumed for future development in either the Future 1 or Future 2 scenarios. For Future 1 the vast majority of future land development will be in rural residential land use. Historically, this type of development has been at a small scale and has not exceeded regulatory thresholds that would require stormwater detention or water quality facilities. While this may change in the future, requirements for such mitigation are not certain at the time of this writing (August, 2005). In Future 2, rural residential development is replaced by urban residential densities which are more likely to install some kind of stormwater facilities that mitigate peak flows and pollutant loadings. At this time, Washington Department of Ecology is publishing a new stormwater manual and the stormwater design standards that will be required by jurisdictions within the pilot area in the future are uncertain. In this context, the Future 2 scenario may be viewed as a "bracketing" scenario with respect to stormwater discharges and their ecological effects. Conversely, the Current scenario may be viewed as a case of Future 2 with both perfect stormwater and water withdrawal mitigation. It is anticipated that results of modeling Future 2 will inform discussion concerning both future and restorative stormwater treatment to achieve salmon recovery goals and also provide a base of information to guide any necessary follow-up work that investigates the benefits of specific stormwater management policies.

Table 3-2 summarizes the features of each scenario and compares and contrasts each in relation to actual historic, actual existing, or future conditions as planned by local jurisdictions.

Table 3-1
Zoning/Comprehensive Plan Aggregated Zoning Categories and Land-cover

Aggregated Land Use Category based on PSRC Zoning	Land-cover Percentages							
	Forest	Agri-culture	Pasture	Grass (Urban)	EIA[1]	TIA[1]	Wet-land	Open Water
Lakes / Open Water (OW)	0	0	0	0	0	0	0	100
Designated Wetlands (WET)	0	0	0	0	0	0	100	0
Industrial Forest (IND FOR): Roaded timber production areas	99.5	0	0	0	0.5	1	0	0
Open Grass (OG): Parks and recreational space	0	0	0	100	0	0	0	0
Mineral Resource Lands: Quarries and mines (MRL)	0	0	0	50	50	50	0	0
Agricultural lands (AG)	0	99	0	0	1	1.3	0	0
Low Density Residential – Forestry (LDR-F): < 1 d.u. per 20 acres[2]	96	0	0	0	4	6	0	0
Low Density Residential (LDR): < 0.2 d.u. per acre	0	0	48	48	4	10	0	0
Medium Density Residential (MDR): 1-3 d.u. per acre	0	0	0	90	10	20	0	0
High Density Residential (HDR): 4-7 d.u. per acre	0	0	0	75	25	38	0	0
Multi-Family Residential (MF): >7 d.u. per acre	0	0	0	52	48	60	0	0
Commercial (COM): commercial, industrial, airport, and transportation corridors	0	0	0	14	86	90	0	0

[1] EIA is Effective Impervious Area, representing the surface from which runoff is conveyed directly to an improved conveyance system with limited opportunity for infiltration to groundwater. EIA summed with other land-covers, excluding TIA, yields 100% of the land area.
[2] The LDR-F category was created for a few portions of the study area that are zoned as forestry, but they have 1 dwelling unit per 20 acres designated in the Comprehensive Plan.

Table 3-2
Scenario Summary

Scenario	Land Use/Cover	Human Water Use	Stormwater Detention	Channel & /Riparian	Comparison to actual historical, actual current or planned basin conditions
1- "Template"	Pristine old growth forest and wetland	None	None	Pristine channel, wood, riparian	Approximate representation of pristine land use, stream flow regime, and habitat conditions for salmon
2- "Current"	Existing based on analysis of 2001 LANDSAT	Current, based on purveyor and census data	Not Modeled	Same as template	Approximate representation of 2001 existing land use and cover as well as stream flow regime resulting from storm runoff and water use. Slight bias toward higher runoff to streams in Church Creek because small amount of existing stormwater detention is neglected. **Scenario combines realistic existing condition flow regime (runoff) with pristine channel habitat structure, LWD, riparian cover. Hybrid condition is distinctly more favorable to salmon productivity than actual observed conditions of highly altered channel habitat and riparian cover.**
3- "Future 1"	**Hypothetical** Maximum Buildout based on Comprehensive Plans	Based on expected households at Complan buildout	Not Modeled	Same as template	Base flow regime approximates buildout allowed by Comprehensive Plans. Simulated storm flows biased slightly high portions of Church Creek that are within UGAs where detention would be required for new subdivisions. Simulated channel and riparian simulated in ecological model much more favorable than actual current conditions.
4- "Future 2"	**Hypothetical** urban density throughout Church Creek and in Pilchuck-1 subbasin	Based on expected households from hypothetical land use	Not Modeled	Same as template	**Land scenario hypothetical, not planned by any jurisdiction.** Modeled base flows are consistent with population projected from assumed land use. Modeled storm flows same as for "Future 1" for Pilchuck Ck except for Pilchuck-1. **Predicted storm flows from hypothetical urban areas in Pilchuck 1 and Church Creek 2, 3, 4, 5, and 6, are biased high because detention is neglected.** Simulated Channel and riparian conditions in ecological model much more favorable than actual current conditions.

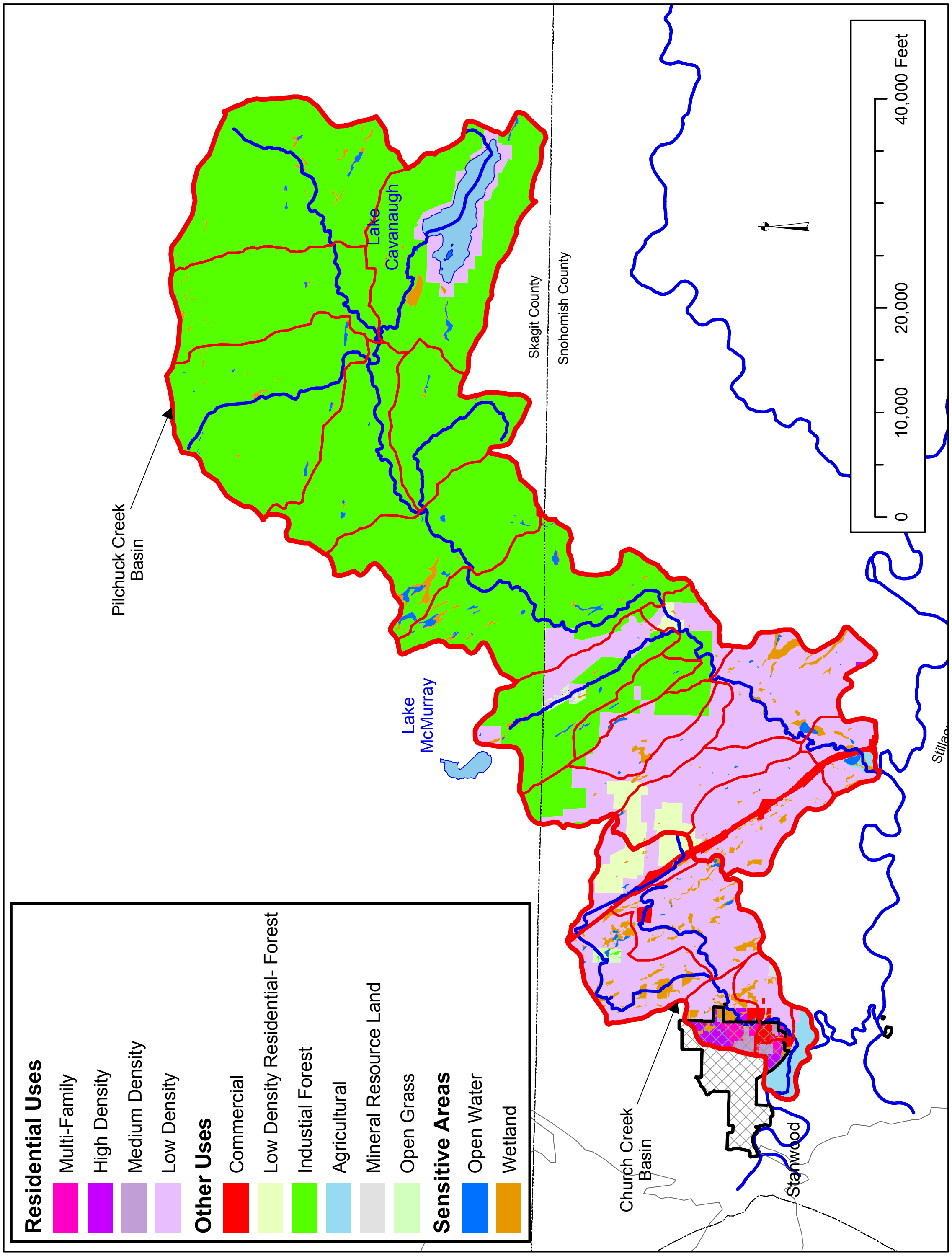

Figure 3-2: Land Use Zoning (Future Land Cover)

3.3 Water Withdrawals, Use, and Return Flows

3.3.1 Critical Assumptions Regarding Hydraulic Continuity of Wells

A hydrogeological review of well logs, well withdrawal data, and USGS hydrogeological reports covering the Church Creek was conducted to assess hydraulic continuity between City of Stanwood well withdrawals and surface flows in Church Creek. The review determined that it is likely that withdrawals from the city's Bryant and Fure wells result in reduced streamflows in Church Creek. For modeling purposes, the streamflows in Church Creek are assumed to be reduced by flows computed as 2/3 of the mean monthly withdrawals from the Bryant and Fure wells, and this impact is evenly distributed over the two miles of channel upstream from the Bryant wells. Use of the 2/3 ratio is based on the work of Morgan and Jones (USGS, 1999) who found pumping from a confined aquifer similar to the Q_{va} aquifer in the Church Creek basin caused local reductions in discharge to adjacent streams that equal approximately 2/3 of the extraction rate. This assumption of hydraulic continuity and application of the 2/3 ratio while admittedly uncertain represents an ecologically conservative approximation of the impact of these wells that is consistent with available data and literature. A detailed hydrogeologic study of the wells would greatly reduce the uncertainty associated with their impact on Church Creek; however, this is far beyond the present study scope. Stanwood's other deeper (and less productive) wells are assumed to not be in continuity with the modeled reaches of Church Creek. For purposes of modeling, exempt wells are assumed to be in full hydraulic continuity with streams draining subbasins within which the wells are located. This seems a reasonable assumption as these wells typically tap shallow aquifers.

3.3.2 Approach to Modeling of Managed Water Effects

For purposes of this study, "managed water" is intended to address three broad components of public and private water supply in the study basins: (1) the total water demands in the study basins by location and type of use; (2) the location and amount of source withdrawals to meet those demands; and (3) return flows at the location of use. A number of assumptions, described below, were made for the modeling of current and future conditions.

Existing patterns and amounts of community public water supply withdrawals and use, unique to the study basins, are assumed to persist into the future. In the case of the City of Stanwood, the existing water use reflects significant industrial demands by Twin City Foods and other commercial users in addition to predominantly-urban municipal demands. In the case of the Tatoosh Water Company, the existing water use is believed to reflect significant use by dairy operations in addition to predominantly-rural domestic demands. The modeling of scenarios 3 and 4 assumes that the current water supply (and consumption) continues as a base demand and identifies new or incremental demands based on projected increases in the numbers of rural and urban service connections. Current water withdrawal data are as reported by the two major purveyors in the study basins. The amounts and monthly distributions for new demands in the basins are based on typical per-connection demands for rural and urban water supply in the Puget Sound region.

Except for the three deeper Stanwood wells, all water supply extractions are assumed to be in complete and direct hydrologic continuity with the stream systems, such that water withdrawals produce reduced streamflows. In the case of the Stanwood wells, the continuity effect is limited to 2/3 of the withdrawals from the Bryant and Fure wells. Total water supply extractions are estimated on a monthly basis and are applied as reduced streamflows in the same month, without a time lag.

The analysis does not explicitly address water supplies to Group A transient public water supply systems or to Group B systems. The transient systems known to exist in the study basins include Stanwood Kingdom Hall, Noah Animal Shelter, and Camp Brotherhood Inc. These systems are addressed in an indirect manner and are included in the estimated number of exempt wells, computed as the number of dwelling units not served by a Group A community system. It is recognized that this approach will not account for water withdrawals from systems which export water from the study area for out-of-basin use. Preliminary review suggests that Camp Brotherhood may be a net exporter of water withdrawn from the same aquifer system used by Tatoosh Water Company, but this has not been confirmed. Based on the information reviewed in this study there are not any significant imports of water from outside the two study basins for use within the basins.

Water supply to urban areas in the study basins is assumed to be provided by a public water supply system and uses are assumed to be fully consumptive. All urban areas are assumed to be completely sewered with water being exported to out-of-basin wastewater facilities, and all irrigation use is assumed to be fully consumptive. The analysis ignores the return flows which occur from leaks in the water supply system, flushing of water mains, and non-consumptive outdoor uses such as vehicle washing and over-watering of lawns. The analysis also ignores the infiltration and inflow (I/I) effects of wastewater exports, in which some groundwater and surface water is inadvertently captured and exported by the sewer system. The demand pattern for new urban connections is described in the following section.

Water supply to rural areas outside of the Tatoosh Water Company's service area is assumed to be from exempt wells or by Group B public water supplies with per-connection withdrawal amounts and consumptive use characteristics which are similar to exempt wells. Water use in rural areas is assumed to be only partially consumptive. All rural areas are assumed to rely entirely on septic systems, and indoor water demands are assumed to be returned to the basin hydrology as return flows. In the hydrologic modeling of managed water effects, only the consumptive fraction of the total use is modeled. The demand pattern for new rural connections is described in the following section.

3.3.3 Water Supply Demand Patterns

Future basin development has been projected in terms of the numbers of dwelling units which would accompany the two scenarios (Future 1 and Future 2) of land use conversions in rural and urban areas. Dwelling unit counts which exceed the current conditions are assumed to reflect new development and to be accompanied by new demands for water supply. Demands estimates are based in part on having 2.5 persons, on average, per dwelling unit.

Rural development is expected to occur on large lots with considerably more outdoor water use than would occur in an urban setting. A demand pattern to match Ecology's estimated beneficial use of 350 gpd per connection was developed with the following use assumptions:

Routine Indoor Use: 125 gallons per day (2.5 persons assumed)
Routine Outdoor Use: 50 gallons per day (livestock, animals)
Irrigation Use: 175 gallons per day on average (0.4 acres irrigated at potential evapo-transpiration rate)

The following chart shows the monthly distribution of assumed rural residential use withdrawals and the estimated consumptive fraction. On an average annual basis, the assumed consumptive fraction is 190 gallons per dwelling per day, slightly higher than Ecology's estimate of 175 gpd. The balance is assumed to return to surface or ground water in close proximity to the withdrawal.

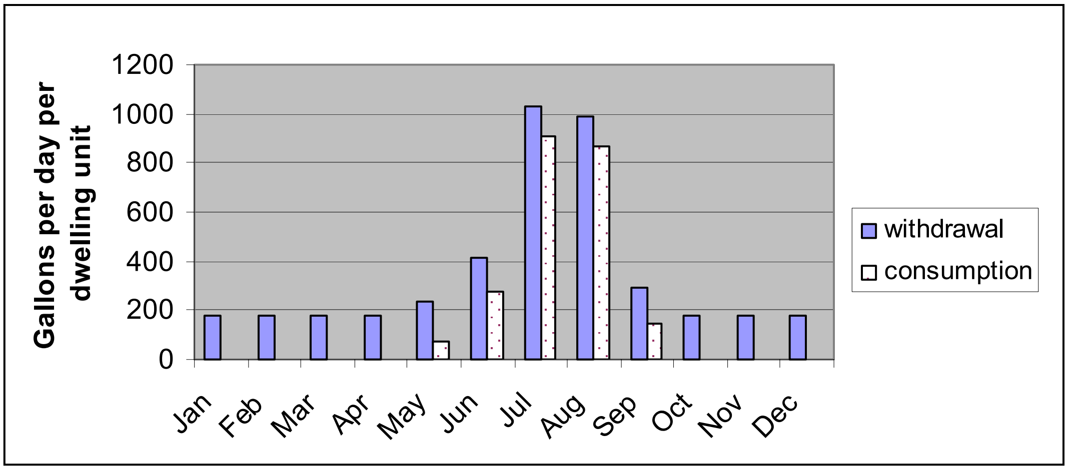

Figure 3-3: Rural Residential Water Withdrawal and Use Pattern (Annual Average Water Withdrawal 350 gpd per connection)

Urban development is assumed to occur largely in the form of urban sprawl with little new industry, as has been experienced elsewhere in the Puget Sound region. Water use demand and monthly distribution for new urban areas was developed by analysis of water supply systems in WRIA 9 for which data were available from a separate study in progress by NHC. Analysis of WRIA 9 data for water supply service to more than 350,000 persons showed that an annualized average water demand ranged from 94 to 185 gallons per person per day. For the current study, new urban development is assumed to create demands equal to 120 gallons per person per day. With the assumption of 2.5 persons per dwelling unit, the urban demand is equivalent to 300 gallons per day per dwelling unit.

The following chart shows the monthly distribution of water demand in new urban areas based on Year 2000 withdrawal distributions for the Covington, Auburn, and Enumclaw water supply systems. Monthly withdrawals for the City of Stanwood were not readily available for use in this study and were assumed to follow the monthly pattern (but not the amounts) of the Urban Area Demand Pattern shown below.

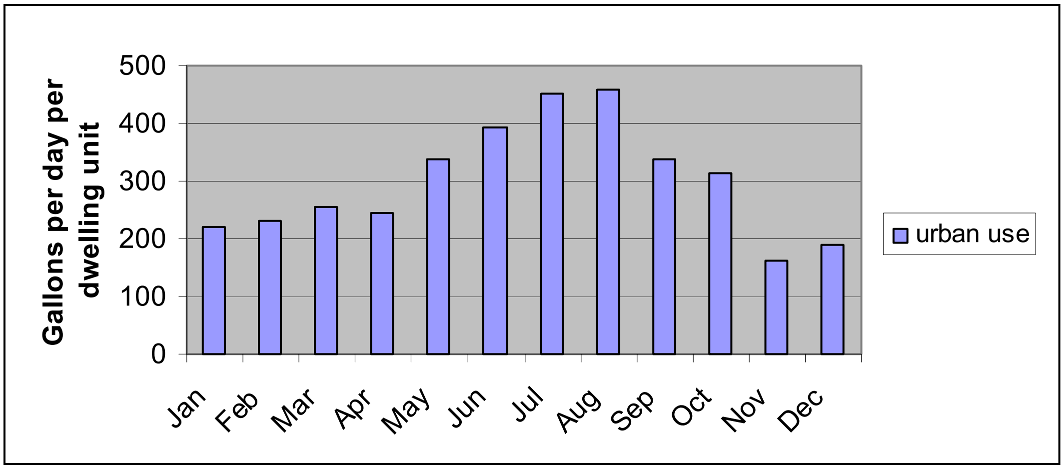

Figure 3-4: Urban Area Water Demand and Use Pattern (Annual Average Withdrawal 300 gpd per connection)

A demand pattern representing current withdrawals by the Tatoosh Water Company was developed on the basis of recent monthly withdrawal data, with some smoothing to reflect long-term mean rates of monthly evapotranspiration. The plot presented below represents total water demands, including system losses, to supply the company's existing 103 connections.

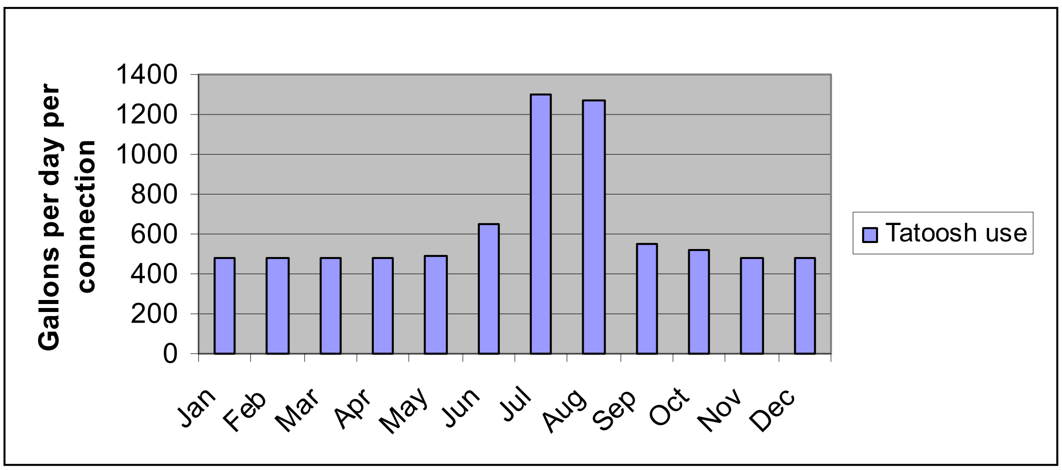

Figure 3-5: Tatoosh Water Company Current Demand Pattern (Annual Average Withdrawal 640 gpd per connection)

On a per-capita (and per-connection unit) basis, the estimated demands for new rural and urban water use are significantly less than the current demands on the existing Stanwood and Tatoosh systems. Total withdrawals by Stanwood in 1999 were equivalent to a per-capita demand of 214 gallons per day and 555 gallons per day per connection, reflecting large industrial use by major accounts including, but not limited to, Twin City Foods. Total withdrawals by Tatoosh were equivalent to a demand of approximately 640 gallons per day per connection, presumably reflecting water supply to area dairy operations. As stated above, these existing uses are assumed to persist into the future, and are treated as a base demand to which additional urban and rural residential demands are added.

3.3.3.1 Total Water Demands in the Study Basins

Water demands in the study basins were estimated for current conditions and for the two future scenarios described above. The initial step in the analysis process was to identify the number of housing units (equivalent water service connections) that correspond to the two future land use scenarios described previously. For current conditions, the number of housing units was determined by an analysis of the Year 2000 census data superimposed on the study basins. Figure 3-6 below shows the housing unit densities by Census block used to estimate number of housing units within each subbasin as of the year 2000 Census.

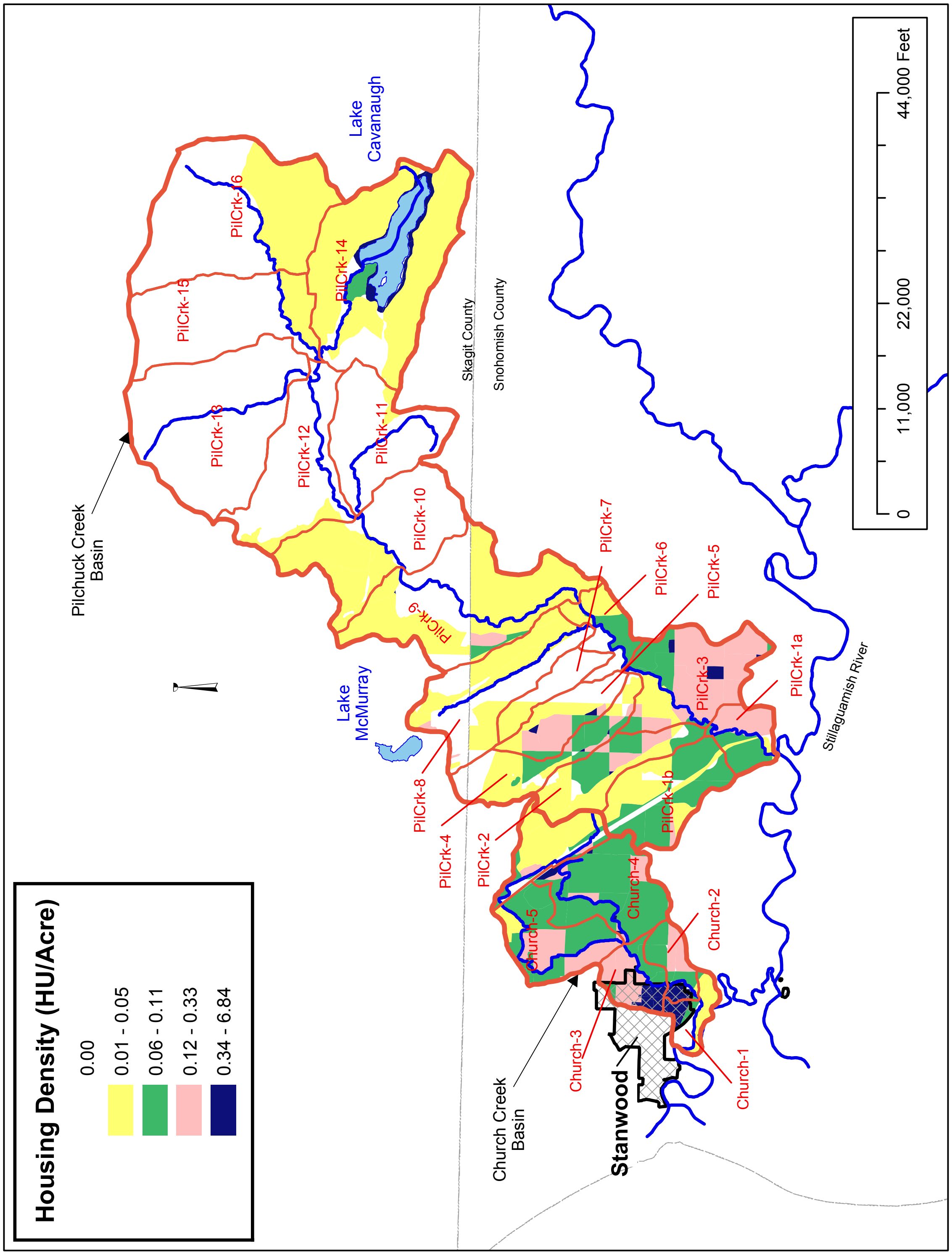

Figure 3-6: Current conditions housing unit densities from 2000 Census block level data

Based on a review of the Stanwood Water Plan, under current conditions in the Church Creek basin, only dwelling units within the City of Stanwood incorporated area are served by the Stanwood Public Water Supply System, and dwellings outside the incorporated area were assumed to be on exempt wells. Similarly, for current conditions in the Pilchuck Creek basin, all dwelling units in excess of the number of connections reported by the Tatoosh Water Company, were also assumed to be on exempt wells.

Table 3-3 summarizes the estimated number of housing units (and water service connections) in each basin, categorized by type of water service and water source. In this table "PWS" stands for public water source.

Table 3-3: Housing Unit Counts for Water Demand Scenarios

Basin	**Water Service**	**Number of Housing Units**		
		Current	Future 1	Future 2
Church	Existing Stanwood Service (PWS)	561	561	561
Church	New Urban	0	4879	21409
Church	Rural Residential (exempt well source)	598	900	0
Pilchuck	Existing Tatoosh Water Service (PWS)	103	103	103
Pilchuck	New Urban (with Tatoosh Service)	0	140	140
Pilchuck	New Rural Residential (with Tatoosh Service)	0	297	297
Pilchuck	New Urban (unknown system)	0	1720	10390
Pilchuck	Rural Residential (exempt well source)	1315	1623	763

Table 3-4 summarizes the water demand scenarios for each basin, computed from a combination of existing withdrawals plus anticipated new demands. The current demands shown for the City of Stanwood reflect the Year 1999 withdrawals from well sources within the Church Creek basin and exclude the City's other major source of water supply at Hatt Slough Springs. An undetermined portion of the tabulated withdrawals provide water supply to areas outside of the Church Creek basins.

Table 3-4: Water Demands for "Current", "Future 1" and "Future 2" Land Use Scenarios

Basin	**Water Service**	**Annual Demand in Acre-Feet[1]**		
		Current	Future 1	Future 2
Church	Existing Stanwood Service (PWS)	589	589	589
Church	New Urban	0	1640	7197
Church	Rural Residential (exempt well source)	235	353	0
Pilchuck	Existing Tatoosh Water Service (PWS)	74	74	74
Pilchuck	New Urban (with Tatoosh Service)	0	47	47
Pilchuck	New Rural Residential (with Tatoosh Service)	0	116	116
Pilchuck	New Urban (unknown system)	0	578	3493
Pilchuck	Rural Residential (exempt well source)	516	636	299
Total Demand Met by Public Systems in Both Basins		663	3044	11516
Total Demand Met by Exempt Wells in Both Basins		751	989	299

[1]For annual demands in units of Millions of Gallons, divide Acre-Feet values by 3.07.

3.3.3.2 Locations and Quantities of Source Withdrawals to Meet Demand

Future water demands in urban areas are expected to be satisfied by: (1) fully exercising the underutilized (inchoate) water rights currently held by the City of Stanwood and by the Tatoosh Water Company; (2) interties between the City and Tatoosh; and (3) interties with out-of-basin wholesale purveyors such as the City of Everett. The study assumptions do not limit urban supply to the water service areas as currently defined for the City and Tatoosh; it is presumed that development at urban densities must be accompanied by a public water supply system. This study does not encompass the hydrologic, habitat or biologic effects of withdrawals in other basins used to meet the water demand in the study basins.

Future rural residential water demands within the Tatoosh service district are assumed to be served by the Tatoosh Water Company. All other rural residential demands are assumed to be supplied by exempt wells at the location of use. The exempt well assumptions do not account for possible constraints by Ecology, implemented through proposed instream flow rules, which would set an upper limit on the total number of new exempt wells in the Stillaguamish basin.

Water rights for the City of Stanwood and the Tatoosh water company were reviewed to determine the presently authorized available water supply within the basin. The review assumed that the City of Stanwood will be successful in transferring an existing water right from the Sill Well to the replacement Cedarhome Well. The City of Stanwood has water rights to approximately 5,280 acre-feet per year, but provides water service to an area which is approximately three times greater than the Church Creek sub-area for which demands have been estimated above. For purposes of total demand estimation, one third of the City's water rights (1,760 acre-feet), is assumed to be available to satisfy demands in the Church Creek basin.

The analysis suggests that all of the City of Stanwood's water sources will need to be fully developed for both the Future 1 and Future 2 scenarios. Of the City's sources, only withdrawals from the Bryant and Fure wells are expected to impact Church Creek flows and the amount of reduced flow is estimated to be 2/3 of the withdrawals from these wells. Table 3-5 lists the estimated stream impacts for current conditions and future scenarios. Because these withdrawals are for urban supply, the amounts are assumed to be fully consumptive with no return flow to the stream. In the HSPF model, 90% of the City of Stanwood water withdrawal is taken from the Church-3 subbasin, and 10% is taken from the Church-4 subbasin.

Water rights held by the Tatoosh Water Company are assumed to be the initial source for supplying new urban demands in the study basins via intertie with the City of Stanwood. For the

Table 3-5: Public Water Supply Flow Reduction Effects in Church Creek

Month	Current (cfs)	Future 1& Future 2 (cfs)
Jan	0.40	1.71
Feb	0.42	1.79
Mar	0.47	1.98
Apr	0.45	1.91
May	0.61	3.11
Jun	0.71	3.21
Jul	0.81	3.21
Aug	0.83	3.21
Sept	0.61	2.63
Oct	0.57	2.44
Nov	0.30	1.28
Dec	0.35	1.48

Future 1 scenario, only a portion of the available Tatoosh water rights would need to be exercised to fulfill total urban demands throughout the study basin. For the Future 2 scenario, the Tatoosh water rights would be fully exhausted and the remaining water demand would presumably be met through wholesale purchases from out-of-basin suppliers.

Withdrawals by the Tatoosh Water Company are assumed to be in complete hydraulic continuity with the headwaters of Tributary 80 in the Pilchuck Creek basin. However, a portion of the water withdrawals for rural water users are expected to return to the stream system. Table 3-6 lists the estimated stream impacts for current conditions and the future scenarios before adjustment for return flows.

Table 3-6
Public Water Supply Flow Reduction Effects in Tributary 80, Pilchuck Creek Basin

Month	Current (cfs)	Future 1 (cfs)	Future 2 (cfs)
Jan	0.08	1.28	3.46
Feb	0.08	1.33	3.46
Mar	0.08	1.44	3.46
Apr	0.08	1.39	3.46
May	0.08	1.89	3.46
Jun	0.10	2.28	3.46
Jul	0.21	2.96	3.46
Aug	0.20	2.97	3.46
Sept	0.09	1.93	3.46
Oct	0.08	1.75	3.41
Nov	0.08	0.98	2.23
Dec	0.08	1.12	3.46

Exempt wells are assumed to provide water supply for all rural residential connections outside of the present service district limits of the Tatoosh Water Company. Exempt wells are assumed to be located at the location of use and to include septic systems which provide recharge to groundwater at the location of withdrawal. Table 3-7 and 3-8 list the estimated cumulative effects of exempt well withdrawals on stream flows in the Church and Pilchuck Creek basins, with impacts being limited to the consumptive use portion of total withdrawals. In the HSPF model, the location of the withdrawals is distributed to subbasins with rural residential land uses (Church-2,3,4 and 5 and PilCrk-1a,1b,2,3,4,6,8,9 and 14) depending on the rural housing unit distribution estimated in each scenario.

Table 3-7: Exempt Well Flow Reduction Effects in the Church Creek Basin

Month	Current (cfs)	Future 1 (cfs)	Future 2[1] (cfs)
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	0	0	0
May	0.07	0.10	0
Jun	0.26	0.39	0
Jul	0.85	1.28	0
Aug	0.81	1.22	0
Sept	0.14	0.20	0
Oct	0	0	0
Nov	0	0	0
Dec	0	0	0

[1]All of Church Creek is assumed to be developed at urban densities that require connection to a public water supply. Therefore there are no exempt well sources active under Future 2.

Table 3-8: Exempt Well Flow Reduction Effects in the Pilchuck Creek Basin

Month	Current (cfs)	Future 1 (cfs)	Future 2 (cfs)
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	0	0	0
May	0.15	0.18	0.09
Jun	0.57	0.70	0.33
Jul	1.87	2.30	1.08
Aug	1.78	2.19	1.03
Sept	0.30	0.37	0.17
Oct	0	0	0
Nov	0	0	0
Dec	0	0	0

3.3.4 Return Flows at the Location of Use

As stated earlier, water supply to urban areas in the study basins is assumed to be provided by a public water supply system and uses are assumed to be fully consumptive. All urban areas are assumed to be completely sewered with water being exported to wastewater facilities that discharge to saltwater or freshwater outside of the pilot study basins, and all irrigation use is assumed to be fully consumptive. The analysis ignores the return flows that occur from leaks in the water supply system, flushing of water mains, and non-consumptive outdoor uses, such as vehicle washing and over-watering of lawns. With these assumptions, there are no return flows to the streams from areas developed to urban densities. These areas account for the majority of the total water demand.

Return flows from exempt wells have been addressed by considering only the consumptive portion of total withdrawals as having an impact on basin and stream hydrology. This assumption is appropriate for exempt wells because the location of withdrawal is for practical purposes the same as the location of the return flow.

Significant return flows in the study basins do occur in the Tatoosh Water Company service area, which is predominantly rural and does not drain to a regional wastewater treatment facility. Return flows in the service area were estimated as being equal to the system water supply demand during winter months. The total return flow under current conditions is estimated to be .077 cfs. Under both future scenarios, the return flow is estimated to be 0.15 cfs based on the winter demand for current conditions plus the winter demand of new rural residential service. In the HSPF model, the return flows are routed to subbasins Church-6, PilCrk-2, 4, and 5, (pilot subbasins within the Tatoosh service area) depending on the housing unit distribution estimated in each scenario.

3.4 Hydrology Model Framework

The primary source for hydrologic and temperature statistics for use in EDT is the HSPF model (Hydrologic Simulation Program Fortran). The model developed for the pilot basins includes 23 subbasins, 24 stream reaches and 2 lakes. The subbasins – 6 in Church Creek and 17 in Pilchuck (see Figure 3-8 and Table 3-9 for subbasin and reach layout and details) – were delineated from USGS quadrangle topography and roads datasets;. Hydraulics of the 24 stream reaches were defined using a simple HEC-RAS (HEC, 2004) hydraulic model that was developed using a variety of data sources. The cross-section overbank areas in the western portion of the study area (Pilcrk-3, -2, -1 and all of Church Creek) were defined from LiDAR elevation data provided by the Puget Sound LiDAR consortium. This data has a vertical accuracy on the order of one foot. To the east of Pilchuck-3, LiDAR data was not available and overbank elevations were defined by USGS topographic mapping, which have vertical accuracies on the order of 20-feet. In addition to providing overbank geometry, these data sources also provided the reach slope used in the HSPF model. The instream channel geometry in Church Creek and Pilchuck Creek downstream of PilCrk-9 was defined using channel dimensions provided by Snohomish County staff, and one section was taken from a USGS survey completed in 1983. No data was available upstream of the PilCrk-9 channel, so channel dimensions were estimated based on drainage area.

A stage-storage-discharge relationship was developed for 844-acre Cavanaugh Lake using bathymetry from Wolcott (1973), a USGS topographic map, and an equation for weir flow at the outlet.

Infiltration characteristics of the soils in the basins were determined from surficial geology data from the Natural Resources Conservation Service (NRCS) and wetlands datasets. The NRCS soil classifications (NRCS, 1983 and 1989) were aggregated into soils with hydrologic characteristics of till, outwash, and wetlands type soils. Areas designated as wetlands by Snohomish County and the National Wetlands Inventory dataset were also used to identify wetlands soils.

Table 3-9: HSPF Model Subbasin and Stream Reach Attributes

Subbasin Name	HSPF Reach ID	Corresponding EDT Reach Name	Common Name	Local Sub-basin Area (Miles^2)	Local Subbasin EIA (%)			Reach Length (Miles)	Reach Slope (ft/ft)
					Current	Future1	Future2		
Church-1	101	Church-1	Church Creek	0.9	12.3	18.1	18.7	1.313	0.0001
Church-2	102	Church-2	Church Creek	1.0	12.5	23.7	32.8	0.854	0.0089
Church-3	103	Church-3	Church Creek	1.4	9.5	22.0	27.0	1.557	0.0182
Church-4	104	Church-4	Church Creek	3.4	3.0	8.5	21.1	3.682	0.0111
Church-5	105	Church-5	Freedom Creek	2.8	2.3	5.9	17.2	4.172	0.0049
Church-6	106	N/A	Freedom Creek	1.9	7.6	17.4	23.4	3.118	0.0097
Church Sub-Total				11.4	6	13	22		
PilCrk-1a	201	PilCrk-Main1	Pilchuck Creek	1.4	6.3	15.4	22	2.216	0.0017
PilCrk-1b	200	PilCrk-Sub1	Pilchuck Creek trib.	3.4	6.3	15.5	22	2.707	0.0140
PilCrk-2	202	PilCrk-Sub2	Pilchuck Creek trib.	2.5	2.3	5.7	5.7	3.000	0.0335
PilCrk-3	203	PilCrk-Main2	Pilchuck Creek	4.1	3.3	6.7	6.7	2.650	0.0021
PilCrk-4	204	PilCrk-Sub4	Pilchuck Creek trib.	2.6	2.3	5.1	5.1	4.000	0.0237
PilCrk-5	205	PilCrk-Sub5	Pilchuck Creek trib.	1.9	2.5	5.3	5.3	3.000	0.0253
PilCrk-6	206	PilCrk-Main3	Pilchuck Creek	1.5	1.5	3.3	3.3	2.173	0.0052
PilCrk-7	207	PilCrk-Sub7	Pilchuck Creek trib.	1.2	0.1	1.1	1.1	0.500	0.0189
PilCrk-8	208	PilCrk-Sub8	Tributary-80	4.4	1.1	2.4	2.4	3.989	0.0047
PilCrk-9	209	PilCrk-Main4	Pilchuck Creek	7.1	0.5	1.2	1.2	5.252	0.0108
PilCrk-10	210	N/A	Pilchuck Creek	5.6	0.7	1.3	1.3	1.716	0.0110
PilCrk-11	211	N/A	Crane Creek	4.1	0.1	0.8	0.8	3.806	0.0945
PilCrk-12	212	N/A	Pilchuck Creek	4.7	0.9	1.4	1.4	4.001	0.0218
PilCrk-13	213	N/A	Bear Creek	8.2	0.0	0.7	0.7	4.430	0.0855
PilCrk-14	214	N/A	Lake Creek	N/A	N/A	N/A	N/A	1.756	0.0108
PilCrk-15	215	N/A	Pilchuck Creek	5.4	0.2	0.8	0.8	2.494	0.0152
PilCrk-16	216	N/A	Pilchuck Creek	8.6	0.2	0.7	0.7	3.482	0.0816
PilCrk-14	264	N/A	Lake Cavanaugh	9.3	1.1	1.9	1.9	N/A	N/A
Pilchuck Sub-Total				76.0	1	3	3		

Note: PilCrk-1 was split to aid EDT model and land cover attributes were applied uniformly to subbasins PilCrk-1a and PilCrk-1b

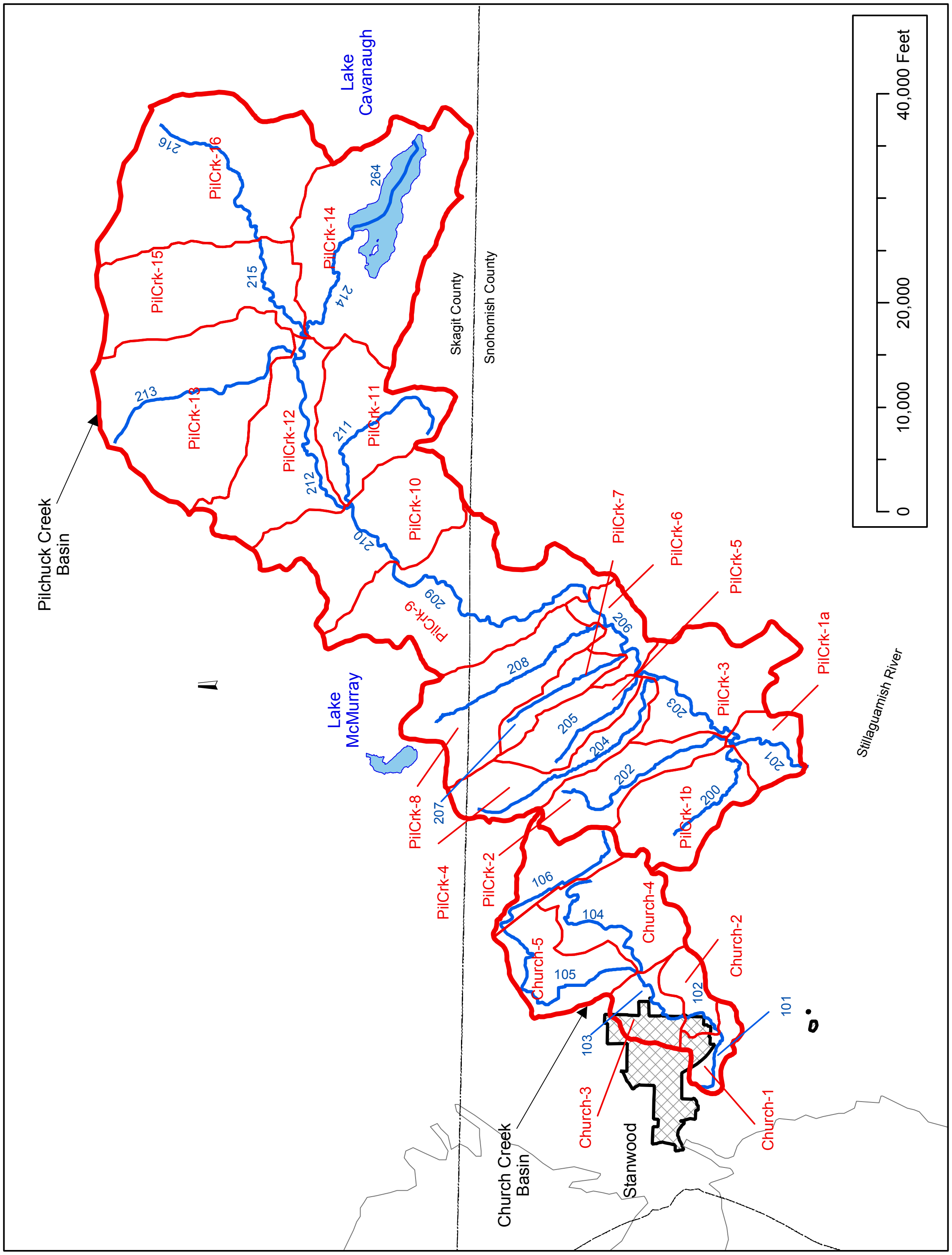

Figure 3-7: HSPF Model Subbasins and Reaches

Two precipitation gage records were used as inputs for HSPF simulations spanning water years 1949 through 2002. A gage record at Everett (elevation 60 ft, annual precipitation 37 inches) was used for study area elevations below 500 feet and a record at Darrington was used for all higher areas. Missing data at Darrington (550 ft, 75 inches) was filled with data from Marblemount (348 ft, 68 inches). Precipitation multipliers derived from Oregon Climate Center reported annual average totals were calculated and applied for all areas to scale the gaged precipitation to higher elevations. Some data at the Snohomish County Arlington gage was used for calibration during water years 2002 and 2003.

Snow accumulation and melt, as well as stream water temperature, were included in the model. This required air temperature data appropriate for the elevations of lands within the modeled basins. To achieve this, the study area was broken up into nine elevation bands of 500 feet each that are used by the model to lapse observed air temperatures at a temperature gage location to elevation bands in the watershed. The elevation bands shown in Figure 3-8 were used to lapse the Everett air temperature record from 1949 to 2002. In addition to air temperature, water temperature simulation also requires meteorological datasets for solar radiation, cloud cover, dew point temperature, and wind. These input time-series are made available by the EPA for 1970 through 1995 at the Marblemount ranger station, located 30 miles to the northeast. Darrington does not have meteorological data available.

3.4.1 Hydrology Model Calibration

A limited amount of calibration was performed on the HSPF model to ensure that discharge and temperature results were being reasonably simulated by the model. Discharge calibration was performed for current watershed conditions using mean daily discharges at USGS gage 12168500 “Pilchuck Creek near Bryant”, located at the downstream boundary of subbasin PilCrk-9 in the model. The record at this gage is continuous from October 1952 through April of 1976. After minor calibration, the total simulated volume and monthly mean volume matched observed conditions well, and instantaneous peaks were reasonable given the lack of basin-specific precipitation data. Final calibration differed only slightly from regionally accepted parameters specified by Dinacola (1990). The only discharge gaging in Church Creek has recently been started by the Washington State Department of Ecology at gage 05L070CH, Church Creek on Jensen Road located in subbasin Church-3. Unfortunately the latest precipitation data readily available in the area does not overlap with this time period, so a detailed calibration was not possible for Church Creek. As a result, the hydrologic parameters were set similarly to those used by Dinacola (1990).

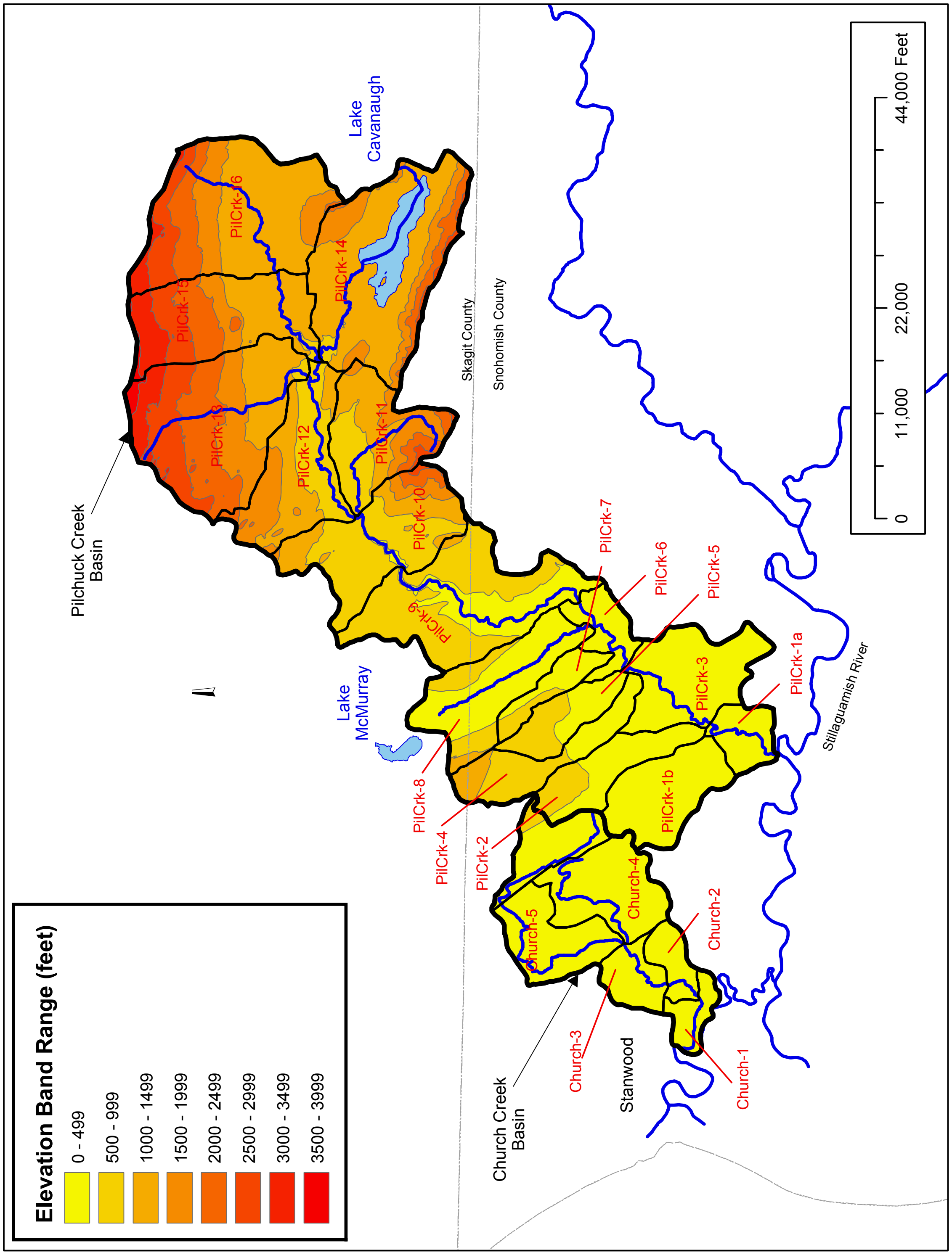

Figure 3-8: Elevation band ranges used in HSPF model

Simulated water temperatures were calibrated in Church Creek and to a lesser extent on Pilchuck Creek. During temperature calibration simulations, current land-cover conditions were simulated and the Church Creek streams were assumed to have only 20 percent vegetative shading. Due to a lack of water temperature data available during the simulation time period, the project team created a substitute record by generating a correlation between the air and water temperatures observed at Ecology gage 05L070CH on Church Creek, which has been in operation for approximately the last 1.5 years. This correlation was then applied to the air temperatures observed at Everett gage 2675 between 1949 and 2002 to create a time-series of Church Creek water temperatures that could be used for calibration. The model was calibrated using daily average air temperatures and placed a higher priority on high summer temperatures than lower winter temperatures. The modeled water temperatures were most sensitive to in-reach heat-balance parameters and less sensitive to parameters controlling the temperature of watershed runoff. At the Pilchuck USGS gage 12168500, temperature data was available from 1957 through 1972; simulated temperatures compared well with these data during warm summer months.

3.5 Scenario Simulations and Results

Production runs of the HSPF model were performed using the same period of record for all four scenarios. With the exception of water temperature, all statistics were calculated from 53 years of simulation record spanning water year 1949 through water year 2002, the length of the Everett and Darrington rainfall records. Water temperature calculations are based on 24 years of simulation from water year 1971 through 1995, the length of the meteorological data at Marblemount.

The hydrologic conditions that are captured with the HSPF model are depicted well by some of the input parameters required for input into EDT in Section 4. These were calculated following guidelines (Lestelle, 2004) and many are presented here in some form. By design, the HSPF model has corresponding subbasins and routing reaches at most of the reach locations to be modeled in EDT. In Tables 3-10 through 3-17, both the EDT reach name and the HSPF routing reach number are included. See Figure 3-9 below for a schematic of the EDT model reach locations.

3.5.1 Summer Base Flow

One of the most meaningful statistics from the hydrologic analysis that can be carried forward into the EDT model is summer base flow. Lestelle (2004) recommends that this be characterized by the average 45-60 day discharge during the driest portion of the year. Preliminary results of HSPF modeling indicated that this approach to low flow characterization results in an erroneous conclusion that urbanization increases base flow. The reason for this is that impervious area delivers a high percentage of summer rainfall to stream channels. This results in a pulse of discharge in the stream followed by very low base flows until the next summer storm occurs. The average discharge over 45-60 days is higher for an intensely urbanized watershed than for a forested watershed which uses up some of the rainfall as evapo-transpiration. Yet, true base flows between storms are lower with urbanization. In order to avoid this problem and better represent the low flow conditions experienced by biota in the streams, the 45-60 average low flow was replaced by the average annual 7-day minimum flow which more accurately characterizes conditions during inter-storm periods in urbanized basins. Values of average 7-day minimum flows presented in Table 3-10 illustrate the effects of reduced base flow associated with urbanization. Church Creek reaches 1-4 show the largest impact illustrating the dominant effect of water withdrawals over land cover change. Church-3 is the reach most impacted by the City of Stanwood water withdrawal, which reduces the average annual 7-day low flow by 57% under current conditions and makes a dry creek a common occurrence under both future scenarios. Church-4 differs from Church-3 in that the exempt well withdrawals that are taken in the Current and Future 1 scenarios are converted to public supplies. This causes a net gain in Future 2 compared to Future 1 for this reach. In Pilchuck Creek, the mainstem low flow statistics stay relatively constant throughout all of the scenarios. This is consistent with what would be expected given the large non-urbanized watershed buffering the impact of water withdrawals and urbanization in the lower portions of the basin. Under current conditions, minimum flows in PilCrk-Sub8 (a.k.a. Tributary-80) have not declined as a result of Tatoosh Water Service's small withdrawals, but demands in either Future 1 or Future 2 are projected to regularly cause the tributary to go dry during the summer.

A secondary effect on minimum flows that should be noted is that the model predicts moderate increases in minimum flows as forests are converted to other cover as long as this is not accompanied by significant water withdrawals. This is the so-called "water harvesting" effect associated with the replacement of forest cover by less consumptive vegetation (barring irrigation). Additionally, in rural areas on septic systems served by Tatoosh, base flows may be augmented by return flows. This gain comes at the expense of significant base flow depletion in Tributary-80 where the water is withdrawn.

For each reach, scenarios that cause an increase in base flow of greater 50% over template conditions are shown in bold italics, while those that cause a decrease of greater than a 50% are shaded. As shown in Table 3-10, compared to template, some pilot study reaches are big gainer

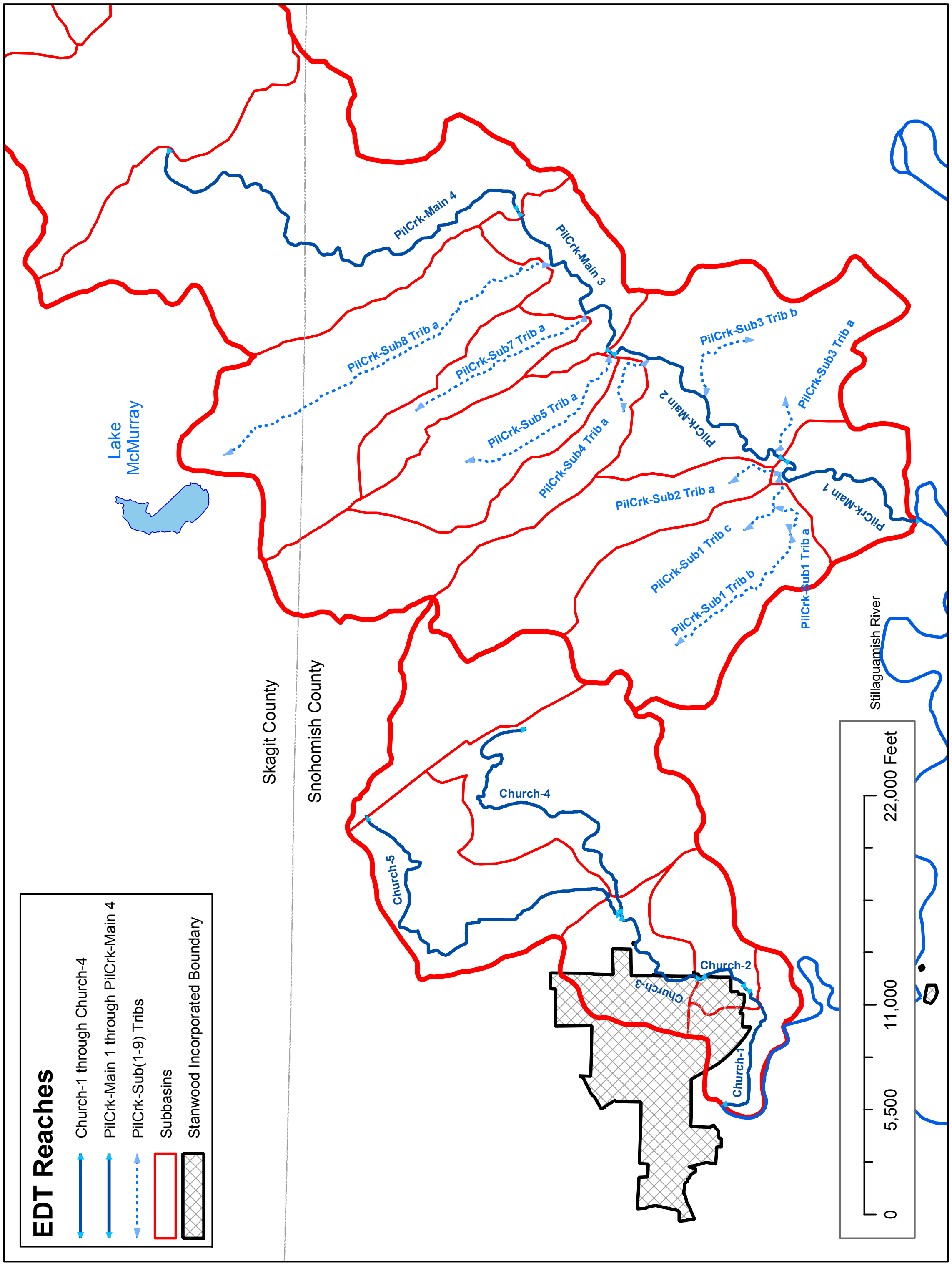

Figure 3-9: EDT Model Reaches, View Zoomed to Church and Lower Pilchuck Basins

Table 3-10: Average of Annual 7-day Minimum Flows (cfs)

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	1.18	0.70	0.21	0.27
Church-2	102	1.08	0.52	0.05	0.13
Church-3	103	0.97	0.42	0.00	0.00
Church-4	104	0.36	0.34	0.16	0.26
Church-5	105	0.48	0.62	0.50	0.66
PilCrk-Main1	201	9.52	11.71	11.24	11.81
PilCrk-Sub1 Trib a	200	0.38	0.48	0.43	0.45
PilCrk-Sub1 Trib b	200	0.38	0.48	0.43	0.45
PilCrk-Sub1 Trib c	200	0.38	0.48	0.43	0.45
PilCrk-Sub2 Trib a	202	0.26	0.35	0.33	***0.40***
PilCrk-Sub3 Trib a	202	0.26	0.35	0.33	***0.40***
PilCrk-Sub3 Trib b	202	0.26	0.35	0.33	***0.40***
PilCrk-Main2	203	8.59	10.52	10.11	10.55
PilCrk-Sub4 Trib a	204	0.26	0.38	***0.40***	***0.42***
PilCrk-Sub5 Trib a	205	0.17	0.30	0.32	0.32
PilCrk-Main3	206	7.55	9.15	8.65	8.85
PilCrk-Sub7	207	0.12	0.17	***0.18***	***0.18***
PilCrk-Sub8	208	0.48	0.56	0.00	0.00
PilCrk-Main4	209	6.65	8.05	7.77	8.29

3.5.2 Maximum Water Temperatures

Simulation of temperatures was performed to capture both the effects of flow reduction on in-channel water temperature and changes in runoff temperature resulting from urbanization. As discussed earlier, the shade offered by riparian vegetation was held constant through all four scenarios. Table 3-11 summarizes the average number of consecutive days in the month of August that instream temperatures exceeded thresholds of 61, 72, and 77 degrees F. These are temperature thresholds used to evaluate EDT attributes for maximum temperature in EDT (Lestelle, 2004). The statistic was also calculated for a threshold of 50 degrees, but all reaches exceeded the temperature throughout the month of August in all four scenarios. The results tend to show an increasing number of days above the threshold with increasing development; this is particularly the case for the 72 and 77 degree thresholds. A similar statistic reported in Table 3-12 summarizes the average total number of days (whether consecutive or not) above 72 F. Also evident in the results is that lower flows allow water temperatures to get closer to air temperature. Reaches with the lowest 7- day average annual minimum flow in Table 3-10 are also the reaches with the highest number of consecutive days exceeding the three temperature thresholds. Thus when minimum flows go up or down from scenario to scenario, a corresponding change in duration of high temperature events may occur.

Table 3-11: Average Number of Consecutive August Days above Threshold

EDT Reach	HSPF Reach	Threshold (Degrees F)											
		61 Degrees				72 Degrees				77 Degrees			
		T	C	F1	F2	T	C	F1	F2	T	C	F1	F2
Church-1	101	0.1	3.2	6.6	6.9	0.0	0.1	0.6	1.0	0.0	0.1	0.6	1.0
Church-2	102	0.1	5.0	9.3	11.9	0.0	0.4	1.1	1.3	0.0	0.4	1.1	1.3
Church-3	103	0.1	5.4	12.3	12.0	0.0	0.4	1.5	1.3	0.0	0.4	1.5	1.3
Church-4	104	7.1	7.8	10.4	9.1	0.6	0.9	1.0	1.0	0.6	0.9	1.0	1.0
Church-5	105	0.1	0.5	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Main1	201	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Sub1 Trib a	200	0.4	1.3	2.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Sub1 Trib b	200	0.4	1.3	2.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Sub1 Trib c	200	0.4	1.3	2.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Sub2 Trib a	202	11.9	11.7	11.3	11.4	1.1	1.3	1.4	1.3	1.1	1.3	1.4	1.3
PilCrk-Sub3 Trib a	202	11.9	11.7	11.3	11.4	1.1	1.3	1.4	1.3	1.1	1.3	1.4	1.3
PilCrk-Sub3 Trib b	202	11.9	11.7	11.3	11.4	1.1	1.3	1.4	1.3	1.1	1.3	1.4	1.3
PilCrk-Main2	203	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Sub4 Trib a	204	11.9	11.6	11.3	10.9	1.2	1.1	1.1	1.0	1.2	1.1	1.1	1.0
PilCrk-Sub5 Trib a	205	13.1	12.6	12.3	12.3	1.5	1.4	1.5	1.4	1.5	1.4	1.5	1.4
PilCrk-Main3	206	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PilCrk-Sub7	207	8.6	8.5	8.5	8.5	1.2	1.2	1.3	1.3	1.2	1.2	1.3	1.3
PilCrk-Sub8	208	6.0	5.5	8.6	8.6	0.6	0.6	1.3	1.3	0.6	0.6	1.3	1.3
PilCrk-Main4	209	0.3	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: All reaches exceeded the 50 degree threshold on all August days in all scenarios
T = Template, C = Current, F1 = Future1 and F2 = Future2

Table 3-12: Average Total August Days above 72 degrees F

EDT Reach	HSPF RCH	Template	Current	Future1	Future2
Church-1	101	0.0	0.3	1.0	2.1
Church-2	102	0.0	0.7	2.0	2.4
Church-3	103	0.0	0.8	2.5	2.4
Church-4	104	1.0	1.3	1.8	1.6
Church-5	105	0.0	0.0	0.2	0.0
PilCrk-Main1	201	0.0	0.0	0.0	0.0
PilCrk-Sub1 Trib a	200	0.0	0.0	0.1	0.0
PilCrk-Sub1 Trib b	200	0.0	0.0	0.1	0.0
PilCrk-Sub1 Trib c	200	0.0	0.0	0.1	0.0
PilCrk-Sub2 Trib a	202	2.2	2.3	2.3	2.3
PilCrk-Sub3 Trib a	202	2.2	2.3	2.3	2.3
PilCrk-Sub3 Trib b	202	2.2	2.3	2.3	2.3
PilCrk-Main2	203	0.0	0.0	0.0	0.0
PilCrk-Sub4 Trib a	204	2.2	2.1	2.2	2.0
PilCrk-Sub5 Trib a	205	2.6	2.4	2.5	2.5
PilCrk-Main3	206	0.0	0.0	0.0	0.0
PilCrk-Sub7	207	1.5	1.5	1.6	1.6
PilCrk-Sub8	208	0.8	0.8	1.6	1.6
PilCrk-Main4	209	0.0	0.0	0.0	0.0

3.5.3 Stage Ramping Rate

EDT requires a stream level ramping rate statistic to characterize the impact of fluctuations caused by hydropower operations or flashy stream flow in highly urbanized watersheds. High ramping rates may strand salmon or otherwise degrade their habitat. Based on guidance provided by Lestelle (2004), HSPF simulated hourly stages were used to calculate the average maximum daily ramping rate in the most variable month of the year. This is November for the Church and Pilchuck Creek basins. The ramping rates in both of the study basins, summarized in Table 3-13, are lower than 2 inches per hour for all reaches and scenarios, which suggests that ramping will not be a significant factor distinguishing scenarios in the EDT model.

Table 3-13: November Average of Maximum Daily Ramping Rate (in/hr)

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	0.168	0.505	0.842	1.202
Church-2	102	0.041	0.178	0.313	0.477
Church-3	103	0.089	0.314	0.541	0.783
Church-4	104	0.043	0.129	0.238	0.407
Church-5	105	0.057	0.175	0.294	0.453
PilCrk-Main1	201	0.343	0.403	0.452	0.475
PilCrk-Sub1 Trib a	200	0.06	0.281	0.475	0.607
PilCrk-Sub1 Trib b	200	0.06	0.281	0.475	0.607
PilCrk-Sub1 Trib c	200	0.06	0.281	0.475	0.607
PilCrk-Sub2 Trib a	202	0.035	0.073	0.11	0.11
PilCrk-Sub3 Trib a	Insufficient Data				
PilCrk-Sub3 Trib b	Insufficient Data				
PilCrk-Main2	203	0.279	0.313	0.336	0.337
PilCrk-Sub4 Trib a	204	0.054	0.088	0.114	0.114
PilCrk-Sub5 Trib a	205	0.035	0.068	0.088	0.088
PilCrk-Main3	206	0.221	0.252	0.258	0.259
PilCrk-Sub7	207	0.023	0.03	0.035	0.035
PilCrk-Sub8	208	0.05	0.084	0.11	0.116
PilCrk-Main4	209	0.224	0.254	0.264	0.263

3.5.4 Discharge Flashiness

Similar to the maximum ramping rate statistic, but more applicable to the study area, is the intra annual flow variability statistic, TQmean. This statistic characterizes stream flashiness during storm flow and is calculated as the ratio of the number of days in a year on which average discharge exceeds the mean annual discharge for that year. The results of average annual TQmean calculations are presented in Table 3-14. In flashy systems, a higher ratio of the annual flow volume occurs in short-duration pulses well above the annual mean, leaving much longer periods that fall below the mean compared to non-flashy systems. The higher the TQmean value, the less flashy the system is. Table 3-15 presents TQmean as a ratio of TQmean values under Template conditions against the TQmean values in the remaining scenarios. This presentation of the statistic shows that the urbanizing reaches in Church and lower Pilchuck Creek will become flashier with increases in development.

Table 3-14: TQmean Statistic of Stream Flashiness (%)

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	33.61	32.97	31.71	29.71
Church-2	102	33.64	32.96	31.31	28.65
Church-3	103	33.69	32.98	31.56	28.87
Church-4	104	33.12	32.25	30.84	27.85
Church-5	105	33.87	33.21	32.10	29.87
PilCrk-Main1	201	34.61	34.11	33.95	33.84
PilCrk-Sub1 Trib a	200	33.58	32.47	29.98	27.89
PilCrk-Sub1 Trib b	200	33.58	32.47	29.98	27.89
PilCrk-Sub1 Trib c	200	33.58	32.47	29.98	27.89
PilCrk-Sub2 Trib a	202	32.78	32.30	31.76	31.76
PilCrk-Sub3 Trib a	202	32.78	32.30	31.76	31.76
PilCrk-Sub3 Trib b	202	32.78	32.30	31.76	31.76
PilCrk-Main2	203	34.37	33.89	33.76	33.67
PilCrk-Sub4 Trib a	204	31.52	31.06	30.87	30.87
PilCrk-Sub5 Trib a	205	31.59	30.97	30.69	30.69
PilCrk-Main3	206	34.27	33.84	33.76	33.67
PilCrk-Sub7	207	32.25	32.00	31.84	31.84
PilCrk-Sub8	208	33.45	33.14	32.99	32.97
PilCrk-Main4	209	34.17	33.75	33.69	33.68

Table 3-15: TQmean Statistic Relative to Template Scenario

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	1.00	0.98	0.94	0.88
Church-2	102	1.00	0.98	0.93	0.85
Church-3	103	1.00	0.98	0.94	0.86
Church-4	104	1.00	0.97	0.93	0.84
Church-5	105	1.00	0.98	0.95	0.88
PilCrk-Main1	201	1.00	0.99	0.98	0.98
PilCrk-Sub1 Trib a	200	1.00	0.97	0.89	0.83
PilCrk-Sub1 Trib b	200	1.00	0.97	0.89	0.83
PilCrk-Sub1 Trib c	200	1.00	0.97	0.89	0.83
PilCrk-Sub2 Trib a	202	1.00	0.99	0.97	0.97
PilCrk-Sub3 Trib a	202	1.00	0.99	0.97	0.97
PilCrk-Sub3 Trib b	202	1.00	0.99	0.97	0.97
PilCrk-Main2	203	1.00	0.99	0.98	0.98
PilCrk-Sub4 Trib a	204	1.00	0.99	0.98	0.98
PilCrk-Sub5 Trib a	205	1.00	0.98	0.97	0.97
PilCrk-Main3	206	1.00	0.99	0.99	0.98
PilCrk-Sub7	207	1.00	0.99	0.99	0.99
PilCrk-Sub8	208	1.00	0.99	0.99	0.99
PilCrk-Main4	209	1.00	0.99	0.99	0.99

3.5.5 Peak Annual Discharge

A common method for characterizing the effect of urbanization and land cover change on stream flow is through shifts in flood frequency curve. EDT utilizes changes in the magnitude of the 2-year peak annual flow to characterize changes in peak discharge of a given scenario compared to template conditions. Tables 3-16 and 3-17 present 2-year peak discharge estimates and factors of change in 2-year peak discharge compared to template conditions. Values indicating increases of 50% or more are shaded in Table 3-17 for illustrative purposes. All values were derived from frequency analysis of the annual peaks generated by the HSPF model. The Church Creek reaches and the westernmost Pilchuck Creek tributary system (PilCrk-Sub1) exhibit the largest increases. Increases in peak discharge on the mainstem of Pilchuck Creek predicted by the model are much more moderate, ranging from 7 to 10%. Rural Pilchuck Creek tributaries draining rural-use or combined rural- and forest-use subbasins also exhibit increases in peak flow that are intermediate between the results for Church Creek and PilCrk-Sub1 and the Pilchuck Creek mainstem.

Table 3-16: 2-year Peak Annual Flow Estimates (cfs)

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	227	345	442	549
Church-2	102	241	417	572	763
Church-3	103	219	367	506	691
Church-4	104	86	151	214	341
Church-5	105	103	159	207	282
PilCrk-Main1	201	2920	3150	3210	3220
PilCrk-Sub1 Trib a	200	77	158	263	346
PilCrk-Sub1 Trib b	200	77	158	263	346
PilCrk-Sub1 Trib c	200	77	158	263	346
PilCrk-Sub2 Trib a	202	55	75	95	95
PilCrk-Sub3 Trib a	202	55	75	95	95
PilCrk-Sub3 Trib b	202	55	75	95	95
PilCrk-Main2	203	2840	3060	3090	3090
PilCrk-Sub4 Trib a	204	84	104	118	118
PilCrk-Sub5 Trib a	205	50	66	75	75
PilCrk-Main3	206	2730	2920	2940	2940
PilCrk-Sub7	207	28	31	33	33
PilCrk-Sub8	208	97	121	135	135
PilCrk-Main4	209	2750	2930	2950	2950

Note: Peaks estimated via frequency analysis using Log Pearson-III distribution

Table 3-17: Estimated Factors of Increase in 2-year Peak Annual Flow

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	1.00	1.52	1.95	2.42
Church-2	102	1.00	1.73	2.37	3.17
Church-3	103	1.00	1.68	2.31	3.16
Church-4	104	1.00	1.76	2.49	3.97
Church-5	105	1.00	1.54	2.01	2.74
PilCrk-Main1	201	1.00	1.08	1.10	1.10
PilCrk-Sub1 Trib a	200	1.00	2.05	3.42	4.49
PilCrk-Sub1 Trib b	200	1.00	2.05	3.42	4.49
PilCrk-Sub1 Trib c	200	1.00	2.05	3.42	4.49
PilCrk-Sub2 Trib a	202	1.00	1.36	1.73	1.73
PilCrk-Sub3 Trib a	202	1.00	1.36	1.73	1.73
PilCrk-Sub3 Trib b	202	1.00	1.36	1.73	1.73
PilCrk-Main2	203	1.00	1.08	1.09	1.09
PilCrk-Sub4 Trib a	204	1.00	1.24	1.40	1.40
PilCrk-Sub5 Trib a	205	1.00	1.32	1.50	1.50
PilCrk-Main3	206	1.00	1.07	1.08	1.08
PilCrk-Sub7	207	1.00	1.11	1.18	1.18
PilCrk-Sub8	208	1.00	1.25	1.39	1.39
PilCrk-Main4	209	1.00	1.07	1.07	1.07

3.5.6 Spawning Gravel Scour

The potential for spawning gravel scour was estimated using average bed shear stress. Basically, bed shear stress represents the tangential force per unit area exerted by stream flow on the channel bed. The approach taken was to define a hypothetical scour event as a day on which average reach bed shear exceeds the critical shear stress necessary to move relatively large spawning gravel. The size selected was one standard deviation higher than the median spawning gravel size observed to be preferred by coho and Chinook salmon (Kondolf and Wolman, 1993). For this study, shear stress thresholds applied were 0.66 lbs/sq. ft (coho) corresponding to a gravel size of approximately 30 mm and 0.99 lbs/ft^2, corresponding to the critical shear necessary to move 45 mm gravel. The smaller gravel size (30 mm) represents the upper end of the range typically utilized by coho while the larger size corresponds to the upper end of the range typically preferred by Chinook. The coho threshold was applied in Church Creek and the Pilchuck Creek tributaries and the Chinook threshold was applied to the Pilchuck Creek mainstem.

The tabulation shown in Table 3-17 shows that differences between reaches are much larger than differences between scenarios for a reach. The differences between reaches are associated with average reach stream gradient. Steeper reaches such as Church-3 and the Pilchuck tributaries 4 and 5 have higher shear stresses than the lower gradient tributaries and mainstem reaches. Average gradient is used as an approximation for friction slope in the shear stress calculations. In reality, spawning gravel scour potential is a complex phenomenon that depends on local stream velocities and may be only roughly correlated with average bed slope over reaches as long as those used in this study. Probably, the most meaningful use of the values in Table 3-17 would be to interpret the ratios of values for a given scenario to template conditions as rough indicators of change in scour potential within the reach cause by changes in erosive flow durations. On this basis, the results suggest that a few study reaches (e.g. Church-2, PilCrk-Sub1 Tributary) are susceptible to significant increases in spawning gravel scour events based on the assumed criteria.

Table 3-18
BdScour, Average Days with Daily Average Shear Stresses above Threshold (lbs/ft^2)

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	0.0	0.0	0.0	0.0
Church-2	102	1.7	2.6	3.1	3.9
Church-3	103	83.6	91.9	87.1	84.3
Church-4	104	0.1	0.3	0.3	0.5
Church-5	105	0.0	0.0	0.0	0.0
PilCrk-Main1	201	0.0	0.0	0.0	0.0
PilCrk-Sub1 Trib a	200	5.3	6.9	8.4	9.2
PilCrk-Sub1 Trib b	200	5.3	6.9	8.4	9.2
PilCrk-Sub1 Trib c	200	5.3	6.9	8.4	9.2
PilCrk-Sub2 Trib a	202	115.1	122.4	123.5	123.6
PilCrk-Sub3 Trib a	N/A	Insufficient Data			
PilCrk-Sub3 Trib b	N/A	Insufficient Data			
PilCrk-Main2	203	0.0	0.0	0.0	0.0
PilCrk-Sub4 Trib a	204	114.9	120.3	120.8	120.8
PilCrk-Sub5 Trib a	205	106.8	113.6	114.5	114.7
PilCrk-Main3	206	0.0	0.0	0.0	0.0
PilCrk-Sub7	207	42.9	44.9	45.9	45.9
PilCrk-Sub8	208	0.0	0.0	0.0	0.0
PilCrk-Main4	209	76.8	78.8	79.0	79.0

Note: Threshold set at 0.66 for all Church Creek reaches and Pilchuck Creek tributaries and 0.99 for Pilchuck Creek mainstem reaches

3.5.7 Ratio of 2-year Peak Annual Flow to Winter Base Flows

This ratio is used in the Habitat Quality Index (May, et al., 1997) to assess the potential for sediment load impacts. It is determined by dividing the 2-year peak annual flow values for each reach and scenario shown in Table 3-16 by the corresponding winter base flow. Winter base flow was estimated as the average of the 80% and 95% exceedance flow level during the season extending from November 1 through March 31. One exception to this method for calculating the winter base flow was made for Tributary 80 in Pilchuck Subbasin 8. The purpose of normalizing the peak flow by the winter base flow is to create a basis for comparing the size of flood flows among different stream reaches of the same stream system, different stream systems, or the same stream reach under different land use scenarios. Under the Future 2 scenario the 95% winter exceedance flow for Tributary 80 is much smaller than for the other scenarios. Since the purpose of this statistic is to characterize the sediment producing potential of peak flows and not to indicate reductions in base flows, only the 80% exceedance level was used to calculate base flows for this reach. Table 3-19 summarizes the winter base flow results. The peak flow to winter base flow ratio utilized in the index method is shown in Table 3-20.

Table 3-19
Winter Base Flows (cfs)

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	13.6	11.4	9.9	10.1
Church-2	102	11.9	9.9	8.6	13.6
Church-3	103	8.8	10.4	9.0	7.5
Church-4	104	3.2	4.0	3.4	2.9
Church-5	105	4.6	5.9	5.4	5.1
PilCrk-Main1	201	186.2	186.2	186.2	186.2
PilCrk-Sub1 Trib a	200	3.2	4.0	4.0	3.4
PilCrk-Sub1 Trib b	200	3.2	4.0	4.0	3.4
PilCrk-Sub1 Trib c	200	3.2	4.0	4.0	3.4
PilCrk-Sub2 Trib a	202	3.2	3.4	3.4	3.4
PilCrk-Sub3 Trib a	202	3.2	3.4	3.4	3.4
PilCrk-Sub3 Trib b	202	3.2	3.4	3.4	3.4
PilCrk-Main2	203	163.7	163.7	163.7	163.7
PilCrk-Sub4 Trib a	204	4.0	4.0	4.0	4.0
PilCrk-Sub5 Trib a	205	2.4	2.6	2.4	2.6
PilCrk-Main3	206	144.0	150.8	150.8	144.0
PilCrk-Sub7	207	1.5	1.7	1.7	1.7
PilCrk-Sub8	208	5.9	6.2	7.0	6.0
PilCrk-Main4	209	144.0	144.0	144.0	144.0

Table 3-20
Ratio of 2-year Peak Annual Flow to Winter Base Flow

EDT Reach Name	HSPF Reach	Template	Current	Future1	Future2
Church-1	101	16.6	30.3	44.6	54.1
Church-2	102	20.2	42.1	66.3	55.9
Church-3	103	24.8	35.4	56.0	92.3
Church-4	104	26.5	38.1	63.2	118.4
Church-5	105	22.3	27.0	38.6	55.5
PilCrk-Main1	201	15.7	16.9	17.2	17.3
PilCrk-Sub1 Trib a	200	23.7	39.9	66.4	102.2
PilCrk-Sub1 Trib b	200	23.7	39.9	66.4	102.2
PilCrk-Sub1 Trib c	200	23.7	39.9	66.4	102.2
PilCrk-Sub2 Trib a	202	17.2	22.1	28.1	28.1
PilCrk-Sub3 Trib a	202	17.2	22.1	28.1	28.1
PilCrk-Sub3 Trib b	202	17.2	22.1	28.1	28.1
PilCrk-Main2	203	17.3	18.7	18.9	18.9
PilCrk-Sub4 Trib a	204	21.2	26.2	29.8	29.8
PilCrk-Sub5 Trib a	205	20.5	25.4	30.8	28.8
PilCrk-Main3	206	19.0	19.4	19.5	20.4
PilCrk-Sub7	207	18.6	18.3	19.4	19.4
PilCrk-Sub8	208	16.5	19.5	19.4	22.6
PilCrk-Main4	209	19.1	20.4	20.5	20.5