DRAFT
INITIAL WATERSHED ASSESSMENT
WATER RESOURCES INVENTORY AREA 8
CEDAR-SAMMAMISH WATERSHED

Open-File Technical Report 95-07

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ABSTRACT

The Cedar-Sammamish Watershed Water Resources Inventory Area (WRIA) 8 is located primarily in King County. This 692-square mile watershed is comprised of two major subbasins (the Cedar River and the Sammamish River systems) which converge into Lake Washington. The watershed is typified by a large number of small lakes, ponds, and wetlands. The WRIA receives an average precipitation ranging from 38 to 102 inches per year, although in the past 15 to 20 years the watershed has experienced less than average precipitation as has been typical of the trends observed at other rain gages in western Washington.

The 1990 census population for the principal cities indicates more than 840,000 people reside within the incorporated areas in WRIA 8. All areas of the watershed are experiencing rapid population growth, and are predicted to continue growing, affecting both land use and water consumption. As area population grows, consumptive use of water will increase, particularly if alternative sources are not sufficient to meet demands. As surface waters are closed to development, increased demands will be placed on ground water sources.

The estimated total quantity of surface water rights and claims for consumptive use in the Cedar-Sammamish Watershed amount to an instantaneous quantity (Qi) of 1,145 cubic feet per second (cfs) and an annual quantity (Qa) of 481,837 acre-feet/year. This quantity is almost four times greater than the estimated quantity of ground water rights and claims which amount to a total Qi of 332.5 cfs and a Qa of 93,533 acre-feet/year. The growth in ground water rights since the 1950's has been relatively constant, while the growth in surface water rights has increased more sporadically. Currently, there are 55 pending applications for ground water rights and 7 pending applications for surface water rights for a total of 136.7 cfs.

Chapter 173-508 of the Washington Administrative Code (WAC) closed many of the surface water bodies in WRIA 8 to further withdrawal including the entire Lake Washington drainage above the Chittenden Locks. Normal instream flows and critical year instream flows were established on the Cedar River at the USGS gage station at Renton. Based on historical flow data for 1980 to 1993, established instream flows for normal year flow have a greater than ten percent probability of not being met for most of the year in the Cedar River at Renton. Based on the exceedence curves for the same period of record at the Renton Gage, there is nearly a 50 percent probability that established normal year minimum flows will not be met from July through October. In the Sammamish River and Issaquah Creek, there is also evidence indicating declining low summer flows over the past 20 years.

The declining trend in static ground water levels in the Issaquah Valley Aquifer indicates that the aquifer is being dewatered. There are also serious ground water declines in some of the zones in the Sammamish Plateau Aquifer System. This appears to be a result of both increased withdrawal and loss of infiltration (recharge) due to urbanization.

Surface and ground water quality are also adversely affected by rapid urbanization within the watershed. The majority of surface water quality problems within the Cedar-Sammamish Watershed are related to elevated levels of fecal coliform bacteria, total phosphorous, and excursions beyond criteria for dissolved oxygen levels. The ground water quality degradation in the watershed includes elevated nitrate concentrations, as well as other localized exceedences of state Ground Water Quality Standards.

Sources of impairment of both ground and surface water quality include land development, urban and highway runoff, landfills, and industrial discharges. Non-point sources of degradation include the cumulative effects of on-site systems and agricultural activities such as crop irrigation and use of manure lagoons. Water quality degradation can also be attributed to channelization and removal of riparian vegetation.

The salmonid habitats of the Cedar-Sammamish drainage have been severely impacted by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the drainage basin. In particular, this includes the Hiram Chittenden Locks and the associated fish ladder, built in 1916 at the outlet of Lake Washington, and the Seattle Water Department's Landsburg diversion dam at river mile 21.8 on the mainstem Cedar River. Because of the blockage problems encountered, the overall habitat available for anadromous salmonid production has been limited to the lower 21.8 miles of the Cedar River Subbasin. Sockeye stocks from the Cedar River and tributaries of Lake Washington and Lake Sammamish are presently depressed based on long-term negative trends in freshwater survival rates and escapement levels. Lake Washington winter run steelhead and coho salmon of mixed stock in Lake Washington and Lake Sammamish are also classified as depressed. Despite these limits, the habitat that is available for spawning salmon in the lower watershed is rated fair to excellent.

INTRODUCTION

The Department of Ecology's Water Resources Program is charged with managing the state's water resources to ensure that the waters of the state are protected and used for the greatest public benefit. An important component of water management relies on permitting and enforcement of water rights, guided by the authority of Chapters 90.03 and 90.44 of the Revised Code of Washington (RCW). When considering whether to grant a permit for water use, Ecology must first determine that the proposed water use passes four statutory tests (Chapter 90.03.290 RCW):

1. The use will be beneficial.
2. The use will be in the public interest.
3. The water is physically available.
4. The use will not impair senior users.

The axioms of beneficial use and public interest have been defined in regulation. The third and fourth tests comprise a broader test of whether the disturbed hydrologic system can perpetually support the requested use along with senior water users. Impairment of older uses might include excessive reductions of streamflow or lowering of ground water levels. In practice, permit decisions often have been made without enough data to adequately predict long-term impacts.

As an efficiency measure, and to help make better water management decisions, Ecology intends to base future allocation decisions on surveys of the hydrologic condition of entire watersheds. The objective of this report is to document the status of surface water and ground water resources in the Cedar-Sammamish Watershed, which comprises Water Resource Inventory Area (WRIA) 8. Key water management issues in the watershed which influence water right permit decisions are identified and documented. Available information was used to assess hydrological, chemical, and biological conditions which broadly indicate the "health" of the watershed. These conditions included water quantity, hydrogeology, water demand, water quality, and the status of stocks of resident and anadromous fish species. Assessment of these conditions was based on readily available information about water rights and claims, streamflow, precipitation, hydrogeology, ground water levels, fish stocks, and water quality. We did not conduct field surveys or begin new data collection projects. None of this data was exhaustively checked for accuracy, given the need for timely completion of the project.

WATERSHED DESCRIPTION

GEOGRAPHIC DESCRIPTION

The Cedar-Sammamish Watershed (WRIA 8) is located primarily in King County. Figure 1 provides a map of the watershed area in relationship to the State of Washington. Less than 15 percent of the watershed's land area is located in the southwest portion of Snohomish County. The northern boundary of WRIA 8 is southwest Snohomish County. The waters of Puget Sound serve as the western boundary of the watershed. The City of Renton is located near the southern boundary. The eastern boundary is located to the east of Lake Sammamish and extends (in the southeast portion of the basin) to include the headwaters of the Cedar River, near Stampede Pass in the Cascade Mountains. The Cedar-Sammamish Watershed receives an average area precipitation of 50 inches per year. The watershed covers 692 square miles and is typified by a large number of small lakes, ponds, and wetlands (King County, 1989a). Notable water bodies in the basin are Lake Washington, Lake Sammamish, Cedar River, and Sammamish River. Prominent creeks include: Issaquah, Coal, Bear, May, Stamp, Holder, North, Evans, Cottage Lake, and Fifteen-Mile Creeks. Lake Sammamish drains into the northern end of Lake Washington by way of the Sammamish River. The Cedar River drains into the southern end of Lake Washington, which drains through Lake Union and the Ballard Locks into Puget Sound. Significant hydrogeological links to ground water exist between the lakes, rivers, and creeks in the basin. Figure 2 provides a map of the basin including water bodies and subbasins.

The geography of the Cedar-Sammamish Watershed is very diverse. The southeastern portion of the basin is heavily forested with large areas of protected watershed set aside for the City of Seattle Water Supply (King County, 1989a). The southwestern portions of WRIA 8 contain areas of mixed residential and industrial development. The middle and western portions are heavily populated and include large areas of dense residential and industrial development (Seattle - Bellevue corridor). The northern portion of the basin is comprised of an extensive system of lakes, ponds, and wetlands (King County, 1989a) interspersed with areas of residential and industrial development (greater Kirkland, Bothell, Woodinville, and Lynnwood areas). Seattle, North Seattle, and the developed coastal areas of Puget Sound, from the Duwamish Waterway to the City of Mukilteo, form the western border of the basin. The watershed elevation generally ranges from sea level to 600 feet (RBC-GWMP, 1994). Elevations of 1,000 feet or more are encountered in the eastern sections of the watershed in the Cascade Range (Upper Cedar River area).

Physiography

The Cedar-Sammamish Watershed is made up of two basic ecosystems. The Puget Sound Lowland accounts for 86 percent of the watershed's land area, while the Cascades Range highlands make up the remaining 14 percent. The Puget Sound Lowland was covered by ice several times during geologically recent periods of glaciation. Thus, most of the topographic features in the Puget Sound Lowland are a direct result of glacial deposition or erosion (Easterbrook and Rahm, 1970).

The climate is typical of the mid-latitude, Pacific marine type. The prevailing winds move moist air inland from the Pacific Ocean, moderating temperatures in both winter and summer. Rains occur primarily in the winter and the summers tend to be dry. The maritime air cools as it pushes up against the Cascade Range, rising to the condensation point, and forming rain or snow. The precipitation is greater and the temperatures are lower in the Cascade Range highlands than in the Puget Sound Lowlands. Fifty percent of the annual precipitation falls in the four-month period from October through January, and 75 percent in the six months between October and March. Average annual precipitation in the watershed ranges between approximately 38 and 102 inches.

Subbasins

Five subbasins found in the Cedar-Sammamish Watershed are briefly described as follows:

The Upper Cedar Subbasin comprises the eastern portion of the Cedar-Sammamish Watershed. This area stretches from just west of Stampede Pass westward to Maple Valley. Notable water bodies in the area include Chester Morse Lake (Cedar Lake), the Cedar River, and Walsh Lake. This subbasin is one of the major sources of water supply for the City of Seattle.

The Squak Subbasin ranges in a general north-south orientation and encompasses the City of Issaquah. The western border lies between Lake Washington and Lake Sammamish, and the eastern border encompasses Beaver Lake and the East Fork of Issaquah Creek. Notable water bodies in the subbasin include Lake Sammamish, Pine Lake, Issaquah Creek, Phantom Lake, and Beaver Lake.

The South Lake Washington Subbasin includes the cities of Renton, Bellevue, Newport Hills, Mercer Island, and the eastern portion of Seattle. The southern portion of Lake Washington is the most notable body of water in the subbasin. Other water bodies of interest are Lake Desire, Otter Lake, Lake Kathleen, Coal Creek, May Creek, Lake Union, and the lower reaches of the Cedar River.

The North Lake Washington Subbasin covers a large area which contains the cities of Kirkland, Bothell, Woodinville, Martha Lake, Redmond, and Lynnwood. The border runs from the northern border of the Cedar-Sammamish Watershed (north of Paine Field) in Snohomish County to Union Bay and the north shore of Lake Union. The southern border roughly follows State Route 520 across Lake Washington. This subbasin's notable water bodies include Green Lake, Sammamish River, Martha Lake, Lake Ballinger, Silver Lake, Bear Creek, North Creek, Swamp Creek, and the northern portion of Lake Washington.

The Puget Subbasin is bounded on the west by Puget Sound and contains the coastal drainage areas along the coastline of Puget Sound from the Duwamish Waterway to Mukilteo. This subbasin includes large portions of the City of Seattle and North Seattle, and Edmonds and Richmond Highlands. Notable water body features include Puget Sound, the Ballard Locks, and Elliott Bay.

LAND COVER AND LAND USE

Land use activities can have a significant impact on ground water and surface water quality and use. As area population grows, consumptive use of water increases proportionally. As surface waters are closed to development, increased demands will be placed on ground water sources. In addition, as development increases, the risk of contamination of water resources is likely to increase. Ground water reserves can also be depleted during development by creation of impervious areas that seal former recharge areas (RBC-GWMP, 1994).

The 1975 data on land use for the watershed indicates that 45 percent of the area was forested, 38 percent was -"urban/built-up", 1 percent was agricultural, and less than 1 percent was rangeland. More recent land use data was found for smaller, more rural portions of the watershed, but not for the entire land area contained in the Cedar-Sammamish Watershed. The information provided below is based on land use within specific portions of WRIA 8 and not on the Cedar-Sammamish Watershed as a whole. Recent data on land use and land cover in highly urbanized sections of WRIA 8 was not found. Examples of the recent land use information on subbasins was found in the Redmond-Bear Creek Valley Ground Water Management Plan, (RBC-GWMP, 1994). This plan indicates that the dominant land uses are low to moderate density residential (1 to 3 homes per acre) and undeveloped land. Most higher density residential development is located in the City of Redmond. In rural areas that have not been sewered, development is limited to 2.5 to 5 homes per acre (RBC-GWMP, 1994).

Within the Issaquah Ground Water Management Area, land uses are characterized as follows: 80 percent forest, 11.2 percent single family residential, 4.6 percent agricultural, 3.5 percent commercial, and less than 1 percent multifamily residential (King County, 1990b). The East Lake Sammamish Basin Conditions Report (King County, 1990a) projected a worst-case land use and land cover scenario in an attempt to plan for growth in the basin. Figure 3 contains the 1989 land use map that provides recent data on land use in the East Lake Sammamish portion of the watershed.

The 1990 census population for the principal incorporated cities in WRIA 8 is indicated below. In general, all areas (incorporated and unincorporated) of the watershed are experiencing large population growth. For example, population data from the Puget Sound Regional Council for the unincorporated areas near Redmond indicates a population increase of 84.5% from 1980 to 1992. Projected growth from 1980 to 2010 is expected to be 207% (RBC-GWMP, 1994).

Based on population and employment growth forecasts prepared by the Puget Sound Regional Council, the Cedar-Sammamish Watershed will likely experience a significant increase (100 to 200 percent) in population during the next 30 years. Along with increased population, employment opportunities in the area will expand significantly as well. These two factors will have a major impact on land uses in the basin. These impacts will include an increase in residential housing densities, expansion and enlargement of vehicular transportation corridors, and growth of commercial and industrial activities (RBC-GWMP, 1994).

Table 1. 1990 Census Data for Incorporated Cities Within the Watershed

Principal Cities in Watershed	1990 Census Population
Seattle	516,259
Bellevue	86, 874
Renton	41,688
Kirkland	40,052
Redmond	35 , 800
Edmonds	30, 744
Lynnwood	28, 695
Mercer Island	20,816
Mountlake Terrace	19,320
Bothell	12, 345
Issaquah	7,786
TOTAL	840, 379

CLIMATE AND PRECIPITATION TRENDS

Precipitation is the principle source of recharge to ground water in the Cedar-Sammamish Watershed. The annual precipitation averages 38 inches per year at the lower elevations in the watershed, with about 75 percent of the precipitation occurring from October through March. Precipitation in the study area is not uniformly distributed, with increasing precipitation at increased altitude to as much as 102 inches per year in the Cascade Range. Much of this precipitation is lost to evapotranspiration, although precipitation also enters surface water drainages and recharges ground water aquifers. Most of the ground water eventually discharges as spring flow or direct seepage into surface water that eventually flows into the Puget Sound.

Statewide Precipitation Trends

Data from precipitation gages were used to examine long-term trends and identify extended periods of above or below average precipitation for all of western Washington. This analysis places the more recent weather patterns into a long-term perspective. This perspective is necessary when considering the issuance of additional water rights because periods of extended drought identified in the historical record can be expected to occur again.

Precipitation stations located at eight sites throughout western Washington were used for the analysis (Figure 4). The criteria used to select a particular station was that the record was relatively long (80 years or more), with few periods of missing data, and was geographically dispersed from the other stations. Periods of missing data were filled using nearby stations, if available, or by at-station monthly mean values if data from a secondary station were not available. Table 2 lists the stations used in the analysis for western Washington (Stations 1 through 8).

Table 2. Long-Term Precipitation Stations

Name	County	Period of Record	Mean Annual Precipitation (inches)
1. Port Angeles	Clallam	1878-1992	25.5
2. Olympia	Thurston	1878-1992	51.6
3. Vancouver	Clark	1899-1992	38.7
4. Sedro Woolley	Skagit	1897-1992	45.9
5. Chester Morse Lake	King	1903-1992	102.7
6. Seattle	King	1878-1992	35.5
7. Aberdeen	Grays Harbor	1891-1992	82.5
8. Centralia	Lewis	1892-1992	45.6

The data for each of the stations were normalized by dividing the annual deviation from the mean by the at-site mean annual precipitation. The normalized data from Stations 1 through 8 were then averaged to obtain a trend line for western Washington (Figure 5). High variability can be seen throughout the period of record. Since the mid-1950's, the precipitation has been typically above the long-term mean. Extended periods of below average precipitation occurred in the 1920's and 1930's and again in the late 1940's. Figure 5 also indicates that precipitation in western Washington was less than average between approximately 1920 and 1950 and higher than average between 1950 and 1980.

Precipitation Trends in the Watershed

Precipitation contours for the Cedar-Sammamish Watershed are provided in Figure 6. Precipitation data from Seatac Airport, Chester Morse Lake, and Landsburg were evaluated to determine if long-term trends in annual rainfall amounts where similar to other locations in western Washington. Based on a period of record from 1948 to 1992, mean annual precipitation at Seatac Airport is 37.7 inches (Figure 7). The mean annual precipitation at Chester Morse Lake is 102.0 inches, based on a period of record from 1931 to 1992 (Figure 8). The mean annual precipitation at Landsburg is 56.0 inches for a period of record from 1931 to 1992 (Figure 9). Annual deviations from the mean demonstrate high variability in rainfall from year to year at all three locations. The trend lines on the graphs are moving averages of the previous 10 years.

In the years since 1976, the lower watershed (Seatac) has experienced less than average precipitation by as much as 13 inches. In the upper watershed, precipitation has also been less than average since 1980 by as much as 38 inches in one year. Annual deviations from the mean demonstrate high variability in rainfall from year to year at both locations. The general trends in precipitation at Seatac Airport, Landsburg, and Chester Morse Lake, as indicated by a ten-year moving average, have been typical of the trends observed at other rain gages in western Washington, with lower than average rainfall occurring over the past 15-20 years (Barker, 1995).

HYDROGEOLOGY

WATERSHED HYDROLOGY

The hydrologic cycle describes the way that water circulates between the earth and atmosphere. In the cycle, water evaporates from the land and the ocean and is deposited back on land as precipitation. A portion of the precipitation transpires from vegetation, some infiltrates into the soil, and some runs off into streams. The infiltrating water becomes soil moisture, some of which percolates to the saturated zone where it becomes ground water. Ground water then flows downward and laterally to discharge through springs and seeps into streams (Figure 10).

The hydrologic cycle of a watershed matches the global cycle, except that watersheds have distinct topographic boundaries and consumptive water use by humans becomes an important factor. Thus, the six dominant features of a watershed's hydrologic cycles are:

1. Precipitation
2. Evapotranspiration (evaporation plus transpiration)
3. Streamflow
4. Long-term changes in ground water storage
5. Natural ground water flow between adjoining watersheds (under topographic boundaries)
6. Consumptive water use by humans

The Natural Water Balance

The long-term, sustained water balance under natural conditions may be written as an equation in the form:

$$PRE - ET \pm XAW \pm CGWS = NSF$$

where:

where:	PRE	=	precipitation
	ET	=	evapotranspiration
	XAW	=	ground water exchange with adjacent watersheds
	CGWS	=	change in ground water storage
	NSF	=	natural streamflow

Precipitation (PRE) on the watershed usually is the principal source of replenishment to the water supply within the watershed. Evapotranspiration (ET) consists of evaporative losses from soils, lakes, and rivers, and the water transpired by vegetation. Evapotranspiration reduces the amount of precipitation that reaches aquifers and streams and constitutes a large fraction of the water balance.

Natural ground water exchange between adjacent watersheds (XAW) either adds to or reduces the water supply in a watershed, depending on the direction of regional ground water flow. Furthermore, one part of a watershed may gain water from an adjoining watershed through a common aquifer, while another part loses to the next watershed. In western Washington, contrary to the popular conception of recharge from distant mountains and high volcanoes, ground water exchange normally represents a small portion of the total water supply in a watershed.

Ground water storage (GWS) is recharged by precipitation as it percolates down to the water table or infiltrates from lakes and streams. In the natural cycle, ground water eventually discharges to streams, except where intercepted by vegetation or in the deepest aquifers, where it may virtually stagnate. Ground water should not be viewed as a static volume, but instead should be conceptualized as the amount that moves through the aquifers on an average annual basis. The recharge rate varies with annual and seasonal precipitation patterns, but ground water storage usually remains within an average annual range, i.e., the recharge rate balances with the average discharge rate to streams. Thus, assuming no long-term climatic change, the CGWS term is zero.

Natural streamflow (NSF) leaving a watershed consists of the remainder after upstream gains and losses. Unfortunately, the natural streamflow in most Washington watersheds was not measured prior to land clearing and the development of water supply systems.

Water Balance and Human Influence

Not all of the natural water supply is available for use by humans because some water must be left in the ground to keep springs and streams flowing. Washington statute (Chapter 90.54 Revised Code of Washington) requires that some water be left in a stream after meeting permitted demands. Also, water in an aquifer must be kept at the level of a "reasonable, feasible pumping lift" (Chapter 173-150 Washington Administrative Code). The sustainable water supply for human consumption is represented by the equation:

$$NSF - CWU = RSF$$

where:	NSF	=	Natural streamflow
	CWU	=	Consumptive water use by humans
	RSF	=	Remaining streamflow

Consumptive water use (CWU) by humans reduces the natural water supply (NSF), usually by increasing ET losses and, occasionally, by exporting water to other watersheds. The remainder of the water pumped from wells or diverted from streams may return to the fresh water supply, though often in a different part of the watershed, or it may be lost directly to Puget Sound following wastewater treatment. For septic systems and following irrigation, it may return to the ground water system through downward percolation.

If the streamflow remaining after human use (RSF) is greater than (or equal to) instream needs (such as navigation, recreation, fisheries resources, and aquatic and riparian ecosystems), then additional water can be appropriated without impairing senior rights.

Simple calculations of the water balance, based on the method of Thornthwaite and Mather (1957), indicate that the monthly distribution of precipitation (PRE), potential ET (soil water not limited), actual ET, soil moisture deficit, and excess soil moisture could become either surface runoff or ground water recharge. Soil moisture deficits occur when the rate of ET outpaces the rate of precipitation, typically during the spring and summer in this area.

GEOLOGY AND GROUND WATER

The Cedar-Sammamish Watershed is comprised of two major physiographic areas. The eastern half of the watershed lies in the Cascade Range while the western half occupies the Puget Sound Lowland. The Cascade Range is composed of Tertiary rocks rising more than five thousand feet above the drift plain. Tertiary rock formations underlie the entire watershed, but they are deeply buried by unconsolidated glacial and fluvial sediments in the northern and western portions of the watershed. Although small domestic supplies can be obtained from Tertiary rocks, the lower permeability of these formations limits the quantity of water produced. The largest yield from bedrock formations in the watershed is found in Newcastle Hills, just south of Lake Sammamish. A Tertiary age conglomerate unit in that area is tapped by several wells, providing enough water for small domestic supplies.

The Puget Sound Lowland consists of a broad, relatively level drift plain extending from the foothills of the Cascades in the east to the Puget Sound in the west. The drift plain was deposited by glacial and fluvial processes and is composed primarily of thick sequences of low permeability glacial tills, and higher permeability glacial outwash deposits. Productive aquifers in the Cedar-Sammamish Watershed consist primarily of unconsolidated sands and gravels of Quaternary age. The majority of these deposits were laid down by the Vashon Glacier that occupied the area during the most recent glaciation. As the Vashon Glacier advanced into the Puget Sound from the north, sequences of permeable sands and gravels were deposited by glacial meltwater. These deposits are described in literature as Vashon Advance deposits (Qva). In locations where the Vashon Advance deposits have significant saturated thickness, they represent a major source of ground water within the Cedar-Sammamish Watershed. Two of the most productive aquifers within the watershed occur in Vashon Advance deposits (Liesch, et al., 1963). These stratified deltaic deposits are found at Issaquah and Redmond, and wells completed in these deposits are capable of producing up to 3,600 gallons per minute (gpm) (Liszak, 1994).

Glacial till, a compact unsorted mixture of cobbles, gravel, and sand in a silt and clay matrix, was deposited directly beneath the Vashon Glacier, overlying the advance deposits. These deposits, termed Vashon Till (Qvt) are normally of low permeability and create aquitards within the watershed area. Although some small domestic water supplies can be derived from coarser grained deposits, the glacial till is not generally a major source of water supply.

As the Vashon Glacier receded from the Puget Sound region, meltwaters deposited additional permeable sediments, described as the Vashon Recessional Outwash (Qvr). The Recessional Outwash consists primarily of well-sorted, stratified sand and gravel deposited by meltwater during wasting of the Vashon Glacier. Outwash deposits are typically highly hydraulically conductive. Ground water supplies can be obtained from shallow wells tapping Qvr deposits where there is sufficient saturated thickness.

The Vashon Glaciation was only the most recent of at least four major glaciations in the Puget Sound area. The nomenclature used to define the Pre-Vashon stratigraphic sequence of Pleistocene sediments in the Puget Sound region varies depending on the sub-region being studied. Stratigraphic nomenclature developed to describe sequences in the northern portion of the Puget Sound do not correlate well with nomenclature in the southern portion. Noble (1990) proposed a revised nomenclature for the Pleistocene stratigraphy of coastal Pierce County. Because it is not clear whether this proposed nomenclature has been widely accepted, this report does not attempt to classify Pre-Vashon stratigraphy beyond its relative stratigraphic position, grain size, and hydrologic properties.

Beneath the Vashon glacial sequences lies the Pre-Vashon Undifferentiated Pleistocene Stratigraphy (Qu), which is characterized by thick sequences of glacial till interbedded with layers of sand and gravel, similar to the Vashon deposits. These formations represent a significant source of ground water in much of the Cedar-Sammamish Watershed. Wells develop yields of up to 700 gpm from thick sequences of Pre-Vashon sands and gravels.

Since the recession of the Vashon Glacier, the Cedar-Sammamish Rivers and their tributaries have deposited significant quantities of sediments within the river floodplains. These recent alluvial deposits vary considerably in their distribution and character, consisting primarily of sand and gravel, interbedded with silts and clays. Near valley margins, landslides deposited mass-wasting debris onto the floodplain alluvium. These deposits are not generally permeable enough to be used as a source of ground water. Where rivers and streams flow into larger valleys, lakes, or the Puget Sound, alluvial fans consisting of course sands and gravels were deposited. These fans may be buried by younger sediments, and are generally good sources of ground water.

GROUND WATER AND SURFACE WATER INTERACTIONS

The Cedar and Sammamish Rivers and their tributaries have cut valleys into the glacial sediments of the drift plain. These valleys have subsequently been filled by recent alluvium, much of which is highly permeable. As a result, aquifers in the vicinity of these valleys are in direct connection with surface water bodies. Since these valleys cut through the Vashon deposits and the deeper undifferentiated Pre-Vashon deposits, a connection between the shallow aquifers and deeper aquifers may exist.

Ground water discharges to surface water when the water level in the aquifer is higher than the surface water level. This occurs throughout most of the lower elevations of the watershed. Conversely, where ground water levels are lower in elevation than the level in a stream or river, water will flow from the surface water body into the ground, recharging the underlying aquifer. Depending on which of these two situations occurs at a specific location, a well pumping from an aquifer near a surface water body can either reduce the quantity of water discharging to the river or increase the quantity of water leaking out of the river.

In several instances, a demonstrated hydraulic connection between ground water and surface water or between aquifers has resulted in conditioned or denied ground water right applications due to the impacts of pumping. The City of Renton Maplewood Golf Course well field ground water rights were conditioned by requiring instream flows on the Cedar River to be maintained. During the application process for pumping in the Issaquah Creek Basin, Ecology recently approved additional ground water appropriation only during the rainy season. The Union Hill Water Association's application for additional pumping was denied based on the hydraulic connection with an already allocated aquifer.

GROUND WATER STATUS

Ecology does not maintain a water level monitoring network in the Cedar-Sammamish Watershed. Such a network could provide valuable data on the status of ground water levels. The data could be used to determine trends of increasing or declining ground water. Such a ground water monitoring network is recommended. Information provided in the subsequent sections has been obtained from specific wells within the watershed.

Issaquah Valley Aquifer

The Issaquah Valley Aquifer lies within glacial delta sand and gravel deposited from Grand Ridge westward to almost the southeast end of Lake Sammamish. There are three main aquifer zones in hydraulic continuity with each other and Issaquah Creek (Liszak, 1994). The major water users in this aquifer are Sammamish Plateau Water and Sewer District (SPWSD) and the City of Issaquah.

Static water levels in City of Issaquah wells from 1981 through 1994 indicate that there has been a gradual 3-foot average ground water decline over this 14 year period. When summer dry season months (June through October) are graphed (Figure 11) separate from winter rainy season monthly averages (November through May), there is over a 4.5-foot average decline in the summer static water levels and a slightly less than 2-foot average decline in winter water levels over the 14-year period.

The declining trend in static water levels in the Issaquah Valley Aquifer suggests that the aquifer is being dewatered. This appears to be the result of increased ground water withdrawals, loss of infiltration (recharge) due to urbanization, and decreased precipitation.

Sammamish Plateau Aquifers

The Sammamish Plateau Aquifer System appears to be composed of several permeable zones or lenses which occur at different depths and have limited lateral extent. The shallowest two aquifers occur above sea level within Vashon advance outwash deposits. These zones are hydraulically interconnected as demonstrated by well hydrograph comparisons. Deeper aquifer zones, generally below sea level, occur within pre-Vashon deposits and appear to be relatively isolated from one another.

Aquifer trend analysis is limited as the data record is only four years, 1991 through 1994. Monitoring wells in the Vashon advance shallow zones have exhibited a 5-foot declining trend in static water levels. There were no good data in the deeper pre-Vashon aquifer zones to analyze for a trend.

The Vashon advance shallow zones are used mainly for exempt single domestic residential use. The Sammamish Plateau Water and Sewer District (SPWSD) and Northeast Sammamish Water District use all of the aquifer zones. Since 1993, the Vashon advance aquifer zones have been artificially recharged during the winter with injection wells by the SPWSD, using water imported from the Issaquah Valley Aquifer. The SPWSD is concerned that the proliferation of exempt wells on the Plateau will extract ground water that the water district has stored for its use to meet summer peak demand. The recharge project is under study by the SPWSD to determine its efficiency and effects.

Redmond-Bear Creek Valley Aquifers

Alluvial unconfined and semi-confined aquifers range up to 40 feet in thickness along the Cottage Lake Creek, Bear Creek, and Evans Creek valleys. From July 1989 to November 1991, data for 36 wells in these aquifers indicate that seasonal water levels fluctuate up to 6 feet annually with no long term declines. However, the data term is too short to validate conclusions (RBC-GWMP, 1994).

Glacial outwash aquifers used by the Cross Valley Water District, near the northern boundary of this area, experienced a 4- to 5-foot ground water decline between June 1986 and January 1993 (Liszak, 1993). These aquifers generally flow southwestward toward Bear Creek.

Sea level aquifers are confined and have pressure gradients of from 160 to 200 feet MSL from the east boundary of the watershed east of Redmond, to low elevations ranging from 60 to 80 feet MSL to the west near the Sammamish River. No information is available on water level trends in the sea level aquifers or in deeper regional aquifers.

Cedar River Valley Aquifers

Glacial and interglacial sediments overlie bedrock in the Cedar River Valley, and provide good aquifers throughout most of the basin. From the Narrows near Renton, to the west, there is an aquifer which was formed by deposition of alluvium at the mouth of the Cedar River. This aquifer lies under the City of Renton close to the surface and has a maximum thickness of about 80 feet. The City of Renton derives most of its water supply from this aquifer. From the Narrows and up-valley, east near the town of Maple Valley, the Cedar Valley alluvial aquifer was deposited by the Cedar River and occurs to depths of about 50 feet below surface. It lies along the Cedar River between bedrock and glacial upland valley walls (RH2 Engineering, 1993).

The Narrows provides a bedrock constriction to the alluvium aquifers to the east. This constriction results in aquifer discharge zones east of the Narrows and aquifer recharge zones west of the narrows. Thus, the Cedar Valley alluvial aquifer discharges directly into the Cedar River providing a portion of the river's base flow. The deltaic aquifer is recharged by the Cedar River, ground water sub-flow through the bedrock narrows, and adjacent uplands. The Cedar Valley alluvial aquifer is believed to receive ground water discharge from adjacent uplands (RH2 Engineering, 1993).

Near the Maplewood Golf Course, two deeper aquifers have been encountered. These aquifers occur at different locations and are not superimposed over one another. The Maplewood aquifer occurs within pre-Vashon alluvium which has been encountered at elevations between -40 to -220 feet mean sea level (MSL) beneath the Maplewood Golf Course, and at elevations between -160 to -220 feet MSL beneath the glacial uplands to the north. The City of Renton is developing this aquifer to meet new and future water demands. The aquifer does not extend to the south and west due to the presence of bedrock, and it pinches out to the east in less than one mile. The Maplewood aquifer is separated from the Cedar Valley alluvial aquifer by a leaky aquitard which consists of 100 feet or more of silty fine sand with sandy silt beds. Aquifer recharge is believed to occur from the north uplands, and discharge occurs via upward flow to the Cedar Valley alluvial aquifer. The static water levels in both aquifers are higher than the water surface elevation of the Cedar River.

Up-valley, immediately east of the Maplewood Golf Course, the Wonderland Mobile Home Park has a well completed in a deep aquifer in unconsolidated Quaternary and possibly Upper Tertiary sediments from 650 to 700 feet below surface. This is a confined, highly pressurized artesian aquifer with a 60 pounds per square inch shut-in pressure. However, the aquifer is limited in extent, occurring within a deep, narrow subsurface bedrock trough which lies northwestward from Lake Youngs toward Maplewood (Liszak, 1992).

Within the glacial uplands between the Narrows and Maple Valley, a stratified aquifer system occurs within Vashon advance and recessional alluvial sands and gravels. Springs emanate from the valley walls where the aquifers crop out. Near Maple Valley, the Vashon advance deposits have been encountered between depths of about 100 feet to more than 200 feet below surface. From there and further up-valley, Vashon recessional outwash and post-glacial fluvial deposits comprise the shallow water table aquifers in the valley.

The Cedar Valley alluvial aquifer and aquifers within the Vashon glacial deposits are most commonly used for single domestic residential use, community water systems, and golf course irrigation. The deltaic aquifer and the Maplewood aquifer provide the City of Renton's water supply. The Wonderland aquifer serves a small community system. No long-term static water level information was readily available to demonstrate aquifer trend analyses.

Another deep aquifer was recently discovered by the Cedar River Water and Sewer District. This aquifer is located east of Maple Valley beneath the Maplewood Estates, in what is believed to be, pre-Vashon Undifferentiated Drift. An exploratory well was drilled and tested which indicated confining conditions (GeoEngineers, 1995). A production well is targeted to tap a zone between 500 and 600 feet below the surface. Further testing and research will determine the extent and hydraulic characteristics of this aquifer.

WATER DEMAND

WATER RIGHTS

Water right information was taken from the Water Resources Information System (WRIS) database and was current as of July 1, 1994. Consumptive water right permits and certificates were summed separately from nonconsumptive uses. Nonconsumptive water use, such as power generation and fish propagation, are uses in which water is returned to the source.

When issuing water rights, the annual quantity (Qa) is allocated based on the beneficial use stated by the applicant, such as the number of irrigated acres or the number of homes to be served. The quantities granted on the water right are the maximum allowable for that use. The instantaneous quantity (Qi) is often the amount requested by the applicant based upon the size of the pump or diversion facility installed. Qi, generally measured in cubic feet per second (cfs), is not necessarily correlated to annual quantity; and no assumption is made that the Qi will be used 24 hours per day.

Prior to the 1960's, Qa was not assigned for most surface water rights. Thus for the purpose of this report, estimates of annual quantity were made for those rights issued for irrigation and single domestic use. Surface water irrigation rights were assigned based on 2 acre-feet/acre/year, and single domestic consumption was estimated at 1 acre-foot/acre annually. No estimate of Qa was made for multiple domestic, municipal, or industrial uses.

A total of 1,601 consumptive ground and surface water rights have been issued in the Cedar-Sammamish Watershed (Table 3). Consumptive water rights for Issaquah Creek Subbasin are presented in Table 3; these are a subset of the total consumptive water rights issued in the watershed. Consumptive ground and surface water rights for the entire watershed were plotted as a function of time in Figure 12. Between the 1950's and the late 1980's, the cumulative quantity of ground water rights increased steadily. During that same period, the cumulative quantity of surface water rights also increased, but more sporadically in some years. Consumptive ground and surface water rights issued since 1965 for the Issaquah Creek Subbasin were plotted as a function of time in Figure 13. This graph indicates very little growth in surface water rights during that time and a steady growth in ground water rights from 1,219 to 9,421 acre-feet/year.

Figures 14 and 15 plot the cumulative annual quantity of water as a percentage of the total quantity against the cumulative number of rights expressed as a percentage of the total number of rights. Figure 14 indicates that 90 percent of the ground water volume is held by 21 percent of the rights. Figure 15 indicates that three of the 1,158 surface water rights, or 0.3 percent, in the Cedar-Sammamish Watershed account for 90 percent of the annual quantity of surface water allocated. The single largest surface water right is for the City of Seattle. The City of Seattle has a 15-year permit that allocates 102,746 acre-feet of water during drought years from Chester Morse Lake, below the outflow. Excluding this temporary permit, there are 124 surface water rights for municipal or multiple domestic use, 85 of which were issued before 1960. Many, if not most, of these diversions may no longer be used, causing the recorded sum of allocations to be an over representation.

There are 400 water rights for diversions from both Lake Washington and Lake Sammamish, or approximately 7 percent of the 5,400 riparian property owners. Ecology's investigation has shown that there is widespread use of lake water for lawn and garden irrigation by lake shore property owners, most of which are unauthorized. In the case of Lake Washington and Lake Sammamish, the recorded water rights under-represent actual water use.

Water rights were summed by primary use, as a percentage of the total. This information is depicted graphically in Figure 16. The primary use of both ground and surface water is municipal and domestic supply, which is not surprising in a highly urbanized area.

Table 3. Current Water Rights in the Cedar-Sammamish Watershed

Source	Qi (cfs)	Qa (acre-feet/year)	Irrigated Acres	Total Number of Rights
Cedar Sammamish Watershed				
Ground	203.6	84,608	1,529	443
Surface	600.0	138,551	4,188	1,158
Issaquah Creek Subbasin				
Ground	29.1	9,421	14	69
Surface	11.2	1,331	295	108

Nonconsumptive Rights

There are 159 nonconsumptive surface water rights issued in the Cedar-Sammamish Watershed. The uses, in order of instantaneous quantity allocated, are power, heat exchange, fish propagation, and commercial uses. The total Qi of nonconsumptive surface water rights is 421 cfs. Only one nonconsumptive ground water right was issued, for heat exchange for 0.25 cfs (110 gallons per minute).

WATER CLAIMS

Claims filed during the registration period between 1969 and 1974 total 6,225 for both surface and ground water. Because most claims were not quantified as they were filed, this assessment estimated a Qi of 0.02 cfs and a Qa of 1 acre-foot per year for each claim for domestic use and/or stockwatering. Claims for irrigation were assigned 0.02 cfs and 2 acre-feet per acre per year. Table 4 lists the ground water and surface water claims in the Cedar-Sammamish Watershed and the claims in the Issaquah Creek Subbasin.

The largest water user in the watershed, the City of Seattle, has a water right claim to 465 cfs and 336,650 acre-feet from the Cedar River and Chester Morse Lake. The capacity of the Cedar River diversion is 205 million gallons per day (or approximately 317 cfs) according to the Seattle Water Department Comprehensive Regional Water Supply Plan (1993). Seattle's claimed Qi and Qa are added into the summation of claims in Table 4.

Water right claims for ground and surface water are plotted by use in Figure 17. The four uses listed in the claims database are domestic, irrigation, stockwatering, and other. Seattle's municipal use is included in the category of "other," and is much greater than all other uses combined.

Table 4. Claims to Water Rights in Cedar-Sammamish Watershed

Source	Qi (cfs)	Qa (acre-feet)	Irrigated Acres	Total Number of Claims
Cedar Sammamish Watershed				
Ground	128.9	8,925	3,007	4,424
Surface	545.0	343,286	2,588	1,801
Issaquah Creek Subbasin				
Ground	14.7	995	N/A	520
Surface	4.7	337	N/A	165

APPLICATIONS

There are currently 7 applications for surface water and 55 for ground water in the Cedar-Sammamish Watershed (Table 5). These are depicted graphically by primary desired use in Figure 18. Four of the surface water right applications are for domestic use, and two are for irrigation.

There are 10 ground water applications in the Issaquah Creek Subbasin alone for multiple domestic or municipal use. These applications request 23.2 cfs (10,390 gpm). This amount approaches the quantity that has already been allocated in the subbasin (29.1 cfs). There are no applications for surface water rights in the subbasin.

Table 5. Water Right Applications in Cedar-Sammamish Watershed

Source	Qi (cfs)	Qa (acre-feet)	Irrigated Acres	Total Number of Applications
Cedar Sammamish Watershed				
Ground	136.3	69,106*	655	55
Surface	0.4	208*	1	7
Issaquah Creek Subbasin				
Ground	23.2	11,637*	0	10
Surface	0	0	0	0

* Estimated quantities

SUMMARY

Surface and ground water rights allocated within the Cedar-Sammamish Watershed total 803.6 cfs and 223,159 acre-feet per year. Surface and ground water claims within the WRIA total 673.9 cfs and 352,211 acre-feet/year. The total quantity of surface water rights and claims for consumptive use in the Cedar-Sammamish Watershed is 1,145 cfs with a calculated annual quantity of 481,837 acre-feet/year. The total quantity of ground water rights and claims in WRIA 8 is 332.5 cfs, with a calculated annual quantity of 93,533 acre-feet/year. Consequently, the quantity of surface water rights and claims is almost four times greater than the quantity of ground water rights and claims. The growth in ground water rights since the 1950's has been relatively constant, while the growth in surface water rights has increased more sporadically.

This assessment does not measure actual water use or verify water rights. Unauthorized water users and recorded or claimed rights no longer exercised are factors that prevent correlation between the amount of water being used and the amount of water allocated by rights. No procedure is in place to track whether or not water rights issued in the past are still used. While numerous old water rights are assumed to be no longer used, unless a relinquishment form is received by Ecology, water rights remain "on the books." A second source of inaccuracy in this assessment arises from the fact that most water right claimants did not specify quantities on their claims. Therefore, quantities for claims were estimated as indicated in the discussion. A survey of actual use would be extremely useful in managing the resource. A third source of error in the preceding discussion is the unauthorized withdrawal. Such water use should be investigated and enforcement action taken, where appropriate. Fourth, ground water withdrawals of less than 5,000 gallons per day with certain use conditions are exempt from registration of that water right with Ecology. These water withdrawals are not tracked by Ecology. A final source of inaccuracy in estimating water allocation within the watershed is the pre-existing federally-granted, tribal water rights.

WATER QUALITY AND FISHERIES

SURFACE WATER QUALITY

Water quality is an important measure of a watershed's overall health and measures the ability of life to exist and flourish within a watershed. The importance of adequate water quality and quantity within the Cedar-Sammamish Watershed is reflected in the following statement taken from the Draft Green-Duwamish Watershed Nonpoint Water Quality Early-Action Plan (King County, 1989b),

> *"Water quality is closely tied to water quantity. Water quality is a significant factor in allocation decisions by water purveyors in that water supplies for municipal and industrial use (e.g., domestic consumption) must be of high quality. At the same time, management of water quality may depend in large part on the availability of large quantities of water to dilute pollutants and maintain proper water temperatures "*

The status of water quality within the Cedar-Sammamish Watershed is monitored by the Department of Ecology, public interest groups, local agencies, and occasional research studies conducted on subbasin water bodies. An overall assessment of conditions within the Cedar-Sammamish Watershed shows that water quality is rated as generally good for the water bodies in the watershed. All of the stream segments within this large watershed are classified as Class AA according to criteria set by the Washington Administrative Code (WAC) 173-201A, which classifies rivers by the beneficial uses that they should be able to support and the level of support that they should provide. Waters under the AA classification are characterized as "markedly and uniformly exceeding the requirements for all or substantially all beneficial uses." Class A and AA waters can be used for municipal water supplies, stock watering, fish and wildlife habitat, and primary contact recreation. There is also a "Lakes" classification which applies to all of the lakes within the watershed. The Lakes standards are closest in stringency to the Class AA standards for rivers and streams.

The majority of water quality problems within the Cedar-Sammamish Watershed are related to elevated levels of fecal coliform bacteria, total phosphorus, and excursions beyond criteria for dissolved oxygen levels. According to the 1994 Section 303(d) list submitted to EPA (Ecology, 1994), the primary problem with water quality in this WRIA is the high number of excursions beyond the Class A criteria for fecal coliform bacteria. The Cedar River was cited with 24 excursions beyond the Class A criteria for fecal coliform at Ecology ambient monitoring station 08C070 between July 1, 1987 and January 1, 1992 with an additional 17 excursions cited at the Municipality of Metropolitan Seattle (METRO) sampling station A438. Similarly, the Sammamish River was found to have elevated fecal coliform counts totaling 36 excursions beyond criteria at METRO station 0450 and 27 excursions at Ecology ambient monitoring station 08B070 between July 1, 1987 and January 1, 1992. Several streams throughout the Cedar-Sammamish Watershed are cited with excursions beyond criteria for fecal coliform bacteria. Table 6 provides the water quality excursions for the water bodies within the watershed from the 303(d) report (Ecology, 1994); this information is depicted on the base map in Figure 19.

The Clean Water Act Section 305(b) Report (Ecology, 1992) indicates that many of the creeks and segments of the Cedar and Sammamish Rivers have been impaired for a number of uses. Commonly impaired uses include: salmonid and other fish migration and spawning, and primary and secondary recreational uses due to the presence of high fecal coliform bacteria and metals concentrations. Sources of impairment listed in the report are diverse ranging from land development, urban and highway runoff, channelization, and removal of riparian vegetation to agricultural activities, pasture lands, manure lagoons, and irrigated crop production.

One potential source of water quality impairment not listed in the report is discharge by municipalities and industries. A total of 37 individual NPDES permittees discharge to surface water bodies within the watershed. Of the 37 discharges, 9 are municipal (8 major and 1 minor) discharges and the remainder (28) are industrial. In addition, there are 75 general permits that allow industries to discharge to surface water and one fish farm that discharges within the watershed. Other sources of impairment listed in the report include: pasture lands, animal management areas, and manure lagoons, channelization, removal of riparian areas, and stream bank modification.

Water quality information is also available from the EPA Storet database. The information was accessed for hydrologic unit codes (HUC) 17110019 and 17110012. HUC 17110019 is the major HUC comprising the watershed but also includes areas in WRIAs 9, 10, and 12. The surface water data were averaged separately from ground water data. Data from HUCs 17110019 indicate the average concentrations for dissolved lead, copper, and silver exceeded the acute freshwater water quality criteria. Because these are average concentrations and exact locations for the exceedences are not readily accessible, the data may reflect specific locations of elevated concentrations, rather than the health of the watershed as a whole.

Table 6. Surface Water Quality Exceedences from 303(d) List

Water Body Segment	Water Body Name	Parameters Exceeding Standards
08-1010	Juanita Creek	Fecal Coliform
08-1012	Forbes Creek	Fecal Coliform
08-1014	Yarrow Bay tributary	Fecal Coliform
08-1016	Fairwether Bay Tributary	Fecal Coliform
08-1018	Kelsey Creek	Fecal Coliform
08-1020	Thornton Creek	Fecal Coliform
08-1030	McAleer Creek	Fecal Coliform
08-1040	Lyon Creek	Fecal Coliform
08-1050	Sammamish River	Fecal Coliform
08-1060	Swamp Creek	Dissolved Oxygen Fecal Coliform
08-1065	North Creek	Fecal Coliform
08-1070	Sammamish River	Fecal Coliform
08-1080	Sammamish River	Fecal Coliform
08-1085	Little Bear Creek	Fecal Coliform
08-1095	Bear-Evans Creek	Dissolved Oxygen Fecal Coliform Mercury
08-1100	Sammamish River	Fecal Coliform
08-1110	Issaquah Creek	Fecal Coliform
08-1115	Tibbetts Creek	Temperature Fecal Coliform
08-1116	Laughing Jacob's Creek	Fecal Coliform
08-1117	Pine Lake Creek	Fecal Coliform

Table 6. Surface Water Quality Exceedences from 303(d) List

Water Body Segment	Water Body Name	Parameters Exceeding Standards
08-1118	Eton Creek	Fecal Coliform
08-1120	Coal Creek	Fecal Coliform
08-1130	May Creek	Fecal Coliform
08-1143	Cedar River	Fecal Coliform
08-1145	Cedar River	Fecal Coliform
08-2100	Mercer Slough	Fecal Coliform PCB (fish tissue)
08-9020	Beaver Lake	Total Phosphorus
08-9070	Cottage Lake	Total Phosphorus
08-9090	Desire Lake	Total Phosphorus
08-9190	Martha Lake	Total Phosphorus
08-9340	Union Lake/Lake Washington Ship Canal	Sediment Bioassay PCBs (fish tissue) Dieldrin (fish tissue)
08-9350	Lake Washington	Sediment Bioassay

Site-specific surface water data was obtained from the U.S. Geological Survey National Water Information System (NWIS) database. A review of these data for the watershed indicate dissolved copper, dissolved lead, and fecal coliform bacteria exceeded the freshwater acute water quality criteria at a number of locations as depicted in Table 7. Several of these locations are storm water sewer outfalls and indicate impacts of non-point source pollution within urban areas.

METRO maintains monthly water quality sampling stations in the Lake Washington and Sammamish River drainages as well as on the major tributaries throughout the watershed. Thirty sampling stations are located throughout the Cedar-Sammamish Watershed. METRO sampling stations are located on the mainstem Cedar and Sammamish Rivers as well as major tributaries such as Swamp Creek, Bear and Evans Creeks, Coal Creek, Issaquah Creek, and Tibbetts Creek. Additional sampling stations are located on several small tributaries to Lake Washington. Figure 20 shows specific METRO sampling station locations throughout the Cedar-Sammamish Watershed.

A wide spectrum of factors are adversely affecting the waters of this watershed including: urbanization, municipal and individual on-site sewage systems, stormwater runoff from residential developments and extensive road systems throughout the watershed, regional industrial and commercial development, agricultural practices, resource extractions and forestry operations. These are but a few of the pollution sources leading to reduced water quality in the Cedar-Sammamish Watershed.

Water from the Upper Cedar River Watershed is one of the primary drinking water sources for the City of Seattle and is therefore considered a very important resource. Protection of this resource has been a major concern to the Seattle Water Department (SWD). Water quality in the upper watershed has been classified as excellent (Class AA) from the headwaters to the City of Renton, where its status is downgraded to Class A.

In accordance with the Nonpoint Rule, Chapter 400-12 WAC, the Watershed Ranking Committee ranked the Lower Cedar River Watershed (the area between Lake Washington and Maple Valley) as the number one watershed for nonpoint pollution planning in King County (King County, 1989a). Criteria used to determine the ranking included water quality, beneficial uses, nonpoint pollution sources, increasing development pressures, naturally occurring environmental factors, and opportunity for prevention of nonpoint pollution before correction is necessary. The Lower Cedar River Basin was ranked number one due to the relative importance of its natural resources and the need to protect the area from further water quality degradation (KCSWM, 1993a).

Table 7. Surface Water Quality Criteria Exceedences in NWIS Database

Gage Location	Dissolved Copper	Dissolved Lead	Fecal Coliform
Sammamish River at Bothell (12126500)	•		•
Issaquah Creek near the mouth, near Issaquah (12121600)			•
Cedar River at Renton (12119000)	•	•	
Lake Hills Storm Sewer Outfall (12119725)		•	•
148th Ave. Storm Sewer at Lake Hills Blvd. (1211973)		•	•
Surrey Downs Storm Sewer Outfall at Belldrainage (1212005)		•	•

In general, water quality is somewhat impaired in the Sammamish River. The Sammamish River is classified as a Class AA stream from the outlet of Lake Sammamish to approximately Bothell, at which point its status is downgraded to a Class A designation. Much of the river is a canal which has been dredged, straightened, and most of the larger riparian vegetation removed. Consequently, water temperatures are higher and dissolved oxygen levels lower than many other rivers in western King County. The Sammamish River contributes consistently to the degraded water quality in the north end of Lake Washington, which tends to be the poorest in the lake. Low levels of transparency and high levels of phosphorus are frequently observed (King County, 1989a).

Swamp Creek and North Creek are important tributaries of the Sammamish River which impact water quality within the subbasin. While the pH in Swamp Creek met the Class AA criteria, the dissolved oxygen, temperature, and fecal coliform levels exceeded the criteria more than most sites. In North Creek, the fecal coliform levels met the criterion only once, and levels have been increasing over the last three years. The temperature and pH levels always met the Class AA criteria while the dissolved oxygen levels were below standards twice (METRO, 1988).

The Issaquah Creek Basin Current/Future Conditions and Source Identification Report (KCSWM, 1991), describes the water quality within Issaquah and Tibbetts Creeks, two major tributaries of Lake Sammamish. This report noted that exceedance of water quality standards for dissolved oxygen, temperature, and fecal coliform bacteria has occurred on Tibbetts Creek. General base flow water quality is characterized by variable turbidity with high levels in the late winter and summer periods, high fecal coliform counts, wide temperature range, and a lower dissolved oxygen content than characterized by Class AA waters. Dissolved oxygen levels failed to meet State water quality criteria five of 12 times. METRO characterized Tibbetts Creek water quality as "fair" (METRO, 1990). Tibbetts Creek is classified as Class AA because all feeder streams to lakes are classified as Class AA unless specifically identified in WAC 173201A-080. Issaquah Creek is classified as Class A, although it usually has higher water quality and rating than Tibbetts Creek. .

GROUND WATER QUALITY

The Clean Water Act Section 305(b) Report (Ecology, 1992) provides a list of contaminants of concern within King County, which encompasses most of the Cedar-Sammamish Watershed. The list of contaminants of concern is broad and includes: heavy metals organic constituents, chlorides, nitrates, petrochemicals, coliform bacteria, cyanide, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxin, and pesticides. This information should not be used to imply that the ground water in the watershed is generally contaminated, but rather that specific pockets of ground water may be degraded. The sources of the contamination listed in the 305(b) report include: rapid population growth, urban runoff, on-site septic systems, landfills, sea water intrusion, and naturally occurring iron and manganese. Industrial sources are also listed in the report as a source of contamination. Within the watershed, four state waste discharge permits have been issued to industrial dischargers that allow discharge of treated wastewater to the ground.

Nitrate-nitrogen concentrations can be used as an indicator of the general health of the ground water. Nitrates are often indicative of a variety of human activities such as the cumulative impacts of septic systems, lawn and garden fertilizer practices, and farm and animal management practices. Nitrate-nitrogen concentrations are provided from public supply wells in Figure 21. The highest measured nitrate concentrations from water supply wells based on the 1989 Department of Health database were used to develop the figure. The vast majority of the wells have nitrate concentrations of less than 2 mg/L, an indicator of generally pristine ground water quality. Twelve of the wells had concentrations that indicated some anthropogenic impacts where the concentrations ranged between 2 and 6 mg/L. Two wells had concentrations between 6 and 10 mg/L; and none of the wells had nitrate concentrations that exceeded the primary drinking water maximum contaminant level (MCL) of 10 mg/L.

The EPA Storet database was accessed for HUCs 17110019 and 17110012 and average parameter concentrations were provided. The average concentrations exceeded the criteria provided in the Ground Water Quality Standards (Chapter 173-200 WAC) for total arsenic, lead, manganese, silver, and fecal coliform in HUC 17110019 and for total arsenic in HUC 17110012. Because these are average concentrations and exact locations for the exceedences are not readily accessible, the data may reflect specific locations of elevated concentrations, rather than the health of the watershed as a whole. It is also noteworthy that the ground water quality criterion for arsenic is based on carcinogenic risk and is exceptionally low (0.05 /μg/L).

A number of Ground Water Management Areas (GWMAs) have been established within the watershed under Chapter 173-100 WAC. These GWMAs can serve as a source of information about the ground water quality in each GWMA. GWMAs that are in the planning process include Redmond-Bear Creek Valley, Issaquah Creek Valley, East King County, and South King County (encompasses portions of WRIAs 8, 9, and 10).

Data gathered from 34 wells within the Redmond-Bear Creek Valley indicate the ground water in that area is generally of good quality. Iron and manganese were elevated in a number of the wells. Elevated levels of these constituents are commonly attributed to glacial deposit aquifers in western Washington from the mineralization of the ground water system (RBC-GWMP, 1994). In seven wells, total organic halogen was measured above the detection levels. In one instance each, chromium and mercury were elevated above the primary drinking water standards.

FISHERIES

The status of fish populations is an important measure of water quality and stream health within a watershed. Good habitat is necessary to support both fish and other wildlife. Some organisms, fish in particular, are considered sensitive indicators of stream health. If large numbers and species of fish are successfully spawning and rearing within a stream reach, then it is likely that the stream has conditions that will support other uses. Ascertaining the status of fish populations within a basin can be a very important and constructive objective of any study, as it can be used as a preliminary measure of a watershed's health.

The Washington Department of Fisheries 1975 Catalog of Washington Streams and Salmon Utilization indicates that anadromous salmonids found within the Cedar-Sammamish Watershed are chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and sockeye (*O. nerka*) salmon. Steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*) are also found throughout the Cedar-Sammamish Watershed (Lake Washington Drainage). Adult or juvenile salmon and/or steelhead trout are present within the basin throughout the entire year.

Habitats and stream characterizations found within the Cedar-Sammamish Watershed vary considerably due to changes in channel gradients, stream morphology, and current levels of commercial or domestic development. For ease of discussion, these habitat areas will be discussed separately for the two principle drainage areas within the basin: 1) the Cedar River system, and 2) the Sammamish River drainage.

The Cedar River originates in relatively high mountain country of the Cascade Range near Stampede Pass. It flows generally west-northwest for nearly 50 miles to its confluence with the southern end of Lake Washington. The river flows through approximately 19 miles of narrow valleyed, steep sloped, and heavily forested mountain terrain before becoming impounded by Lake Chester Morse and the City of Seattle Landsburg diversion dam located downstream at river mile 21. Below the diversion dam the river flows through a relatively shallow and broad valley with habitat consisting of gentle gradient stretches with many pool-riffle areas. Below the town of Maple Valley the lower thirteen miles of river meander over a shallow, relatively broad valley containing increasing summer home and urbanization developments. The lower three miles of the stream flow through an intensely industrialized area (Williams et al., 1975). The lower reach of the Cedar River has been channelized, straightened, and dredged as a flood control measure after the channel was relocated. Due to the artificial dikes and revetments, as well as increased development, riparian areas have suffered along the lower river. Tree growth is largely prohibited in some diked areas resulting in stream banks that provide little shade to the river.

Fisheries habitat within the Cedar River consists primarily of cascades and rapids confined in relatively narrow, steep-sloped valleys. Substrates are dominated by boulders, rubble, and large cobble in the upper watershed. The City of Seattle Landsburg water diversion dam blocks all upstream migration of salmonids to a substantial part of the Upper-Cedar River Subbasin. Presently, no spawning occurs upstream of the diversion dam. Below Maple Valley the Cedar River maintains predominantly a low gradient pool-riffle character with spawnable sized gravel, providing excellent spawning and rearing conditions for both anadromous and resident fishes

(Williams et al., 1975). Important tributaries of the Cedar River drainage include Rock, Downs, and Peterson Creeks. These streams provide accessible habitat for anadromous salmonids.

The Sammamish River runs north and west from the north end of Lake Sammamish twelve miles to the north end of lake Washington exhibiting predominant characteristics of sluggish flow as it meanders westward. The surrounding terrain consists mainly of cleared, level farm land with an increasing number of urbanization projects. Almost the entire Sammamish corridor has been developed for residential or commercial properties. The Sammamish River drainage consists of Lake Sammamish and its principle tributaries, Issaquah and Tibbetts Creeks; and the Sammamish River and its tributaries, Big Bear, North and Swamp Creeks. Of the Lake Sammamish tributaries, Issaquah Creek provides the greatest amount of pool-riffle stream area which is highly suitable for fish spawning and rearing (Williams et al., 1975). Although the Issaquah Creek Hatchery takes a portion of the fish for artificial spawning, a substantial portion of fish are transported and can use the upstream habitat.

The Sammamish River is used by a wider variety of fish than many other streams in western Washington because it connects two large lakes, Lake Sammamish and Lake Washington. In addition, a major Washington Department of Fisheries hatchery is located on Issaquah Creek within the City of Issaquah, the principal tributary to Lake Sammamish. The Sammamish River thus serves as the sole migration route for young salmon originating at the hatchery and in tributaries of Lake Sammamish and the river itself. Similarly, adult salmon must migrate through the river to reach their natal spawning grounds upstream. The University of Washington also operates a small hatchery on Portage Bay in the canal between Lakes Union and Washington. Some of the fish that originate there may rear for some period of time in the lake, and possibly enter the river in low numbers (Sammamish River Corridor Conditions and Enhancement Opportunities, KCSWM, 1993).

The salmonid habitats of the Cedar-Sammamish drainage have been severely impacted by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the drainage basin. In particular, these include the Hiram Chittenden Locks and the associated fish ladder, built in 1916 at the outlet of Lake Washington and the Seattle Water Department's Landsburg diversion dam at river mile 21.8 on the mainstem Cedar River. The Landsburg diversion dam restricts the passage of all anadromous fish species. All salmon and steelhead that enter the Lake Washington Drainage must first pass through the fish ladder or go through the Hiram Chittenden Locks. Because of the blockage problems encountered, the overall habitat available for, anadromous salmonid production has been limited to the lower 21.8 miles of the Cedar River Subbasin. Despite these limits, the habitat that is available for spawning salmon in the lower watershed is rated as fair to excellent.

Anadromous fish production in the Cedar-Sammamish Watershed is relatively low and has been below historic level for many years. Declining production of salmon species can be attributed to many causes. There are many complex and interacting factors which are contributing to the low production. One of the most important reasons for low production is the chronically low escapement levels of returning adult salmon. Some of the adverse conditions resulting in the low escapement levels of anadromous salmon and steelhead include seasonal flooding, low summer flows, unstable stream beds, physical barriers, poor water quality, high stream temperatures, the destruction of spawning habitat, and overharvest of wild stocks. Low streamflows are experienced during many years.

Adult salmonids migrate upstream through the Hiram Chittenden Locks throughout the year. Although the Pacific salmon species (chinook, sockeye, and coho) migrate upstream during late summer, fall, and early winter, steelhead trout migrate in both winter and summer runs. Timing of upstream migration of the Pacific salmon is largely controlled by rainfall, stream flow, and barometric pressure. Migrating salmon aggregate near the mouth of the ship canal downstream of the locks during July and August before migrating predominantly between September through January (Wydoski and Whitney, 1979). Adult sockeye salmon enter Lake Washington in mid-June with the run continuing until the first of October. Downstream migration by juvenile salmon and steelhead primarily occurs in late winter and early spring. Both chinook and coho salmon begin to outmigrate in early April. Outmigration usually lasts through mid-July to early August for most species.

Sockeye salmon outmigrate from the Cedar River and into lakes immediately upon emerging from their gravel beds in the spring, typically between March and July. All sockeye and kokanee (landlocked non-migratory resident sockeye) require a lake environment for a major part of their life cycle. Sockeye fry will remain in the Cedar-Sammamish basin for 1 to 2 years before migrating to saltwater, where they mature. Juvenile sockeye utilize extensive areas of this basin for rearing habitat. Juvenile sockeye rear throughout the accessible length of the basin streams with major rearing in the waters of Lake Sammamish and Lake Washington. Important rearing areas for the juvenile outmigrants also exist in Lake Union, Salmon Bay Waterway, and in the basin's estuarine waters (Williams et al., 1975).

Two of the most prominent studies regarding the health of fish stocks in Washington State are: 1) A paper published in the March-April 1991 issue of Fisheries entitled, "Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington" (Nehlsen et al.,

1991) and 2) The "1992 Salmon and Steelhead Stock Inventory" (SASSI) published in March 1993. The former paper attempted to assess the future risk of extinction for selected stocks.

The SASSI report examined the current status of salmon and steelhead stocks for Washington State. Figure 22 show water bodies in which salmon inventories have been adversely affected.

The primary anadromous species present within the Cedar-Sammamish system are the coho and sockeye salmon. Cedar River spawning coho are of a mixed stock with wild production and are currently classified as a healthy stock. Coho salmon utilizing the Lake Washington and Lake Sammamish tributaries are of a mixed stock with composite production and their present status is classified as depressed due to a short-term severe decline in escapement (WDFW, 1993). According to the SASSI report and the Department of Fisheries stream catalog (1975), coho spawn in the Cedar River and all tributaries of Lake Washington and Lake Sammamish. There have been off-station releases of hatchery-origin coho into Lake Washington and the Cedar River. The magnitude of genetic impacts caused by these hatchery-origin fish is unknown.

The Cedar River and Lake Washington and Sammamish tributaries sustain a substantial population of non-native and unknown origin sockeye salmon. Cedar River sockeye are a non-native stock which were introduced into the Cedar River in the 1930's through fry plants of Skagit River sockeye. These fish spawn in the lower 21 miles of the Cedar River and its tributaries and are maintained through wild production. Escapement levels for the Cedar River Sockeye range from 76,000 to 365,000 individuals based on information from 1967 to 1991. Genetic studies suggest that sockeye salmon utilizing the Lake Washington and Lake Sammamish tributaries are of a different stock than Cedar River stocks, although the origin of this stock is unknown. Escapement levels for Lake Washington and Sammamish tributaries ranges from 3,601 to 29,713 individuals based on information from 1982 to 1991. The majority of spawning escapement occurs in the Big Bear Creek and Issaquah Creek systems with some utilization of smaller tributaries. Sockeye stocks from the Cedar River and tributaries of Lake Washington and Sammamish are presently depressed based on long-term negative trends in freshwater survival rates and escapement levels (WDFW, 1993).

Summer/fall run chinook salmon are found throughout the Cedar-Sammamish Watershed. Chinook stocks primarily spawn in late September through October in Issaquah Creek, the Cedar River, and numerous tributaries of Lake Washington. Chinook salmon utilizing the Cedar River and Lake Washington tributaries are classified as native stocks with wild production. Cedar River escapement averages about 1,900 individuals per year. Despite this average escapement, status of this stock is unknown at this time. In contrast, non-native chinook produced in the Issaquah Creek system are considered a healthy stock comprised of composite production.

Winter run steelhead from the Lake Washington system have escapement levels ranging from 474 to 1,816 individuals based on Washington Department of Fish and Wildlife (WDFW) information from 1984 to 1992. The winter run steelhead stock in Lake Washington is considered a distinct native stock based on geographical isolation of the spawning population in tributaries to Lake Washington, the Cedar River, Lake Sammamish, and the Sammamish River. This population is sustained by wild production and its current status is classified as depressed due to chronically low spawner escapement (WDFW, 1993). The Lake Washington/Sammamish Watershed also contains numerous resident rainbow and cutthroat (O. clarki) trout species. The former have been extensively planted in Lakes Sammamish and Washington as game fish. A self-sustaining rainbow trout population exists in Lake Chester Morse, an impoundment of the Cedar River. This is only one of two known self-sustaining populations of rainbow trout in the state (KCSWM, 1993b).

Mathews and Olson (1980) studied factors which can affect Puget Sound coho salmon runs. They concluded that summer streamflow was an important determinant of Puget Sound coho run strength since 1952, apparently due to its affect on zero-age salmon. They also reference earlier studies which indicate a relationship between rearing flows and coho run strength beginning in 1935. Mathews and Olson's report suggests survival of hatchery coho may be positively dependent upon the same environmental conditions that affect stream-reared coho.

STREAMFLOW STATUS

OBJECTIVES OF ANALYSIS

As previously discussed, the demand on surface and ground water use has grown rapidly over the past 20 to 30 years in the Cedar-Sammamish Watershed. Increasing water demands and periodic declines in precipitation can affect the streamflow status of rivers and streams, most notably by reducing summer low flows. To better understand the characteristics of the river and stream systems in the basin, flow and precipitation data from the watershed were analyzed.

In 1980, Chapter 173-508 WAC established instream flow requirements and closures for WRIA 8. This regulation was adopted as part of the State's Instream Resource Protection Program (IRPP), with flow recommendations based on historical flow records, as well as input by the Department of Ecology and other state agencies (Ecology, 1979). The intent is to retain base flows in perennial streams, rivers, and lakes at levels necessary to protect wildlife, fish, scenic, aesthetic, recreation, environmental, and navigational values. Closures within the WRIA include the entire Lake Washington drainage above the Chittenden Locks, with the exception of the Cedar River Subbasin. These closures include not only Lake Washington, Lake Sammamish, Issaquah Creek, and the Sammamish River, but also all of the smaller tributaries to these water bodies. Cedar River normal instream flows and critical year instream flows were established at the USGS gage station at Renton (12119000) (Figure 23). Issuance of further water rights that would interfere with meeting the established flows were prohibited.

Flow data from USGS gages along the Cedar River, the Sammamish River, and Issaquah Creek were evaluated for flow exceedence values and low flow trends. The number of days per year that flows in the Cedar River at Renton did not meet minimum flow requirements established by WAC 173-508 was determined. In the analyses presented below, all available records were included unless otherwise noted. Flow data for the Cedar River were collected from 1944 to 1993 at Renton (USGS gage 12119000), from 1894 to 1993 near Landsburg (USGS gage 12117500), and from 1913 to 1993 near Cedar Falls (USGS gage 12116500). For the Sammamish River near Woodinville (USGS gage 12125200), data were collected from 1964 to 1993. For Issaquah Creek (USGS gage 12121600), data were collected from 1963 to 1993.

FLOW EXCEEDENCE

Flow exceedence curves were developed for each of the selected gage stations (Figures 24 to 29). The full record of flow data were used in calculating the monthly flow exceedence curves for each of the gages. In addition, for the Cedar River Gage at Renton, data collected since implementation of WAC 173-508 were used to develop exceedence curves (Figure 25) for comparison to curves based on the full period of record (Figure 24). Based on the flow data, 90, 50, and 10 percent exceedence curves were developed. The 90 percent curve represents low flow conditions, since flow at any time during a given year has a 90 percent probability of exceeding the plotted values. The 50 percent curve shows the median flow values throughout the year. The 10 percent curve is representative of high flow conditions.

The established minimum instream flows for the Renton Gage are shown with the exceedence curves to indicate the relative frequency that the minimum flows are not met during the different seasons of the year (Figure 24). For the exceedence curves based on the full period of record (Figure 24), the 90 percent exceedence curve is above the instream flow requirements for normal year flow December through May but drops below the instream flow requirements from June through November. This indicates that there is probability of greater than one in 10-years that the established instream flow requirements for normal year flow are not met for about five months of the year. There is also about a 10 percent probability that critical year flow requirements are not met from mid-June through mid-November. The 50 percent exceedence curve indicates that median flow conditions at the Renton Gage station are above established instream flows throughout the year except during the month of October. However, from July through September, the median flow in the river is closely aligned to the established minimum flow requirements for a normal year flow.

The exceedence curves for the Cedar River at Renton, based on data from 1980 to 1993 (Figure 25), are similar to those based on the full period of record (Figure 24) but generally have lower values for a given exceedence curve. Based on the 1980 to 1993 data, flows in the river have at least a 10 percent probability of not meeting minimum flow requirements for normal year flow throughout most of the entire year. The median flow is close to, or below, the minimum flow requirements for normal year flow from July to October. The fact that established minimum instream flows frequently are not met likely results from decreased precipitation, the withdrawal of surface water, and the withdrawal of ground water in hydraulic continuity with surface water.

To characterize flow conditions in the watershed, flow exceedence curves also were developed for the Cedar River near Landsburg and Cedar Falls, for the Sammamish River near Woodinville, and for Issaquah Creek near the mouth (Figures 25 to 28). In general, flow rates are at their lowest level from July through October and reach their highest level from December through February. In the Cedar River near Landsburg, low flows (90% exceedence) range from 210 to 500 cfs throughout the year, while high flows (10% exceedence) vary from 460 to 1620 cfs (Figure 26). At the Cedar Falls Gage, low flows range from 40 to 170 cfs throughout the year, while high flows vary from 190 to 960 cfs (Figure 27). The increase in flows in the Cedar River from April through June indicate the influence of snowmelt from the headwaters, with this being most apparent .closer to the headwaters at the Cedar Falls Gage (Figure 26). In the Sammamish River near Woodinville, low flows range from 50 to 300 cfs throughout the year, while high flows vary from 100 to 1,070 cfs (Figure 28). In Issaquah Creek near the mouth, low flows range from 20 to 110 cfs throughout the year, while high flows vary from 50 to 510 cfs (Figure 29).

LOW FLOWS

The flow exceedence data presented and discussed above are based on the full period of flow record and provide no indication of flow trends over time. To evaluate trends in flow over time, seven-day minimum flow values were calculated for each year. The seven-day flow duration is conventionally used in evaluating low flows because shorter flow durations have much greater variability. A ten-year moving average was used to analyze trends in the data.

To evaluate low flow conditions; seven-day low flows, and corresponding ten-year moving averages, were calculated for each of the selected gage locations (Figures 29 to 32). The Cedar River Gage at Renton shows a downward trend in seven-day low flows from about 1956 until 1967, an upward trend from 1967 to about 1980, and a relatively flat ten-year average trend since 1980 (Figure 30). The 1956 to 1967 time period coincides with a generally greater than average precipitation at both Seatac and Chester Morse Lake Stations. The gage near Landsburg shows a slight, but consistent, increase in seven-day low flows from about 1945 with a relatively flat ten-year average over the last 20 years (Figure 31). Seven-day low flows at the Cedar Falls Gage show relatively lower values in recent years compared to those of the past (Figure 32). There is more variation in low flows at the Cedar Falls gage compared to the others, perhaps due to the influence of upstream flow controls. Reductions in average seven-day low flows have occurred over the last 20 years in the Sammamish River (Figure 33) and Issaquah Creek (Figure 34), although these rivers have been closed to further water rights during that period.

In the Cedar River at Renton, the number of days per year that flows were less than the established instream normal year and critical year flows was calculated. Normal year Cedar River minimum flows were not met an average of about 81 days per year at the Renton Gage since 1980. Ecology has never officially declared a critical year for Cedar River flows. However, for comparison purposes, critical year minimum flows were not met an average of about 15 days per year since 1980. A ten-year moving average was used to evaluate trends in recent years (Figures 35 and 36). Although the minimum instream flows were not established in WAC 173-508 until 1980, years prior to this time are shown to give a perspective of historical flow conditions. Since 1980, there appears to have been an upward trend in the number of days per year flows were less than required (normal year) instream flows at the Renton Gage (Figure 35). The trend since 1980 is less evident at the Renton Gage for the less stringent critical year instream flow requirements (Figure 36).

Landsburg weather station precipitation data were compared with mean annual flow and seven-day low flow for the Sammamish River near Woodinville and Issaquah Creek at the mouth (Figures 37 and 38). The units of rainfall were converted from inches to cfs by multiplying the rainfall amount by the basin area and dividing by the number of seconds in a year. There is an apparent declining trend in rainfall contributions from 1965 to 1992 amounting to 13 percent in the Sammamish River and 10 percent in Issaquah Creek. In the Sammamish River mean annual flow declined 34 percent and the decline in the seven-day low flow was about 8 percent (Figure 37). This lack of a significant trend in low flows is probably due to the storage capacity of Lake Sammamish and the buffering effect this has on low summer flows in the river. In Issaquah Creek, the decline in mean annual flow was 24 percent and the decline in seven-day low flow was 31 percent (Figure 38). The decline in rainfall undoubtedly accounts for a portion of the observed declines in mean annual flow and seven-day flow in these systems; however, additional factors, such as increased water demands and urbanization, appear to be responsible particularly in the Issaquah Creek Subbasin. .

INTERPRETATION OF STREAMFLOW STATUS

Based upon the preceding analyses, it is evident that maintaining established required flows is an issue in the Cedar River. Based on historical flow data for 1980 to 1993, established instream flows for normal year flow have a greater than ten percent probability of not being met for most of the year in the Cedar River at Renton. Based on the exceedence curves for the Renton Gage, there is also nearly a 50 percent probability that established normal year minimum flows will not be met from July through October (Figures 28 and 29). In the Sammamish River and Issaquah Creek, there is also evidence indicating declining low summer flows over the past 20 years (Figures 33 and 34).

Increasing demands for surface and ground water can affect low flows. Furthermore, increases in impervious surface areas from expanding urbanization reduces ground water recharge and can have compounded effects by further reducing low flows in the watershed. Evidence of impacts such as these were identified in the Sammamish River and Issaquah Creek. The impacts from increasing water demands and reduced ground water recharge would be of greater consequence during an extended period of below average precipitation.

DISCUSSION AND CONCLUSIONS

The Cedar-Sammamish Watershed is located primarily in King County with approximately 15 percent of the watershed in Snohomish County. The WRIA receives an average precipitation ranging between 38 to 102 inches per year, although during the past 15 to 20 years the watershed has experienced less than average precipitation as has been typical of the trends observed at other rain gages in western Washington. The 692-square mile watershed is comprised of two major subbasins (the Cedar River and the Sammamish River system) which converge into Lake Washington. The watershed is typified by a large number of small lakes, ponds, and wetlands.

The 1990 census population for the principal cities indicates more than 840,000 people reside within the incorporated areas in WRIA 8. All areas of the watershed are experiencing rapid population growth that affects both land use and water consumption. As area population grows, consumptive use of water will increase, particularly if alternative sources are not sufficient to meet demands. As surface waters are closed to development, increased demands have been placed on ground water sources.

The estimated total quantity of surface water rights and claims for consumptive use in the Cedar-Sammamish Watershed amount to a Qi of 1,145 cfs and a Qa of 481,837 acre-feet/year. This quantity is almost four times greater than the estimated quantity of ground water rights and claims which amount to a Qi of 332.5 cfs and a Qa of 93,533 acre-feet/year. The growth in ground water rights since the 1950's has been relatively constant, while the growth in surface water rights has increased more sporadically.

The assessment of water rights and claims in this report does not measure actual water use or verify water rights for a number of reasons. Unauthorized water users and recorded or claimed rights no longer exercised are factors that prevent correlation between the amount of water being used and the amount of water allocated by rights. No procedure is in place to track whether or not water rights issued in the past are still used. While numerous old water rights are assumed to be no longer used, unless a relinquishment form is received by Ecology, these water rights typically remain "on the books." Second, most water right claimants did not specify quantities on their claims; therefore, the quantities for claims had to be estimated. A survey of actual use is critical to proper management of the resource. Third, unauthorized withdrawal has been documented but not eliminated. Such water use should be investigated and enforcement action taken, where appropriate. Forth, ground water withdrawals of less than 5,000 gallons per day with certain use conditions are exempt from registration of that water right with Ecology. These water withdrawals are not tracked by Ecology.

Chapter 173-508 WAC closed many of the surface water bodies in WRIA 8 to further withdrawal including the entire Lake Washington drainage above the Chittenden Locks, with the exception of the Cedar River Subbasin. Normal instream flows and critical year instream flows were established for the Cedar River at the USGS gage station at Renton (12119000). Based on historical flow data for 1980 to 1993, established instream flows for normal year flow have a greater than ten percent probability of not being met most of the year in the Cedar River at Renton. Based on the exceedence curves for the Renton Gage, there is also nearly a 50 percent probability that established normal year minimum flows will not be met from July through October. In the Sammamish River and Issaquah Creek, there is also evidence indicating declining low summer flows over the past 20 years. Normal year Cedar River minimum flows were not met an average of about 81 days per year at the Renton Gage since 1980. Ecology has never officially declared a critical year for Cedar River flows. However, for comparison purposes critical year minimum flows were not met an average of about 15 days per year since 1980.

Chapter 173-509 WAC states that, "In future permitting actions relating to ground water withdrawals, the natural interrelationship of surface and ground water shall be fully considered in water allocation decisions to assure compliance with the intent in the chapter." Determining how ground water pumping in the various aquifers in WRIA 8 has effected Cedar River flows can be complex due to the overriding effects of the dam, Seattle's diversion, and the precipitation decline. In the Issaquah Creek Subbasin though, the relationship between ground water pumping and stream flow is much better understood.

The declining trend in static ground water levels in the Issaquah Valley Aquifer suggests that the aquifer is being dewatered. This appears to be a result of successive years of below normal rainfall, as well as increased withdrawals and loss of infiltration (recharge) due to urbanization. Issaquah Creek baseflow has significantly declined in the summer (indicated by the decline in seven-day low flow) as a result of decreased rainfall and a decrease in ground water discharge caused by lower aquifer water levels. There is also notable ground water decline in the Vashon advance shallow aquifer zones in the Sammamish Plateau Aquifer System as a result of increased withdrawal and loss of recharge due to recent urbanization.

Increasing demands for surface and ground water can affect low flows. Furthermore, increases in impervious surface areas from expanding urbanization reduce ground water recharge and can have compounded affects by further reducing low flows in the watershed. Evidence of impacts such as these were identified in the Sammamish River and, particularly, Issaquah Creek. The impacts from increasing water demands and reduced ground water recharge would be of greater consequence during an extended period of below average precipitation.

Surface and ground water quality are also adversely affected by rapid urbanization within the watershed. Maintenance of high quality water is necessary to preserve its beneficial uses. The majority of surface water quality problems within the Cedar-Sammamish Watershed are related to elevated levels of fecal coliform bacteria and total phosphorous, and excursions beyond criteria for dissolved oxygen levels. Excursions for heavy metals, pesticides and PCBs have also been measured in some locations. Many of the water bodies have been impaired for a number of uses including fish migration and spawning, and primary and secondary recreational uses, due to the presence of high fecal coliform bacteria and metals concentrations.

The list of contaminants of concern for ground water in the WRIA includes heavy metals, organic constituents, chlorides, nitrates, petrochemicals, coliform bacteria, cyanide, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxin, and pesticides. This information should not be used to imply that the ground water in the watershed is generally contaminated, but rather that specific pockets of ground water may be degraded. The ground water quality degradation in the watershed includes elevated nitrate concentrations, as well as other localized exceedences of State Ground Water Quality Standards.

Sources of impairment of both ground and surface water quality include urbanization, urban and highway runoff, landfills, and industrial discharges. Non-point sources of pollution include the cumulative effects of on-site septic systems and agricultural activities such as use of manure lagoons, and crop irrigation. Channelization and removal of riparian vegetation have had adverse impacts on surface water quality.

The salmonid habitats of the Cedar-Sammamish drainage have been severely impacted by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the drainage basin. In particular, this includes the Hiram Chittenden Locks and the associated fish ladder, built in 1916 at the outlet of Lake Washington and the Seattle Water Department's Landsburg diversion dam at river mile 21.8 on the mainstem Cedar River. Because of the blockage problems encountered, the overall habitat available for anadromous salmonid production has been limited to the lower 21.8 miles of the Cedar River Subbasin. Sockeye stocks from the Cedar River and tributaries of Lake Washington and Lake Sammamish are presently depressed based on long-term negative trends in freshwater survival rates and escapement levels. Lake Washington winter run steelhead and coho salmon of mixed stock in Lake Washington and Lake Sammamish are also classified as depressed. Despite these limits, the habitat that is available for spawning salmon in the lower watershed is rated fair to excellent.

Any assessment of water resource allocation should consider the water-related conflicts in the watershed. A number of conflicting uses and interests exist in the Cedar-Sammamish Watershed. To properly manage water within a basin, all water consumption within the watershed should be known. Pre-existing federally-granted, tribal water rights for consumptive water use may not be completely quantified and because some dispute surrounds the quantification of these rights, current water resource management and future planning are limited in their accuracy. Because water is critical to the maintenance of all communities within the watershed, every effort should be made to ensure that the resource can be accurately quantified for management and planning purposes.

The Puyallup and the Muckelshoot Tribes have claimed fishing rights within the watershed that are considered to be from time immemorial. State regulations dictate that water quality and quantity be maintained. The threat of an adjudication associated with the Bolt Phase II decision may compel a negotiated settlement above and beyond current statutory mandates.

Currently, the City of Seattle, Ecology, the Muckelshoot Indian Tribe, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the Washington Department of Fish and Wildlife are negotiating instream flows in the Cedar River. Although its claim to divert water at Landsburg is not subject to Chapter 173-508 WAC, Seattle has taken responsibility for maintaining Cedar River instream flows. As Seattle's physical ability to control the Cedar River ends at Landsburg, it views its interest as better served if instream flows were established at that location. Instream flows at Landsburg would not be affected by downstream surface water withdrawals or ground water pumping in hydraulic continuity with the Cedar River. Because of the tribe's interest in maintaining fishing habitat as it relates to fishing rights, they are concerned about this proposed change.

RECOMMENDATIONS

Thus initial watershed assessment relied on existing information. There are an abundance of reports on the study area, but there are some specific areas where data were lacking. The following recommendations call for additional information that will be helpful if a more comprehensive watershed assessment is conducted in the future.

- All currently active weather stations and USGS stream flow gages should continue to be monitored and properly maintained.

- An active water level monitoring network should be established for all major users of ground water within the watershed. A government agency should be made responsible for maintaining a database. Data gathering should be coordinated to include static water level and water quality parameters, with static water levels measured at least monthly. This monitoring program could enlist the assistance of the GWMA programs within the watershed as a partial database.

- Additional study should be conducted regarding the relationships between the deeper aquifers in the WRIA (such as beneath the Sammamish Plateau) and the surface waters.

- Actual water use within the basin should be determined through a system of annual reporting. This activity may lead to relinquishment of unused rights and improve the technical analyses of water use effects.

- Unauthorized water withdrawal should be investigated and enforcement action should be taken to cease unauthorized use. This action could return water to the system and may improve streamflow and water quality conditions in localized areas.

- Additional study should be conducted to determine how salmon are adversely affected by low flows, as well as other habitat removal factors such as channelization, vegetation removal, and gravel mining.

- Water quality data that are gathered for ground and surface water in the watershed should be consolidated into a single database and access provided in a user-friendly electronic format.

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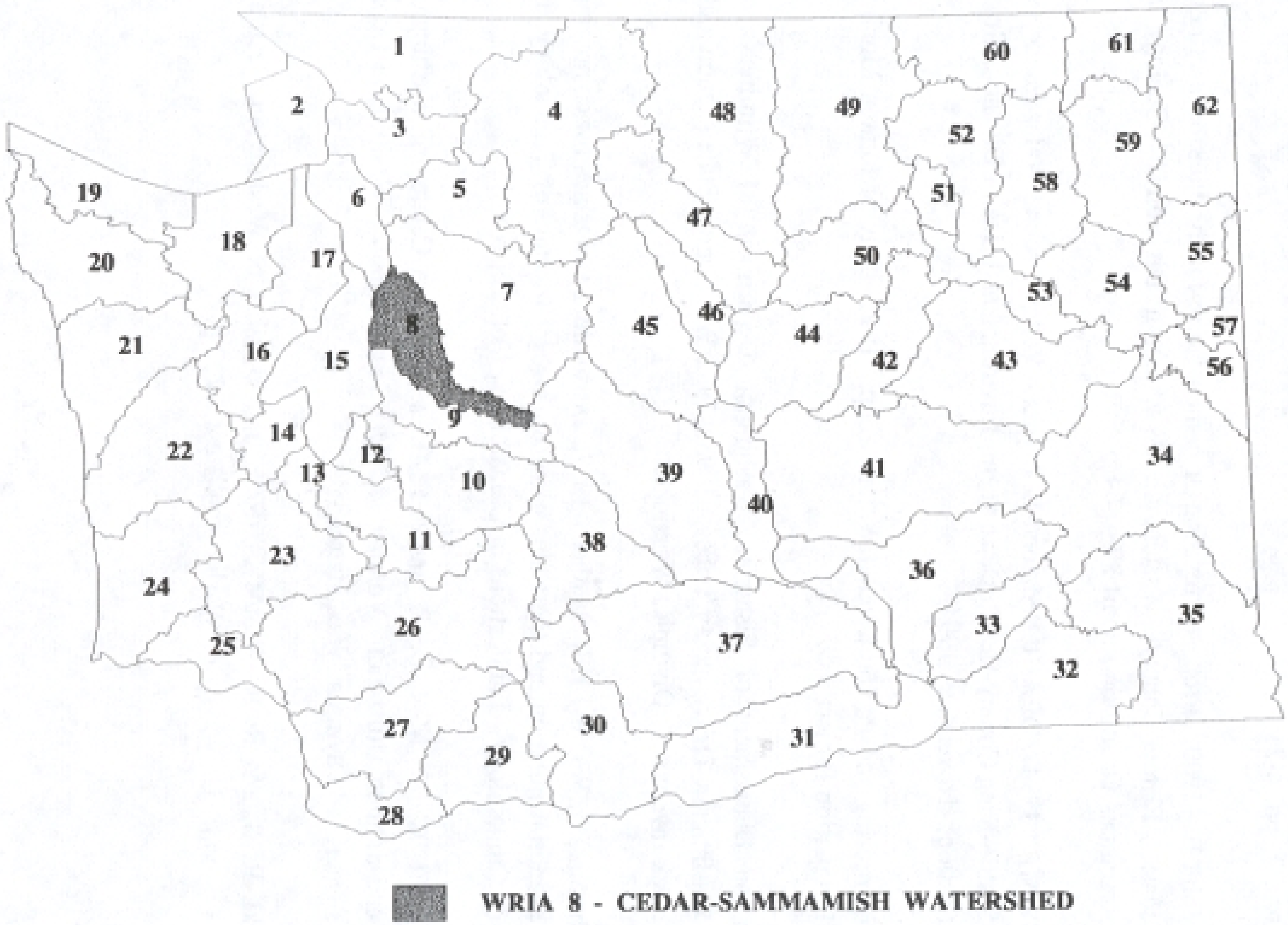
Figure 1: Water Resource Inventory Area (WRIA) Locator Map



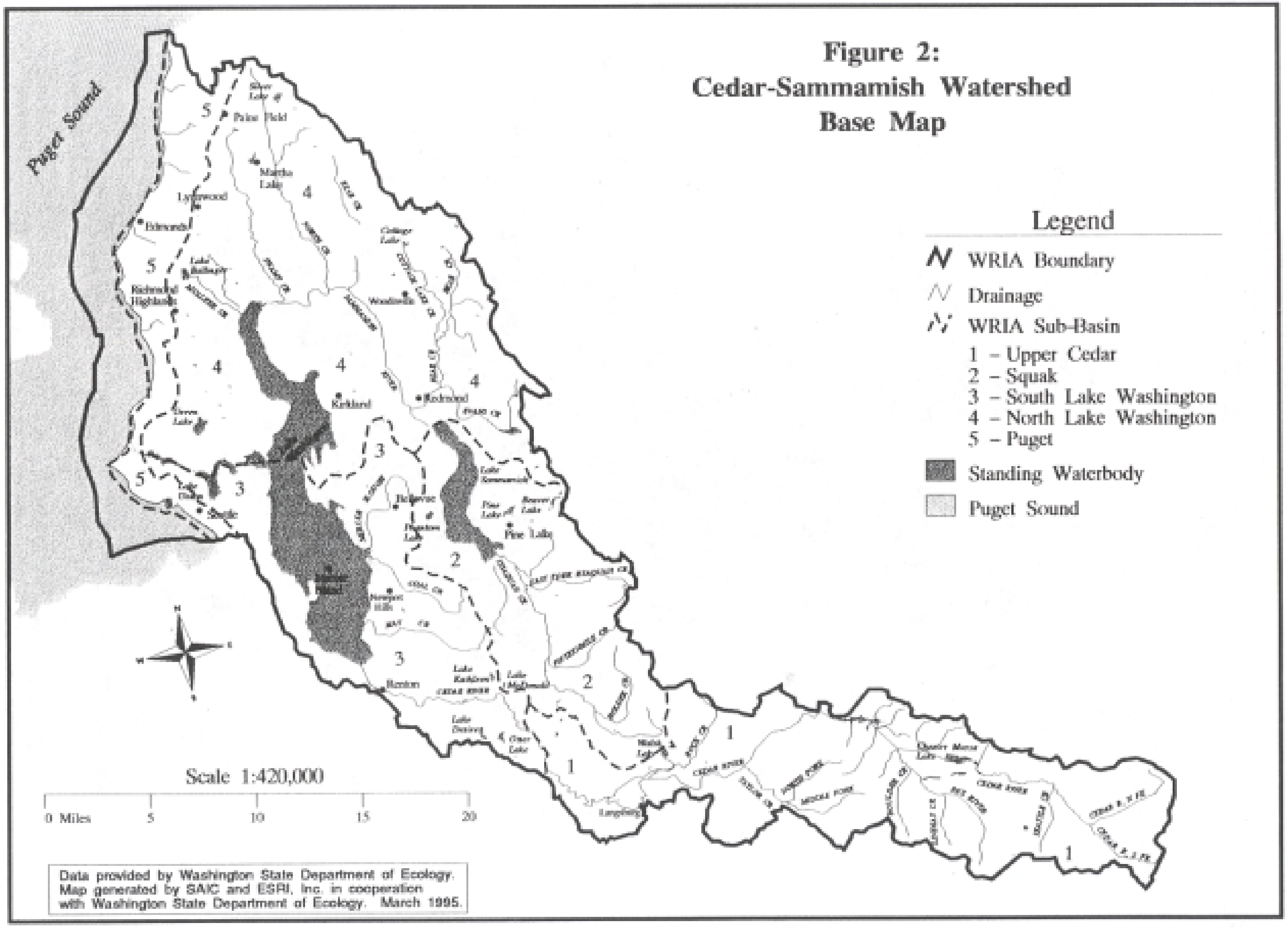
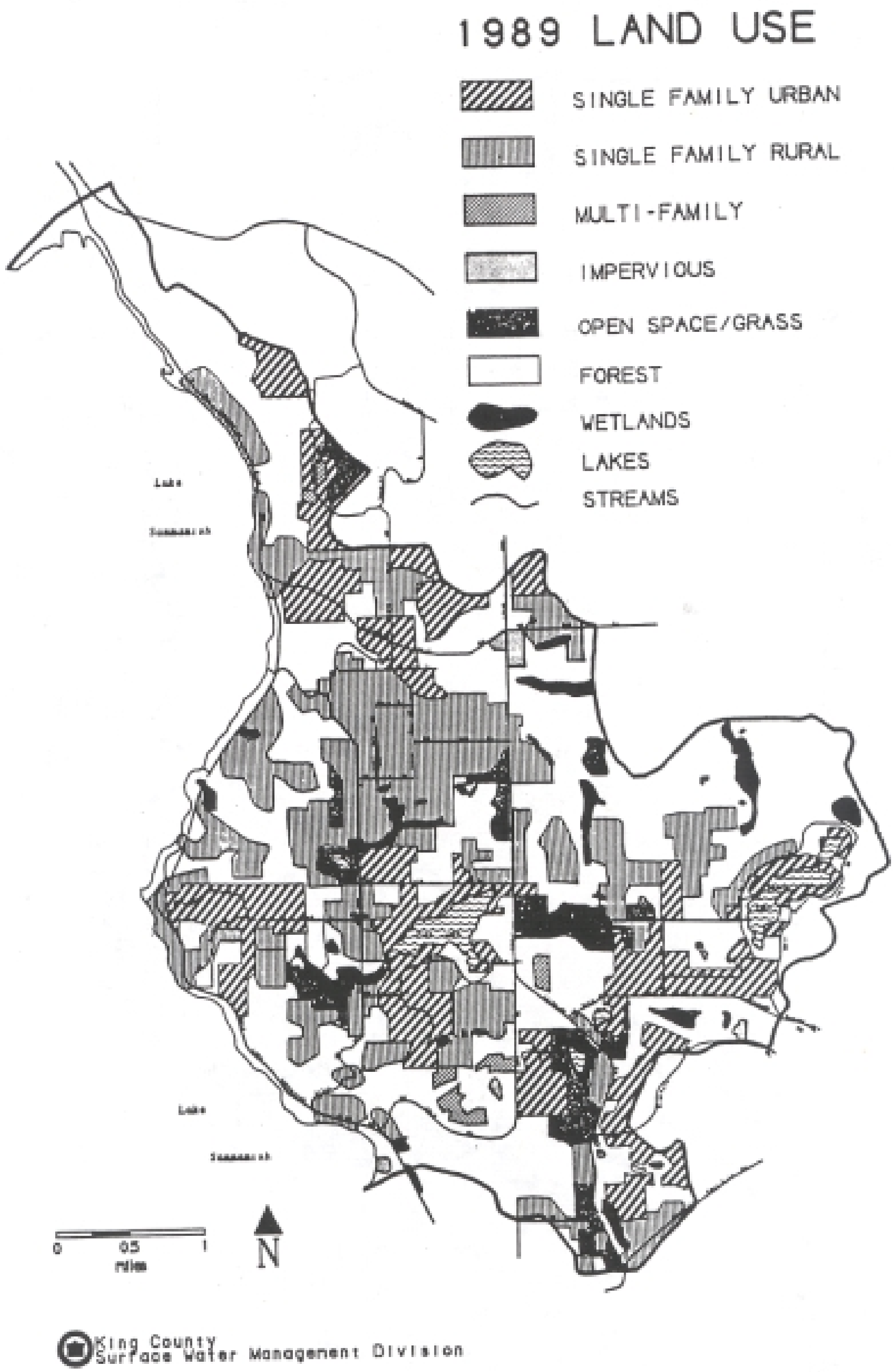


Figure 2:
Cedar-Sammamish Watershed
Base Map
Legend
WRIA Boundary
Drainage
WRIA Sub-Basin
1 – Upper Cedar
2 – Squak
3 – South Lake Washington
4 – North Lake Washington
5 – Puget
Standing Waterbody
Puget Sound
Puget Sound
Scale 1:420,000
0 Miles
5
10
15
20
Data provided by Washington State Department of Ecology.
Map generated by SAIC and ESRI, Inc. in cooperation
with Washington State Department of Ecology. March 1995.
Edmonds
Kirkland
Redmond
Woodinville
Seattle
Bellevue
Renton
Pine Lake
Richmond Highlands

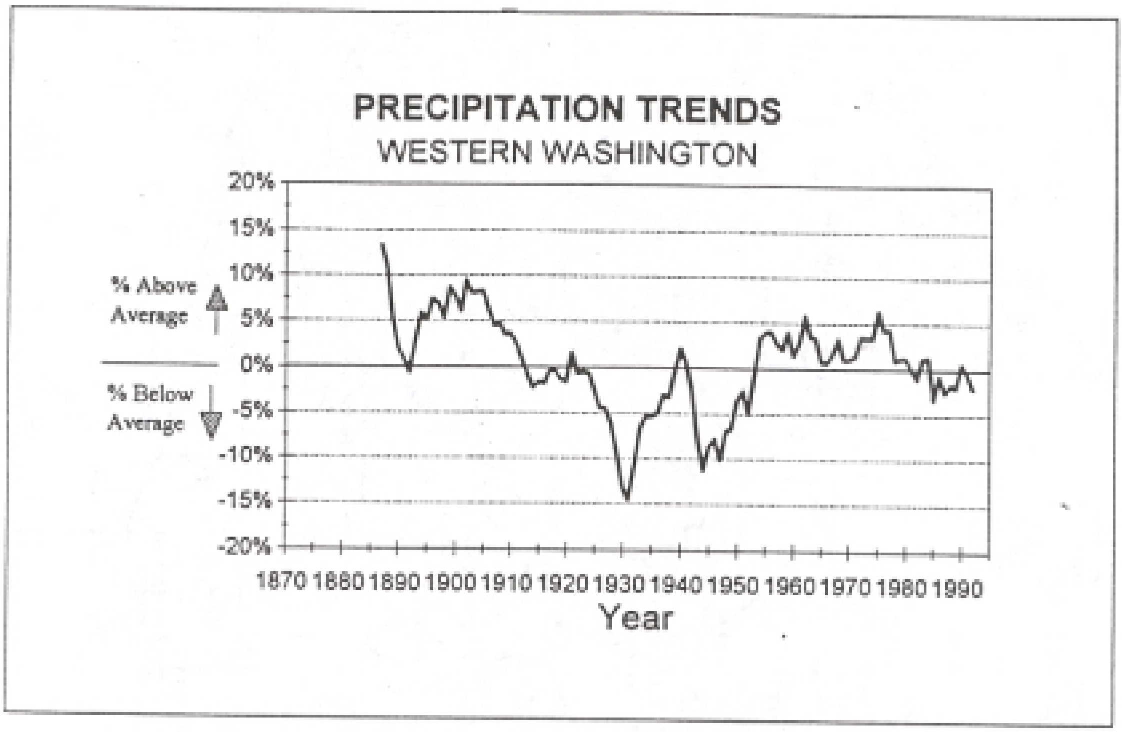


EAST LAKE SAMMAMISH BASIN
CONDITIONS REPORT - PRELIMINARY ANALYSIS
SEPTEMBER, 1990

Figure 3. East Lake Sammamish Basin 1989 Land Use

Figure 4. Western Washington Precipitation Stations Used to Calculate Trends

Figure 5. Precipitation Trends in Western Washington



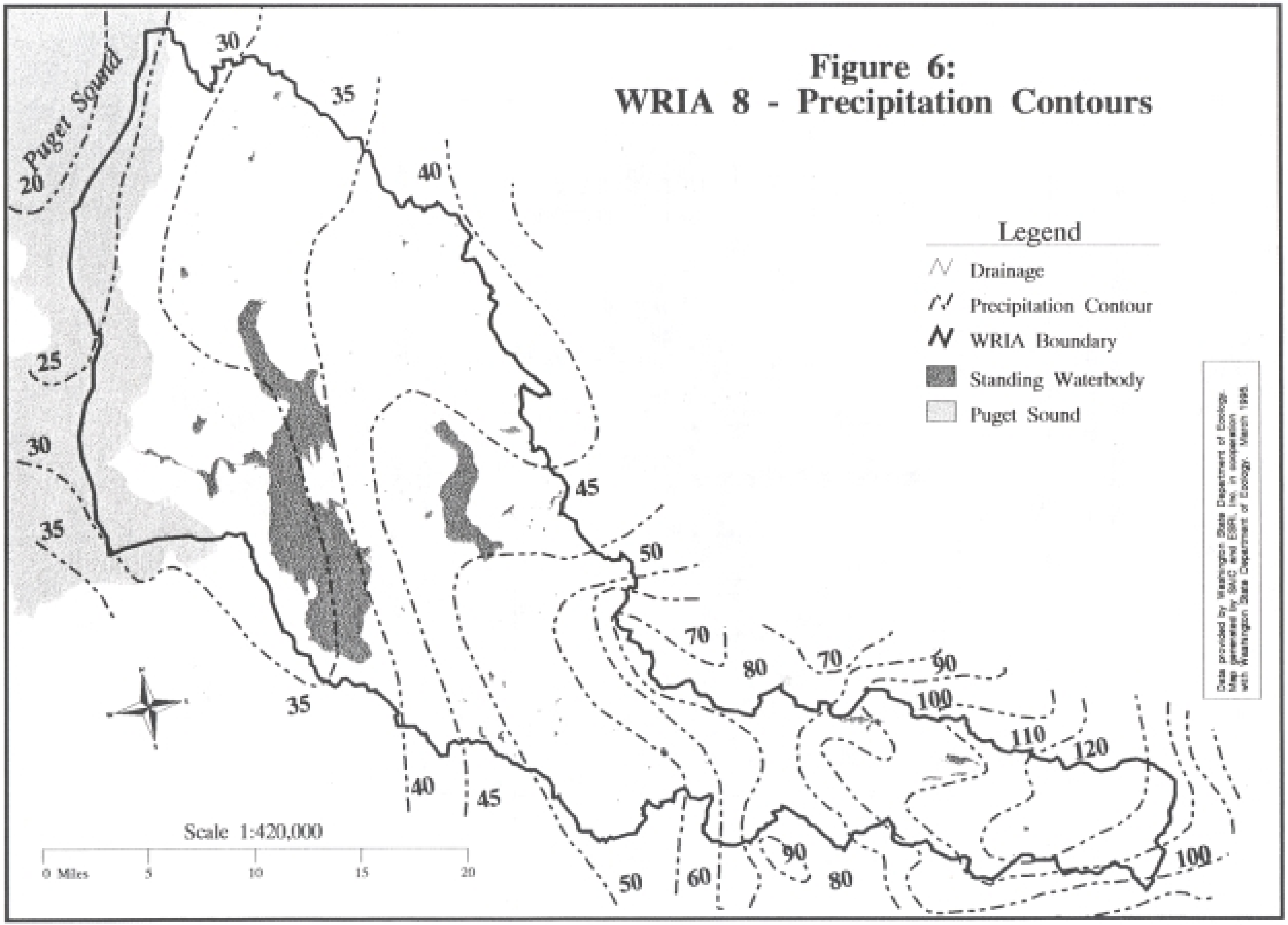


Figure 6:
WRIA 8 - Precipitation Contours

FIGURE 7 - PRECIPITATION MEASURED AT SEATAC AIRPORT - 10-YEAR MOVING AVERAGE

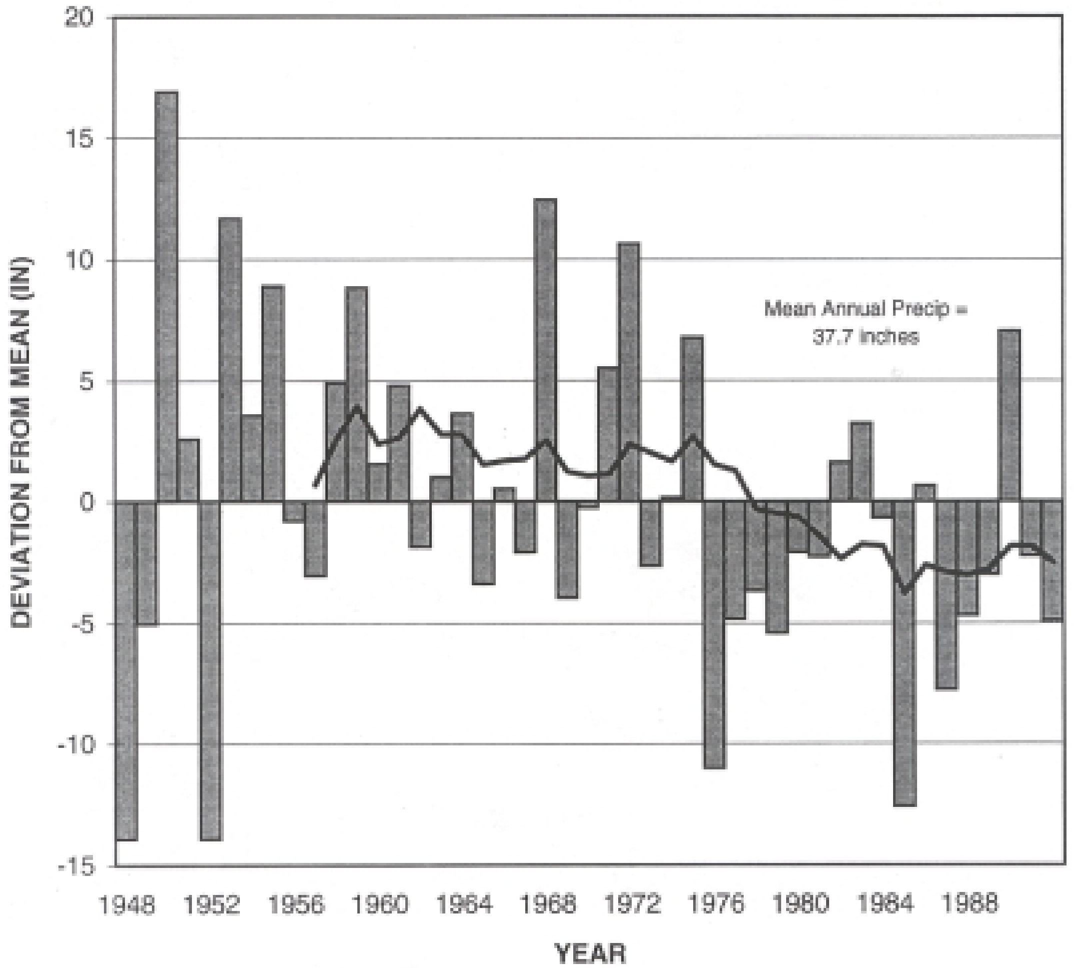


FIGURE 8 - PRECIPITATION MEASURED AT CHESTER MORSE - 10-YEAR MOVING AVERAGE

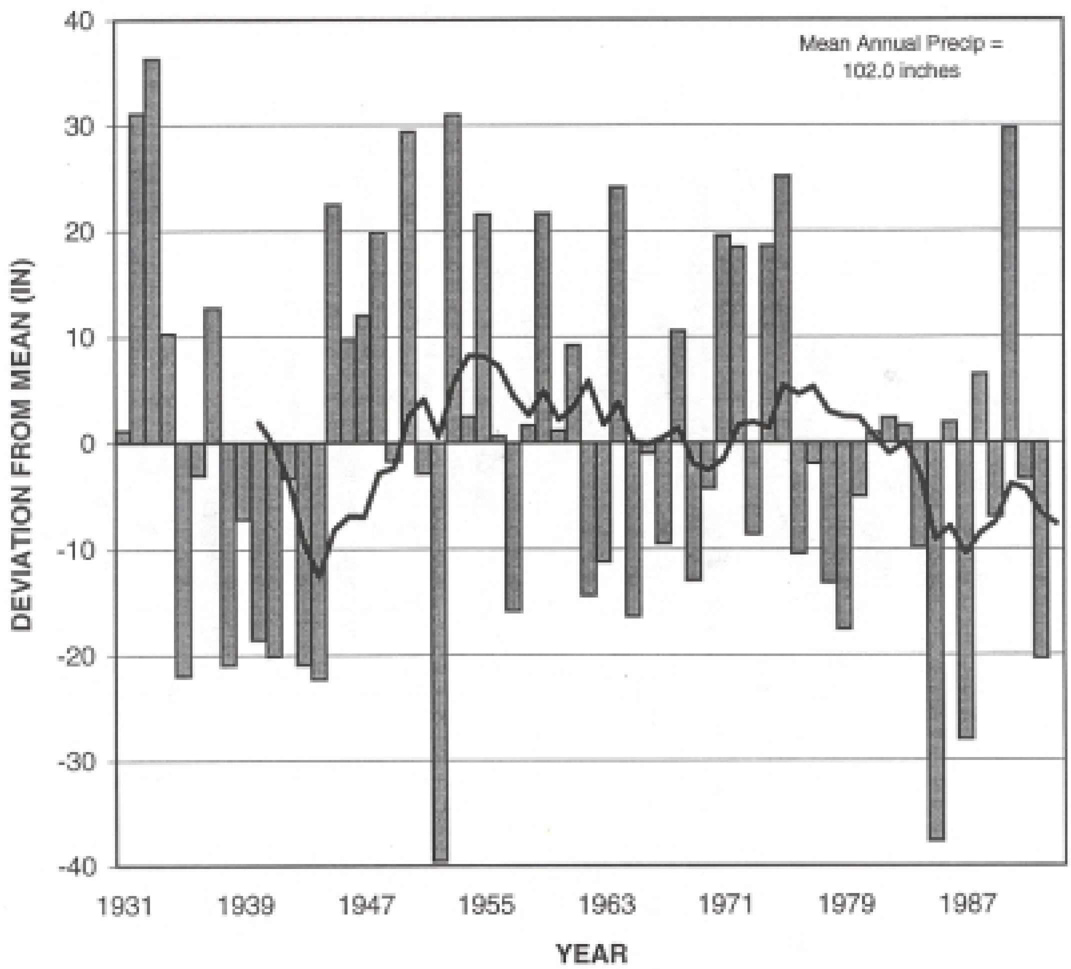
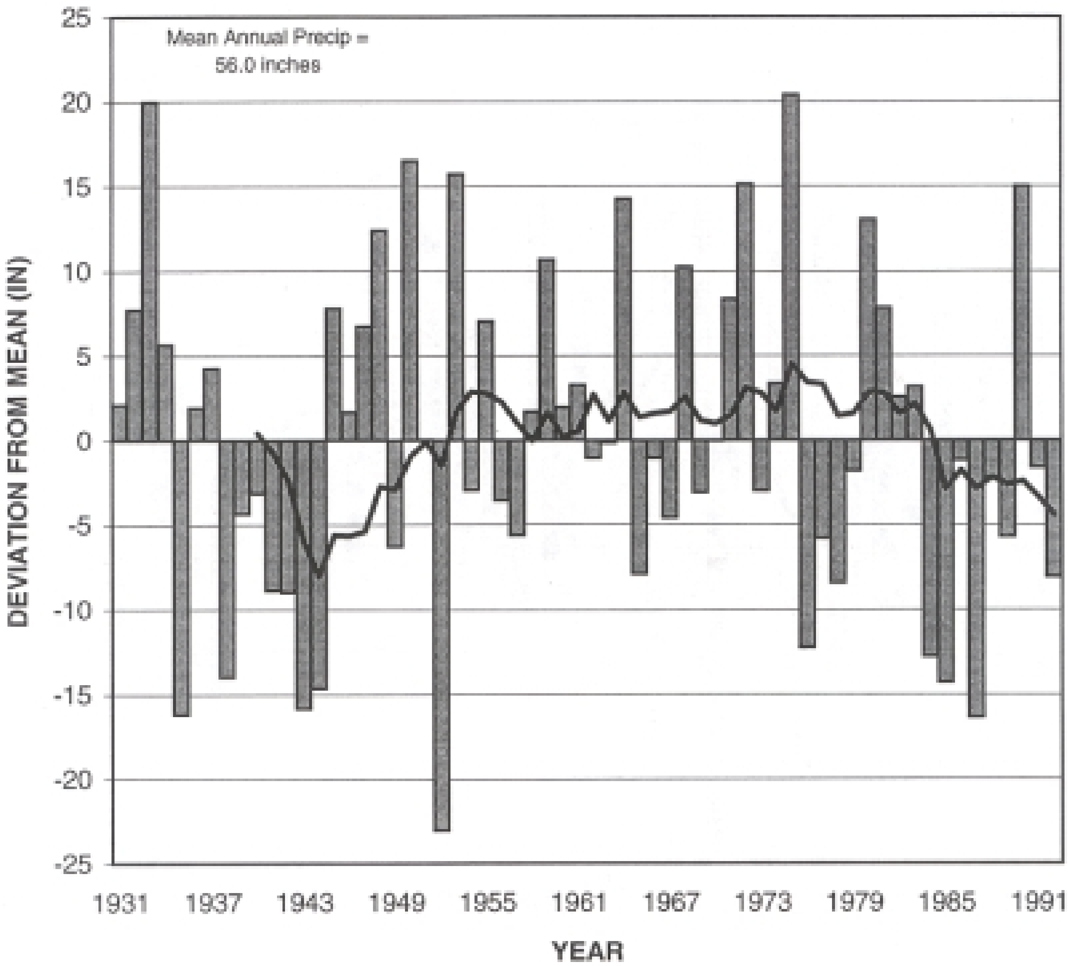


FIGURE 9 - PRECIPITATION MEASURED AT LANDSBURG - 10-YEAR MOVING AVERAGE



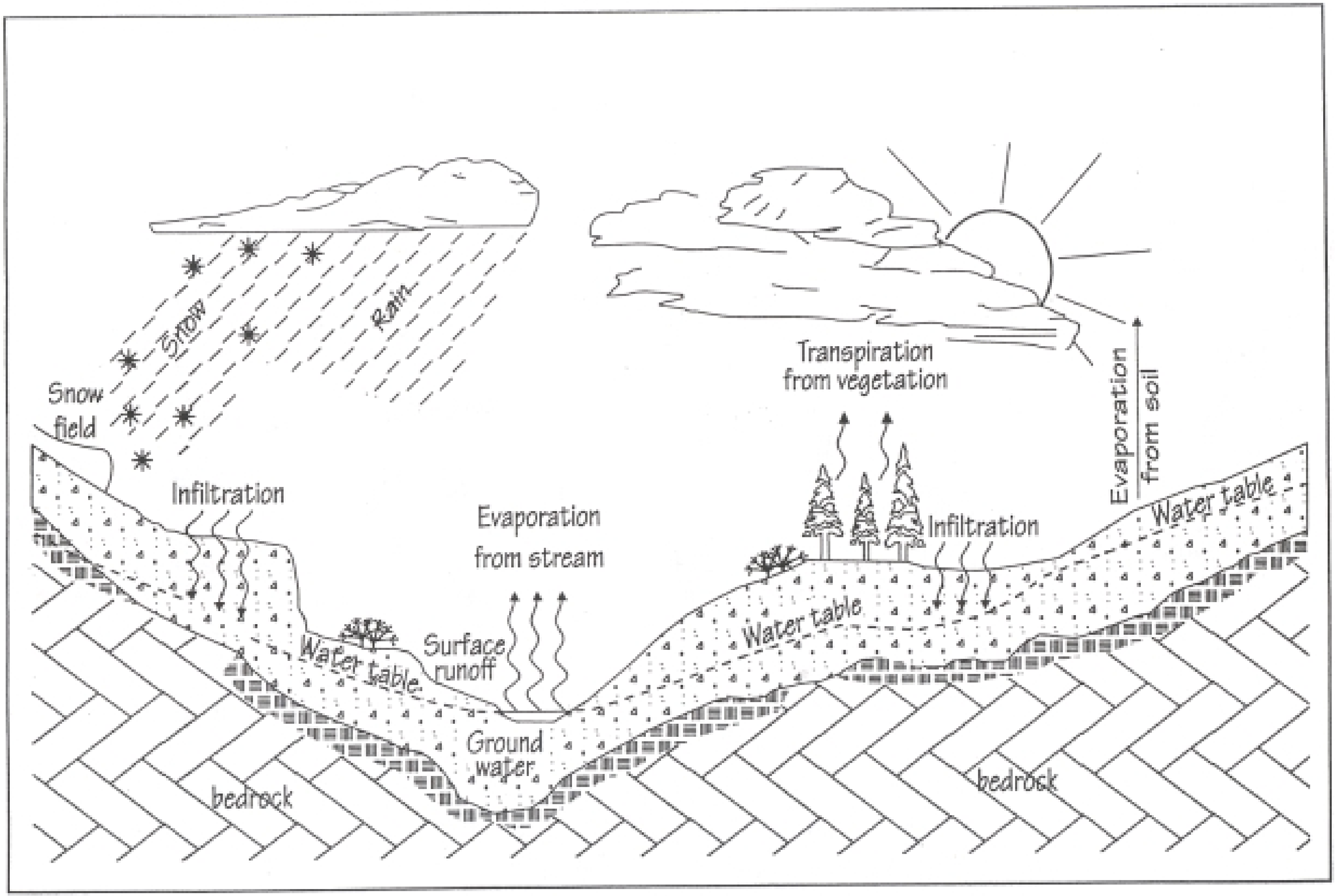


Figure 10. The Hydrologic Cycle

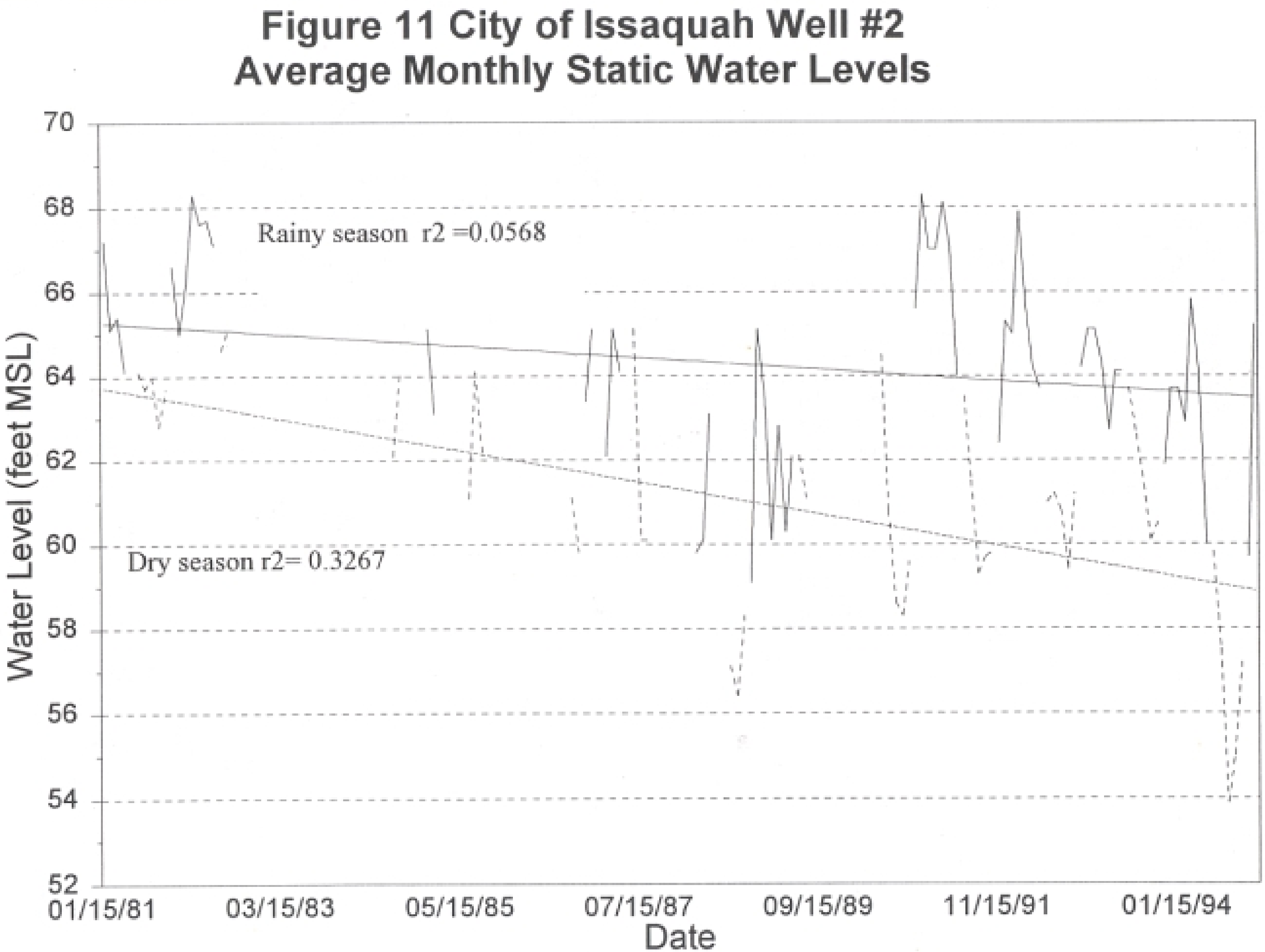


Figure 11 City of Issaquah Well #2
Average Monthly Static Water Levels
Water Level (feet MSL)
70
68
66
64
62
60
58
56
54
52
Rainy season r2 =0.0568
Dry season r2= 0.3267
01/15/81
03/15/83
05/15/85
07/15/87
09/15/89
11/15/91
01/15/94
Date

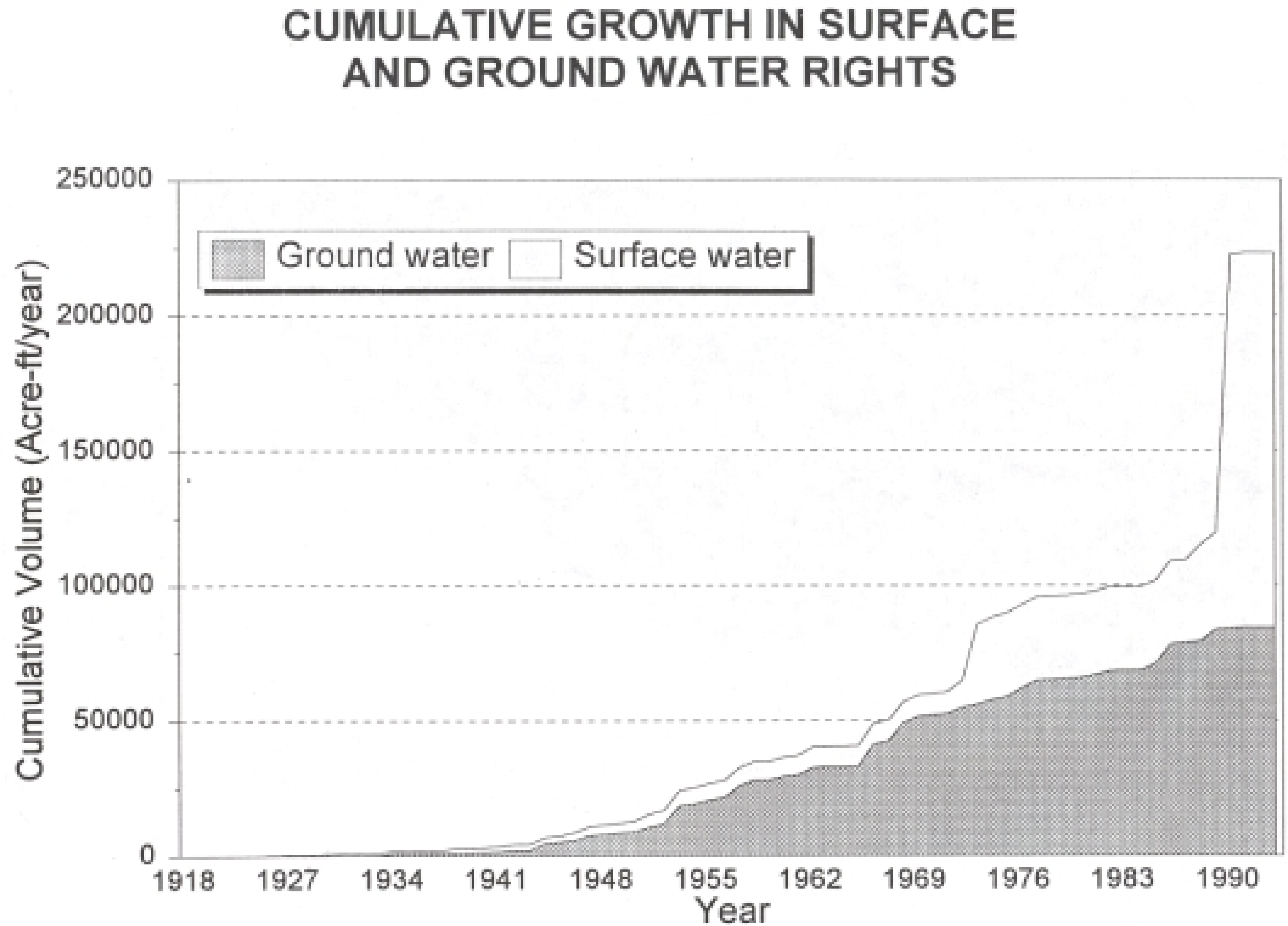

CUMULATIVE GROWTH IN SURFACE
AND GROUND WATER RIGHTS
Ground water
Surface water
Cumulative Volume (Acre-ft/year)
250000
200000
150000
100000
50000
0
1918
1927
1934
1941
1948
1955
1962
1969
1976
1983
1990
Year

Figure 12

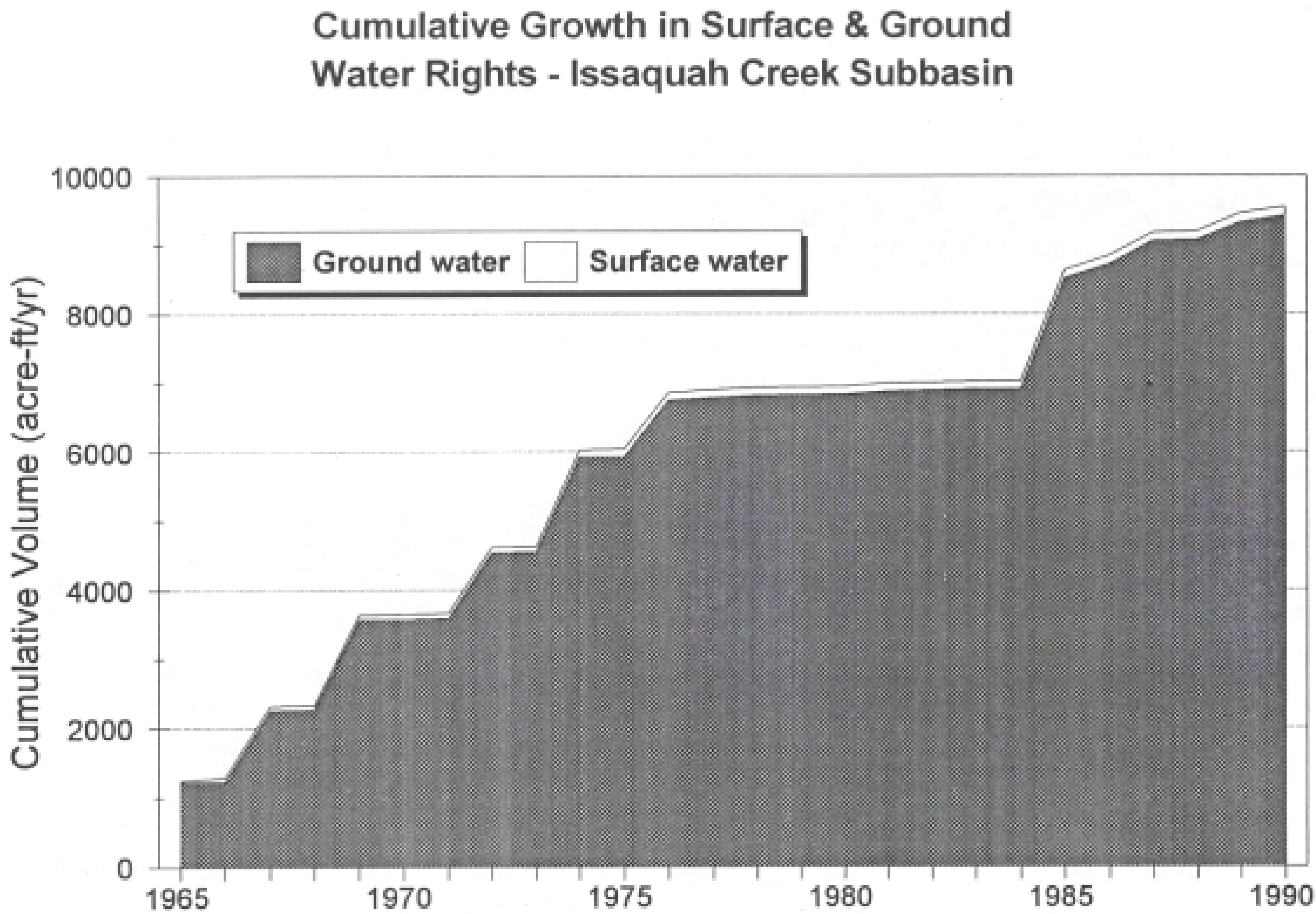

Cumulative Growth in Surface & Ground
Water Rights - Issaquah Creek Subbasin
Ground water
Surface water
Cumulative Volume (acre-ft/yr)
10000
8000
6000
4000
2000
0
1965
1970
1975
1980
1985
1990
Year

Figure 13

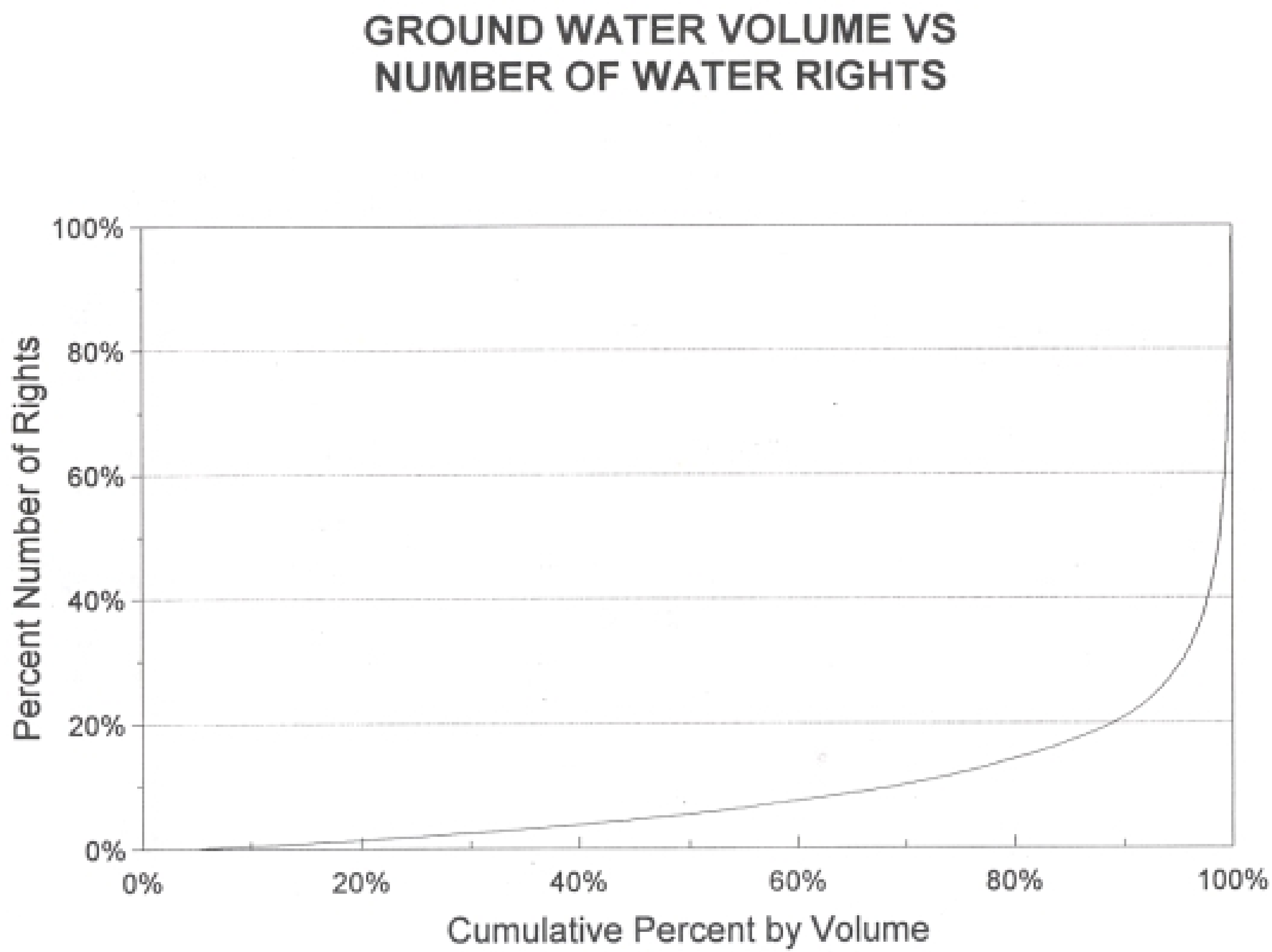

GROUND WATER VOLUME VS
NUMBER OF WATER RIGHTS
100%
80%
60%
40%
20%
0%
Percent Number of Rights
0%
20%
40%
60%
80%
100%
Cumulative Percent by Volume

Figure 14

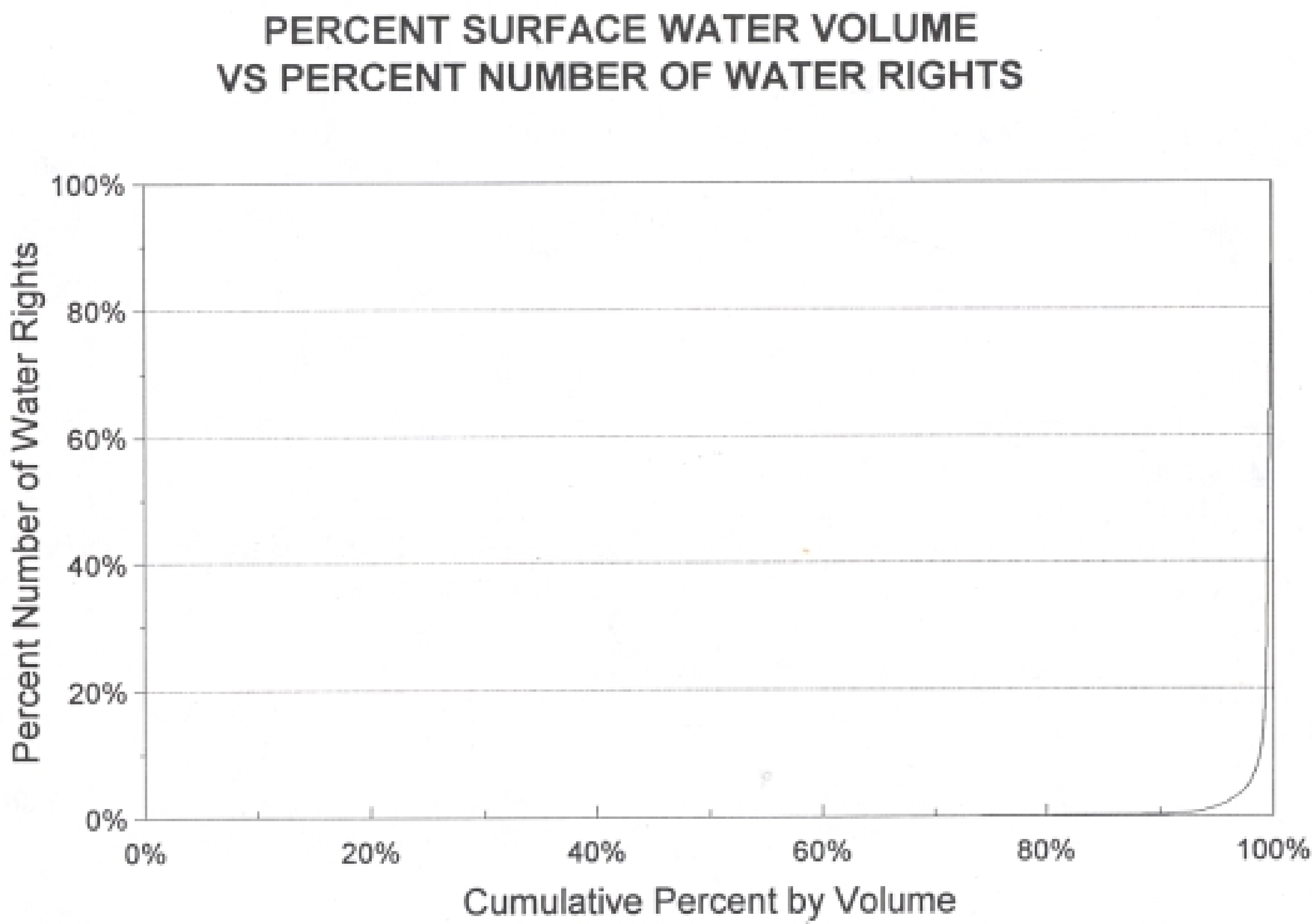

PERCENT SURFACE WATER VOLUME
VS PERCENT NUMBER OF WATER RIGHTS
Percent Number of Water Rights
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
100%
Cumulative Percent by Volume

Figure 15

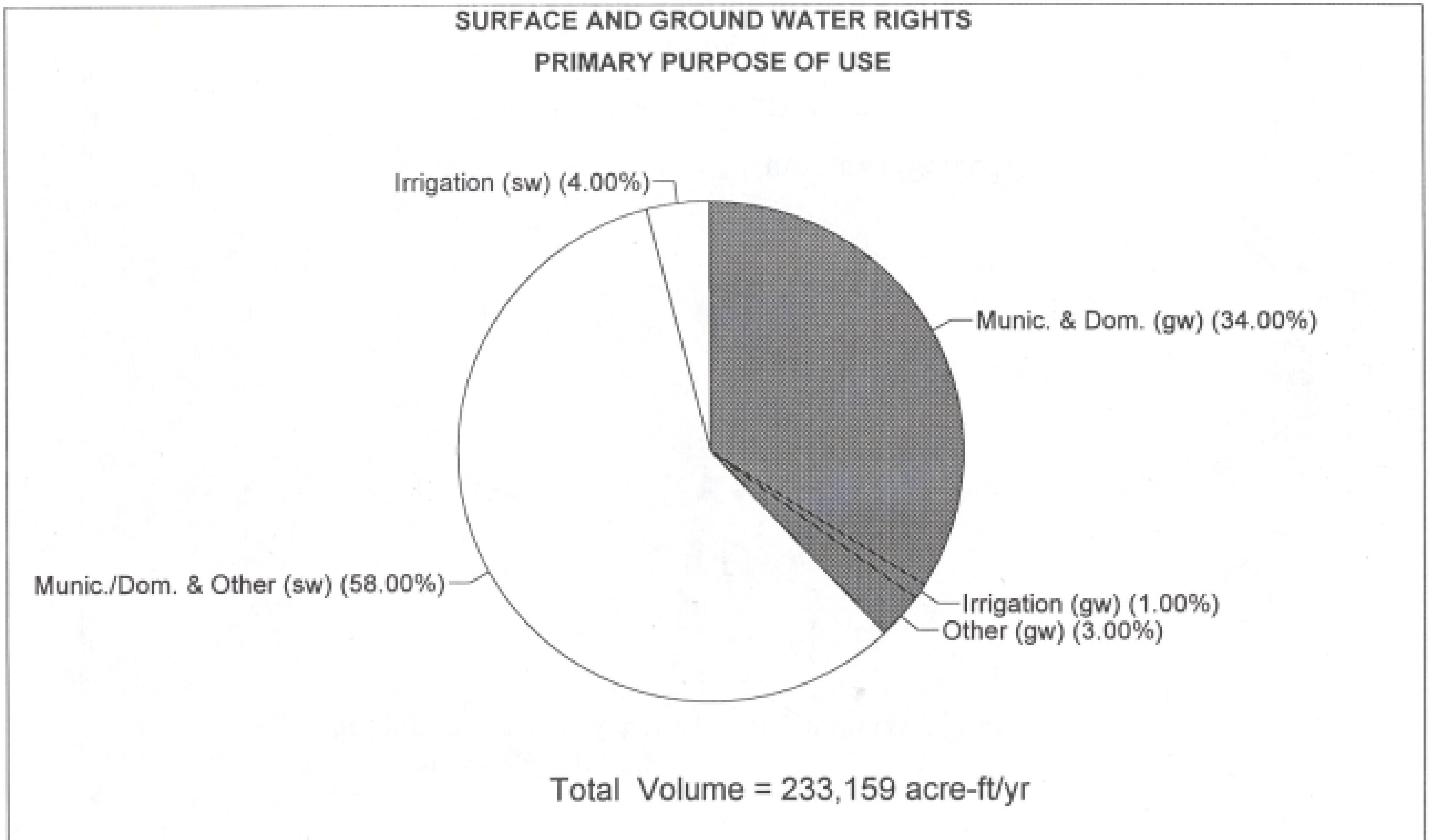

SURFACE AND GROUND WATER RIGHTS
PRIMARY PURPOSE OF USE
Irrigation (sw) (4.00%)
Munic. & Dom. (gw) (34.00%)
Munic./Dom. & Other (sw) (58.00%)
Irrigation (gw) (1.00%)
Other (gw) (3.00%)
Total Volume = 233,159 acre-ft/yr

Figure 16

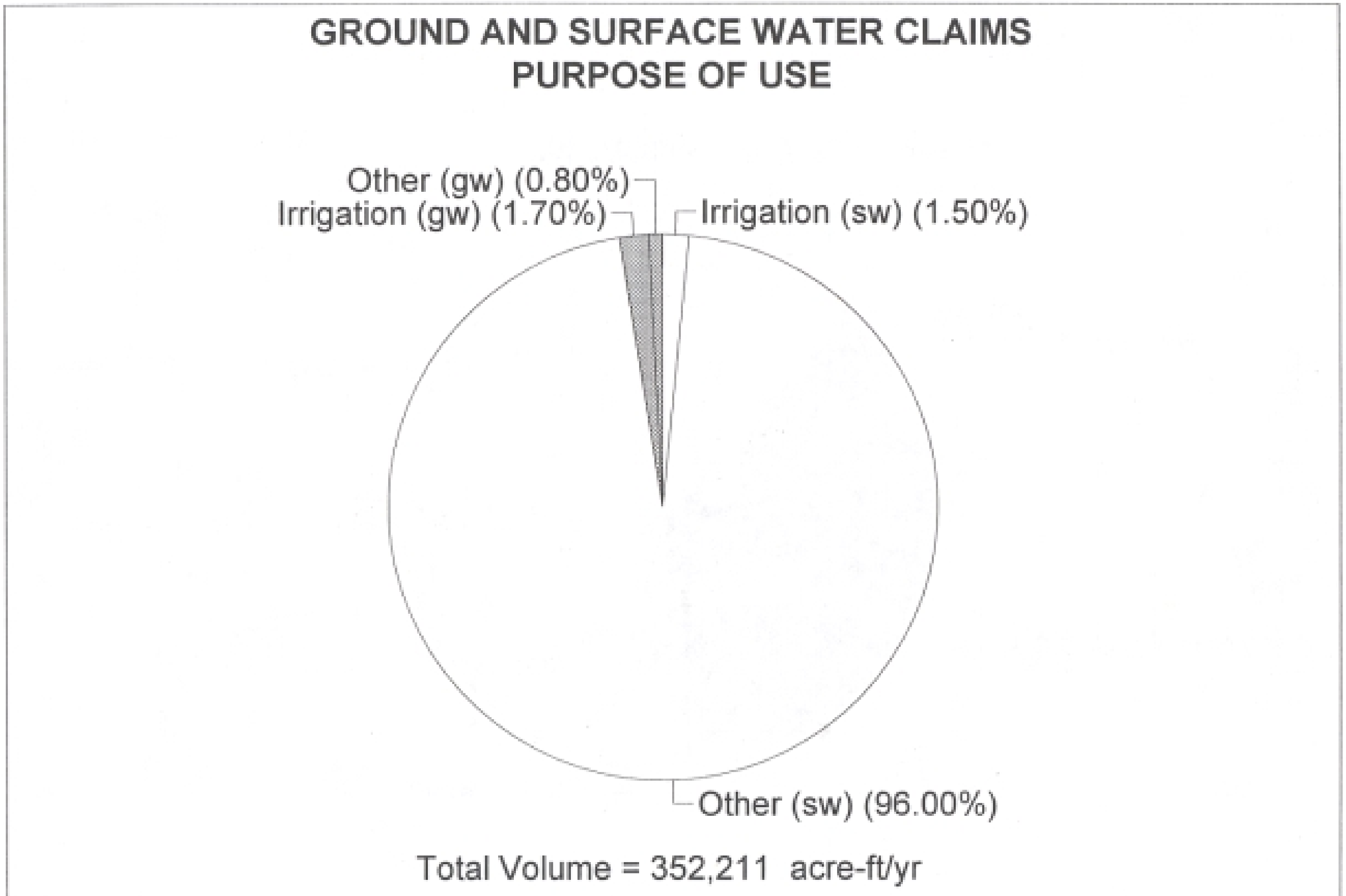

GROUND AND SURFACE WATER CLAIMS
PURPOSE OF USE
Other (gw) (0.80%)
Irrigation (gw) (1.70%)
Irrigation (sw) (1.50%)
Other (sw) (96.00%)
Total Volume = 352,211 acre-ft/yr

Figure 17

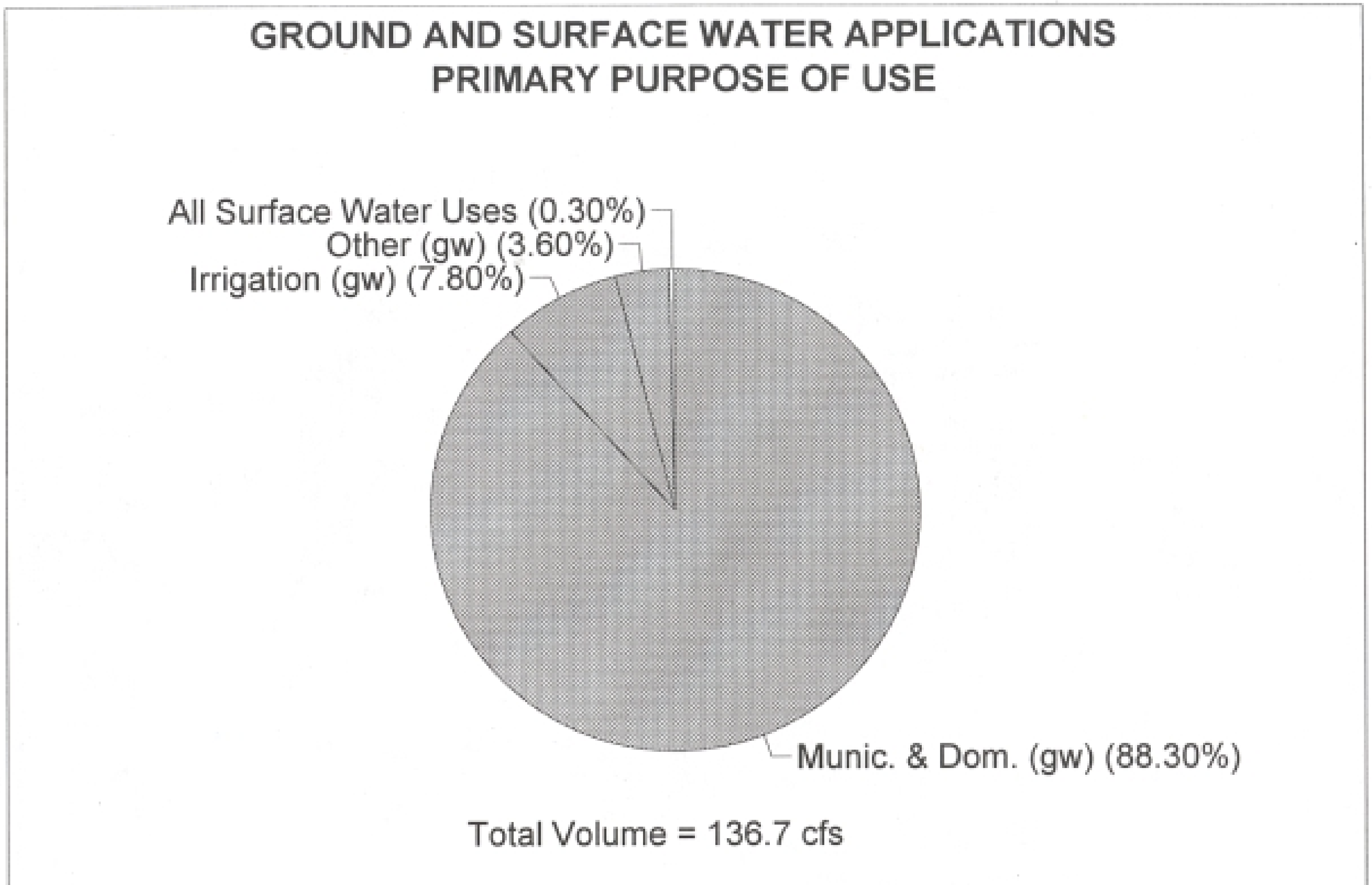

GROUND AND SURFACE WATER APPLICATIONS
PRIMARY PURPOSE OF USE
All Surface Water Uses (0.30%)
Other (gw) (3.60%)
Irrigation (gw) (7.80%)
Munic. & Dom. (gw) (88.30%)
Total Volume = 136.7 cfs

Figure 18

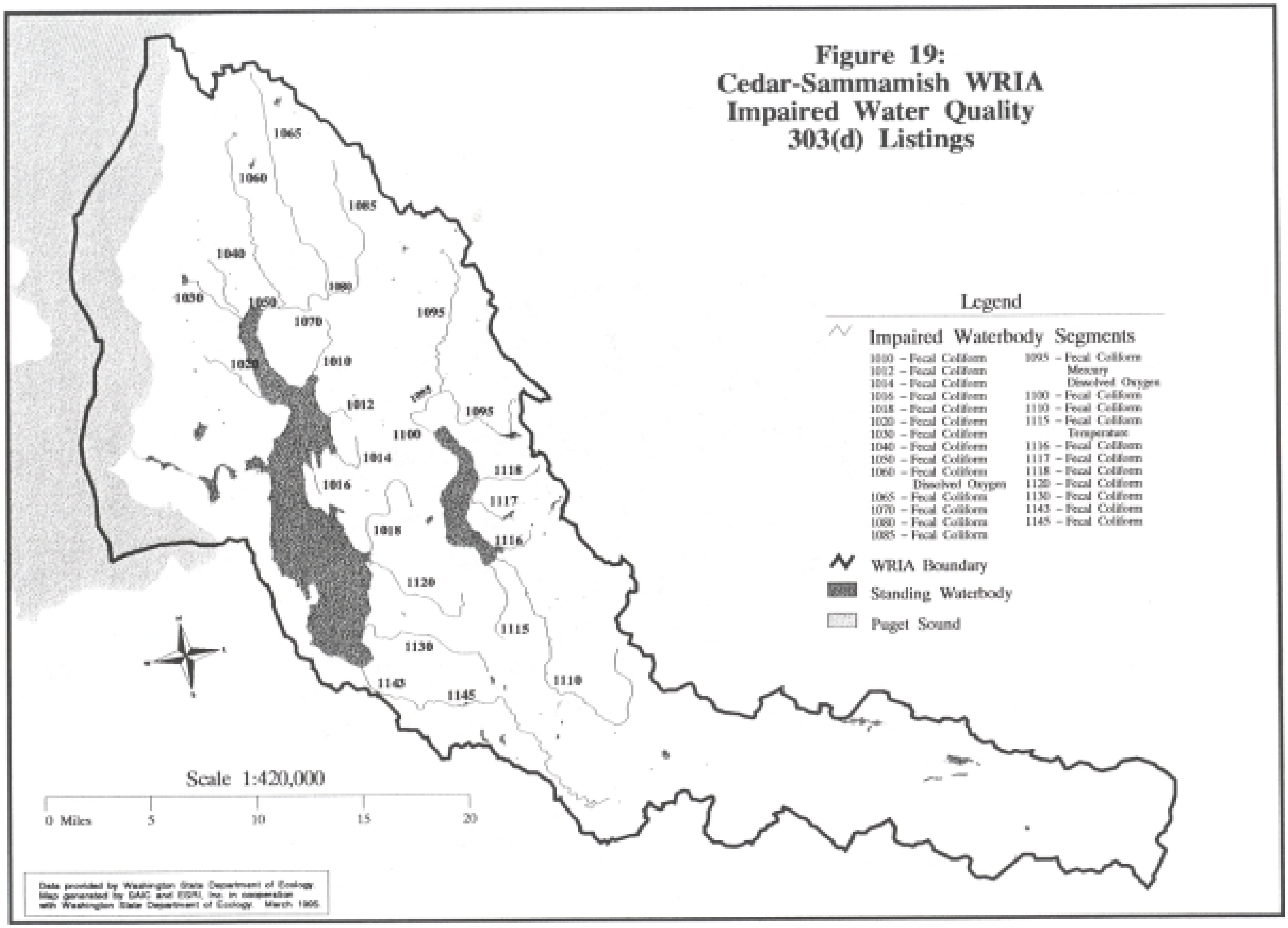


Figure 19:
Cedar-Sammamish WRIA
Impaired Water Quality
303(d) Listings
1065
1060
1085
1040
1030
1050
1080
1070
1095
1020
1010
1012
1100
1095
1014
1016
1118
1117
1018
1116
1120
1115
1130
1110
1143
1145
Legend
Impaired Waterbody Segments
1010 – Fecal Coliform
1012 – Fecal Coliform
1014 – Fecal Coliform
1016 – Fecal Coliform
1018 – Fecal Coliform
1020 – Fecal Coliform
1030 – Fecal Coliform
1040 – Fecal Coliform
1050 – Fecal Coliform
1060 – Fecal Coliform
Dissolved Oxygen
1065 – Fecal Coliform
1070 – Fecal Coliform
1080 – Fecal Coliform
1085 – Fecal Coliform
1095 – Fecal Coliform
Mercury
Dissolved Oxygen
1100 – Fecal Coliform
1110 – Fecal Coliform
1115 – Fecal Coliform
Temperature
1116 – Fecal Coliform
1117 – Fecal Coliform
1118 – Fecal Coliform
1120 – Fecal Coliform
1130 – Fecal Coliform
1143 – Fecal Coliform
1145 – Fecal Coliform
WRIA Boundary
Standing Waterbody
Puget Sound
Scale 1:420,000
0 Miles
5
10
15
20
Data provided by Washington State Department of Ecology.
Map generated by SAIC and ESRI, Inc. in cooperation
with Washington State Department of Ecology.

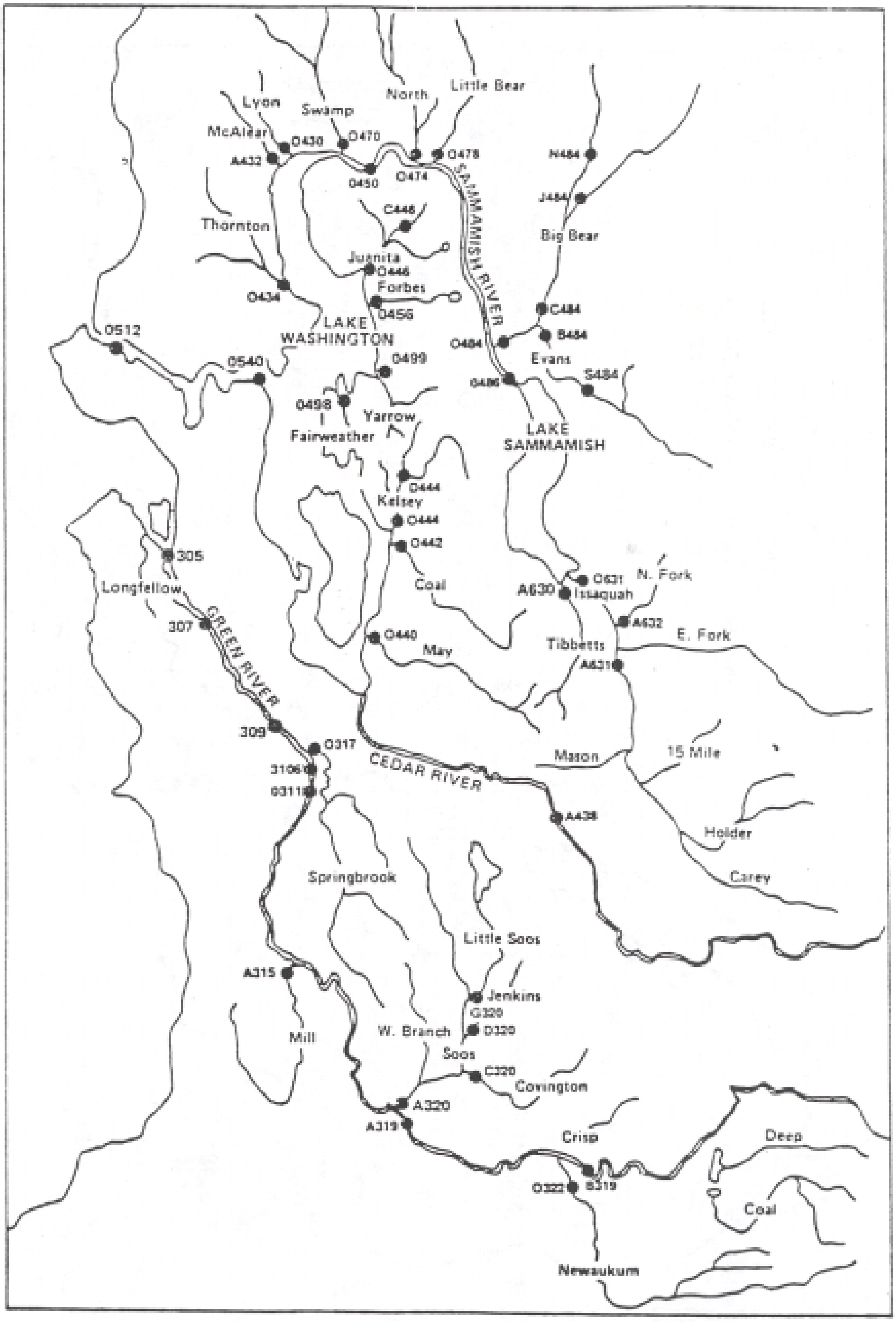


Figure 20. Metro Ambient Water Quality Monitoring Stations

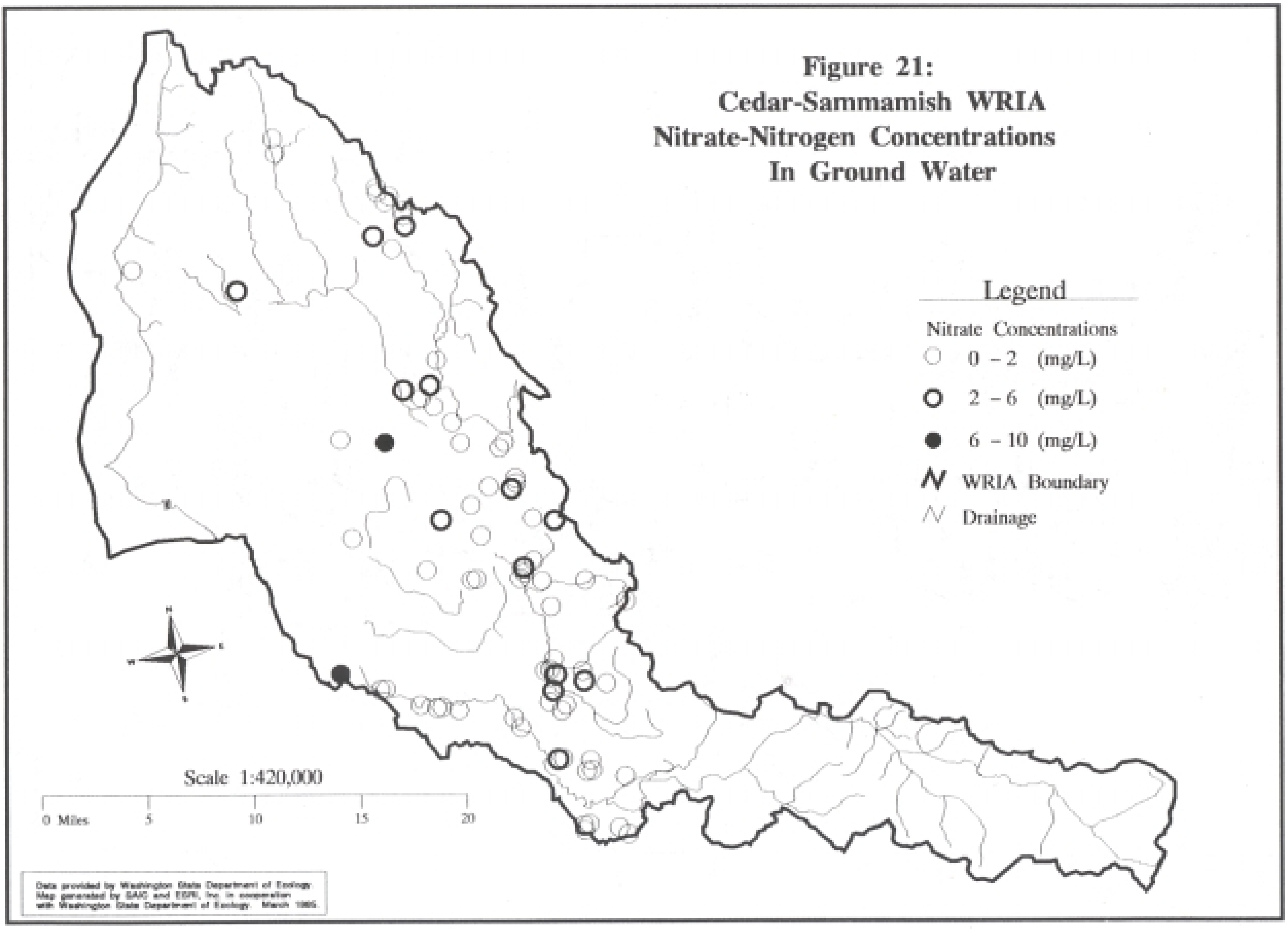


Figure 21: Cedar-Sammamish WRIA Nitrate-Nitrogen Concentrations In Ground Water

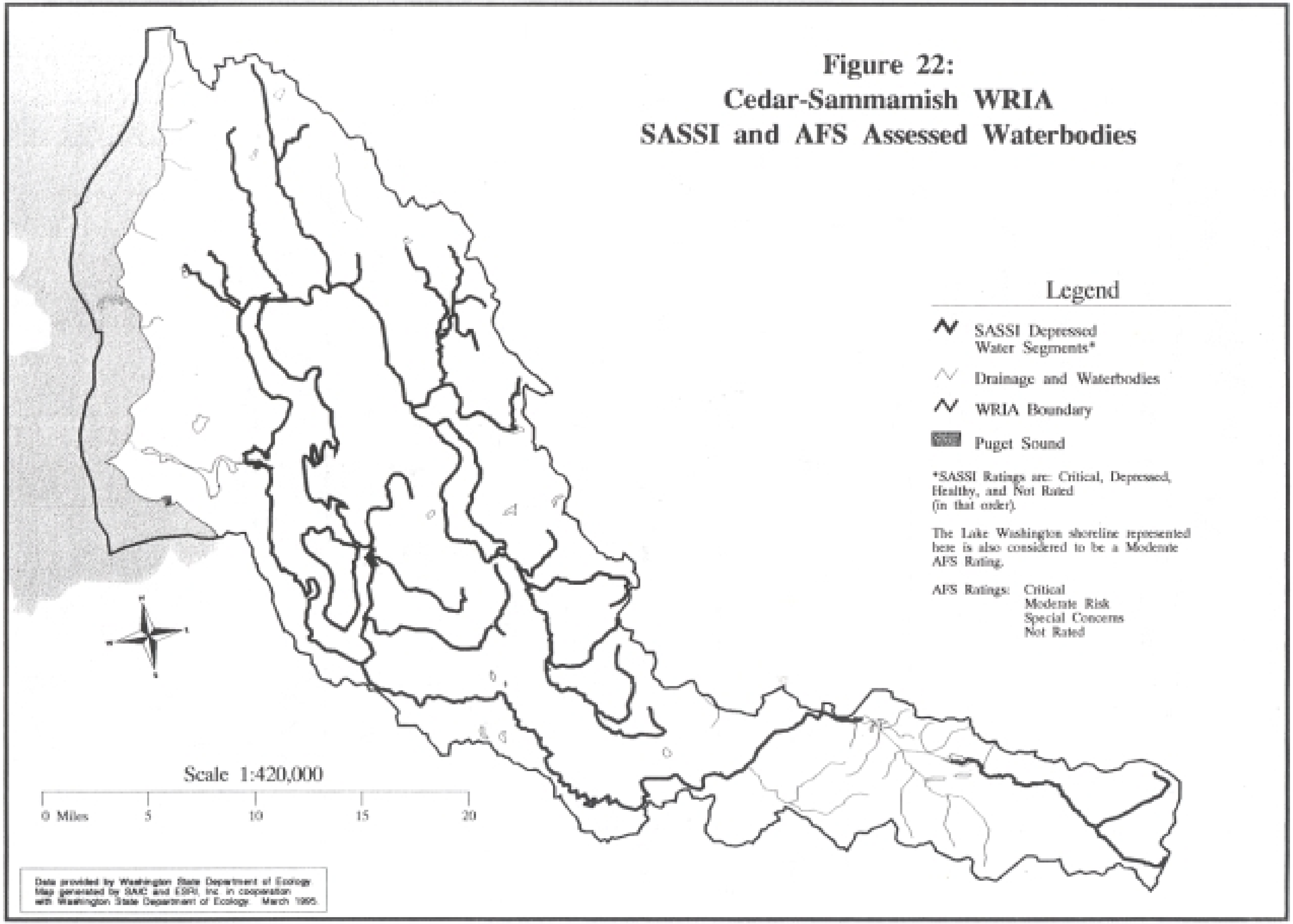
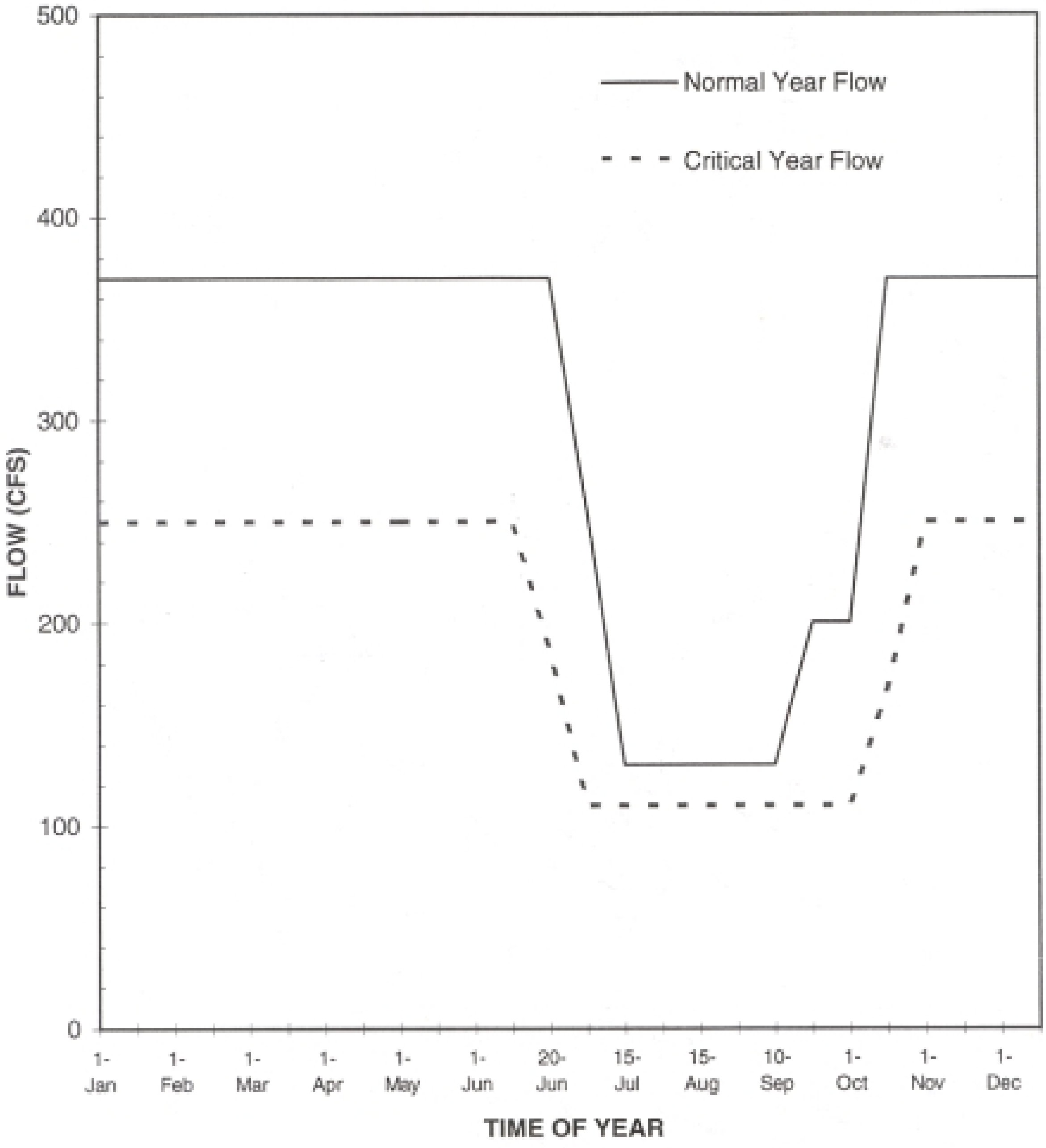


Figure 22: Cedar-Sammamish WRIA SASSI and AFS Assessed Waterbodies

FIGURE 23 - CEDAR RIVER AT RENTON (GAGE 12119000) INSTREAM FLOWS AS ESTABLISHED PER WAC 173-508



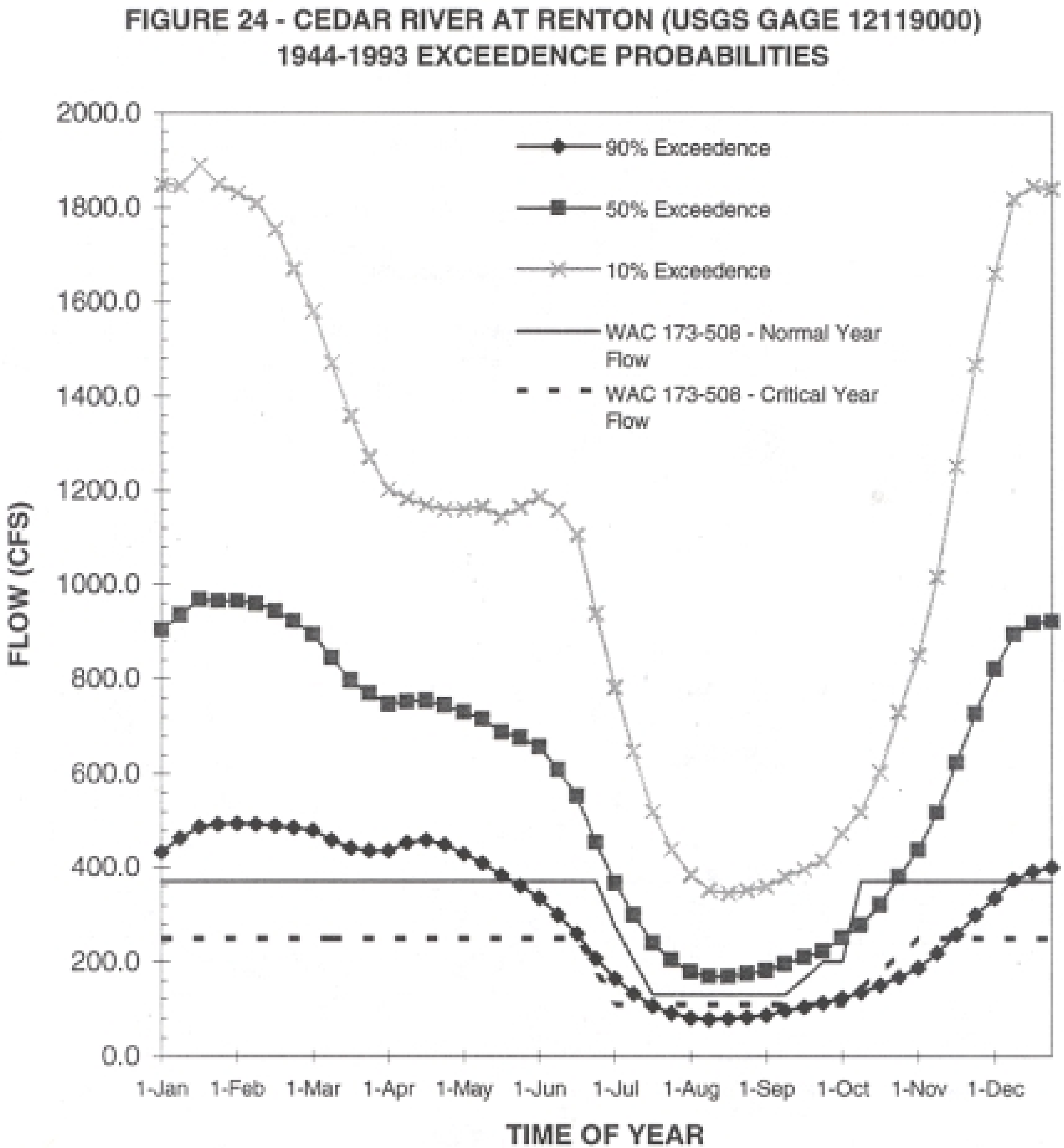


FIGURE 24 - CEDAR RIVER AT RENTON (USGS GAGE 12119000)
1944-1993 EXCEEDENCE PROBABILITIES
90% Exceedence
50% Exceedence
10% Exceedence
WAC 173-508 - Normal Year Flow
WAC 173-508 - Critical Year Flow
FLOW (CFS)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
TIME OF YEAR

FIGURE 25 - CEDAR RIVER AT RENTON (USGS GAGE 12119000)
1980-1993 EXCEEDENCE PROBABILITIES

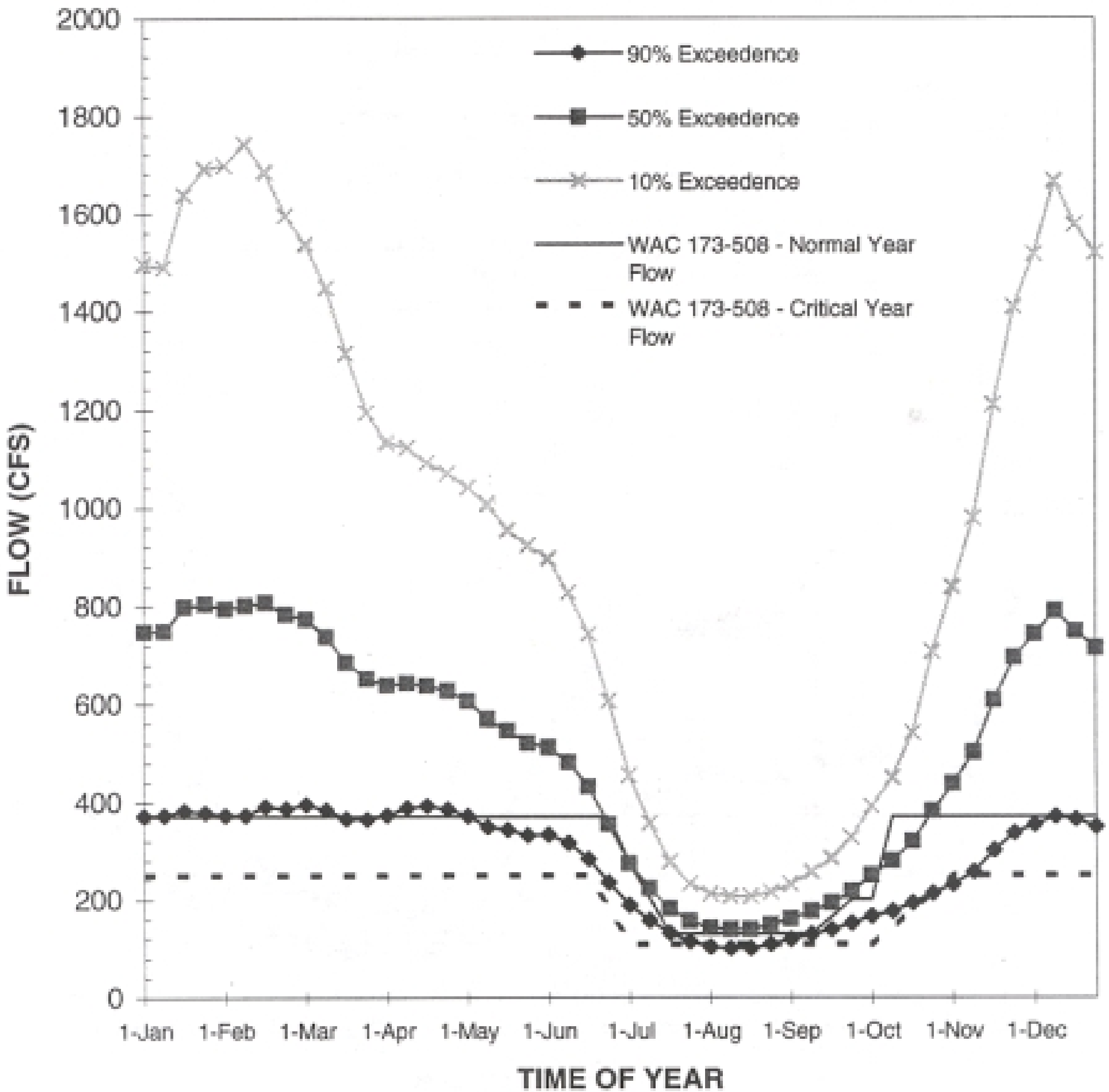


FIGURE 26 - CEDAR RIVER NEAR LANDSBURG (USGS GAGE 12117500) 1894-1993 EXCEEDENCE PROBABILITIES

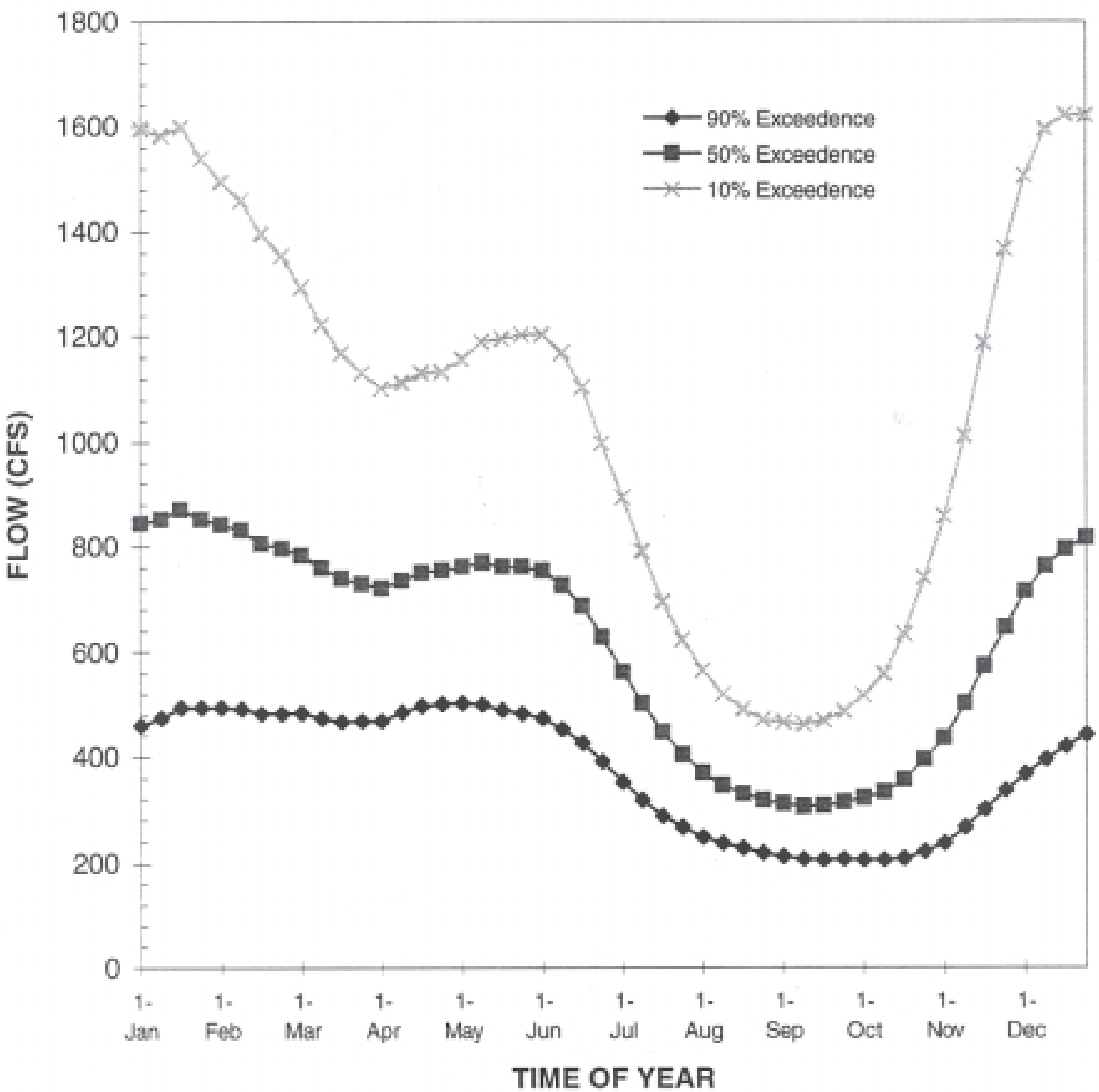


FIGURE 27 - CEDAR RIVER AT CEDAR FALLS (USGS GAGE 12116500) 1913-1993 EXCEEDENCE PROBABILITIES

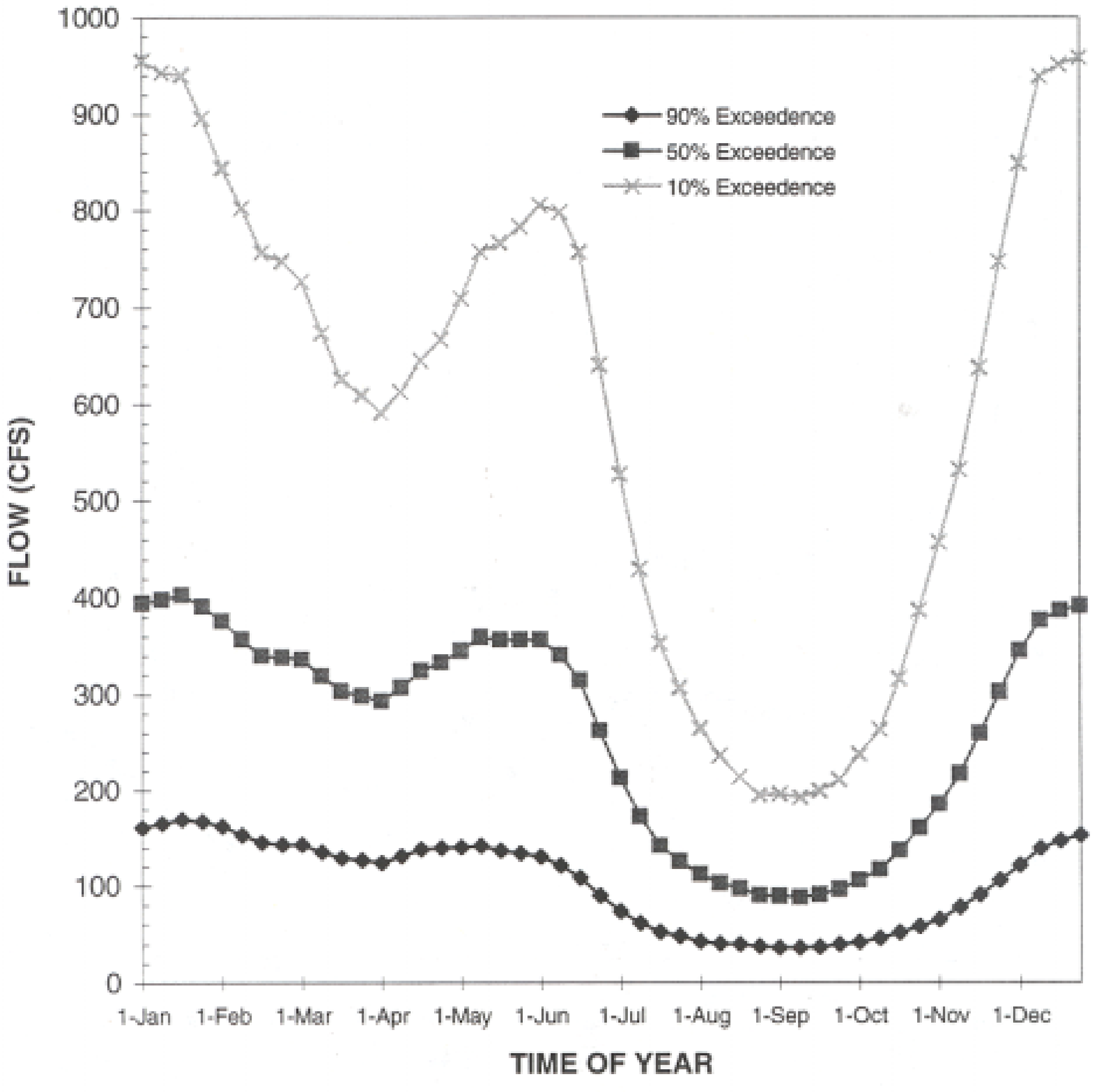
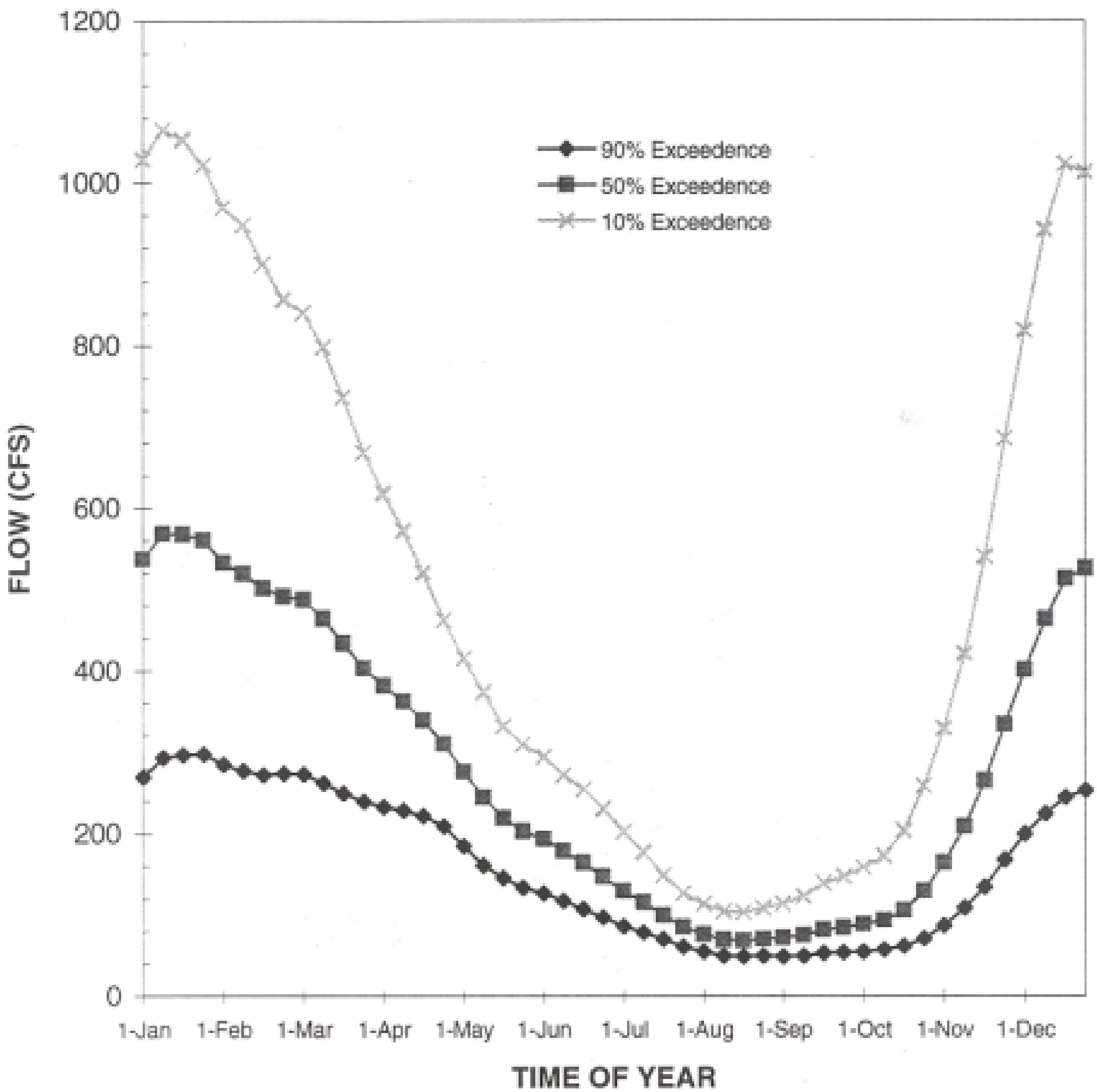


FIGURE 28 - SAMMAMISH RIVER NEAR WOODINVILLE (USGS GAGE 12125200) 1964-1993 EXCEEDENCE PROBABILITIES



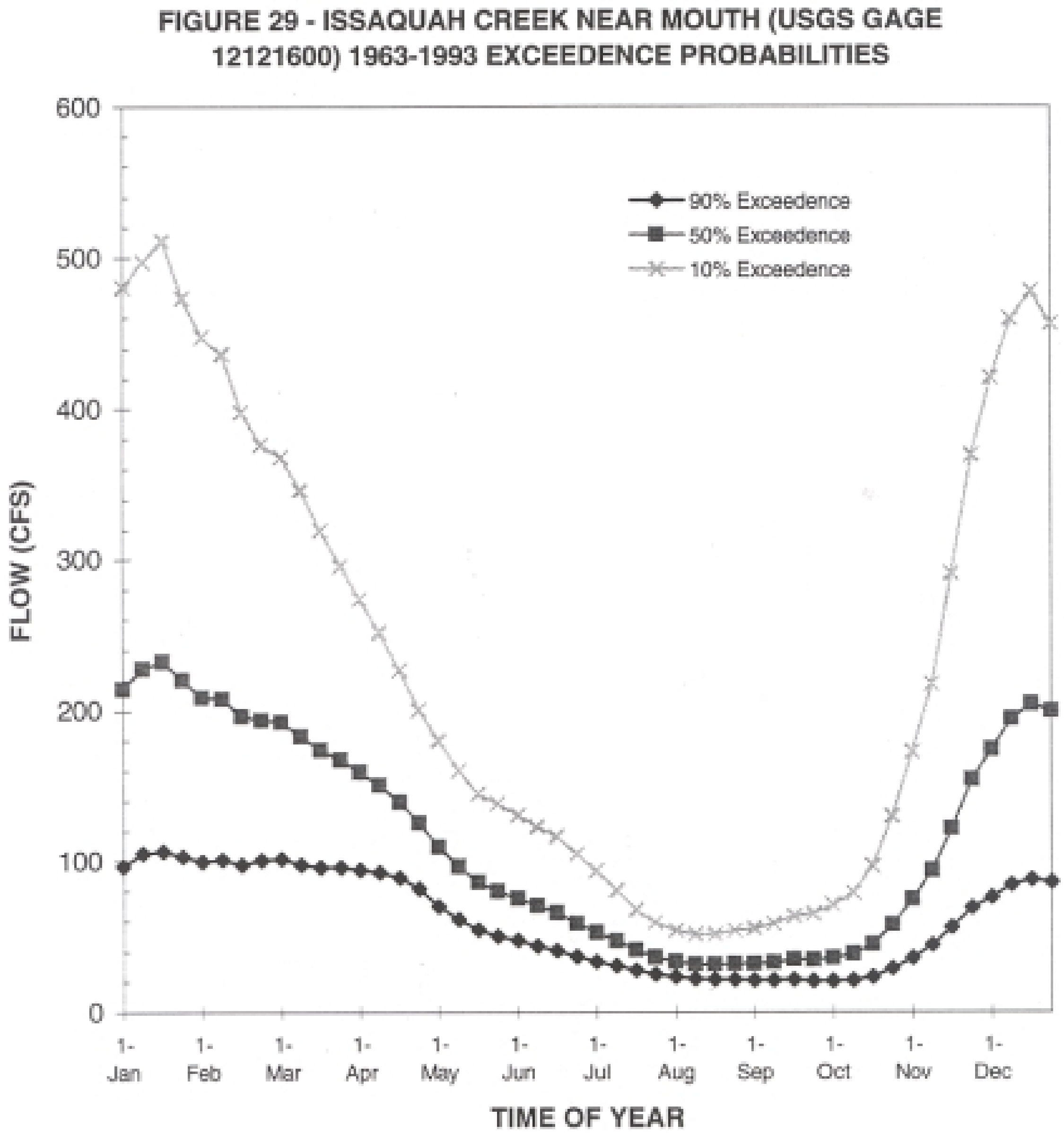
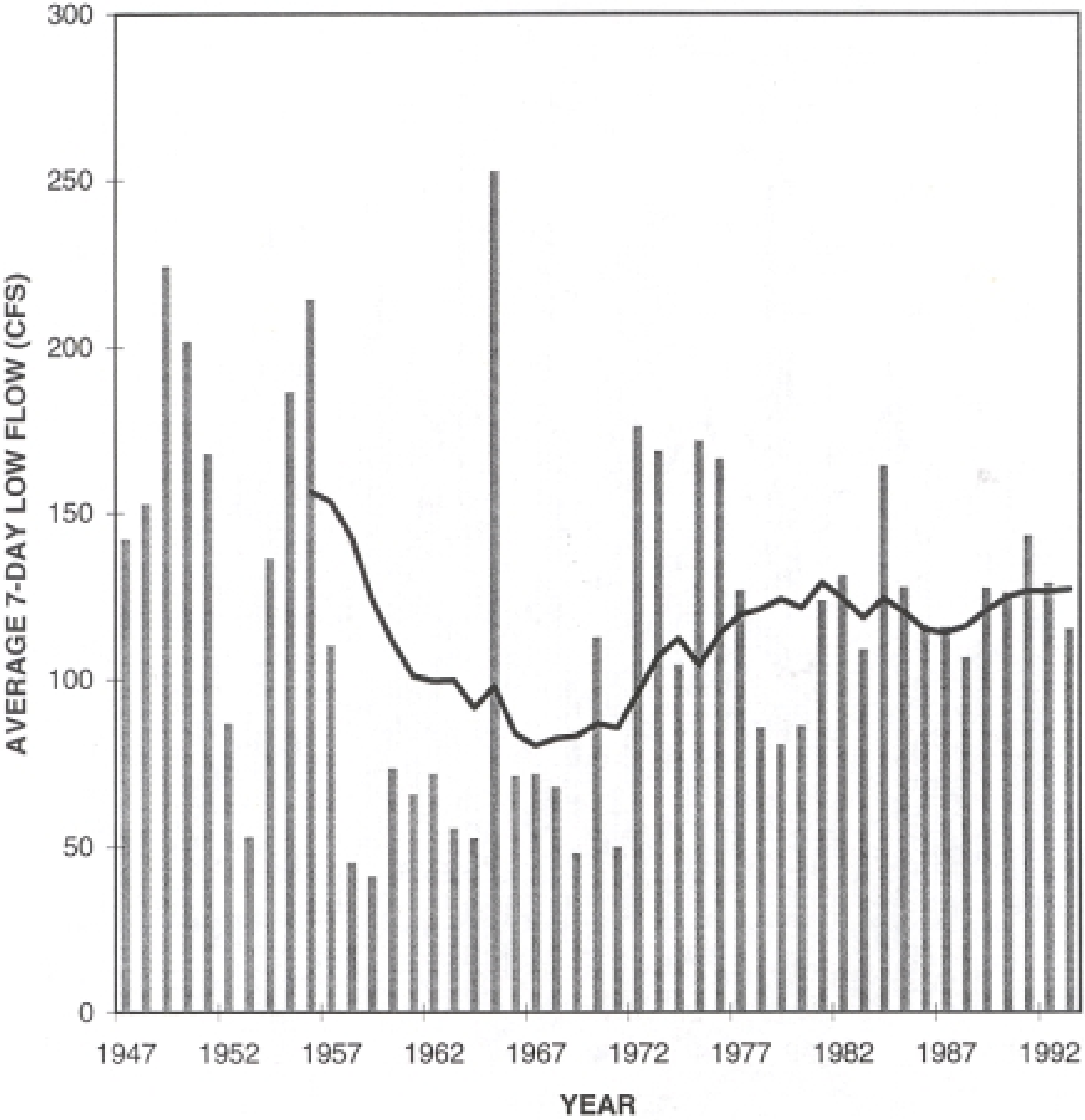


FIGURE 29 - ISSAQUAH CREEK NEAR MOUTH (USGS GAGE 12121600) 1963-1993 EXCEEDENCE PROBABILITIES
90% Exceedence
50% Exceedence
10% Exceedence
FLOW (CFS)
600
500
400
300
200
100
0
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
TIME OF YEAR

FIGURE 30 - CEDAR RIVER AT RENTON, WA (USGS GAGE 12119000) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE



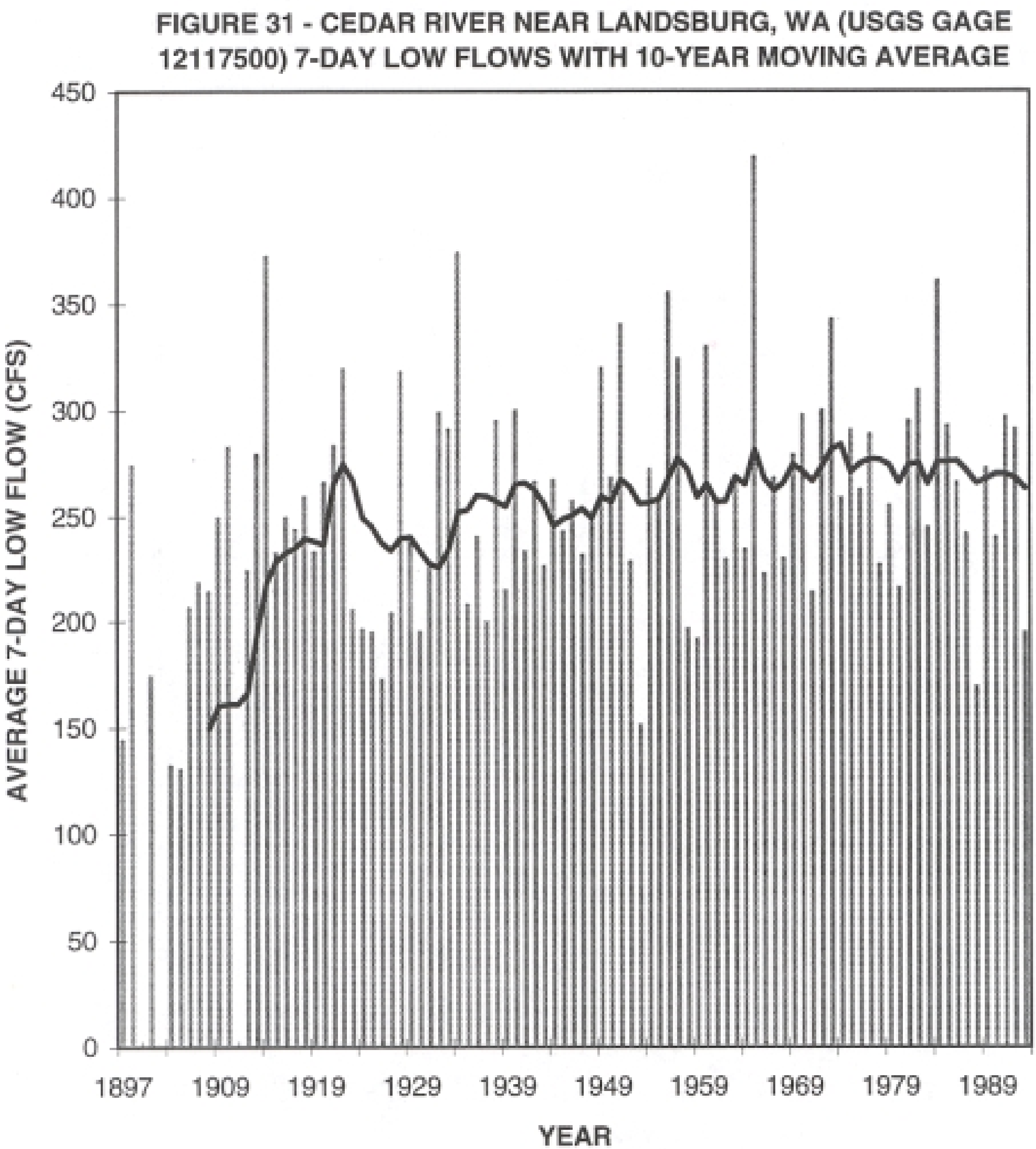


FIGURE 31 - CEDAR RIVER NEAR LANDSBURG, WA (USGS GAGE 12117500) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE
AVERAGE 7-DAY LOW FLOW (CFS)
450
400
350
300
250
200
150
100
50
0
1897
1909
1919
1929
1939
1949
1959
1969
1979
1989
YEAR

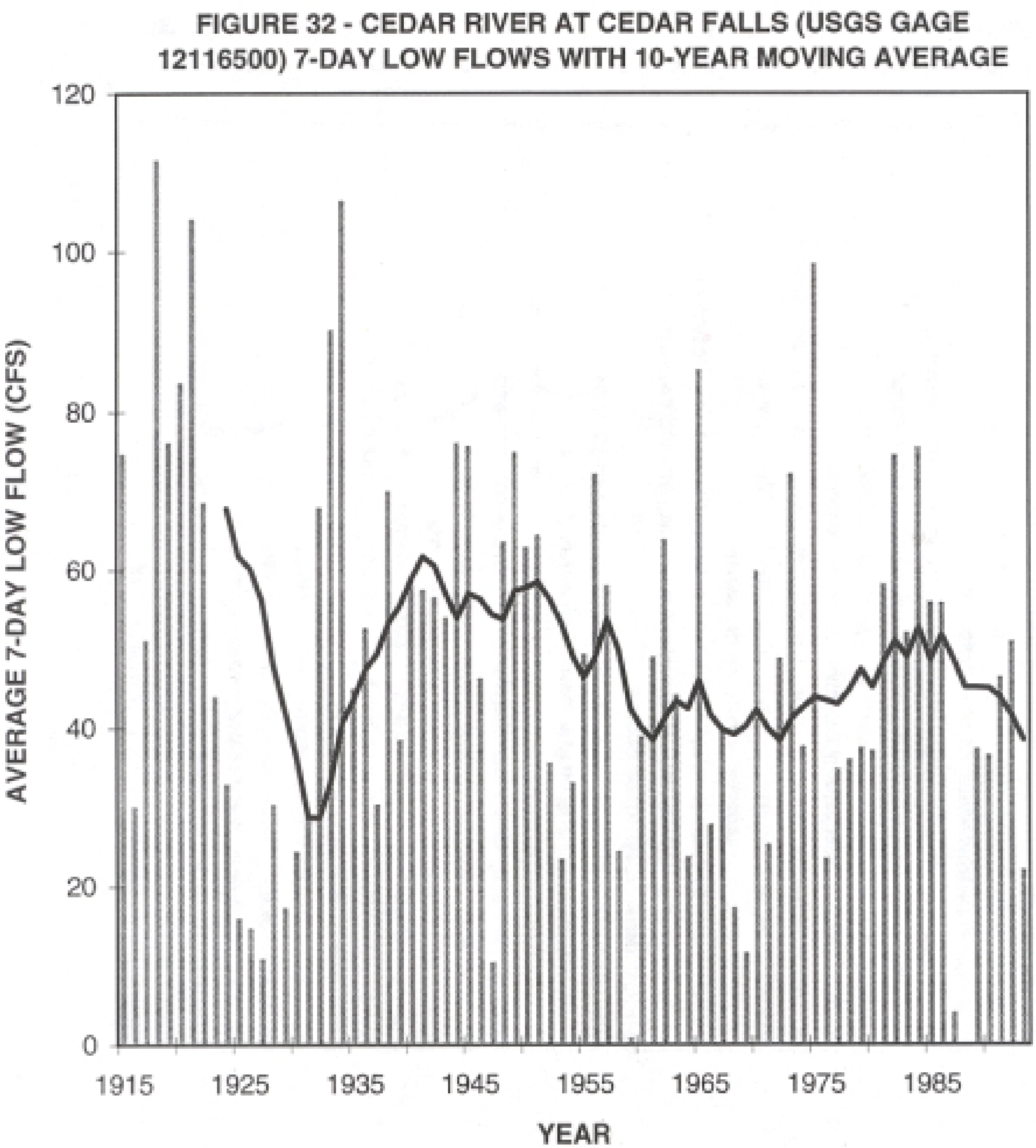


FIGURE 32 - CEDAR RIVER AT CEDAR FALLS (USGS GAGE 12116500) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE
AVERAGE 7-DAY LOW FLOW (CFS)
0
20
40
60
80
100
120
1915
1925
1935
1945
1955
1965
1975
1985
YEAR

FIGURE 33 - SAMMAMISH RIVER NEAR WOODINVILLE (USGS GAGE 12125200) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE

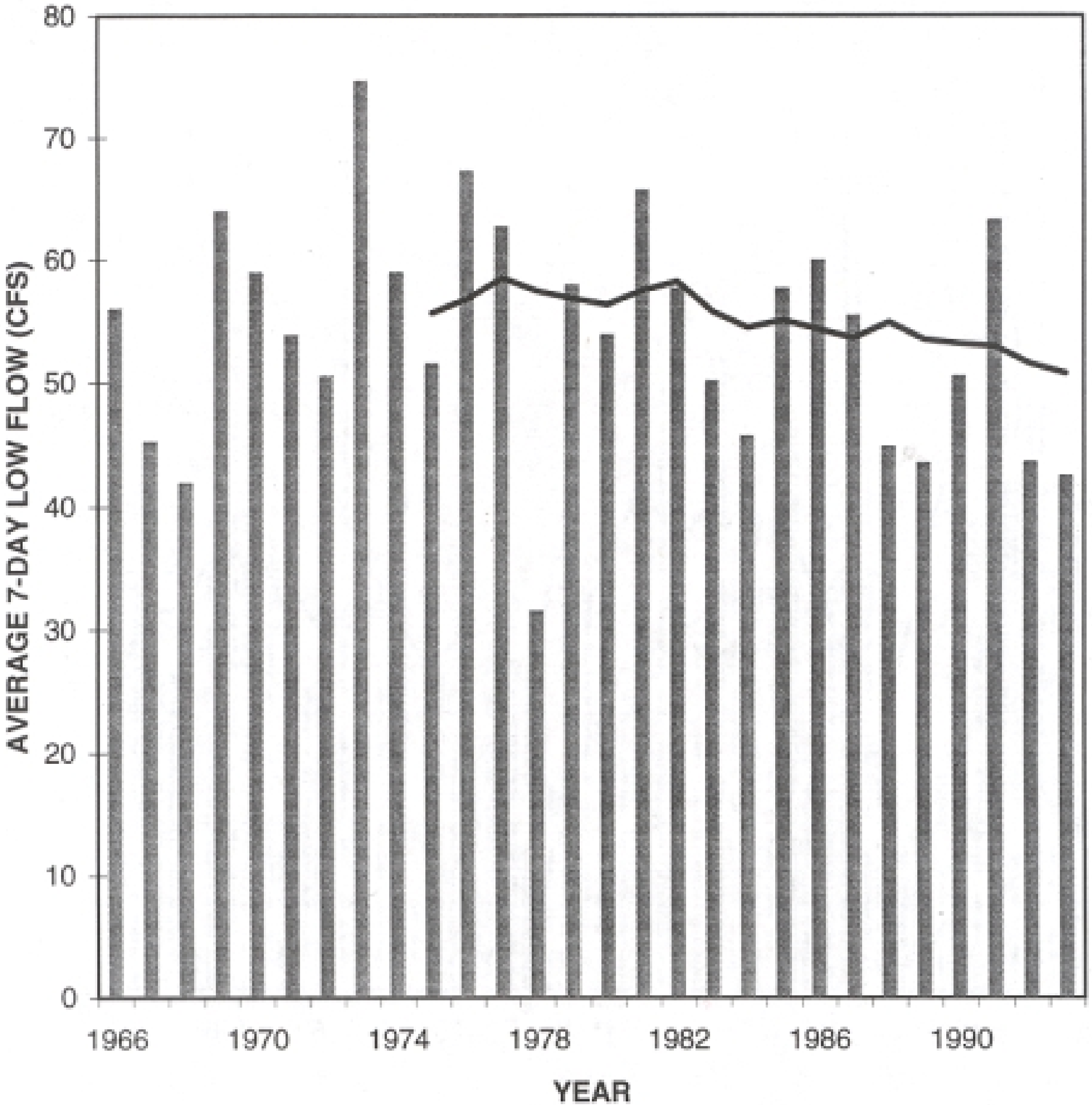


FIGURE 34 - ISSAQUAH CREEK NEAR MOUTH (USGS GAGE 12121600) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE

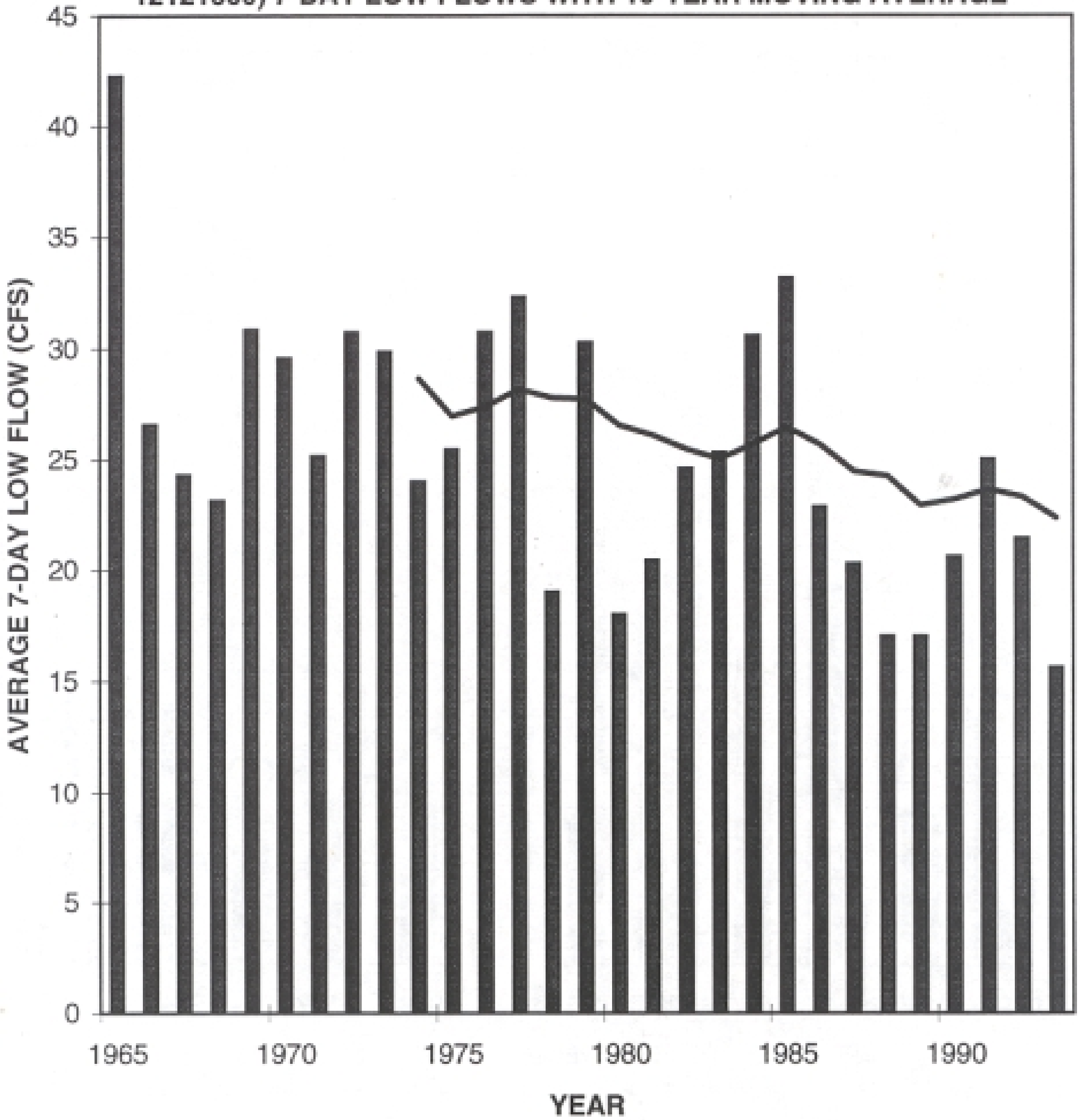
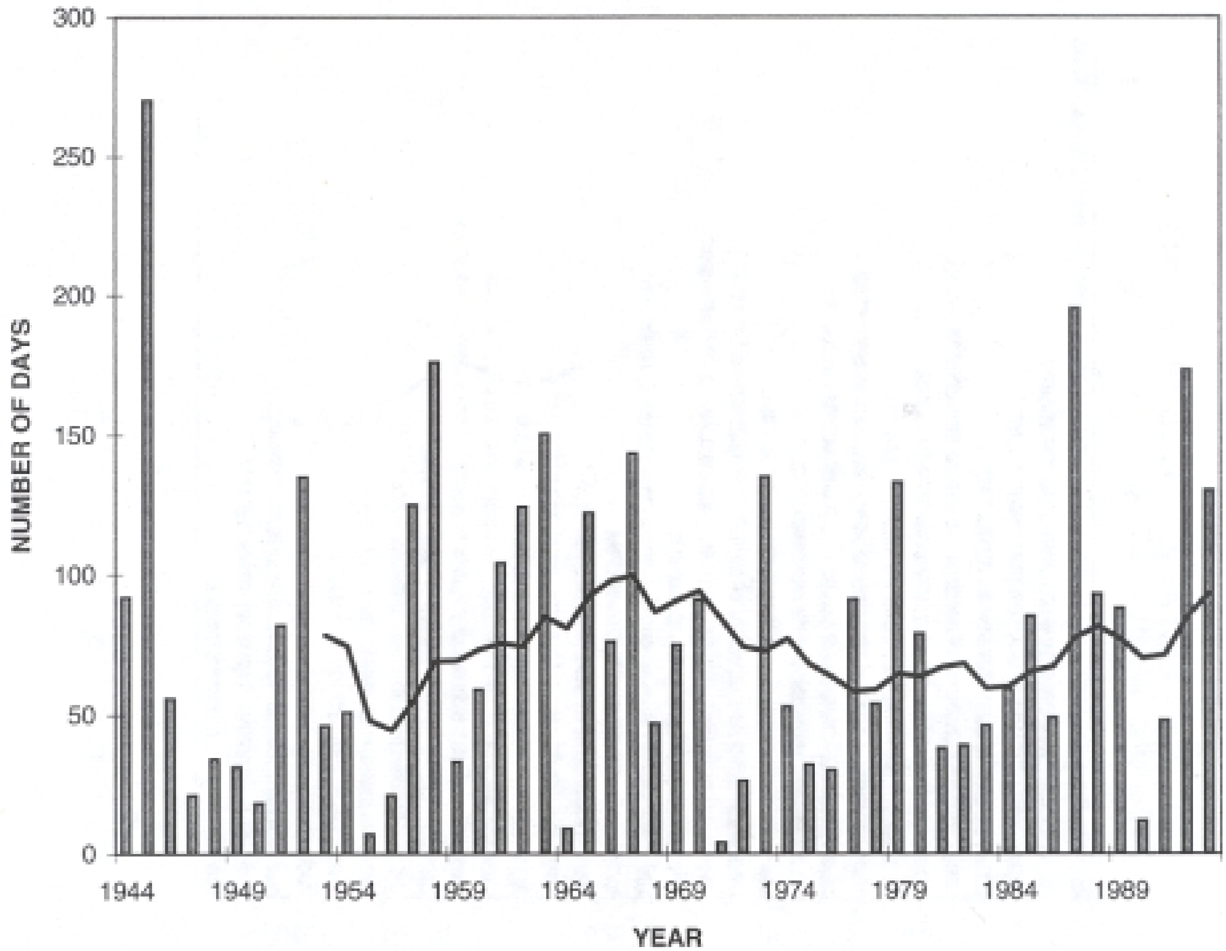
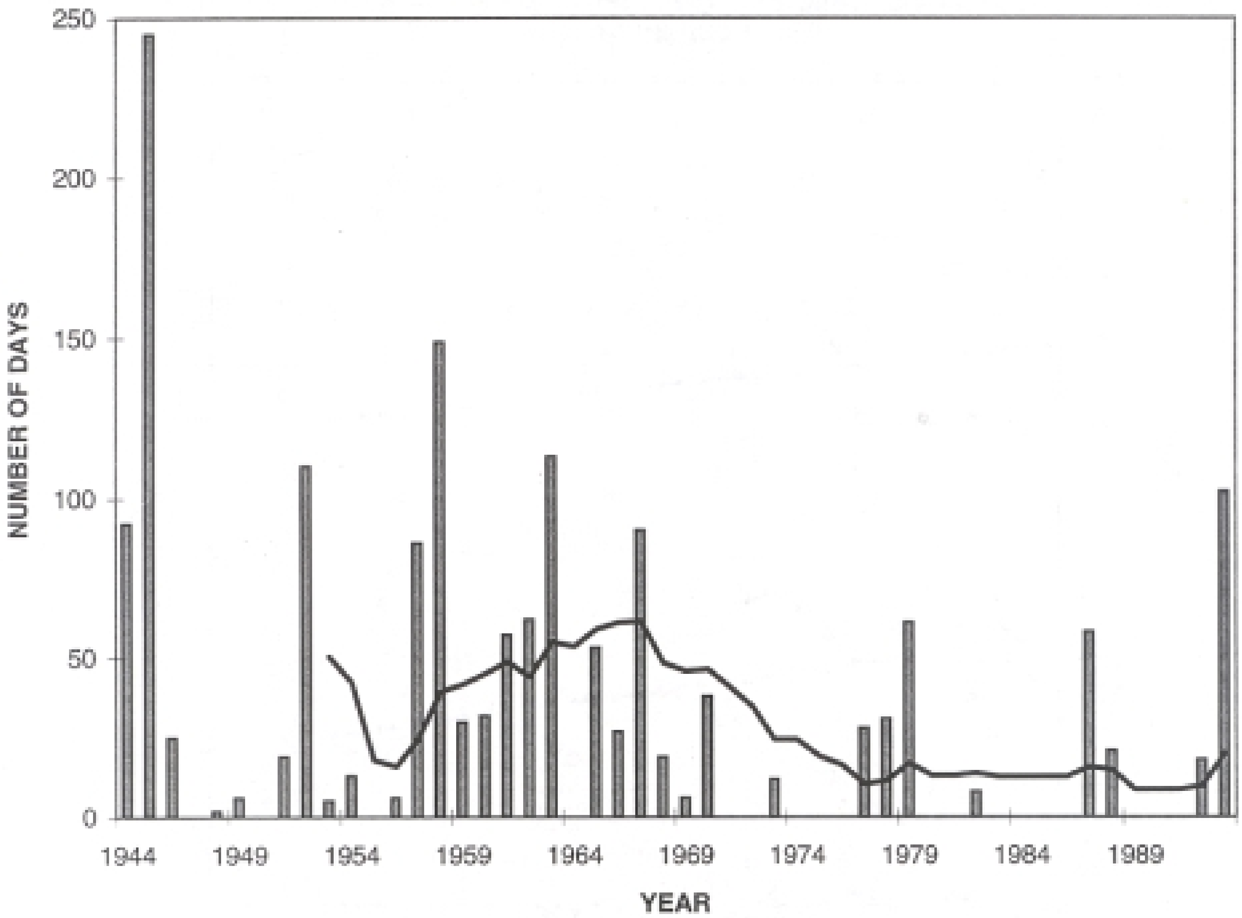


FIGURE 35 - NUMBER OF DAYS PER YEAR FLOWS AT THE CEDAR RIVER GAGE AT RENTON WERE LESS THAN WAC 173-508 INSTREAM FLOWS FOR NORMAL YEAR FLOWS WITH 10-YEAR MOVING AVERAGE



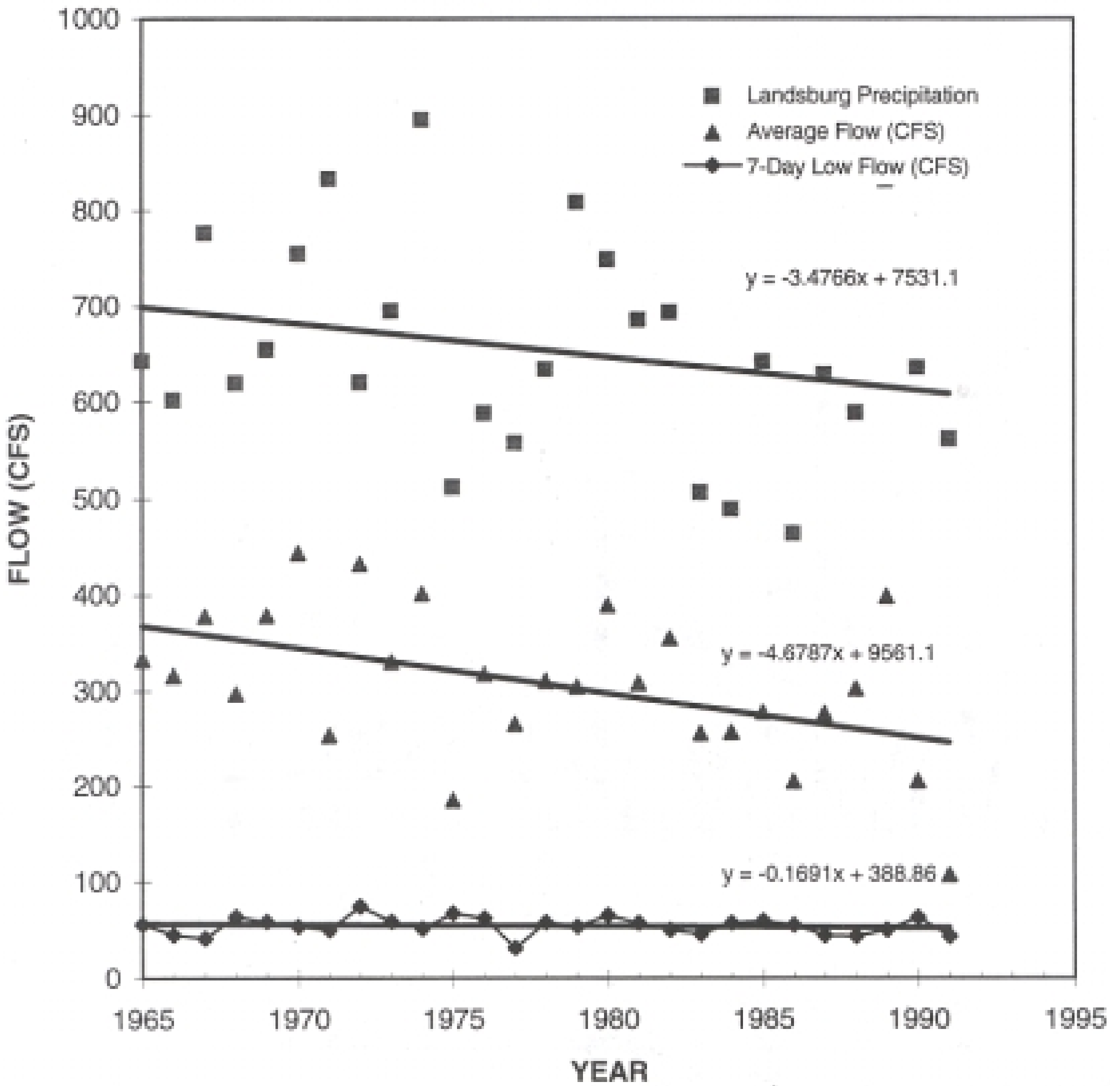
Note: WAC 173-508 instream flows were adopted in 1980 and years previous to 1980 are shown to reflect historical flow characteristics of the river.

FIGURE 36 - NUMBER OF DAYS FLOWS AT THE CEDAR RIVER GAGE AT RENTON WERE LESS THAN WAC 173-508 INSTREAM CRITICAL YEAR FLOWS WITH 10-YEAR MOVING AVERAGE



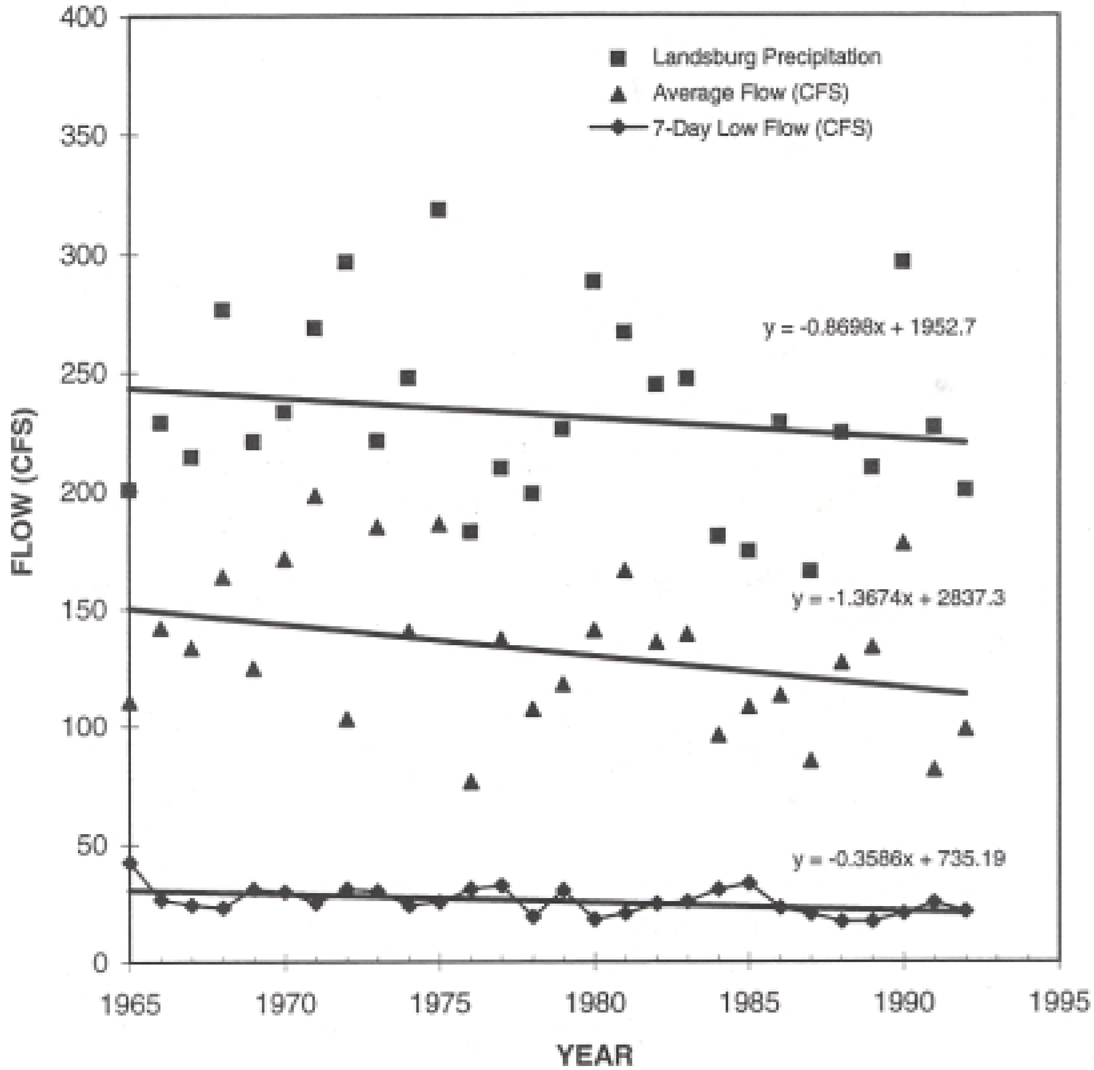
Note: WAC 173-508 instream flows were adopted in 1980 and years previous to 1980 are shown to reflect historical flow characteristics of the river.

FIGURE 37 - COMPARISON OF SAMMAMISH RIVER NEAR WOODINVILLE FLOWS TO PRECIPITATION MEASURED AT LANDSBURG



Note: Annual precipitation was converted to units of CFS by multiplying measured rainfall by the basin area in the Sammamish River basin (159 sq miles) and dividing by seconds/year.

FIGURE 38 - COMPARISON OF ISSAQUAH CREEK FLOWS TO PRECIPITATION MEASURED AT LANDSBURG



Note: Annual precipitation was converted to units of CFS by multiplying measured rainfall by the basin area in Issaquah Creek (56.6 sq miles) and dividing by seconds/year.