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INITIAL WATERSHED ASSESSMENT
WATER RESOURCES INVENTORY AREA 10
PUYALLUP-WHITE WATERSHED

Open-File Technical Report 95-08

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ABSTRACT

The Puyallup-White Watershed, Water Resource Inventory Area (WRIA 10), covers 972 square-miles and includes all of the lands drained by the Puyallup, Carbon, and White Rivers. The headwaters of these river systems are on Mount Rainier and all three rivers discharge through the Puyallup River into Commencement Bay and Puget Sound at Tacoma. The eastern half of the WRIA, a mountainous physiographic province, is forested. Below the forests, the watershed is a mix of agricultural, residential, urban, and industrial areas with the degree of development and industrialization increasing toward Tacoma.

Water rights and registered claims for the Puyallup-White Watershed are 453 cubic feet per second (cfs) and 61 cfs, for surface- and ground-water use, respectively. Water rights plus claims total 513 cfs. Recent trends have indicated an increasing demand for ground water rather than surface-water rights. Current applications on file with the Department of Ecology and pending action request a total of 126 cfs. Actual water use in the watershed is unknown.

Median annual streamflow at the Lower Puyallup Gage, located at the downstream end of WRIA 10, equals 2,922 cfs for the period 1914 to 1993. Thus, water rights and claims equal approximately 18 percent of the median annual streamflow. Low flows (defined as flows at the 90-percent-exceedence between September and November have averaged 1,156 cfs which closely coincides with minimum instream-flow requirements. Known water demands (water rights and claims) represent 44 percent of the minimum low flow. This period of low flow coincides with the Pacific salmon species' upstream migrations for spawning.

Maintaining flows is an issue in the Puyallup River. Established minimum instream flows are not met approximately ten percent of the time for periods in October through November in the Lower Puyallup River. Over the last 20 years, there has been a trend of decreasing low flows in the Puyallup River. The trend is most evident in the Lower Puyallup, and is also evident in the White River near Buckley. Since 1980, minimum instream flows required by Chapter 173-510 of the Washington Administrative Code (WAC) for the Lower Puyallup Gage have not been met an average of approximately 35 days per year. This number has increased from 15 in 1964 to 40 in 1993, despite higher than average precipitation at the Seattle Station and McMillin. Minimum instream flows for the Upper Puyallup Gage have not been met an average of approximately 37 days per year for the period from 1987-1992. Additional water withdrawal within the watershed will exacerbate this situation. For the White River near Buckley, a 10-year moving average of the seven-day low flows suggests that low flows have decreased over the past 20 years.

Recent surface-water quality studies by Ebbert, et al. (1987) and Ecology (1994), indicate the surface-water-quality criteria for fecal coliform and temperature are being exceeded throughout much of the Puyallup-White Watershed. Low dissolved oxygen and toxicity from ammonia and residual chlorine are water-quality concerns (Pelletier, 1993). In addition, dissolved concentrations of copper, lead, mercury, and zinc exceeded the water-quality criteria in Hylebos Creek (LPWMC, 1992), and dissolved copper exceeded water-quality criteria at several sampling stations. Ground-water-quality data, although generally less extensive, indicate ground water is of generally high quality based on nitrate-nitrogen concentrations measured in public water supply wells.

The salmonid habitats of the White River and the Lower Puyallup drainage have been severely affected by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the Puyallup Basin. Three engineered physical barriers including Mud Mountain Dam, the Puget Sound Power (PSPL) and Light Company's diversion at Buckley, and PSPL's diversion at Electron have significantly impaired salmon resources. A water flow study conducted on the White River by the U.S. Fish and Wildlife Service in 1974 concluded that the most critical problem confronting anadromous fish in the White River is the lack of adequate water for passage of adult fish to their spawning grounds.

The 1992 Salmon and Steelhead Stock Inventory (SASSI) report indicates that status of chinook stocks for the Puyallup and White Rivers is either critical or unknown. Coho on the Puyallup River are currently classified as depressed. The American Fisheries Society (AFS) has identified White River spring chinook as being at moderate risk for extinction and fall chinook as being of special concern because available information suggests stocks are depleted. Native stocks of Puyallup River spring chinook have been identified as extinct (Nehlsen, et al., 1991). Anecdotal information from the Puyallup Tribe indicates severe dewatering of Wapato Creek has impeded salmon migration.

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. In addition Ecology must consider the following factors when making permit decisions: the need to guard against impairment through excessive reductions of streamflow or lowering of ground-water levels, the state's non-degradation laws for water quality, and the need to preserve aquatic and riparian habitat. 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 Puyallup-White Watershed, which comprises WRIA 10. 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 were 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 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 Puyallup-White Watershed, Water Resource Inventory Area 10 (WRIA 10), covers 972 square-miles and includes all of the lands drained by the Puyallup, Carbon, and White Rivers. Figure 1 shows the location of WRIA 10. The headwaters of these river systems are on Mount Rainier, and all three rivers discharge through the Puyallup River into Commencement Bay and Puget Sound at Tacoma (Figure 2). Elevations within the WRIA start at the 14,114-feet peak of Mount Rainier and descend to sea level at Commencement Bay. The Upper Puyallup River and White River flow from the glaciers at the peak of Mount Rainier, while the Carbon River system begins on the northwestern flank of the mountain, between the other two rivers.

Subbasins

The three river systems divide the WRIA into three major subbasins, each draining a slice of the flank of Mount Rainier. The subbasins form, in effect, smaller watersheds that share a common discharge point through the lower Puyallup River into Puget Sound.

The Upper Puyallup River starts on the Tahoma and Puyallup Glaciers on the west side of Mount Rainier and becomes the Lower Puyallup River at the confluence with the Carbon River at Orting. The Upper Puyallup Subbasin covers 90 square miles in a thin strip along the southern margin of the WRIA and includes six major tributaries (LPWMC, 1992). The Upper Puyallup contributes approximately 20 percent of the total watershed mean annual flow as measured at Puyallup (USGS, 1988).

The Carbon River flows from the Carbon and Russell Glaciers and joins the Lower Puyallup River at Orting. The Carbon River Subbasin covers 230 square-miles (LPWMC, 1992). A total of 19 tributaries join the Carbon along its 32-mile course (PRBWQMP, 1974), contributing about 30 percent of the mean annual flow from the WRIA (USGS, 1988).

The White River begins at the Emmons Glacier on the north side of Mount Rainier and flows 66 miles to join the Lower Puyallup River at Sumner. The White River Subbasin occupies 468 square-miles, covering the northern half of the WRIA (LPWMC, 1992). There are 35 major tributaries that contribute 50 percent of the mean annual flow from the watershed (USGS, 1988).

Before 1906, the White River flowed down the present Green River Valley (WRIA 9) and joined the Black River at Tukwila to form the Duwamish River. The Duwamish discharges into Elliott Bay at Seattle. Occasional floods on the White overflowed into the Stuck River near Auburn. During a flood in 1906, overbank flow dammed the channel of the White and diverted flow into the Stuck River. This change was made permanent with the construction of a diversion dam at Auburn, forcing the White River's flow into the Puyallup Watershed (PRBWQMP, 1974).

In addition to the glaciers at the headwaters of the rivers, major surface water bodies include Lake Tapps and the Mud Mountain Reservoir in the White River Subbasin. The Lake Tapps Reservoir was formed by diking a natural lake in 1910. Storage began in 1911 with flow diverted from the White River along the Lake Tapps Flume. Prior to 1986, the diverted flow could not exceed 2,000 cfs and was required to leave 30 cfs in the river. In 1986, Puget Power and the Muckelshoot Tribe settled a lawsuit involving instream flow. Puget Power agreed to increase the minimum instream flows from 30 to 130 cfs, and to give the tribe an on-demand budget equivalent to 10 cfs year-round, but primarily for summer use. Flow is diverted at RM 24.3 and is returned below the hydroelectric plant at Dieringer (RM 3.6). Lake Tapps covers 2,296 acres and holds 46,660 acre-feet of water (PRBWQMP, 1974).

Mud Mountain Dam was constructed on the White River at RM 29.6 by the Army Corps of Engineers (ACOE) in 1953 for flood control. Mud Mountain Reservoir covers 1,200 acres and has a storage capacity of 106,000 acre-feet. Of the remaining lakes in the WRIA, only Lake Kapowsin (512 acres) exceeds a surface area of 100 acres.

Physiography

Three physiographic provinces comprise the WRIA: mountains, terraces, and lowland valleys. The mountains begin southeast of South Prairie Creek and occupy the eastern half of the WRIA. Typical crest elevations along the Cascade Range reach 7,000 feet, although Mount Rainier peaks at 14,114 feet.

Three terraces bounded by high bluffs with steep slopes divide the three major river systems. Terrace elevation gains range from about 400 to 750 feet. The Northwest Terrace occupies the northwestern corner of the WRIA and is bounded by the Lower Puyallup to the south and the last reach of the White River to the east. The Eastern Terrace begins on the east side of the White River, opposite the Northwest Terrace, and rises gradually to Buckley. The Southern Terrace stands south and west of the Puyallup River, along the southern margin of the WRIA (PRBWQMP, 1974).

The three lowland valleys start at Commencement Bay and follow the courses of the Puyallup and White Rivers. The lower Puyallup River Valley runs from Commencement Bay to Puyallup; the Orting Valley lies along the Puyallup River from Orting to Sumner; and the White River Valley starts in the Puyallup-Sumner area and runs north to Auburn. Valley floor elevations rise from sea level to 120 feet at Auburn and 240 feet at Orting (PRBWQMP, 1974).

LAND COVER AND LAND USE

The Puyallup-White Watershed is located primarily in Pierce County, although the northern border is in King County. The eastern half of the WRIA, the mountainous physiographic province, is forest, with three broad bands of ownership. The headwaters of the WRIA are within Mount Rainier National Park and are managed by the Department of the Interior. Snoqualmie National Forest lands (managed by the Department of Agriculture) form a broad belt around the park and extend almost down to Carbonado. Below the national forest lands, most of the forest lands are private, belonging principally to the Champion and Plum Creek timber companies. The Washington Department of Natural Resources also manages state holdings in the lowest band (PRBWMQ, 1974).

Below the forests, the WRIA is a mix of agricultural, residential, urban, and industrial areas with the degree of development and industrialization increasing toward Tacoma. Much of the area from Orting and Buckley down to Puyallup and Sumner is zoned for suburban agriculture (agriculture and single-family residences up to three units per acre). Below Puyallup, the WRIA is almost completely urban, commercial, and industrial.

The population within the WRIA is approximately 241,500. This number is based on 1990 census data and includes the major populated areas (cities and towns) within the watershed. The population of Tacoma (176,664) is included in the WRIA, although the city straddles WRIAs 10 and 12. There are 14 other incorporated communities in the WRIA, of which the largest are Fife, Bonney Lake, Puyallup, Enumclaw, Sumner, Buckley, and Orting. The most extensive development has occurred along the I-5 corridor and along the state routes that lead west from the interstate.

CLIMATE AND PRECIPITATION TRENDS

Precipitation, either in the form of rain or snow, is the principle source of recharge to ground water in the Puyallup-White Watershed. Near Tacoma, annual precipitation averaged 39.4 inches per year from 1884 to 1961. Precipitation in the study area is fairly uniformly distributed, with increasing precipitation at increased altitude, reaching 130 inches per year in the Cascade range. Precipitation enters surface-water drainages and recharges aquifers, and some of this precipitation is lost to evapotranspiration. Most of the ground water eventually discharges as spring flow or direct seepage into surface water that eventually flows into the Puget Sound. Precipitation contours for the watershed are presented in Figure 3.

Statewide Precipitation Trends

Precipitation data from gages located throughout the state were used to examine long-term trends and identify extended periods of above or below average precipitation. This analysis places the more recent weather patterns into a long-term perspective. Such a 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 16 sites throughout the state were used for the analysis (Figure 4). The criteria used to select a particular station were that the record should be relatively long (80 years or more), have few periods of missing data, and be geographically disperse 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 1 lists the stations used in the analysis for Western Washington (Stations 1 through 8).

The data for 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 in Western Washington were then averaged to obtain a trend line for the region (Figure 5). In Western Washington, 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 6 also indicates that precipitation in Western Washington was less than average between approximately 1920 and 1950 and higher than average between 1950 and 1980.

Watershed Precipitation Trends

Seatac Airport, McMillin Reservoir, and Longmire precipitation data 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 6). Based on a period of record from 1942-1991, mean annual precipitation at McMillin Reservoir is 40.8 inches. Annual deviations from the mean demonstrate high variability in rainfall from year to year (Figure 7). The general trends in precipitation at McMillin Reservoir and Seatac Airport, as indicated by a ten-year moving average for each station, have been typical of the trends observed at other rain gages in Western Washington (Barker, 1995). In the years since 1976, the lower watershed (Seatac) has experienced less than average precipitation. Based on a period of record from 1979-1991, mean annual precipitation at Longmire is 79.8 inches (Figure 8). Because of a shorter record of data at Longmire, a five-year moving average was calculated to evaluate trends. The mean annual precipitation is substantially higher at Longmire compared to McMillin Reservoir and Seatac, but the data show similar magnitudes of variation.

Table 1. 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. Cedar 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

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 surface water and is deposited back on land as precipitation, either rain or snow. 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 9).

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 from vegetation)
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:

$$\text{PRE} - \text{ET} \pm \text{XAW} \pm \text{CGWS} = \text{NSF} \qquad \text{Equation 1}$$

where "PRE" represents precipitation, "ET" represents evapotranspiration, "XAW" represents ground-water exchange with adjacent watersheds, "CGWS" represents change in ground-water storage, and "NSF" represents natural streamflow. All terms represent average annual values for the purposes of this discussion but could apply to other statistical measures and durations.

Precipitation (PRE) on the watershed is the principal source of replenishment to the water supply of most watersheds.

Evapotranspiration (ET) consists of evaporation from soils, vegetation, lakes, and streams, in addition to transpiration by plants. Evapotranspiration reduces the amount of precipitation which reaches aquifers and streams and constitutes a large percentage of the water balance for most watersheds.

Natural ground-water exchange with adjacent watersheds (XAW) may add to or reduce the water supply of a watershed. In western Washington, natural ground-water exchange between watersheds often represents only a small portion of a watershed's total water supply.

Ground-water storage (GWS) is recharged either by precipitation which percolates down to the water table or by infiltration from streams or other surface water bodies. In the natural cycle, ground water eventually discharges to surface water bodies, except where intercepted by plants or humans. In a few very deep aquifers, ground water may be relatively stagnant. Rates of ground-water recharge vary with annual and seasonal precipitation. Barring long term climatic change or human water use, ground-water storage usually stays within a narrow range, and the average recharge to an aquifer is equivalent in volume to the average discharge from the aquifer to streams or other surface water bodies. Thus, barring long term climate change or excessive water use by humans, "CGWS" equals zero.

Natural streamflow (NSF) consists of the flow remaining after natural upstream gains and losses. We cannot accurately estimate natural streamflow in most watersheds because streamflows generally were not measured prior to land clearing and development of water supplies.

Simple calculations of the soil-water-balance, based on the method of Thornthwaite and Mather (1948), yield average monthly amounts for precipitation, actual ET, and excess soil moisture. Precipitation is more abundant in fall and winter when vegetation requires less water. As soils become saturated, excess soil moisture percolates beyond the reach of plant roots to recharge ground water. During spring and summer, ground-water recharge practically ceases when the rate of ET exceeds precipitation. These alternating cycles are reflected in the low and high seasonal flows in the Puyallup and White Rivers.

Annual ET losses are roughly one half of the annual precipitation. The remainder is available for streamflow and ground-water recharge. More than 80 percent of the annual precipitation falls between October and April, with much of it running off in streams a short while later.

Very little ground-water recharge occurs from May through September, and water levels decline as some of the water drains to streams. These seasonal imbalances lead to large seasonal swings in streamflow and ground-water storage.

The Water Balance as Influenced by Humans

Given the mandate to protect senior water rights, instream baseflows, water quality, and ground-water levels, all of the naturally occurring water in a watershed is not available for allocation. This leads to another equation defining the available water supply for human use.

$$\text{NSF} - \text{ISF} = \text{ASF} \qquad \text{Equation 2,}$$

"NSF" represents natural streamflow. "ISF' represents in-stream flow (also called base flow) which is reserved for instream needs. Instream flow is intended to serve navigation, recreation, aquatic and riparian ecosystems, fish, wildlife, and esthetics. "ASF" represents available streamflow, assuming no water use by humans.

Consumptive water use (CWU), due to diversions of surface water and pumping of ground water, reduces the available streamflow (ASF). Consumptive water use refers to that portion of the diverted or pumped water which is removed from the watershed -- usually by increasing evapotranspiration (ET), or by exporting water to other watersheds through canals or pipes. The remainder of the water returns to the water supply, though often in a different part of the watershed. It may return by percolation to ground water and, thence, to streams, or it may return by direct discharge from a pipe. This can be represented as:

$$\text{WD} - \text{RTF} = \text{CWU} \qquad \text{Equation 3}$$

where "WD" represents water diverted (surface water or ground water) and "RTF" represents return flow to the stream.

Adding Equations 2 and 3 yields:

$$\text{NSF} - \text{ISF} - \text{CWU} = \text{RASF} \qquad \text{Equation 4}$$

where "RASF" represents remaining available streamflow. After satisfying senior water rights (CWU) and in-stream flow rights (ISF), the remaining available streamflow (RASF) may be available for appropriation (Equation 4).

The above water-budget equations serve only to illustrate the major components of the hydrologic cycle in WRIA 10. Unfortunately, the equations are too simplistic to use in accurately deriving the available water supply. The complex changes (monthly, seasonal, and annual) in all the components, as well as in the factors influencing them, must be measured and interpreted statistically before reasonably accurate estimates of water availability can be made. Such is not within the scope of this initial watershed assessment.

GEOLOGY AND GROUND WATER

The Puyallup-White Watershed is composed of a broad, poorly drained, upland drift plain intersected by several broad river valleys. The watershed ranges in altitude from 0 to approximately 14,000 feet above sea level and is bounded on the east by the Cascade Range and on the west by Puget Sound. Volcanic and sedimentary rocks of Tertiary age outcrop in the eastern portion of the watershed. These formations underlie the entire watershed, but they are deeply buried by unconsolidated glacial and fluvial sediments in the 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 drift plain was deposited by glacial and fluvial processes and is composed primarily of thick sequences of low permeability glacial tills, and higher permeability outwash deposits. The drift plain is terminated to the west by the Puget Sound, a deep marine embayment that was once continuous with a marine embayment that occupied the Puyallup River Valley. The Puyallup River Valley, and its tributary valleys were subsequently filled with alluvium glacial outwash, and lahars (mudflows), creating important aquifers within the study area.

Productive aquifers in the Puyallup-White 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 (e.g., in central Pierce County).

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 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 are the principle source of ground water in much of the Puyallup-White watershed. Wells yield up to 2,000 gallons per minute from thick sequences of Pre-Vashon sands and gravels.

The Osceola Mudflow originated on the northeastern flank of Mount Rainier approximately 5,700 years ago (Dragovitch, et al., 1994). Reaching thicknesses of up to 100 feet, the mudflow consisted of clay-rich gravel, cobbles, and boulders. The mudflow moved down the White River valley and spilled into the Green and Puyallup drainages, ultimately changing the course of the White River to its current position. Due to the poorly sorted nature and abundance of fine-grained clay and silt, the mudflow deposits have low permeability. The mudflow deposits create an aquitard that confines underlying aquifers and perches water tables in overlying aquifers.

Since the recession of the Vashon Glacier, the Puyallup and White Rivers and their tributaries have deposited large quantities of sediments within the river floodplains. These 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 alluvium. Generally, these deposits are not 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 connection between ground water and surface water in the watershed is not widely appreciated nor necessarily well understood. The principal of conservation of mass dictates that the water recharging an aquifer either must be stored or discharged to the surface. In a consistent climate, ground-water storage tends to remain constant, and the discharge equals the recharge. Pumping from wells reduces discharges to springs and streams by capturing ground water that would otherwise have discharged naturally. If the well is close enough to the stream, surface water may be drawn directly back to the well. Consumptive water use (that portion not returned to the aquifer) eventually diminishes streamflow, both seasonally and as average annual recharge.

The Puyallup and White Rivers and their tributaries have cut deep 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 deep valleys are in direct connection with surface-water bodies.

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 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.

GROUND-WATER STATUS

Because precipitation varies greatly with the season, ground-water recharge changes accordingly. Ground-water levels adjust to the amount of flow into (recharge) and out of (natural discharge or pumping) an aquifer. Thus, ground-water levels change naturally with the seasons, particularly in the uppermost aquifer which receives the first recharge. Pumping lowers ground-water levels. If the pumping rates are only a small portion of the flow through the aquifer, the water levels may change only slightly and might not be noticed within the seasonal variations of water levels.

Three of the largest ground-water users in the Puyallup-White Watershed are the cities of Federal Way, Puyallup, and Sumner. In addition, the City of Tacoma derives a portion of its water supply from wells in the Puyallup-White Watershed.

According to *Hydrogeologic Analysis of the Federal Way Area, Washington* (Robinson and Noble, Inc., 1992), the City of Federal Way's production wells draw water from three general hydrostratigraphic units or layers: Layer 2, Layer 4, and Layer 6. Layer 2 consists almost exclusively of the Redondo-Milton Channel Aquifer (RMC) and is correlated with the Qva unit. Layer 4 consists of the Mirror Lake Aquifer, Eastern Uplands Aquifer, and the North Shore Aquifer and is correlated with the Qu unit. Layer 6 consists of several units collectively termed the Deep Aquifer and also correlated with the Qu unit.

The RMC Aquifer of Layer 2 is a major production aquifer and is tapped locally by approximately 60 wells. Well discharges range from approximately 10 to 2500 gpm and average 700 gpm. Ground-water extraction and land-use changes have caused water-level declines in several wells in the RMC Aquifer of between 9 and 18 feet between 1977 and 1987. Additional declines were observed in some wells between 1987 and 1991. The Mirror Lake Aquifer of Layer 4 is the most widespread and productive aquifer in the Federal Way area and is tapped by approximately 12 wells. Overall, water levels in this aquifer are greatly influenced by pumping rates. For example, declines of between 30 and 50 feet have been observed since 1977 in one production well. The North Shore Aquifer of Layer 4 is tapped by approximately 9 wells. No information was reported regarding long-term water-level trends in this aquifer. The Eastern Uplands Aquifer is tapped by approximately 40 wells. Water levels in this aquifer are influenced by pumping rates but not to as great an extent as those in the Mirror Lake Aquifer. Declines in some Eastern Uplands wells of 10 to 20 feet have been observed; however, there has also been a general rise in water levels in some parts of the aquifer. The Deep Aquifer of Layer 6 is tapped by approximately 12 production wells. No information was reported regarding long-term water levels in this aquifer (Robinson and Noble, 1992).

According to *Draft Water System Comprehensive Plan for the City of Puyallup* (Gray and Osborne, 1994), the City of Puyallup uses ground water from two springs (Salmon Spring and Maplewood Spring) and three production wells. Several additional wells are under consideration or construction. Salmon Spring is correlated with the Qva unit. Correlation of Maplewood Spring is uncertain. Based on depths of approximately 600 feet, it is likely that the production wells tap the Qu unit. Maplewood Spring has sustained an approximately 15-percent decrease in capacity in recent years; however, this has been attributed to a loss of efficiency of the collection system rather than a decrease in water level. No decreases in flow or water levels were reported for Salmon Spring or the existing production wells.

The City of Sumner uses ground water from three springs and two production wells. These sources supply approximately 1,500 gpm (Parametrix, Inc., 1993). The springs are correlated with the Qva unit; based on depths of approximately 300 feet, it is likely that the wells tap the Qu unit. No decreases in flow or water levels were reported for the springs or production wells.

According to a personal communication with Mr. Doug Dow of AGI Consultants (December 22, 1994), the City of Tacoma uses ground water from wells tapping three aquifers: The Shallow Aquifer, which lies between about 150 and 250 feet MSL; the Sea Level Aquifer, which lies near sea level; and the Deep Aquifer, which lies between about -700 and -900 feet MSL. Except for one well (Well 12A in the Shallow Aquifer), no significant drawdown has been observed in these aquifers.

Ecology does not maintain a water-level-monitoring network in the Puyallup White Watershed. Such a network could, if installed, maintained, and monitored, 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.

WATER DEMAND

WATER RIGHTS AND CLAIMS

Water consumption for the Puyallup-White River watershed has not been consistently recorded over the years, and an accounting of actual consumption has never been undertaken. It is likely that illegal water users are using water for irrigation or other purposes; however, it is also likely that numerous recorded or claimed rights are no longer in use. Although we lack water-use data and an understanding of actual use, we must assume that all recorded water rights and claims are fully in use today and represent consumptive water use.

Surface-water use has increased steadily throughout the years (Figure 10), with a total annual withdrawal of 160 cfs and 11,645 acre-feet authorized from the surface waters of the watershed as of the date of this report. As of September 1994, 10 applications for surface-water rights, requesting a total of 57 cfs for domestic supply, commercial/industrial use, fish propagation and irrigation purposes are on file with the Department of Ecology (Table 2).

Ground-water withdrawals have shown a rapid and steady increase (Figure 11), and a total annual withdrawal of 292.6 cfs and 112,175 acre-feet has been authorized from the watershed. As surface-water rights have ceased to increase, the number of ground-water rights have increased dramatically (Figures 10 and 11). As of September 1994, 34 applications for ground-water rights, requesting a total of 69.1 cfs for municipal supply, fish propagation, domestic supply, and commercial and mining purposes are on file with Ecology (Table 2).

For many water rights, no "Qa" was assigned when the right was granted. This tabulation accurately reflects paper records, but the total Qa would have been larger if values had been assigned.

Surface-water and ground-water withdrawal rights are shown by type of use with instantaneous withdrawals (Qi), and annual quantities (Qa) in Table 3. These uses are depicted graphically in Figures 12 and 13, with the indicated values representing the primary purposes of use as a percentage of the total allocated Qi. Because only primary purpose of use was evaluated, some large secondary uses, such as irrigation, were not accounted for.

To estimate quantity of consumptive use claimed, an instantaneous quantity (Qi) was assigned, and an annual quantity (Qa) was calculated for the major types of use to reflect the average withdrawal for most domestic, stockwatering and incidental uses. These assigned values are listed in Table 4.

A conservative instantaneous withdrawal of 1.0 cfs (450 gpm) was assigned to municipal use to allow ease of sorting and to establish an allocation base.

A total of 2,057 claims (378 surface water claims and 1,679 ground water claims) have been filed in the watershed. Table 5 shows the uses, instantaneous withdrawals, and annual quantities assigned to the claims.

Table 2. Current Water-Right Applications

PURPOSE	SURFACE WATER		GROUND WATER	
	Number	Total Qi (cfs)	Number	Total Qi (cfs)
Commercial	3	38	2	0.1
General Domestic	1	0.5	0	0
Multiple Domestic	1	0.1	17	10.7
Single Domestic	3	15	1	1.0
Fish Propagation	1	3	2	24.5
Irrigation	1	0.1	0	0
Mining	0	0	1	0.9
Municipal	0	0	11	31.9
TOTAL	10	56.9	34	69.1

Table 3. Water-Right Uses and Quantities

USE	SURFACE WATER RIGHTS		GROUND WATER RIGHTS	
	Qi (cfs)	Qa (a-f/y)	Qi (cfs)	Qa (a-f/y)
Commercial/Industrial	1.6	138	31.1	20,190
General Domestic	0	0	1.9	265
Multiple Domestic	22.0	1,039	88.5	27,732
Single Domestic	42.0	66	9.7	1,276
Environmental Quality	0	0	0.7	10
Frost Protection	0	0	0.2	9
Fire Protection	4.1	300	3.8	100
Fish Propagation	0	0	8.5	5,415
Heat Exchange	0	0	3.2	2,269
Irrigation	58.6	3,849	40.7	4,162
Mining	0	0	0.1	15
Municipal Supply	31.7	6,196	98.3	49,729
Recreation	0	50	2.3	434
Stockwater	0.5	8	3.6	560
TOTAL	160.5	11,646	293	112,176

Table 4. Values Used To Estimate Claims

USE	Qi (instantaneous; cfs)	Qa (annual; gpm)
Domestic	0.02	0.5
Stockwater	0.02	0.5
Irrigation	0.02	2.0
Municipal	1.0	(not calculated)
Other	0.02	0.5

Table 5. Water Claims Uses and Amounts

PURPOSE	SURFACE WATER CLAIMS		GROUND WATER CLAIMS	
	Qi (cfs)	Qa (a-f/y)	Qi (cfs)	Qa (a-f/y)
Domestic Supply	4.9	123.5	30.3	757.5
Stockwater	2.0	49.5	6.6	164.5
Irrigation	3.2	2,532	8.9	4,892
Municipal Supply	0	0	2.0	Not Calculated
Other	1.0	25.5	1.8	95
TOTAL	11.2	2,731	50	5,909

WATER QUALITY AND FISHERIES

SURFACE-WATER QUALITY

The status of water quality within the Puyallup River System is continuously monitored by the Washington Department of Ecology, USGS, and public-interest groups. The importance of adequate water quality and quantity within the Puyallup Basin is reflected in the following statement taken from the 1989 Draft Green-Duwamish Watershed Nonpoint Water Quality Early-Action Plan, "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."

Water quality within the Puyallup River Basin is less than ideal from both natural and human causes. Factors adversely affecting the waters of this basin include a wide spectrum of causes: high turbidity and glacial-sediment transport experienced during the summer months; logging operations in the mid and higher elevations; non-point pollution sources such as on-site septic systems and livestock operations; and regional stormwater from industrial and residential development.

The Puyallup River and its two main tributaries, the White and Carbon Rivers, have glacial origins from Mount Rainier. Glacial runoff has naturally high levels of suspended sediments (glacial "flour"). Anthropogenic sources of erosion are also sources of suspended sediments. Erosion may be caused by clearing and grading of land, increased streamflows which scour creek banks, and inadequate pasture and crop-land management. While naturally occurring sediments are important sources of nutrients for estuarine habitat, anthropogenic sources of sediment from accelerated erosion may carry phosphorous in excess amounts. Also, toxic substances adhere to sediments and may be transported into surface waters through erosion (Lower Puyallup Watershed Phase 1 Report, March 1992). Suspended sediment levels measured by USGS indicated fairly high averages of about 280 mg/L for the Lower Puyallup main stem. Suspended sediment levels were found to be significantly higher for the Puyallup and White Rivers than levels found for contributing creeks (Ebbert, et al., 1987).

The majority of water-quality problems within the Puyallup River System appear to occur in the lower Puyallup and White Rivers. Under the Federal Clean Water Act Section 303(d), Ecology prepares a biennial list for EPA of water bodies that do not meet the state's surface-water-quality standards. According to the 1994 Section 303(d) list submitted to EPA (Ecology, 1994), these problems are largely restricted to numerous violations of the Class A criteria for fecal coliform. The Puyallup River had 21 violations of the criteria at Ecology's Ambient Monitoring Station 10A070 between January 1, 1990 and January 1, 1992, with an additional 10 violations of criteria for USGS's Monitoring Station 12102050 near Puyallup. Similarly, the White River was cited with 11 violations of criteria at Ecology Monitoring Station 10C070 between January 1, 1988 and January 1, 1992. Figure 14 depicts the locations of violations described in the 303(d) Report. The estuarine City Waterway, which is classified only as a Class B waterway, is also listed in the Section 303(d) list as having excursions for both organics and metals in sediments.

Many smaller creeks and rivers add to water-quality problems within the Puyallup-White Drainage Basin (WRIA 10). Among these are Hylebos and Wapato Creeks which drain into Commencement Bay and are cited in Ecology's 303(d) list for excursions in fecal coliform and dissolved oxygen. The most significant water-quality problem occurring in tributaries of the Puyallup and White Rivers (such as Boise Creek, Scatter Creek, Clearwater River, and Greenwater River) appear to be excursions for elevated temperature levels.

The Clean Water Act Section 305(b) Report (Ecology, 1992) also indicated that Hylebos Creek (stream segments 10-1011 and 10-1013), the Puyallup River (segment 10-1020) and the White River (segment 10-1030) have been impaired for primary and secondary recreational use due to the presence of high fecal-coliform counts. One source of water-quality impairment listed in the report was discharge by municipalities and industries. A total of 44 individual NPDES permittees discharge to the watershed. Of the 44 discharges, 13 are municipal discharges and the remainder are industrial. In addition, there are 28 general permits that allow discharge to surface water within the watershed. Other sources of impairment listed in the report include pasture lands, animal-management areas, 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 Code (HUC) areas 17110019 and 17110014. HUC 17110019 is the major HUC comprising the watershed but also includes areas in WRIAs 8 and 9. The surface water data were averaged separately from ground water data. Data from HUCs 17110019 and 17110014 indicate that concentrations exceeded the water-quality criteria for dissolved copper, lead, and silver, in addition to fecal-coliform bacteria. 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.

Site-specific surface-water data were obtained from the U.S. Geological Survey NWIS database. A review of these data for the watershed indicate dissolved copper exceeded the water quality criterion in the Puyallup River at Orting and Puyallup and in the White River near Buckley and Sumner. The sampling locations near Sumner and at Puyallup also indicated excursions for dissolved lead.

The Lower Puyallup Watershed Action Plan (LPWMC, 1992) indicates that the water quality of many of the subbasins has been adversely affected. The study indicated elevated levels of fecal coliform in the Hylebos, Clarks/Clear Creek, and Lower White subwatersheds. High concentrations of total phosphorus and nitrogen species which potentially limit nutrients in freshwater systems, were noted in the Hylebos, and Clarks/Clear Creek subwatersheds. Most noteworthy are the concentrations of copper, lead, mercury, and zinc in the Hylebos that exceeded the water quality criteria.

The most in-depth water-quality study of the watershed was *Puyallup River Total Maximum Daily Load for Biochemical Oxygen Demand, Ammonia, and Residual Chlorine* performed by Ecology (Pelletier, 1993). The report indicates that dissolved oxygen, ammonia, and chlorine are water-quality concerns especially during summer periods of high temperature and pH and low flows. For the White River between RM 24.3 and 3.6 during summer months the water-quality-problems were attributed primarily to the NPDES dischargers that were not regulated for ammonia. The report also indicates that nitrogen may be more limiting to algal growth than phosphorus during the growing season. The newly issued permits for Buckley and Enumclaw, which discharge to the White River, have ammonia effluent limits. The report predicted that dissolved oxygen in the Lower Puyallup River would violate water quality standards if existing NPDES facilities reach their design capacity.

Anecdotal evidence also suggests certain areas with high densities of failing septic systems, improperly managed sewage treatment plants, and sewage-treatment-system bypasses contribute to surface-water degradation.

Surface-water-quality data are also available for public water supplies for the analytical parameters required to be monitored under the Safe Drinking Water Act. These data are maintained by the Washington Department of Health (Health) on two databases that will be merged into a single database within the next 6 months. Health provides updated electronic data to the Department of Ecology (Environmental Investigation and Laboratory Services) and to the USGS on a semiannual basis.

GROUND-WATER QUALITY

Ground-water quality may be affected by point and non-point sources of pollution within the watershed. The 305(b) Report (Ecology, 1992) cited commercial activities, industrial development, and rapid urbanization as causes of ground-water pollution. There are two municipal and one industrial permitted dischargers to the ground under the State Waste Discharge Permit Program. The 305(b) Report also cited the cumulative effects of on-site septic systems, small farms, and stormwater runoff as sources of non-point-source pollution. Anecdotal evidence also suggests certain areas of high densities of failing septic systems could contribute to ground-water degradation.

Fewer data are available on the ground-water quality than on surface-water quality. Nitrate 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 effects 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 15. The highest measured nitrate concentrations from water supply wells based on the 1989 Health database were used to develop the figure. All but five of the wells had nitrated concentrations less than 2 mg/L, and none of the wells had nitrate concentrations that exceeded the primary drinking water maximum- contaminant level (MCL) of 10 mg/L. While these nitrate concentrations are not the sole indicator of ground-water quality, they do indicate that the ground water in the watershed is of relatively good quality.

Ebbert, et al. (1984) assessed ground-water quality within the watershed. The data indicate that water quality was generally good, and better in the lower aquifer than in the upper unconfined aquifer. The pH for the two aquifers ranged from 6.3 to 8.2, generally within the water-quality criterion of 6.5 to 8.5. Dissolved iron and manganese concentrations were high in both shallow and deep aquifers and often exceeded the water-quality criteria of 0.3 and 0.05 mg/L for iron and manganese, respectively. These two constituents do not adversely affect human health at the concentrations measured. Four of the 15 shallow wells sampled exceeded the ground-water criterion for dissolved solids (i.e., the concentrations were greater than 500 mg/L) and one of these wells also exceeded the criterion for sulfate. While these criteria do not limit water potability, they do serve as indicators of potentially degrading conditions. In fact, such conditions were found in the more industrialized areas near Interstate 5.

Ebbert, et al. (1984) investigated saltwater intrusion in the ground water within the watershed by monitoring chloride concentrations. High chloride concentrations found in wells near the coast are generally indicative of saltwater intrusion. Chloride concentrations were generally less than 10 mg/L in the upland areas and higher in the lower valley (28 to 51 mg/L). The report also indicates that the elevated concentrations are supported by two earlier studies of saltwater intrusion that concluded there is a potential for salt water to intrude in the lower valley. The maximum chloride concentration Ebbert et al. observed was 220 mg/L in a shallow well north of Interstate 5 in the lower part of the Puyallup River Valley. While the observed concentration indicates saltwater intrusion, it does not exceed the primary drinking water standard maximum contaminant level of 250 mg/L.

The EPA Storet database was searched for water quality in HUC areas 17110019 and 17110014 and average parameter concentrations were obtained. The average concentrations exceeded the criteria provided in the Ground Water Quality Standards (Chapter 173-200 WAC) for arsenic, manganese, and fecal coliform in both HUCs. 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).

FISHERIES

The Washington Department of Fisheries' 1975 Catalog of Washington Streams and Salmon Utilization indicates that anadromous salmonids found throughout the Puyallup-White River Basin are chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), salmon and steelhead trout (*O. mykiss*). Adult or juvenile salmon of all species are present within the basin throughout the entire year.

Adult salmonids migrate upstream through the Puyallup River throughout the year. Chinook, chum, pink, and coho salmon migrate upstream during late summer, fall, and early winter, and steelhead trout migrate in both winter and summer. Timing of upstream migration of the Pacific salmon is largely controlled by rainfall, streamflow, and barometric pressure. Migrating salmon collect near the mouth of the Puyallup River during July and August before migrating predominantly between September through January (Wydoski and Whitney, 1979).

Downstream migration (out-migration) by juvenile salmon and steelhead primarily occurs in late winter and early spring. Chum salmon out-migrate beginning in late February and both chinook and coho begin in early April. Out-migration usually lasts through mid-July (or early August) for most species. Downstream migration by juvenile salmonids calls for spending more time in the Lower Puyallup River than during upstream migration. During this time, juveniles use the City Waterway and estuary to feed and physiologically adapt to marine salinities. Among numerous beneficial uses of estuarine habitats identified by Metro, use as transportation and rearing habitat for out-migrating juvenile salmonids was listed as the most important (Harper-Owes, 1983).

The salmonid habitats of the White River and the Lower Puyallup drainage have been severely degraded by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the Puyallup Basin. Also, this drainage provided sub-optimal conditions for salmonids even in the pristine state due to the glacial origin of its waters. Because of this, the human impairment of the habitat has been particularly devastating (Grette and Salo, 1985). Three projects in particular, the Mud Mountain Dam constructed in 1947, the Puget Sound Power and Light Company's (PSPL) diversion dam at RM 24.3 on the White River, and Electron Dam operated by Puget Sound Power and Light diverting water at RM 41.7 of the Puyallup River have had significant effects on salmon resources.

Mud Mountain Dam was designed as a single purpose flood-control facility located 29 miles upstream from the confluence of the White and Puyallup Rivers. The dam constitutes a complete barrier to upstream fish migration; however, a trap and haul operation has transported fish to a point upstream of the dam since 1940 (Salo and Jagielo, 1983). The trap and haul operation currently transports chinook and coho salmon, and steelhead trout adults from the PSPL diversion dam at Buckley to a point upstream of the dam. This practice results in a 5.3 mile stretch of river (between the diversion dam and Mud Mountain Dam) which is not used for salmon spawning (Grette and Salo, 1985).

Mortality of juvenile outmigrants occurs at both the Mud Mountain Dam and the PSPL Diversion structure at Buckley. Washington Department of Fisheries reports claim that mortalities, delays in outmigration, and passage into Lake Tapps have resulted from the ineffectual operation of the screens at the PSPL Diversion Dam, although specific mortality figures were not cited (Regenthal, 1953 and Heg, 1953). Mortality of outmigrants through Mud Mountain Dam is caused primarily during discharge of water through a secondary outlet structure which causes significant juvenile losses. Discharge of water through this secondary outlet is limited however, so overall mortality is not significant.

Although the flood-control aspect of the operation of Mud Mountain Dam is very beneficial to the people of the lower valley and is even beneficial to the instream resources during flood periods, salmon productivity is adversely affected by the release of water carrying high silt and debris concentrations.

The PSPL diversion dam at Buckley diverts water which ultimately enters Lake Tapps and is used for power generation. It is returned to the river at Dieringer. This diversion results in drastically reduced instream flows in a bypassed 21-mile reach of the mainstem White River. The existing artificial minimum flow of 130 cfs at the PSPL diversion, presently sustained during low-flow periods between Buckley and Dieringer, is inadequate and not based on the minimum preservation needs of the salmon species within the White River. According to the Department of Fisheries, a minimum flow of 435 cfs must be maintained within the Lower White River to insure the viability of salmon species (Ecology, 1980). Thus, the bypassed reach presents a block to migrating adult salmonids and provides limited rearing habitat at low flows (Salo and Jagielo, 1983; Grette and Salo, 1985).

The PSPL hydro-power diversion at Electron withdraws water from the Puyallup River at RM 41.7 through the powerhouse and discharges the water at RM 31.2. Thus, 10 miles of salmon habitat are substantially dewatered, not allowing fish passage to the upper waters for spawning.

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* and 2) The *1992 Salmon and Steelhead Stock Inventory* (SASSI) published in March 1993. The first paper attempted to assess the future risk of extinction for selected stocks, while the SASSI report examined the current status of salmon and steelhead stocks for Washington State.

The SASSI report indicates that chinook populations for the Puyallup and White Rivers are either critical (due to chronically low escapement levels) or unknown. Coho on the Puyallup River are currently classified as depressed. According to the SASSI report, this is due to a short-term severe decline in index-escapement counts. White River Coho are classified as a healthy stock. Puyallup River pink salmon as well as winter-run steelhead are all classified as healthy for the Puyallup-White River System. The American Fisheries Society (AFS) has identified White River spring chinook as being at a moderate risk for extinction due to present or threatened destruction, modification, or curtailment of its habitat or range. This includes mainstem passage and flow problems. Native stocks of Puyallup River spring chinook have been identified as extinct (Nehlsen et al., 1991). The AFS has also identified Puyallup River fall chinook as being of special concern because available information suggests depletion. The population is not presently at risk, but requires attention because of its unique character (Nehlsen et al., 1991). The SASSI and AFS reports are presented graphically in Figure 16, which shows a habitat loss for at least one species for each stretch indicated on the figure.

Additional information on Puyallup River salmon runs has been provided by the Puyallup Tribe for the years 1980 to 1989 and are shown in Figure 17(A). The graph shows a high number of returning coho, the majority of which are of hatchery origin. Compared to the coho run, chinook and chum runs are comparatively small. In fact, the Puyallup Indian Tribe has identified the chinook run as being severely impaired. The chum counts may not be reliable, but they are the best available. Figure 17(B) depicts a graph comparing hatchery steelhead runs between 1980 and 1989. The wild-run size for steelhead is not known at this time (Puyallup Tribe of Indians, 1991; LPWMC, 1992).

Anadromous-fish production in the Puyallup-White River Basin is relatively low and has been below historic levels for many years. There are many complex and interacting factors which are contributing to the low production. Some of these adverse conditions 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 an increasing number of years. These low flows are aggravated by diversion of water for hydroelectric purposes on the Puyallup and White Rivers (Ecology, 1980).

A water-flow study conducted on the White River by the U.S. Fish and Wildlife Service in 1974 concluded that the most critical problem confronting anadromous-fish resources in the White River is the lack of adequate water for passage of adult fish to their spawning grounds, both above and below Mud Mountain Dam and PSPL's diversion dam. The report advised that minimum standards must be achieved to accommodate the freshwater activities and life phases of anadromous fish including their migration, spawning, incubation, and rearing. Furthermore, the report made recommendations as to appropriate annually fluctuating minimum flows commensurate with the needs of salmon species inhabiting the White River. These recommendations included minimum flows of 500 cfs for adult chinook migration, 250 cfs for adult coho migration, and maintaining at all times a minimum flow of 180-190 cfs below the Buckley diversion dam to protect salmonid spawning and rearing habitats (U.S. Fish and Wildlife Service, 1974).

A study conducted by Caldwell and Hirschey (1989) on the Green River using the Instream Flow Incremental Methodology (IFIM) concluded that, "There is no one flow at which habitat for fish is optimum. The different fish species and lifestages exist simultaneously in the river and each has a different optimum flow requirement. Providing an optimum habitat flow for one lifestage will usually result in the habitat loss for another lifestage. Peak habitat flow does not necessarily equate with peak fish production. Flows higher than peak habitat flows are needed for juvenile fish at certain times of the year to maintain existing production levels." These statements point out the need for specific adjustments in minimum flows at different times of year for different species. This leads to great difficulty in reaching the best compromise for flows which meet the needs for all species and lifestages.

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. The IRPP document also presents data which suggest a positive relationship between the magnitude of the lowest recorded flow and the steelhead production for each year, but results are not conclusive.

STREAMFLOW STATUS

OBJECTIVES OF ANALYSIS

As previously discussed, the demands on surface-water and ground-water use have grown rapidly over the past 20 to 30 years in the Puyallup River basin. Higher 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 discharge characteristics of the river systems, flow and precipitation data from the watershed were analyzed. Flow data from USGS gages were evaluated for flow exceedence values and low-flow trends. For gages which have minimum flows established by WAC 173-510 (Figure 18), the number of days per year that these flows were not met was calculated. In the analyses presented below, all available records were used.

FLOW EXCEEDENCE

Flow-exceedence curves were developed for the Lower and Upper Puyallup River (Figures 18 and 19). More than 75 years of flow data were used to calculate the monthly flow curves for the Lower Puyallup (USGS gage 12101500). Data for the Upper Puyallup River (USGS gage 12096500) were collected from 1914 to 1993, although data were missing from 1927-1942 and 1958-1986. Based on these lengthy periods of flow record, 90-, 50-, and 10-percent flow-exceedence curves were developed. The 90-percent curve represents low-flow conditions, since flows at any time during a given year have a 90-percent probability of exceeding the plotted values. The 50-percent curve shows the median flow values and approximates normal-flow conditions throughout the year. The 10-percent curve is representative of high flow conditions.

Minimum instream flows for the two gage locations established by WAC 173-510 are shown with the exceedence curves to indicate the relative frequency that the minimum flows are not met (Figures 19 and 20). For the Lower Puyallup Gage Station, the 90-percent exceedence curve is above the instream flow requirements established by WAC 173-510 December through September, but drops below (or is very close to) the minimum instream-flow requirements from October through November (Figure 19). Based on the 90-percent-exceedence curve, there is a 10-percent probability that the established minimum instream-flow requirements will not be met for a period of time from October to November. The 50-percent-exceedence curve indicates that normal flow conditions at the Lower Puyallup Gage are above established instream flows. For the Upper Puyallup Gage Station, the 90-percent-exceedence curve is critically close to or below the instream flow requirements for the entire year (Figure 20). Practically speaking, there is a 10-percent probability that the established instream flow requirements will not be met at any given time of the year. The 50-percent-exceedence curve indicates that under normal conditions, flows at the Upper Puyallup Gage are above instream-flow requirements.

Minimum flows also have been established for USGS gage 12095700 along the Carbon River. However, no continuous data are available for this gage to allow a detailed flow evaluation.

Flow-exceedence curves also were developed for the White River near Buckley (USGS gage 12098500), South Prairie Creek (USGS gage 12095000), and the Puyallup River near Electron (USGS gage 12092000) to characterize flow conditions in these regions of the watershed (Figures 21-23). No minimum flows have been established for these gage locations. The high flow values that occur in June at the White River and Puyallup River near Electron indicate the influence of glacier melt from the headwaters (Figures 21 and 23). South Prairie Creek is not fed by glaciers and lacks this early summer high flow period (Figure 22).

LOW FLOWS

Low flows in the river were evaluated by calculating seven-day low flow values for each year of record. The seven-day flow duration is conventionally used in evaluating low flows because shorter flow durations have much greater variability. The *deviation* of the seven-day low flow from the established instream flow requirements were calculated for the Lower Puyallup River. When plotted over time, there is a strong downward trend in average seven-day-low flows over the past 20 years as indicated by the ten-year moving average (Figure 24). Over the last ten years threshold values of the seven-day low flow have passed below the minimum instream flow requirement as indicated by the negative deviations in Figure 24. Flow data for a continuous period in recent years for the Upper Puyallup River was not available so a similar evaluation of the minimum flow was not performed.

For the White River near Buckley, South Prairie Creek, and the Puyallup River near Electron, seven-day low flows were calculated for the flow record (Figures 25-27). For the White River near Buckley, there were no discontinuities in the data and a ten-year moving average was computed (Figure 25). The moving average suggests that low flows have decreased over the past 20 years. Gaps in the data for Prairie Creek make the prediction of trends difficult (Figure 26). The ten-year moving average computed for the Puyallup River near Electron (Figure 27) shows an increasing trend since 1981.

Finally, for the Lower and Upper Puyallup River, the number of days per year that flows were less than the established instream flows were calculated (Figures 28 and 29). Since the data were continuous for the Lower Puyallup, a ten-year moving average was used to evaluate trends in recent years. Consistent with Figure 24, over the past 20 years there has been an increasing number of days per year that established instream flows have not been met at the Lower Puyallup. From 1964 to present, the average number of days minimum instream flows were not met increased from about 15 to 40. Missing periods of data for the Upper Puyallup make the prediction of trends difficult for this gage location (Figure 29).

INTERPRETATION OF STREAMFLOW STATUS

Based upon the preceding analyses, it is evident that maintaining low flows is an issue in the Puyallup River. Established instream flows are not met ten percent of the time for periods in October through November in the Lower Puyallup River. Over the last 20 years there has been a trend of decreasing low flows in the Puyallup River. The trend is most evident in the Lower Puyallup, and is also evident in the White River near Buckley. In the Upper Puyallup River, established instream flows are not met ten percent of the time throughout the entire year.

Increasing surface and ground water withdrawals can affect low flows and would be of greater consequence during an extended period of below-average precipitation. Recurrence of an extended drought, such as the one in the 1920s and 1930s, combined with increased water use and increases in impervious surface areas from urbanization would have compounded the effects of reducing low flows in these portions of the watershed.

SUMMARY AND CONCLUSIONS

The Puyallup-White Watershed (WRIA 10) covers 972 square-miles and includes all of the lands drained by the Puyallup, Carbon, and White Rivers. The headwaters of these river systems are on Mount Rainier and all three rivers discharge through the Puyallup River into Commencement Bay and Puget Sound at Tacoma.

The eastern half of the WRIA, a mountainous physiographic province, is forested and encompasses three broad bands of ownership: Mount Rainier National Park (managed by the Department of the Interior); and Snoqualmie National Forest lands (managed by the Department of Agriculture); is private. Below the forests, the watershed is a mix of agricultural, residential, urban, and industrial areas with the degree of development and industrialization increasing toward Tacoma. Much of the area from Orting and Buckley down to Puyallup and Sumner is zoned for suburban agriculture. Below Puyallup, the watershed is almost completely urban, commercial, and industrial.

Water rights and registered claims for surface and ground water use for the Puyallup-White Watershed are 453 cubic feet per second (cfs) and 61 cfs, respectively. Water rights plus claims total 513 cfs. Recent trends have indicated an increasing demand for ground water rather than surface water rights. Current applications on file with the Department of Ecology and pending action total 126 cfs. Actual water use in the watershed is not known.

Median annual streamflow at the Lower Puyallup Gage, located at the downstream end of WRIA 10, equals 2,922 cfs for the period 1914 to 1993. Thus, water rights and claims equal approximately 18 percent of the median annual streamflow. The minimum low flow (defined as the 90-percent-exceedence level) between September and November averaged 1,156 cfs which closely coincides with the minimum-flow requirements. Water demand (rights and claims) represents 44 percent of the minimum low flow during this period of the year. This period of low flow coincides with the Pacific salmon species upstream migrations for spawning. Because the actual water use is not known and unauthorized water withdrawals are suspected based on anecdotal information, total water withdrawal cannot be accurately assessed. During particularly dry years, a number of seldom-used water rights or claims might be exercised to the extent that streamflow could drop below presently recorded levels.

Maintaining minimum-instream flows is an issue in the Puyallup River. The minimum instream flows established by Chapter 173-510 WAC are not met ten percent of the time for periods in October through November in the Lower Puyallup River. Over the last 20 years there has been a trend of decreasing low flows in the Puyallup River. Of the gage stations analyzed, the trend is most evident in the Lower Puyallup, and is also evident in the White River near Buckley. Since 1980, minimum streamflows required by Chapter 173-510 of the Washington Administrative Code (WAC) for the Lower Puyallup Gage have not been met an average of 35 days per year. This number has increased from 15 in 1964 to 40 in 1993, during a period of higher than average precipitation at the Seattle and McMillin weather stations. Minimum instream flows for the Upper Puyallup Gage were not met an average of 37 days per year (1987-1992).

For the White River near Buckley, a 10-year moving average of the seven-day low flows suggests that the seven-day low flows have decreased over the past 20 years. A 10-year moving average was also computed for the Puyallup River near Electron (above the Puget Sound Power and Light diversion). The 7-day low flows appear to have increased since 1981. For the White River near South Prairie Creek, gaps in the data make the analysis of trends difficult. To provide more accurate water resource data for allocation, continued monitoring of gage stations is strongly recommended.

Recent surface-water-quality studies by Ebbert, et al. (1987), Ecology (1994), and others indicate the surface-water-quality criteria for fecal coliform and temperature are being exceeded throughout much of the Puyallup-White Watershed and the tributaries. Low dissolved oxygen and toxicity from ammonia and residual chlorine are water-quality concerns (Pelletier, 1993). In addition, dissolved concentrations of copper, lead, mercury, and zinc exceeded the water-quality criteria in Hylebos Creek (LPWMC, 1992), dissolved copper exceeded the water-quality criteria at several sampling stations.

Ground-water-quality data, although generally less extensive, indicate the ground water is of generally high quality based on nitrate-nitrogen concentrations for public-water-supply wells. Exceedences of the ground water-quality-criteria have been recorded for locations within the hydrologic unit code that generally coincides with the watershed. Parameters that have been recorded to exceed the ground-water-quality criteria include fecal coliform, arsenic, and manganese.

Because both ground-water and surface-water quality data do not provide a comprehensive understanding of the watershed as they currently exist, two recommendations are made. First, surface-water gaging stations should be monitored for selected water-quality parameters as well as flow. A ground-water-quality network should be established for monitoring water levels and water-quality parameters. Second, existing data should be compiled into a single user-friendly and publicly accessible database. Measures that coordinate water quality and quantity data gathering can assist in more efficient and effective water-resource allocation. Protocols should be adopted for collecting water-quality data to ensure that the data are comparable.

Point and non-point pollutant sources to ground and surface water include municipal and industrial discharges to surface and ground water; commercial and industrial development; stormwater runoff; agricultural activities; stream channelization; and cumulative effects of high densities of on-site sewage systems.

The salmonid habitats of the White River and the Lower Puyallup drainage have been severely degraded by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the Puyallup Basin. Also, this drainage provided sub-optimal conditions for salmonids even in the pristine state due to suspended rock "flour" from the glacier. Because natural conditions are sub-optimal, the human effects on the habitat have been particularly devastating (Grette and Salo, 1985). Three projects in particular, the Mud Mountain Dam constructed in 1947, the PSPL's diversion dam on the White River, and the Electron diversion operated by Puget Sound Power and Light have significantly reduced the salmon resources.

A water-flow study conducted on the White River by the U.S. Fish and Wildlife Service in 1974 concluded that the most critical problem confronting anadromous fish in the White River is the lack of adequate water for passage of adult fish to their spawning grounds, both above and below Mud Mountain Dam and PSPL's diversion dam at Buckley. The report advised that minimum streamflow standards must be achieved to accommodate the freshwater activities and life phases of anadromous fish, including minimum flows of 500 cfs for adult chinook migration, 250 cfs for adult coho migration, and maintaining a minimum flow of 180-190 cfs at all times below the Buckley diversion dam to protect salmonid spawning and rearing habitats (U.S. Fish and Wildlife Service, 1974).

The 1992 Salmon and Steelhead Stock Inventory (SASSI) report indicates that chinook populations for the Puyallup and White Rivers are either critical (due to chronically low escapement levels) or unknown. Coho on the Puyallup River are currently classified as depressed. White River Coho are classified as a healthy stock as are Puyallup River pink salmon and winter-run steelhead. The American Fisheries Society (AFS) has identified White River spring chinook as being at moderate risk for extinction due to present or threatened destruction, modification, or curtailment of its habitat or range, and fall chinook as being of special concern because available information suggests depletion. Native stocks of Puyallup River spring chinook have been identified as extinct (Nehlsen, et al., 1991). Information on

Puyallup River salmon runs has been provided by the Puyallup Tribe of Indians for the years 1980 to 1989 has identified the chinook run as being severely impaired (Puyallup Tribe of Indians, 1991; LPWMC, 1992). Anecdotal information from the Puyallup Tribe indicates severe dewatering of Wapato Creek has impeded salmon migration.

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. First, unauthorized-water users and claimed rights no longer exercised prevent correlation between the amount of water being used and the amount which are 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." Second, most water-right claimants did not specify quantities on their claims; therefore, quantities for claims were estimated for this report. 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.

Ecology also must manage the water resources of WRIA 10 without information on water use by the military and by the Puyallup and Muckleshoot Tribes. Federal government facilities do not need water rights and are not required to report water use or consumption to the State of Washington. Thus, McChord Air Force Base and Fort Lewis operate their own water supplies independent of Washington's system of water management. Also, though the Federal government granted water rights to the tribes, some dispute surrounds the amount of these rights.

In addition, both the Puyallup and the Muckelshoot Tribes have fishing rights within the watershed that are considered to pre-date water rights and claims. In accordance with the Bolt Phase II decision, water quantity and water quality must be maintained to ensure adequate salmonid habitat. Implementation of this decision may require Ecology to consider the tribal fishing rights as the driving factor in water allocations, as well as issuance of wastewater-discharge permits and non-point-source pollutant controls.

RECOMMENDATIONS

This initial watershed assessment relied on existing information. There are an abundance of reports on the study area, but there are some 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.

- Actual water use within the basin should be determined through a system of annual reporting. This activity could allow relinquishment of unused rights and improve the technical analyses of water-use effects, and allow more informed allocation of future water rights.

- 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.

- All currently active weather stations and USGS gages should continue to be monitored and should be properly maintained. A streamflow gage should be established on the Carbon River in order to monitor the status of minimum instream flows which were set in Chapter 173-510 WAC. Establishing gages in critical areas not currently monitored should be considered.

- An active network of water-level-monitoring wells should be established. This program could include all major users of ground water within the watershed as well as installation of monitoring wells. Data gathering should be coordinated to include static water level and water-quality parameters. This data would be used to determine trends in ground-water levels and quality. Standard protocols for data collection should be established.

- Salmon resources should be protected by maintaining adequate instream flows, and re-establishing natural habitat where such habitat has been removed by channelization, vegetation removal, or gravel mining.

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

- The Lower Puyallup Watershed Management Committee (or a similar body) should be expanded to include the entire watershed (ground and surface water). Planning activities should include water-quality and water-quantity issues. Planning should empower the residents within the watershed, and include tribal, state, and local interests in the decision-making.

- The Puyallup and Muckelshoot Tribes should be included in all decisions for the Puyallup-White Watershed.

- Tribal water withdrawal should be recorded and used to improve the technical analyses of water-use effects.

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

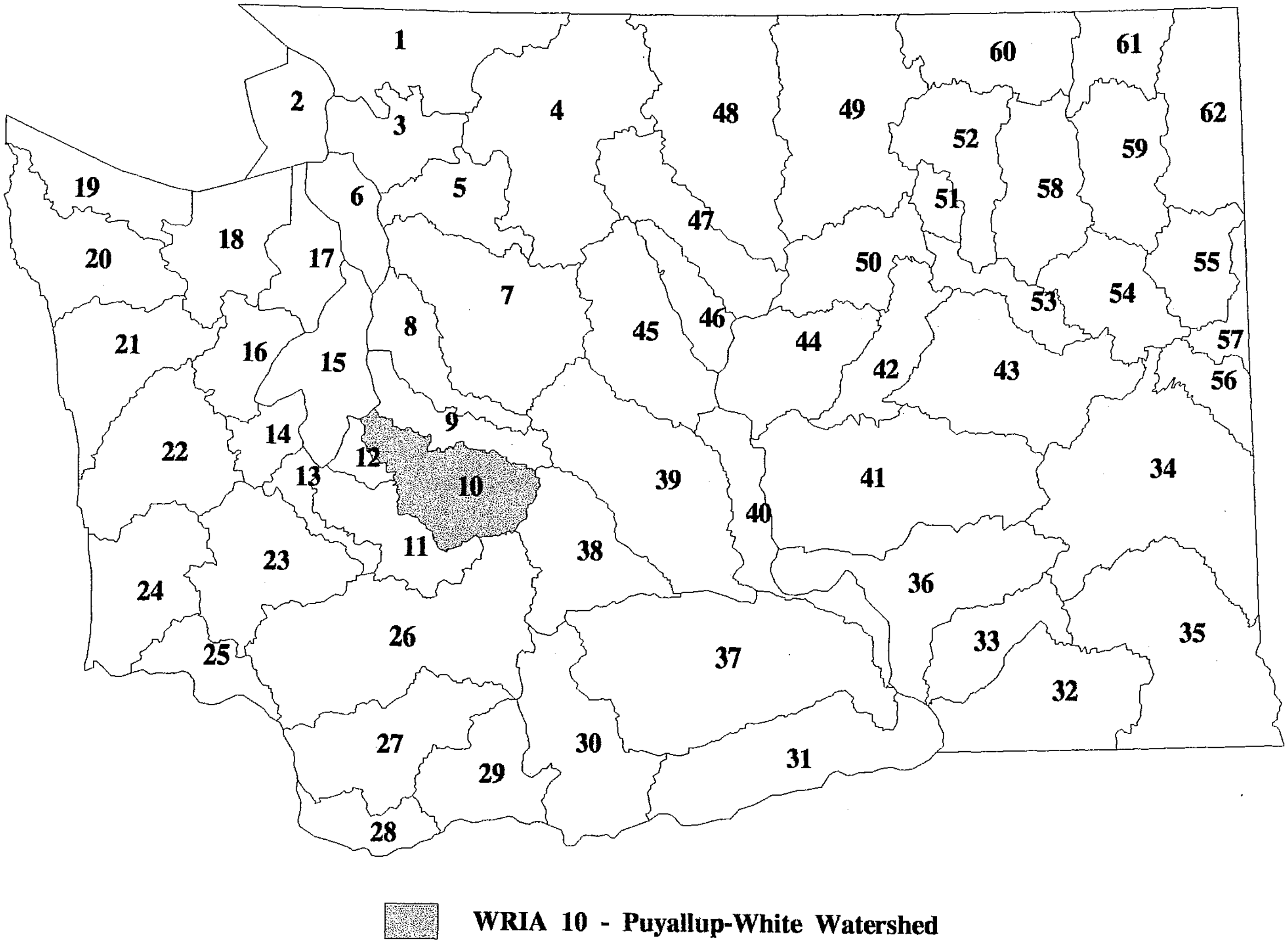
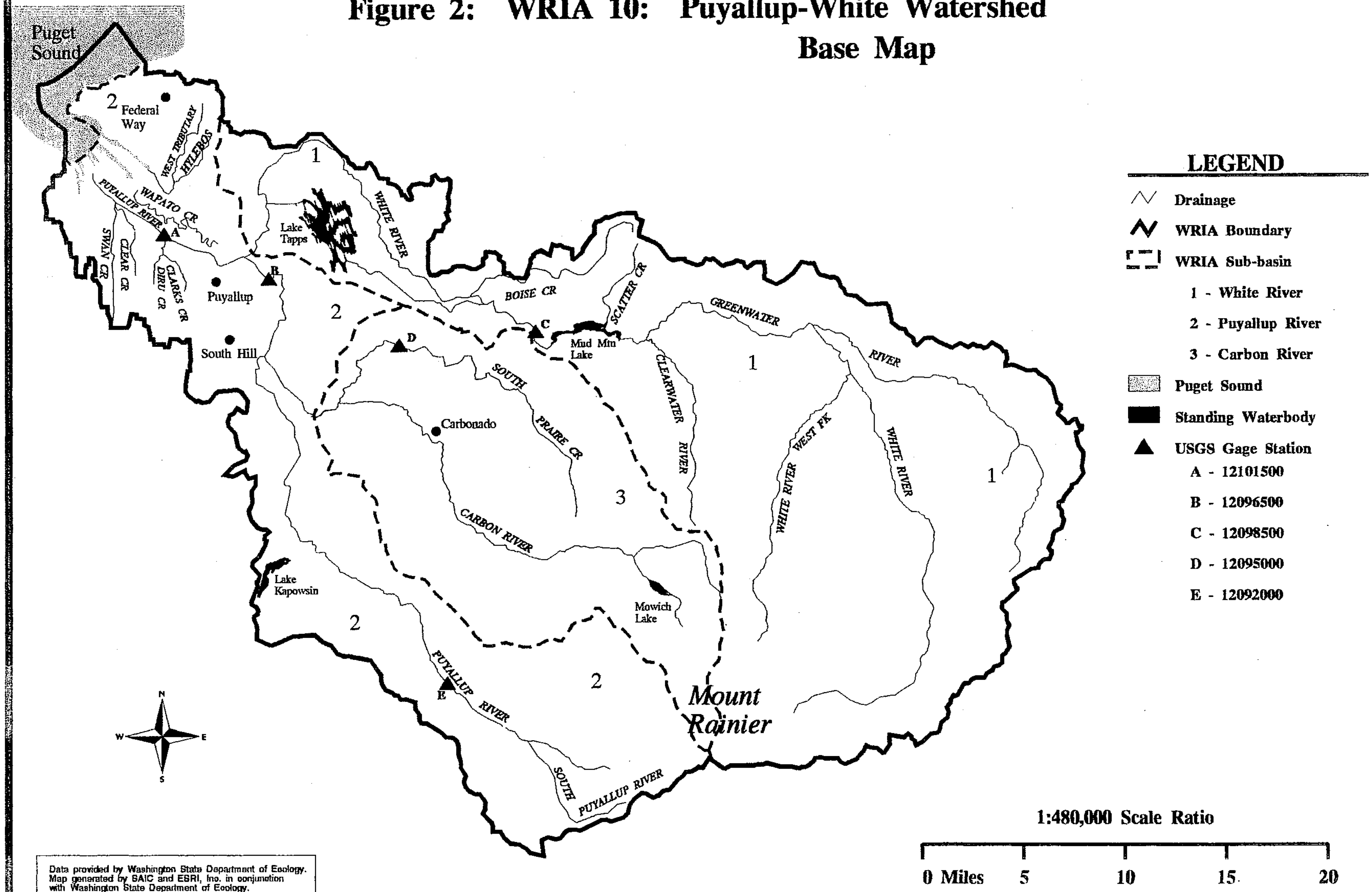
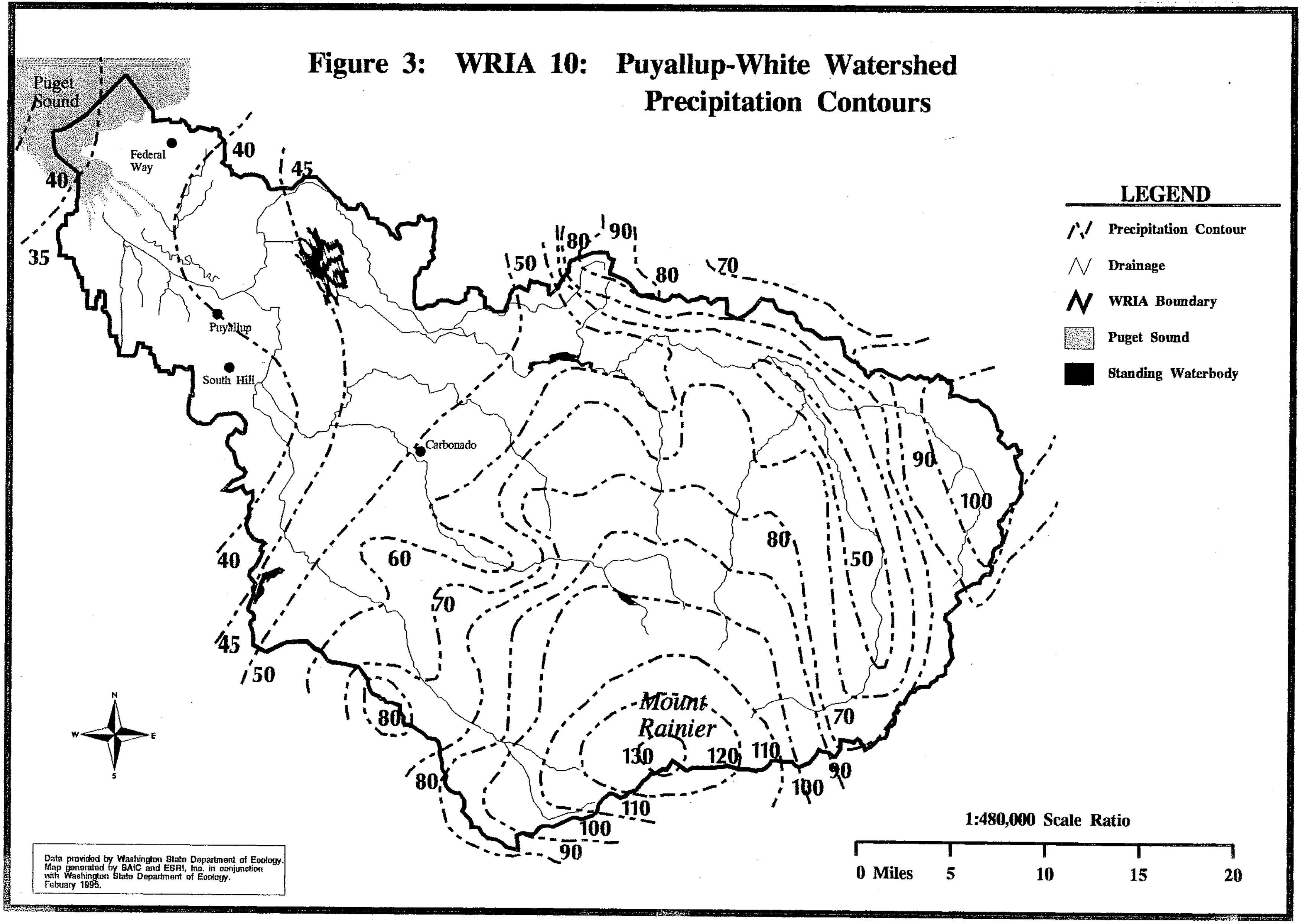


Figure 2: WRIA 10: Puyallup-White Watershed Base Map



Data provided by Washington State Department of Ecology.
Map generated by SAIC and ESRI, Inc. in conjunction
with Washington State Department of Ecology.
Febuary 1995.

Figure 3: WRIA 10: Puyallup-White Watershed Precipitation Contours



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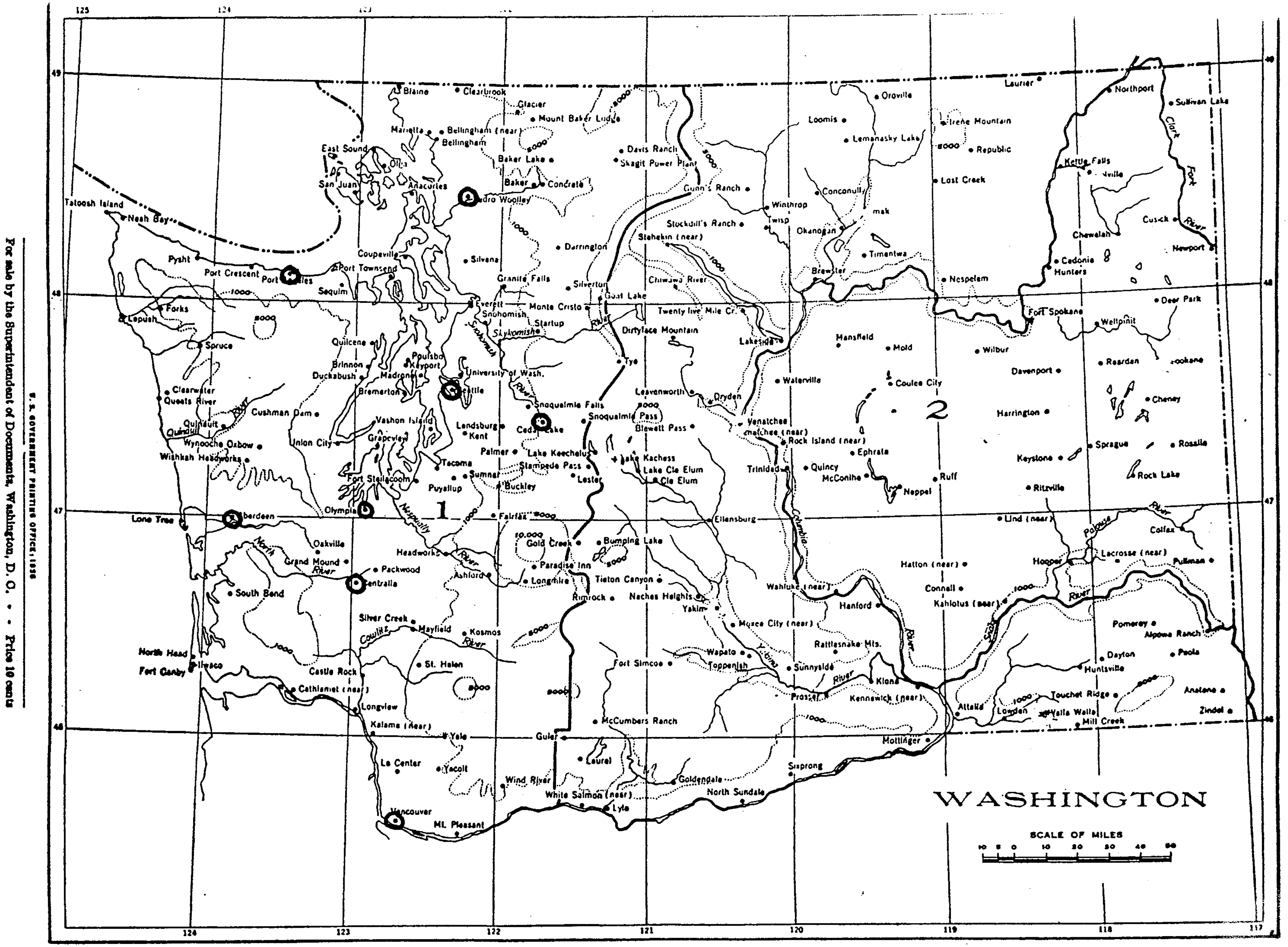


Figure 4. Precipitation Station Locations

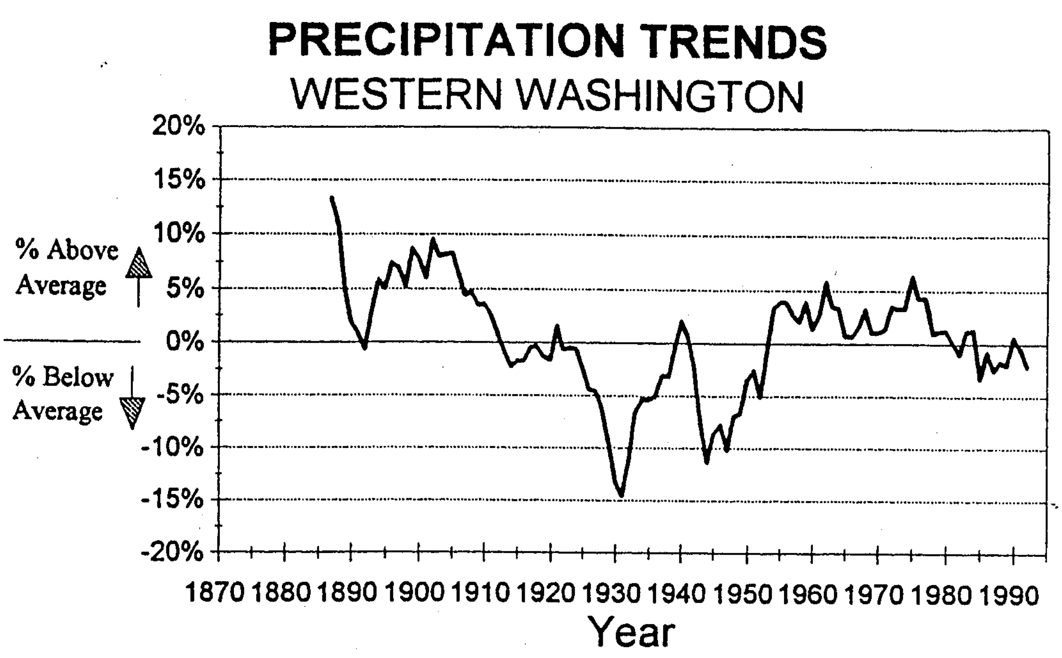


Figure 5. Precipitation Trends in Western Washington

FIGURE 6 - PRECIPITATION MEASURED AT SEATAC AIRPORT - 10-YEAR MOVING AVERAGE

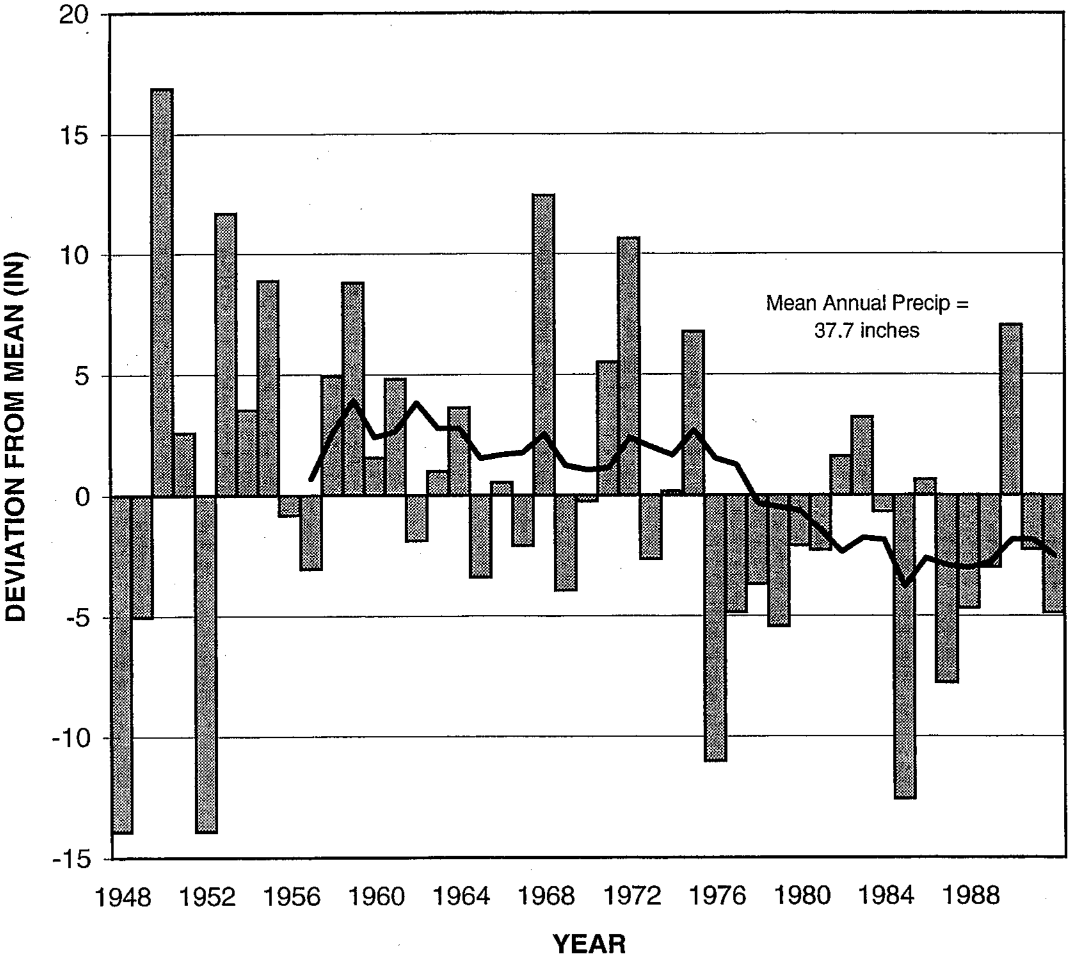


FIGURE 7 - PRECIPITATION MEASURED AT MCMILLIN RESERVOIR - 10-YEAR MOVING AVERAGE

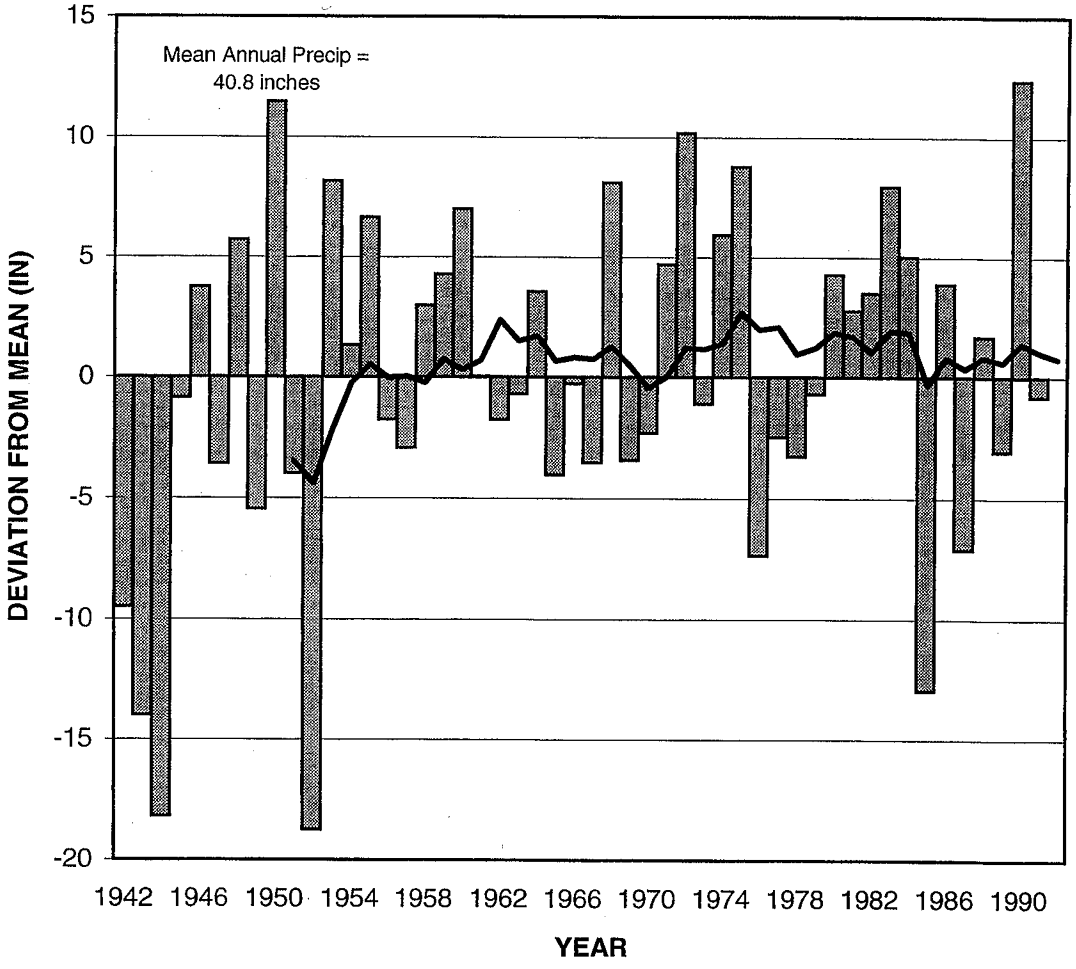
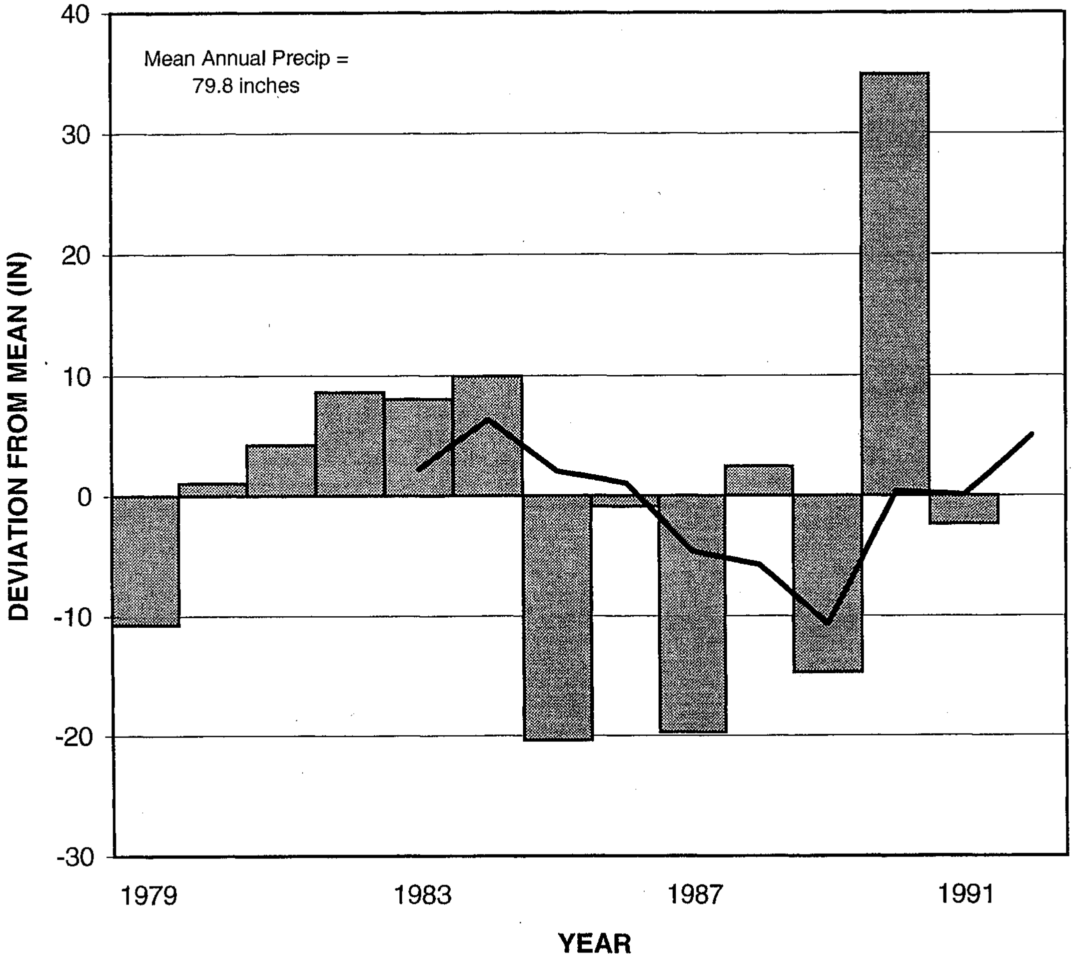


FIGURE 8 - PRECIPITATION MEASURED AT LONGMIRE - 5-YEAR MOVING AVERAGE



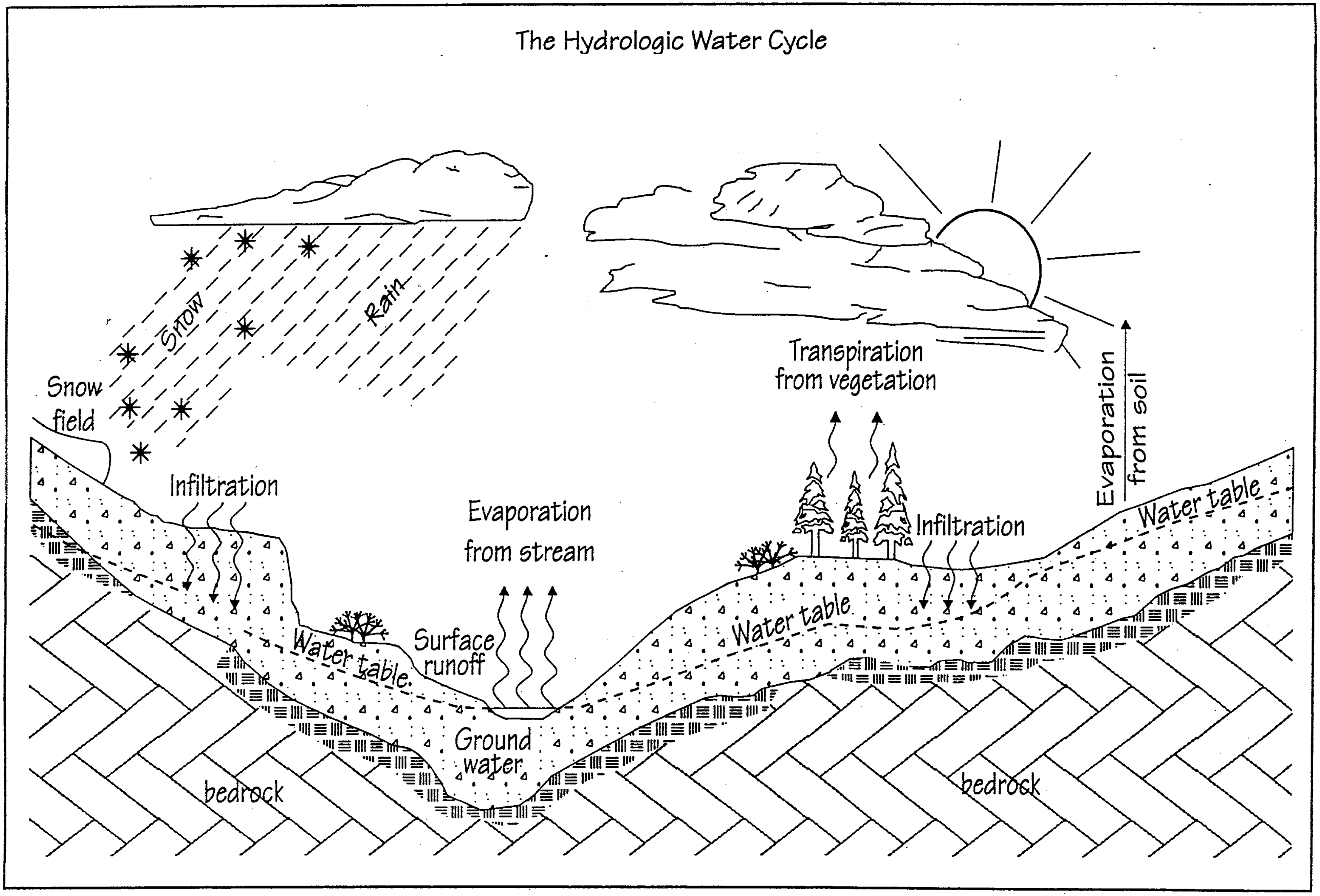

The Hydrologic Water Cycle
Snow
Rain
Snow field
Transpiration from vegetation
Evaporation from soil
Infiltration
Evaporation from stream
Infiltration
Water table
Water table
Surface runoff
Water table
Ground water
bedrock
bedrock

Figure 9.

CUMULATIVE GROWTH

IN SURFACE-WATER RIGHTS

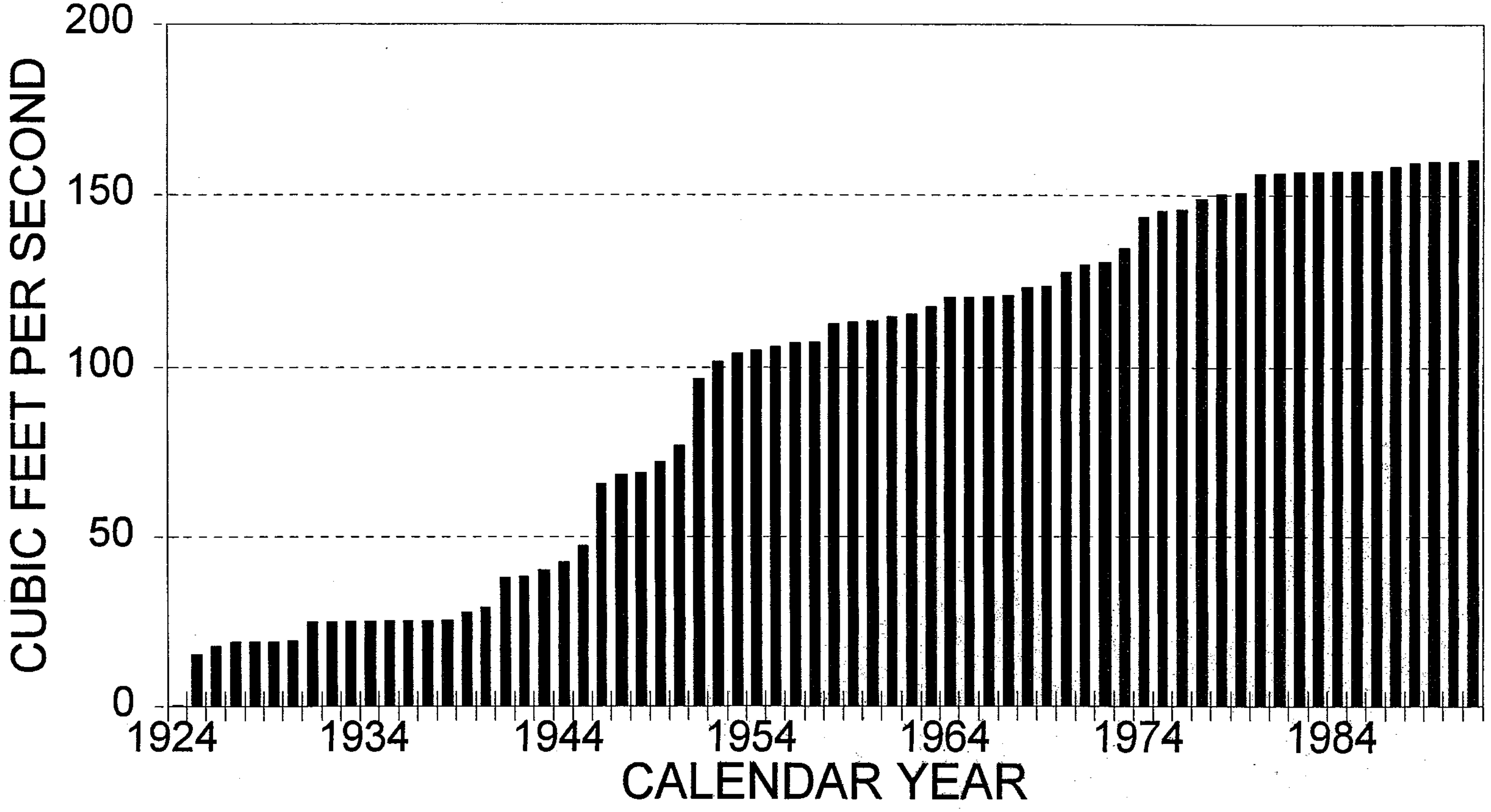
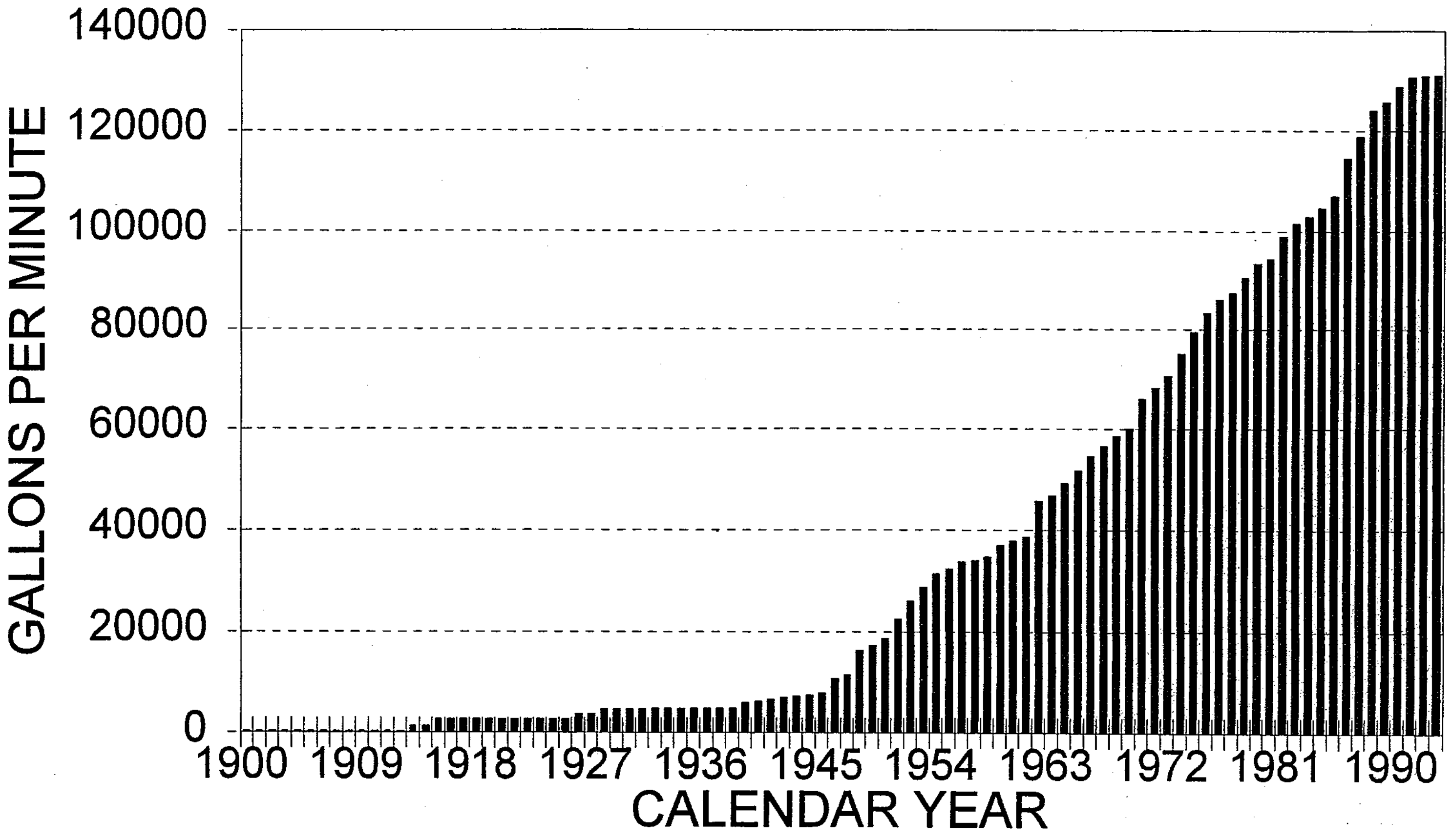


FIGURE 10



CUMULATIVE GROWTH

IN GROUND-WATER RIGHTS

FIGURE 11

SURFACE-WATER RIGHTS

PRIMARY PURPOSE OF USE

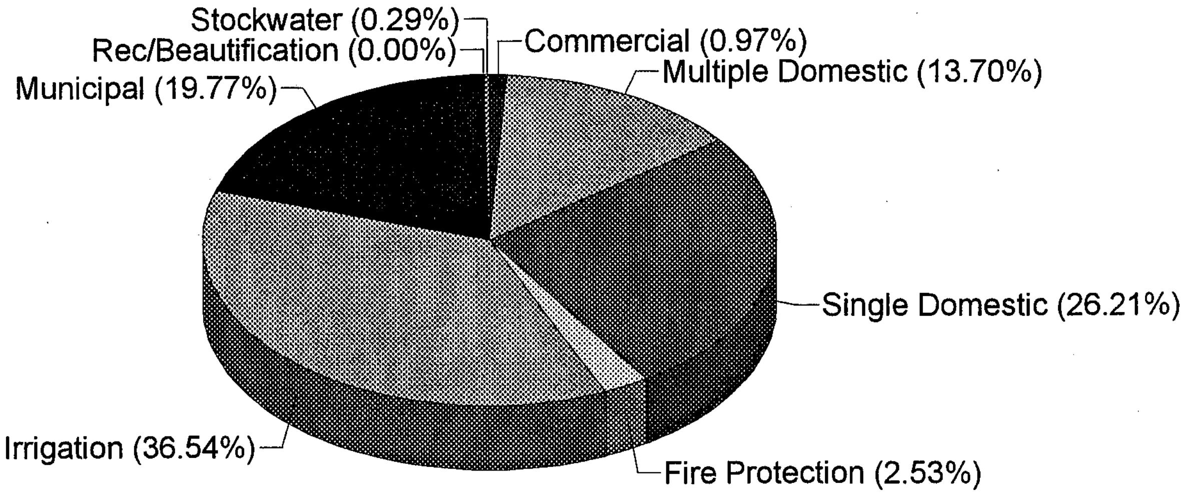
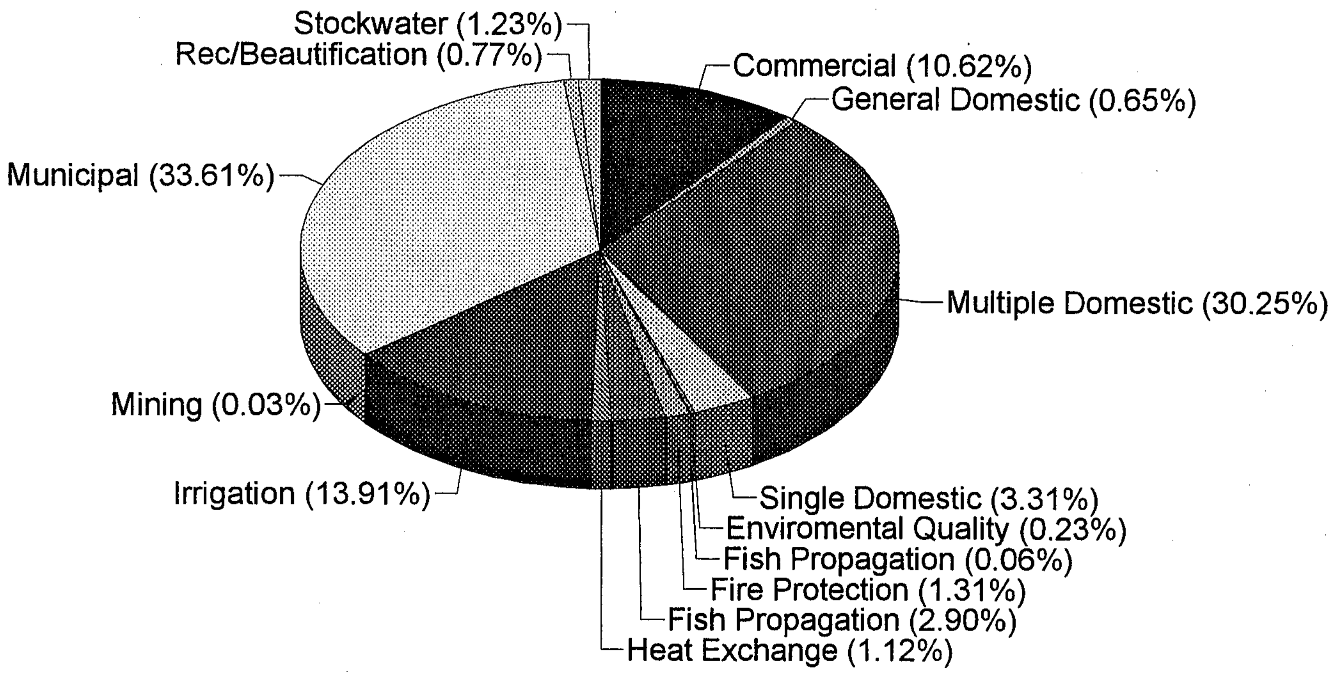


FIGURE 12

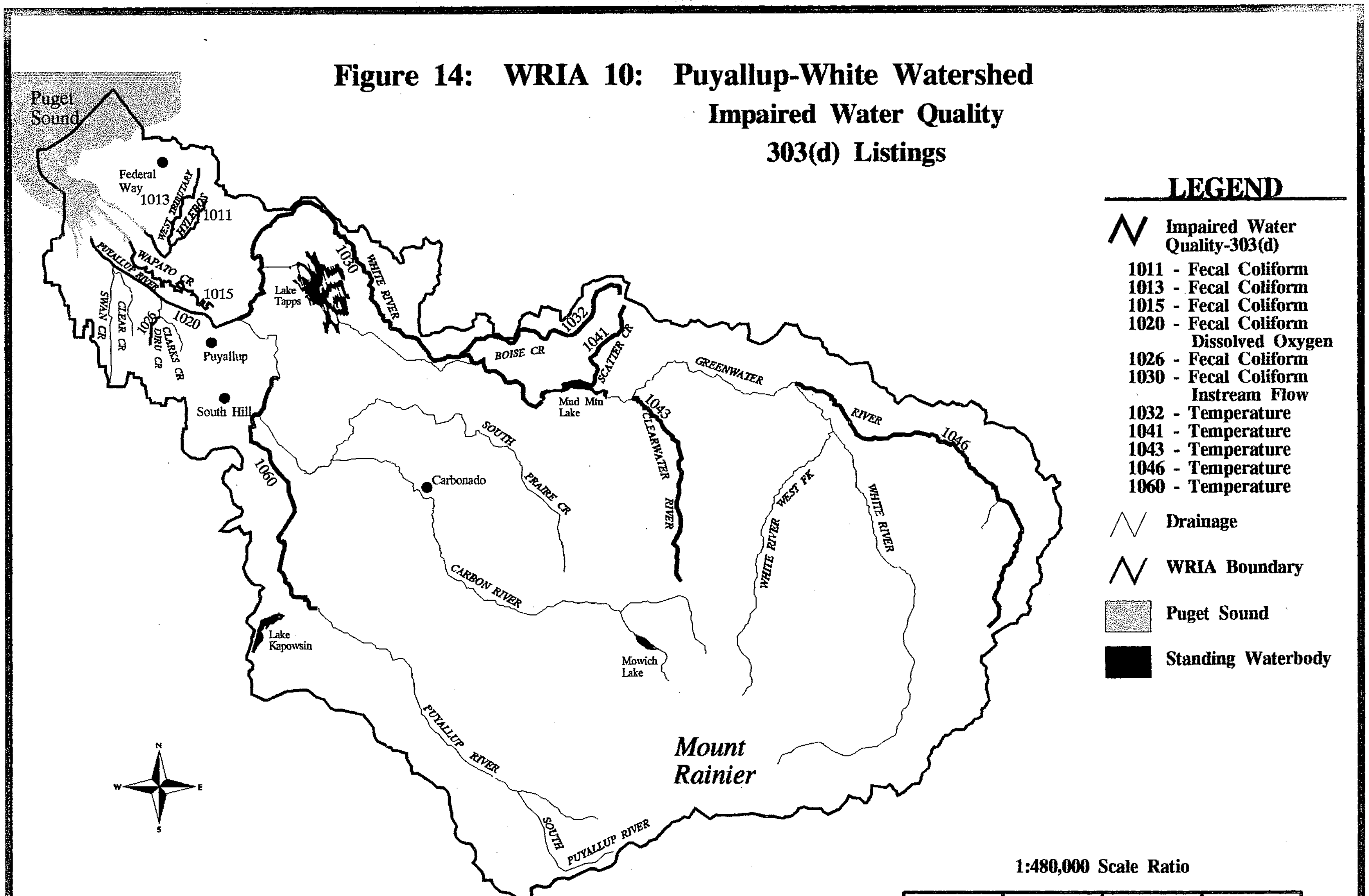


GROUND-WATER RIGHTS

PRIMARY PURPOSE OF USE

FIGURE 13

Figure 14: WRIA 10: Puyallup-White Watershed
Impaired Water Quality
303(d) Listings



Data provided by Washington State Department of Ecology. Map generated by SAIC and ESRI, Inc. in conjunction with Washington State Department of Ecology. February 1995.

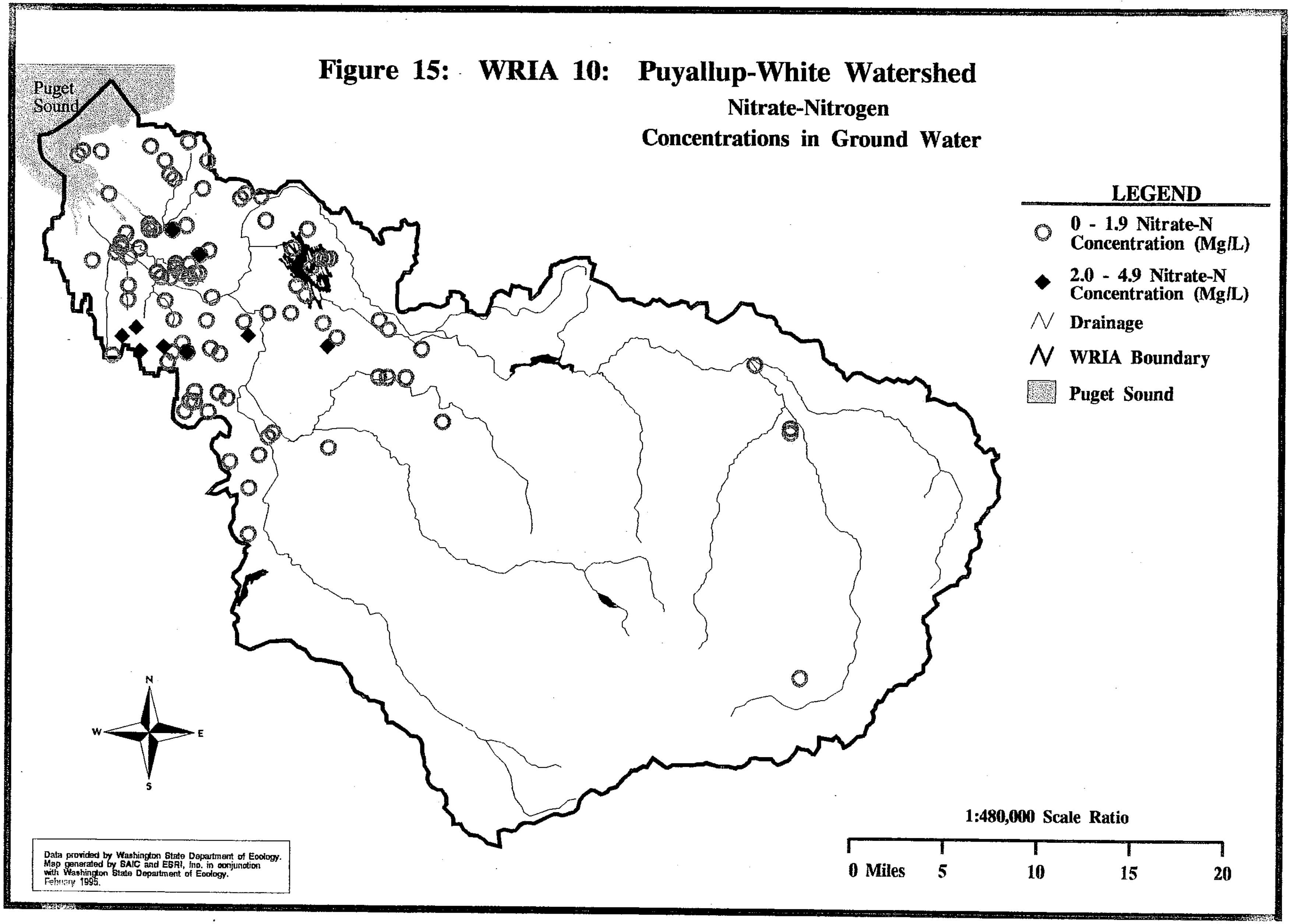


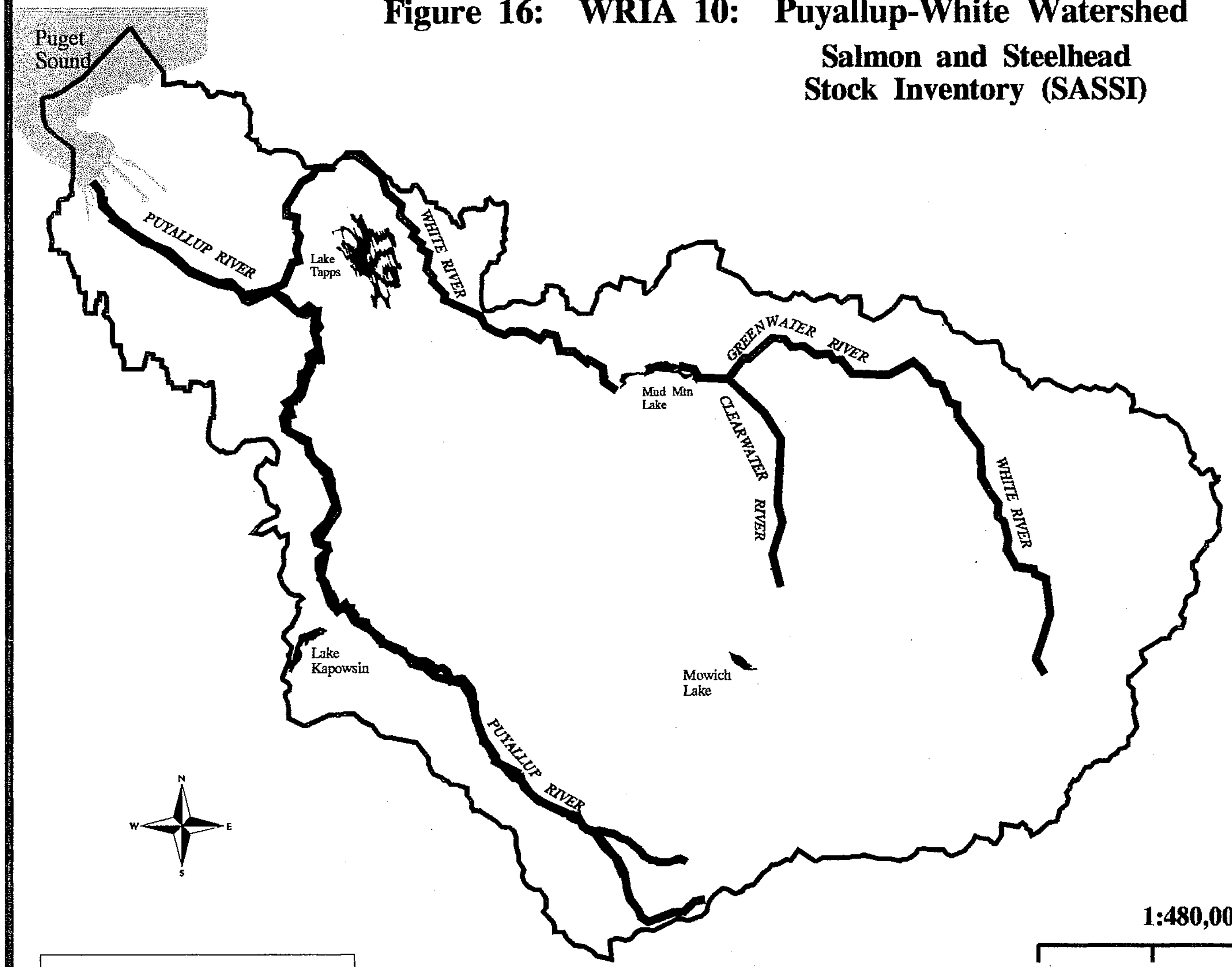
Figure 15: WRIA 10: Puyallup-White Watershed

Nitrate-Nitrogen Concentrations in Ground Water

Data provided by Washington State Department of Ecology. Map generated by SAIC and ESRI, Inc. in conjunction with Washington State Department of Ecology. February 1995.

Figure 16: WRIA 10: Puyallup-White Watershed

Salmon and Steelhead Stock Inventory (SASSI)



LEGEND

Special Note:

According to AFS ratings, the White River is ranked as having a moderate risk, while the Puyallup River is a special concern.

AFS ratings are:
High Risk
Moderate Risk
Special Concerns
Not Rated

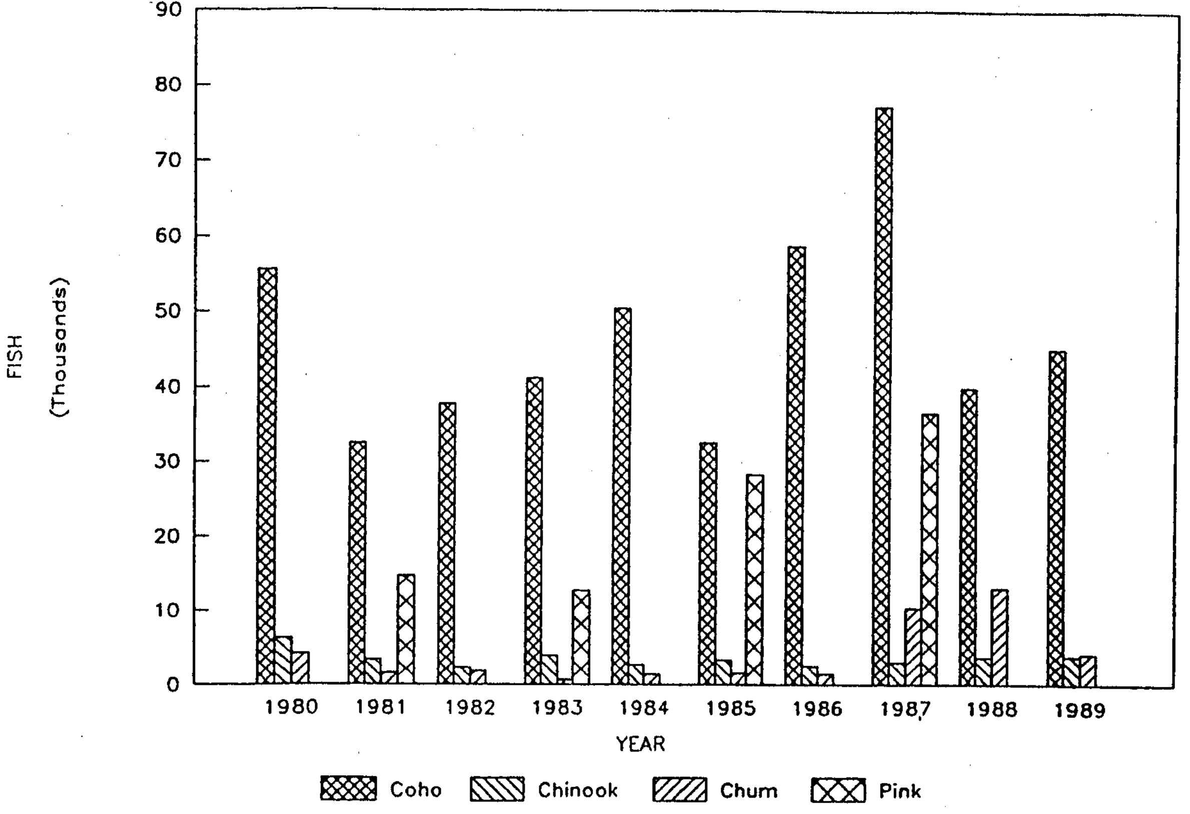
Data provided by Washington State Department of Ecology. Map generated by SAIC and ESRI, Inc. in conjunction with Washington State Department of Ecology. Febuary 1995.

* *Streams given a status based on the lowest rating of all the species. Sassi ratings: Critical, Depressed, Healthy and Not Rated.*

Figure 17.

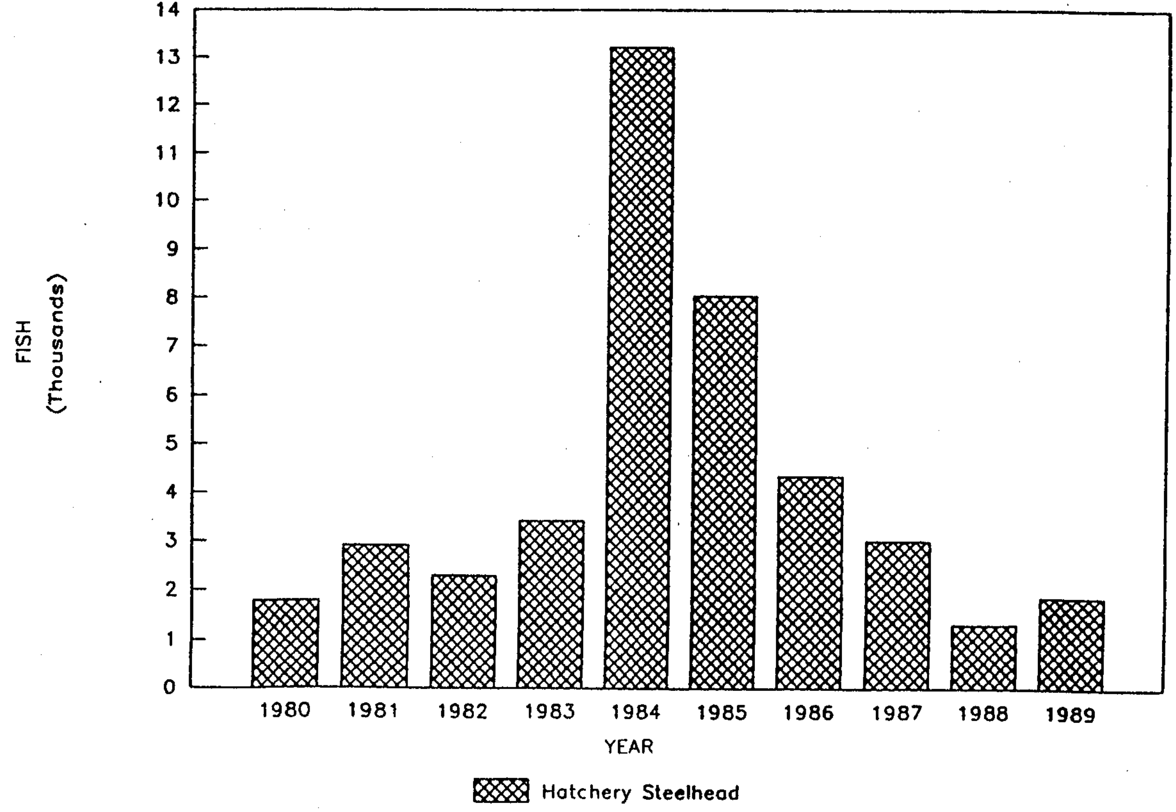
(A) PUYALLUP RIVER SALMON RUNS

(1980–1989)



(B) PUYALLUP RIVER STEELHEAD RUN

(1980–1989)



(PUYALLUP INDIAN TRIBE, 1991)

FIGURE 18 - WHITE RIVER INSTREAM FLOWS AS ESTABLISHED PER WAC 173-510

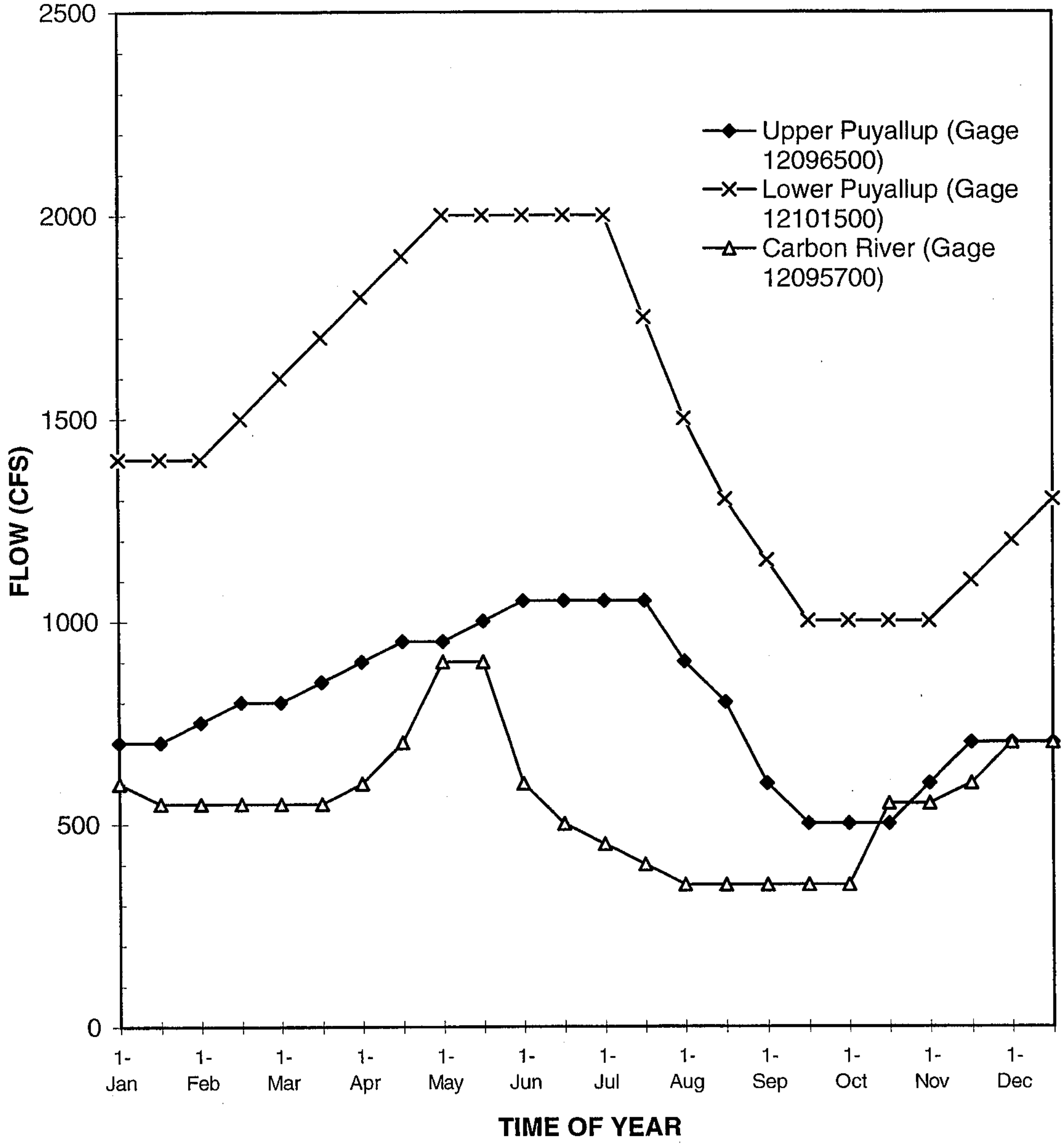


FIGURE 19 - LOWER PUYALLUP RIVER (USGS GAGE 12101500) 1914-1993 EXCEEDENCE PROBABILITIES

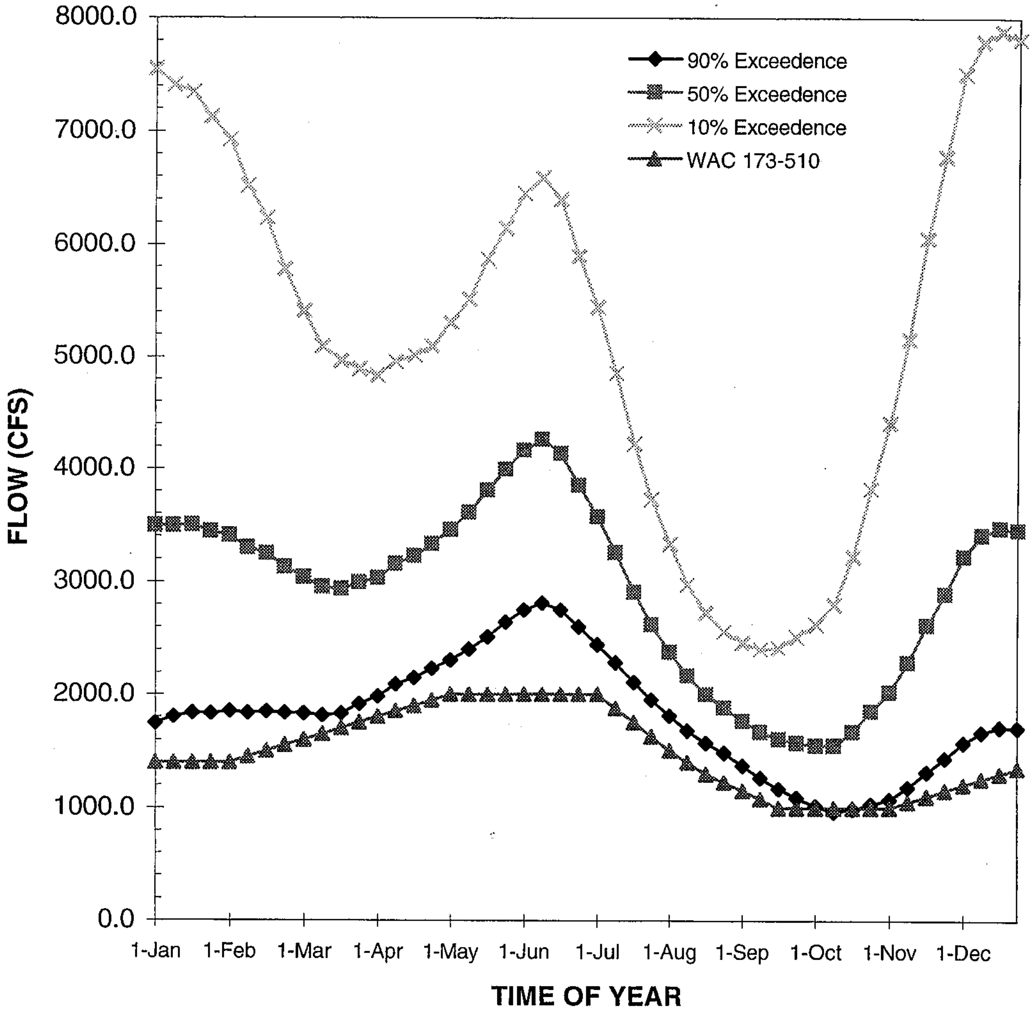


FIGURE 20 - UPPER PUYALLUP RIVER (USGS GAGE 12096500) 1914-1992 (WITH DISCONTINUITIES) EXCEEDENCE PROBABILITIES

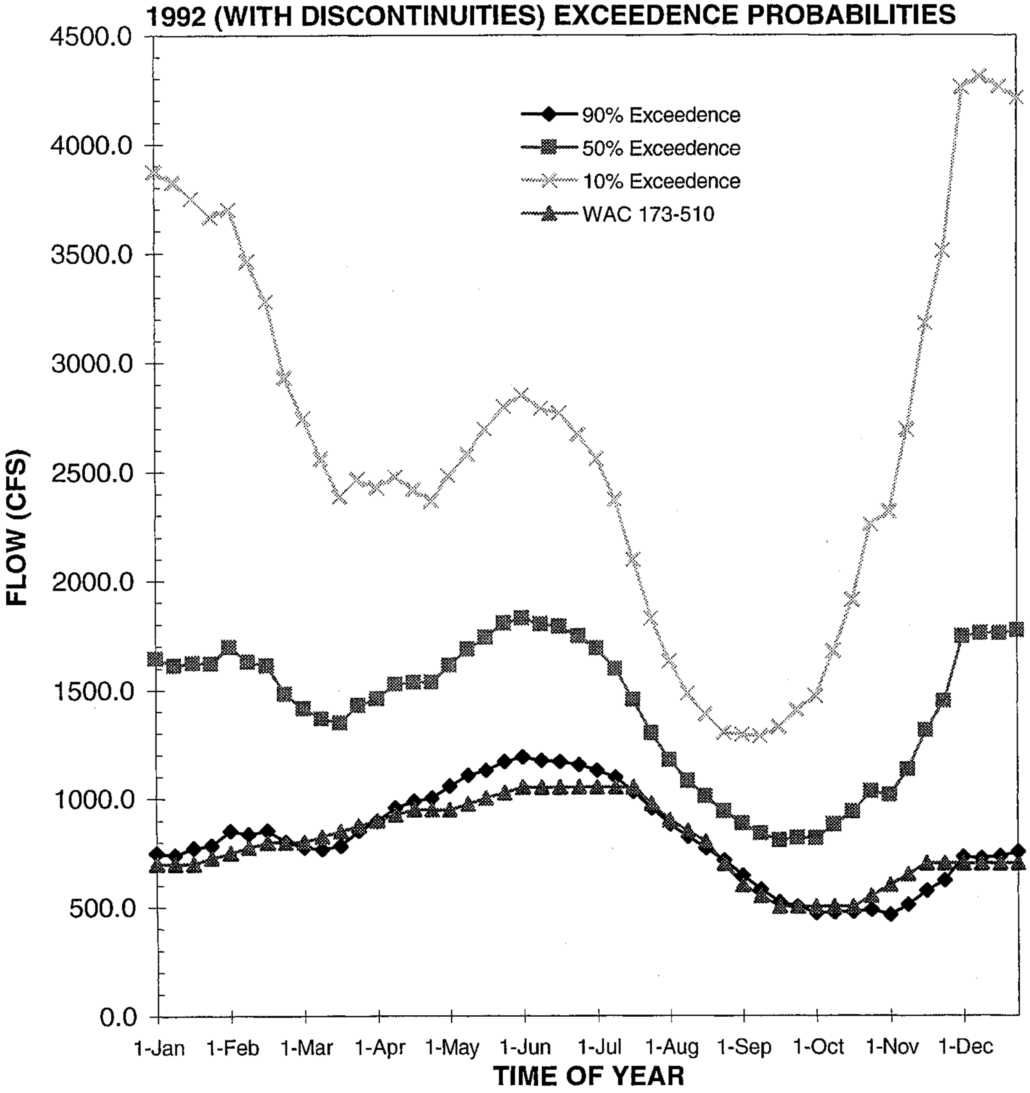


FIGURE 21 - WHITE RIVER NEAR BUCKLEY (USGS GAGE 12098500) 1928-1933, 1938-1993 EXCEEDENCE PROBABILITIES

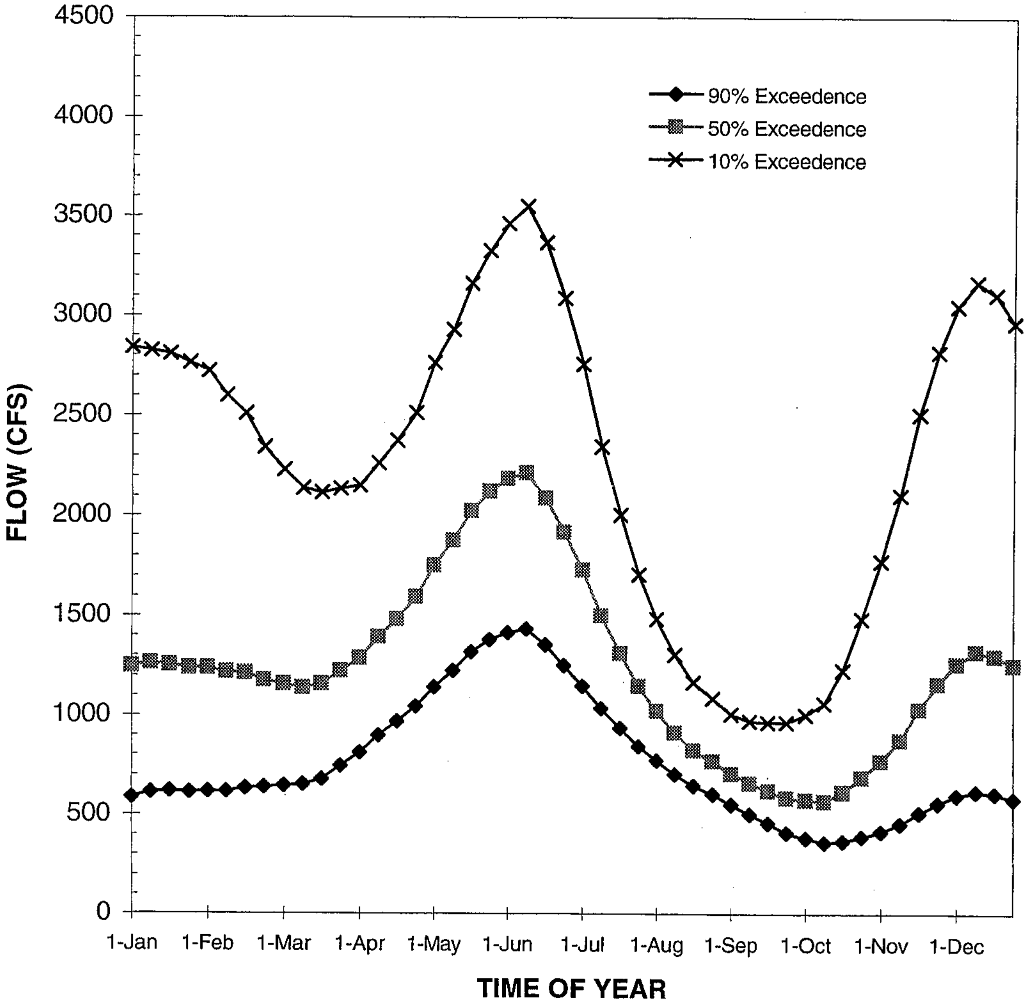


FIGURE 22 - SOUTH PRAIRE CREEK AT SOUTH PRAIRE (USGS GAGE 12095000) 1949-1971, 1987-1993 EXCEEDENCE PROBABILITIES

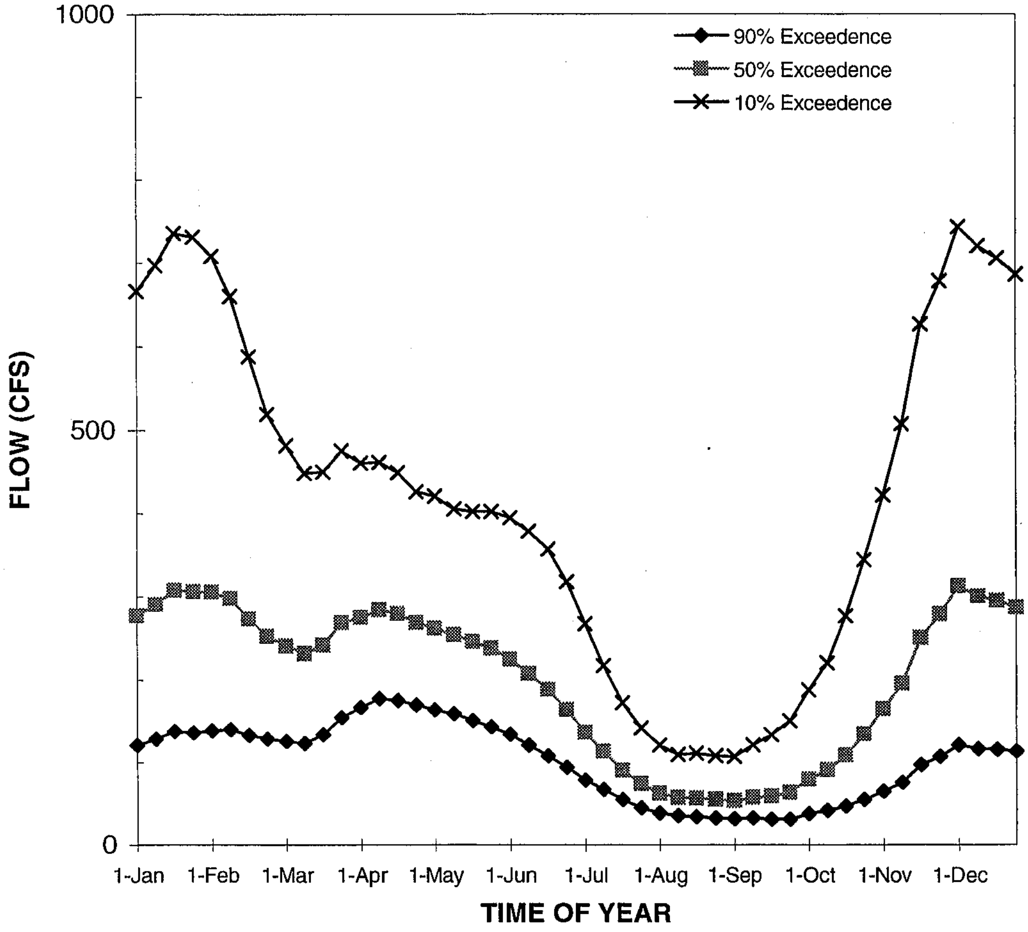


FIGURE 23 - PUYALLUP RIVER NEAR ELECTRON (USGS GAGE 12092000) 1909-1993 EXCEEDENCE PROBABILITIES

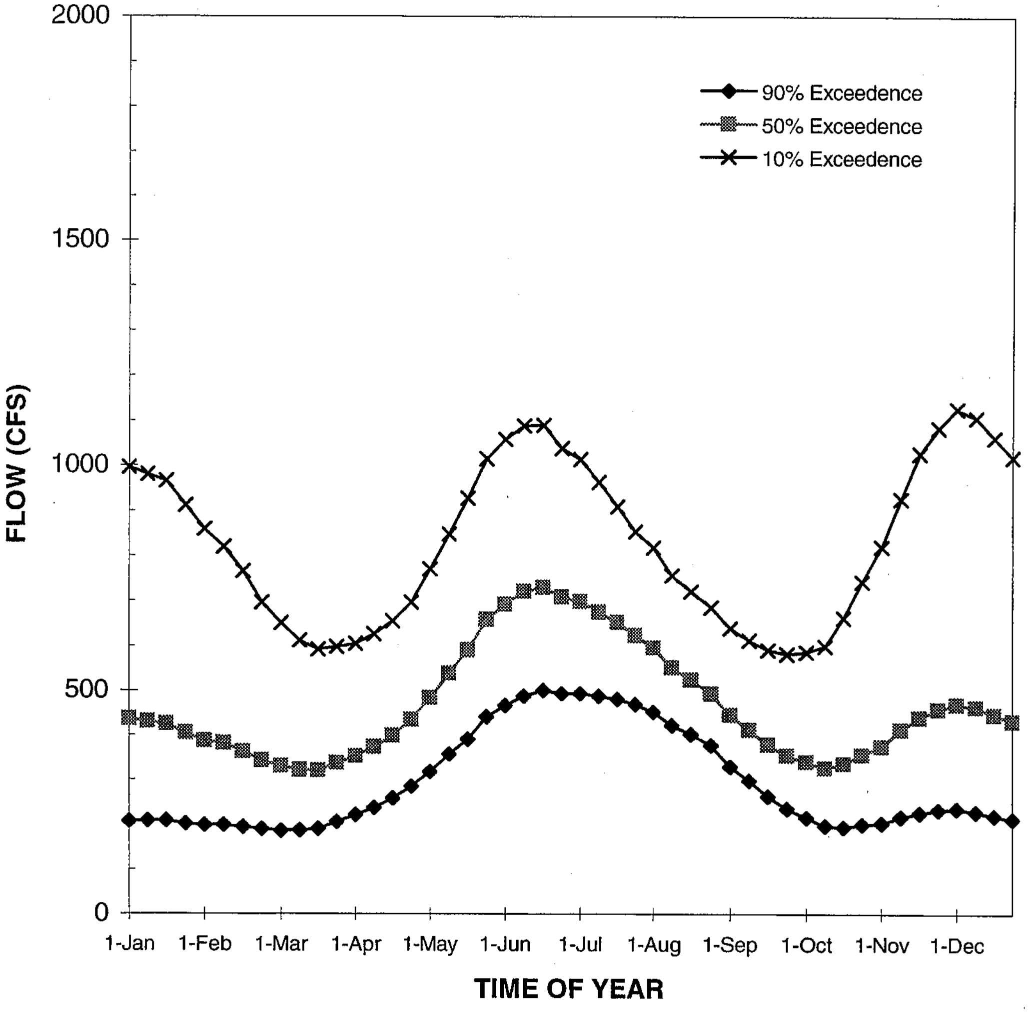


FIGURE 24 - LOWER PUYALLUP RIVER (USGS GAGE 12101500) DEVIATION OF 7-DAY LOW FLOWS FROM WAC 173-510 INSTREAM FLOW WITH 10-YEAR MOVING AVERAGE

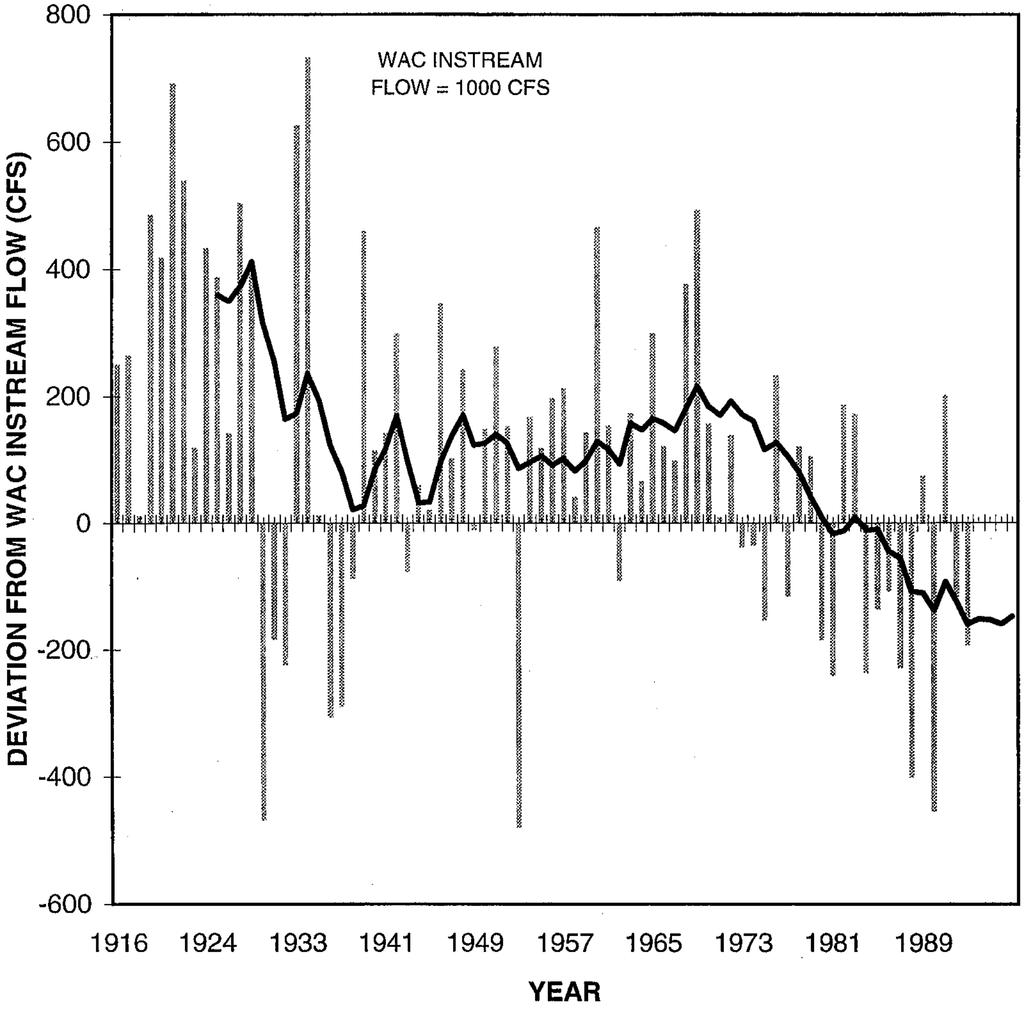


FIGURE 25 - WHITE RIVER NEAR BUCKLEY (USGS GAGE 12098500) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE

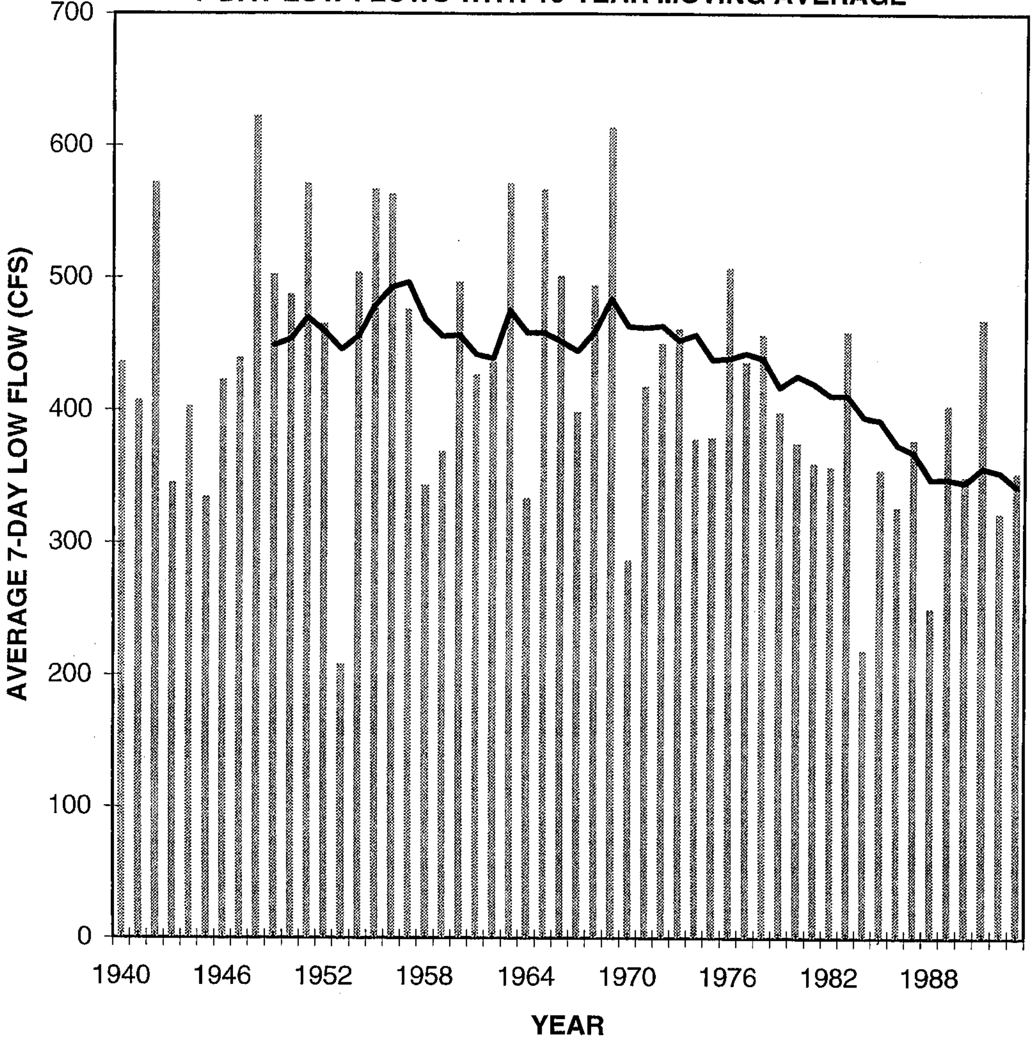


FIGURE 26 - SOUTH PRAIRE CREEK AT SOUTH PRAIRE (USGS GAGE 1209500) 7-DAY LOW FLOWS

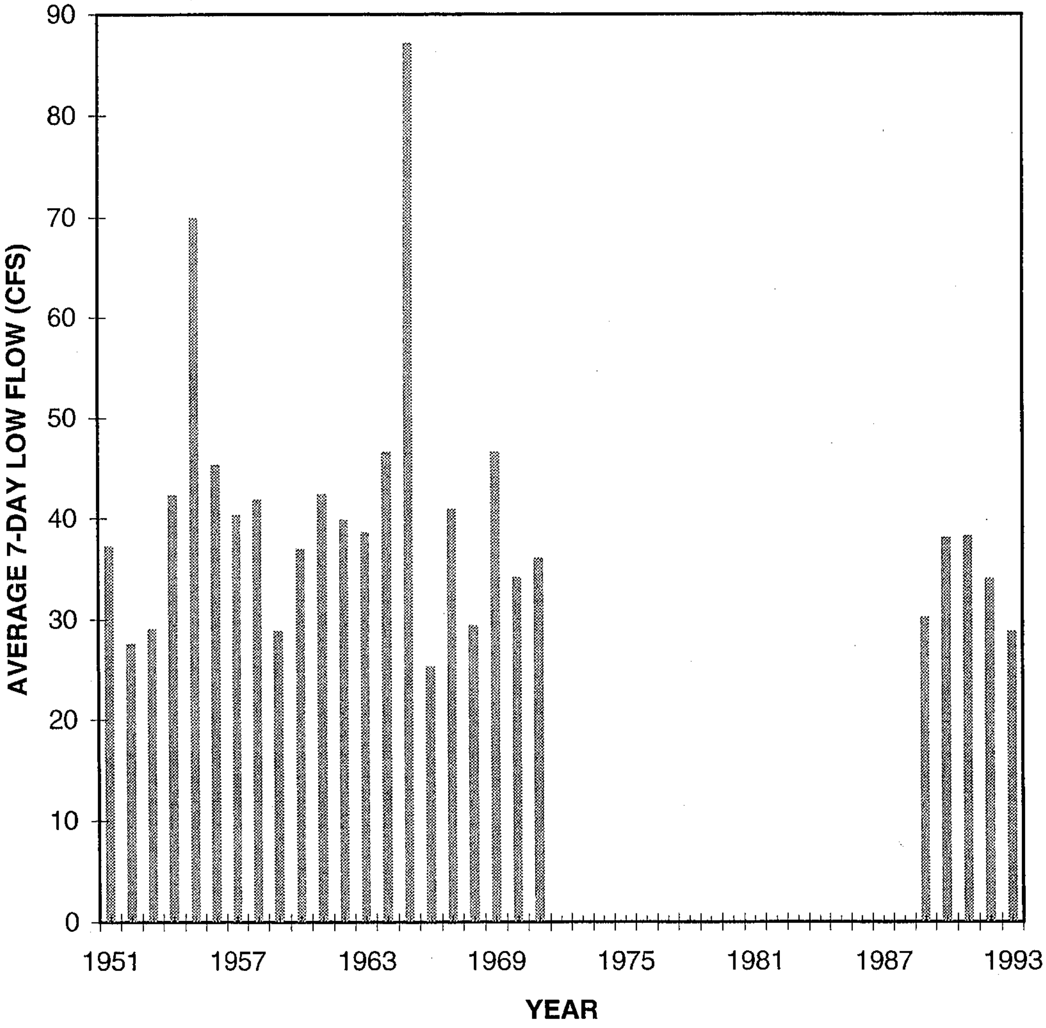


FIGURE 27 - PUYALLUP RIVER NEAR ELECTRON (USGS GAGE 1209200) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE

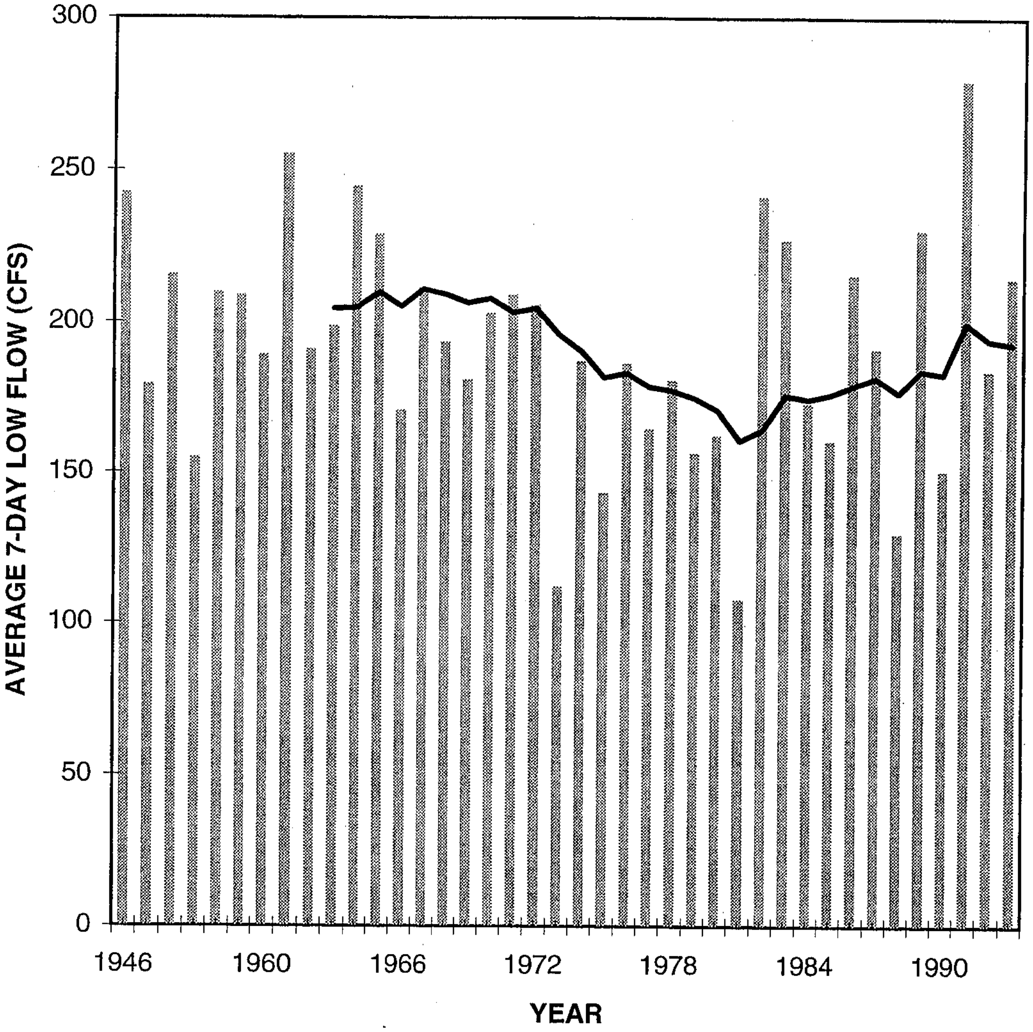


FIGURE 28 - NUMBER OF DAYS PER YEAR LOWER PUYALLUP GAGE FLOWS WERE LESS THAN WAC 173-510 INSTREAM FLOWS WITH 10-YEAR MOVING AVERAGE

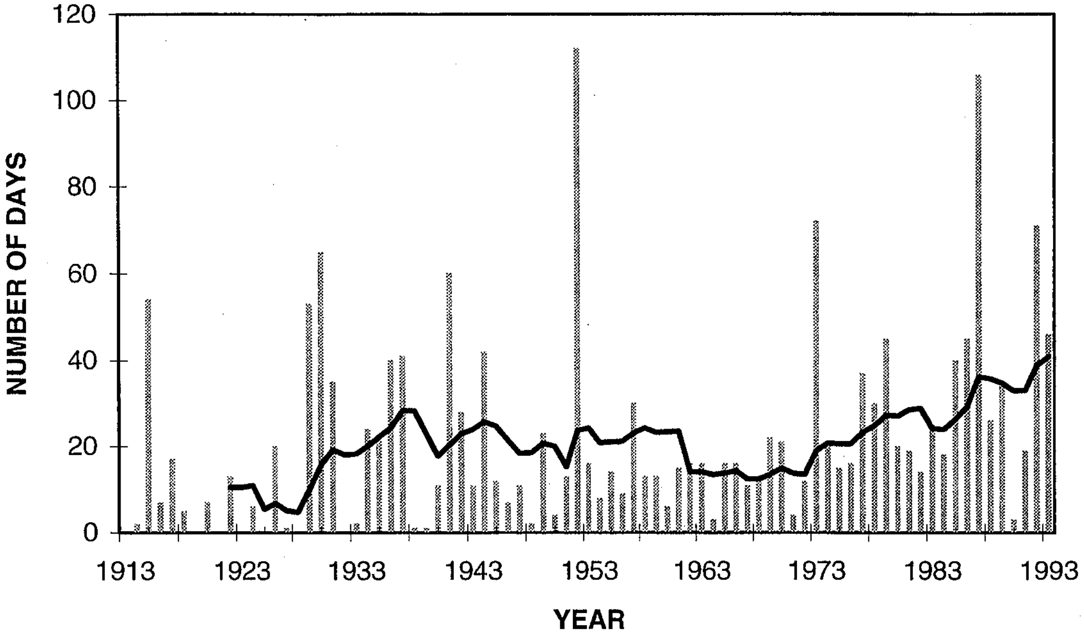


FIGURE 29 - NUMBER OF DAYS PER YEAR UPPER PUYALLUP GAGE FLOWS WERE LESS THAN WAC 173-510 INSTREAM FLOWS