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INITIAL WATERSHED ASSESSMENT
WATER RESOURCES INVENTORY AREA 12
CHAMBERS-CLOVER CREEK WATERSHED

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ABSTRACT

The Chambers-Clover Creek Watershed (Water Resource Inventory Area [WRIA] 12) is located entirely within Pierce County, Washington between Puget Sound on the west and the community of Graham on the east. WRIA 12 covers 144 square miles and includes approximately 2k020 acres of lakes, extensive wetlands, as well as Chambers Creek and Clover Creek (PCPWU, 1994). The watershed is predominantly urbanized, consisting of residential, urban, and light industrial uses.

Since 1950, rapid urbanization and suburbanization has resulted in a population of more than 267,000 within the Chambers-Clover Creek Watershed. This period of population growth in the watershed was accompanied by equally rapid expansion of water consumption. Since 1947, combined surface-water and ground-water rights have risen from 91 to 585 cfs (from 12,940 to 147,926 acre-ft/year).

Despite closures to further surface-water rights in the major streams, seven-day low flows as well as summer flows in Flett Creek and Leach Creek, the major tributaries of Chambers Creek have decreased severely in recent years.

Anadromous fish production in the Chambers-Clover Creek Watershed 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 affecting salmon and steelhead include seasonal flooding, low summer flows, unstable stream beds (sediment transport), physical barriers, poor water quality, high stream temperatures, the destruction of spawning habitat, and overharvest of wild stocks.

The interconnection between surface and ground water is apparent in this watershed. Increased demands for ground water probably have reduced low flows in the streams. Increases in impervious surface areas from expanding urbanization have reduced ground-water recharge and have contributed to reduction of low flows in the drainage basin. The effects of increased water demand and reduced ground-water recharge will have even greater consequences during an extended period of below-average precipitation.

The entire are encompassed within the Chambers-Clover Creek Watershed has been designated by the EPA as part of a Sole Source Aquifer System. This designation is provided to areas in which ground water has been identified as serving large populations; over 169,000 people within the Chambers-Clover Creek Watershed depend on the Chambers-Clover Creek aquifer as their

only source of drinking water (PCPWU, 1994). Despite the need for protection of ground-water quantity and quality, only limited recent data for static water levels were found. Monitoring of many more wells at locations dispersed throughout the Chambers-Clover Creek Watershed would be required over extended time periods to develop the data necessary for a scientifically-sound, analysis of static-water-level trends.

The National Groundwater Association has classified the uppermost aquifer within the system as either moderately or highly vulnerable to contamination because of the extremely well-drained soils that are common throughout the area (EPA, 1993). The vulnerability has been substantiated by a number of instances of contamination.

The Clover/Chambers Creek Basin Ground Water Management Program (Brown and Caldwell, 1991) suggests a number of control measures to prevent further degradation of the ground water in the Sole Source Aquifer. These include: underground storage-tank management, cleanup of hazardous sites, modification of on-site sewage-disposal regulations, development of a well-construction and abandonment program, and maintaining effective solid-waste programs.

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 hydrologic system can perpetually support the requested use along with senior water users. Examples of impairment of older uses include excessive reductions of streamflow or lowering of ground-water levels. In practice, water-right-permit decisions often have been made without enough data to adequately predict long-term effects.

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 Chambers-Clover Creek Watershed, which comprises Water Resource Inventory Area (WRIA) 12. Key water-management issues in the watershed which influence water-right permit decisions are identified and documented. Available information was used to assess hydrological, chemical, and biological conditions which broadly indicate the "health" of the watershed. These conditions included water quantity, hydrogeology, water demand, water quality, and the status of stocks of resident and anadromous fish species. Assessment of these conditions was based on readily available information about water rights and claims, streamflow, precipitation, hydrogeology, ground-water levels, fish stocks, and water quality. We did not conduct field surveys or begin data-collection projects. None of this data was exhaustively checked for accuracy, given the need for timely completion of the project.

WATER DESCRIPTION

GEOGRAPHIC DESCRIPTION

The Chambers-Clover Creek Watershed (Water Resources Inventory Area [WRIA] 12) is located entirely in Pierce County, Washington between Puget Sound on the west and the community of Graham on the east. The waters of Puget Sound off Point Defiance serve as the northern boundary of the watershed; the City of Dupont is located near the southern boundary. Figure 1 shows the location of WRIA 12 in relationship to the State of Washington. The watershed covers 144 square miles and includes approximately 2,020 acres of lakes, extensive wetlands, as well as Chambers Creek and Clover Creek (PCPWU, 1994). Elevations within the WRIA start at sea level and extend up to 600 feet. The drainage boundary is defined by topographic highs from which most runoff is directed toward the center of the basin (PCPWU, 1994).

The Chambers-Clover Creek drainage originates from spring and ground-water discharge to springs and seeps in the northeast corner of the watershed. The two most prominent creeks are Chambers Creek and Clover Creek. The ground-water discharge forms the headwaters of Clover Creek, which cuts through the center of the watershed, flowing from east to northwest, ending just west of Interstate 5. Clover Creek enters Steilacoom Lake at river mile (RM) 5.8. Chambers Creek is then formed from the outlet of Steilacoom Lake flowing 4.0 miles north and west down a narrow ravine where it is joined by Flett and Leach Creeks before it discharges to Puget Sound through Chambers Bay. The watershed is also typified by a number of small lakes. American Lake (the largest lake in the WRIA) is hydrologically linked to ground water and has no natural outlet (Figure 2).

Subbasins

Four subbasins are recognized by the Chambers-Clover Creek Watershed Management Committee. Each of the subbasins is equivalent to a smaller watershed. These include: Chambers Bay, Clover Creek/Steilacoom Lake, Tacoma West, and American Lake.

The Chambers Bay Subbasin represents 18 percent of the watershed and comprises 17,300 acres. This subbasin includes all drainages downstream of Steilacoom Lake and includes such water bodies as: Chambers Creek, Flett Creek, Leach Creek, Snake Lake, and Wapato Lake. There is an extensive wetland system within this subbasin associated with Flett and Leach Creeks. The City of Tacoma has jurisdiction over a large portion of this subbasin (PCPWU, 1994).

The Clover Creek/Steilacoom Lake Subbasin is the largest subbasin in the WRIA and comprises 47 percent of the watershed or approximately 45,200 acres. This subbasin includes Clover Creek, Steilacoom Lake, Spanaway Lake, Spanaway Creek, and Morey Creek. There is an extensive wetland system in the area south of Spanaway Lake. McChord Air Force Base and the unincorporated cities of Parkland and Spanaway are included in this subbasin (PCPWU, 1994).

Tacoma West Subbasin is the smallest subbasin within the watershed comprising 8,700 acres or 9 percent of the watershed. Most of the water bodies within this subbasin are small streams that discharge directly to Puget Sound including Puget Creek, Mason Creek, Day Creek, and Narrows Creek. This subbasin is dominated by the marine shoreline. Most of this subbasin is within the jurisdiction of the City of Tacoma and the Town of Ruston (PCPWU, 1994).

The American Lake Subbasin represents 25 percent of the watershed (24,200 acres) and is dominated by lakes including American Lake, Gravelly Lake, Lake Louise, and Sequalitchew Lake. Two creeks within the watershed are Sequalitchew Creek and Murray Creek. There are extensive wetland systems within the subbasin associated with Murray Creek in the area of Dupont. The military installations of Fort Lewis, McChord Air Force Base, and Camp Murray comprise a substantial amount of land use within the subbasin. (PCPWU, 1994).

Physiography

The Chambers-Clover Creek Watershed lies within the central part of the Puget Sound Lowland, an elongated topographic trough that extends from the Canadian border to the Willamette Valley in Oregon. The Puget Lowland is bounded on the east by the Cascade Mountains and on the west by the Olympic Mountains and Willapa Hills. Lowland topography is generally flat with almost all of the region lying below 500 feet in altitude (Easterbrook and Rahm, 1970).

The northern part of the lowland was occupied several times by glaciers during the geologically recent periods of glaciation. Thus, most of the topographic features in the Puget Lowland, including the Chambers-Clover Creek Watershed, are a direct result of glacial deposition or erosion (Easterbrook and Rahm, 1970).

Several channels were cut through the area by high-velocity glacial-meltwater streams. These channels often have steep slopes or bluffs defining their boundaries. One of these, the Clover Creek Channel, starts near South Hill on the northeast boundary of the watershed and runs southwest to the Brookdale and Canyon Road area and into the current floodplain of Clover Creek (PCPWU, 1994). Another, the Kirby Channel, starts just north of Graham on the southeastern border of the watershed and runs through Fredrickson near Canyon Road and 176th Avenue until it intersects with Clover Creek Channel (PCPWU, 1994). A third, the South Tacoma Channel, starts near South Tacoma Way and Highway 16 and runs south into the headwaters area of Flett Creek (PCPWU, 1994).

Elevations within the watershed range from sea level to 600 feet. There are relatively steep bluffs bordering Puget Sound that have steep canyons intersecting them to allow surface-water drainage of the upland areas. The northwestern portion of the watershed, near Fircrest and University Place, has more steeply rolling hills and valleys which trend in a north-south direction. The Clover Creek floodplain intersects the center of the watershed, flowing from east to west and ending just west of Interstate 5. The Chambers Creek canyon is another significant topographic feature associated with a stream reach. The canyon is two miles long and up to 200 feet deep. It drains to Chambers Bay on Puget Sound, on the north edge of the town of Steilacoom (Brown and Caldwell, 1985).

LAND COVER AND LAND USE

The Chambers-Clover Creek Watershed is located entirely in Pierce County. The WRIA is predominantly urbanized, with land use consisting of residential, urban, and light industrial activities. Forty-two percent of the land in the watershed is classified as built-up (PCPWU, 1994). Large portions (approximately 68%) of the Tacoma West and Clover Creek/Steilacoom Lake subbasins are considered urbanized. The Tacoma West Subbasin is distinguished by higher industrial and higher density commercial land uses, while the Clover Creek/Steilacoom Lake Subbasin is dominated by suburban and medium-density development (PCPWU, 1994).

The least urbanized portion of the Chambers-Clover Creek Watershed is the American Lake Subbasin, particularly within the northern portion of Fort Lewis and along the southwest portion of the subbasin (PCPWU, 1994).

The American Lake Subbasin includes Sequalitchew Lake and Sequalitchew Creek which flows west into Puget Sound. The development of the Town of DuPont and surface-water usage at the Fort Lewis Army Reservation have severely impaired the flow and character of Sequalitchew Creek, which has been documented in a report by Andrews and Swint (1994). The 38.4-square mile drainage basin of Sequalitchew Creek includes Kinsey Marsh which drains into American Lake through Murray Creek; seasonal overflow from American Lake flows into Sequalitchew Lake from which Sequalitchew Creek begins. A Fort Lewis diversion dam, canal, and a set of complicated culverts carry water from the creek into Puget Sound at Tatsolo Point. The remainder of the natural creek flows through Edmond Marsh, a 130-acre wetland bordering Fort Lewis and DuPont, then through a lush, steep canyon, supplemented by a spring and several seeps, into a salt marsh, and finally through a culvert under a railroad dike into the Sound.

The original purpose of the Fort Lewis diversion is unclear, and detailed analysis of its effect on flow is difficult because of the lack of data on stream flows before construction of the diversion dam and canal. Controversy remains regarding authorization of the diversion, its effect on the salmon fishery, and current authority and responsibility for the dam's operation.

A development (Northwest Landing) is adding another 15,000 residents and additional commercial and industrial development along the banks of the creek. The development is on property originally owned by E.I. DuPont de Nemours Company, which manufactured explosives here for about 75 years. Over 800 acres of the property was contaminated with arsenic, mercury, cadmium, and lead. The DuPont Company and Weyerhaeuser, the current land owner, have completed the remedial investigation and are cleaning up the contaminated areas. In addition, a large gravel mine is approved for 360 acres lying north of Sequalitchew Creek and one-half mile from the boundary of the Nisqually National Wildlife Refuge.

Agricultural land includes active and open agriculture. Less than 300 acres (0.3 % of the watershed) are classified as agricultural. Small farms in the area were not included in this classification estimate, but typically support livestock (PCPWU, 1994).

Natural cover accounts for 36 percent of the watershed and includes primarily grasses, shrubs, and brush, but schools, golf courses, cemeteries, landfills, and small farms also were included in this classification scheme (PCPWU, 1994). The Clover Creek Subbasin supports approximately 19,000 acres of natural habitat or 43 percent of the subbasin. The American Lake Subbasin is 38 percent natural cover, or approximately 6,500 acres, much of which lies within Fort Lewis (PCPWU, 1994).

The population of Pierce County increased by 112.5 percent from 1950 to 1990. Between 1980 and 1990, the population of the county increased 20.7 percent. Population growth historically spreads from city centers outward to rural areas. The majority of the population growth during the 1980s occurred in the unincorporated areas of the county. Thus, population dynamics have affected land use within the watershed substantially.

The 1990 census population within the Chambers-Clover Creek Watershed was 267,344 (PCPWU, 1994). A portion of the population of Tacoma (176,664) is included in the WRIA. The incorporated jurisdictions in the WRIA include Steilacoom, Ruston, University Place, Dupont, and Fircrest. Other unincorporated communities include Lakewood, Spanaway, and Parkland. The most extensive development has occurred along the Interstate 5 corridor, especially from Tacoma south to Highway 512 and east to Highway 7.

CLIMATE AND PRECIPITATION TRENDS

Precipitation, either in the form of rain or snow, is the principle source of recharge to the water supply in the Chambers-Clover Creek Watershed. No weather stations are located within WRIA 12, however, based on gages in the vicinity, precipitation in the study area is fairly uniformly distributed, with slightly increasing precipitation toward the south end. Near Tacoma, at the northern boundary of the watershed, annual precipitation averaged 39.4 inches per year from 1884 to 1961. The average annual precipitation is 51.6 inches at the Olympia Station which is approximately 15 miles south of the Chambers-Clover Creek Watershed. Much of the precipitation in WRIA 12 is lost to evapotranspiration (up to 26 inches per year according to Brown and Caldwell [1985]). Precipitation also enters surface-water drainages and recharges ground water. Most of the ground water eventually discharges as spring flow or direct seepage into surface water that eventually flows into the Puget Sound.

Statewide Precipitation Trends

Precipitation data from gages located throughout Western Washington were used to examine long-term trends and identify extended periods of above-average 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 eight sites throughout Western Washington were used for the analysis (Figure 3). 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 dispersed from the other stations. Periods of missing data were filled using nearby stations, if available, or by at-station monthly mean values if data from a secondary station were not available. Table 1 lists the stations used in the analysis for Western Washington.

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 each region (Figure 4). In Western

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

Washington, high variability can be seen throughout the period of record. Since the mid-1950s, the precipitation typically has exceeded the long-term mean. Extended periods of below-average precipitation occurred in the 1920s and 1930s and again in the late 1940s. Figure 4 also indicates that precipitation in Western Washington was less than average between approximately 1920 and 1950 and higher than average between 1950 and 1980. The Western Washington trends indicate a recent decline in average precipitation.

Precipitation Trends in the Watershed

Precipitation contours for the watershed are presented in Figure 3. The Chambers-Clover Creek Watershed is located between the Seattle and the Olympia Stations. The deviations of the annual precipitation totals from the means for these two stations are shown in Figure 6. The trend line on the graph is a moving average of the previous 10 years. The trend line indicates that precipitation was less than average between 1910 and 1953 and higher than average between 1970 and 1992 at the Seattle Station. At the Olympia Station, 15 miles farther southwest and out of the rain shadow of the Olympic Mountains, precipitation fluctuated more around the average. The 10-year moving average was less than the mean between 1920 and 1935, and three periods since that time. From 1980 until 1993, the 10-year moving average has also been less than the mean. In 1993, the moving average was its lowest since 1933. The Western Washington trends indicating a recent decline in average precipitation were evidenced at the Olympia Station but not at the Seattle Station.

Precipitation data from McMillin Reservoir, located approximately 4 miles northeast of the watershed, were also 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 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, as indicated by a ten-year moving average, has been typical of the trends observed at other rain gages in Western Washington (Barker, 1995).

HYDROGEOLOGY

WATERSHED HYDROLOGY

The hydrologic cycle describes the way that water circulates between the earth and atmosphere. In the cycle, water evaporates from the land and the 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 8).

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'' 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:

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

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 (Figure 6). 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 streams.

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.

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

"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:

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

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

Adding Equations 2 and 3 yields:

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

where "RSF" represents remaining 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 12. 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 Clover-Chambers Creek Watershed is comprised of a broad, poorly drained upland drift plain ranging in altitude from sea level to 600 feet. The drift plain was deposited by glaciers and streams and is composed primarily of thick sequences of low-permeability glacial tills, and higher permeability outwash deposits. Volcanic and sedimentary rocks of Tertiary age underlie the entire watershed, but are deeply buried by the unconsolidated glacial and fluvial sediments. The nearest consolidated rock or bedrock exposures occur about 4 miles east of the study area near the Puyallup River. The deepest wells in the study area (over 2,000 ft deep) did not encounter bedrock (Walters and Kimmel, 1968).

Un-lithified deposits in the Chambers-Clover Creek Watershed can be divided into two major categories based on the environment of deposition and hydrogeologic characteristics. One category consists of sediments deposited as a result of glacial activity. The second category contains non-glacial sediments deposited between periods of glaciation. These materials are also being deposited today in the form of fine-grained bottom sediments in the Puget Sound, floodplain sediments in stream valleys, and organic clays in lakes and bogs. Generally, the non-glacial deposits are more finely grained than the glacial deposits, and, as a result, are of lower permeability.

During the Pleistocene Epoch (approximately 1.6 million to 10 thousand years ago), Cordilleran glaciers advanced into the Puget Sound lowland, and then retreated out of the area several times. Thousands of years elapsed between each of the advances; and glaciers varied in thickness and extent. The most recent of these glaciers (Vashon) was approximately one mile thick in the vicinity of Seattle in the Puget Sound lowland. Each of the glaciers deposited a variety of till and outwash. The outwash is further divided into advance and recessional deposits.

Advance outwash, consisting of sand and gravel, was deposited by meltwater streams in front and along the margins of the glaciers during the advance of the glaciers into the area. Advance outwash consists of poorly sorted mixtures of sands, gravels, and boulders. These deposits are characterized by a tendency for grain sizes to increase toward the top of the deposit, and they are generally the most permeable deposits found within the study area. Although the advance outwash tends to be coarse grained and permeable, and therefore forms the major aquifers of the area, these deposits tend to be heterogeneous and areally discontinuous.

As the glaciers receded from the Puget Sound, meltwater streams deposited recessional outwash, similar in character to the advance outwash, over the compacted till. Recessional outwashes tend to have moderate to high permeabilities, making them a good source of ground water. As the glaciers receded from the area, the velocity of the streams was reduced, resulting in finer grained depositions. Recessional outwashes exhibit a tendency to have finer grained sediments near the top of the deposits. The upward fining and the stratigraphic position relative to the glacial tills can be used to differentiate advance deposits from recessional deposits.

Glacial till is a poorly sorted mixture of sediments ranging in size from clay to boulders. Basal till is deposited directly beneath the glacier, and is compacted by the weight of the glacier. Lodgement till, a type formed as ice fragments melt in place, is far less abundant than basal till and of little consequence for water supplies in the area. Further references to till will be about basal till, only. Generally, tills are too fine grained and compacted to serve as a source of ground water. Instead, tills tend to serve as aquitards, limiting flow of ground water. However, tills may be absent in localized areas, or may contain courser grained materials. Either of these conditions may result in transport of ground water and potential contamination across or below till layers.

Each of the major glaciations that occurred during the Pleistocene created at least one set of the advance outwash, till, and recessional outwash. The youngest of these deposits are present at, or close to, the land surface, although some deposits may be missing due to erosion. The aquifer system in the Chambers/Clover Creek Watershed consists of alternating layers of higher and lower permeability deposits (outwash alternating with till of non-glacial clay and silt). In the Clover/Chambers Creek Basin Ground Water Management Program (Brown and Caldwell, 1991) these layers are denoted as layers A through G. The major aquifers are the glacially deposited layers A, C, and E. Lower permeability aquitards (B, D, and F) are non-glacial in origin. The uppermost permeable layer (Layer A) was deposited by the Vashon glacier, and is one of the most productive aquifers in the watershed, commonly referred to as the shallow aquifer. However, this aquifer'' unconfined position at the top of the stratigraphic column makes it vulnerable to contamination. Another highly productive aquifer is layer E (termed the deeper aquifer), located beneath several confining (low permeability) layers and offering greater protection from contamination.

The depth to ground water in the watershed ranges from 0 to more than 100 feet. The north end of the watershed is characterized by depths to water of greater than 50 feet, while ground water in the areas of Lakewood and Parkland are generally shallow at less than 20 feet. Most of the ground water moves to the west toward Puget Sound. However, ground water along the northeastern boundary of the watershed flows toward the Puyallup River valley (Brown and Caldwell, 1985).

Ground water within the basin moves relatively rapidly. Velocities are estimated between 0.02 and 63 feet per day, although a velocity of 93 feet per day has been reported. The average flow rate is 4.4 feet per day (Brown and Caldwell, 1985).

GROUND-WATER AND SURFACE-WATER INTERACTIONS

Stratigraphic cross-sections in the Clover/Chambers Creek Basin Ground Water Management Program (Brown and Caldwell, 1991) show that the valleys cut by the Clover and Chambers Creeks do not pass through the first confining layer (B) below the Vashon deposits. The cross-sections also suggest that the confining layers (B, D, and F) are discontinuous, allowing paths for vertical travel of ground water between aquifers. Whether ground water would flow upward or downward from one aquifer to the next depends on the hydrostatic pressures within the aquifers. In general, surface water infiltrates to recharge the upper aquifers, and these aquifers provide recharge (leakage) to the deeper aquifers in the upper elevations found in the eastern portion of the watershed. At lower elevations toward the west, the process is reversed; the deep aquifers provide water to the shallower aquifers that discharge to streams.

Depending on the situation, a well pumping from an aquifer near a stream or other surface-water body can either reduce the amount of ground water discharging to the stream or increase the quantity of water leaking out of the stream. Ground water will discharge to surface water when the water level in the aquifer is higher than the surface-water level, as is the case for American Lake which receives much of its water from the hydrologically connected ground water. 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.

The interconnection between ground and surface water is evidenced by the relatively high proportion of recharge contributed from stormwater infiltration to ground water (21 percent). Precipitation accounts for 66 percent of the recharge, and septic tank drainage and surface-water bodies account for 11 and 2 percent, respectively (Brown and Caldwell, 1985).

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.

Ground water is the dominant source of water supply in the watershed. The Clover/Chambers Creek Basin has been designated as a Sole Source Aquifer by the U.S. Environmental Protection Agency. The aquifer supplies drinking water to more than 167,000 people, or approximately 63 percent of the population, within its boundaries. Despite the importance of ground water within the watershed, Ecology does not maintain a water level monitoring network in the Chambers-Clover Creek Watershed, and only limited data for static water levels (reported to Ecology) were found. The data were reported on wells operated by Parkland Light and Water (1989 to 1994) and Dupont Public Works (1992 to 1994). Except for regular seasonal fluctuations in static ground-water levels, no significant increases or decreases were noted. These data are not sufficient to permit a reliable analysis of water-level trends. Monitoring over an extended period of time at many locations dispersed throughout the Chambers-Clover Creek Watershed would be required to develop the data necessary for a scientifically-sound analysis of static water-level trends.

In closed-basin lakes in the area, such as American Lake, Gravelly Lake, Lake Louise, Snake Lake, and Wapato Lake, the lake levels reflect ground-water levels in the surrounding area. In the summer of 1994, the level of these lakes declined substantially. Carp Lake, located a half mile south of Lake Louise, has been dry for several years.

WATER DEMAND

WATER RIGHTS AND CLAIMS

Water-use statistics for the Chambers-Clover Creek Watershed have not been consistently recorded over the years, and an accounting of actual use 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 9), with a total annual withdrawal of 131 cubic feet per second (cfs) and 2,478 per year acre-feet authorized from the surface waters of the watershed. As of September 1994, one application, requesting a total of 12 cfs for fish propagation was on file at Ecology (Table 2).

Ground-water withdrawals have shown a steady increase (Figure 10), and a total annual withdrawal of 453.2 cfs (203,401 gallons per minute [gpm]) and 144,705 acre-feet per year has been authorized from the watershed. As of September 1994, 17 applications, requesting a total of 50 cfs (22,395 gpm) for municipal supply, domestic supply, and irrigation were on file (Table 2).

Surface-water and ground-water rights were sorted by type of use and totaled, and are shown with instantaneous withdrawals and annual quantities in Table 3. These uses are graphically depicted in Figures 11 and 12, 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. The surface-water right issued in 1990 for 96 cfs is a non-consumptive use (for flood control) that diverts flow from Leach Creek into culverts in Nalley Valley. This diversion occurs to prevent flooding and is only triggered when Leach Creek flows exceed 60 cfs.

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.

To estimate the quantity of consumptive use claimed, an instantaneous quantity (Qi) was assigned, and an annual quantity (Qa) was calculated to reflect the average withdrawal for most domestic, stockwatering, and incidental uses. The 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 2,133 claims (221 surface-water claims and 1,912 ground-water claims) were 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)**
Multiple Domestic	0	0	9	27.0
Fish Propagation	1	12.0	0	0
Irrigation	0	0	1	0.5
Municipal	0	0	7	22.5
TOTAL	1	12.0	17	50.0

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	10.2	2,519.3	50.0	21,790.1
General Domestic	0	0	0.4	174.5
Multiple Domestic	11.1	0	160.3	61,937.7
Single Domestic	3.7	12.0	9.8	956.7
Environmental Quality	96.0	0	0	0
Fire Protection	2.9	46.0	0	0
Fish Propagation	0	0	4.1	1,741.8
Heat Exchange	0	0	1.0	419.0
Irrigation	7.2	171.3	16.2	2,245.1
Municipal Supply	0	0	207.5	54,432.5
Recreation/Beautification	0	0	0.1	1.0
Stockwatering	0	0	2.1	590.3
Railway	0	0	1.6	405.0
Wildlife Propagation	0	0	0.1	11.5
TOTAL	131.1	2,748.6	453.2	144,705.2

Table 4. Values Used To Estimate Claims

USE	Qi (instantaneous; cfs)	Qa (annual; gpm)
Domestic	0.02	0.5
Stockwatering	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	2.0	49.0	30.6	751.5
Stockwatering	0.6	1.5	6.4	160.0
Irrigation	2.5	2,110.0	8.5	2,732.0
Municipal Supply	0	0	1.0	Not calculated
Other	0.6	14.5	2.2	488.8
TOTAL	5.7	2,167.0	48.7	4,132.3

WATER QUALITY

Surface-Water Quality

Water quality is an important measure of a watershed's overall health and affects the ability of life to survive and flourish within a watershed. The importance of adequate water quality and quantity within the Chambers-Clover Creek Watershed is reflected in the following statement:

> *"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."*

While this statement is taken from the Draft Green-Duwamish Watershed Nonpoint Water Quality Early-Action Plan (King County, 1989), it is equally applicable to the Chambers-Clover Creek Watershed.

Many factors adversely affect water quality in the watershed. The geology of the watershed allows rapid infiltration and percolation of degraded or contaminated surface waters. Non-point pollution sources include on-site septic systems and livestock operations, stormwater runoff from regional industrial and residential development, and changes in land uses and cover. Point pollution sources include industrial and municipal discharges.

The status of water quality within the Chambers-Clover Creek Watershed is monitored by the Department of Ecology (Ecology), public interest groups, local agencies, and occasional research studies conducted on the drainage basin's water bodies. An overall assessment of conditions within the Chambers-Clover Creek Watershed shows that water quality is rated as fair to excellent for all water bodies in the basin. All of the stream segments within the Chambers-Clover Creek Watershed are classified as Class A according to criteria set by the Washington Administrative Code (WAC) 173-201A. Class A streams are of excellent quality and must be maintained at that quality. There is also a lakes classification which applies to all of the lakes within the watershed. The lakes' standards are closest in stringency to the Class AA (extraordinary quality) standards for streams (PCPWU, 1994). These classifications identify the standards these water bodies should meet, if the streams and lakes are to continue to support beneficial uses such as drinking water, recreational use, etc.

The majority of water-quality problems within the Chambers-Clover Creek Watershed appear to occur in only a few water bodies throughout the basin. According to the 1994 Section 303(d) list submitted to EPA, these problems are largely restricted to excursions beyond the Class A criteria for fecal-coliform bacteria and total phosphorous loading. Chambers Creek was cited with 10 excursions beyond the Class A criteria for fecal coliform at Ecology ambient monitoring station 12A070 between January 1, 1990 and January 1, 1992. Three lakes within the basin (American Lake, Snake Lake, and Steilacoom Lake) were found to have elevated total phosphorous, in addition to problems associated with toxic blue-green algae blooms which have resulted in animal poisonings and public-health advisories. Figure 13 depicts the locations of excursions described in the 303(d) report.

The Clean Water Act Section 305(b) Report (Ecology, 1992) indicated that in 1992, Chambers Creek (stream segment 12-1101) and Clover Creek (segment 12-1115) were impaired for primary and secondary recreational use due to the presence of fecal-coliform bacteria at elevated concentrations. One source of water-quality impairment listed in the report was municipal discharges.

A total of four individual NPDES permittees discharge to surface water within the watershed. Two of these permittees are municipal dischargers and two are industrial dischargers. In addition, eight general NPDES permits are on file along with two general permits for fish hatcheries. One municipality is permitted to discharge treated wastewater to the ground. The other source of impairment listed in the report was on-site septic systems which may have contributed to the degradation of American, Louise, and Steilacoom Lakes which were reported to be impaired for primary contact recreation due to elevated fecal-coliform bacteria.

Water-quality information is also available from the EPA Storet database. The information was accessed for Hydrologic Unit Code (HUC) 17110019. HUC 17110019 covers most of the watershed but also includes areas in WRIA's 8, 9, and 10. The surface-water-quality data were averaged separately from ground-water-quality data. Data from HUC 17110019 indicate that concentrations exceeded the water-quality criteria for fecal coliform, dissolved copper, dissolved lead, and dissolved silver. These are average concentrations and exact locations for the exceedences are not readily accessible. Thus, the data may reflect elevated concentrations in only small areas or at locations within the HUC but outside the watershed. It would be difficult to use these data to derive statements about the health of the watershed as a whole.

Site-specific surface-water-quality data was obtained from the U.S. Geological Survey National Water Information System (NWIS) database. A review of these data for the watershed indicate that the mean dissolved copper concentration exceeded the acute water-quality criterion in Flett Creek at Tacoma and in Leach Creek near Steilacoom. The mean fecal-coliform count exceeded the water-quality criterion at these same stations, as well as in Chambers Creek at Steilacoom and Clover Creek near Tillicum.

The Preliminary Draft Chambers-Clover Creek Watershed Characterization Plan (PCPWU, 1994) indicates that water-quality excursions have occurred in water bodies as indicated in Table 6. In addition, elevated concentrations of metals (copper, lead, antimony, cadmium, and silver) and polycyclic aromatic hydrocarbons were detected in the sediments of American Lake.

Ground-Water Quality

The entire Chambers-Clover Creek Watershed has been designated by the EPA as part of a Sole Source Aquifer System. This designation is provided to areas in which drinking water supplies have been identified as serving large populations and where alternative drinking water supplies are scarce. The purpose of the designation is to provide limited federal protection to drinking water sources and to identify areas where water quality should be more stringently protected (EPA, 1993). Over 169,000 people or approximately 63 percent of the population within the Chambers-Clover Creek Watershed depend on the Chambers-Clover Creek aquifer as their only source of drinking water (PCPWU, 1994). The National Groundwater Association classified the uppermost aquifer as either moderately or highly vulnerable to contamination because of the excessively well drained soils that are common throughout the area (EPA, 1993). The vulnerability has been substantiated by a number of instances of contamination.

In 1981, the Washington Department of Social and Health Services (DSHS) surveyed the quality of the ground water in the watershed. The survey reported fecal-coliform bacteria in 29.5 percent of the 117 wells sampled. The southeastern portion of the drainage basin exhibited the highest levels of contamination (Littler, et al. 1981). In the same study, DSHS reported that average nitrate-nitrogen concentrations had risen from 0.5 mg/L in the 1960s to 1.6 mg/L in 1981. Three organic chemicals (tetrachloroethylene, trichloroethylene, and 1,2-dichloroethylene) were detected at one sampling well south of the intersection of Interstate 5 and Clover Creek. The source of these contaminants was thought to be the former large-scale cleaning practices at McChord Air Force Base (Littler, et al., 1981).

Nitrate and chloride concentrations are often used as indicators of the general health of ground water. According to the 1981 DSHS study (Littler, et al., 1981), the naturally occurring concentration of nitrate-nitrogen in the Clover/Chambers Creek Watershed ground water is

Table 6. Additional Water-Quality Excursions in Chambers-Clover Creek Watershed (PCPWU, 1994)

Water Body	Fecal Coliform	Dissolved Oxygen	Total Dissolved Gases	Temperature	pH	Turbidity	Metals
Chambers Creek	●		●		●	●	
Clover Creek	●				●		●
North Fork							●
Morey Creek				●			
Spanaway Creek				●	●		
Sequalitchew Creek	●				●		
American Lake	●	●		●	●		
Louise Lake	●	●					
Steilacoom Lake	●	●					
Snake Lake		●		●	●	●	
Wapato Lake		●				●	
Spanaway Lake		●					
Gravelly Lake		●					
Waughop Lake				●			

assumed to be approximately 0.25 mg/L, based on analyses conducted before 1970. Analyses performed between 1975 and 1982 indicated generally higher concentrations of nitrate, although well below the drinking water standard of 10 mg/L. Roughly one-third of the more recent analyses indicated nitrate-nitrogen levels greater than or equal to 1.8 mg/L. The highest concentration measured was 6.1 mg/L in one well (Brown and Caldwell, 1985). Concentrations of nitrate-nitrogen measured in 1984 and 1985 spanned from 0.10 mg/L to 6.64 mg/L in the shallow aquifer, with an overall mean concentration of 1.8 mg/L. The mean nitrate-nitrogen concentration in the deep aquifer was 0.8 mg/L. The Brown and Caldwell study concluded that there has been little or no general increase in nitrate concentrations in the deep aquifer over the last two decades (1965-1985) and a moderate increase in the shallow aquifer.

Chloride concentrations have exhibited a similar trend. According to the 1981 DSHS study (Littler et al., 1981), the naturally occurring chloride level in ground water in this watershed is assumed to be approximately 2.5 mg/L. More recent historical analyses (1975-1982) have shown that chloride concentrations are greater than or equal to 10 mg/L in nearly half of the samples (Brown and Caldwell, 1985). There was no statistical correlation of nitrate, chloride, and total dissolved solids concentrations in these samples. Analytical data collected in 1984 and 1985 showed higher levels of chloride in the shallow aquifer than in the deep aquifer. The mean year-round concentration of chloride in the shallow aquifer was 8.1 mg/L, and 5.2 mg/L in the deep aquifer. Concentrations varied over a greater range in the shallow aquifer. The trend toward higher chloride concentrations in the shallow aquifer, although not statistically proven, indicates greater impairment of the shallow aquifer than to the deeper aquifer from land use activities (Brown and Caldwell, 1985). Shallow aquifer nitrate and chloride concentrations were found to have increased most significantly in the Lakewood, Parkland, and Spanaway areas. Chloride increases are not believed to have been caused by saltwater intrusion, but are more likely the result of the cumulative affects of septic-tank usage and stormwater infiltration.

Nitrate-nitrogen concentrations from public-supply wells are depicted in Figure 13 and provide more recent estimates of the quality of the ground water in the watershed. The highest measured nitrate concentrations from water-supply wells, based on the 1989 Department of Health database, were used to develop Figure 14. Forty-six of the wells indicated some evidence of degradation in water quality, having concentrations between 2 and 6 mg/ of nitrate-nitrogen. Only five of the wells had concentrations greater than 6 mg/L. None of the wells had nitrate concentrations that exceeded the primary drinking water maximum-contaminant level (MCL) of 10 mg/L. No pattern of localized contamination was detectable from the nitrate concentrations. Based on this analysis, the ground-water quality appears to be of drinking water quality, although pristine conditions are no longer present.

Newer data have recently been collected by Pierce County on ground-water quality. Nitrate levels will be documented in the Central Pierce County Nitrate Study, due to be issued in late March or April 1995, by the Tacoma/Pierce County Health Department, and Robinson and Noble, Inc. Analyses of 34 wells in Pierce County, including bacteria, nitrogen, anions, cations, metals, chlorinated pesticides, and primary inorganics, have recently been completed and are available on the Storet database. Results are anticipated to be analyzed and put in report format later this year. In addition, Tacoma/Pierce County Health Department maintains water-quality data on all new wells constructed in the county, including over 2,000 wells since 1991; as well as on all Group A and Group B public-water-supply systems.

The EPA Storet database was accessed for HUC 17110019 and the average water-quality-parameter concentrations were provided. The average concentrations exceeded the criteria provided in the Ground Water Quality Standards (Chapter 173-200 WAC) for arsenic, manganese, and fecal coliform. Because these are average concentrations and exact locations for the exceedences are not readily accessible, the data may reflect specific locations of elevated concentrations or locations outside of the watershed, 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).

The Clover/Chambers Creek Basin Ground Water Management Program (Brown and Caldwell, 1991) suggests a number of control measures to prevent further degradation of the ground water in the Sole Source Aquifer. These include: underground-storage-tank management, cleanup of hazardous sites, modification of on-site sewage-disposal regulations, development of a well-construction and abandonment program, and maintaining effective solid-waste programs.

FISHERIES

The status of fish populations is related to water quality, streamflow, and stream-health within a watershed. As stated in the 1994 Draft Tacoma Watershed Action Plan, "Good habitat is necessary to support both fish and other wildlife. Some organisms, fish in particular, are considered sensitive indicators of stream health. If large numbers and species of fish are successfully spawning and rearing within a stream reach, then it is likely that the stream has conditions that will support other uses." Ascertaining the status of fish populations within a drainage basin can be a very important and constructive objective of any environmental study, as it can be used as a preliminary measure of a watershed's health.

The Washington Department of Fisheries' 1975 Catalog of Washington Streams and Salmon Utilization indicates that anadromous salmonids found within the Chambers-Clover Creek Watershed are chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and chum (*O. keta*) salmon. Steelhead (*O. mykiss*) and cutthroat trout (*O. clarki*) are also found throughout the Chambers-Clover Creek Watershed (PCPWU, 1994). Adult or juvenile salmon and/or steelhead trout are present within the basin throughout the entire year.

The salmonid habitats of the Chambers-Clover Creek drainage have been severely degraded by human activities. Physical barriers, both anthropogenic and natural, pose a serious problem to anadromous fish movement within the drainage basin. A dam with a spillway and fish ladder forms the head of Chambers Bay approximately 0.75 miles upstream from the Burlington Northern Railroad dike at tidewater. The outlet of Chambers Bay is very narrow and restricted due to the railroad dike and tracks across the mouth (Williams, et al., 1975). In addition, a fish trap near the mouth of Chambers Creek and an impassible dam at the outlet of Steilacoom Lake, restrict the passage of anadromous fish species. All salmon and steelhead that enter Chambers Creek have been netted and placed on the upstream side of the fish trap. Because of the blockage problems encountered, the overall habitat available for anadromous salmonid production has been limited to 9.0 stream miles in the lower watershed. Despite these limits, the habitat that is available for spawning salmon in the lower watershed is rated as fair to excellent quality.

Anadromous fish production in the Chambers-Clover Creek Watershed is relatively low and has been below historic levels for many years. Many complex and interacting factors contribute to the low production. Some of these conditions adversely affecting anadromous salmon and steelhead include seasonal flooding, low summer flows, unstable stream beds, physical barriers, poor water quality, high stream temperatures, the destruction of spawning habitat, and overharvest of wild stocks. Low streamflows experienced over a period of several years are particularly problematic in this watershed.

Adult salmonids migrate upstream through Chambers Creek estuary throughout the year. Although the Pacific salmon species (chinook, chum, and coho) migrate upstream during late summer, fall, and early winter, steelhead trout migrate in both winter and summer runs. Timing of upstream migration of the Pacific Salmon is largely controlled by rainfall, streamflow, and barometric pressure. Migrating salmon aggregate near the mouth of Chambers Creek during July and August before migrating predominantly between September through January (Wydoski and Whitney, 1979). Downstream migration by juvenile salmon and steelhead primarily occurs in late winter and early spring. Chum salmon outmigrate beginning in late February and both chinook and coho begin in early April. Outmigration usually lasts through mid-July to early August for most species.

Two of the most prominent studies regarding the health of fish stocks in Washington State are: 1) A paper published in the March-April 1991 issue of Fisheries entitled, "Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington" (Nehlsen et al., 1991) and 2) The "1992 Salmon and Steelhead Stock Inventory" (SASSI) published in March 1993. The former paper attempted to assess the <u>future</u> risk of extinction for selected stocks. The SASSI report examined the <u>current</u> status of salmon and steelhead stocks for Washington State. The American Fisheries Society risk and SASSI depressed status of streams are presented graphically for all species in Figure 15.

The primary anadromous species present within the Chambers-Clover Creek system are the coho and chum salmon. Chambers Creek coho are of a mixed stock with wild and hatchery production and are currently classified as healthy with annual escapements ranging from 287 to 5,848 fish (WDFW, 1993). According to the SASSI report, coho spawn in Chambers Creek and all tributaries. Large numbers of adults from Lake Sequalitchew and the Fox Island Net Pen stray into Chambers Creek, and hatchery-origin coho are released into the system above Steilacoom Lake. The magnitude of genetic effects caused by cross-breeding these hatchery-origin and natural stock is unknown.

Chambers Creek sustains a healthy population of winter-run chum salmon. These fish are of a native stock and are produced by natural or wild production. These fish are produced naturally. Escapement levels for this winter chum stock range from 200 to 6,300 individuals based on information from 1968 to 1991. A Washington Department of Fisheries hatchery on Chambers Creek uses the natural spawning chum run as broodstock. Fish from the hatchery are used to maintain runs in the Puyallup River system (WDFW, 1993). Chambers Creek formerly had a native summer run of chum salmon. Their escapement and number of fish returning to the creek to spawn ranged from 0 to 200 individuals between 1975 and 1980. They spawned from mid through late October in Chambers and Leach Creeks. The last three fish were seen in October of 1983. The stock has been declared extinct (WDFW, 1993; PCPWU, 1994).

The SASSI report (Figure 15) indicates that summer/fall chinook populations within Chambers Creek and other South Sound Tributaries are of a mixed stock and are regarded as healthy. Chinook stocks are of a composite production meaning that stock status depends mainly upon hatchery production, although some sustained natural spawning occurs.

Mathews and Olson (1980) studied factors that can affect Puget Sound coho salmon runs. They concluded that summer streamflow was an important determinant of coho run strength since 1952, apparently due to its affect on the first year of the salmon's life. 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 dependent upon the same environmental conditions that affect stream-reared coho.

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 Chambers-Clover Creek Watershed. Increasing water demands and periodic declines in precipitation can affect the streamflow status, most notably by reducing summer low flows. To better understand the characteristics of the stream systems in the basin, streamflow and precipitation data from the watershed were analyzed.

Streamflow data from one USGS gage along Flett Creek and three gages along Leach Creek were evaluated for flow-exceedence statistics and low-flow trends. In the analyses presented below, all available records were used which did not include unusual or atypical flow conditions. The data for Flett Creek at Tacoma (USGS Gage 12091100) were collected from 1958 to 1993. For Leach Creek, data were collected from 1966 to 1990 at Holding Pond (USGS Gage 12091180), from 1956 to 1993 near Fircrest (USGS Gage 12091200), and from 1956 to 1993 near Steilacoom (USGS Gage 12091300). For each of these gages, summer flow data were not collected for a number of years since 1986. For the Leach Creek Gage near Fircrest, no summer flow data were collected during May through September from 1987 through 1988. For the Leach Creek gages near Steilacoom and the Holding Pond and for the Flett Creek Gage at Tacoma, no summer flow data were collected during May through September since 1985. For the Flett Creek Gage near Tacoma, no summer data were collected from May through June in 1991, from June through August in 1992, and from June through September in 1993.

Other gage stations exist but did not meet the criteria for analysis because they did not have an adequate period of record or the period of record was interrupted. Gages are located at Clover Creek near Tillicum; on Flett Creek at Mountain View Memorial Park; and on Chambers Creek by Leach Creek near Steilacoom. These gages should be maintained and monitored consistently to establish a broader, more representative database of instream flows within the WRIA.

FLOW EXCEEDENCE

Flow-exceedence curves were developed for each of the selected gage stations along Flett Creek and Leach Creek (Figures 16-19). Thirty-five years of flow data for Flett Creek and 24 to 38 years (depending on the gage) of flow data for Leach Creek were used in calculating monthly flow curves for 90, 50, and 10 percent exceedence probabilities. 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. Based on the 10-percent exceedence curves, one can conclude that even at the maximum flow neither Flett Creek nor Leach Creek drains vast quantities of water from the basin. The 10-percent exceedences reach approximately 43 cfs for Flett Creek and 27 cfs for Leach Creek.

The gages along Flett Creek and Leach Creek show flow patterns typical for streams in Western Washington. In general, flow rates are at their lowest level from May through September (Figures 16-19) and reach their highest level in the wet winter months. During summer, low flows in Flett Creek at Tacoma are about 1 cfs, median flows range from 2-3 cfs, and high flows are about 5 cfs (Figure 16). During the winter, the difference between low and high flows in Flett Creek can be up to 40 cfs.

Leach Creek gages at Holding Pond and near Fircrest indicated low flows of about 2 cfs throughout the year (Figures 17 and 18). Median flow values ranged from 2 cfs in the summer to 6 cfs in the winter. High flow values ranged from 3 to 5 cfs in the summer to as high as 14 cfs in the winter.

The gage on Leach Creek near Steilacoom indicated low flows of 6 to 7 cfs, on average, throughout the year (Figure 19). Median flow values ranged from 8 cfs in the summer to 14 cfs in the winter. High flow values ranged from 10 to 12 cfs in the summer to as high as 26 cfs in the winter.

LOW FLOWS

The flow-exceedence curves presented in Figures 16 through 19 are based on statistics calculated for the entire flow record and provide no indication of flow trends over time. To evaluate trends in flow, low flows were evaluated by calculating the lowest seven-day-mean flow for each year. The seven-day flow duration is conventionally used in evaluating low flows because shorter flow durations have much greater variability. A ten-year moving average was used to analyze trends in the data. The ten-year moving average for a given year serves to smooth out annual variations and is slow to respond to drastic changes from year to year.

When plotted over time, the Flett Creek Gage data indicate an increasing trend in the lowest seven-day mean flow (hereinafter, seven-day low flow) each year from 1975 to 1985 (Figure 20). Summer flows, however, have not been recorded since 1986 which precluded analysis of recent tends in seven-day low flow. For several of the summers recorded, seven-day low flows were below 0.5 cfs in Flett Creek.

No summer flow data were collected since 1986 for the Leach Creek gages at the Holding Pond (Figure 21) and near Steilacoom (Figure 22) which precluded analysis of recent trends in seven-day low flow. Low flows tended to increase from 1968 through 1982 at the Holding Pond Gage and diminish slightly thereafter. The gage on Leach Creek near Steilacoom showed decreasing low flows from the 1960s until 1979 and an increase between 1975 and 1986 (Figure 22).

For the Fircrest Gage, flow data were not collected during the summers 1987 and 1988 (Figure 23). The ten-year moving average is shown up to 1986 for the Fircrest Gage, where the discontinuity in summer flow data occurs. Recent seven-day low flows have been about 1 cfs since 1989, which is lower than average in comparison to the full period of record (Figure 23).

INTERPRETATION OF STREAMFLOW STATUS

No minimum instream-flow requirements have been established for this watershed. However, WAC 173-512 (1980) closed Chambers, Clover, and Sequalitchew Creeks, and their tributaries (including lakes) to further water withdrawals.

Because the summer flows have not been measured since 1986 at three of the gages (previously discussed), no conclusions can be drawn about trends in low flows. For the Fircrest Gage on Leach Creek, the recent record indicates below average seven-day low flows.

Increasing demands for surface and ground water can affect low flows. Furthermore, increases in impervious surface areas due to expanding urbanization reduces ground-water recharge and, thereby would reduce base flows in the drainage basin. The effects of increased water demands and reduced ground-water recharge will have even greater consequences during an extended period of below-average precipitation.

SUMMARY AND CONCLUSIONS

The watershed covers 144 square miles and includes approximately 2,020 acres of lakes, extensive wetlands, as well as Chambers Creek and Clover Creek (PCPWU, 1994). The watershed is predominantly urbanized, consisting of residential, urban, and light industrial uses. Forty-two percent of the land in the watershed is classified as built-up (PCPWU, 1994). Since the 1950 rapid urbanization and suburbanization (112.5 percent from 1950 to 1990) has resulted in a population of more than 267,000.

The period of population growth in the watershed was accompanied by equally rapid expansion of water consumption. During the period since 1947, combined surface-water and ground-water rights have risen from 91 to 585 cfs and from 12,940 acre-ft/year to 147,926 acre-ft/year. After the 1980 closure of Chambers, Clover, and Sequalitchew Creeks and their tributaries, the rise in water consumption has been dominated by the granting of ground-water rights.

The interconnection between surface water and ground water is apparent in this watershed. Increased demands for ground water probably have affected low flows in the streams, although not enough data are available to draw quantitative conclusions. Increases in impervious surface areas from expanding urbanization have reduced ground-water recharge and base flow.

Because the summer flows have not been measured since 1986 at three key gages, no conclusions can be drawn about trends in low flows. For the Fircrest Gage on Leach Creek, the recent record indicates below average seven-day low flows.

No minimum instream-flow requirements have been established for this watershed in WAC 173-512. Establishment of minimum flows should be considered for the major stream sin the watershed. The minimum flows could be based on pre-1980s flow data. Once established, water-conservation and reallocation plans could be implemented to re-establish base flows in the creeks. Future ground-water withdrawal should be curtailed until the minimum flows are met. To assist in re-establishing flows, a program to account for all water withdrawals (including the exempt withdrawals of less than 5,000 gallons per day) could be established. Unauthorized withdrawals also should be eliminated.

Anadromous fish production in the Chambers-Clover Creek Watershed is relatively low and has been below historic levels for many years. Many complex and interacting factors contribute to the low production, including 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.

Salmon habitat is limited to 9.0 stream miles in the lower watershed. The outlet of Chambers Bay is very narrow and restricted due to the railroad dike and tracks across the mouth (Williams, et al., 1975). A fish trap near the mouth of Chambers Creek and an impassible dam at the outlet of Steilacoom Lake, restrict the passage of anadromous fish species. All salmon and steelhead that enter Chambers Creek have been netted and placed on the upstream side of the fish trap.

Low streamflows and poor water quality experienced over a period of several years have been particularly detrimental to fish in this watershed. The summer low flows experienced in Leach and Flett Creeks are not conducive to fish migration and spawning. Chambers Creek used to have a native summer run of chum salmon which are now extinct (WDFW, 1993; PCPWU, 1994). Water-quality excursions for fecal-coliform bacteria and for phosphorus in lakes have also reduced the quality and productivity of fish habitat.

The entire Chambers-Clover Creek Watershed has been designated by the EPA as part of a Sole Source Aquifer System. Over 169,000 people depend on the Chambers-Clover Creek aquifer as their only source of drinking water (PCPWU, 1994). Despite the need for protection of ground-water quantity and quality, ground-water levels have not been comprehensively monitored. Long-term monitoring of wells at locations dispersed throughout the Chambers-Clover Creek Watershed would provide the data needed for analysis of water-level and water-quality trends.

The National Groundwater Association has classified the uppermost aquifer within the system as either moderately or highly vulnerable to contamination because of the excessively well drained soils that are common throughout the area (EPA, 1993). The vulnerability has been substantiated by a number of instances of contamination.

The Clover/Chambers Creek Basin Ground Water Management Program (Brown and Caldwell, 1991) suggests a number of control measures to prevent further degradation of the ground water in the Sole Source Aquifer. These include: underground-storage-tank management, cleanup of hazardous sites, modification of on-site sewage-disposal regulations, development of a well-construction and abandonment program, and maintaining effective solid-waste programs.

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 12 without information on water use by the military. 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.

In addition, the Puyallup Tribe has 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.

The original purpose of the Fort Lewis diversion is unclear, and detailed analysis of its effect on flow is difficult because of the lack of data on stream flows before construction of the diversion dam and canal. Controversy remains regarding authorization of the diversion, its effect on the salmon fishery, and current authority and responsibility for the dam's operation.

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.

- Salmon resources should be protected by re-establishing adequate instream flows, and re-establishing natural habitat where such habitat has been reduced due to low base flow.

- Minimum instream flows should be established, water reallocation programs planned and implemented, and future water withdrawal curtailed until the pre-1980s minimum flows can be re-established. To assist as part of the re-establishment of minimum flows:

  - Actual water use within the basin should be determined through a system of annual reporting. This activity could allow relinquishment of un-used rights and improve the technical analyses of water-use effects.

  - Unauthorized water withdrawal should be investigated and enforcement action should be taken to curtail unauthorized use, if determined to be a factor. This action could return water to the system and may improve streamflow and water-quality conditions locally.

- An active water-monitoring network 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.

- 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.

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

- Efforts of the Chambers-Clover Creek Watershed Management Committee, the Clover/Chambers Creek Basin ground Water Management Committee, and Ecology's South Puget Sound Water Quality Management Planning should be integrated to include protection of both ground and surface water within the watershed. Planning activities should include resolution of water-quality and water-quantity issues.

REFERENCES

Andrews, E. and M. Swint. 1994. A Twentieth Century History of Sequalitchew Creek. October 1994.

Barker, Bruce. 1995. Long-term precipitation trends in Western Washington. Internal technical memo. Department of Ecology. Olympia, Washington.

Brown and Caldwell. 1991. Clover/Chambers Creek Basin Ground Water Management Program. Prepared for the Clover/Chambers Creek Basin Ground Water Advisory Committee. December 1985.

Brown and Caldwell. 1985. Clover/Chambers Creek Geohydrologic Study. Prepared for the Tacoma-Pierce County Health Department. July 1985.

Easterbrook, D. and D. Rahm. 1970. Landforms of Washington. Western Washington State College. Bellingham, Washington.

Ecology, 1994. 1994 Section 303(d) List, Department of Ecology, Olympia, WA.

Ecology. 1992. 1992 Section 305(b) Report, Washington State Department of Ecology, Olympia, Washington.

EPA. 1993. Support document for Sole Source Aquifer Designation of the Central Pierce County Aquifer System. U.S. Environmental Protection Agency, Region 10, Water Division. Seattle, Washington February 1993.

King County. 1989. Draft Green-Duwamish Watershed Nonpoint Water Quality Early-Action Plan. Department of Parks, Planning, and Resources, and other members of the Green-Duwamish Watershed Management Committee.

Littler, J. D., T J. Aden, and A. F. Johnson. 1981. Survey of Groundwater and Surface water Quality for the Chambers Creek/Clover Creek Drainage Basin, Pierce County. Washington Department of Social and Health Services, Health Services Division, Water Supply and Waste Section. Olympia, Washington.

Mathews, S. B. and F. W. Olson. 1980. Factors affecting Puget Sound coho salmon (Oncorhynchus kisutch) runs. Can. J. Fish Aquat. Sci., Vol 37.

Nehlsen, W., J. E. Williams, J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

PCPWU. 1994. Chambers-Clover Creek Watershed Management Committee, Preliminary Draft Watershed Characterization. Pierce County Public Works and Utilities Water Resources Division.

Thornthwaite, C. W., and J. R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Institute of Technology, Laboratory of Climatology. Publications in Climatology, Vol. 10, No. 3.

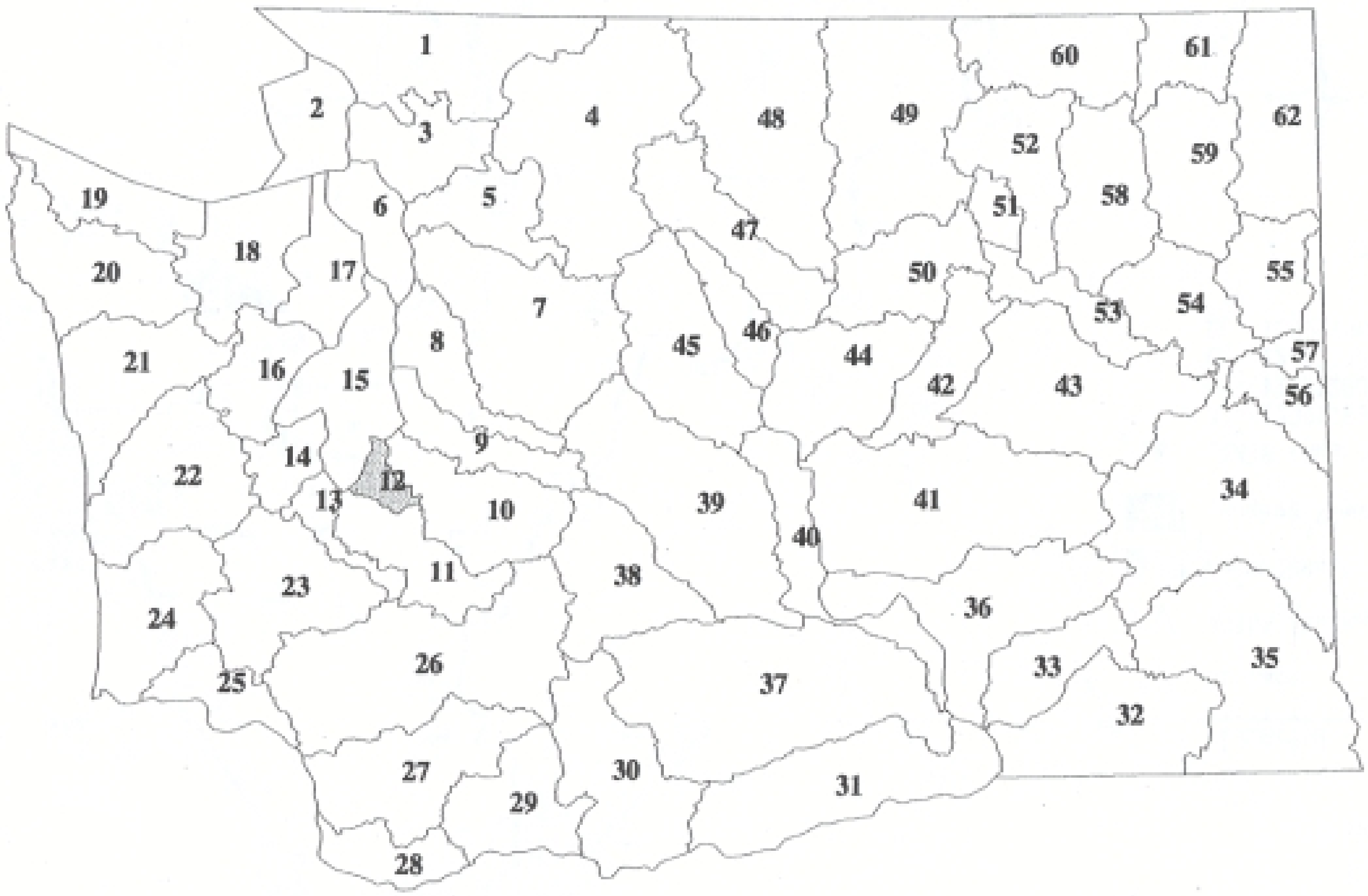
WDFW. 1993. 1992 Washington State salmon and steelhead stock inventory. Washington Department of Fisheries, Washington Department of Wildlife, and Western Washington Treaty Indian Tribes. Olympia, Washington.

Walters, K. L. and G. E. Kimmel. 1968. Groundwater Occurrence and Stratigraphy of Unconsolidated deposits, Central Pierce County, Washington: Washington Department of Water Resources Water Supply Bulletin 22, Olympia, Washington, 428 p.

Williams, R. W., R. M., Laramie, and J. J. Ames. 1975. A catalog of Washington streams and salmon utilization. Volume 1, Puget Sound Region. Washington Department of Fisheries, Olympia, Washington.

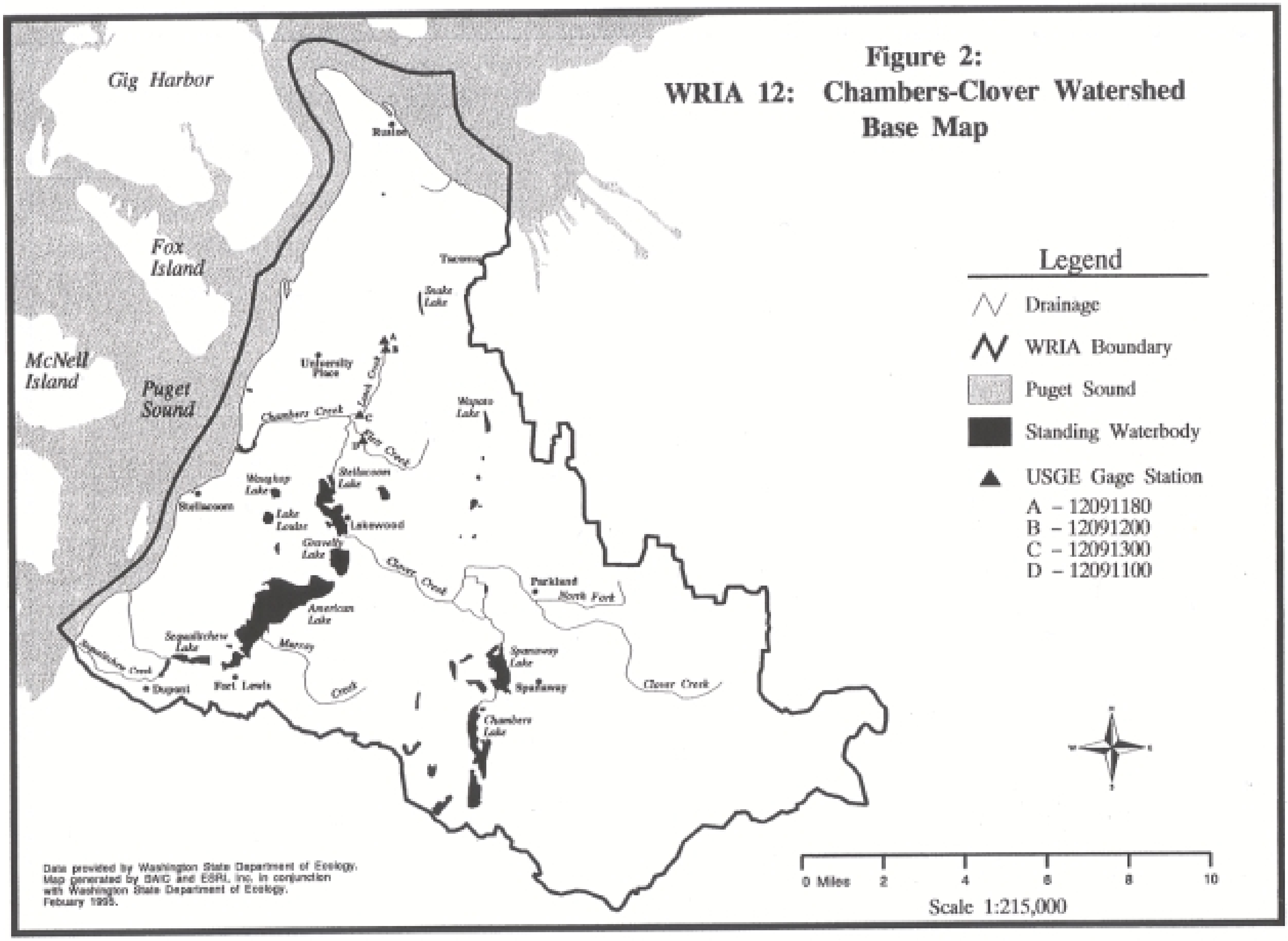
Wydoski, R. S. and R. R. Whitney. 1979. Inland fishes of Washington. Seattle, WA and London. University of Washington Press. 220 p.

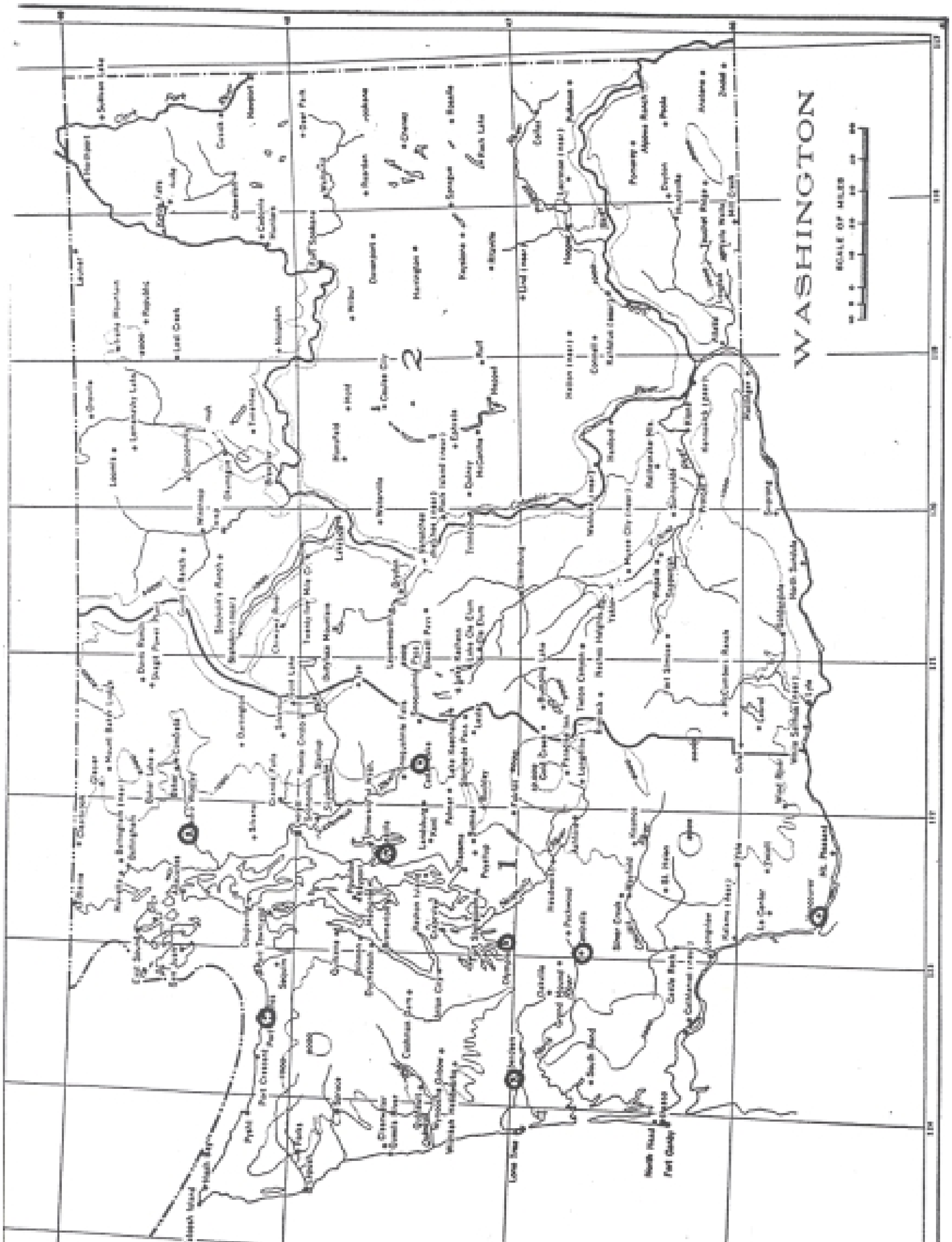
Figure 1: Water Resource Inventory Area (WRIA) Locator Map



WRIA 12 - Chambers-Clover Watershed

Figure 2:
WRIA 12: Chambers-Clover Watershed Base Map





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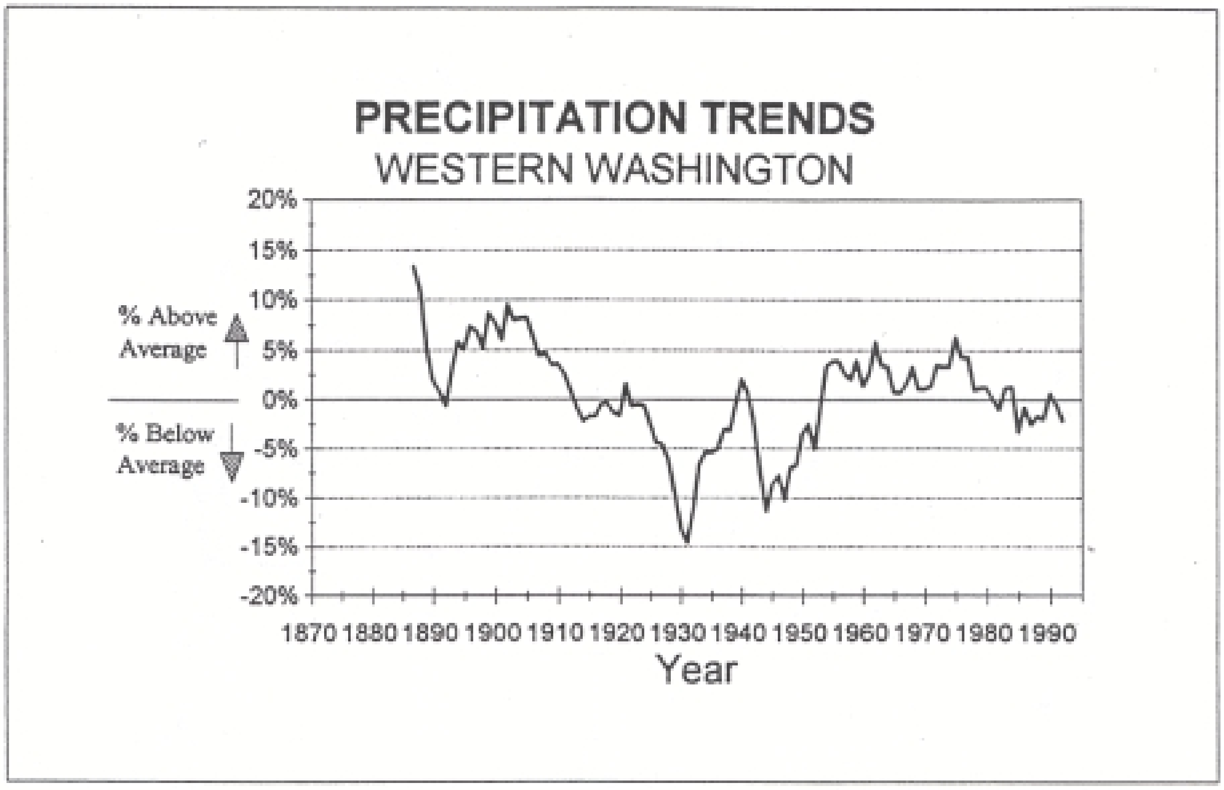
For sale by the Superintendent of Documents, Washington, D. C. - - Price 10 cents

Figure 3. Precipitation Station Locations

Figure 4. Precipitation Trends in Western Washington



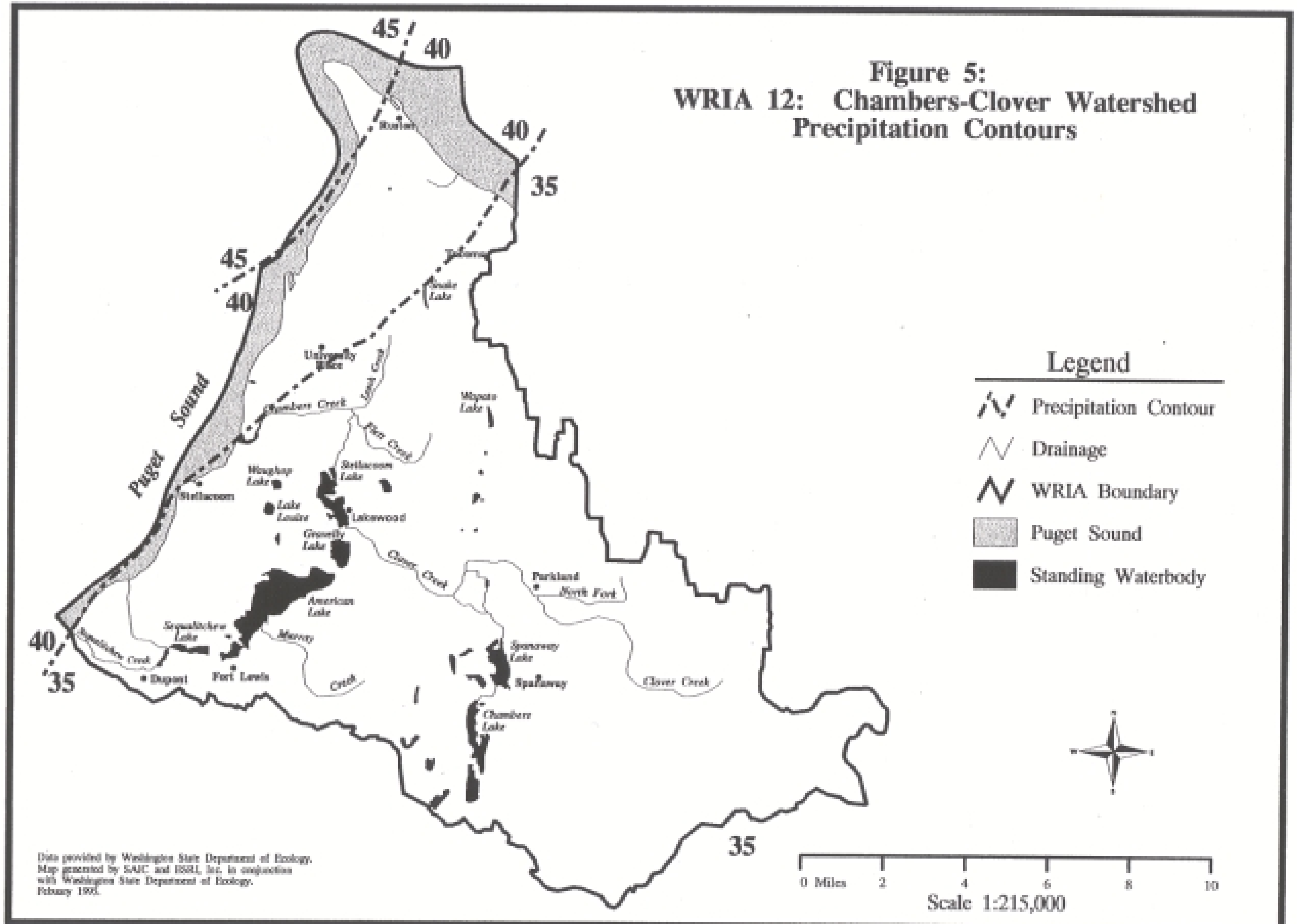
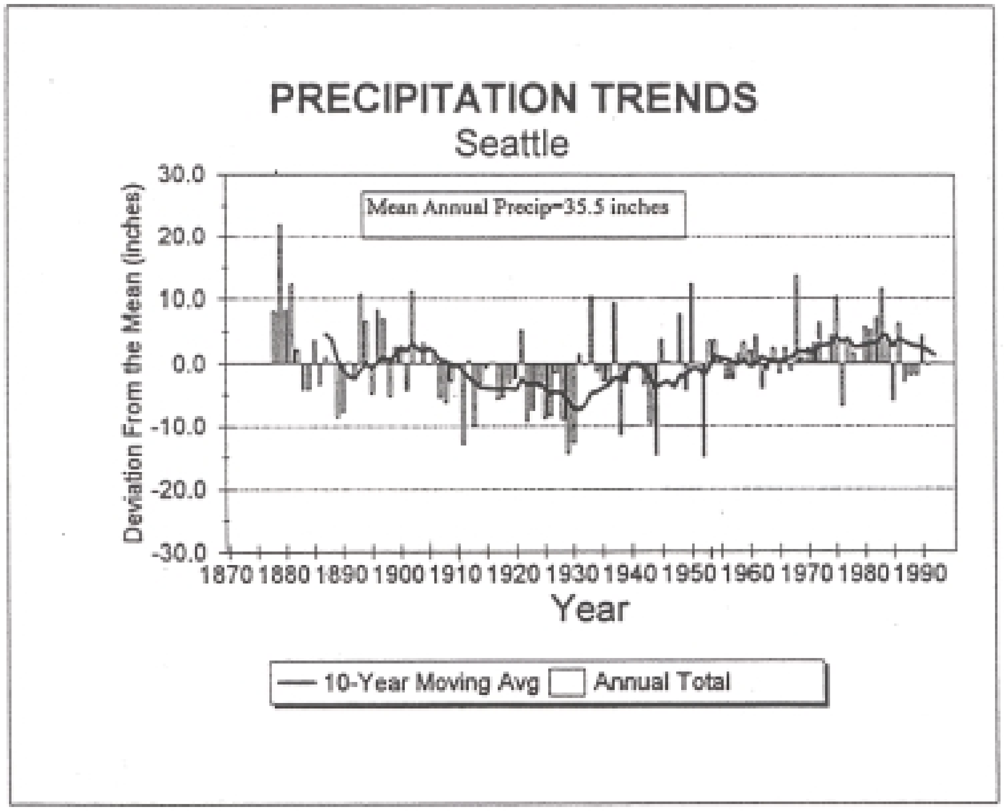


Figure 5:
WRIA 12: Chambers-Clover Watershed
Precipitation Contours
Legend
Precipitation Contour
Drainage
WRIA Boundary
Puget Sound
Standing Waterbody
45
40
35
Puget Sound
Steilacoom
Chambers Creek
Waughop Lake
Lake Louise
Steilacoom Lake
Lakewood
Gravelly Lake
American Lake
Clover Creek
Parkland
North Fork
Spanaway Lake
Spanaway
Chambers Lake
Fort Lewis
Dupont
Murray Creek
Snake Lake
Clover Creek
0 Miles 2 4 6 8 10
Scale 1:215,000
Data provided by Washington State Department of Ecology.
Map generated by SAIC and ESRI, Inc. in conjunction
with Washington State Department of Ecology.

Figure 6. Seattle and Olympia Stations Precipitation Trends



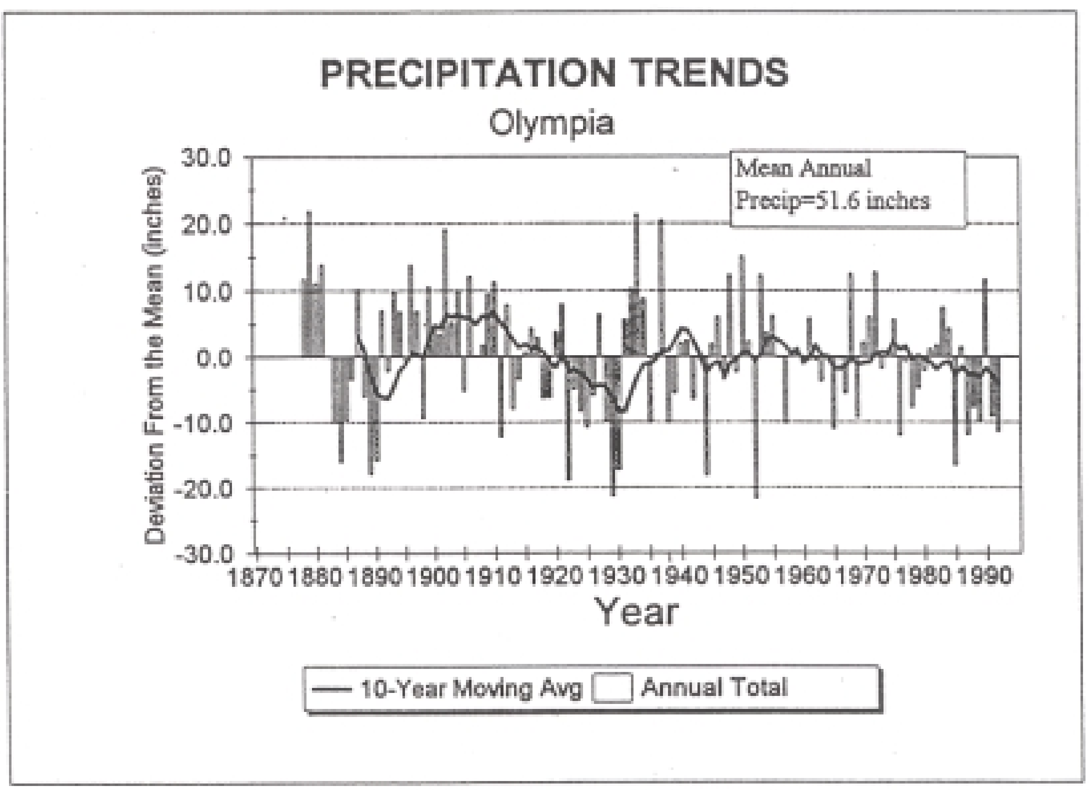


FIGURE 7 - PRECIPITATION MEASURED AT MCMILLIN RESERVOIR - 10-YEAR MOVING AVERAGE

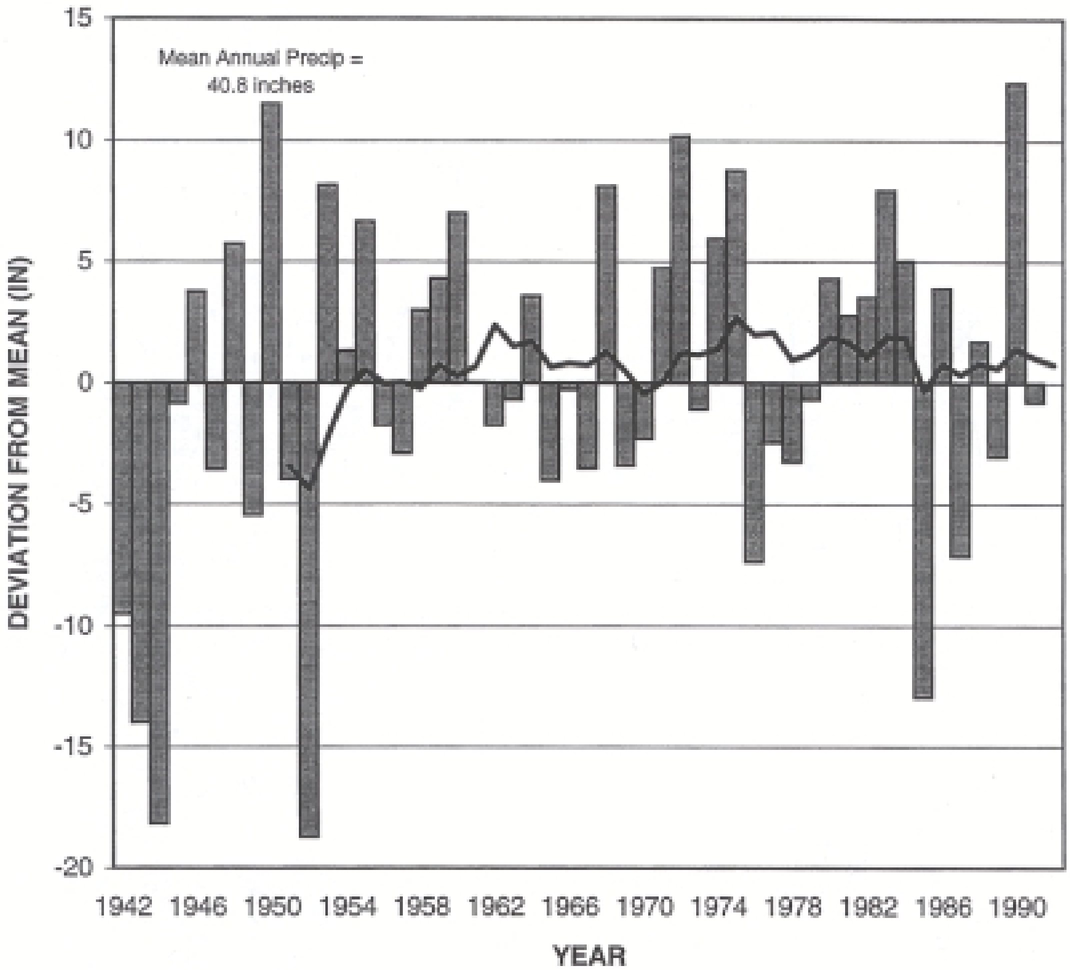
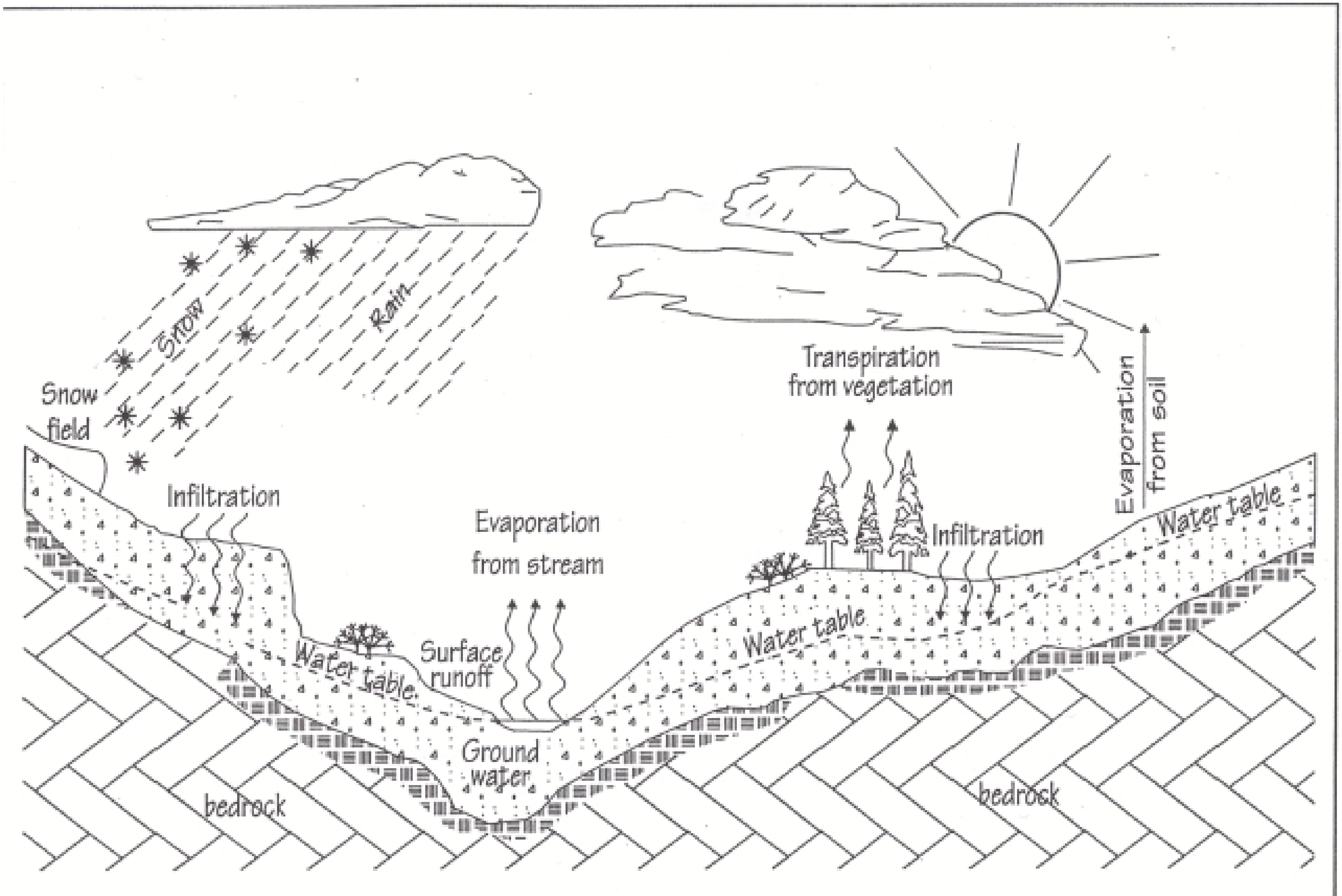


Figure 8. The Hydrologic Cycle



CUMULATIVE GROWTH IN SURFACE-WATER RIGHTS

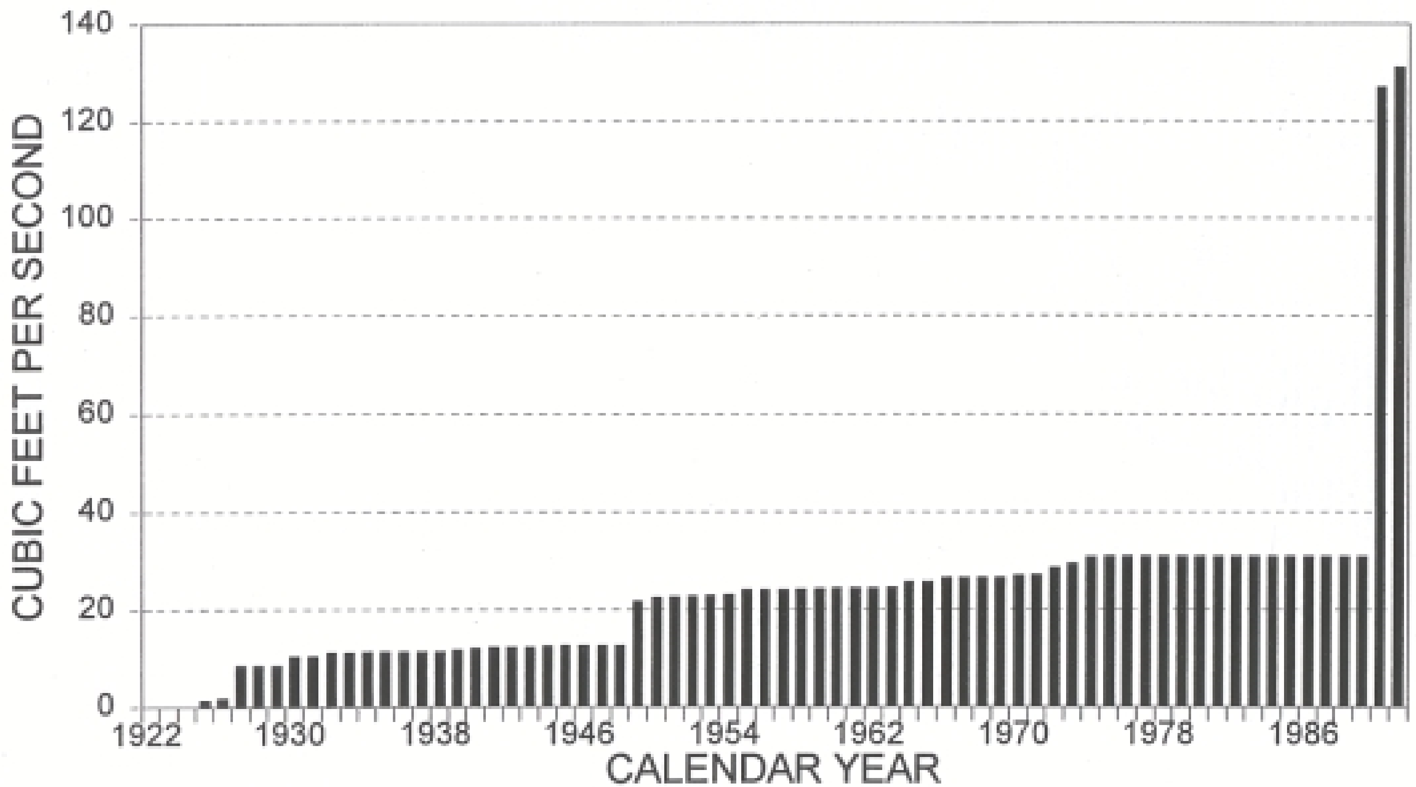


FIGURE 9

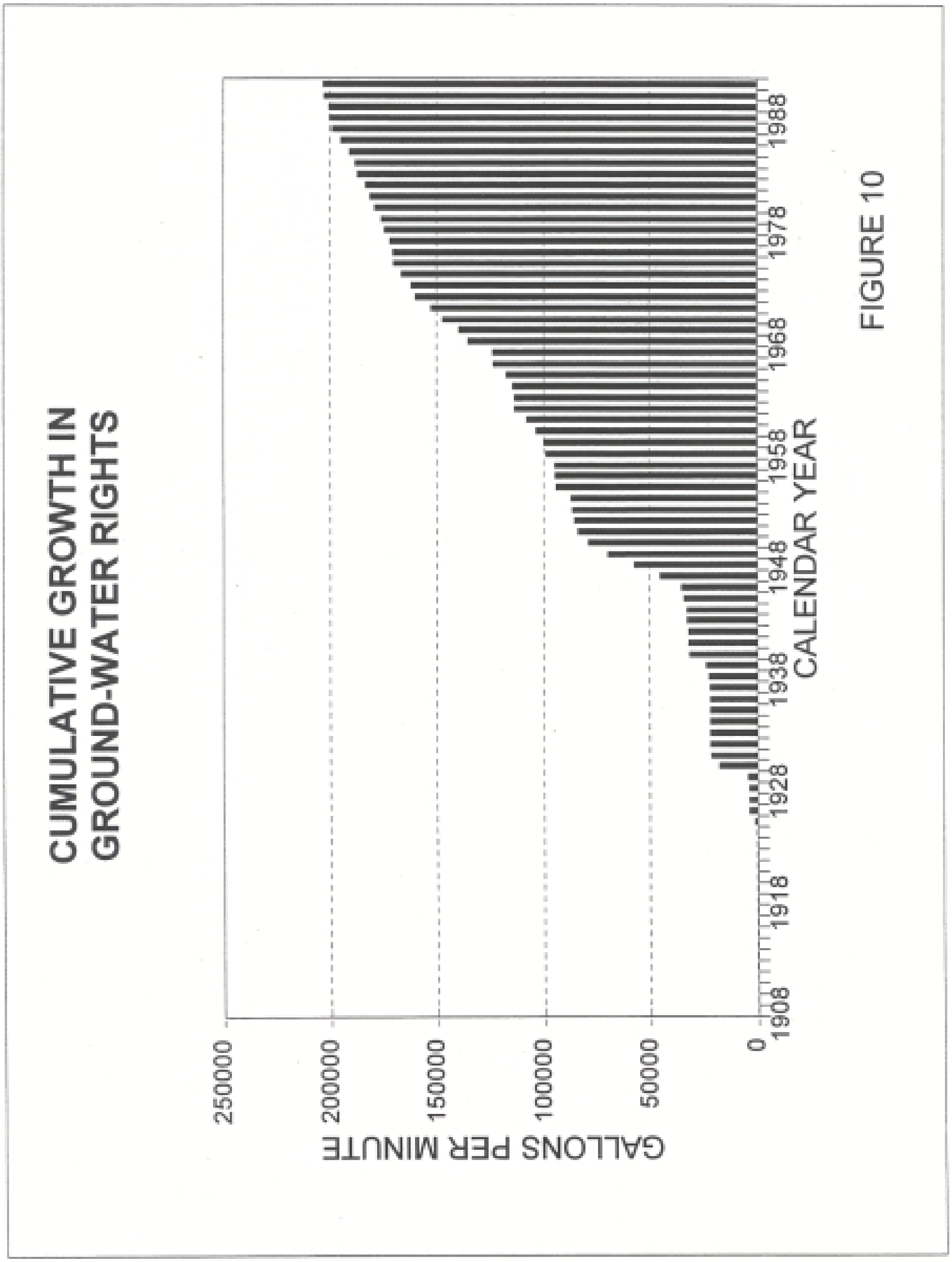

CUMULATIVE GROWTH IN
GROUND-WATER RIGHTS
GALLONS PER MINUTE
250000
200000
150000
100000
50000
0
1908
1918
1928
1938
1948
1958
1968
1978
1988
CALENDAR YEAR

FIGURE 10

SURFACE-WATER RIGHTS

PRIMARY PURPOSE OF USE

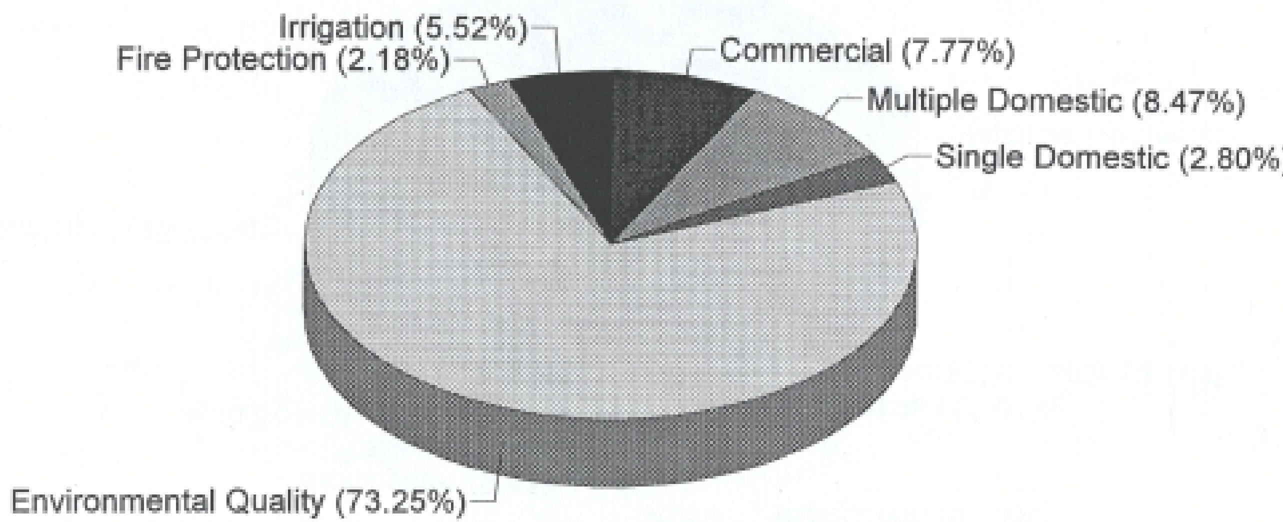


FIGURE 11

GROUND-WATER RIGHTS

PRIMARY PURPOSE OF USE

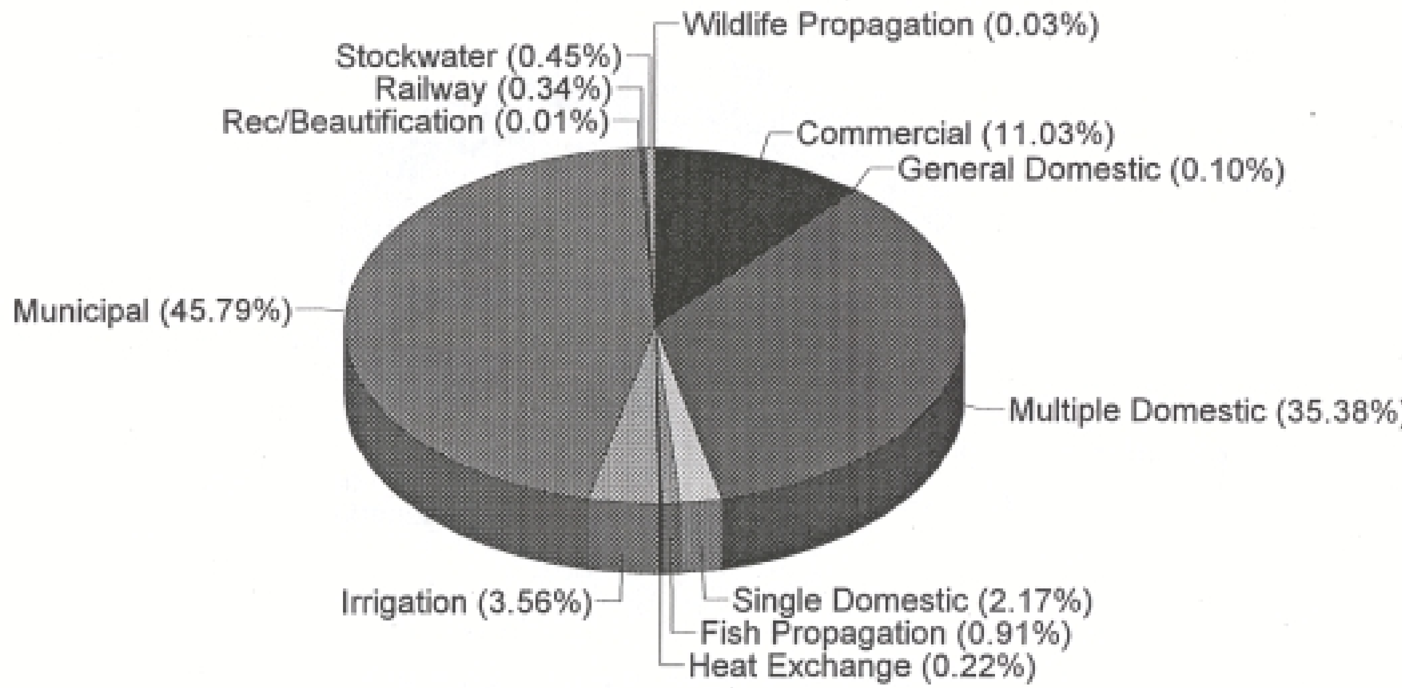
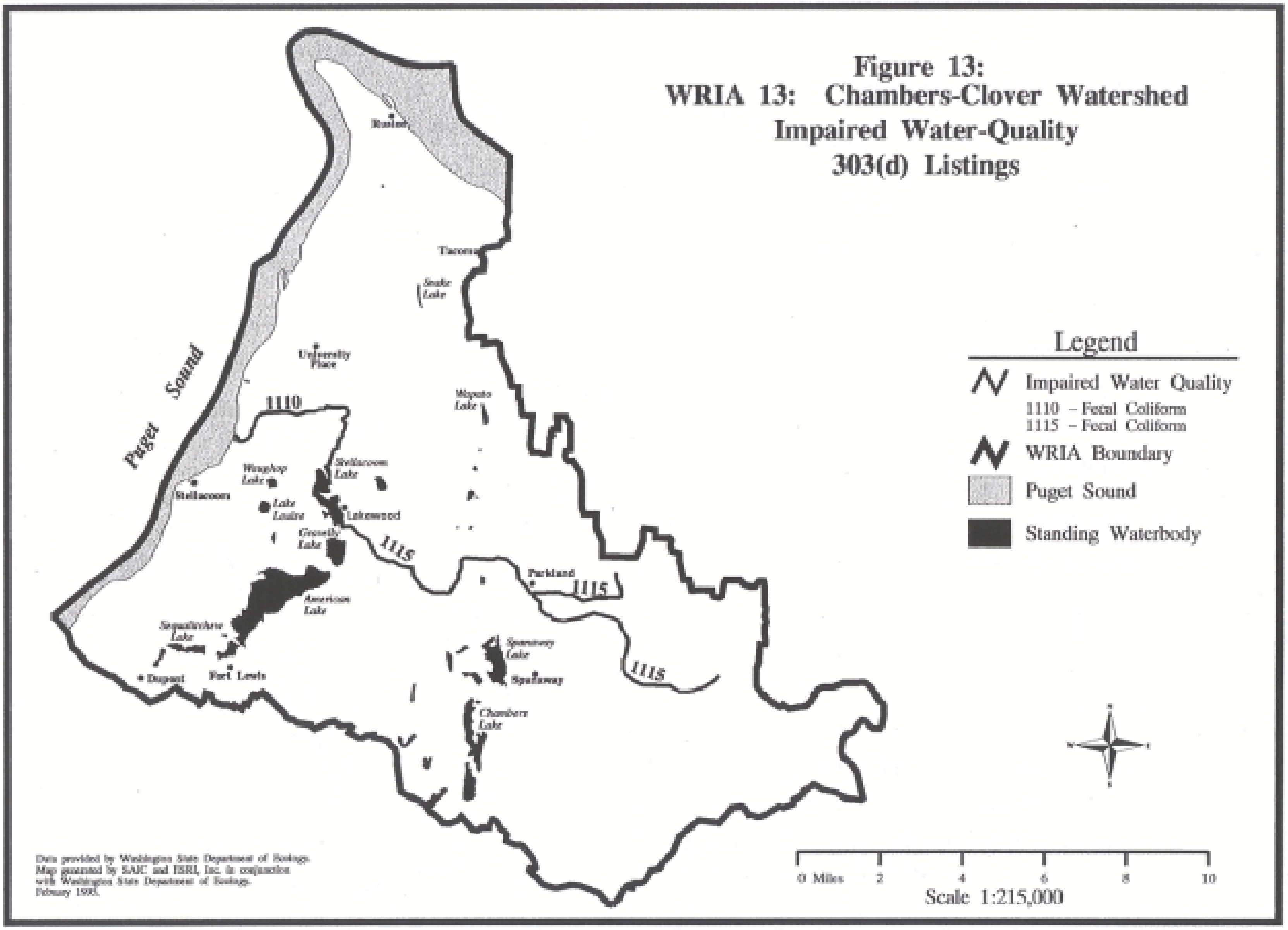


FIGURE 12

Figure 13:
WRIA 13: Chambers-Clover Watershed
Impaired Water-Quality
303(d) Listings



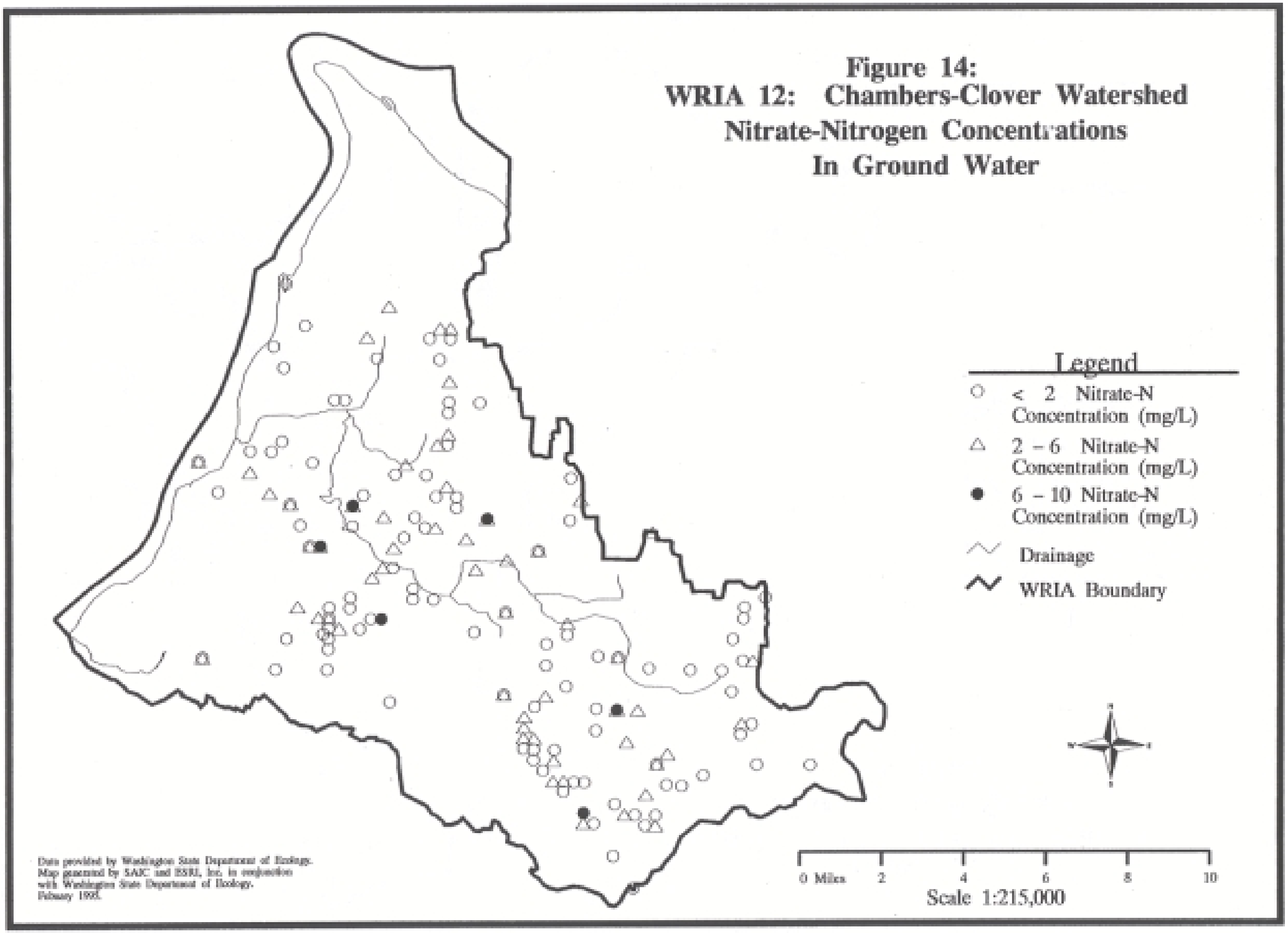


Figure 14:
WRIA 12: Chambers-Clover Watershed
Nitrate-Nitrogen Concentrations
In Ground Water

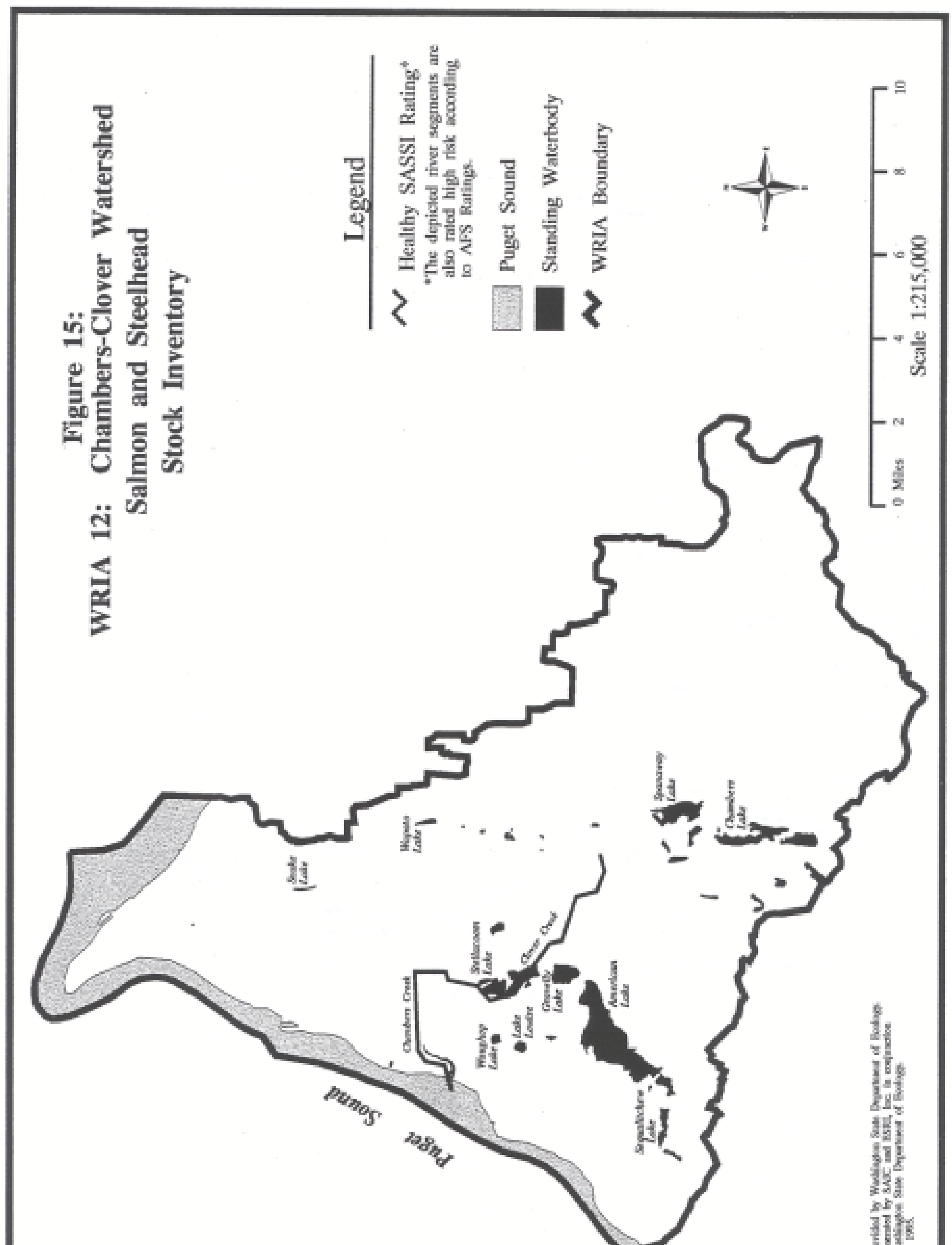


Figure 15:
WRIA 12: Chambers-Clover Watershed Salmon and Steelhead Stock Inventory

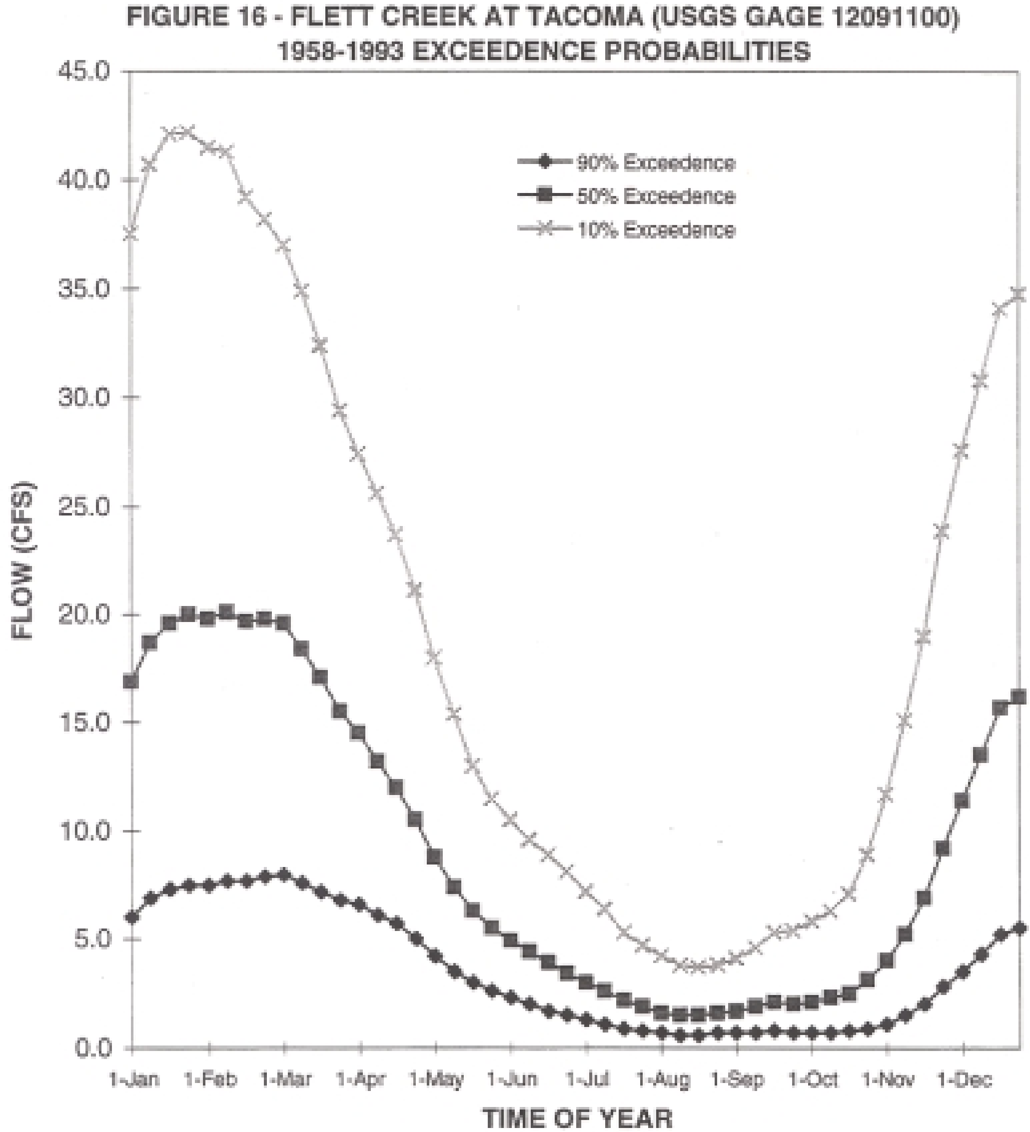


FIGURE 16 - FLETT CREEK AT TACOMA (USGS GAGE 12091100)
1958-1993 EXCEEDENCE PROBABILITIES
90% Exceedence
50% Exceedence
10% Exceedence
FLOW (CFS)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
TIME OF YEAR

FIGURE 17 - LEACH CREEK AT HOLDING POND (USGS GAGE 12091180) 1966-1990 EXCEEDENCE PROBABILITIES

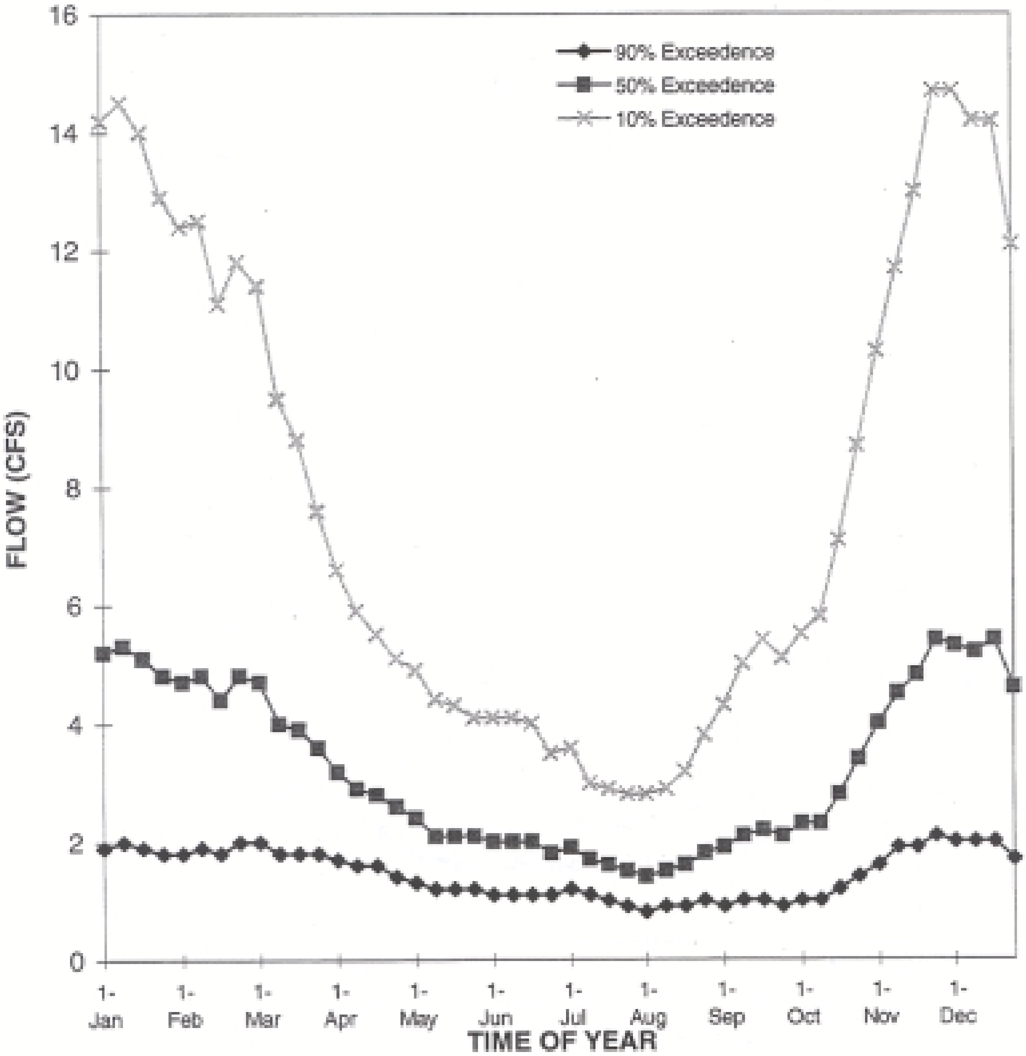


FIGURE 18 - LEACH CREEK NEAR FIRCREST (USGS GAGE 12091200) 1956-1993 EXCEEDENCE PROBABILITIES

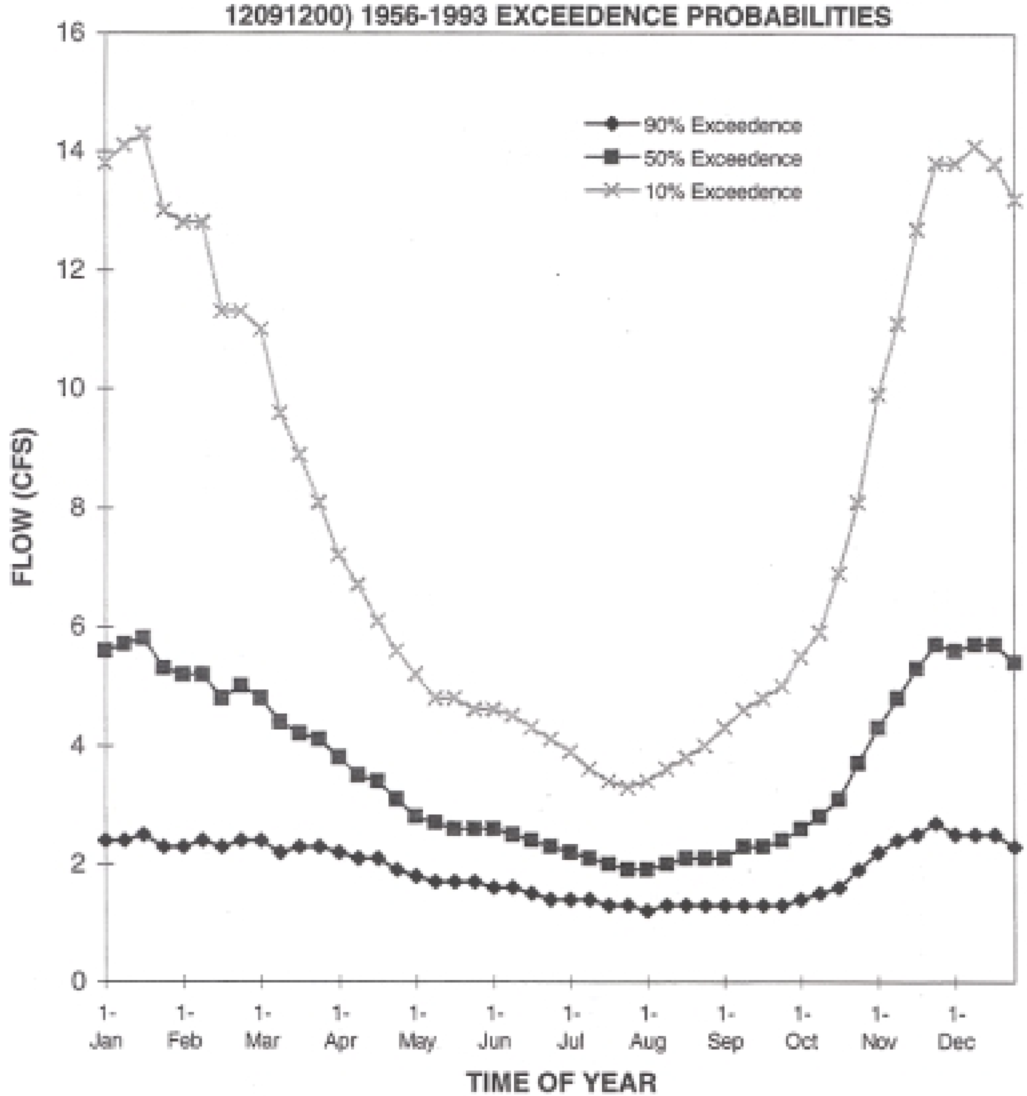


FIGURE 19 - LEACH CREEK NEAR STEILACOOM (USGS GAGE 12091300) 1956-1993 EXCEEDENCE PROBABILITIES

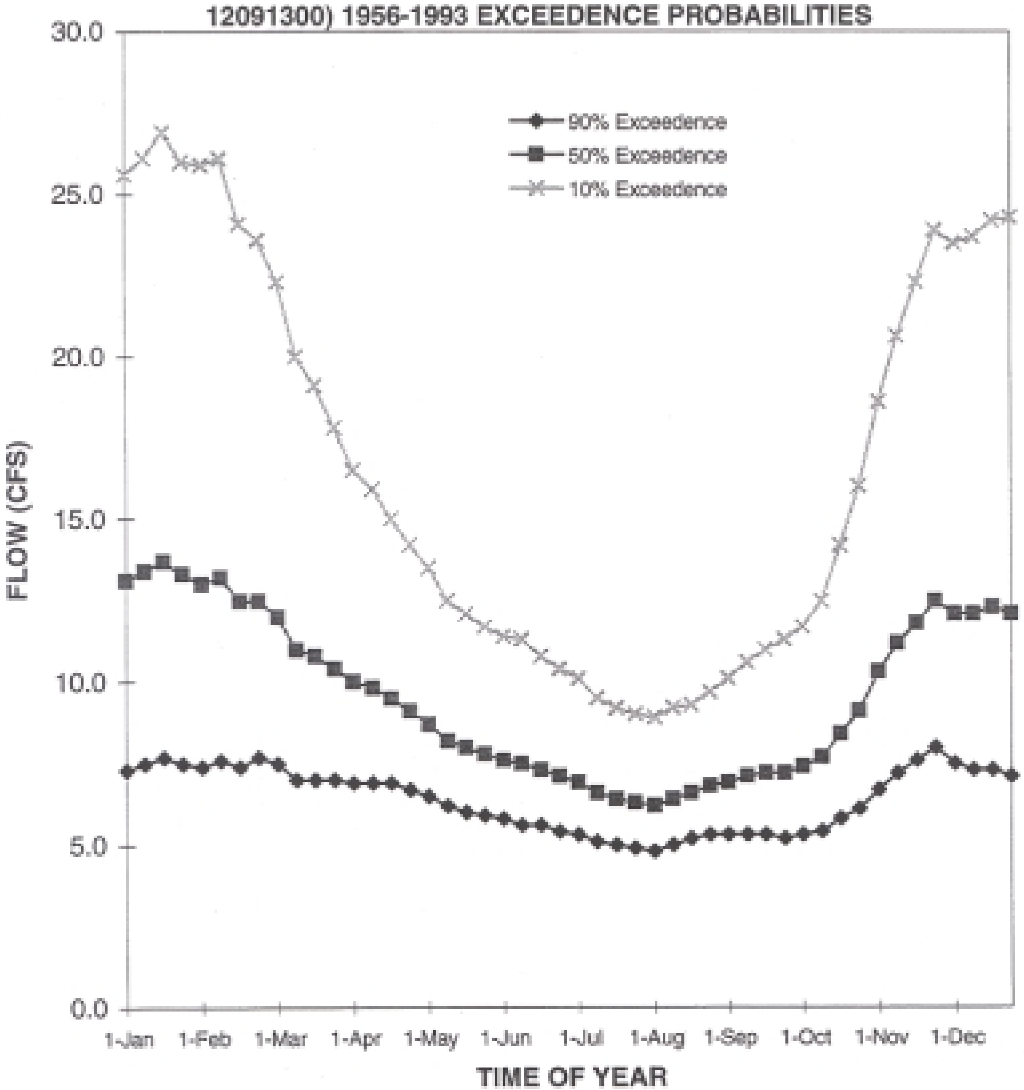


FIGURE 20 - FLETT CREEK AT TACOMA (USGS GAGE 12091100) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE

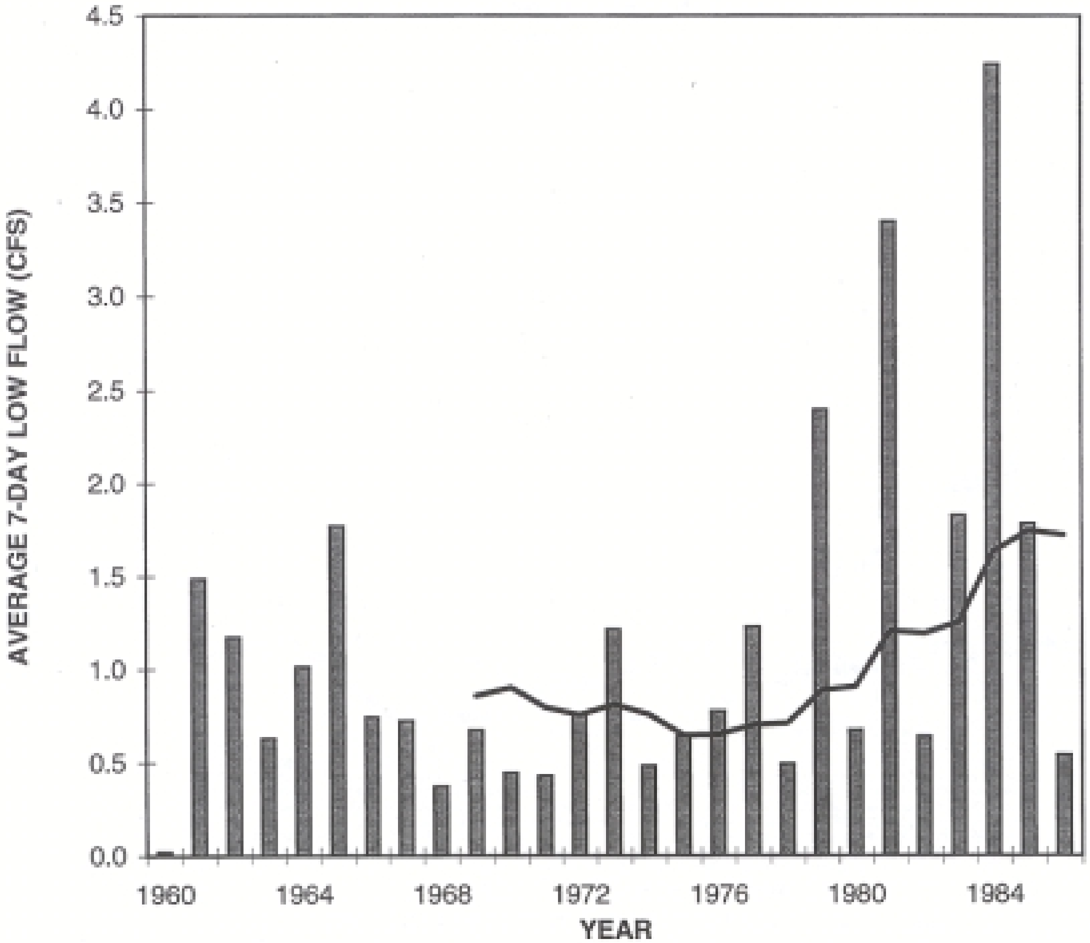


FIGURE 21 - LEACH CREEK AT HOLDING POND (USGS GAGE 12091180) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE

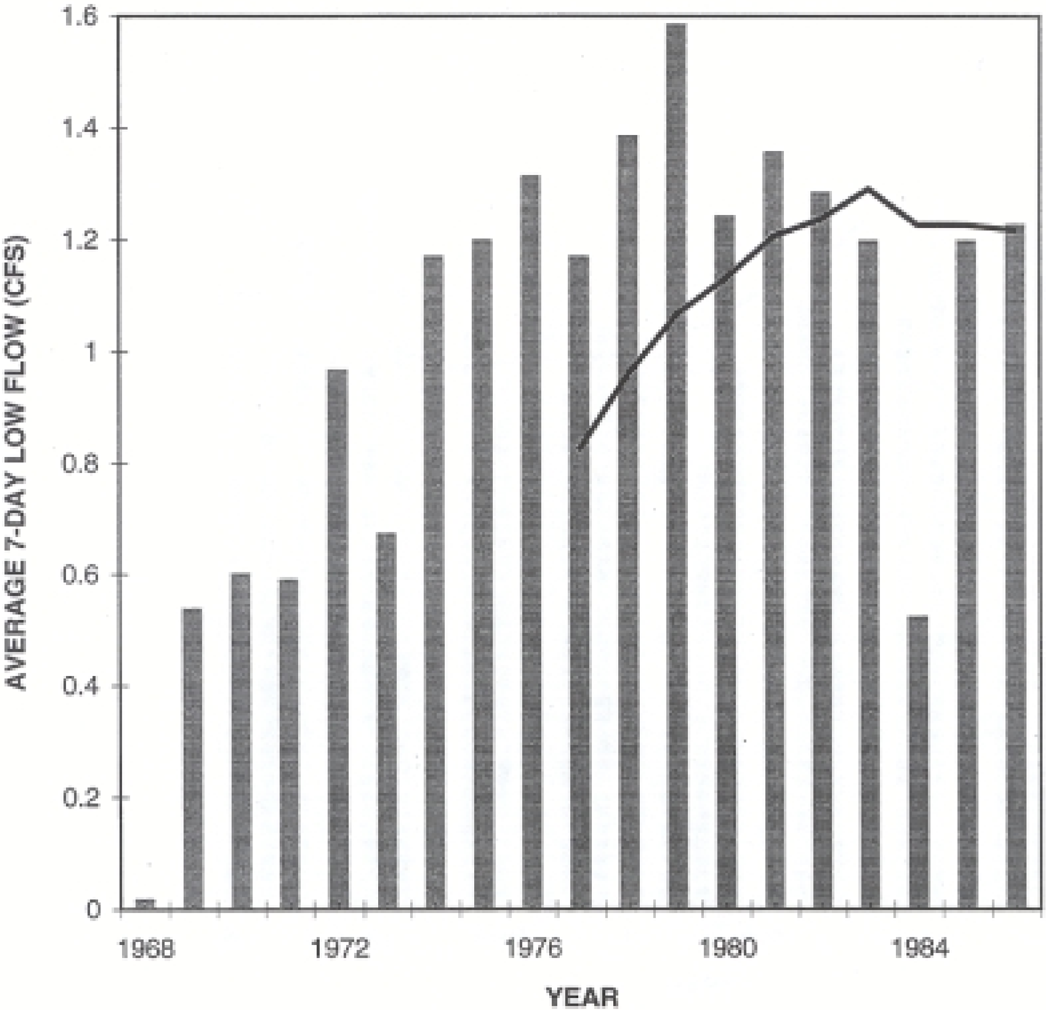


FIGURE 22 - LEACH CREEK NEAR STEILACOOM (USGS GAGE 12091300) 7-DAY LOW FLOWS WITH 10-DAY MOVING AVERAGE

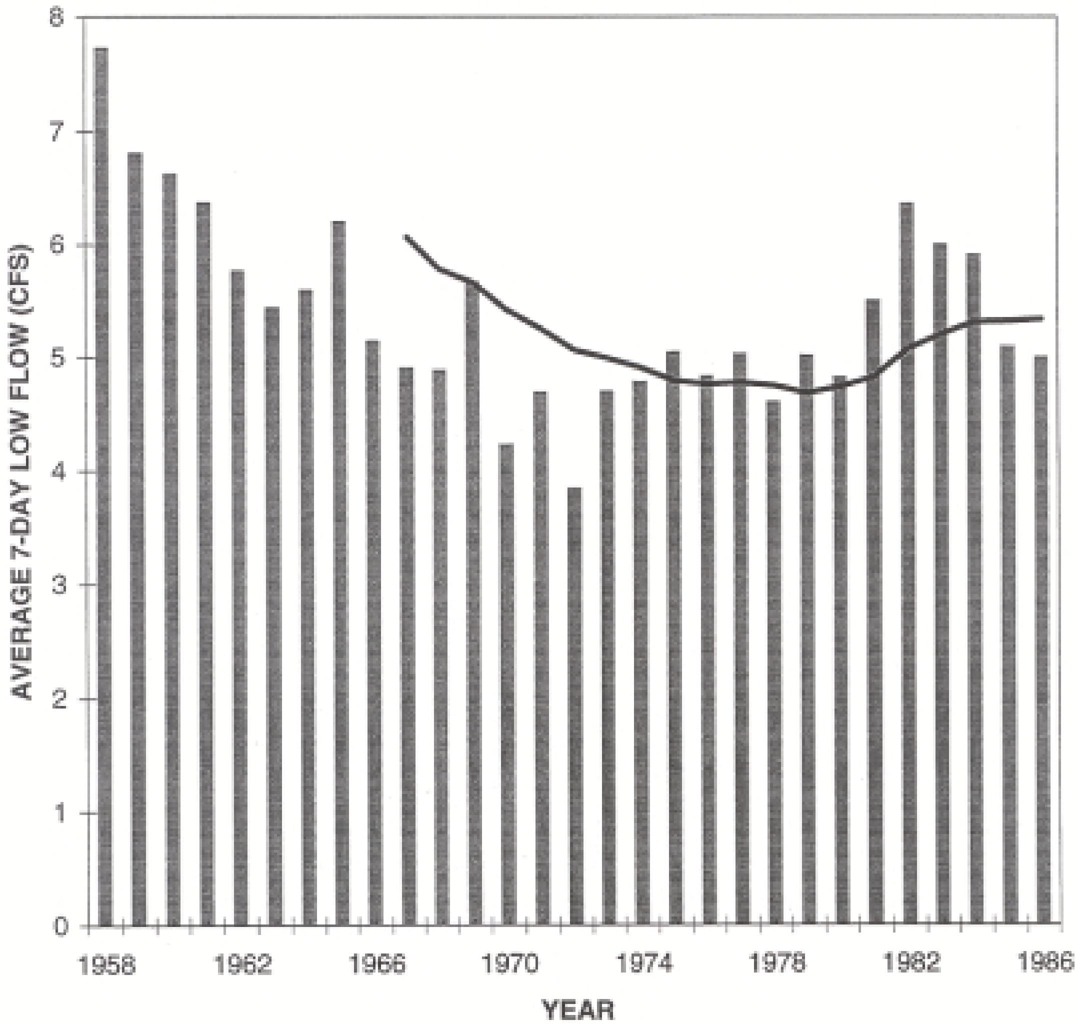


FIGURE 23 - LEACH CREEK NEAR FIRCREST (USGS GAGE 12091200) 7-DAY LOW FLOWS WITH 10-YEAR MOVING AVERAGE