DRAFT

AMENDMENTS TO:

INITIAL WATERSHED ASSESSMENT WATER RESOURCES INVENTORY AREA 9 GREEN-DUWAMISH WATERSHED

by:

Washington Department of Ecology
Science Applications International Corporation
Shapiro and Associates
Taylor Associates
Environmental Systems Research Institute

January 20, 1995

These amendments replace the text of Department of Ecology, Water Resources Program OFTR 95-01, as well as Figures 3, 4, 15, 16, 17, 18, 24 and 25. Figures 26 and 27 from the original report have been removed in the revised version.

Amendments prepared by:

Tom Culhane and Jerry Liszak

Washington Department of Ecology Northwest Regional Office
Water Resources Program
3190 160th Avenue SE
Bellevue, Washington 98008

November 22, 1995

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Initial Watershed Assessments

The Washington Department of Ecology (Ecology) Water Resources Program is charged with managing the state's water resources to ensure that they are protected and used for the greatest public benefit. One of the components of this water management is permitting for the use of surface and ground water. Historically, the Program has evaluated most water right applications on a case-by-case basis and, increasingly, this has become an inefficient way to deal with the large numbers of applications received. Furthermore, individual permit review usually required relying on the results of relatively short duration pump tests in order to make long term resource decisions. This approach frequently has resulted in ignoring the cumulative impacts that many individual pumping wells may have on surface water flows. These initial watershed assessments are part of an effort to evolve the permitting of water rights to consider the environmental health of the entire watershed system.

These assessments focussed on assembling and reviewing existing information; no new data were collected. The information assembled was chosen to broadly indicate the overall condition of water resources within the watershed, including water quantity, hydrogeology, water demand, and water quality, as well as the relative health of aquatic ecosystems.

The Green-Duwamish Watershed (WRIA)

Washington is divided into 62 Water Resource Inventory Areas (WRIAs) delineating the major drainage networks that flow into the Columbia River, the Pacific Ocean, and Puget Sound (Figure 1). WRIA 9, in southern King County, drains a section of the west slope of the Cascades into Puget Sound at Seattle. This area includes the Green-Duwamish watershed as well as a small portion of additional coastal land south of the mouth of the Duwamish River. Consequently, although the entire WRIA may not technically constitute a watershed, it will be referred to as such in this report.

WATERSHED DESCRIPTION

Area Description

The Green River begins in the Cascade Mountains near Stampede Pass and flows west through the Snoqualmie National Forest. Thirty miles downstream from its source, the river encounters Howard A. Hansen (Hansen) Dam at river mile (RM) 64.5 and then the City of Tacoma Water Diversion Dam at RM 61. The river continues to the town of Kanasket and the start of the Green River Gorge. Two major tributaries, Newaukum Creek (at RM 40.7) and Big Soos (Soos) Creek (at RM 33.7) join the Green River upstream from Auburn. The river then turns northward at Auburn and flows through Kent and Tukwila, becoming the Duwamish River at RM 11.

The Green River was radically altered between 1900 and 1916. Once a tributary of the White River (which was a tributary of the Duwamish River), the Green River was diverted to flow directly into Puget Sound. The lowering of Lake Washington and a major flood in 1906 were the primary causes of this diversion. The river changes names at the former confluence of the Green and Black Rivers, even though regrading of the surface has obliterated the channel of the Black. The lower part of the river retained the name Duwamish River. WRIA 9 encompasses approximately 700 square miles, including the 72 square mile Soos Creek and the 27 square mile Newaukum Creek subbasins (Figure 2).

Historically, the U.S. Geological Survey has operated a total of 24 stream gaging stations in WRIA 9, of which seven are located on the main stem of the Green River. Two of the most significant of these are located at Palmer (USGS Station No. 12106500) and at Auburn (USGS Station No. 12113000), as these are the two points within the WRIA where Ecology has established minimum instream flows (Chapter 173-509 Washington Administrative Code (WAC)). The upper half of the watershed is presently administratively closed to future water rights and only two stations were deemed necessary to provide adequate managerial control over future diversions.

The release schedule for flows from the dam prescribe flows to be monitored at the Palmer gage, located 1.2 miles downstream from the City of Tacoma diversion. Flow levels for the lower Green River reach measured at Auburn are critical for low flow dilution and flood stage flow releases from the Hansen Dam. The Auburn gage measures flow as the river enters the most densely populated and heavily industrialized part of the WRIA, from the 408 square mile upper Green River watershed which includes the Newaukum and Soos Creek subbasins.

Land Cover and Land Use

The King County Watershed Ranking Final Report (King County 1989), divided the Green River Watershed into Upper, Middle, and Lower Green River Watersheds, and the Soos Creek Watershed. The Upper Green River Watershed, the area above the Hansen Dam, is managed by the City of Tacoma and the U.S. Forest Service to protect the quality of the water supply for the City of Tacoma. The area is closed to the public, however there is extensive logging activity.

The Middle Green River Watershed includes Coal Creek, Deep Creek, Middle Green River, and Newaukum Creek and is sparsely populated compared with the western portion of the WRIA. Coal Creek, Deep Creek, and Newaukum Creek's headwaters are in the Cascade foothills where the primary land use is managed forest. In the Lower Newaukum Creek subbasin, dairy farming is the most prevalent land use and is likely to continue for the foreseeable future. Other land uses include beef cattle raising, crop farming, racehorse breeding and training, and single family residences. The City of Enumclaw is partially located in the upper reaches of this watershed.

The Soos Creek Watershed includes Soos Creek with its main tributaries Little Soos Creek, Soosette Creek, Covington Creek and Jenkins Creek. The southern and eastern portions of the watershed are mostly rural. The north and west portions of this area have been designated for urban-density development by the 1985 King County Comprehensive Plan (King County 1985). This area is experiencing some of the fastest residential and commercial development in King County.

The Soos Creek Basin Plan (King County, 1990) predicts that current periodic flooding, erosion and sedimentation problems will increase in frequency and severity in the future. The plan states that, "Even with many examples of excellent habitat, the habitat is starting to exhibit the system wide effects of rapid development as well as localized habitat problems. These problems include livestock-related bank trampling, wetland filling, channelization loss of forested stream corridors, fish passage barriers, dewatering, and damage from high flows and sediment movement. These habitat problems are expected to worsen in the future as both human intrusion into previously undisturbed stream corridors and stormwater runoff increase." The plan further states that subcatchments that change from forested land cover to urban uses on till soils are predicted to have the greatest increases in peak flows, and that impervious surfaces are the most influential hydrologic parameter in determining how storm flows will increase from existing to future conditions.

The Lower Green River Watershed contains the wide flood plain of the lower Green and Duwamish Rivers and includes the cities of Renton, Tukwilla, Kent, and Auburn. Land use has shifted almost entirely from rural farming to commercial and industrial during the last 25 years. Consequently, many of the development related problems recently or soon to be experienced within the Soos Creek Watershed have already occurred in the Lower Green River Watershed including periodic flooding, erosion, and sedimentation problems, as well as localized habitat degradation.

Climate and Precipitation Trends

The climate is typical of mid-latitude, Pacific marine areas, with prevailing winds moving moist air inland from the Pacific Ocean, and moderating temperatures in both winter and summer. Rains come primarily in the winter, and the summers tend to be dry. The maritime air cools as it pushes up against the Cascade Range, rising to the condensation point, and forming rain or snow. In the Cascade Range highlands, the precipitation is greater and the temperatures are lower than in the Puget Sound lowlands.

Precipitation provides the input that supplies stream runoff and ground water recharge. Variation in precipitation must be taken into account when addressing trends in streamflow and ground water levels. Average annual precipitation ranges from about 38 inches at SeaTac (elevation 386 feet) to over 91 inches at Stampede Pass (elevation 3,700 feet) (Figure 3). Although the trend is generally toward increasing precipitation moving from west to east within the WRIA, a localized area of lower precipitation does exist starting just east of Palmer and following the Green River valley above the Hansen Dam.

Long-term precipitation data is available for gages located at SeaTac and Palmer within the WRIA, and at Landsburg and Mud Mountain Dam just outside the WRIA. Data primarily from Landsburg was chosen for comparison purposes for the Soos Creek subbasin because it lies near the northern border of the watershed and has similar precipitation characteristics (Figure 3). Data from the Mud Mountain Dam and Palmer precipitation gages were chosen for comparison purposes with Newaukum Creek because the subbasin lies in between these two gages.

Temporal variation and trends in precipitation occur on seasonal, short-term, and long-term scales. On a seasonal basis, approximately fifty percent of the annual precipitation falls in the four-month period October through January, and about seventy-five percent in the six months between October through March. Departures from these seasonal statistics, such as "dry winters" or "wet summers", do occur.

Annual precipitation data is presented in Figures 4a, 4b, 4c and 4d, which present deviation from the mean plots for SeaTac from 1950 to 1992, Palmer from 1932 to 1992, Landsburg from 1931 to 1991, and Mud Mountain Dam from 1940 to 1992, respectively; corresponding to mean annual precipitation totals of 38.2, 91.2, 56.1, and 55.2 inches per year, respectively. The 5-year moving average of the deviation from the mean is also presented in these plots to help identify long-term cycles in weather patterns.

Variations which occur over periods of several years are demonstrated in Figures 4a, 4b, 4c and 4d. These short-term departures from the mean generally do not follow discernable patterns, but recent precipitation has been generally below average since 1977 at all but the Mud Mountain Dam gage. Since 1977, the lower watershed (SeaTac) has experienced about 3.5 inches per year less precipitation than the 1950 to 1992 average for that gage. Precipitation patterns in the upper watershed are less clear, as the Palmer gage data suggests generally lower than average precipitation since 1977 (approximately 7.3 inches), while the data from Mud Mountain Dam gage suggests generally above average precipitation since 1971 (approximately 3.1 inches).

HYDROGEOLOGY

Hydrology

Ultimately, all of the surface and ground water in the Green-Duwamish Watershed comes from precipitation as rain or snowmelt. A portion of the precipitation evaporates back to the atmosphere or is consumed by plants (evapotranspiration). Some precipitation occurs as snow and accumulates at higher elevations to form winter snowpack. Each spring and summer, the meltwater from this snow combines with rainfall to provide surface runoff to the Green River system. However, a significant portion of the snowmelt and rainfall also infiltrates downward into the soil to become ground water. Eventually, most of this ground water discharges into the river and its tributaries, thereby supplying river flow during late summer through the winter. Wetlands may function either as a source of ground water recharge or as a means of ground water discharge, with some performing both functions at different time of the year. The hydrologic cycle is illustrated schematically in Figure 5.

In addition to the sources mentioned above, some ground water recharge within the study area is due to water which seeps from Lake Youngs. The lake is currently used as a reservoir storing Cedar River water (WRIA 8), thus the seepage constitutes a source of water from outside of the Green-Duwamish Watershed.

Not all of the natural water supply is available for use by humans because some water must be left in the ground to keep springs and streams flowing. Washington statute (Chapter 90.54 Revised Code of Washington (RCW)) requires that some water be left in a stream after meeting permitted demands. Also, water in an aquifer must be kept at the level of a "reasonable, feasible pumping lift" (Chapter 173-150 WAC). If the streamflow remaining after human use is greater than (or equal to) instream needs (such as navigation, recreation, fisheries resources, and aquatic and riparian ecosystems), then additional water can be appropriated without impairing senior and instream rights.

Consumptive water use by humans reduces the natural water supply, usually by increasing evapotranspiration losses and by exporting water to other watersheds. The remainder of the water pumped from wells or diverted from streams may return to the fresh water supply, though often in a different part of the watershed, or it may be lost directly to Puget Sound following wastewater treatment.

Geology and Ground Water

Volcanic and sedimentary rocks are exposed throughout much of the eastern half of the study area. Most of these rocks have too few fractures to yield more than 50 gallons per minute (gpm) to wells, with most yielding much less. The remainder of the study area is characterized mainly by a thick sequence of unconsolidated Quaternary-aged glacial and alluvial deposits that form aquifer systems which yield economical quantities of ground water. Table 1 summarizes the stratigraphy of these deposits.

Table 1

Nomenclature and Regional Correlation of Stratigraphy
South King County

Unit Symbol	Stratigraphic Sequence	Suggested Regional Correlation	Geologic Character
Qal	Recent Alluvium	Quaternary Alluvium	Principally fine grained sand, silt, clay, and peat. Clean sand and gravel deposits locally occur in vicinity of the White River near Auburn and the Cedar River upstream of Renton.
Qom	Osceola Mudflow	Osceola Mudflow	Unsorted mixture of andesite rock fragments and wood in a clayey sand matrix. Large boulders near the base. Occurs primarily in the southern portion of the study area.
Qvr	Vashon Recessional Outwash	Vashon Recessional Outwash	Well-sorted sand and gravel deposits. Includes outwash plain, valley train, delta, and ice-contact kame and kame terrace deposits. Qvrl is a fine grained subset where material was locally deposited in recessional lakes.
Qvt	Vashon Till	Vashon Till	Compact mixture of gravel and occasional boulder in a gray clayey, silty sand matrix. Locally includes some cleaner sand and gravel lenses. Occurs typically as an undulating carpet at the ground surface in south King County.
Qva	Vashon Advance Outwash	Vashon Advance Outwash, Colvos Sand, Esperance Sand	Predominantly sand and gravelly sand in Des Moines Upland. Usually has a higher percentage of gravel in most other portions of the study area. May locally include very fine sand and silt.
Qvl	Lawton Clay	Lawton Clay	Lacustrine deposits primarily composed of clay, silt, and fine sand deposited in the Vashon pro-glacial lake. More widespread in north King County than in the study area.
Qvu	Undifferentiated Vashon Deposits	Undifferentiated Vashon Deposits	An assortment of deposits including till, outwash, and lacustrine deposits that were deposited during the Vashon Stade of the Frazer Glaciation.
Qf(1)	First Fine Grained Unit	Olympia Interglacial	Principally fine-grained fluvial and lacustrine deposits consisting of sand, silt, clay, and peat. May locally contain some sand and gravel deposits.

Table 1 (continued)

Unit Symbol	Stratigraphic Sequence	Suggested Regional Correlation	Geologic Character
Qc(2)	Second Coarse Grained Unit	Possession Drift, Double Bluff Drift	Principally granular soils and till with a relatively fresh appearance. This unit is difficult to distinguish from Vashon Till in outcrop. Found only in the Covington upland where it is an important groundwater aquifer. Tentatively correlated with the Possession Drift suggesting that the Double Bluff advance did not reach as far south.
Qf(2)	Second Fine Grained Unit	Whidbey Formation, Kitsap Formation	Principally fine grained fluvial and lacustrine deposits consisting of sand, silt, clay, and peat. May locally contain some sand and gravel deposits.
Qc(3)	Third Coarse Grained Unit	Salmon Springs Drift	Typically recognized by its oxidized character both in outcrop and in well logs (rusty Gravel). Occurs ubiquitously in all upland subareas in this study. An important source of groundwater in south King County.
Qf(3)	Third Fine Grained Unit	Puyallup Formation	First recognized by Willis which he labeled the Puyallup Sand. Later upgraded to Formation status by Crandell. Composed chiefly of fine to medium sand derived from Mt. Rainier. The andesitic source gives the Puyallup Fm. its characteristic purple tinge. Usually is found around sea level in south King County/
Qc(4)	Fourth Coarse Grained Unit	Uncertain	Coarse grained deposits
Qf(4)	Fourth Fine Grained Unit	Uncertain	Fine grained deposits
Qf(u)	Older Undifferentiated Fine Grained Unit	Uncertain	Fine grained deposits
Qc(u)	Older Undifferentiated Coarse Grained Unit	Uncertain	Coarse grained deposits
Qu	Undifferentiated Deposits	Uncertain	Highly variable in character
Tbr	Tertiary Bedrock	Puget Group	Principally arkosic, micaceous sandstone and interbedded shale and coal. Locally includes thick sequence of volcanic sandstone and conglomerate, tuffaceous siltstone, tuffbreccia, and lava flows.

Source: South King County Ground Water Management Plan (SKCGWAC 1989).

The geology of the western portion of the study area was discussed in the 1989 South King County Ground Water Management Plan, Background Data Collection and Management Issues, Volumes I & II (SKCGWAC, 1989). This report divides the Lower Green-Duwamish Watershed into four sub-areas and these areas include the Covington Upland Des Moines Upland, Federal Way Upland, and Green River Valley.

The Covington Upland, which is drained by Soos Creek, is bounded by the Green River to the west and south, and the Cedar River to the north. It can be thought of as a former bedrock foothill of the Cascade Range mantled by a wedge of Pleistocene glacial deposits. The thickness of these sediments apparently ranges from a feather edge in the extreme southeast to 1,200 feet in the western portion of the upland, with information generally only available for the upper 100 to 500 feet. This westerly thickening wedge is complicated by an east-west trending, buried sandstone ridge along the northern edge of the upland. The ridge is important because it limits the discharge of deep ground water from the Upland to the Cedar River.

The hydrogeology of the western half of the study area is complicated due to the variable nature of the aquifers and aquitards. According to the background data for the GWMP (SKCGWAC, 1989), the principal aquifers of the Covington Upland include Qvr, Qva, Qc(2), Qc(3), and Qc(4) (shallowest to deepest). In many portions of the upland, distinguishing between the top three or four aquifers is very difficult. Consequently, for the purposes of developing the water level contour map, Qvr, Qva, and Qc(2) water level data were combined. The GWMP map indicates that the highest ground water elevations within the Covington Plateau occur within the Black Diamond and Lake Youngs areas. The recharge mound within the Lake Youngs area appears to be largely related to seepage losses from the reservoir.

The Des Moines and Federal Way Uplands occupy the upland drift plain that lies between the Green/Duwamish Rivers to the east, and the Puget Sound to the west. The Des Moines Upland occupies the north half of the drift plain, while the Federal Way Upland lies to the south. The subsurface geology in this area is dominated by glacio-fluvial sediments. Vashon glacial deposits typically extend from land surface to as deep as 150 feet, while correlations between pre-Vashon stratigraphic units are not well understood. The GWMP identifies the principle aquifers in this area as Qvr, Qva, Qc(3), Qc(4), and Qc(u) (Table 1). These aquifers vary in thickness and permeability, with the Qva and Qc(3) being the most productive. A ground water divide runs north-south through the uplands; this divide is generally coincident with the surface water divide in this area.

The Green River Valley separates the Covington Upland from the Des Moines and Federal Way Uplands. The valley floodplain is quite flat, with a gentle slope to the north. Aquifer materials are composed of recent alluvium (Qal) and Vashon Recessional Outwash (Qvr). The Vashon outwash deposits are thickest (over 300 feet) in the east-central part of the Auburn area and comprise a major source of ground water.

Ground Water-Surface Water Interaction

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 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, pumping may induce additional recharge from surface water which may be drawn directly into the well. Consumptive water use (that portion not returned to the aquifer) eventually diminishes streamflow, both seasonally and as average annual recharge.

The Green River and its 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 will discharge to the Green River system when the head is higher than the surface water level. This occurs throughout the study area, but is especially true in the upper reaches of the watershed. Conversely, the Green River and its tributaries lose water to aquifers when the stream level is higher than the water table. Depending on the direction of the hydraulic gradient, well pumping can either reduce the amount of water discharging to the river or increase the quantity of water leaking out of the river.

The GWMP (SKCGWAC, 1989) includes ten generalized cross sections for the Soos Creek subbasin. These suggest that Qc(3) intersects Qc(2) and even Soos Creek itself, in places, which results in hydraulic continuity between Qc(3) and the overlying shallower system. Furthermore, the cross sections indicate that Qc(3) and Qc(4) are both under artesian head and that the intervening materials are silty clay aquitards. Consequently, pumping even from these two deeper, semi-confined aquifers will increase the vertical hydraulic gradient between Qc(3) and Qc(4) and the overlying aquifers and increase ground water flow from shallow to deeper aquifers. However, the timing and magnitude of such effects are poorly understood. To what degree heads are changed by pumping and what volumetric transfer of water can be expected during various times would require complex modeling analysis which was beyond the scope of this initial analysis.

Woodward, et al. (1995) includes the results of a recharge model calibrated to precipitation and runoff data for the Soos Creek subbasin for data collected from 1967 through 1987. The water-balance estimates included 49.5 inches per year of precipitation, 19.7 inches per year of evapotranspiration, 9.2 inches per year of runoff, and 21.6 inches per year of recharge. The results of the analysis suggest that the majority of upland recharge is discharged to springs or returns to Soos Creek via shallow baseflow. The average amount of recharge reaching deeper aquifer systems was estimated to be 2 inches, or about 10 percent of total recharge to the Covington Upland. The study also concluded that ground water from the deeper aquifer system discharges to regional drainage features, such as the Cedar and Green Rivers. Such discharge is reasonable in light of the numerous springs and seeps in the Covington Upland bluff along the Green and Cedar Rivers.

The USGS is also currently completing a report on modeling the effects of ground water withdrawals on surface water bodies in small basins typical of the Puget Sound Lowland

(Morgan and Jones, in press). The initial hydrogeology upon which this digital model was based is that of the Soos Creek subbasin, although this was simplified and changed as the model was developed. This generic model provides useful insights into surface water interactions with ground water within the Puget Sound lowland, and specifically to Soos Creek subbasin. Preliminary reports on the study suggest that pumping even from the deepest aquifers will reduce flows in surface water bodies within the greater watershed, such as the Green River.

Crisp Creek is surrounded on three sides by the Soos Creek subbasin and has similar hydrogeologic characteristics. It is dominated by ground water discharge (baseflow) which enters the creek as springs about one half mile upstream of the Keta Creek Hatchery, with stormwater contributing a minor amount to the annual hydrograph. Inter-basin transfers of ground water occur with the Soos Creek subbasin in the upper reaches of Crisp Creek.

The Newaukum Creek basin and vicinity are part of the Osceola Mudflow Plain. Cross sections constructed by Luzier (1969) indicate that this area's hydrogeology is similar to the Covington Upland, except that large portions are covered by mudflow deposits up to 75 feet thick. Luzier's mapping indicates that much of Newaukum Creek cuts through the mudflow, thus establishing continuity between the creek and many of the underlying aquifers.

In the Des Moines and Federal Way Uplands, ground water discharges either to the Puget Sound (west of the divide) or to the Green/Duwamish Rivers (to the east). Several smaller streams (Miller, Des Moines, and Hylebos Creeks) appear to intercept the uppermost aquifer (Qva). Water levels in the Qva aquifer surrounding these creeks indicate that the aquifer is currently discharging to surface water in this area. Increased production from this or underlying aquifers could reverse this situation.

Ground Water Status

Because precipitation varies greatly with the seasons, 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.

The three largest ground water supply areas in the Covington Upland are the Covington Water District Lake Sawyer well field, the King County Water District No. 111 (KCWD 111) well field, and the Kent spring source. Additionally, the City of Kent's Clark Springs source, located on the hydrologic divide between WRIA 8 and WRIA 9 utilizes water which is tributary to both the Cedar and Green Rivers. These springs emanate from an outwash channel aquifer which contributes water to Rock Creek (Noble, 1979).

The Lake Sawyer well field taps the Qc(2) aquifer, which occurs throughout much of the Covington Upland and is often difficult to distinguish from the Qva aquifer. The KCWD 111 wells draw their water from the Qva and Qc(2) aquifers, which are referred to as intermediate aquifers in the GWMP. The Qva aquifer occurs primarily in the western portion of the upland and serves many domestic wells. The shallow Qvr aquifer provides the source for the springs used by the Kent water system. The GWMP noted a decline in one of these springs, which indicates that some ground water declines are occurring within the area. Approximately 1 to 2 feet of water level decline may have occurred within the last five years within the Qva and Qvr aquifers used by the City of Kent (written communication from Hart Crowser, 1995). These aquifers are known to discharge into an un-named creek which is a tributary of Jenkins Creek. They also discharge via the City of Kent's Clark Springs into Rock Creek, a tributary of the Cedar River in the adjacent watershed to the north. The City of Kent also has wells within the deeper Qc(3) and Qc(4) aquifers within the Kent area, but no water level data are available for these wells.

The GWMP states: "The data suggest there are no significant impacts associated with existing levels of development within these (Lake Sawyer well field and KCWD 111) areas." However, the data indicated for the Lake Sawyer well field included only records from 1977 through 1988. The water levels appear stable, however most of the water level data used was collected under pumping conditions. This information is questionable, as the period of record is relatively short.

The GWMP data for KCWD 111 is from Well 3, which taps the Qc(2) aquifer and is representative of wells 1 through 6. The GWMP states that the water levels initially declined about 20 to 30 feet, then stabilized to follow climatic trends. This reported stabilization at a much lower level indicates dewatering of the aquifer, which may significantly alter the local ground water gradient. This would lead to a decrease in ground water discharge to local streams such as Soos Creek. Unfortunately, the period of record referred to is only 3½ years (6/84 to 12/87); thus it is insufficient to make sound conclusions about water level trends.

The GWMP contains considerable information on the remainder of WRIA 9. It states that significant water level declines were identified in the Des Moines area and the Federal Way Upland. In the Des Moines area, the Qc(4) aquifer shows a long-term decline of 1 foot per year 1966 to 1981 in well T22N/R04E-08A01. Unfortunately, the well was destroyed, and the data collection ceased. This trend does not appear to be correlated with precipitation or ground water withdrawal. It appears to be related to a reduction in recharge to the area as a result of changing land use patterns and urbanization. In the Federal Way Upland, the Qva aquifer shows about 5 feet of water level decline during the early 1970's as a result of ground water development. Seven additional feet of water level decline has occurred in recent years due to an increase in ground water withdrawal. Within the Qc(3) aquifer, about 50 feet of decline has occurred since 1983 which was directly correlated with ground water withdrawal from the aquifer. The data is from 1981 through 1988 from well T21N/R4E-07R01 which shows trends proportional to every other well in the aquifer.

WATER DEMAND

History of the City of Tacoma Diversion and the Hansen Dam

Surface water is diverted from the upper Green River basin for municipal supply by the City of Tacoma, which built a water diversion dam at RM 61 on the Green River in 1911. In 1913, construction of a pipeline was completed with a capacity of 65 cubic feet per second (cfs; 1 cubic foot is approximately 7.5 gallons) and, in 1948, a second pipeline was completed adjacent to the first, for a total diversion of 112 cfs. The City of Tacoma filed a water right claim in 1971 for a maximum of 400 cfs. In 1985, Ecology granted a water right permit to the City of Tacoma for an additional 100 cfs diversion (priority date 1933), subject to the minimum instream flows for the Green River as set forth in Chapter 173-509 WAC. The City of Tacoma also operates a 72 million gallon per day (mgd) (equivalent to 111 cfs) capacity well field in the North Fork Green River Valley, above the Hansen Dam. This ground water replaces a portion of the City of Tacoma's surface water supply during periods of high river turbidity.

The U.S. Army Corps of Engineers (COE) began filling the Hansen Reservoir on December 5, 1961. The dam was authorized by Congress for flood control (prevention of flows over 12,000 cfs at Auburn) and conservation storage to augment low flows for fisheries enhancement (minimum flows of 110 cfs below the dam). 50% exceedence probability plots conducted during our study (not presented in this report), indicate decreased flows at the Palmer gage (below Tacoma's diversion) March through mid-September, when comparing post-dam (1962 to 1993) to pre-dam (1932 to 1958) flows.

Although the COE releases 110 cfs plus additional flows up to the City of Tacoma's 112 cfs diversion capacity during the dry season, in dry years this can be less than sufficient to meet the City of Tacoma's full diversion capacity and ensure 110 cfs flows at Palmer. Currently the COE does not operate the Hansen Dam for water supply purposes, though this may change as a result of Congressional authorization in conjunction with the City of Tacoma's second supply line (Pipeline 5).

The COE monitors the weather, snowpack, and reservoir inflow to decide whether to start filling the reservoir in April, May, or June to try and ensure a 110 cfs instream flow. Filling of the reservoir is delayed as late as possible in the spring to allow downstream passage of coho, chinook, and steelhead smolts, but reservoir filling often starts during the peak of smolt outmigration. Consequently, some smolts are prevented from migrating to the ocean. If reservoir filling is delayed just one week too late, however, Hansen Reservoir can run out of winter storage before the expected October rain. Flow is then so low that fall chinook spawning is severely disrupted (Caldwell and Hirschey, 1989).

Water Rights and Claims

The State of Washington regulates ground water and surface water withdrawal through a legal system of water allocations. Water withdrawals for all but specific small ground water uses must be permitted by Ecology. Upon receiving an application for a water right, Ecology may issue a permit to develop the water resource. Water right certificates are issued after the water withdrawal has been perfected (actually put to beneficial use).

In this report, permits and certificates are collectively referred to as water rights. Water rights have been required by existing laws since 1917 for surface water, and 1945 for ground water. Not all uses of water developed before these dates were registered as part of the water rights process. In order to protect active withdrawals developed prior to these two dates, the State allowed individuals to register withdrawals during a "claims period" between 1969 and 1974. A water right claim is not an authorization to use water, but rather a statement that in claim to a water withdrawal developed prior to 1917 or 1945. The validity of existing claims has yet to be determined through an adjudication.

According to a South King County Ground Water Advisory Committee report (1989), about 25 percent of the population of south King County draws water from small systems with five or fewer connections. These systems are exempt from the water right permitting process. For the Soos Creek subbasin alone, Carlson (1994) estimated total withdrawals of 3,525 acre-feet per year (af/y) from exempt wells (based on an estimated population of 95,350 and an annual use of 132 gallons/capita/day). Although these small systems were not addressed further during this initial assessment due to time constraints and scarcity of information, they do constitute a significant portion of legal water use.

Water right allocations are not necessarily equal to quantities of actual water use. In the Green-Duwamish watershed many quantities registered with the State have not been perfected either because they are still being perfected or because they have reverted back to the State following a five year period of non-use. Consequently, a discrepancy exists between allocations and use, and a distinction between these must be drawn in assessing stress on the hydrologic system. Actual use cannot be enumerated through water allocation statistics, but must be arrived upon by surveying major water users and estimating the sum of minor uses. Although total allocation differs from actual use, total allocation is a significant figure because it is the major portion of the maximum potential legal withdrawal rate from the hydrologic system.

From a hydrologic perspective, not all water withdrawn by a well should be treated in the same manner. Water which is pumped or drained from the ground then conducted by pipeline to a location outside of a subbasin, represents a different type of impact than water used locally. Similarly water which is partially consumed and partially wasted to a sanitary sewer, represents a different type and magnitude of impact than water which is partially consumed and partially wasted to a septic system. No distinctions between these considerations was made during this assessment.

Certain inchoate rights exist which have not been fully developed. These include federal and tribal reserved rights, instream riparian rights, public-trust rights for purposes of navigation, and fisheries, recreation, and other instream uses. The Puyallup and the Muckleshoot Tribes have claimed fishing rights within the watershed that are considered to be from time immemorial. State regulations dictate that water quality and quantity be maintained. In the future when these rights are put to full use, there may be an effect on other water users.

A total of 860 consumptive water rights (certificated and permitted) have been issued in the Green-Duwamish watershed for both surface and ground water (Table 2a). The total instantaneous allocation of surface water rights in the watershed is 195.2 cfs, while the total allocation of ground water rights is 350 cfs. Annual quantities (Qa) were not regularly assigned on surface water rights issued prior to the 1960's and a review of the data suggests that about 40 percent of the consumptive surface water rights within the WRIA have no associated Qa. Consequently, the Qa listed for surface water in Table 2a involves some underestimation.

A total of 3,330 claims were filed during the claims registration period for both surface and ground water (Table 2b). As mentioned previously, the validity of these claims cannot be determined unless an adjudication occurs. Most claimants did not specify quantity, so this assessment estimated an instantaneous quantity (Qi) of 0.02 cfs and an annual quantity (Qa) of 1 acre-foot per year for each claim for domestic use and/or stockwatering. These estimates were generated taking into account that much of the claimed use is in a rural setting and that, by definition, single domestic use may include up to one half acre of irrigation. Claims for irrigation were assigned 0.02 cfs and 2 acre-feet per acre. Using these estimates, the total Qi of claimed surface water within the watershed is 444.9 cfs (including the City of Tacoma's claim for 400 cfs), while the total Qi of claimed ground water is 96 cfs.

It is significant to note that the City of Tacoma accounts for a major portion of allocated and claimed water uses within the WRIA. More than 50 percent of the surface water and nearly 40 percent of the ground water allocated through water rights (as Qi) belong to the City of Tacoma. Furthermore nearly 90 percent of the surface water claimed (estimated as Qi) is also associated with the City of Tacoma.

The total Qi of all surface and ground water rights within the WRIA is 545 cfs, while the total Qi of all surface and ground water rights and claims combined is 1086 cfs.

Table 2a Green-Duwamish Watershed Water Rights

Source	Qi (cfs)	Qa (af/y)	Irrigated Acres	Total Number of Rights
Ground	350.0	117,137	1,711	360
Surface	195.2	78,587*	5,543	500

*Total for rights issued since mid-1960's.

Table 2b Green-Duwamish Watershed Claims (estimated quantities)

Source	Qi (cfs)	Qa (af/y)	Irrigated Acres	Total Number of Claims
Ground	96.0	7,299	2,513	2,613
Surface	444.9	3,917	1,670	717

Fifty two nonconsumptive surface water rights (not included in the tables above) totalling 98.6 cfs have been issued for fish propagation, hydroelectric power generation, and recreation.

Of the water rights issued by Ecology in the Green-Duwamish watershed, the principal use is municipal-domestic consumption. 57 percent of the surface water rights and 76 percent of the ground water rights are allocated to municipalities (Figures 6 and 7). The largest municipal user is the City of Tacoma, which has a surface water permit for 100 cfs (Pipeline 5, priority date 1933) and a ground water permit for 62,500 gpm (139.3 cfs, priority date 1970). These two permits account for the large increase in cumulative rights in those years, as shown in Figures 8 and 9.

Figures 10 and 11 plot the cumulative instantaneous quantity as percentages of the total quantity against the cumulative number of rights expressed as percentages of total number of rights. This illustrates the fact that 10 percent of the surface water right holders account for 84 percent of the surface water allocated in the watershed, and 10 percent of the ground water right holders account for 78 percent of the ground water allocated in the watershed. This is significant from a water resource management perspective, as it gives an indication of what percentage of water right holders might be used to provide information on the bulk of actual water use. The graphs are a bit deceptive, however, as all of the larger purveyors in the basin have multiple water rights, thus the percentage of water right holders using say 90 percent of the water is far smaller than indicated.

Figures 11.1 and 11.2 are plots of the ground and surface water rights issued per section for the entire Green-Duwamish Watershed.

Water Right Applications

Maximum withdrawal information on water right applications is generally limited to instantaneous quantities (Qi), largely because Ecology has not made final decisions as to the maximum allowable annual withdrawals (Qa). Consequently, applications cannot be directly compared to allocations. Requested Qi's are generally not issued for continuous withdrawal, and the Qa's allocated by Ecology are typically much smaller than a calculated volume associated with continual withdrawal of Qi's over an annual period. During this assessment no estimate of annual quantity for applications was made.

There are 54 ground water applications on file with Ecology in the Green-Duwamish watershed requesting a total of Qi 54,410 gpm (121.2 cfs). Of these, 42 are for municipal or multiple domestic use and the rest are mainly for irrigation. Approximately 12 of the applications are for ground water downstream of the Auburn gage, requesting a total Qi of 34,000 gpm, a quantity which accounts for over 60 percent of the ground water quantity applied for within the WRIA. The applications below the Auburn gage are primarily attributable to the City of Seattle, the City of Tukwilla, and the Federal Way Water and Sewer District. There are eight surface water applications in the WRIA requesting a total Qi of 6.3 cfs.

Soos Creek Subbasin

The majority of water rights issued in the Soos Creek subbasin are ground water rights for municipal use. Twelve municipal ground water rights account for 67 percent of the allocated instantaneous quantity (Qi) and 81 percent of the annual quantity. The City of Kent, Covington Water District, and King County Water District #111 are the area's largest purveyors. No surface water rights have been issued since the early 1980's.

Due to upstream diversions by the State fish hatchery prior to 1967, the useable period of record for streamflow data for Soos Creek extends from 1967 to present. Consequently for the purposes of subsequent streamflow analysis in this report, it is significant to look at the growth in water rights during this time period. The Qi of ground water allocated in the subbasin from 1967 to present increased from 5.3 cfs to 40.8 cfs, and the annual quantity (Qa) grew from 1,412 af/y to 19,297 af/y. Ground and surface water rights and claims are totalled in Tables 3a and 3b. Currently, there are 30 applications for water rights for ground water in the Soos Creek subbasin, requesting a total Qi of 40.9 cfs, an amount equal to the instantaneous quantity already allocated.

Table 3a Soos Creek Subbasin Water Rights

Source	Qi (cfs)	Qa (af/y)	Irrigated Acres	Total Number of Rights
Ground	40.8	19,297	369	99
Surface	6.1	891*	103	89

*Total for rights issued since mid-1960's

Table 3b Soos Creek Subbasin Claims (estimated quantities)

Source	Qi (cfs)	Qa (af/y)	Irrigated Acres	Total Number of Claims
Ground	43.3	3,194	1,118	1,374
Surface	21.2	357	309	296

Newaukum Creek Subbasin

There are three ground water rights for municipal use in the Newaukum Creek subbasin for the city of Enumclaw, representing 56 percent of the allocated Qi and 75 percent of the Qa. Enumclaw also holds two surface water certificates for 1.75 cfs. The remaining water rights in the subbasin are predominately for irrigation and small multiple domestic systems. Water rights and claims are tabulated in Tables 4a and 4b.

Table 4a Newaukum Creek Subbasin Water Rights

Source	Qi (cfs)	Qa (af/y)	Irrigated Acres	Total Number of Rights
Ground	14.2	5,045	469	41
Surface	8.4	160*	663	36

*Total for rights issued since mid-1960's

Table 4b Newaukum Creek Subbasin Claims (estimated quantities)

Source	Qi (cfs)	Qa (af/y)	Irrigated Acres	Total Number of Claims
Ground	6.3	1,029	467	163
Surface	1.2	495	241	32

Minimum Flows

The Green-Duwamish River Basin Instream Resources Protection Program (IRPP) document (Ecology 1980) discussed many of the issues regarding the establishment of instream flow restrictions for the basin. A minimum flow of 110 cfs at the Palmer gage was established by the COE for reservoir operations, under Congressional authorization. Releases from the reservoir augment the natural summer low flow in the Green River in order to provide adequate flow for the fisheries resource. The Washington Department of Fish and Wildlife considered these flows inadequate for the protection of instream resources and requested supplemental releases above the 110 cfs minimum flow. METRO commented that Green River flow releases were often insufficient to alleviate poor water quality conditions in the lower Duwamish River. They believed that 550 cfs at the Auburn gage would be necessary to achieve State water quality standards by diluting pollutants and flushing out the intruding salt water wedge from Elliott Bay.

The IRPP for the Green-Duwamish watershed (Chapter 173-509 WAC) was enacted in 1980. The intent, in accordance with RCW 90.54 and 90.22, is to retain base flows in perennial streams, rivers, and lakes at levels necessary to protect wildlife, fish, scenic, aesthetic, recreation, environmental, and navigational values. This IRPP is based on an Ecology methodology for selecting minimum instream flow requirements, and involves statistical analysis of streamflow records and consideration of other instream flow values. In choosing streams for regulatory protection, each stream was rated by the Departments of Ecology, Fish, and Game. A stream rated to have greater environmental and scenic values required higher levels of flow protection. Ecology can initiate a review of the

IRPP whenever new information, changing conditions, or statutory modifications make it necessary to consider revision.

The IRPP establishes instream flows for two control stations on the Green River, including *normal* year flow requirements at Auburn (gage 12113000) and both *normal* and *critical* flow requirements at Palmer (gage 12106700) (Figure 12). The IRPP states that Ecology's director may authorize a reduction in instream flows to critical levels in consultation with the State Departments of Fisheries and Wildlife. Since the laws enactment, about 30 surface water rights for less than 2 cfs have been issued for the Green River (which compares to the current total allocation of 195.2 cfs).

Beyond the flow restrictions on the main stem, the IRPP closes all tributaries of the Green-Duwamish River to additional surface water withdrawals. With respect to future ground water withdrawal permits, the IRPP states that these will not be affected unless such withdrawal would clearly have an adverse impact upon the surface water system contrary to the intent and objectives of the law. The IRPP states that no water rights in existence at the time of its establishment shall be effected.

The City of Tacoma's diversion of 112 cfs, is based on their claim (water diverted before the 1917 Water Code) and is not subject to Washington State's 1980 minimum instream flow restriction. The COE is required only to release 110 cfs from storage for instream flows during periods of very low natural flow.

Water Quality

As stated in the Draft Green-Duwamish Watershed Nonpoint Water Quality Early-Action Plan (King County, 1989b), "Water quality is closely tied to water quantity. Water quality is a significant factor in allocation decisions by water purveyors in that water supplies for municipal and industrial use (e.g., domestic consumption) must be of high quality. At the same time, management of water quality may depend in large part on the availability of large quantities of water to dilute pollutants and maintain proper water temperatures."

Surface Water

Seattle METRO monitors water quality sampling stations monthly throughout the Green-Duwamish Watershed (Figure 13). Three sampling stations (305, 307, and 309) monitor the Duwamish Estuary, while four sampling stations (3106, 311, A319 and B319) monitor the lower Green River. METRO sampling stations are also located on Newaukum Creek (0322), and in the Soos Creek subbasin (A320, C320, D320, and G320). Chapter 173-201A WAC outlines the surface water quality standards for the State, and sets forth criteria based on water use and numerical standards. Waters within the three Duwamish estuary sampling stations are classified by Ecology as Class B waters. Water quality of this class is considered "good", and meets or exceeds the requirements for most uses specified in the WAC including water supply, stock watering, fish and wildlife habitat and recreation. The lower Green River and its tributaries are classified by Ecology as Class A waters. Water quality of this class is considered "excellent", and meets or exceeds the requirements for all or substantially all the same uses specified in the WAC.

Under the Federal Clean Water Act (Section 303[d]), Ecology prepares a biannual list for EPA of "troubled waters," rivers, lakes, estuaries, and coastal waters that exceed water quality standards. The majority of water quality problems on the main stem of the Green River appear to occur below the Auburn gage. According to the Section 303(d) list (Ecology, 1994), these problems include numerous excursions beyond the Class A criteria for mercury, temperature, dissolved oxygen, and fecal coliform. The Duwamish River, which is classified as a Class B waterway, is also listed in the Section 303(d) list as having excursions for dissolved oxygen and fecal coliform. The list also cites excursions beyond criteria in sediment for copper, lead, zinc, polyaromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs). Since moving the discharge of METRO's Renton Treatment Plant effluent from the Green River to Elliot Bay in March 1987, the DO has increased and total-Phosphorous and ammonia have decreased (METRO, 1989).

The most significant water quality problem in the Soos Creek subbasin relates to elevated fecal coliform levels. According to the 1994 Section 303(d) list submitted by Ecology to EPA, a total of 73 excursions beyond the Class A fecal coliform criteria occurred at four Soos Creek stations between July 1987 and July 1991. Soos Creek is classified as a Class A stream segment by the State according to WAC 173-201 WAC. Livestock access to streams appears to be the primary cause of the high fecal coliform levels. The 303(d) list also indicates that two excursions beyond the mercury criteria occurred at one Soos Creek station between October 1989 and January 1990. The 1990 Soos Creek Basin Plan discusses adverse effects on fish stocks specifically caused by nonpoint stormwater pollution. These problems include pollutants carried by stormwater runoff and increased water borne sediments in the basin's streams.

According to the Section 303(d) list (Ecology, 1994), four Newaukum Creek stations had a total of 119 excursions beyond the Class A fecal coliform criteria between July 1987 and July 1991. Again, livestock stream access appears to be the primary cause of these high levels. When compared with other King County monitored sites, the water appeared to be cooler and better oxygenated than most. However, nitrate and ammonia values were also higher, presumably due to dairy farming and cattle ranching upstream. The nutrient loading rate for nitrate and ammonia from Newaukum Creek to the Green River were the first and the third highest, respectively, for all the basins which METRO studied.

Ground Water

Background data in the GWMP (SKCGWAC, 1989) indicates that ground water quality conditions found in the shallow and deep wells evaluated since 1970 were satisfactory with no trend of water quality degradation. Exceptions were overall high levels of naturally occurring iron and manganese, and some site specific occurrences of contamination.

According to, "The State of Our Groundwater: a report on documented chemical contamination in Washington" (Stewart et al., 1994) nitrate is both the most prevalent and most frequently documented ground water contaminants in the State. Nitrates are highly soluble and easily leach into the ground water as a result of human-induced contamination and typical sources include agricultural practices, urban use of nitrogen fertilizers, and septic systems. The Washington State Department of Health (DOH) sampled 681 well systems in King County and found that 18 wells exceeded half the MCL (5 mg/L) in the federal drinking water standards for nitrates. Of these 18 wells, 11 were in the Green-Duwamish watershed. Only one well in King County exceeded the MCL (10 mg/L) and this also was in the Green-Duwamish watershed.

Fisheries

The 1980 Green-Duwamish River Basin IRPP document (Ecology, 1980) states that anadromous salmonids found in the Green River are chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and chum (*O. keta*) salmon and steelhead trout (*O. mykiss*). Pink salmon were once abundant but have not been reported in recent years. Chum runs have declined, but a viable native population remains and is now being augmented by an enhancement program by the Muckleshoot Tribe. Figure 14 shows the major channels that have been identified at risk by the American Fisheries Society (AFS) or are listed as depressed by the Salmon and Steelhead Stock Inventory (SASSI).

The Washington Department of Fisheries operates a large salmon hatchery near the mouth of Soos Creek. Annual returns of adult fish to the hatchery range from 12,000 to 14,000 for fall chinook salmon and 6,000 to 10,000 for coho salmon (Goldstein, 1982). Three to six thousand coho are released upstream to spawn naturally. In addition to supporting natural spawning and rearing, the upstream areas of the hatchery are utilized for rearing by hatchery fry that are planted throughout the basin.

Habitats found within the watershed vary considerably due to changes in channel gradients, stream morphology, and current levels of commercial or domestic development. These habitats can be separated into 4 generalized river reaches:

1) Upper-Middle Green River
2) Lower Green River
3) Newaukum and Soos Creek Subbasins
4) the Duwamish Estuary

Fisheries habitat within the Upper-Middle Green River consist primarily of cascades and rapids confined in relatively narrow steep-sloped valleys. Substrates are dominated by boulders, rubble, and large cobbles. The City of Tacoma's water diversion dam blocks all upstream migration of salmonids to a substantial part of the upper-middle Green River watershed. Presently, no spawning occurs upstream of the diversion dam, but juvenile salmonids are outplanted in tributaries upstream of HAH dam. Tributaries in the upper-middle Green River drainage provide little accessible habitat for anadromous salmonids (Grette and Salo, 1986).

The Lower Green River, below RM 40, takes on the characteristics of a large river. Stream gradients decrease, river widths increase and the river begins to meander through a broad glacially carved valley that has been filled with fluvial deposits. The lower Green River is diked or protected by revetments from RM 38 to the dredged portion of the Duwamish waterways (RM 5.2). Due to the artificial dikes and revetments, as well as increased development, riparian areas have suffered along the lower river. Tree growth is largely prohibited in some diked areas resulting in streambanks that provide little shade to the river. Although a substantial amount of spawning occurs in the main stem of the river from RM 26 (Kent area) to the City of Tacoma Diversion Dam (RM 62), spawning activity is most intense between RM 32 (Auburn) and R.M 47. The River below Kent appears to be poorly utilized for salmonid spawning (METRO, 1989).

The two most important tributaries of the Green River enter in this lower section. Newaukum Creek enters the south bank at RM 40.7 and Soos Creek joins on the north bank at RM 33.7. Stream gradients are typically low, substrates are dominated by large gravels, and riparian areas are typically wooded or well vegetated except for areas of pastureland and some residential development (King County, 1990). There are significant runs of chinook and coho salmon, and steelhead trout throughout the Soos Creek subbasin. The stream is used for migration, spawning, and rearing. Significant runs of chum salmon occur in the lower reaches of Newaukum Creek, and coho salmon are found throughout the system. However, spawning substrate is the limiting factor on Newaukum Creek, as there is only a moderate amount of fine gravel. The lower reaches of the creek have been straightened and have limited quantities of riparian vegetation (King County, 1989a).

The Duwamish Estuary is defined for this report as the area from RM 12 to Elliott Bay. Fish habitat has been degraded in the Duwamish Estuary by extensive residential and commercial development. Riparian zones and adjacent lands are characterized by intensive commercial and industrial developments that are often built up to or directly over the surface of the water. River sediments are contaminated and the Duwamish is considered to be a major source of pollutants for Puget Sound (Harper-Owes 1983). The natural estuarine habitats in this area have been totally destroyed except for a remnant on Kellogg Island, which itself has been affected by disposal of dredge materials (Grette and Salo, 1986).

The Green-Duwamish River Basin IRPP report (Ecology, 1980) explains that intergravel egg development occurs over an 11-month period due to the overlapping spawning period of various species. High flows during the period of March through June apparently mark the peak of out-migration for all species, although several of these redistribute within the stream system throughout the year.

Adult salmonids migrate upstream through the Duwamish River 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, stream flow, and barometric pressure. Migrating salmon congregate near the mouth of the Duwamish River during July and August before migrating predominantly between September through January (Miller and Stauffer, 1967). Although dissolved oxygen values in the lower river have improved since discontinuation of the upstream wastewater discharge from the Renton treatment plant (METRO, 1990), levels as low as 3.1 mg/l prior to diversion did not appear to hinder migration (Miller and Stauffer, 1967).

Downstream 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 to early August for most species. Downstream migration by juvenile salmonids calls for spending more time in the lower Duwamish River than upstream migration. During this time, juveniles use the estuary to feed and physiologically adapt to marine salinities. Among numerous beneficial uses of the lower Duwamish River identified by METRO, use as habitat for out-migrating juvenile salmonids was listed as the most important (Harper-Owes, 1983).

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 former paper attempted to assess the future risk of extinction for selected stocks. That report described the status of chum salmon stocks only for the Green/Duwamish Rivers, which it described as being at high risk of extinction. The SASSI report examined the current status of salmon and steelhead stocks for Washington State. That report described chinook, coho, and steelhead stocks on the Duwamish and Green Rivers as healthy, and chum status as unknown.

Caldwell and Hirschey (1989) conducted a study of the Green River using the Instream Flow Incremental Methodology. Their report 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."

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 indicate a positive relationship between the magnitude of the lowest recorded flow and the steelhead production for each year, but results are not conclusive.

Adverse conditions affecting the migration of fish include poor water quality, high stream temperatures, physical barriers, the destruction of spawning habitat, and detrimentally low streamflows. A water temperature investigation conducted by Caldwell (1992) concluded that portions of the middle-lower Green (RM 13 to RM 45) frequently exceeded Washington State water quality standards for temperature, and that salmonid rearing capabilities were adversely affected. The report indicates a potential for blockage or delay of upstream migration of fish during August and hypothesizes that warm summer minimum temperatures are the result of several factors including limited ground water inflow, increased impervious surfaces, and higher daily temperatures.

STREAMFLOW STATUS

Objectives of Analysis

There have been significant changes in the Green-Duwamish watershed since collection of flow data began decades ago. As discussed previously, the demands for surface and ground water use has grown rapidly over the past 20 to 30 years. Population growth and urbanization in the watershed has increased impervious land areas, thereby reducing ground water recharge (King County, 1990; Carlson, 1994). In addition, declining annual precipitation over the last few decades has had an impact. Each of these factors can affect the streamflow in the river, most notably by reducing summer low flows.

To better understand the impacts of changing conditions in the watershed on streamflow status, and to assess potential cause and effect mechanisms, flow and precipitation data from the watershed were analyzed for trends. Flow data from USGS gages located on the Green River near Auburn and Palmer (Figure 2), on Soos Creek above the hatchery, and on Newaukum Creek were evaluated for low flow trends. In addition, the Auburn and Palmer gage data were evaluated for flow exceedence values.

For the Auburn and Palmer gages data was used beginning in 1961, since the Hansen Dam began filling in December of that year. The issue of the dam's effect on Green River flows was beyond the scope of this report. IRPP instream flows were established taking into account the existence of the dam thus, for the purposes of this study, we analyzed river conditions since reservoir operations began. Water was diverted upstream of the Soos Creek gage by the State fish hatchery prior to 1968. Because protection of the hatchery's water supply was a primary reason for the Soos Creek closure, we used only data collected after that date. For the Newaukum Creek gage, we used data collected starting in 1953, since there was a break in data prior to that time.

Flow Exceedence

NOTE: the original Figures 15 and 16 are replaced by the attached versions.

Flow exceedence curves were developed for the Auburn and Palmer gage stations (Figures 15 and 16). More than 30 years of flow data were used in calculating the monthly flow curves for 90, 50 and 10 percent exceedence probabilities. The 90 percent curve represents low flow conditions which can be expected approximately once in 10 years, 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 average flow conditions throughout the year (flows which can be expected half of all years). Because such a long period of data was used to develop these curves, the results cannot be used to define specific impacts.

For the Auburn gage station, the 90 percent exceedence curve is less than the instream flows mid-May through December (Figure 15). Based on this curve, for each day during that time period there is a 10 percent probability that instream flows will not be met. The 50 percent exceedence curve indicates that average flow conditions (flows met half of all years) at the Auburn gage are well above instream flows on any given day except during a seven week period of the summer.

As stated previously, both *normal* and *critical* year instream flow requirements have been established for the Palmer gage station. The 90 percent exceedence curve is below the *normal* year instream flows for this gage mid-May through early November (Figure 16). Thus, for each day during that time period, there is a 10 percent probability that instream flows will not be met. The 50 percent exceedence curve indicates that under average conditions (flows met half of all years), flows at the Palmer gage are above *normal* year instream flows on any given day except during a four week period of the summer. The 90 percent exceedence curve is below the *critical* year instream flow line mid-May through mid-November.

Low Flows

NOTE: the original Figures 17 and 18 are replaced by the attached versions.

Low flows in the river were evaluated by calculating the mean flow during the 7 consecutive days with the lowest flow for each year (7-day low flow). The 7-day flow duration is conventionally used in evaluating low flows because shorter flow durations have much greater variability.

When plotted over time, there is an apparent downward trend in average 7-day low flows at the Auburn gage (Figure 17), during the same time as an upward trend at the Palmer gage (Figure 18). The upward trend at Palmer appears to be related to buffering effects of the Hansen Reservoir. The downward trend at Auburn is apparently related to a decrease in the amount of water being added to the river between the two gages. As both Soos Creek and Newaukum Creek join the Green River between Palmer and Auburn, it is likely that decreased flow from these tributaries is partially responsible. Declining trends in 7-day low flows are apparent in Soos Creek (Figure 19) and Newaukum Creek (Figure 20), both of which are uncontrolled systems. Low flows in these streams are entirely a function of baseflow which, in turn, can be affected by such variables as precipitation, loss of recharge area, and ground water use.

The 7-day low flow data for the Auburn and Palmer gages illustrate that, in most years, instream flows are not met during low flow periods. At the Auburn gage there were only three years between 1963 and 1993 when the 7-day low flows met instream flows (Figure 17). At the Palmer gage, there were only four years between 1964 and 1993 when the average 7-day low flow met instream flows (Figure 18). Figure 18 also indicates that 110 cfs flows were not maintained at Palmer for nine of the past 29 years. As mentioned previously, the COE does not operate the Hansen Dam for water supply purposes and it is only required to meet a 110 cfs flow established under Congressional authorization. Although it releases 110 cfs, plus additional flows up to the City of Tacoma's 112 cfs capacity during the dry season, in dry years this can be less than sufficient to meet the City's full diversion capacity and ensure 110 cfs flows at Palmer.

Additional duration analyses, not presented here, were conducted for a 60-day low flow period for both the Auburn (1963-1993) and Palmer (1965-1993) gages and compared to established instream flow requirements. For the 60-day period, established instream flows were not met at either gage location 50 percent of the time.

The total number of days that Chapter 173-509 WAC instream flows were not met were calculated on an annual basis, and also for specific seasonal low flow periods. Since 1980, instream flows were not met an average of 103, 100, and 82 days, compared with Auburn *normal* year, Palmer *normal* year, and Palmer *critical* year instream flows, respectively. Based on linear regression analyses of the data, there is a weak correlation between years and the number of days that minimum flows were not met (Figures 21 through 23).

Based on the Auburn gage trend line, the total annual number of days instream flows were not met increased from about 75 to 135 days during the period 1980-1992 (Figure 21). Figure 21 also contains a line representing the number of days flows are not met during the period from July 15 to October 1. The large difference between this line and the line representing the entire year suggests that instream flows were not met for a significant number of days outside the lowest flow period.

Based on the Palmer gage trend line, the total annual number of days *normal* instream flows were not met increased from about 78 to 123 days during the period 1980-1992 (Figure 22). Figure 22 also contains a line representing the number of days flows are not met during the period from July 15 to September 15. As with the Auburn data, the large difference between this line and the line representing the entire year suggests that instream flows were not met for a significant number of days outside the lowest flow period. From 1980-1992, the total annual number of days *critical* instream flows were not met increased from about 65 to 110 days at the Palmer gage station (Figure 23). The similarity between the annual and seasonal (July 15 to September 15) flow values here, suggests that there were relatively few days when instream flows were not met outside this lowest flow period. Since 1980, when the instream flows were adopted, Ecology has never officially declared a *critical* flow year for the Palmer gage.

Interpretation of Streamflow Status

NOTE: Figures 26 and 27 have been dropped from the report.

Based on Figure 19, Soos Creek average 7-day low flows have shown a fairly predictable, approximately 10 cfs downward trend since 1967 with an R^2 coefficient of 0.48. During that same period, precipitation at SeaTac and Landsburg were generally below average (Figures 4a and 4c). Figure 20 indicates that Newaukum Creek average 7-day low flows demonstrated a fairly predictable, approximately 4.5 cfs downward trend since 1953 with an R^2 coefficient of 0.19. During that same period Mud Mountain Dam precipitation was generally above average (Figure 4d), while Palmer precipitation was generally below average (Figure 4c).

A direct comparison between the cfs decline in precipitation and streamflows is problematic. Rainfall variation may or may not follow a temporal linear pattern, and the processes whereby precipitation effects streamflow are complex. Some precipitation reaches streams by a fairly direct route via overland flow. Other water infiltrates into the ground, then enters streams through seeps. As the relationships between precipitation and streamflow are complex, two different analyses were used to compare Soos Creek and Newaukum Creek flow declines, with changes in precipitation.

Percentage Analysis

Linear regression analyses of the data, indicates a correlation between years and the declines in precipitation, and mean annual and summer low flows for both Soos Creek and Newaukum Creek. For Soos Creek, we estimate a 7 percent decline in mean annual flow, and a 31 percent decline in low flows from 1967 to 1992 (Figure 24). During that same period, precipitation declined about 13 percent at the Landsburg gage, and about 14 percent at the SeaTac gage. Comparing the decline in mean annual flow, with the proportionately larger precipitation decline, suggests that much of the difference is due to increased stormwater runoff associated with increasing impervious area. Within the Soos Creek subbasin, King County Surface Water Management Division estimates a three-fold increase in impervious area from 1985 to future high-density development (King County, 1990).

Comparing the relatively large percent decline in Soos Creek low flows, with declines in Landsburg and SeaTac precipitation (Figure 24), indicates that precipitation does not account for all of declining summer flows. The southern and eastern portions of this subbasin are mostly rural, while the remainder has been designated for urban-density development. Consequently this area is experiencing some of the fastest residential and commercial development in King County, and there have been large increases in impervious surfaces and ground water pumping. It is likely that the streamflow decline is tied to these changes. After conducting a related analysis on two streams in addition to Soos Creek and Newaukum Creek, Carlson (1994) concluded that declining flows in Soos Creek from 1967-1992 were not caused primarily by decreased precipitation, but rather by increases in impervious area and ground water withdrawals. Carlson's conclusion was based, in part, on the much greater decline in Soos Creek flows than in other drainages in the vicinity.

For Newaukum Creek, we estimate an 18 percent decline in mean annual flows and a 24 percent decline in low flows from 1953 to 1992 (Figure 25). During that same period, precipitation at Palmer decreased about 17 percent, and Mud Mountain Dam precipitation increased about 5 percent. Based on the precipitation contours on Figure 3, the precipitation at Mud Mountain Dam is a better indicator of conditions in the subbasin, and precipitation has probably been about average or slightly above average since 1953.

Comparing the percentage changes in precipitation, to percent declines in Newaukum Creek mean annual and low flows (Figure 25), suggests that precipitation changes have not been the major cause of declining flows in the subbasin. Impervious surface area has not increased at the rates observed near Soos Creek, and that may explain the similarity in mean monthly and low flows declines in Newaukum Creek. Based on this percentage analysis, it appears likely that additional ground and/or surface water withdrawals may largely be responsible for the declining flows in the Newaukum Creek subbasin.

Adjusted Volumetric Analysis

Due to its proximity, data from the Landsburg precipitation gage was used for comparison with Soos Creek flows during this analysis. When compared with a 1931 to 1991 mean of 56.1 inches, precipitation at this gage was below average from 1976 to

1979, above average 1980 to 1983, below average 1984 to 1989, above average in 1990, and below average in 1991.

At Landsburg, average precipitation from 1967 to 1991 nearly equalled that from 1931 to 1991 (56.2 compared to 56.1 inches, respectively). A comparison between average 1976 to 1991 precipitation and that from 1967 to 1991 indicates a deficit of about 2.8 inches (53.4 compared to 56.2 inches, respectively). A comparison between average 1984 to 1991 precipitation and that from 1967 to 1991 indicates a deficit of about 5.1 inches (51.1 compared to 56.2 inches, respectively). For comparison purposes with Soos Creek's 7-day low flows from 1967 to 1993, it was assumed that use of a 3 to 4 inch deficit was appropriate. A three inch loss would equate to about a 16 cfs precipitation decline when normalized over the 72 square mile watershed (converted by multiplying inches of rainfall by the basin area and dividing by the number of seconds in a year). A four inch loss would equate to about a 21 cfs precipitation decline.

Clearly decreased precipitation has contributed to the Soos Creek streamflow decline. A straight volumetric comparison suggests that while precipitation declined between 16 to 21 cfs, 7-day low flows declined only about 10 cfs from 1967 to present. However, not all of precipitation is available to recharge aquifers. A detailed water budget analysis was beyond the scope of this initial study, however, the USGS has conducted recharge modeling of the Covington Upland (Woodward, 1995). This modeling indicates that out of 49.5 inches per year of precipitation, 19.7 inches per year (39 percent) is lost to evapotranspiration and 9.2 inches per year (18 percent) is lost to stormwater runoff, leaving 21.6 inches per year (43 percent) for recharge.

Low summer flows are equivalent to stream baseflow (ground water contribution alone), so one would expect a correlation between low flow trends and that portion of precipitation attributable to recharge. Based on Woodward's (1995) recharge estimates, the portion of precipitation which recharges ground water is about 43 percent. Consequently, if precipitation declined about 16 cfs this would be equivalent to about a 7 cfs decline in aquifer recharge. Similarly, if precipitation declined about 21 cfs this would be equivalent to about a 9 cfs decline. This 7 to 9 cfs range compares with an estimated 7-day low flow decline of about 10 cfs. This comparison suggests that while precipitation decline does account for the majority of the low flow decline, some additional factor(s) are responsible.

As discussed previously, there is no precipitation gage which is completely representative of the Newaukum Creek subbasin. As the records from the Mud Mountain Dam and Palmer gages differ significantly, we used data from both for comparison purposes. Since 1953, the year that Newaukum Creek flows were first collected, Mud Mountain Dam precipitation has been about 1.7 inches above average compared with the 1940 to 1992 record (56.9 compared with 55.2 inches). During that same period, Palmer precipitation has been about 0.5 inches below average compared with the 1932 to 1992 record (90.7 compared with 91.2 inches). By comparison, Mud Mountain Dam precipitation since 1982 has been about 0.6 inches above average compared with the 1953 to 1992 record (57.5 versus 56.9 inches), while Palmer precipitation since 1982 has been about 7.4 inches below average compared with the 1953 to 1992 record (83.3 compared with 90.7 inches). Based on Figure 3, Mud Mountain Dam precipitation more accurately reflects conditions in the subbasin, consequently for comparison purposes with

Newaukum Creek 7-day low flows, it was assumed that use of between a zero and 3 inch precipitation deficit was appropriate. A three inch loss would equate to about a 6 cfs precipitation decline when normalized over the 27 square mile watershed.

A straight volumetric comparison for the Newaukum Creek subbasin suggests that while precipitation declined between 0 to 6 cfs, 7-day low flows declined only about 4.5 cfs from 1953 to present (Figure 20). As no recharge modeling data was readily available for the subbasin, however, it was difficult to place this volumetric comparison in perspective. Assuming that the USGS estimates for the Covington Upland are roughly similar to those in Newaukum Creek, the portion of precipitation destined to be aquifer recharge is about 43 percent. Consequently, if precipitation declined 6 cfs this would be equivalent to about a 2.6 cfs decline in aquifer recharge. By contrast, if there was no overall change in precipitation this would have no effect on aquifer recharge. This 0 to 2.6 cfs range compares with an estimated 7-day low flow decline of about 4.5 cfs for the subbasin. This comparison strongly indicates that while precipitation may account for a portion of the low flow decline, some additional factor(s) are responsible.

Combining the Results of Both Analyses

The above analyses suggest that precipitation decline alone does not account for declining flows in either subbasin. As mentioned previously, the southern and eastern portions of the Soos Creek subbasin are mostly rural, while the remainder has been designated for urban-density development. Consequently this area is experiencing some of the fastest residential and commercial development in King County, and there have been large increases in impervious surfaces and ground water pumping.

Increases in impervious areas in the watershed will reduce recharge, and subsequently reduce summer flows. As stated previously, about a three-fold increase (5 to 15 percent) in impervious area from 1985 to future high-density development has been predicted for the Soos Creek subbasin (future high land use with 2-10 year on site detention) (King County, 1990). As our analysis was for a period primarily preceding the period analyzed by King County (1967 to 1992 as compared with 1985 on), we assumed a 4 percent increase in impervious area during our analysis. Assuming an average annual precipitation rate of about 300 cfs and aquifer recharge which is 43 percent of this, the annual basin recharge was estimated to be about 129 cfs. If this rate were reduced by 4 percent, a total reduction in basin recharge of about 5 cfs would be likely. This is potentially significant compared with a Soos Creek 7-day low flow decline of 10 cfs.

The hydrogeology of the Soos Creek and Newaukum Creek subbasins indicates that ground water pumping, particularly from shallow aquifers, will affect streamflow. There is, however, no simple method to quantify this impact. Newaukum Creek flows have declined since 1953, during a period with no clear precipitation trend and no large increase in impervious area. In the Soos Creek subbasin, it may be tempting to conclude that the reduction in streamflow was due entirely to declines in precipitation and loss of recharge area. There is, however, a large degree of uncertainty in all these analyses. Due to such factors as the timing of changes in precipitation and annual streamflow, many of the estimates described above may be off by a factor of two or greater. This leaves ample room to include a ground water pumping component in the causes of the low flow declines.

DISCUSSION

There have been significant changes in the Green-Duwamish watershed since collection of flow data began decades ago. Population growth and urbanization have increased impervious land areas thereby reducing ground water recharge. Demands on surface and ground water use has grown rapidly over the past 20 to 30 years. Additionally, declining annual precipitation over the last few decades has had an impact. Each of these factors can affect the flow status of the river.

Precipitation provides the input that supplies stream runoff and ground water recharge. Average annual precipitation ranges from about 38 inches at SeaTac, to over 92 inches at Stampede Pass. Variations which occur over periods of several years are demonstrated in Figures 4a, 4b, 4c and 4d. These short-term departures from the mean generally do not follow discernable patterns, but recent precipitation has been generally below average since 1977 at all but the Mud Mountain Dam gage. Since 1977, the lower watershed (SeaTac) has experienced about 3.5 inches per year less precipitation than the 1950 to 1992 average for that gage. Precipitation patterns in the upper watershed are less clear, as the Palmer gage data suggests generally lower than average precipitation since 1977 (approximately 7.3 inches), while Mud Mountain Dam gage data suggests generally above average precipitation since 1971 (approximately 3.1 inches).

Water-budget analyses can be a valuable tool for gaining a conceptual understanding of watershed hydrology. However, all of elements of water budgets, such as evapotranspiration, recharge, discharge, and water use are difficult to ascertain and often derived through the use of assumptions. As a proper water budget analysis requires a great deal of effort and the results are of limited use, a water budget analysis was not performed during this initial watershed analysis.

Instream flows are monitored and controlled at several points within the watershed. The COE monitors precipitation, snowpack, and reservoir inflow at Hansen Dam to determine optimal reservoir levels and downstream releases. Downstream of the dam, the City of Tacoma removes up to 112 cfs under its water right claim. Below these points, the Palmer and Auburn gages have instream flows established in Chapter 173-509 WAC.

When plotted over time, there is an apparent downward trend in average 7-day low flows at the Auburn gage, during the same time as an upward trend at Palmer. The Palmer upward trend appears to be related to buffering effects of the Hansen Reservoir, while the Auburn downward trend is apparently related to a decrease in the amount of water being added between the two gages. As both Soos Creek and Newaukum Creek join the Green River between Palmer and Auburn, it is likely that decreased flow from these tributaries is partially responsible.

Since 1980, Chapter 173-509 WAC instream flows were not met an average of 103, 100, and 82 days per year, compared with Auburn normal year, Palmer normal year, and Palmer critical year instream flows, respectively. Based on linear regression analyses of the data, there is a weak correlation between years and the number of days that minimum flows were not met.

Based on the Auburn gage trend line, the total annual number of days that instream flows were not met increased from about 75 to 135 days during the period from 1980 to 1992. The Auburn gage trend line indicates that the total annual number of days that *normal* year instream flows were not met increased from about 78 to 123 days during the period from 1980 to 1992. The likely causes for all these changes include decreased precipitation, operation of the Hansen Dam, increased pumping by the City of Tacoma, increased (non-Tacoma) ground and surface water pumping, decreased aquifer recharge, and the nature of how flows were established in the first place.

The Hansen Dam is required only to meet 110 cfs instream flows, an amount significantly less than that required by Chapter 173-509 WAC. The City of Tacoma's current surface water diversion is based on a claim and thereby exempt from meeting instream flows. Consequently, operations of both the Hansen Dam and the City of Tacoma Diversion are significant with regard to the probability of meeting Green River instream flows. The City of Tacoma has yet to develop the additional 100 cfs authorized under an Ecology permit issued in 1985. If perfected, this water will be subject to Chapter 173-509 WAC, and the quantity taken should only be that above the established minimum instream flows. The use of additional water would likely require increased storage behind the Hansen Dam, in order to increase flow above the current target rate. The COE has considered the potential need for operational modifications, however it appears unlikely that these will occur in the near future. Currently, the COE works in cooperation with Ecology, the City of Tacoma, the Muckleshoot Tribe, and the Department of Fisheries and Wildlife to balance flow with competing needs.

Chapter 509-030 WAC requires that diversions subject to regulation by the Palmer gage be discontinued when Green River flows fall below critical year instream flows and that those subject to regulation by the Auburn gage be discontinued when Green River flows fall below normal year instream flows. The WAC also states that, "Future ground water withdrawal permits will not be affected by this chapter unless such withdrawal would clearly have an adverse impact upon the surface water system contrary to the intent and objectives of this chapter."

Ground water declines with partial dewatering of aquifers have been recorded in developed areas throughout the watershed. As a result, local ground water gradients have been modified with a resultant decrease in ground water discharge to local springs and streams. In the Covington Upland, ground water discharge to springs in the area have affected Jenkins Creek and Soos Creek, both closed tributaries of the Green River. Rock Creek, a tributary of the Cedar River has also been affected. In the Des Moines and Federal Way Uplands significant dewatering of aquifers has occurred with resultant decreased ground water discharge to the Green River.

For the wells in the watershed where there is a clear physical relationship between ground water pumping and surface water flows, Ecology has a legal mandate to restrict ground water pumping. This can be a fairly straight forward determination for shallower aquifers, however, for deeper confined aquifers implementation of the WAC is much more complex. Unfortunately, it is impossible to halt the effects of deep wells only during those periods when instream flows are not met. Soos Creek, Newaukum Creek, and all other tributaries of the Green River have been closed since 1980 per Chapter 173-

509 WAC. Nonetheless, declining trends in the average 7-day low flows were detected in both Soos and Newaukum Creeks for the last 26 and 40 years, respectively.

As the relationships between precipitation and streamflow are complex, two different types of analyses were used to compare Soos Creek and Newaukum Creek flow declines, with changes in precipitation. While the results of those analyses were somewhat confusing, they do suggest that precipitation decline alone does not account for declining flows in either subbasin. Within the Soos Creek subbasin, the southern and eastern portions are mostly rural, while the remainder has been designated for urban-density development. Consequently this area is experiencing some of the fastest residential and commercial development in King County, and there have been large increases in impervious surfaces and ground water pumping. Increases in impervious areas in a watershed will reduce recharge and subsequently reduce summer flows. In this subbasin, an increase in impervious area of 4 percent may translate to a total reduction in basin recharge of about 5 cfs. This is a potentially significant quantity compared with a Soos Creek 7-day low flow decline of 10 cfs.

The hydrogeology of both the Soos Creek and Newaukum Creek subbasins indicates that ground water pumping, particularly from shallow aquifers, will affect streamflow. There is, however, no simple method to quantify this impact. Newaukum Creek flows have declined since 1953, during a period with no clear precipitation trend and no large increase in impervious area. Based on our analysis in the Soos Creek subbasin, it may be tempting to conclude that the reduction in streamflow was due entirely to declines in precipitation and loss of recharge area. There is, however, a large degree of uncertainty in all these analyses. Due to such factors as the timing of changes in precipitation and annual streamflow, many of the estimates described during our analyses may be off by a factor of two or greater. This leaves ample room to include a ground water pumping component in the causes of the low flow declines.

Background data for the GWMP (SKCGWAC, 1989) contains ten generalized cross sections for the Soos Creek subbasin. These suggest direct hydraulic continuity between Qc(3) and the overlying shallower system in places. Furthermore, they indicate that Qc(3) and Qc(4) are both under artesian pressure and that the intervening materials are silty clay aquitards. Consequently, pumping even from these two deeper, confined aquifers will increase the vertical hydraulic gradient between them and the overlying aquifers, and increase ground water flow from shallow to deeper aquifers.

USGS recharge modeling of the Covington Upland (Woodward, et al, 1995) suggests that ground water from the deeper aquifers discharges to regional drainage features including both the Green and Cedar Rivers. Consequently, while pumping the Soos Creek subbasin's deeper aquifers may produce only minor impacts on Soos Creek flows, the probability of meeting Green and Cedar River instream flows will be an issue. If there are cumulative effects on the Green River, these may not be apparent unless determined at a downstream point such as near Kent. Although the established instream flows do apply to the Kent vicinity, no flow data exists below Auburn.

Nearby Crisp Creek is surrounded on three sides by the Soos Creek subbasin and has similar hydrogeologic characteristics. It is dominated by ground water flow which enters the creek as springs about one half mile upstream of the Keta Creek Hatchery, with stormwater contributing a minor amount to the annual hydrograph. Inter-basin transfers of groundwater occur with the Soos Creek subbasin in the upper reaches of Crisp Creek.

Water right allocations are not necessarily equal to quantities of actual water use. Many quantities registered with the State have not been perfected either because they are still being perfected or because they have reverted back to the State. Furthermore, much of the population draws water from small systems exempt from the water right permitting process, and there are certain inchoate rights (such as federal and tribal reserved rights, and instream riparian rights) which exist, but have not been fully developed. Consequently, a discrepancy exists between the total of water rights issued and the legal rights which actually exist. From a hydrologic perspective, it is significant to focus on consumptive water use (that quantity exported or lost to evapotranspiration), and in that regard not all water rights should be treated alike. No distinctions between any of these considerations was made during this assessment. Despite the limitations, however, total allocation is a significant figure because it is the major portion of the recorded maximum potential legal withdrawal rate from the hydrologic system.

The total Qi of surface and ground water rights within the WRIA is 445 cfs. This is approximately 40 percent of the mean annual flow of the Green River at Auburn (based on USGS data from the water years from 1961 to 1991) and is greater than the mean flows from July through September inclusive. The total quantity of all surface water rights and claims within the WRIA is 1086 cfs or 81 percent of the mean annual flow of the River at Auburn. In the Soos Creek subbasin, allocations of ground water have risen from 5.3 to 40.8 cfs (Qi) and from 1,412 to 19,297 af/y from 1967 to 1994.

There are 54 ground water applications on file with Ecology in the entire Green-Duwamish Watershed requesting a total of 121.2 cfs (54,410 gpm). Of these, 18 are for 2.2 cfs or more. There are eight surface water applications for the entire watershed for a total of 6.3 cfs. These numbers compare with a 50 percent probability that Green River Flows at Auburn range from 288 to 2,013 cfs (average 1,151) based on 1962 to 1993 data. Currently, there are 30 applications for water rights for ground water in the Soos Creek subbasin, totaling 40.8 cfs, an amount equal to that already allocated. This compares with a 50 percent probability that Soos Creek flows range from 31 to 218 cfs (average 108 cfs) based on 1967 to 1993 data.

CONCLUSIONS

Maintaining minimum instream flows is a key factor in managing water quality in the Green-Duwamish River system. A continued supply of clean water is needed to dilute pollutants in the rivers and to hold back saltwater intrusion at the mouth of the Duwamish. Instream flows are also important for protection of fish and aquatic habitat. Intergravel egg development occurs over an 11-month period due to the overlapping spawning period of various species, and low flow periods exacerbate temperature stress and other water quality problems.

Operations of both the Hansen Dam and the City of Tacoma Diversion are significant with regard to the probability of meeting Green River instream flows. Since 1980, instream flows were not met an average of 103, 100, and 82 days, compared with Auburn normal year, Palmer normal year, and Palmer critical year instream flows, respectively. Causes for this include decreased precipitation, operation of the Hansen Dam, increased pumping by the City of Tacoma, increased (non-Tacoma) ground and surface water pumping, decreased recharge, and the nature of how flows were established in the first place.

All tributaries of the Green River have been closed since 1980. Nonetheless, declining trends in average 7-day low flows have been recorded in both Soos and Newaukum Creeks for the last 26 and 40 years, respectively. Our analyses suggest that while decreased precipitation and increased impervious area likely account for much of the streamflow decline in Soos Creek, these were not as significant in effecting flows in Newaukum Creek. The hydrogeology of both the Soos Creek and Newaukum Creek subbasins, however, indicates that ground water pumping, particularly from shallow aquifers, will affect streamflow. Unfortunately, there is no simple method to quantify this impact.

Ground water from the Soos Creek subbasin's deeper aquifers discharges to regional drainage features including both the Green and Cedar Rivers. Consequently, while pumping these deep aquifers may produce only minor impacts on Soos Creek flows, the probability of meeting Green and Cedar River instream flows are an issue. Discharge to regional features is consistent with the numerous springs and seeps in the Covington Upland bluff along the Green and Cedar Rivers.

RECOMMENDATIONS

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

- An active water use and water level monitoring program should be established for all major users of ground water within the watershed and an agency made responsible for maintaining the data base. Historical data on water production should be incorporated into this data base and, whenever possible, all this should be segregated by aquifer. The pumping wells should be equipped with a calibrated totalizing-flow meter or equivalent, with meters and static water levels measured on a monthly basis. This monitoring program should be coordinated with the South King County Ground Water Management Plan which already has a partial database for some of these wells.

- Actual water use (both pumped and consumed) within the watershed should be determined, with distinctions made between water that is exported and water that is used locally.

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

- More study should be directed toward the cause of declining flows on Soos Creek and Newaukum Creek. Additional work should be conducted to gather and use existing information that characterizes the inter-relationships of various aquifers and defines their discharge locations and characteristics, as well as their recharge areas. This information could then be used to develop hydrologic models of the areas.

- More study should be directed to the effects of deep well pumping in the Covington Upland.

- A study should be made of the benefits of streamflow augmentation and habitat restoration as a means of protecting and restoring fish and aquatic resources in the watershed.

- The current area of impervious surfaces within the watershed should be estimated, so that a comparison can be made to 1985 and future levels.

REFERENCES

Armour, C. L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. U.S. Fish & Wildlife Service, Instream Flow Information Paper 28, Washington, D.C.

Driscoll, F. G. 1986. Groundwater and Wells. Johnson Division, St. Paul, MN.

Caldwell, B. and S. Hirschey. 1989. Green River fish habitat analysis using the instream flow incremental methodology. IFIM Technical Bulletin, Department of Ecology.

Caldwell, J. E. 1992. Green River Temperature Investigation 1992. Caldwell & Associates Environmental Consulting, Olympia, WA.

Carlson, C. V. 1994. Big Soos Creek low flow trend and water right analysis. Muckleshoot Indian Tribe, Fisheries Department. Auburn, Washington. November 1994.

Goldstein, L. Soos Creek Stream Resource Inventory. Technical Report WR-82-7. 1982. Prepared for the Municipality of Metropolitan Seattle. Seattle, WA.

Grette, G. B. and E. O. Salo. 1986. The status of anadromous fishes of the Green/Duwamish River system. Final report submitted to the US Army Corps of Engineers by Evans-Hamilton, Inc. Seattle, WA.

Hall, J. B. and K. L. Othberg. 1974. Thickness of unconsolidated sediments, Puget Lowland, Washington. Washington State Department of Natural Resources, Division of Geology, Geologic Map GM-12.

Harper-Owes. 1983. Water Quality Assessment of the Duwamish Estuary. Prepared for METRO Seattle. Seattle, WA.

Hart Crowser. 1995. Written comments on Draft Initial Watershed Assessment, Open-File Report 95-01.

King County. 1985. King County Comprehensive Plan. King County Planning and Community Development Division. Seattle, WA.

King County. 1989a. King County Watershed Ranking Final Report. King County Natural Resources and Parks Division, King County Public Works Department, METRO, Muckleshoot and Suquamish Indian Tribes, Seattle/King County Environmental Health Department, Washington State University King County Cooperative Extension.

King County. 1989b. 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.

King County. 1990. Soos Creek Basin Plan. King County Surface Water Management Division. Seattle, WA. June 1990.

Lufkin, T. 1993. Declining fish stocks in Washington State: A comparison of the American Fisheries Society list and the Salmon and Steelhead Stock Inventory. Washington State Department of Ecology.

Luzier, J. E. 1969. Geology and Ground-Water Resources of Southwestern King Co., Washington. Washington State Water Supply Bulletin No. 28.

Mathews, S. B. and F. W. Olson. 1980. Factors affecting Puget Sound coho salmon (Oncorhynchus kisutch) runs. Canadian Journal of Fish and Aquatic Science, Volume 37.

METRO. 1990. Quality of local lakes and streams. Annual Status Reports. Municipality of METRO Seattle. Seattle, WA.

Miller, D. M. and G. D. Stauffer. 1967. Study of the migration and spawning distribution of the runs of chinook and coho in the Green-Duwamish River system in the fall of 1965. Fisheries Research Institute Circular No. 67-4. University of Washington. Seattle, WA.

Morgan, D. S. and J. L. Jones. Numerical model analysis of the effects of ground-water withdrawals on discharge to streams and springs in small basins typical of the Puget Sound lowland, Washington. U. S. Geological Survey Water Supply Paper to be released in 1996.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stock at risk from California, Oregon, Idaho, and Washington. Fisheries, Volume 16, No. 2, pages 4-21.

Noble, J. B. 1979. Preliminary Ground Water Study for King County Water District 105. Robinson & Noble Consultant Report.

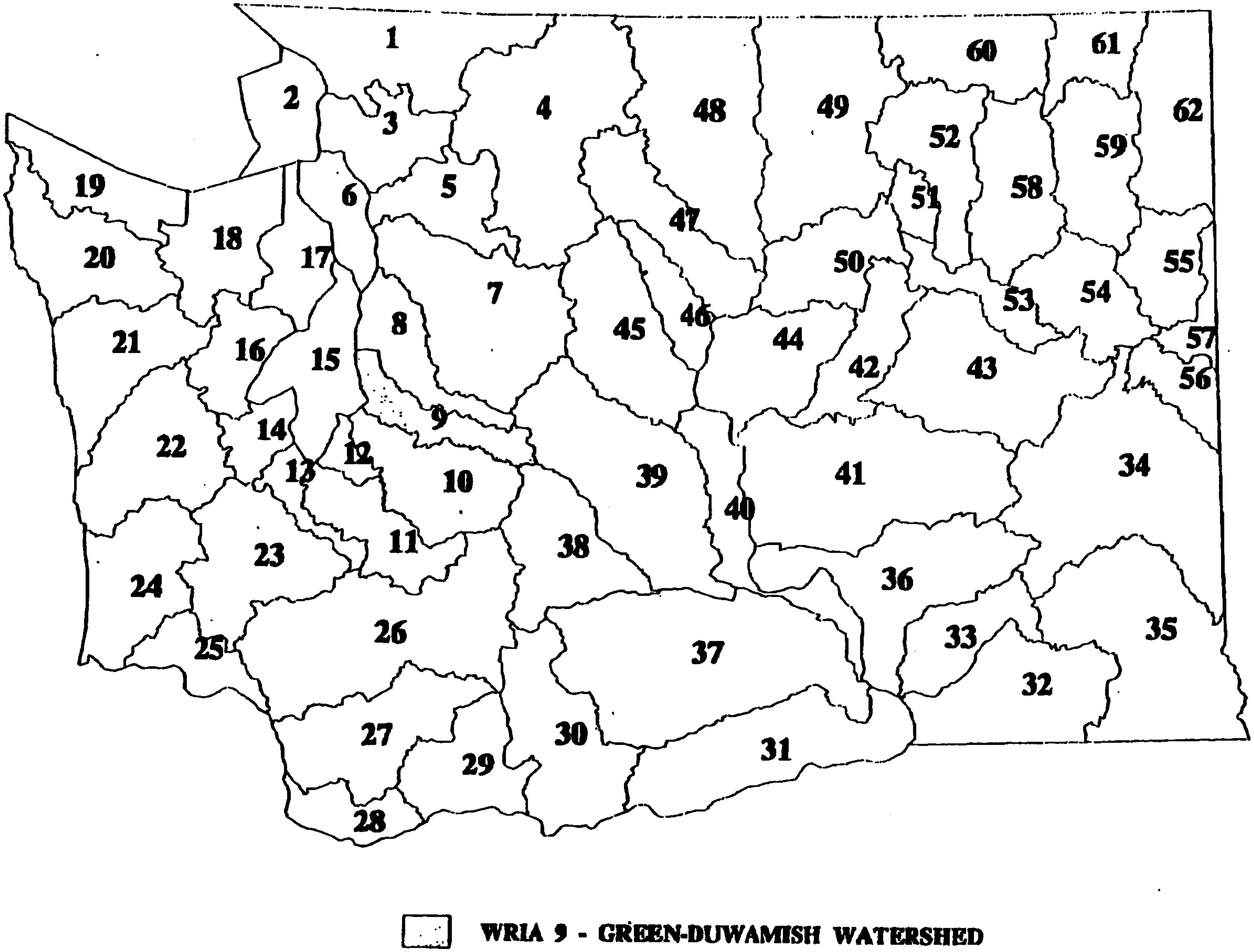
SASSI. 1993. Washington Department of Fisheries, Washington Department of Wildlife, and Western Washington Treaty Indian Tribes. 1992 Washington State Salmon and Steelhead Stock Inventory. Olympia, WA.

South King County Ground Water Advisory Committee (SKCGWAC). 1989. South King County Ground Water Management Plan, Background Data Collection and Management Issues, Volumes I & II.

Stewart, S., et al. 1994. The State of Our Groundwater: a report on documented chemical contamination in Washington. Washington State University Cooperative Extension and Washington Toxics Coalition.

Washington Department of Ecology (Ecology). 1980. Green-Duwamish River Basin Instream Resources Protection Program Including Proposed Administrative Rules

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

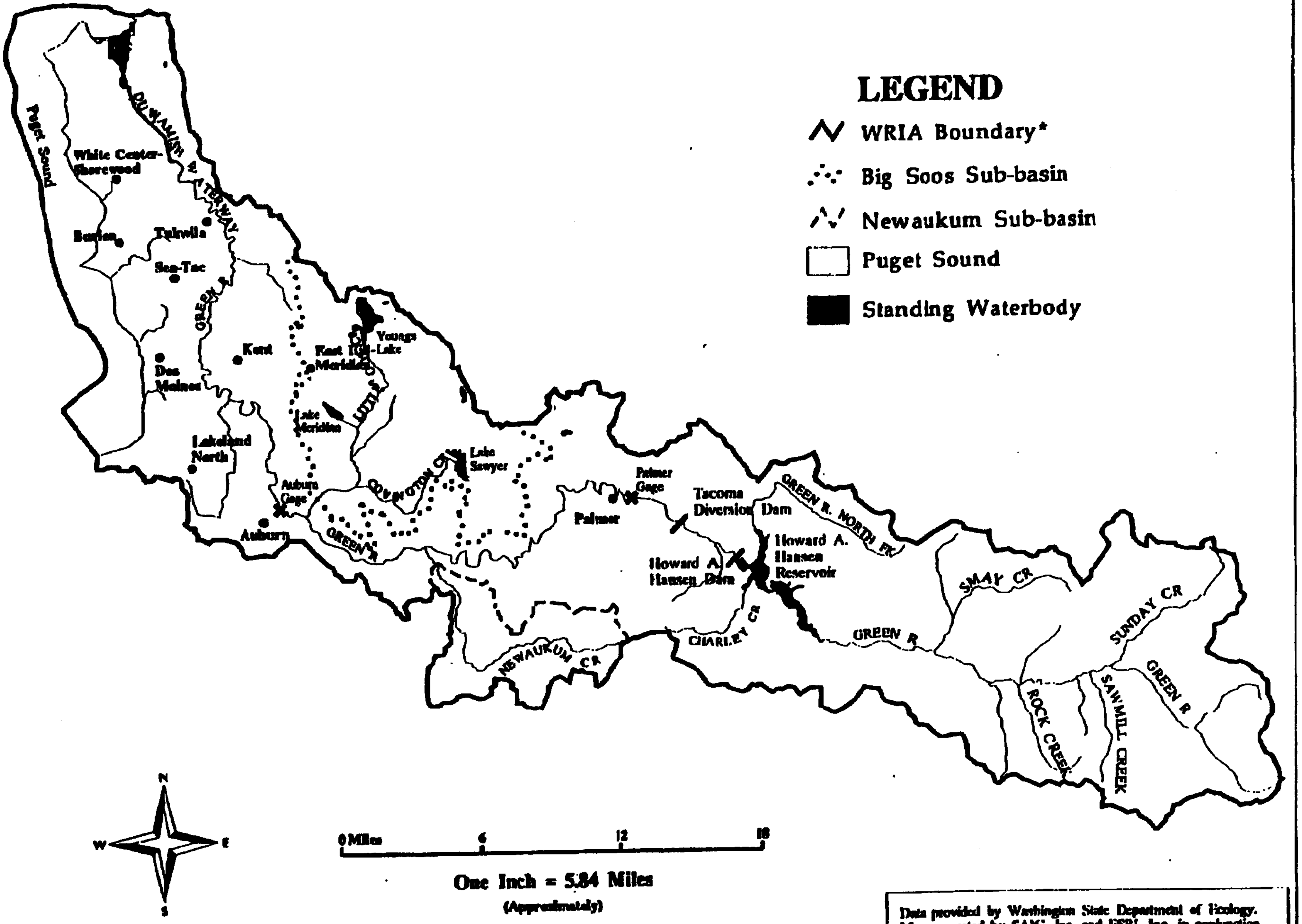


and Supplemental Environmental Impact Statement (Water Resources Inventory Area 9).

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

Woodward, D. G., et al. 1995. Occurrence and quality of ground water in southwestern King County, Washington. U. S. Geological Survey Water-Resources Investigations Report 92-4098.

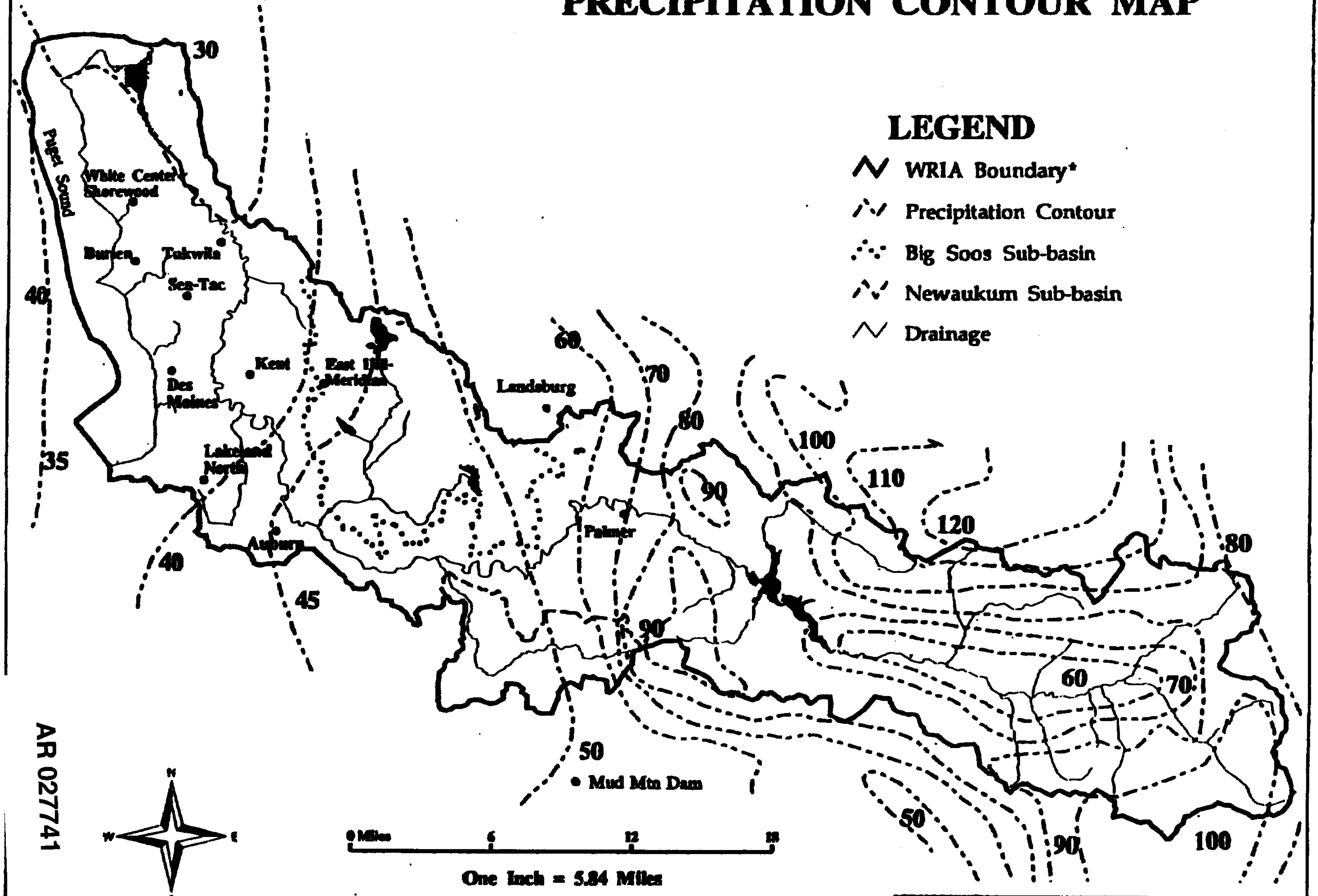
Figure 2 - WRIA 9: GREEN-DUWAMISH WATERSHED



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

*WRIA Boundary is also outer boundary for sub-basins.

Figure 3 - WRIA 9: GREEN-DUWAMISH WATERSHED PRECIPITATION CONTOUR MAP



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

*WRIA Boundary is also outer boundary for sub-basins.

FIGURE 4a - 1950-1992 PRECIPITATION AT SEATAC

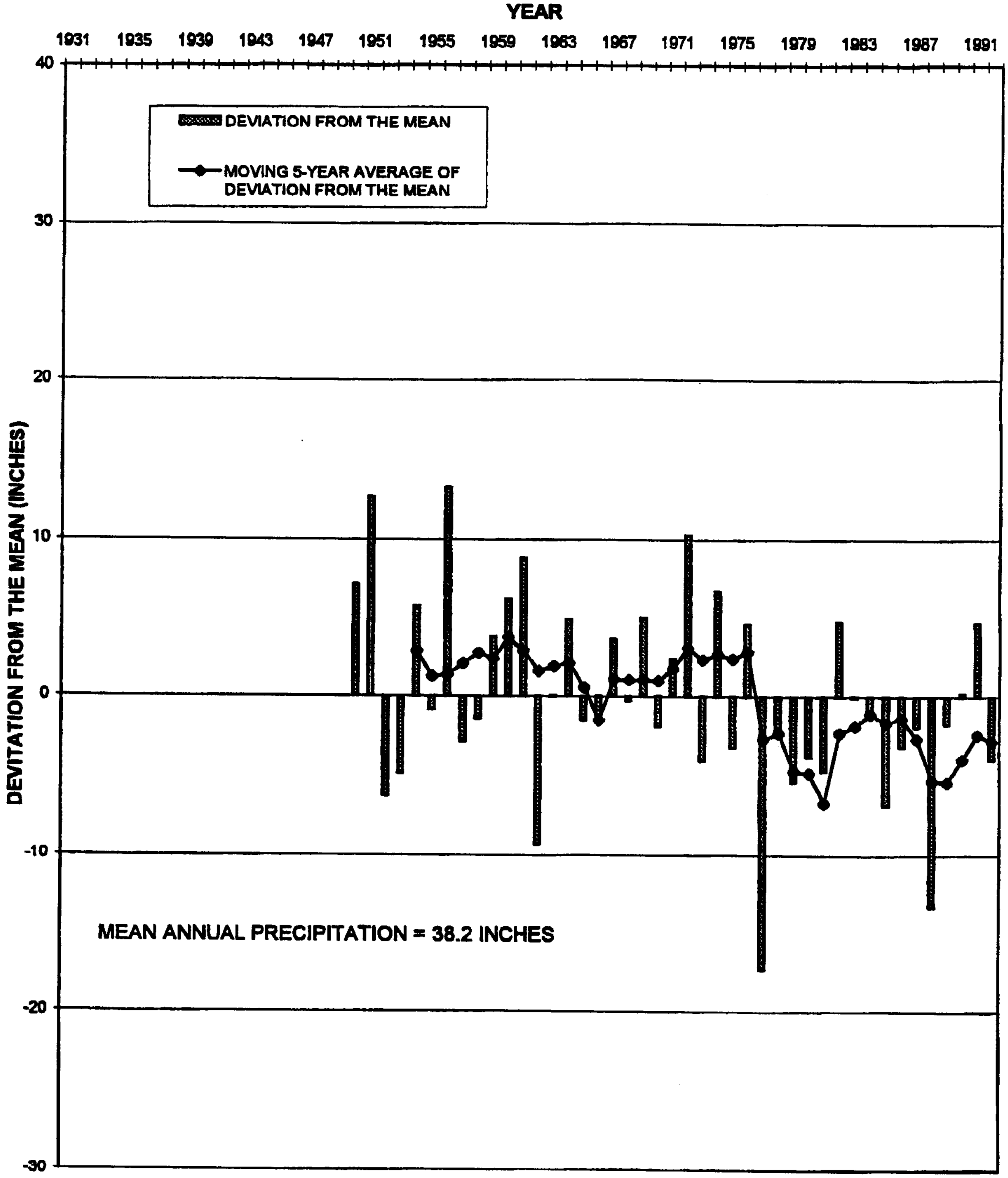


FIGURE 4b - 1932-1992 PRECIPITATION AT PALMER

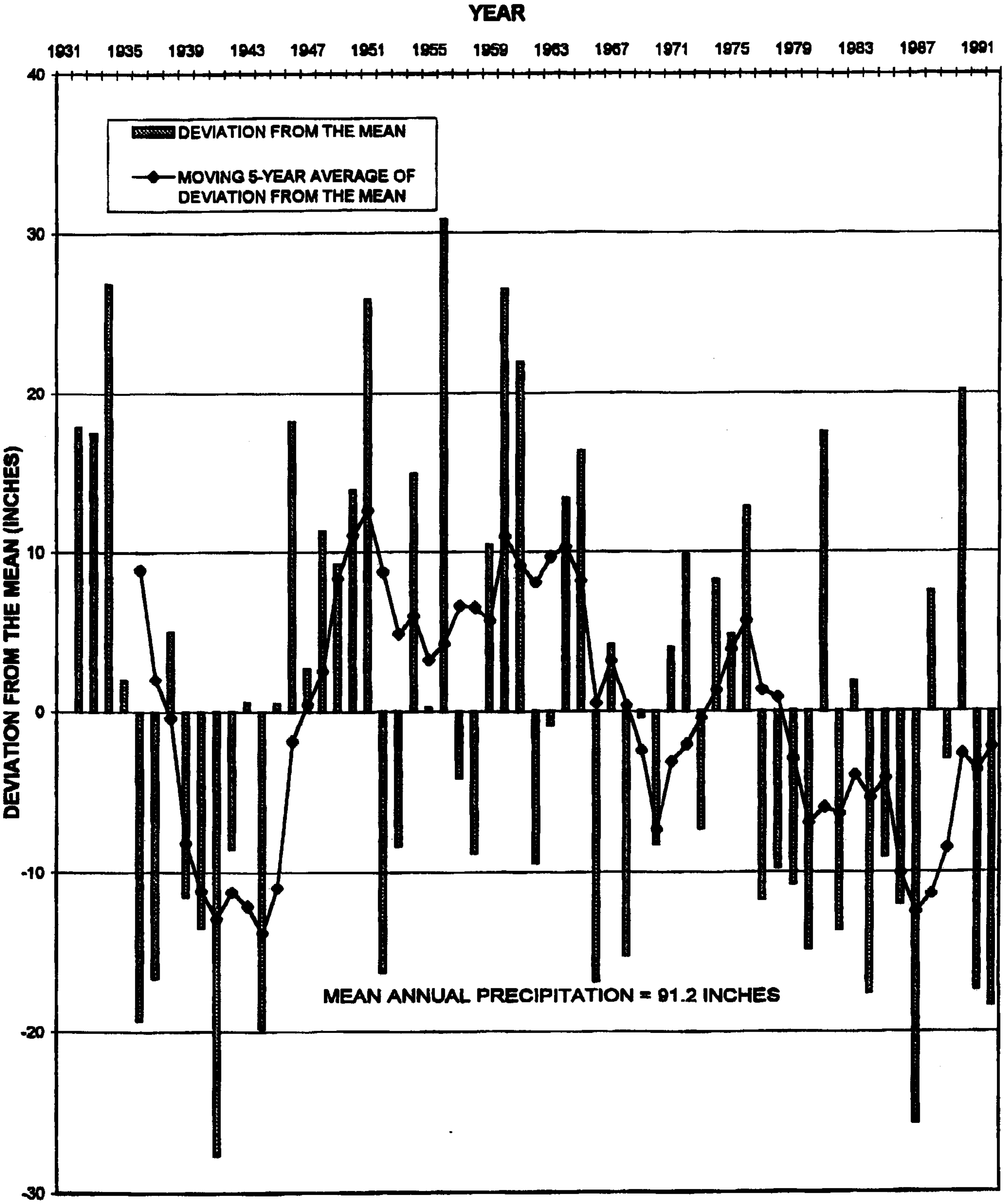


FIGURE 4c - 1931-1991 PRECIPITATION AT LANDSBURG

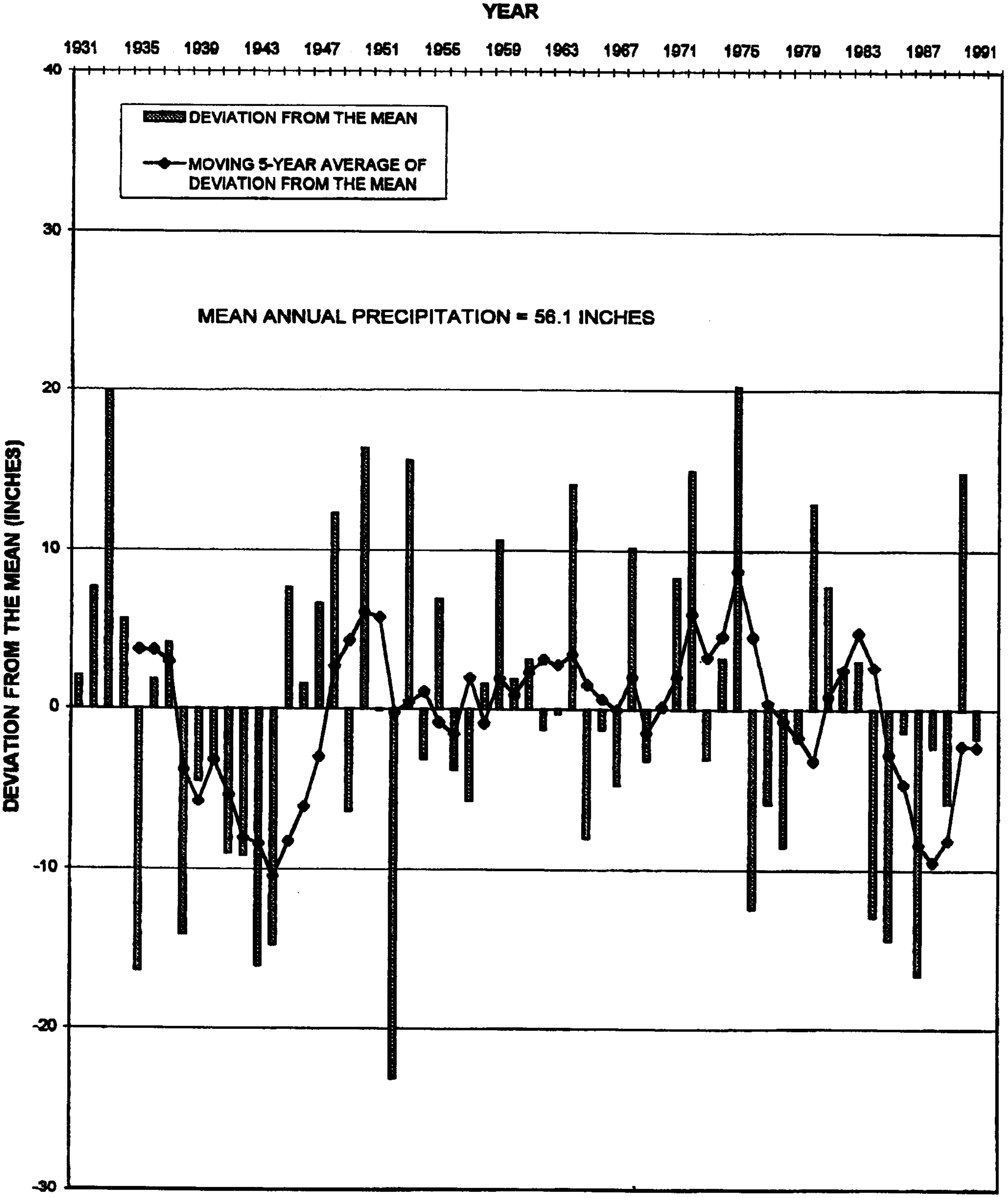


FIGURE 4d - 1940-1992 PRECIPITATION AT MUD MOUNTAIN DAM

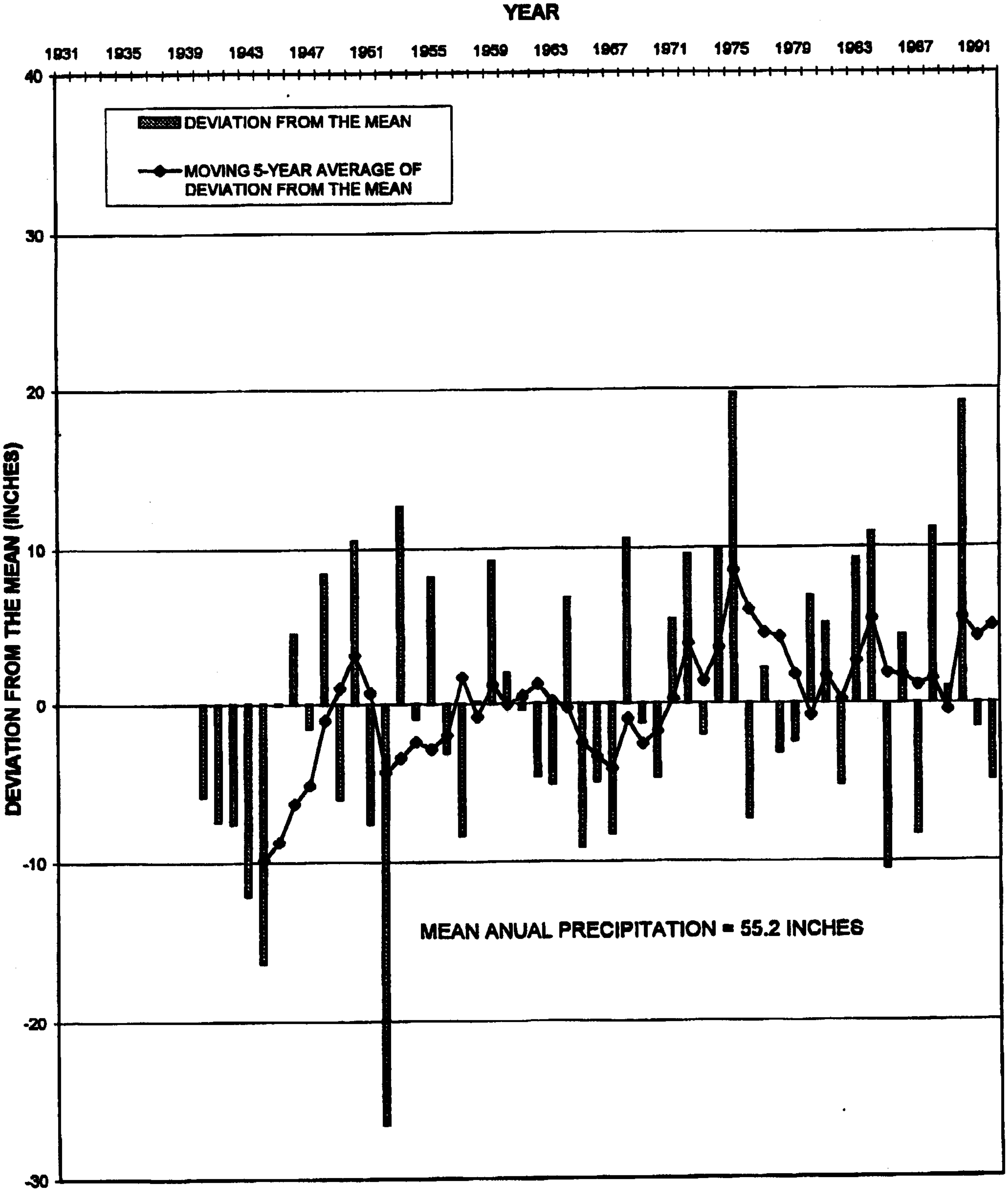
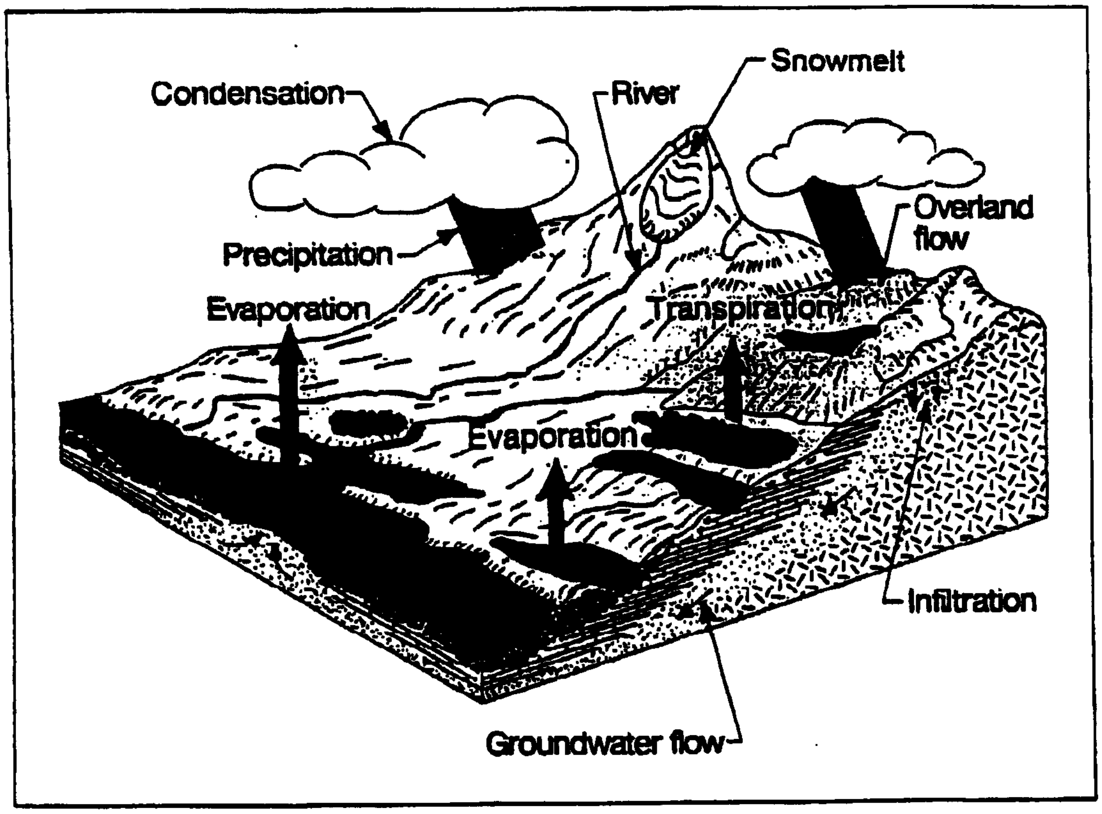
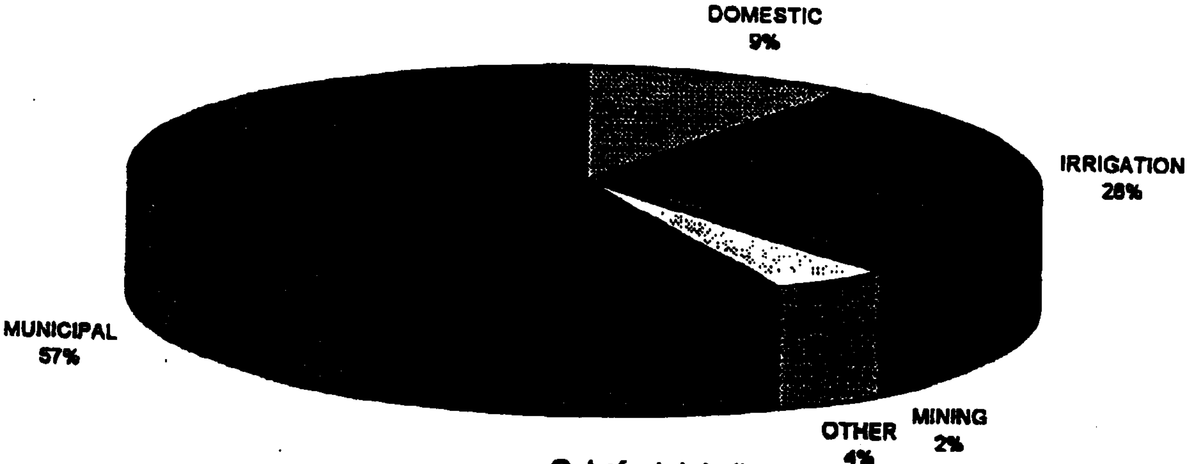


Figure 5 - The Hydrologic Cycle



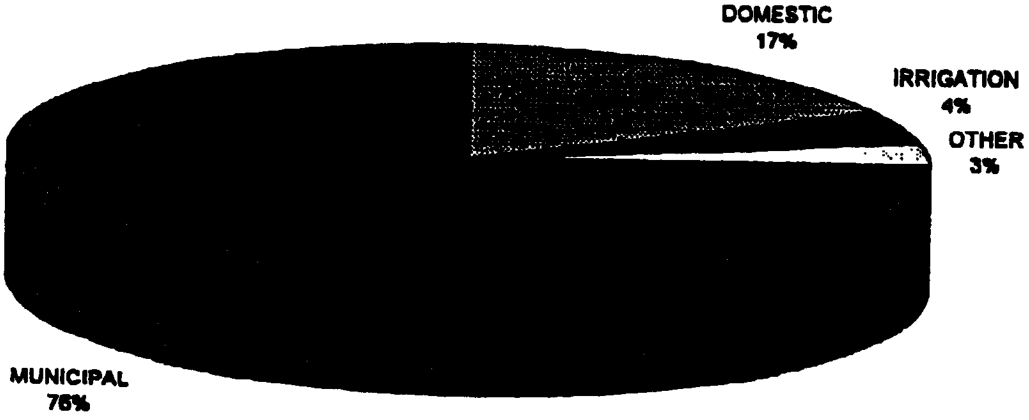
Source: Driscoll (1986)

FIGURE 6 - GREEN-DUWAMISH WATERSHED SURFACE WATER RIGHTS PRIMARY PURPOSE OF USE AS A PERCENTAGE OF TOTAL ALLOCATION



Out of a total allocated quantity of 195.2 CFS

FIGURE 7 - GREEN-DUWAMISH WATERSHED GROUND WATER RIGHTS PRIMARY PURPOSE OF USE AS A PERCENTAGE OF TOTAL ALLOCATION



Out of a total allocated quantity of 350 CFS

FIGURE 8 - GREEN-DUWAMISH WATERSHED CUMULATIVE GROWTH IN SURFACE WATER RIGHTS

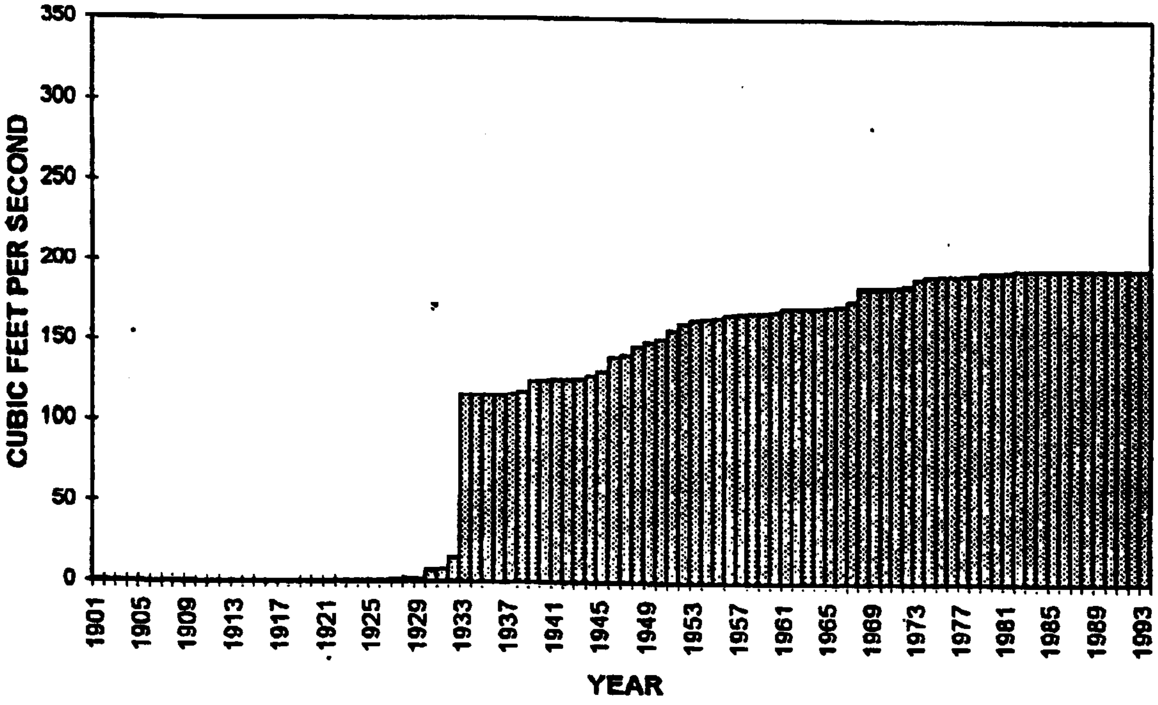


FIGURE 9 - GREEN-DUWAMISH WATERSHED CUMULATIVE GROWTH IN GROUND WATER RIGHTS

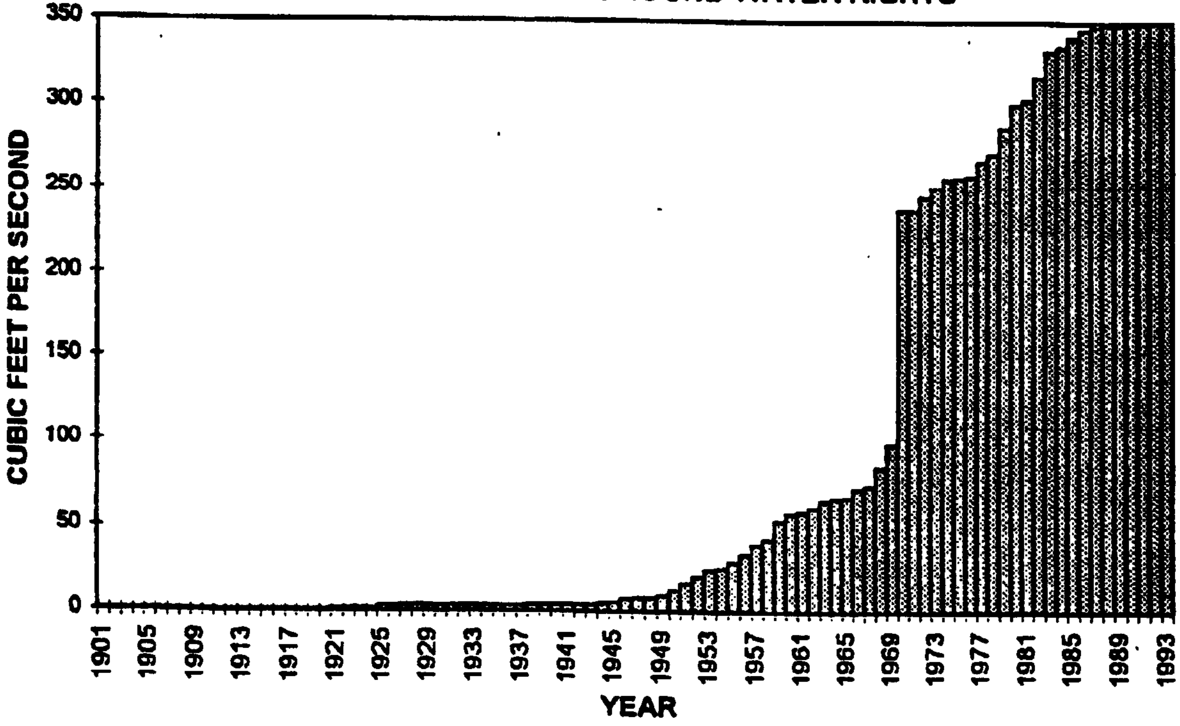


FIGURE 10 - GREEN-DUWAMISH WATERSHED SURFACE WATER VOLUME VS. NUMBER OF WATER RIGHTS

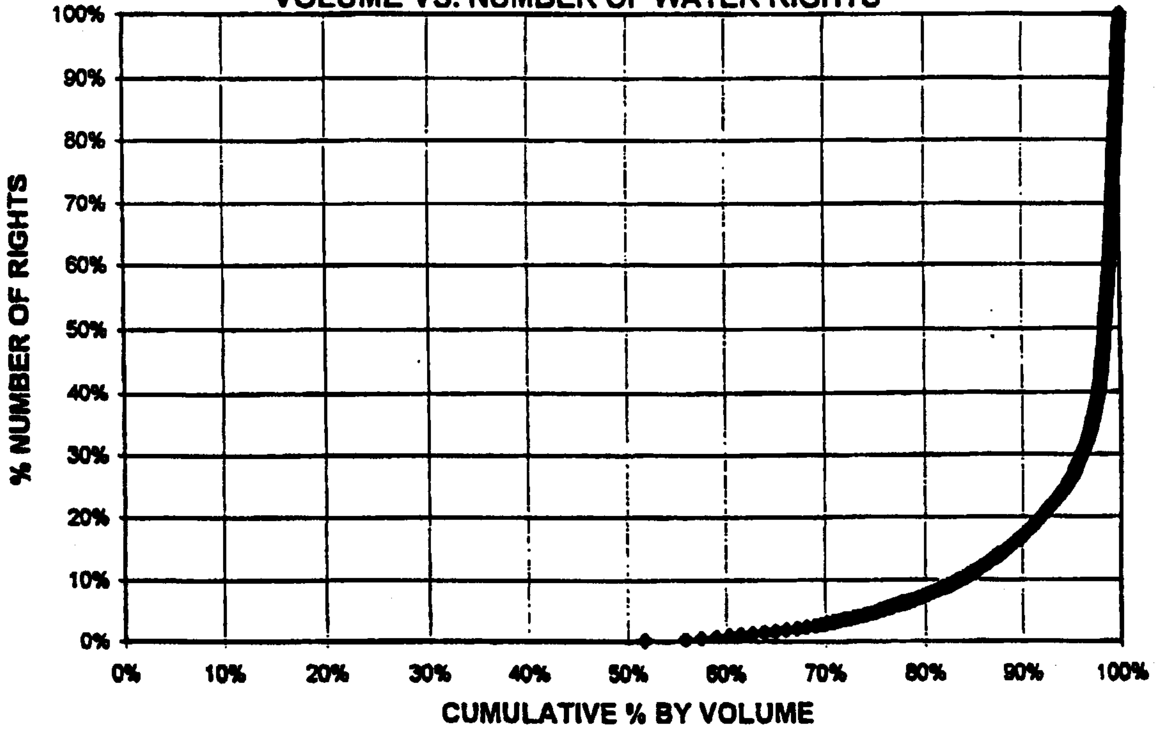
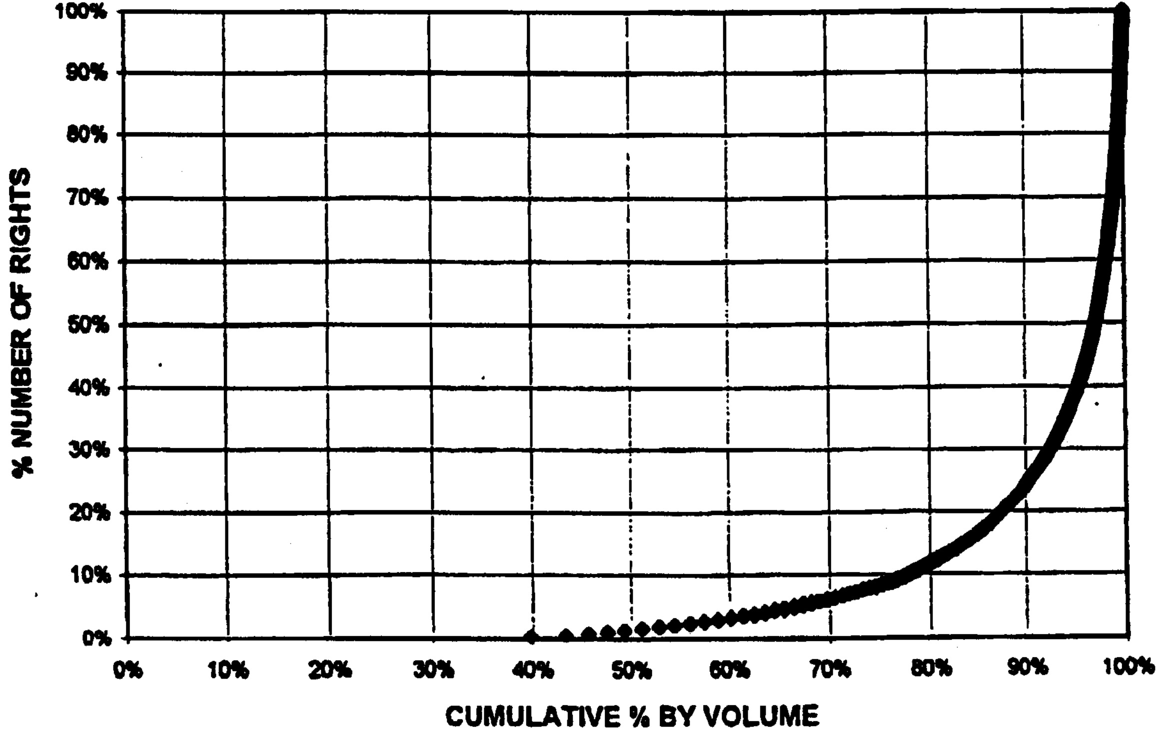


FIGURE 11 - GREEN-DUWAMISH WATERSHED - GROUND WATER VOLUME VS. NUMBER OF WATER RIGHTS



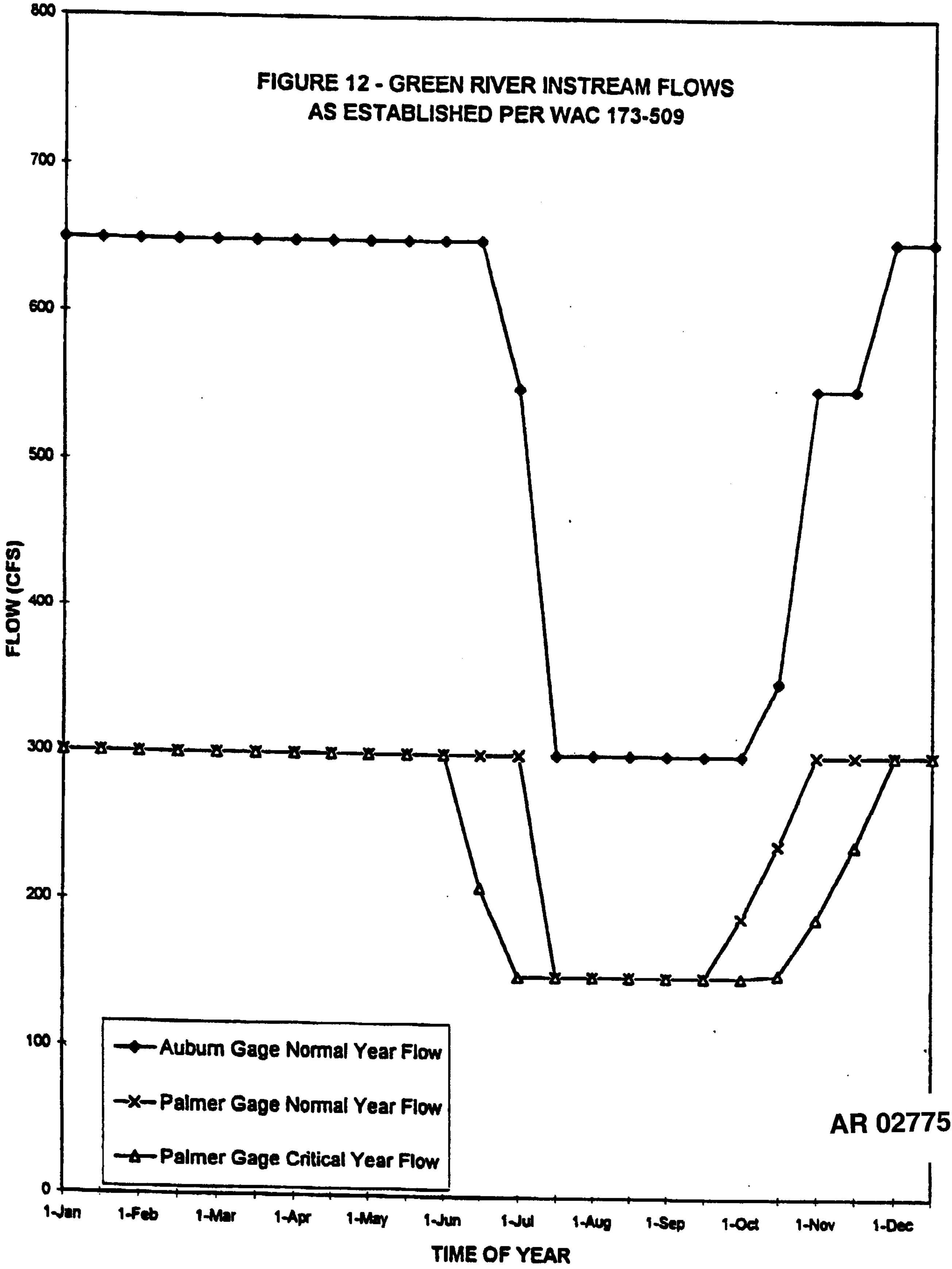


FIGURE 12 - GREEN RIVER INSTREAM FLOWS
AS ESTABLISHED PER WAC 173-509
FLOW (CFS)
800
700
600
500
400
300
200
100
0
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
TIME OF YEAR
Auburn Gage Normal Year Flow
Palmer Gage Normal Year Flow
Palmer Gage Critical Year Flow

FIGURE 11.1 - GREEN-DUWAMISH WATERSHED SURFACE WATER RIGHTS BY SECTION

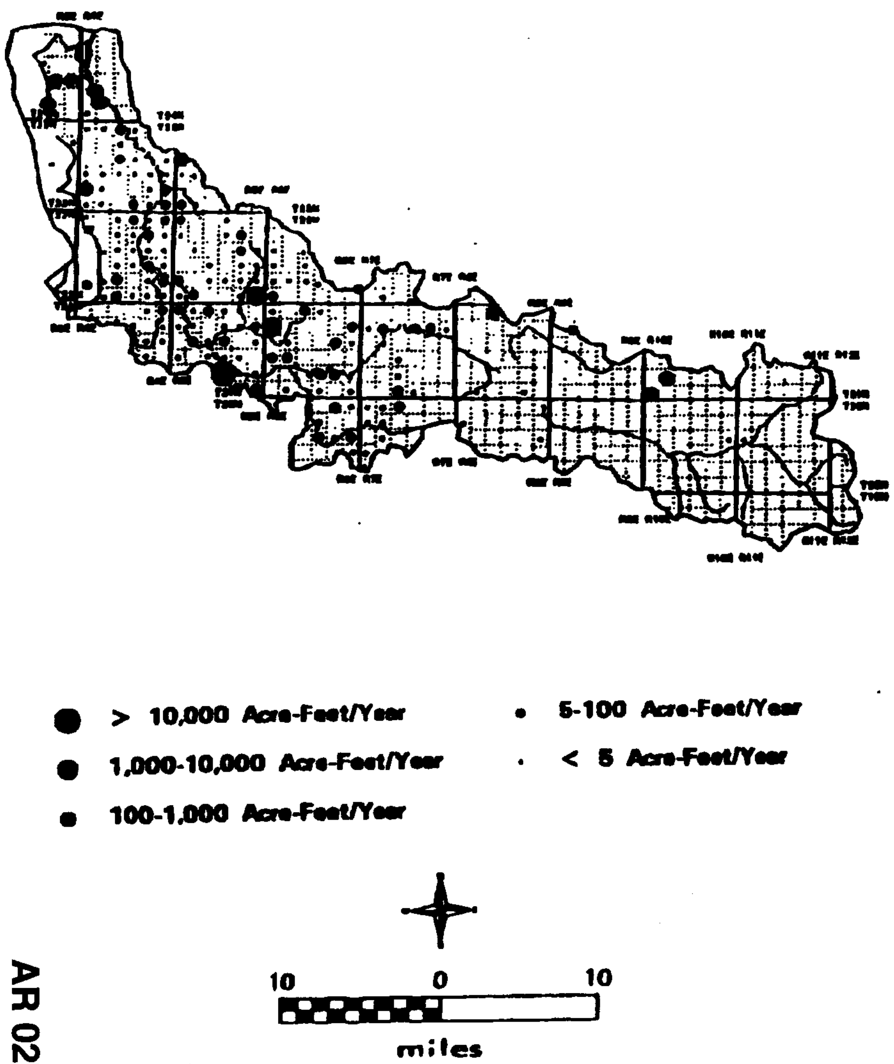


FIGURE 11.2 - GREEN-DUWAMISH WATERSHED GROUND WATER RIGHTS BY SECTION

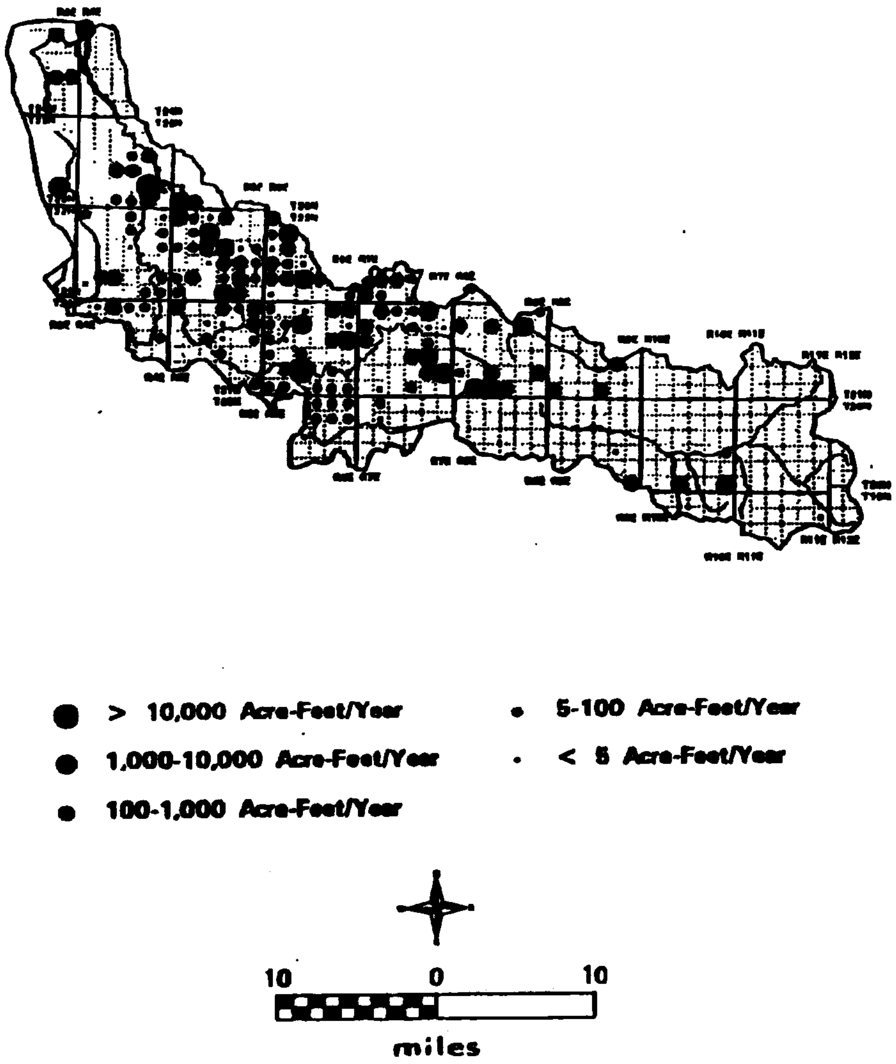
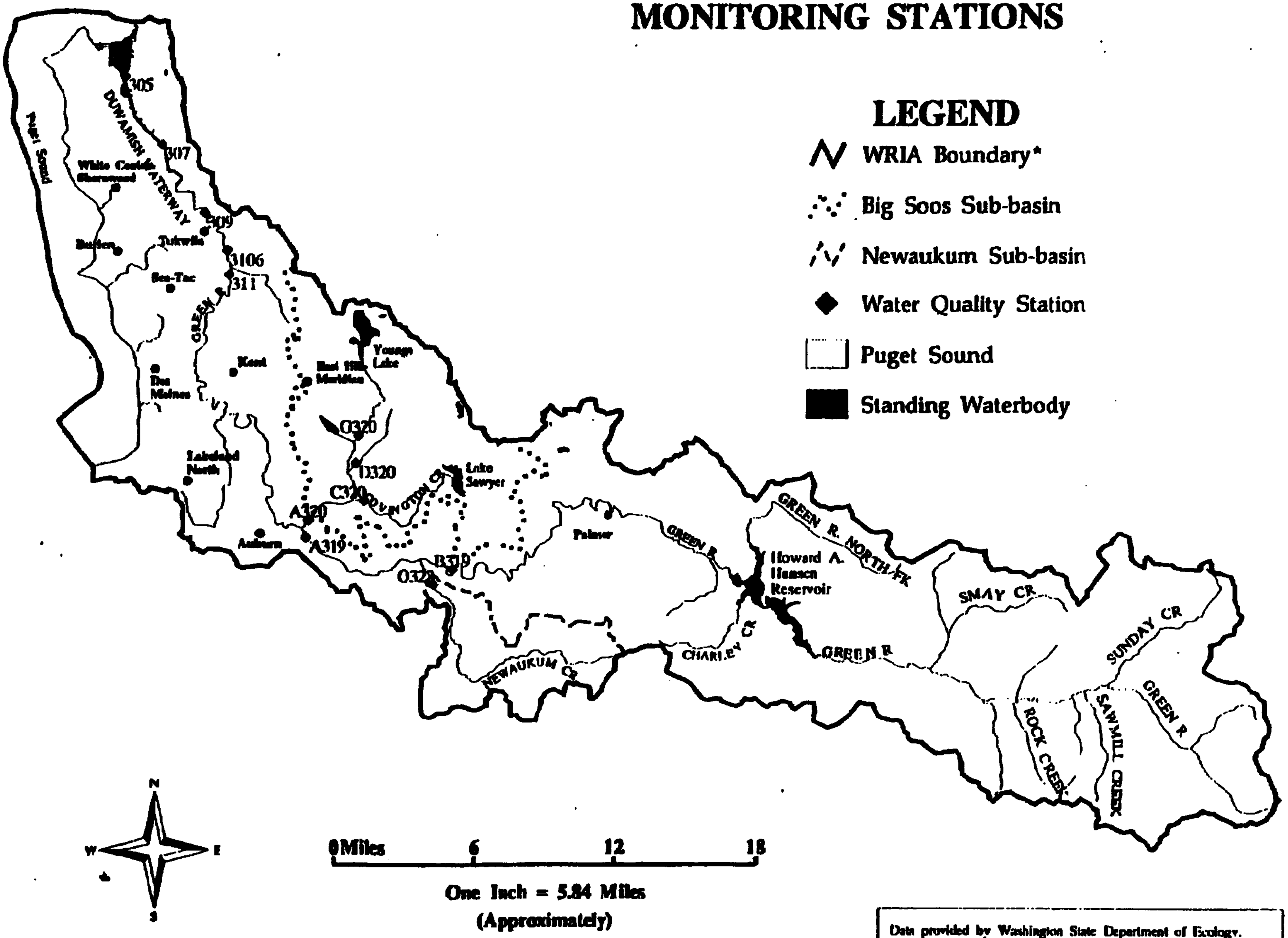


Figure 13 - WRIA 9: GREEN-DUWAMISH WATERSHED
METRO WATER QUALITY MONITORING STATIONS

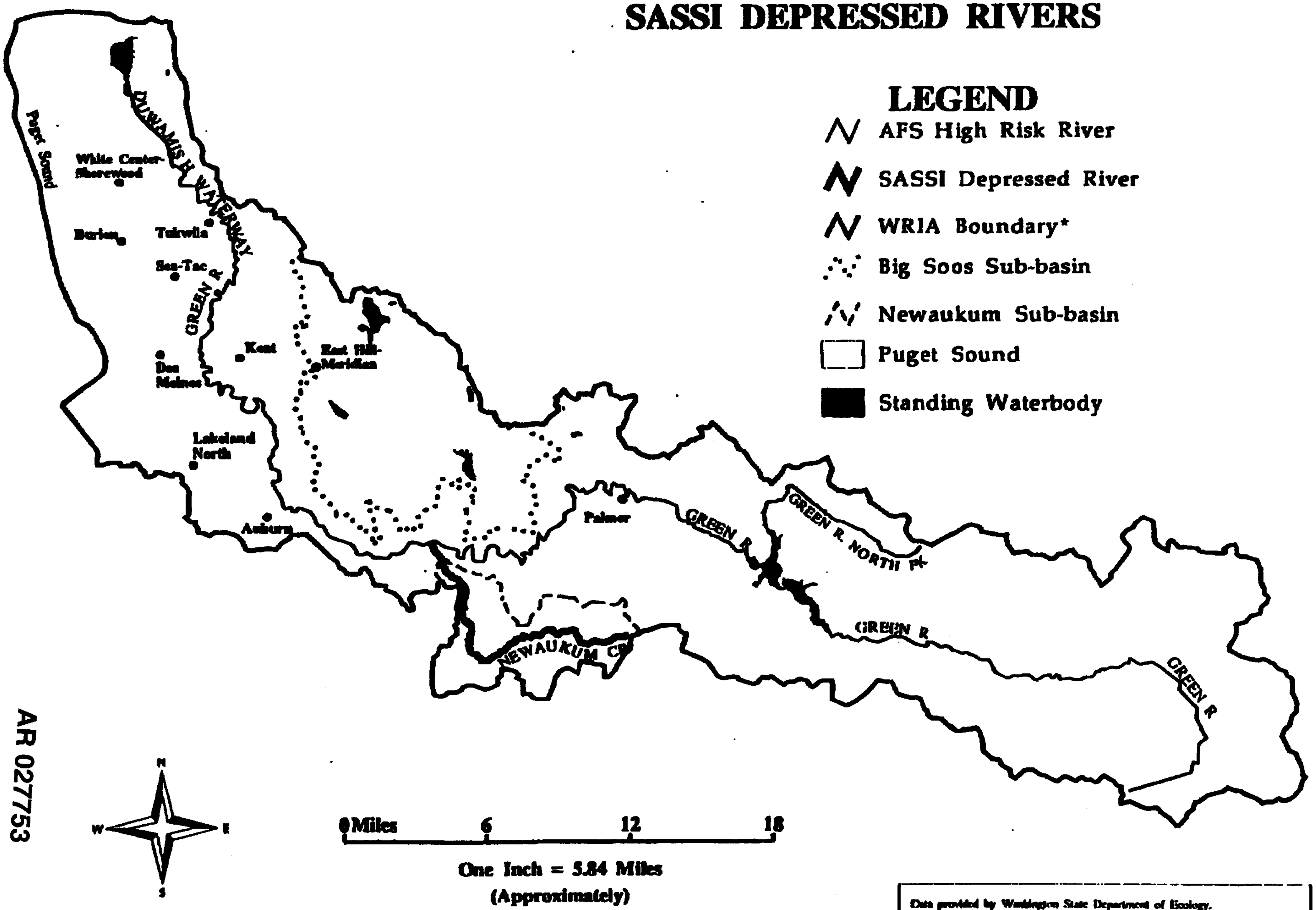


One Inch = 5.84 Miles
(Approximately)

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

*WRIA Boundary is also outer boundary for sub-basins.

Figure 14 - WRIA 9: GREEN-DUWAMISH WATERSHED AFS RISK AND SASSI DEPRESSED RIVERS



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

*WRIA Boundary is also outer boundary for sub-basins.

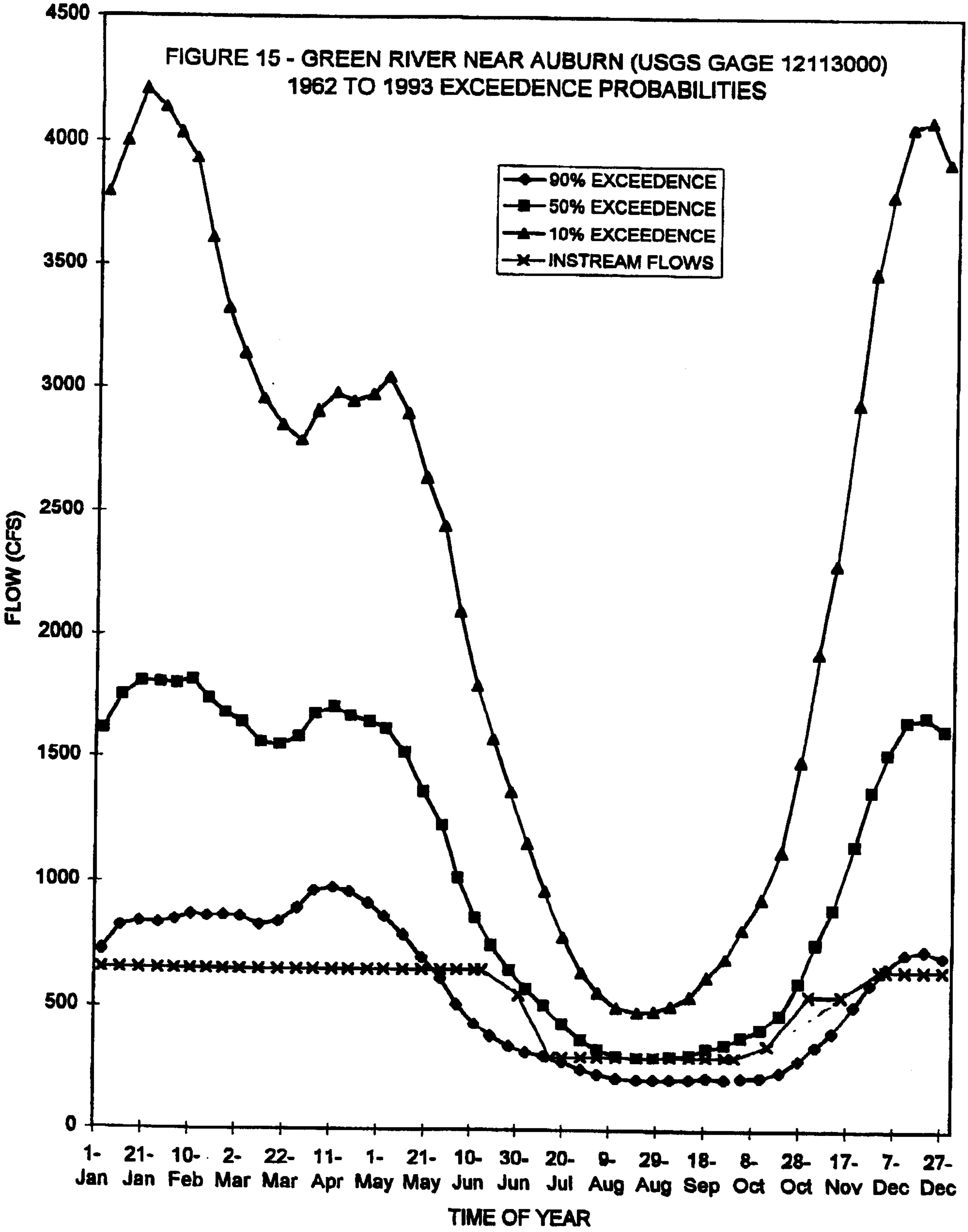


FIGURE 15 - GREEN RIVER NEAR AUBURN (USGS GAGE 12113000)
1962 TO 1993 EXCEEDENCE PROBABILITIES

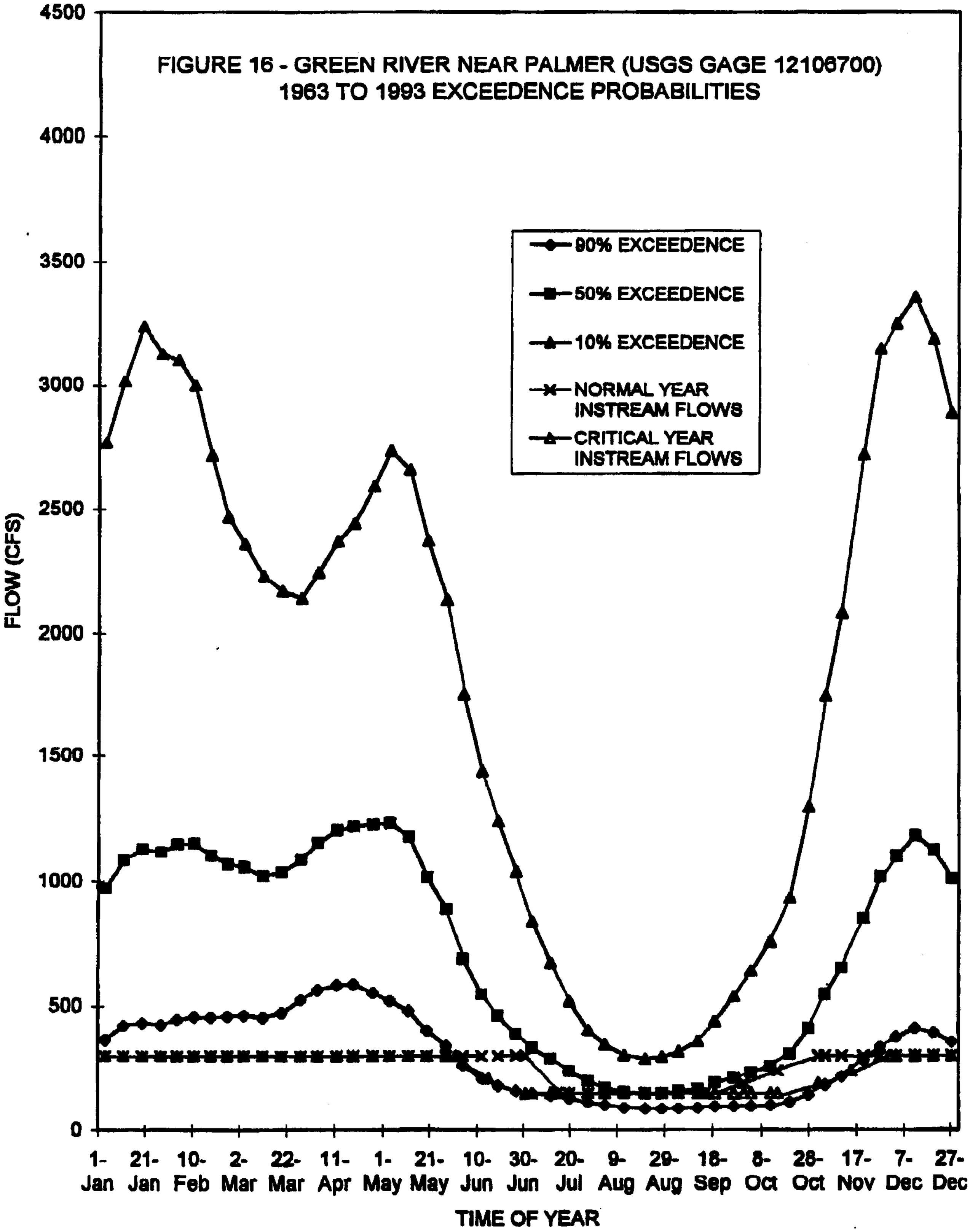


FIGURE 16 - GREEN RIVER NEAR PALMER (USGS GAGE 12106700)
1963 TO 1993 EXCEEDENCE PROBABILITIES
90% EXCEEDENCE
50% EXCEEDENCE
10% EXCEEDENCE
NORMAL YEAR INSTREAM FLOWS
CRITICAL YEAR INSTREAM FLOWS
FLOW (CFS)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1-Jan
21-Jan
10-Feb
2-Mar
22-Mar
11-Apr
1-May
21-May
10-Jun
30-Jun
20-Jul
9-Aug
29-Aug
18-Sep
8-Oct
28-Oct
17-Nov
7-Dec
27-Dec
TIME OF YEAR

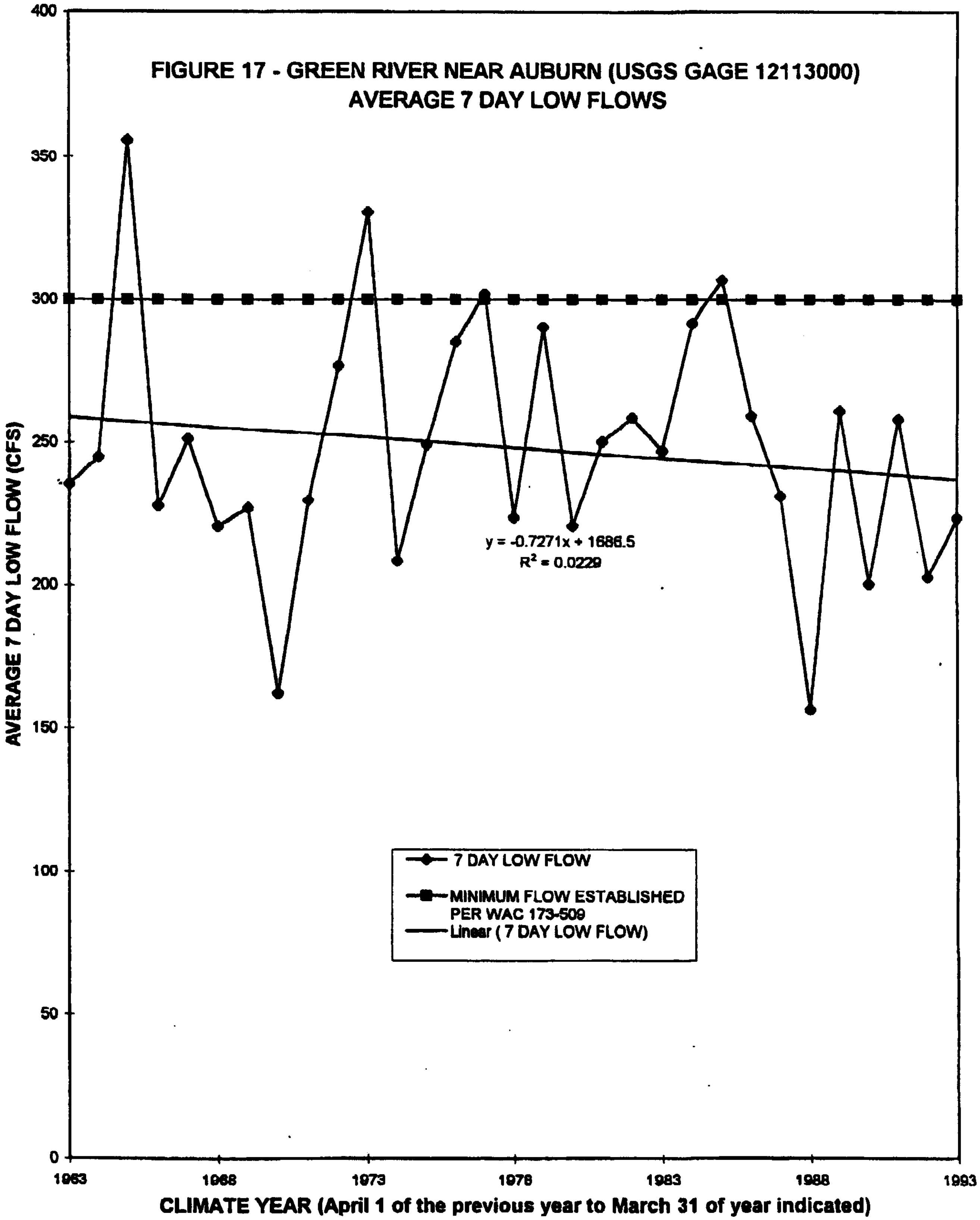


FIGURE 17 - GREEN RIVER NEAR AUBURN (USGS GAGE 12113000)
AVERAGE 7 DAY LOW FLOWS

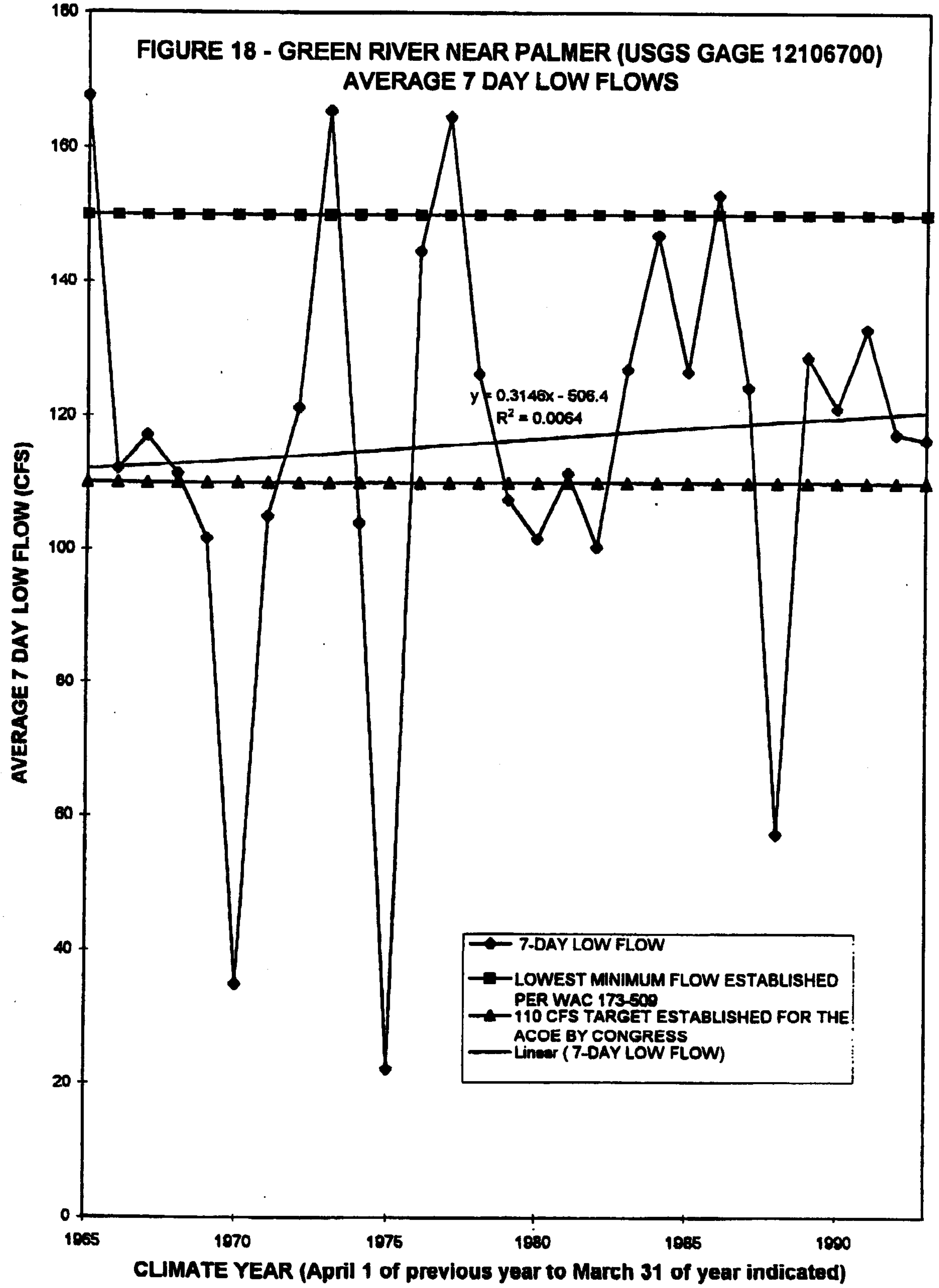


FIGURE 18 - GREEN RIVER NEAR PALMER (USGS GAGE 12106700)
AVERAGE 7 DAY LOW FLOWS

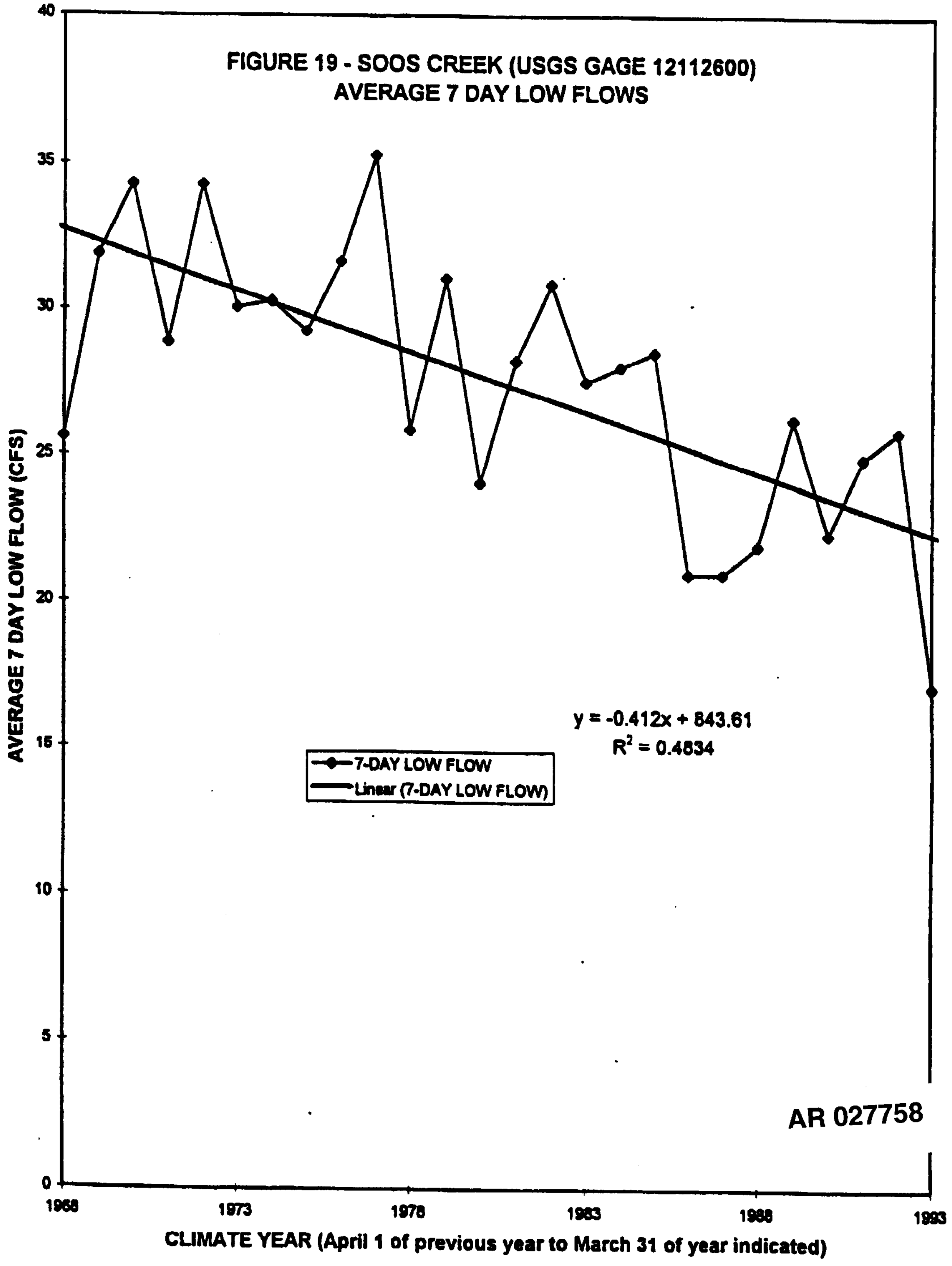


FIGURE 19 - SOOS CREEK (USGS GAGE 12112600)
AVERAGE 7 DAY LOW FLOWS

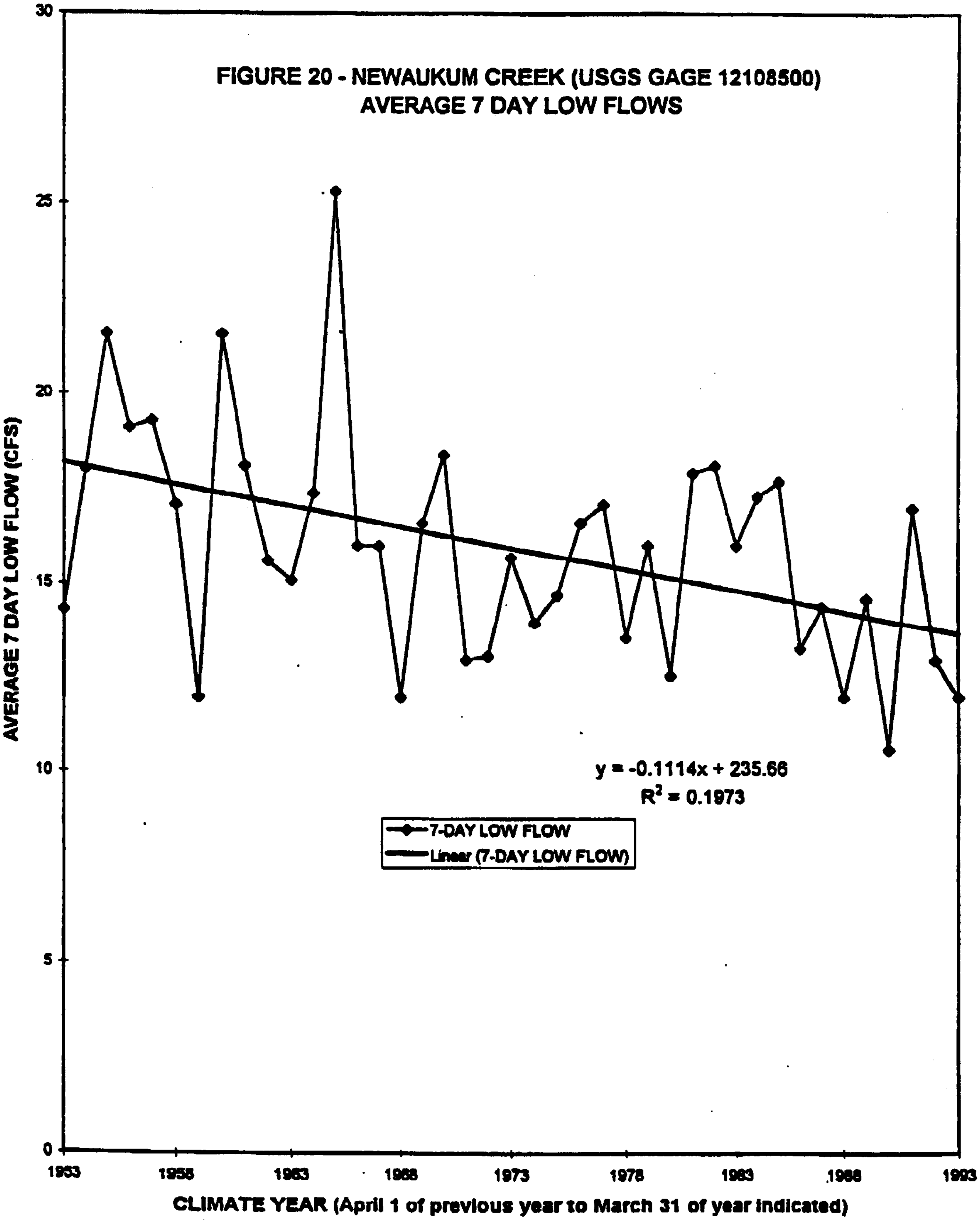


FIGURE 20 - NEWAUKUM CREEK (USGS GAGE 12108500)
AVERAGE 7 DAY LOW FLOWS

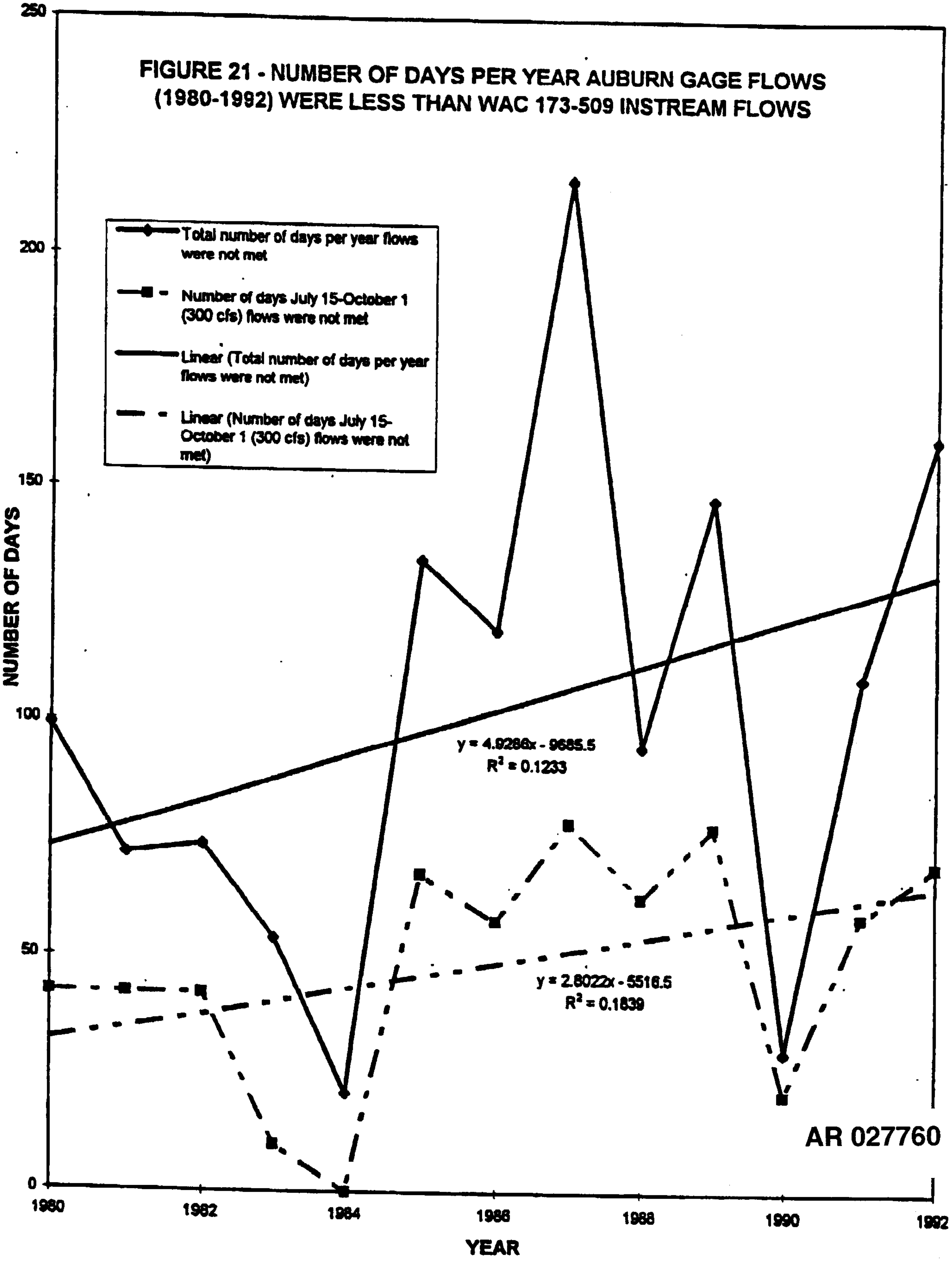


FIGURE 21 - NUMBER OF DAYS PER YEAR AUBURN GAGE FLOWS (1980-1992) WERE LESS THAN WAC 173-509 INSTREAM FLOWS

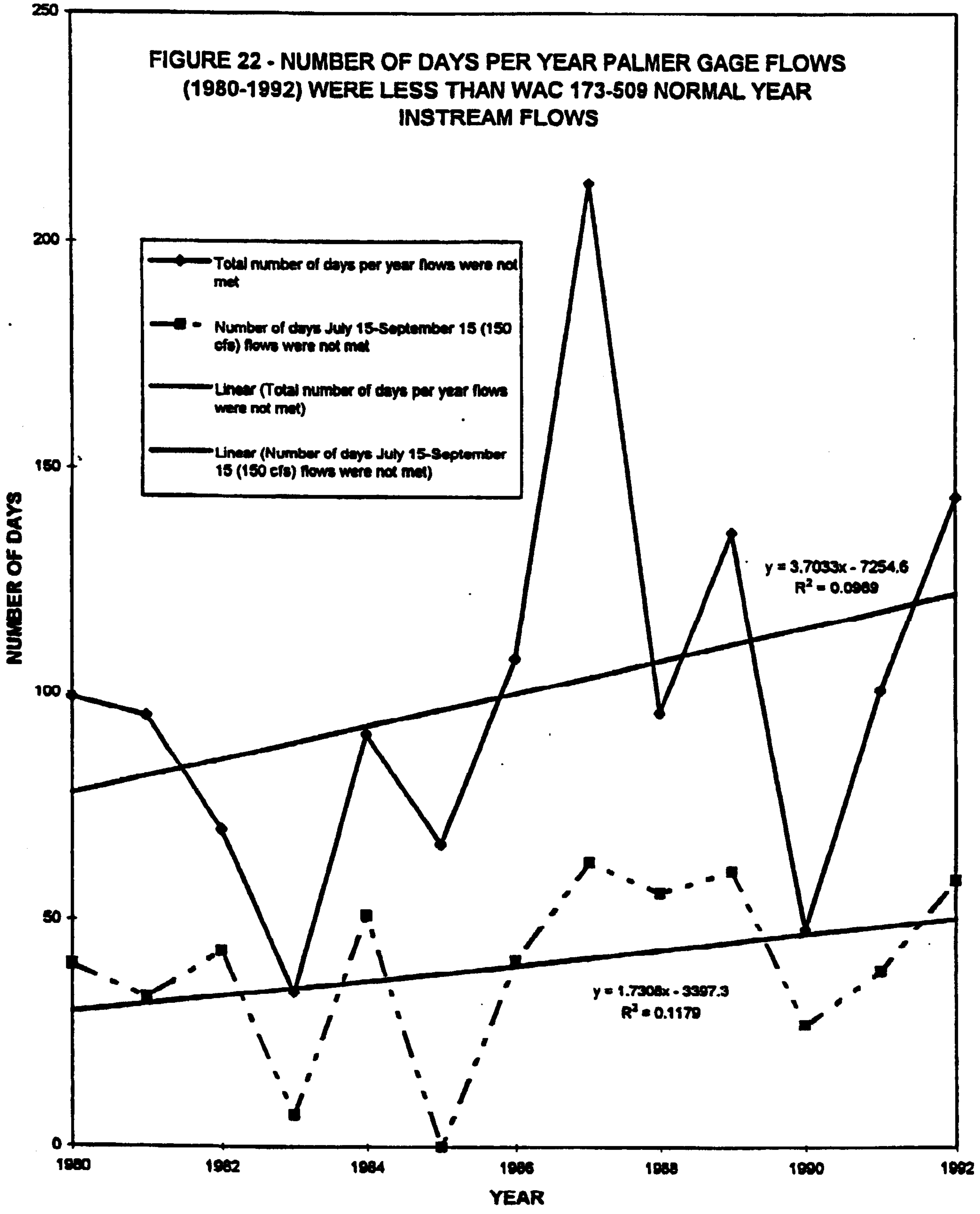


FIGURE 22 - NUMBER OF DAYS PER YEAR PALMER GAGE FLOWS (1980-1992) WERE LESS THAN WAC 173-509 NORMAL YEAR INSTREAM FLOWS

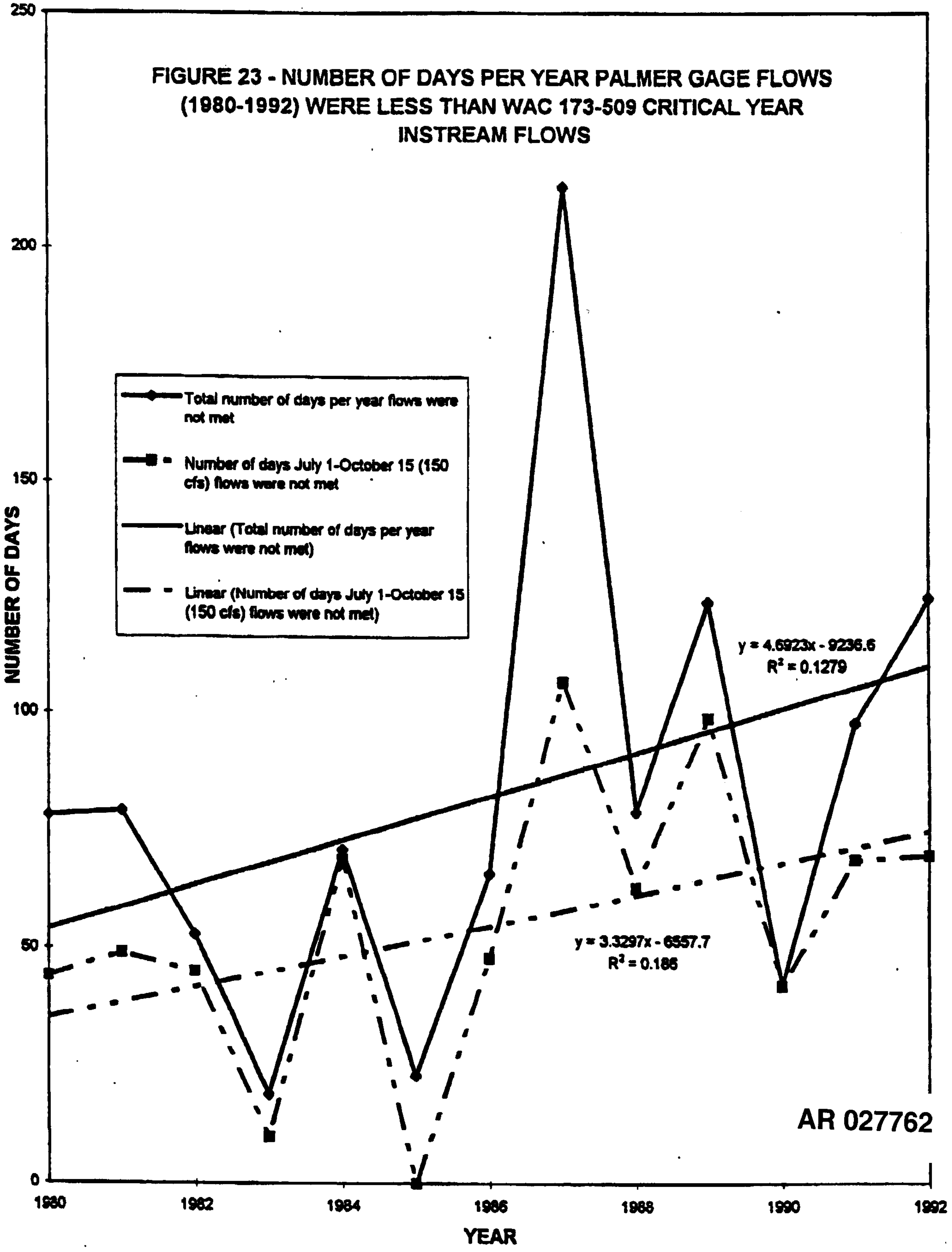


FIGURE 23 - NUMBER OF DAYS PER YEAR PALMER GAGE FLOWS (1980-1992) WERE LESS THAN WAC 173-509 CRITICAL YEAR INSTREAM FLOWS

FIGURE 24 - COMPARISON OF SEATAC AND LANDSBURG PRECIPITATION, AND SOOS CREEK FLOWS 1967-1991

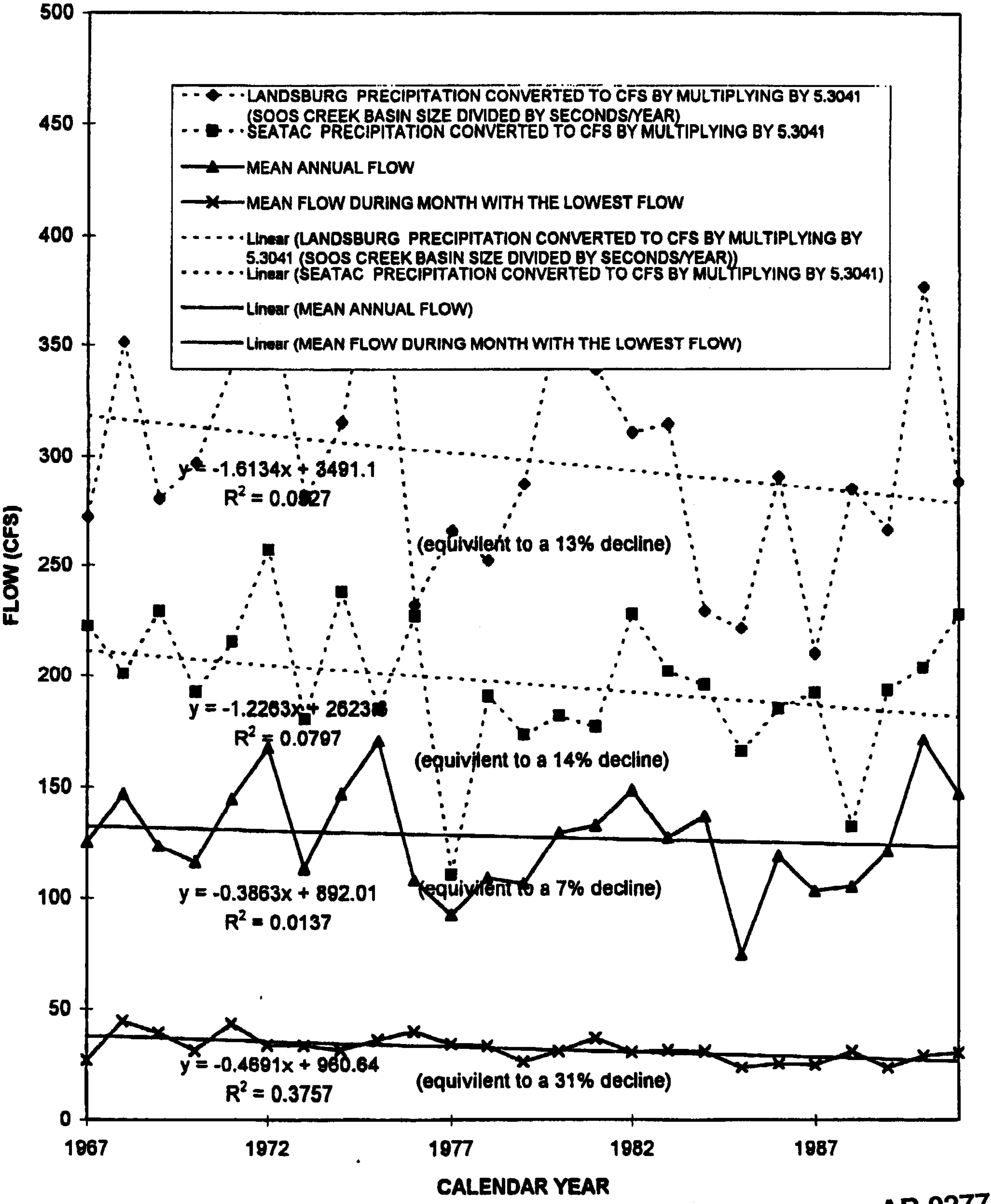


FIGURE 25 - COMPARISON OF PALMER AND MUD MOUNTAIN DAM PRECIPITATION, AND NEWAUKUM CREEK FLOWS 1953-1992