WATERSHED ASSESSMENT

WATER RESOURCE INVENTORY AREA 28,

SALMON-WASHOUGAL

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ABSTRACT

This report provides a compilation of hydrogeologic and hydrologic data and interpretations relevant to water management in the Salmon-Washougal Water Resource Inventory Area 28, a grouping of adjacent watersheds that are tributary to the Columbia River. The Washington Department of Ecology may use this information when processing water-rights applications, regulating permitted uses of water, and protecting water quality.

Water-supply conditions in Water Resource Inventory Area (WRIA) 28 result from a complex set of factors, particularly (1) the cool, moist climate, (2) the volcanic and sedimentary geologic units, (3) the varied and distinctive topographic features and terrain, and, in places, (4) human intervention.

Water use, as reflected in water rights and claims, has increased steadily since establishment of the water-rights system in 1917. Withdrawals now consume significant amounts of water when compared to dry-season streamflows (excepting the Columbia River) and to the average annual ground-water replenishment in the densely developed areas of WRIA 28. Little is known about actual water use, but it is probably less than the amount authorized by water rights. Unauthorized uses have been surveyed only in the Salmon Creek and Burnt Bridge watersheds. Water-use reporting would be extremely beneficial for scientific water management, as would the accurate mapping of stream diversions and wells.

Heads have declined five feet or more throughout the western portion of WRIA 28, particularly in areas where municipal wells serve the growing population. This may continue until pumping rates stabilize. These declines have limited water production and impaired senior water rights in a few localities. At least one major spring has been nearly depleted by withdrawals from the contributing aquifer.

Capture of surface water by ground-water withdrawals has probably reduced streamflow in some stream reaches. However, streamflow gaging was not initiated until the 1980's, well after withdrawals had begun. Presently, only Salmon Creek is adequately monitored. An extensive monitoring network for ground-water levels measured by Clark Public Utilities and the Department of Ecology, combined with a growing network of stream gages operated by Clark Public Utilities and Clark County, eventually will provide more definitive answers to water quantity, quality, and habitat concerns. Expansion of streamflow monitoring to multiple locations on every major stream would greatly enhance our understanding of water availability and warn of long-term decreases in rates of flow.

Surface-water quality has been degraded in much of the Lake River, Salmon Creek, and Burnt Bridge Creek watersheds. Less widespread degradation has occurred in most of the other principle rivers and creeks. Most of the degradation originates from non-point sources such as agriculture, inadequately controlled land clearing, and contaminated runoff. In the Salmon Creek and Lackamas watersheds, Clark Public Utilities and the Conservation District have accomplished restoration of several miles of riparian habitat, which significantly, reduced erosion, sediment loads, and runoff of animal waste.

Ground-water quality is very good, with only local sites of contamination due to industrial leaks and spills.

Only about 5% of the original salmon and steelhead populations have survived in WRIA 28. High water temperature and loss of spawning and rearing habitat rank high among the factors limiting recovery of the fisheries. In March 1998, the National Marine Fisheries Service announced the listing of steelhead as endangered in the lower Columbia River area.

INTRODUCTION

WATER-RESOURCES MANAGEMENT IN WASHINGTON

The Department of Ecology's Water Resources Program is responsible for managing the waters of the state to ensure that they are protected and used to the greatest benefit. An important component of this responsibility is the permitting and enforcement of water rights, as authorized by Chapters 90.03, 90.22, 90.44, and 90.54 of the Revised Code of Washington (RCW).

When considering whether to grant a permit for water use, the Department of Ecology must determine that the proposed use passes four statutory tests (Chapter 90.03 RCW):

1) The use will be beneficial,
2) The use will be in the public interest,
3) Water is physically available for the requested use, and
4) The proposed use will not impair senior water rights or minimum streamflows.

Beneficial use and public interest have been defined in regulation. The third and fourth tests require broader evaluations of the hydrologic system to determine whether the requested use can be perpetually sustained without: (1) impairing senior water users, (2) causing excessive reductions of streamflow or lowering of the ground-water level (head), (3) violating the state's non-degradation laws for water quality, or (4) degrading aquatic and riparian habitat.

The intent of this report is to provide background information and data that describe the hydrologic conditions of the watershed. This compilation of information will enable the Department of Ecology to make decisions on pending water right applications by providing a greater understanding of the baseline conditions needed to predict the long-term effects of new allocations on senior water right holders, instream flows, and the hydrologic system.

SCOPE OF REPORT

This report documents the status of surface-water and ground-water resources in the Salmon/Washougal Water Resource Inventory Area (WRIA) 28 (Figure 1). Also identified are key water-management issues that influence water-right permit decisions.

This report relies on readily available information about water rights and claims, streamflow, precipitation, hydrogeology, ground-water levels, fish stocks, and water quality. Because this report is intended as an initial summary, limited by time and budget, we did not conduct field surveys or collect data.

Data sources used included Ecology's Water Right Information System (WRIS), Water Rights Application Tracking System (WRATS), well logs, and the Water Quality Program's 303b and 305b databases, and the United States Geological Survey's Ground Water Information System (GWIS). None of this data was exhaustively checked for accuracy.

WATERSHED DESCRIPTION

PHYSICAL GEOGRAPHY and GENERAL TOPOGRAPHY

The Salmon/Washougal Water Resource Inventory Area (WRIA 28) consists of the southern portion of Clark County and southwestern Skamania County, located in southwestern Washington, about 60 miles inland from the Pacific Ocean (Figure 1). The inventory area is bounded by the Columbia River to the south and west, the Wind River watershed (part of WRIA 29, Wind/White Salmon) to the east, and the East Fork Lewis River (part of WRIA 27, Lewis) watershed to the north.

The Salmon/Washougal Water Resource Inventory Area is not a single watershed but a composite of several adjoining watersheds which are tributary to the Columbia River. These tributary watersheds include the drainages of Lake River, Salmon Creek, Burnt Bridge Creek, the Washougal River, and numerous smaller streams. Together these drainages cover 316,365 acres, or 494 square miles, with approximately 75% in Clark County and 25% in Skamania County. Of the total drainage area, Salmon Creek covers 89 square miles, or 18%; Lackamas Creek covers 66 square miles, or,13%; and the Washougal River covers 145 square miles, or 29% (Gladwell and Mueller, 1967a).

The study area is part of a sediment-filled structural depression known as the Willamette-Puget Trough. This trough, which lies between the Cascade and Coast Ranges, extends from the Puget Sound in Washington State through the Willamette Valley of west central Oregon. The terrain in the western half of the area is generally level, rising in a series of benches and terraces toward the north and northeast from the alluvial floodplain of the Columbia River. The terrain slowly ascends toward the east, eventually becoming the foothills of the Cascade Range. Land elevations vary from less than ten feet above sea level along the south and west (on the Columbia River floodplain) to over 3,000 feet in the Cascade foothills. (Gladwell and Mueller, 1967a).

HYDROGRAPHY

Most streams in the study area originate in the Cascade foothills. Those in Skamania County, such as the Washougal River and Lacamas Creek, drain into the Columbia River. Those in Clark County, such as Gee Creek, Salmon Creek, and Burnt Bridge Creek, drain into the Lake River, a slough along the edge of the Columbia River's floodplain, north of Vancouver Lake. Several small streams to the east of the Washougal River, known collectively as the Bonneville tributaries, drain directly to the Columbia River.

The total surface area of WRIA 28's lakes is approximately 4,500 acres, with the majority, 2,858 acres, in Vancouver Lake. This lake is situated on the western boundary of the watershed, and lies at the edge of the Columbia River floodplain, about one mile from the river. The other lakes are considerably smaller and are distributed more or less uniformly throughout the lower elevation, western portion of the area.

LAND COVER

In the foothills and mountains of the eastern part of the study area, forests dominate the landscape's vegetative cover. To the west, where the topography transitions to the plains and prairies, grass and shrubs predominate, with small patches of trees remaining along the stream corridors. Much of the land has been cleared for agriculture and residential development. At the western and southern edges lies the Columbia River bluff and floodplain, occupied by marshes, lakes, sloughs, grasslands, croplands, and scattered patches of forest.

LAND USE

Agriculture dominates land use in the western and central parts of the study area, while the eastern portions are used extensively for silviculture. Much of the Columbia River flood plain and alluvial terraces (known locally as plains) on the southern part of the study area, have been converted to urban uses. The most dense settlements occupy the southwestern third of the area, with the City of Vancouver being the largest urban center. Other towns include Battle Ground, Brush Prairie, Camas, North Bonneville, Orchards, and Washougal.

The largest manufacturing centers are located in the Vancouver and Camas areas. Manufacturing employment in Clark County has been growing rapidly in the 1990's, particularly in the technology sector. Traditional industries such as forest products, the retail and service trade, and government are also major employers (Washington Employment Security Department, 1990; Washington Office of Financial Management, 1994).

Three National Wildlife Refuges are located along the Columbia River. Lake Steigerwald National Wildlife Refuge, located southeast of Camas, and the Franz Lake National Wildlife Refuge and Pierce Ranch National Wildlife Refuges, located near Beacon Rock State Park, are presently being managed to restore additional wetland habitat lost when the lakes and ranch areas were diked and drained. These refuges, and many other areas within the watershed provide important wildlife habitat for migratory and resident wildlife.

POPULATION GROWTH

The population of the study area is concentrated in southern Clark County, primarily within the Vancouver and Camas-Washougal areas. The population within Clark County and the greater Vancouver area grew at a slow but generally steady rate through the 1940's. With the advent of cheap electrical power, construction of the main north-south highway Interstate 5 and improved road transportation, and the ability to barge large quantities of goods on the Columbia River in the 1940's and 1950's, the population more than doubled in Clark County and nearly doubled in Vancouver during that time period. In 1995, the population of Clark County reached approximately 291,000, an increase of 126% since 1970. The 1997 population is estimated to be 316,526, and since 1990, the county has attracted nearly 78,500 new residents, yielding a growth rate of 33%. This growth rate qualifies Clark County as the fastest growing county in the State. During the past two decades, Clark County has experienced an average annual population growth rate of 2.8%, nearly twice that of the state as a whole. (US Bureau of the Census, 1998).

In recent decades, development has stretched out along Interstate Highway 5 and northward across the plains. The influx of well known computer-technology companies, as well as the proximity to the metropolitan area of Portland, Oregon, has resulted in a rapidly expanding developed area.

WATER DEMAND

WATER RIGHTS

A water right permit or certificate is a legal authorization to use the public's water for a specific beneficial purpose. With the exception of an exemption for limited use of ground water, (less than 5,000 gallons per day, with restrictions), Washington State law requires users of public water to receive approval from Department of Ecology prior to actual use of the water. Department of Ecology also recognizes statements of Water Right Claims, which are recorded statements of water use that began before the State Water Codes were adopted.

While large amounts of ground and surface water are used annually within WRIA 28 for domestic supply, irrigation, industry, and other uses, water withdrawals from streams or wells are seldom measured by holders of water rights, with the exception of water utilities. In 1991 Ecology conducted a field investigation to determine which surface-water rights were active in the Salmon and Burnt Bridge Creek subbasins (Phillips and Van Hulle, 1991) but did not quantify the amount of water in use. Collins and Broad (1993) estimated the annual water use in 1988 for agriculture, industry, and municipalities throughout the Portland Basin (Figure 2). However, the presence of unauthorized water withdrawals and the numerous recorded or claimed rights that are no longer in use, further complicate attempts to quantify actual water use.

Records from Ecology's Water Rights Information System (WRIS) were examined to verify the quantity and location of both ground-water and surface-water rights. The withdrawal points were plotted on base maps and will be digitized to create geographic coverages using ARC/INFO software.

WATER-RIGHTS QUANTITIES FOR VARIOUS USES

To evaluate the distribution, purpose of use, and amount of water use within the study area, the authorized instantaneous and annual quantities were sorted by purpose and totaled (Table 1). These water rights are depicted (Figures 3 and 4) by percentage of purpose of use. The indicated values represent the <u>primary</u> purpose of use as a percentage of the total allocated "instantaneous" withdrawal rates (Qi).

The amount of surface water diverted has increased steadily over time to a total withdrawal rate of 1,236 cfs and 78,470 ac-ft/year (Figure 5). Similarly, authorized ground-water withdrawals have steadily increased since 1938 and now total 295,677 gpm and 273,104 ac-ft/year (Figure 6). As counted in acre-feet per year, approximately four times as much ground water as surface water is authorized for use under permits and certificates (Table 1).

Table 1. Estimated Quantities for Surface-Water and Ground-Water Rights

TYPE OF USE	GROUND WATER		SURFACE WATER	
	Qi* (gpm)	**Qa* (ac-ft/yr)**	**Qi (cfs)**	**Qa (ac-ft/yr)**
SINGLE DOMESTIC	20,705	9,06	3	1351
COMMERCIAL	102,857	157,44	277	45461
MULTIPLE DOMESTIC	38,530	19,51	9	2144
ENVIRONMENTAL	500	85		
FIRE PROTECTION	765	30	13	19
FISH PROPAGATION	2,310	245	96	5128
HEAT EXCHANGE	13,000	26,241		
IRRIGATION	35,443	10,991	7	9157
MUNICIPAL	79,925	48,43	9	6482
HYDROPOWER	****	****	381	7653
RECREATION \ BEAUTIFICATION	300	115	301	2
RAILWAY	800	33	2	50
STOCK WATER	542	34	1	23
WILDLIFE	****	****	3	100
TOTAL	**295,677**	**273,104**	**1236**	**78,470**

*Qa, annual appropriation rate; cfs = cubic feet per second; ac-ft/yr = acre-feet per year

*Qi, "instantaneous" appropriation rate; gpm = gallons per minute;

APPLICATIONS FOR NEW WATER RIGHTS

Information about pending ground-water and surface-water applications was compiled from written records, the Water Rights Applications Tracking System (WRATS), and WRIS (Table 2). Most of the pending surface-water applications request the use of water from tributaries to the Washougal or Columbia Rivers, or from streams within the Salmon Creek or Lacamas watersheds. The ground-water applications generally are for withdrawals in the Vancouver Lake, Salmon Creek, Burnt Bridge Creek, and Lacamas Creek watersheds.

To evaluate the applications for new water rights, the requested instantaneous diversion was verified, and an annual quantity was estimated if not specifically requested. Assigned annual quantities were determined using standard annual withdrawals specified in Quantity Allocation Standard Operating Procedure, POL-1070 and PRO-1070.

As of December 31, 1997, 20 surface-water applications are on file, for a total request of 40.01 cfs and approximately 1,420 acre-feet, to be used for domestic supply, commercial/ industrial supply, fish propagation, and irrigation (Table 2).

Table 2. Ground-Water and Surface-Water Applications

SURFACE-WATER APPLICATIONS			
TYPE OF USE	Qi (cfs)	Acre Feet per Year	Acres
Multiple-domestic supply	0.02	1	****
Multiple domestic supply and irrigation	1.30	950	120
Multiple domestic supply, stock water, and irrigation	0.12	8	6
Single domestic supply	0.07	1	****
Single, domestic supply, fish propagation, and wildlife	0.01	1	****
Single domestic supply and stock water	0.03	2	****
Single domestic supply and irrigation	0.02	10	5
Single domestic supply and commercial	0.04	5	****
Fish propagation	0.05	36	****
Irrigation	1.14	325	162
Irrigation and wildlife	26.00	80	520
Recreation and wildlife	0.006	0	****
Wildlife	11.20	0	
TOTAL	**40.01**	**1,419**	**813**

GROUND-WATER APPLICATIONS			
TYPE OF USE	Qi (gpm)	Acre Feet. per Year	Acres
Multiple domestic supply	3,746	4,121	****
Multiple domestic supply and irrigation	270	355	1.52
Multiple domestic supply and commercial	2,660	7,563	****
Single domestic supply	6	1	****
Single domestic supply and irrigation	524	167	40
Single domestic supply and wildlife	15	2	****
Single domestic supply and commercial	39	9	****
Irrigation	5,008	1,232	619
Irrigation and stockwater	50	65	50
Irrigation and frost protection	300	100	32
Wildlife	1,000	0	****
Commercial	2,200	3,226	****
Mining	500	322	****
Municipal supply	1,800	2,435	****
TOTAL	**18,118**	**19,598**	**893**

As of December 31, 1997, 61 ground-water applications are on file, for requests totaling 18,118 gpm and approximately 19,598.7 acre-feet, to be used for domestic supply, irrigation, mining, wildlife enhancement, commercial/industrial supply, and municipal supply (Table 2).

ESTIMATES OF ACTUAL GROUND-WATER USE

Very little ground-water use data has been collected for the study area. In 1987-88, Collins and Broad (1993) inventoried municipal, industrial, and irrigation wells in the Portland Basin of Washington and Oregon and estimated total ground-water pumpage for each of these water uses. Using this data, we interpreted that 88,280 acre-feet of the estimated water use applied to the WRIA 28 portion of the Portland Basin. In comparison, Ecology's records for 1997 indicate that the authorized annual pumpage is now approximately 263,000 acre-feet, roughly three times the estimated 1987-88 use. This comparison applies to the same categories of use; municipal, industrial and irrigation (Table 3).

Table 3. Comparison of U. S. Geological Survey's Estimated Pumpage and Water Rights

TYPE OF USE:	**Water Rights Through 1997 (ac-ft/yr)**	**Estimate fo1987-88:(Collins and Broad,1993) (ac-ft/yr)**
MULTIPLE DOMESTIC	19,512	****
MUNICIPAL	48,432	****
SUBTOTAL	**67,944**	**32,955**
COMMERCIAL	157,449	****
HEAT EXCHANGE	26,241	****
SUBTOTAL	**183,690**	**52,687**
IRRIGATION	10,991	****
STOCK WATER	340	****
SUBTOTAL	**11,331**	**2,638**
TOTAL	**262,965**	**88,280**

WATER-RIGHT CLAIMS

Chapter 90.14 Revised Code of Washington, dealing with Water Rights-Registration-Waiver and Relinquishment, etc., was enacted in 1967 to document the volume of water used in the state, in order to more efficiently administer the state's water resources. The resultant water-right claims are recorded statements of water use by all persons using water at that time. Claims for surface-water use prior to June 7, 1917 and claims for ground-water use prior to June 7, 1945 may constitute "vested rights." A vested right can be legally confirmed only through a general adjudication.

Experience has shown that much of the information submitted in support of the claims is inaccurate. However, a claim must be taken at face value until its validity is determined through a general adjudication by the Superior Court (Chapter 90.03.110 to.240 RCW). The study area has not yet been adjudicated - nor is it likely to be in the near future.

Information about ground-water and surface-water claims was compiled from written records, and databases of water-right claims. Many claims lack information on instantaneous withdrawals (Qi) or annual quantities (Qa). For these, we assigned a reasonable instantaneous withdrawal according to the use of the water and assigned an annual quantity based on the instantaneous withdrawal standard annual withdrawals specified in Quantity Allocation Standard Operating Procedure, POL-1070 and PRO-1070. Municipal uses were tallied separately by totaling the actual claimed amounts (Table 4).

A total of 7,019 claims (902 surface-water and 6,117 ground-water) were filed for WRIA 28. Claims for surface water total 29 cfs, and claims for ground-water total 98,682 gpm (220 cfs).

Table 4. Ground-Water and Surface-Water Claims -- Estimated Quantities

USE	**Qi**		**Qa**
CATEGORY	**cfs**	**Gpm**	**Ac/ft/yr**
Domestic	0.02	9	0.5
Stockwater	0.02	9	0.5
Irrigation	0.02	9	2.0
Other	0.02	9	0.5
Municipal	0.02	Totaled separately	

Table 5. Ground-Water and Surface-Water Claims -- Total Quantities

TYPE OF USE	**GROUND-WATER CLAIMS; Qi (gpm)**	**SURFACE-WATER CLAIMS Qi (cfs)**
Domestic, supply	50,959	12
Stockwater	14,188	7
Irrigation	20,251	9
Municipal	7,050	----
Other	6,233	1
TOTAL	**98,682**	**29**

These claimed uses are graphically depicted in Figures 7 and 8, with the indicated values representing the primary purposes of use as a percentage of the total instantaneous withdrawal for all claims.

RELATIONSHIP BETWEEN WATER RIGHTS AND WATER-RIGHT CLAIMS

Comparisons between water-right claims versus actual water-right permits plus certificates is complicated by the likelihood that some quantity of "claimed" water is also used under the authorization of water-right certificates. In addition, because the claims were filed in the early 1970's prior to extensive population growth and exempt well development, the information contained within them is many years out of date.

The claims filing period was reopened by the passage by the 55th Legislature of Substitute House Bill 1118. The claim filling period is open from September 1, 1997 until June 30, 1998 for all persons or entities claiming a right to withdraw or divert and beneficially use surface-water or ground-water. The current claims filing period is open for all water users to register surface-water and ground-water uses which predated passage of the surface-water code (Chapter 90.03 RCW) in 1917 and the ground-water code (Chapter 90.44 RCW) in 1945.

SURFACE-WATER SOURCE LIMITATIONS

Under the authority of Chapter 75.20 RCW, "Construction Projects in State Waters," the Department of Fish and Wildlife may object to the approval of a water-right application, if issuing a permit would result in lowering streamflow below that necessary to adequately support food and game fish populations in the stream. Water rights may be denied or be provisioned in accordance with Department of Fish and Wildlife recommendations. Provisions placed on permits commonly require that water not be diverted if the stream's flow falls below a certain rate, or may stipulate a specific period of use.

In the study area, 49 surface-water rights, totaling 28.66 cfs, have been issued with streamflow provisions. These rights authorize the diversion of water from Salmon Creek, the Washougal River, Lake River, and several tributaries of the Columbia River, with limitations based on streamflow at a nearby gage, or at the point of diversion. These rights were issued primarily for irrigation, power production, and domestic supply. The Department of Ecology has not consistently enforced the streamflow provisions of these water rights.

RESERVATION OF FUTURE PUBLIC WATER SUPPLY

Chapter 173-592 WAC was adopted in 1986 to reserve ground water within Clark County for future public water supply. The Department of Ecology, after investigation and public comment, found that ground water was generally available within the county for additional appropriation and reserved 97,000 gpm and 65,300 acre-feet/year to serve a projected population of 629,200 in the year 2136.

The reserved water is to be withdrawn from within the supply-area boundary (Figure 9), either from the Columbia River alluvium and Sandy River mudstone (77,000 gpm and 51,800 af/yr) or from the Upper Troutdale aquifer, (20,000 gpm and 13,500 af/yr). The water must be used within the geographic boundaries of Clark County, consistent with the 1983 Clark County

Coordinated Water System Plan. All water-right permits issued pursuant to the Clark County Reservation will have a priority date of August 13, 1986, the effective date of the regulation.

The regulation reserves ground water to be developed for public supplies. All water rights issued after the reservation for uses other than public supply will be junior in priority to rights established under authority of the reservation. Exempt wells with priority dates subsequent to August 13, 1986 also are junior to reserved rights. The quantities appropriated through exempt uses and water rights issued for purposes other than public supply will not be subtracted from the reserved quantities. However, Ecology must take into account these nonreserved uses to determine whether sufficient water remains available for public water supply.

The regulation also requires that a record of all ground-water permits issued pursuant to the reservation be maintained and show the amounts that have been allocated from the reservation, that remain in reserved status, and are available for additional allocation. Table 6 shows the amounts authorized from the particular aquifers within the reservation, and the quantities that remain available.

Table 6. Allocations of Ground Water Under the Clark County Reservation, Chapter 173-592 WAC.

AQUIFER SOURCE	**GPM**	**AC-FT/YR PRIMARY**	**AC-FT/YR SUPPLEMENTAL**	**AC-FT/YR REMAINING UNDER RESERVATION**
Columbia River alluvium	25	1	Combined with	Sandy River mudstone (see below)
Sandy River mudstone	16,020	1,504	12,000	50,295
Upper Troutdale	10,090	1,911	5036	11,588
Total	26,135	3,416	17,036	61,883

The amounts appropriated through exempt uses, such as domestic wells and water rights issued for purposes other than public supply, will not be counted against the reserved quantities.

Also, in Chapter 173-592 WAC, the Department of Ecology was directed to implement a comprehensive monitoring program to gather information on the quantity and quality of the reserved ground water. Stream flows and stages, lake stages, and ground-water heads are to be periodically measured and recorded. Any appropriation that would cause lowering of ground-water levels below the reasonable and feasible pumping lift of any senior water-right holder is specifically forbidden (albeit such lift is difficult to define). The Department of Ecology has been able to implement only a small portion of this specified monitoring. However, Clark Public Utilities has voluntarily assumed much of this responsibility as described in a memorandum of understanding with the Department of Ecology.

HYDROLOGY

THE WATER CYCLE

Water endlessly circulates around the earth, evaporating from the land and the oceans, then returning as rain and snow. A portion of the precipitation falling on land evaporates from vegetation or soil. Some of the water infiltrates into the soil, and some runs off the land surface into streams. The infiltrating water replenishes soil moisture which either is transpired by plants or percolates down to the saturated zone to become ground water. Ground water then flows away from the point of recharge, partly downwards and partly horizontally, ultimately discharging at the surface through springs or seeps, along stream beds, or along the ocean (Figure 10).

The water cycle of an inhabited watershed includes all the elements of the world-wide water cycle, presented above, except that the hydrologic system is bounded by a topographic divide (the watershed) and is affected by consumption and re-distribution of water by humans. The six dominant features of the water cycle are:

1) Precipitation,

2) Evapotranspiration (evaporation plus transpiration by plants),

3) Natural ground-water exchange with adjoining watersheds (in the subsurface, beneath and beyond the topographic boundary),

4) Consumptive water use by humans (actually is consumed as evapotranspiration),

5) Long-term changes in ground-water storage, and

6) Streamflow.

Within the study area, precipitation supplies nearly all of the replenishment to the water supply. Topographic and geologic conditions suggest that the adjoining watersheds contribute insignificant quantities of deep subsurface flow. Evapotranspiration consists of evaporation from soils, vegetation, lakes, and streams, in addition to transpiration by plants. Evapotranspiration reduces the amount of precipitation that reaches aquifers and streams, and generally constitutes a large percentage of the water balance.

Natural ground-water exchange (ground-water flow) with adjacent watersheds may add to or reduce the water supply of a watershed, but appears to be insignificant in the study area.

Ground-water storage is recharged principally by precipitation that percolates down to the water table, or by infiltration from streams and other surface-water bodies. Rates of ground-water recharge vary with annual and seasonal precipitation and with geologic conditions. In the natural cycle, ground water is always moving and eventually discharges to surface-water bodies, except where intercepted by plants or humans. In a few very deep aquifers, ground water may be relatively stagnant. Barring long-term climatic change, ground-water storage usually stays within a narrow range, and the average annual recharge rate may be assumed to be equivalent to the average discharge of ground water to streams, springs, or other surface-water bodies.

Natural streamflow consists of the flow remaining after natural upstream gains and losses. We can only estimate the historic rates of natural streamflow in the study area because streamflows were not measured prior to land clearing, cultivation, and development of water supplies.

CLIMATE

The climate of southwestern Washington is strongly influenced by its physical geography and position between the coastal Willapa Range to the west and the Cascade Range to the east. The Columbia River, to the south and west, and Pacific Ocean (70 miles to the west) moderate temperatures year-round, warming the air in the winter, and cooling the air in the summer. The proximity of the nearby mountain ranges further insulates against dramatic climate changes.

The prevailing winds blow from the northwest during the summer and from the southeast during the winter. These winds are tempered by nearly uniform ocean temperatures that range from 50-55°F and cause relatively high precipitation and a moderate range in air temperature from summer to winter. The average annual temperature in Clark County is 50°F, with temperatures below freezing or above 80°F occurring only rarely. Wet, mild winters and moderately dry summers typify the region.

PRECIPITATION

The orographic effects of the two bordering mountain ranges and regional atmospheric patterns create large seasonal differences in precipitation throughout the area. The average annual precipitation near the Willapa Range to the west and the Cascade Range to the east exceeds 110 inches, whereas precipitation in the lower altitudes near the center of WRIA 28, at Vancouver, averages only about 37 inches annually (Figure 11).

The National Weather Service has operated several climate stations in the area, measuring precipitation and temperature at various locations (Figure 11). The currently active stations include Battle Ground, Vancouver (designated Vancouver 4NNE), and Skamania Fish Hatchery, located on the upper Washougal River. In addition, Bonneville Power Administration coordinates a network of "backyard" climatic stations operated by citizen volunteers, though data from those stations is neither included nor analyzed in this report.

The highest monthly rainfall occurs during the late fall and winter months, with approximately two-thirds (66% at Battleground) of the average annual precipitation occurring during the five month period between November and March (Figure 12). Summer months tend to be moderately dry, leading to soil-moisture deficits, and the need for irrigation of crops, shrubs, and lawns. December is usually the wettest month, while July is usually the driest.

PRECIPITATION TRENDS

Graphical analysis of annual precipitation at Vancouver, using a 10-year moving average, indicates periods when regional precipitation trended above or below average (Figure 13). Extended periods of below-average precipitation occurred from the early 1900's through the 1920's, mid-1950's through the 1960's, and mid-1980's to mid-1990's. Except for the latter two periods, precipitation in the study area typically has been above the long-term mean since about 1950.

The longest precipitation record for the study area has been collected at Vancouver from 1898 to the present (Figure 14). Precipitation at the Skamania Hatchery and Battle Ground have much shorter periods of record. Annual rainfall has varied by a factor of about two and one-half (26 to 64 inches). Also, irregular "cycles", or groups, of drier and wetter years are evident, as shown by the line indicating the 10-year moving average.

From 1949 to present, water-year precipitation at Battle Ground varied from about 37 inches to about 68 inches, with an average of 51.5 inches (Figure 14). The 10-year moving average indicates a less pronounced drying trend than at Vancouver for 1982 through 1995.

From 1966 to present, water-year precipitation at Skamania Fish Hatchery varied from about 59 inches to about 111 inches, with an average of 84.3 inches (Figure 14). This station also indicated drier conditions from 1982 through 1995.

THE SOIL-WATER BALANCE: EVAPOTRANSPIRATION AND DEEP PERCOLATION

Precipitation is more abundant in fall and winter, the same period when vegetation requires less water because it is either dormant or growing slowly. As soils become saturated, excess soil moisture tends to percolate beyond the reach of plant roots and recharges ground water. In some areas, water logging of the soils results in overland flow of excess water to streams. During spring and summer, ground-water recharge practically ceases because the actual evapotranspiration rate (AET) usually exceeds the rate of precipitation, though a small amount of soil water may continue to percolate downward. This annual cycle is reflected in low streamflows during summer and fall and the much higher flows during winter and spring.

Analyses by soil-water-balance methods provide estimates of average monthly rates of AET and excess soil moisture (which tends to become ground-water recharge by the process of deep percolation). Using a sophisticated accounting model, Synder, et al. (1994) estimated AET and recharge for the Salmon Creek watershed for 1949-74 (Figure 15). They did not describe the amount of AET in the text, but judging from the graph, the average annual AET is about 23-25 inches. For recharge, the estimated average annual rate is 27 inches.

An earlier, less rigorous soil-water budget (USGS, 1972) for the Vancouver area assumed 6 inches of soil-water capacity (Figure 16) and estimated that average annual AET equals approximately 20 inches, or 51 percent of the average annual precipitation of 39 inches. The remaining 19 inches of precipitation is available for runoff and ground-water recharge. Both water balances indicate that, under natural conditions, very little ground-water recharge occurs from June through September because a soil-water deficit develops, leaving little water to percolate down to the water table. During this period, heads decline as ground water drains to streams. These seasonal imbalances in recharge lead to large seasonal swings in streamflow and ground-water storage.

HYDROGEOLOGY

GEOLOGIC SETTING

Swanson et al. (1993) completed the most recent geologic and hydrogeologic mapping in WRIA 28 (excluding the mountainous part in Skamania County). They studied the much larger Portland Basin, a northwest-southeast trending structural basin about 20 miles wide and 45 miles long, filled mostly with continental sediments of late Miocene (uncertain), Pliocene, and Pleistocene age (Figure 17). In this basin, they mapped eight hydrogeologic units, grouped into three major subsystems (Figure 18). From youngest to oldest, these subsystems are the (1) unconsolidated sedimentary aquifer, (2) Troutdale gravel aquifer (sedimentary rocks), and (3) older rocks (including marine sediments, basalt, volcanic breccia, and volcaniclastic sediment).

The older rocks underlie the Columbia River floodplain and terraces at varying depths and, also, form the western foothills of the Cascade Range. To the north and east of Washougal, the older rocks belong to several geologic formations, including the Skamania Volcanics and the Columbia River Basalt Group. These late Eocene to Miocene age rocks consist largely of andesite, basalt, and associated volcaniclastic deposits, including tuff, breccia, and conglomerate. An area of intrusive granodiorite and granite (Miocene) straddles the Clark/Skamania County border near the northern edge of the study area.

West of Washougal, a thick sequence of sediments, deposited during the Miocene through the Pleistocene epochs, fills a structural basin formed during faulting or downwarping of the older rocks. These sediments belong to several geologic formations, including the Sandy River mudstone and the Troutdale Formation, both of Eocene age. The Sandy River mudstone consists of mudstone, siltstone, sand, and claystone that directly overlie the older rocks. The Troutdale Formation consists of vitric sandstone and quartzite-bearing conglomerate and generally overlies the Sandy River mudstone (Swanson, et al, 1993). Overlying and, in some cases, interfingered with the Troutdale formation are basalt and basaltic andesite flows and breccias of Cascade Range volcanics and Boring Lava. These rocks crop out as irregular isolated bodies in the central and eastern parts of the study area (Mundorff, 1964).

During late Pleistocene time, large quantities of sediments were deposited over the Troutdale Formation. These sediments consist of basaltic boulders and cobbles within a gravel and sand matrix and were deposited throughout most of the study area north and east of Washougal, during repeated catastrophic floods of the Columbia River. The flood deposits generally are coarsest near the present channel of the Columbia River, then grade into finer-grained facies of stratified sand, silt, and clay to the northwest (Swanson, et al, 1993).

Holocene age alluvium occurs along the flood plains of the Columbia River and its major tributaries. Columbia River alluvium consists largely of sand and silt, while alluvium of the major tributaries consists chiefly of cobbles and gravel.

HYDROGEOLOGIC UNITS AND WELL YIELDS

The movement of ground water and the productivity of wells is controlled largely by the distribution of lower permeability materials (confining units) and higher permebility materials (aquifers). The amount of water available is expressed as a function of the drainable storage (storativity), and the ability of the aquifer to transmit water (transmissivity). Swanson, et al. (1993) assigned the various geologic units in WRIA 28 to eight hydrogeologic units on the basis of their water-development potential. From lowermost to uppermost these are: (1) older rocks, (2) sand-and-gravel aquifer, (3) confining unit 2, (4) Troutdale sandstone aquifer, (5) confining unit 1, (6) undifferentiated fine-grained confining unit (interfingers with units 2 through 5), (7) Troutdale gravel aquifer, and (8) unconsolidated sedimentary aquifer. These units are described in some detail below (also see the summary in Swanson, et al., 1993; Figure 18).

The older rocks consist of Miocene and older volcanic and marine sedimentary rocks, including the Columbia River Basalt Group, Skamania Volcanics, Gobble Volcanics, and Scappoose Formation. With the exception of the Columbia River Basalt Group, the older rocks are generally dense and have little potential to store and transmit water. Accordingly, within the study area, older rocks are not a significant aquifer. The unit generally supplies 5 to 10 gpm to wells, at rates sufficient for single-domestic supplies. The top of the unit lies at land surface in the Cascade foothills and dips to depths of 1,600 feet below sea level in the Vancouver area.

The sand-and-gravel aquifer consists primarily of sandy gravel, silty sand, sand, and clay, which Swanson, et al. (1993) consider to be a relatively coarse-grained facies equivalent to Trimble's (1963) Sandy River mudstone and Mundorff's (1964) lower member of the Troutdale Formation. The unit consists of coarser materials near the present Columbia River channel, with finer material predominating as distance from the river increases. This unit is restricted to the lower reaches of the Washougal and Lacamas creek drainages where it may be as much as 800 feet thick. In thicker, coarser-grained sections, well yields can reach 2,000 to 3,000 gpm, as in the case of production wells for the Portland Bureau of Water Works. In the area between the Washougal and Columbia Rivers, domestic wells completed in this unit yield 5 to 30 gpm.

Confining unit 2 consists of silt and fine-to-medium-grained basaltic-sand lenses in a matrix of clay and silt. This unit underlies the Troutdale sandstone aquifer and overlies the sand and gravel aquifer, where both are present. The top of confining unit 2 ranges from more than 500 feet above sea level near Camas, to more than 400 feet below sea level in the Orchards/ Hazel Dell area, and ranges from less than 200 to more than 800 feet in thickness. The scattered sand and silt lenses of confining unit 2 can yield sufficient water for domestic purposes, although it is usually only used for water supply when more productive units are absent.

The Troutdale sandstone aquifer consists of two lithologic sub-units; the bottom one-third is quartzite-bearing basaltic conglomerate, and the upper two-thirds is chiefly vitric sandstone. This unit underlies much of the Fourth Plain/Mill Plain area and typically is less than 200 feet thick. Within the study area, the altitude of the top of the unit ranges from more than 600 feet above sea level near Camas, to more than 300 feet below sea level west of Interstate 205. The Troutdale sandstone aquifer yields up to 2,500 gpm, although it yields 500 gpm or less outside of Portland's well-field area.

Confining unit 1 consists of fine-to-medium grained arkosic sand, silt, and clay, with occasional vitric sand beds. Where the Troutdale sandstone aquifer is present, this unit is part of a thick sequence of undifferentiated fine-grained sediments that extend from the top of the unit to the top of the older rocks. Within the study area the top of confining unit 1 ranges from greater than 300 feet above sea level near Camas, to more than 100 feet below sea level west of Orchards. This unit underlies much of the Fourth Plain/Mill Plain area and is typically less than 200 feet thick. It generally produces small amounts of water sufficient for domestic purposes only.

The undifferentiated fine-grained confining unit is similar in lithology to confining units 1 and 2. This unit underlies much of the western portion of the study area including the lower reaches of Salmon Creek below Mill Creek and all of the Hazel Dell/Vancouver area. It also extends as a narrow band from the lower reaches of the Washougal River northwestward to the upper reaches of Salmon Creek. In the western part of the study area, it reaches a thickness of more than 1200 feet, while, in the east, it is generally less than 200 feet thick. The altitude at the top of the unit ranges from greater than 700 feet above sea level in the east to more than 300 feet below sea level near Vancouver Lake. This unit generally yields little water to wells, although, in areas containing extensive sand beds, it may produce more than 500 gpm.

The Troutdale gravel aquifer consists of poorly-to-moderately cemented, sandy conglomerate with local, often thick, accumulations of lava. In many areas, the upper surface of the unit is highly weathered and mantles the underlying conglomerate as a thick clayey soil. The Troutdale gravel aquifer underlies most of the study area south and west of the Cascade foothills and is an important and productive ground-water source. Wells completed in this unit can yield up to 1,000 gpm. This unit is generally thickest (200-400 feet) in the southern portion of the study area and thins to less than 200 feet as one moves north toward Salmon Creek. Within the study area, the top of the unit ranges in altitude from greater than 300 feet near the Cascade foothills, to more than 200 feet below sea level near Vancouver Lake.

Wherever it is found, the unconsolidated sedimentary aquifer (hereinafter called the regolith aquifer) is the youngest and uppermost hydrogeologic unit in WRIA 28. It consists of catastrophic flood deposits of late Pleistocene age, as well as Holocene alluvium deposited by the Columbia River or it's major tributaries. Its lithology varies from bouldery gravel to silt and can be distinguished from the underlying Troutdale gravel aquifer by lack of cementation. The top of the regolith aquifer defines the land surface throughout much of the study area lying west of the Cascade foothills. The aquifer is generally 50 to 100 feet thick, and where saturated, yields up to 6,000 gpm to properly constructed wells.

GROUND-WATER RECHARGE

Snyder, et al. (1994) estimated ground-water recharge within the western lowlands of the study area. The estimates were developed with a complex computer model, with the area represented as a grid of cells, 1640 feet on each side. The estimates were based on a number of factors, including topography, percentage of impervious area, elevation, soil type, slope, vegetation type, and spatial variation in precipitation. As one might expect from these complex factors, the estimates vary greatly from place to place.

For the entire Portland Basin, Snyder, et al. (1994) estimated that recharge varies from 0 to 49 in/yr, and averaged 22 in/yr. Infiltration of precipitation accounts for 20.8 inches (94%) of the annual average recharge, runoff into drywells (storm drains connected to infiltration boreholes) accounts for 0.9 in/yr (4%), and infiltration from septic systems accounts for about 0.4 in/yr (2%). In areas with numerous drywells, such as the urban centers of Clark County, infiltration from precipitation constitutes only 45% of the annual total, while recharge through drywells and from septic systems constitute 38% and 17%, respectively.

For approximately the western half of the study area, Snyder, et al. (1994) estimated that recharge varies from zero to 39 in/year, depending on local conditions, and averages about 17 in./yr. (Figure 19). Infiltration from precipitation varies from zero to 36 in/yr and averages 15.2 in/yr. Recharge through drywells and from septic systems varies from 0 to 26 in/yr and averages 1.3 and 0.3 in./yr., respectively.

Recharge in the eastern half of the study area has not been estimated. However, because much of this area is forested and only sparsely populated, precipitation is likely the primary source of recharge.

GROUND-WATER MOVEMENT AND DISCHARGE

In the study area, ground water naturally discharges from the subsurface by seepage into streams and lakes, with lesser amounts discharging to springs. In addition to these natural pathways, ground water is withdrawn through wells for industry, public water supply, irrigation, and other uses.

Below the water table, the geologic materials in the Portland Basin are continuously saturated, whether fine-grained, coarse-grained, regolith, or rock, and whether low permeability or high. In general, ground water moves from upland recharge areas along the western flank of the Cascade range, toward natural points of discharge along the Columbia River or other major streams (Figure 20). Smaller volumes discharge along local topographically low areas as hillslope springs or seepage to channels. Ground water within the regolith aquifer flows from elevations greater than 250 feet above sea level near the eastern extent of the aquifer, toward the Columbia River and other major streams. Salmon Creek is a significant discharge area for the regolith aquifer (McFarland and Morgan, 1997).

Ground water within the Troutdale gravel aquifer flows south and west toward the Columbia River, receiving recharge all along the flow paths from the western foothills of the Cascade Mountains to the discharge areas situated along the valleys. Heads within this unit, range from greater than 900 feet above sea level near Mt. Norway in the eastern part of the study area to less than 10 feet above sea level near the Columbia River. Recharge to this aquifer comes principally from the overlying regolith aquifer. In areas of ground-water discharge, such as lower Salmon Creek, vertical flow is reversed, and ground water within the Troutdale gravel aquifer flows upward into the regolith aquifer before discharging to Salmon Creek.

Ground water within the Troutdale sandstone aquifer also generally flows south and west. The unit receives recharge from above, all along the regional flow paths, just as in the overlying

Troutdale gravel aquifer. Within this unit, heads range from more than 200 feet above sea level, near the eastern edge of the unit, to less than 50 feet above sea level near the Columbia River.

The sand-and-gravel aquifer occurs only in a small area south of the Washougal River and mostly on the Oregon side of the basin. Ground water within this unit generally moves southward from uplands near Mt. Norway toward the discharge area along the Columbia River. Heads within this unit range from more than 500 feet above sea level to less than 100 feet above sea level near the Columbia River.

SEEPAGE TO STREAMS

To assess the rate of ground-water exchange with streams, McFarland and Morgan (1996) conducted seepage assessments along streams within the western half of the study area. Streamflow was measured at 21 sites on 4 streams during September and October in both 1987 and 1988 (Figure 21). Most of the measurements indicate "gaining" (ground-water inflow) conditions between measurement stations on a given stream. Inflow varied from 0.01 to 3.73 cfs/river-mile, while losses (surface-water recharging ground water) varied from 0.01 to 1.42 cfs/river-mile (Table 7). Three stream reaches consistently lost water during the two assessment periods, while 9 reaches consistently gained water. The remaining 12 reaches exhibited one condition in 1987, then the opposite condition in 1988. Pacific Groundwater Group (1995) measured seepage at additional sites along Salmon Creek and found that some reaches switched from gaining to losing on a seasonal basis.

Table 7. Streamflow Measurement Sites for Estimating Seepage Gains and Losses in Selected Streams, WRIA 28 (McFarland and Morgan, 1996).

Site ID	Stream Description	Site Location	River Mile	Measurement Date	Seepage (cfs)*	Ave Seepage (cfs)
1	Burnt Bridge Cr. at 112th Ave.	2N/2E-16DBA	8.9	9/15/1987	0.54	0.53
				10/7/1988	0.51	
2	Burnt Bridge Cr. at Burton Rd.	2N/2E-20DAC	7.4	9/15/1987	1.01	0.98
				10/7/1988	0.95	
3	Burnt Bridge Cr. at Evergreen St.	2N/1E-24DDC	5.0	9/15/1987	0.01	0.18
				10/7/1988	0.35	
4	Burnt Bridge Cr. at St. Johns Blvd.	2N/1E-24BBC	3.6	9/15/1987	0.44	0.20
				10/7/1988	-0.04	
5	Burnt Bridge Cr. at Leverich Park	2N/1E-14CCA	2.2	9/15/1987	-0.01	0.33
				10/6/1988	0.66	
6	Burnt Bridge Cr.	2N/1E-15BAD	1.0	9/15/1987	-0.02	-0.18
				10/6/1988	-0.33	
7	Fifth Plain Cr. NE 121th Ave.	3N/3E-20DDD	5.3	9/17/1987	0.03	0.06
				10/13/1988	0.08	
8	Fifth Plain Cr. at NE Davis Rd.	3N/3E-32CBD	3.3	9/17/1987	0.08	0.08
				10/12/1988	0.09	
9	Shanghai Cr. at NE 212 Ave.	2N/3E-05ADD	1.8	9/17/198	-0.13	-0.04
				10/12/1988	0.05	
10	Fifth Plain Cr. at Ward Rd.	2N/3E-06BBA	1.9	9/17/1987	-0.06	-0.04
				10/13/1988	-0.03	
11	Fifth Plain Cr. at Hwy. 500	2N/3E-07CBA	0.2	9/18/1987	1.42	1.35
				10/12/1988	1.29	
12	Lacamas Cr. at NE 217th Ave.	2N/3E-09BCD	12.0	9/18/1987	-0.10	0.23
				9/21/1988	0.57	
13	Lacamas Cr. at Hwy. 500	2N/3E-07CAA	9.9	9/18/1987	-0.02	0.04
				9/21/1988	0.10	
14	Lacamas Cr. at Lacamas Park	2N/3E-20DDA	5.5	9/21/1987	0.98	0.92
				9/22/1988	0.87	
15	Little Washougal R. at Blair Gage	2N/4E-31BDA	1.1	9/21/1987	-0.06	-0.15
				9/16/1988	-0.23	
16	Salmon Cr. at 182nd Ave.	3N/3E-07ABC	17.5	9/9/1987	0.07	0.06
				9/29/1988	0.05	
17	Salmon Cr. at 167th Ave.	3N/2E-12AAC	16.6	9/9/1987	-0.32	-0.03
				9/29/1988	0.26	
18	Salmon Cr. at Hwy. 503	3N/2E-15DBC	3.2	9/9/1987	-0.13	0.12
				9/29/1988	0.38	
19	Salmon Cr. at 112th Ave.	3N/2E-15CCC	12.6	9/10/1987	0.38	0.17
				9/29/1988	-0.03	
20	Salmon Cr. at 72nd Ave.	3N/2E-20CBB	9.8	9/16/1987	1.76	0.71
				9/30/1988	-0.06	
21	Salmon Cr. at Hwy. 99	3N/1E-26DCC	5.5	9/9/1987	-1.31	-0.01
				9/30/1988	1.29	
22	Salmon Cr. Below Klineline Pond	3N/1E-27DDD	4.6	9/15/1987	3.73	1.14
				9/30/1988	-1.42	
23	Salmon Cr. Above 36th Ave.	3N/1E-28BBD	2.2	9/9/1987	-0.78	0.20
				9/30/1988	1.19	
24	Whipple Cr. at 179th St.	3N/1E-08CDC	2.5	9/10/87	0.50	0.67
				10/06/1988	0.84	

SPRINGS

Natural discharge of ground water to springs occurs at a number of sites along the Columbia River. In 1949, Mundorff (1964) measured the flow at all large springs along the Columbia River between Vancouver and Prune Hill, located just west of Camas. He found approximately 24.75 cfs (11,110 gpm) of ground water discharging along the contact between the regolith aquifer and the Troutdale gravel aquifer. In 1988, McFarland and Morgan (1996) measured all known springs with discharge greater than 0.1 cfs along this reach, including most of the springs measured by Mundorff (Table 8). (The springs that were not re-measured are not shown in the Table 8).

Table 8. Spring Discharges, Clark County, Washington (McFarland and Morgan, 1996).

SPRING: LOCATION/	ALTITUDE (ft)	DISCHARGE (gal/min)	MEASUREMENT DATE	RATIO OF DISCHARGE (1988 to 1949)
1N/2E-2cba1(M)	50	1760	4/11/49	
		898	5/24/88	0.5
1N/2E-2dca1(Q)	50	675	4/11/49	
		346	5/24/88	0.51
1N/2E-2dcbl(Q)	100	280	4/11/49	
		269	5/25/88	0.96
1N/2E-3acc1(G)	70	1200-1500 estimated	4/--/49	
		213	9/24/90	0.14-0.18
1N/2E-3bca1(E)	60	200 estimated	4/11/49	
		202	4/10/88	1.01
1N/2E-3daa1(J)	50	665	4/18/49	
		682	5/24/88	1.03
1N/2E-4aacl(A)	100	200	4/11/49	
		250-300 estimated	5/10/88	1.25-1.5
1N/2E-4bbbl(D)	100	75 estimated	4/15/49	
		50	5/10/88	0.67
1N/3E-7bbd1(D)	50	550	4/11/49	
		256	5/25/88	0.46
1N/3E-7bdal(F)	60	520	4/19/49	
		269	5/25/88	0.51
1N/3E-7bda2(F)	60	185	4/18/49	
		60	5/25/88	0.32
1N/3E-7bdbl(F)	60	100	4/18/49	
		4.5	5/25/88	0.045
2N/3E-7daal(J)	150	100 estimated	4/15/49	
		107	5/10/88	1.07
2N/2E-33(C) (3 springs)	220	2085	10/15/45	
		2790	4/28/88	1.34
TOTALS	1945-49 Partly estimated	8595 - 8945		
	1988 Partly estimated	6400 - 6450		0.72

[1]Locations are by township (ex., TIN); range (ex., 2E); section (1 through 36 possible); ¼,¼,¼ section system used by Oregon (aaa to ddd); ¼, ¼ system used by Washington (A through R); full example is then 1N/2E-5acb(G), also see original report.

The largest single decrease occurred at the spring supplying the Washington Department of Game fish hatchery [1N/2E-3ACC1(G)], near Vancouver (Table 8 and Figure 22). In 1990, spring discharge at the hatchery was 213 gpm, roughly 15 percent of the 1200-1500 gpm discharge estimated by Mundorff for 1949. As a result of this decline, the hatchery found it necessary to drill three production wells, one of which exceeded 1,000 feet in depth, in order to replace the depleted spring. By 1995, the discharge had further decreased to about 25 gpm (hatchery manager, personal communication). The reduction in discharge has been attributed to ground-water withdrawals and land-use changes (mostly construction of impervious surfaces) on the uplands to the north.

One spring-fed stream (1N/2E-3K) measured by Mundorff (1964) flowed at 13.66 cfs 6,130 gpm), approximately 39% of the total spring flow (35 cfs) measured at that time. This stream was not re-measured, and is not shown in Table 8, due to uncertainty that the stream was entirely spring-fed.

Though the flow at Ellsworth Springs (2N/2E-33C) appears to have increased since 1945, nitrate contamination forced its abandonment as water supply for the City of Vancouver in 1973. This spring is fed by the uppermost aquifer, which has, apparently, not been affected by withdrawals in the vicinity.

Comparisons between the two sets of measurements for the springs (Table 8) indicate that total discharge had decreased approximately 27%, from 19.54 cfs (8,770 gpm; mean of high and low estimates in Table 8) in 1949 to 14.32 cfs (6,425 gpm; mean of high and low estimates in Table 8) in 1988.

GROUND-WATER WITHDRAWALS

Ground-water withdrawals for public supply, industry, and irrigation constitute a significant portion of the ground-water discharge. With the exception of Camas, all the cities and larger towns in Clark County use ground water as their sole source of drinking water. Several water utilities also use only ground water. Collins and Broad (1993) estimated ground-water withdrawals during 1987-88 for the various usage categories to be 88,280 acre-feet/year (ac-ft/yr). Of the total withdrawals, public suppliers pumped 37.3% (32,955 ac-ft/yr), industries pumped 59.7% (52,687 ac-ft/yr), and irrigators pumped 3% (2,638 ac-ft/yr). These estimates do not include lesser withdrawals for other uses, such as single domestic supply, fish propagation, and fire protection. Withdrawals from more than 14,000 domestic wells probably account for less than 3% of the total pumpage.

GROUND-WATER CONDITIONS

EFFECTS OF GROUND-WATER WITHDRAWALS

The response of the ground-water system to withdrawals depends upon (1) the well's proximity to recharge and discharge areas, (2) the nature of the recharge (percolation of precipitation, leakage from a surface-water body, etc.), and (3) the hydraulic properties (storativity and transmissivity) of the pumped aquifer and the surrounding flow system (aquitards and other aquifers).

In the absence of withdrawals, ground-water systems exhibit a state of dynamic equilibrium, with recharge to and discharge from the system balancing over time. From season-to-season and year-to-year, the amount of ground-water storage varies within a limited range and is reflected by the variation in head. Pumping a well alters this balance by reducing ground-water storage (head drawdown) and by changing the hydraulic gradient. As a result, a well eventually "captures" either ground-water which would have discharged to the surface or additional recharge from surface water, or both (Theis, 1940). For a steady rate of pumping, the head will continue to decline until capture from surface water balances the pumping rate. Until then, the head decline (known as the cone-of-depression) will continue to spread outward through the flow system, through both aquifers and aquitards. For intermittent pumping -- even the brief withdrawal of a few gallons from a domestic well -- the total amount withdrawn will be captured from surface waters, although probably at a lower rate and for a longer duration than that of the pumping.

Predicting the specific response of an aquifer system to ground-water withdrawals is difficult, particularly when trying to identify the surface waters affected by capture, because the necessary detailed information often is not available. Even so, general knowledge about the hydrogeologic environment in an area, together with the principles explained above, provide a means to make initial estimates of capture and where it occurs. This has been demonstrated by computer modeling of a hypothetical watershed, typical of those in the Puget Sound lowland (Morgan and Jones, 1995). The hydrogeology of the hypothetical watershed is similar in lithology and hydraulic-property contrasts, if not origin, to the hydrogeology of the sedimentary rocks in much of WRIA 28.

The three-dimensional numerical model demonstrates that a well pumping from an unconfined aquifer, which discharges directly to a stream, captures most of its water from ground-water that would have discharged to the nearest stream reach. As the distance between a well and stream increases, the proportion of capture from more distant stream reaches also increases, and the area influenced by pumping increases. In addition, the drawdown is greater for wells located at larger distances from natural discharges than it is for wells located close to natural discharges. This follows from general aquifer hydraulic theory and is in accordance with Theis's (1940) theory of capture.

When wells are separated from a nearby stream by an aquitard, pumping effects spread over a larger area than for an unconfined aquifer, all other factors being equal. Accordingly, capture from the nearest stream reach probably is less pronounced than if the same well pumped from the overlying unconfined aquifer at the same geographic location. As the number of confining layers increases, the area where surface water is captured also tends to increase, while the effect on individual springs or stream reaches progressively decreases. At the mouth of the ground-water basin, the total capture is always equal to the amount pumped, assuming no underflow out of the basin.

Evidence of these general responses to ground-water use are readily apparent within the study area. Reductions in ground-water storage have occurred, and natural discharges to some springs have greatly diminished. Streamflow declines have probably occurred but are not apparent because long-term stream flow data are lacking.

URBAN CONSTRUCTION

According to an inventory of dry wells in Clark County (unpublished data, Dept. of Ecology, 1988), the mean dry well density in Vancouver and vicinity (44-$mi.^2$ Study area) was 46 dry wells/ $mi.^2$. However, no study has ever measured the flow into these dry wells. As part of their recharge study, Snyder, et al. (1994) estimated that the percentage of impervious surface in the dry-well inventory area of Clark County was 26 percent. Using a recharge model, they estimated that dry wells contribute 9.4 in/yr recharge over the inventoried area, or 27.1 cfs on a year around basis.

Snyder, et al. (ibid.) also estimated recharge from on-site waste disposal systems (septic systems, cesspools) to be 5 in/yr over the area, or 4.7 cfs on a year around basis, from more than 10,000 such systems in the Burnt Bridge Creek vicinity of Clark County.

CHANGES IN GROUND-WATER LEVELS AND STORAGE

Reductions in ground-water levels (head) and ground-water storage due to withdrawals have been thoroughly documented in the study area. Declining heads are readily apparent over large areas where municipalities depend on ground water (Clark Public Utilities and Washington Department of Ecology, 1994; McFarland and Morgan, 1996; Appendices B and C). Heads have declined five feet or more throughout much of the western portion of WRIA 28 (Figure 24). The largest declines (up to 25 feet) have occurred in the Troutdale gravel and regolith aquifers within the Burnt Bridge and Salmon Creek drainages. As a consequence, several dozen shallow (i.e., less than 120 feet deep) domestic wells in the Orchards area either lost production or dried up between 1988 and 1990.

A "predevelopment" simulation (Morgan and McFarland, 1994, p. 50) with the digital flow-system model of the Portland Basin provides some insight into the ground-water conditions that probably existed prior to urbanization and ground-water extraction. As such, it provides a worst case estimate of the magnitude and extent of head declines that may have occurred in the modeled portion of WRIA 28 in response to urbanization and ground-water withdrawals. Evaluation of the simulation results indicates moderate head decline (less than 10 feet) throughout most of the basin, primarily in response to reduced recharge in urban areas. Larger declines occurred around well fields serving public supply and industrial uses in southern Clark County. The most extensive simulated declines in Clark County occurred in the Troutdale gravel aquifer, with a maximum of 50 feet and minimum of 20 feet decline over a broad area within Range 2 East, bounded by the Columbia River on the south, and Salmon Creek on the north.

Evaluation of long-term (over 20 years) water-level hydrographs (Appendices A and B; Mundorff, 1964; McFarland and Morgan, 1996), for wells within the study area, generally support these conclusions: The largest declines occurred in the interior of the study area where sources of additional recharge are not readily available, and where distances to natural points of discharge are large. Heavy pumping from well fields in the regolith aquifer adjacent to the Columbia River has not resulted in significant head declines due to the proximity of the river.

REDUCED GROUND-WATER DISCHARGE TO STREAMS AND RIVERS

Based on the conceptual model of ground-water/surface-water interactions, pumping of ground water has and will continue to capture and reduce streamflows. Some of the capture will occur entirely from tributary streams, some capture will occur from the Columbia River or other surface waters along its floodplain, and some capture will occur from adjoining watersheds, such as the East Fork Lewis River. Stream gaging in the study area, however, has been too sparse and too short-term to detect any changes in streamflow due to water use. The Salmon Creek gage near Battleground is the only long-term gage currently active within the Salmon-Washougal study area. Fortunately, Clark Public Utilities and Clark County have been operating several gages on Salmon Creek and Lacamas Creek for four or five years. As gaging records accumulate, detection of capture may become possible if the signal is not masked by weather variability.

Comparison of computer simulations for predevelopment conditions with 1987-88 conditions provides some insight into the probable streamflow conditions prior to urbanization and ground-water extraction. Based on this simulation Morgan and McFarland (1994, p. 57) explained the following: "Greater recharge from infiltration of precipitation, and the absence of pumping left more ground water available to discharge to rivers and streams during predevelopment conditions. Discharge to rivers was 33 percent greater and discharge to streams was 18 percent greater than under 1987-88 conditions. Less recharge as a result of more impervious surfaces has decreased the flow rate through the shallow aquifers and decreased discharge to rivers and streams. The addition of pumpage near rivers and streams has increased the quantity of seepage from rivers (from 1 to 36 cfs) and streams (from 48 to 88 cfs) to the ground-water system. Streams and rivers throughout the basin received less ground-water discharge in 1987-88 than during predevelopment conditions. In some areas where the simulation shows that pumping has lowered the water table, the streams may have stopped receiving discharge completely, or if they have sufficient flow, they have become a source of recharge to the shallow aquifers. Some river and stream reaches that contributed recharge to the ground-water system under predevelopment conditions, contributed more recharge after the water table was lowered by nearby pumping."

REDUCED GROUND-WATER DISCHARGE TO SPRINGS

As described above in the section entitled "Springs," the quantity of ground-water discharge to springs along the Columbia River, in the area between Camas and Vancouver, declined by 5.22 cfs (2,345 gpm), or 27%, between 1949 and 1988 (McFarland and Morgan, 1996). Withdrawal of ground water and urban construction appear to be the predominate causes of these declines.

EFFECTS OF ADDITIONAL GROUND-WATER WITHDRAWALS

An important use of the Portland Basin model is to simulate and estimate the probable response of the ground-water system to future increases in ground-water withdrawals. One such simulation was conducted by Morgan and McFarland (1994) to determine the probable effects of increased ground-water use within the Portland Basin, based on estimated water use in the year 2010. The simulation assumed an overall increase in ground-water use of 55 percent (92 cfs) compared to 1987-88 conditions, with 54 cfs of the increase assigned to Clark County and 38 cfs assigned to the Columbia South Shore well field in Oregon.

Pumping rates for the simulation were assigned as follows to various hydrogeologic units: 44 cfs to the regolith aquifer, 10 cfs to the Troutdale gravel aquifer, 12 cfs to the Troutdale sandstone aquifer, and 16 cfs to the upper coarse-grained sub-unit of the sand and gravel aquifer. The remaining amount, 10 cfs, was distributed among the other hydrogeologic units. For the Clark County portion of the model, the majority of the future pumpage was assigned to the Troutdale gravel aquifer and Troutdale sandstone aquifer. At the Columbia South Shore well field in Oregon, most of the increased withdrawals were assigned to the regolith aquifer, the Troutdale sandstone aquifer, and the upper coarse-grained subunit of the sand-and-gravel aquifer. Recharge was maintained at the same rates used in the 1987-88 pumpage simulation (Morgan and McFarland, 1994).

For Clark County, simulated declines of water levels in the regolith aquifer were as much as 20 feet. The large declines in Clark County probably resulted from increased downward leakage from the regolith aquifer due to withdrawals from the underlying Troutdale gravel aquifer. Declines of 20-40 feet were simulated in the Troutdale gravel aquifer in response to increased pumping from the unit south of Salmon Creek and near Camas. The broadest area of large simulated water-level declines occurred within the Troutdale sandstone aquifer. Declines in the Troutdale sandstone aquifer also affected heads in the undifferentiated fine-grained deposits where the two units are in contact and resulted in declines of 10-20 feet within a small area north of Vancouver (Morgan and McFarland, 1994).

The water budget derived from this simulation indicates that much of the additional pumpage is supplied by decreased discharge to, or increased recharge from, the Columbia River. Lesser portions of the pumpage were supplied by decreased ground-water discharge to other rivers and streams within the basin. An example is the simulated 8 percent reduction in the mean annual base flow of Salmon Creek (McFarland and Morgan, 1996).

Simulations of this type are important, not only for predicting responses of the ground-water system to anticipated future withdrawals, but also for determining where additional withdrawals will cause the least number of undesirable consequences. For example, additional head declines, beyond those which have already occurred within the interior of the Salmon Creek and Burnt Bridge Creek watersheds, could be minimized by developing future ground-water supplies from shallow wells located adjacent to the Columbia River and the tidally influenced power reaches of the creeks and rivers. The model simulation shows that additional ground-water development in the interior of the study area, where distances to areas of additional recharge or areas of natural discharge are great, will result in increased head declines and decreased ground-water discharge to streams and rivers.

SURFACE WATERS AND STREAMFLOW

FACTORS AFFECTING SURFACE WATERS

WRIA 28 comprises several adjoining, yet distinct, watersheds that are tributary to either the Columbia River or the Lake River. Important streams include Burnt Bridge Creek, Salmon Creek, the Washougal River, Whipple Creek, and Lacamas Creek (Table 9). The study area also contains numerous small creeks with drainage areas of less than 20 square miles. Information on these streams may be found in Richardson (1962).

Table 9. Watershed Areas for Selected Tributaries to the Columbia River, WRIA 28.

STREAM NAME	TRIBUTARY TO:	DRAINAGE AREA (mi^2)
Burnt Bridge Creek	Lake River	27
Hamilton Creek	Columbia River	Undetermined
Lackamas Creek	Washougal River	66
Rock Creek	Columbia River	41
Salmon Creek	Lake River	90
Washougal River	Columbia River	145
Whipple Creek	Lake River	Undetermined.

Although many of the large lakes once found along the Columbia River Flood Plain have been diked and drained, several still remain -- the largest being Vancouver Lake at 2,858 acres. Upland waterbodies include Battleground Lake (28 acres), Dead Lake (16 acres), and Lackamas/Round Lake (347 acres, a reservoir), all found in the Clark County portion of the study area. These are the only lakes of notable size not located on the Columbia River's flood plain, though numerous small ponds, mostly constructed for storage, dot the area.

The pathways of water to streams in the study area are (1) direct rainfall during storms, (2) overland runoff during and shortly after storms, (3) storm drains, and (4) ground-water discharge. Between storms, after the snow in the higher elevations has melted, ground-water discharge is the predominate source of streamflow. Many of the smaller streams are not fed by snowmelt because they originate at lower elevations. Only Lackamas Creek contains a reservoir (Lackamas Lake) large enough to maintain streamflows through the dry season.

DATA SOURCES AND GAGING HISTORY

In the past, the United States Geological Survey (USGS) operated streamflow gages in the study area, but all of these gages were discontinued. Clark County and Clark Public Utilities reactivated several gages formerly operated by the USGS or established new gages, on both Salmon Creek and Burnt Bridge Creek. No stream gages are active in the Skamania County portion of the study area. The gages are described below in Table 10.

Table 10. Selected active and inactive stream gages in WRIA 28.

CPU / ECOLOGY SITE NUMBER	USGS SITE NUMBER	SITE NAME	RIVER MILE	DRAINAGE AREA (Square Miles)	PERIOD OF RECORD
S-01	14212000	**Salmon Creek near Battle Ground:** 100 ft upstream from Hwy. bridge, 150 ft downstream from Rock Creek, 4.3 mi. E of Battle Ground. Operated by CPU	22.1	18.3	1944-75, 1988-89, 1992 - present
S-04		Salmon Creek at 156th St.: At bridge crossing of NE 156th St. Operated by Clark Co.,	13.3	35.7	1992 - present
S-08	14213000	Salmon Creek near Vancouver. Near Northcutt residence; along left bank, about 0.15 mile downstream of I-205, just downstream of abuttment for former bridge and at lower end of reach with steep left bank. Operated b CPU.	6.9	76.9	1944-75, 1988-89, 1992 - present
S-10		Salmon Creek at Klineland Pond: At foot bridge from parking lot toward swimming beach on south side of Klineline Pond, in Clark County's Salmon Creek Park, about 0.2 mile downstream of southbound I-5. Operated b Clark Co.,	5.6	-80	1992 - present
	14143500	Washougal River near Washougal: 0.6 miles upstream from Cougar Creek, 4.0 miles northeast of Washougal.	9.2	108	1945-81
	14144000	Little Washougal River near Washougal			1951-56 '

Since 1976, Clark County has operated three gages on Burnt Bridge Creek: at Royal Oaks, at E. 18th St., and at Alki Road. The gage at Royal Oaks was discontinued in 1995 due to backwater effects of in-channel vegetation. Unfortunately, the records for all three gages for the period prior to 1989 are not available in the tabular form needed for computer input and are of suspect quality because the stage/discharge relationship was not well defined; therefore, data for these three gages are not included in this study.

ANNUAL RUNOFF

Annual runoff from the study area generally increases from west to east, and ranges from 25 inches near Vancouver to 120 inches in the headwaters of the Washougal River (U.S. Geological Survey et al., 1972). Estimated mean annual runoff is 56 inches, or 1,500,000 acre-feet.

The lowest streamflows usually occur in late summer and early fall during dry weather. Hydrologists refer to the flows during this period as "baseflow." Because there are no glaciers or perennial snowfields in the mountains to help sustain baseflows, natural baseflow in the streams consists entirely of ground-water discharge. Likewise, no large dams release stored water to support baseflows in the watershed.

The topographic difference between ground-water heads and various stream reaches and springs determines the amount and duration of baseflow contributed by ground water. During a typically dry summer and early fall, the portion of ground-water storage which contributes discharge to a given stream may become nearly depleted, lowering streamflow at a time when water generally is most needed.

The 7-day lowflow is a statistical measure of baseflow and is calculated as the lowest flow during any seven consecutive days for a given year. The 7-day low flows for a number of years provide a means to evaluate variability and probable recurrence intervals.

U.S. Geological Survey, et al. (1972) rated the distribution of low-flow yields in southwest Washington according to the following classification (Table 11). The poor and fair yields reflect the lack of meltwater from glaciers or perennial snowfields during warm weather and, also, indicate that the streams receive only small amounts of ground-water inflow.

Table 11. Distribution of low-flow yields from stream basins in southwest Washington among five quantitative classes (U.S. Geological Survey, et al., 1972).

Class	Yield Interval in class (cfs/mi^2)[1]	Number of stream basins in class
Poor	≤ 0.2	8
Fair	0.21 - 0.40	18
Good	0.41 - 1.00	29
Very Good	1.01 - 1.60	16
Excellent	≥ 1.61	9

[1] Yield computed from 7-day low flows for 2-year recurrence intervals at stream stations.

The volcanic bedrock in the highlands stores only small amounts of water per unit volume of rock and therefore contributes only low rates of ground-water discharge to baseflow. On the other hand the glaciofluvial, alluvial, and catastrophic flood deposits (together referred to as regolith), covering bedrock in the lowlands and lower valleys of the eastern foothills, have a much larger contributing storage capacity.

U.S. Geological Survey, et al. (1972) estimated a low-flow (same as baseflow) yield of 0.57 cfs/mi^2 for the Washougal River near Washougal, from a drainage area of 108 mi^2. This yield rates as good, probably due to adequate ground-water inflow from regolith in the valleys. They also estimated a low-flow yield of 0.14 cfs/mi^2 for Salmon Creek near Battle Ground (USGS 14212000, river mile 22.1, drainage area 18.3 mi^2). This rates as poor yield, probably due to the scarcity of regolith and dominance of bedrock as the ground-water reservoir. Using data starting in 1988, when the station was re-activated, the low-flow yield has been only 0.10 cfs/mi^2.

By comparison, data for Salmon Creek near Vancouver (USGS 14213000, river mile 6.9, drainage area 76.9 mi^2, aka Northcutt gage), starting in 1988, indicate a low-flow yield of 0.17 cfs/mi^2. The long-term yield for this station may be slightly more than 0.2 cfs/mi^2, adjusting for the drier-than-average weather during the last decade. This slightly higher yield (poor to fair), compared to Salmon Creek near Battle Ground, results from the influence of the Pleistocene regolith and alder sedimentary rocks, which underly the plains, terraces, and stream valleys and store somewhat larger amounts of ground water per unit volume than does bedrock in the foothills.

SEASONAL PATTERNS AND ANNUAL TRENDS

Seasonal streamflow patterns in the Salmon Washougal watershed follow the same pattern as precipitation, as demonstrated by the mean monthly flows in Salmon Creek and the Washougal River (Figure 26; Appendices D and E). Streamflows begin to increase in September or October after the late summer or early fall rains have replenished soil moisture, and continue to increase over the ensuing months, with the highest flows occurring in December or January. Streamflows tend to decrease, on average, through late winter, spring, and summer, usually reaching the lowest levels in August. This pattern repeats with some variation each year.

The water year, October 1st through September 30th of the following year, was used as an accounting period when comparing precipitation and streamflow conditions. Accounting by water year assists in comparing streamflows during the wetter fall and/or winter weather with the ensuing drier weather of spring and summer. As can be seen from the monthly graphs, the precipitation from each fall/winter sequence influences the low flows of the following August and September, but only slightly influences the flows of the following October through December. The latter flows depend on the return of storms during late summer and fall. Accounting for precipitation by calendar year may give misleading indications of what that year's low flow may have been.

To characterize the variability of flow throughout the year, the annual exceedence probabilities were computed for 48 periods throughout the year. The flow record was first divided into four periods per month, then flow for each period was averaged over the same period for each year of record. Because of the relatively limited sample sizes of data available for calculation, usually on the order of several tens of years, there can be high variability between consecutive periods in the statistics used to compute the flow exceedences. This results in fluctuations in the flow exceedence values from one period to the next, which are not physically reasonable. To correct this problem, mathematical routines were used to smooth the statistics between the computation periods. A five-point central averaging was tried for calculating the mean; that is, averaging a value computed for a given period with values for the immediately preceding periods and values for the two immediately following periods. The standard deviation and skew for these smoothed means, however, still exhibited higher values than desired, so the smoothing was recalculated using a nine-point central averaging, that is, with four periods preceding and four periods following a given period. The data points on this plot represent the unsmoothed flows shown previously in Figure 1 and the line represents the smoothed flow-frequency curve computed by the 9-point central averaging (Bruce Barker, personal communication). The curves were calculated using the widely used Log Pearson Type 3 statistical distribution.

Using this method, we calculated the exceedence probabilities throughout the year for Salmon Creek (Figure 27) and the Washougal River (Figure 28). The three curves on each graph show the streamflow rates which will probably be exceeded 90% of the time (lower flows), 50% of the time (approximately average flows), and 10% of the time (highest flows) throughout the year. For Salmon Creek, the exceedence patterns follow those of the average monthly flows (Figure 26). During very wet years, represented by the 10% exceedence curve, the highest flows occur in January, and lowest flows occur in August and early September. During very dry years, represented by the 90% exceedence curve, the highest flows also occur in January, but the lowest flows tend to occur throughout September, rather than in August.

For the Washougal River, the exceedence patterns follow those of the average monthly flows, but with some significant exceptions (Figure 26). During the very wet years (10% exceedence curve), the peak flows occur during January and the lowest flows occur during August, the same pattern as the mean monthly flows. During the dry years (90% exceedence), the peak flows occur during April rather than January as expected from average monthly precipitation, while the lowest flows occur during September rather than August. The delay in peak flows probably reflects the influence of snow melt following dry, cold winters with little rain in the lowlands.

LOW FLOWS COMPARED TO WATER-YEAR PRECIPITATION

The lowest 7-day lowflow (moving-average for seven consecutive days) for Salmon Creek near Battleground varied from year-to-year by a factor of more than eight -- from 0.7 to 5.9 cfs (Figure 29). During water years 1992 to 1994, the 7-day lowflow dropped to between 0.7 and 1.0 cfs, substantially below previous levels. This significant decrease approximately matched the trend of antecedent (water-year) precipitation.

For Salmon Creek near Vancouver (aka Northcutt), low flows have been measured only for eight years, during the water years 1988 to 89 and 1992 to present, however daily records are incomplete for some of these water years. During these periods the 7-day lowflow varied by a factor of about six, from about 3 to about 18 cfs. Also, the pattern of 7-day lowflow for this gage approximately followed the pattern of the antecedent precipitation (Figure 29).

The pattern of 7-day lowflows differs at the two gages on Salmon Creek. One reason may be that the lowflow records for the gage at Salmon Creek near Battleground are inaccurate. For many stream gages, the low flow records tend to be the least accurate of the water year because shallow depths create added inaccuracy to current-meter measurements and tend to cause rating-curve shifts. Also, flow measurements may be too few to adequately define the rating curve.

The dramatic decrease in 7-day low flows for the Battleground gage - equivalent to a decrease by about two-thirds of the average during 1992-94 -- may be attributable to the continuing dry weather. This decrease may also signal increased water use upstream in response to the dry conditions.

ANNUAL FLOWS COMPARED TO WATER-YEAR PRECIPITATION

For the Washougal River at Washougal, the annual average discharge (1944-80 water years) varied by a factor of more than two, from 530 to 1180 cfs (Figure 30). The trends tended to match those in the water-year precipitation at Vancouver (Figure 14). Recent trends in discharge for this river cannot be determined due to discontinuance of gaging. Given the low :population and slow industrial growth in the Washougal watershed, flows probably have not been greatly affected by water use.

For Salmon Creek near Battleground, the annual average discharge (1945-75, 1988-89, 1993-94 water years), varied by a factor of less than two, ranging from about 85 to 235 cfs (Figure 30). This variation probably would have been greater if streamflow for the very dry 1977 water-year had been recorded at the gage. The trends in flow also tended to match those in the water-year precipitation at Vancouver (Figure 14) and matched trends in streamflow for the Washougal River at Washougal (Figure 30).

WATER QUALITY

QUALITY OF SURFACE WATERS

Water-quality standards for the surface waters of Washington State are defined in Chapter 173-201A WAC. The standards are intended to protect and preserve water quality for present and potential uses, while considering the naturally occurring water-quality limitations that may affect a stream. Based on defined criteria for selected parameters (fecal coliform bacteria; dissolved oxygen; total dissolved gas; temperature; pH; turbidity; toxic, radioactive, or deleterious material concentrations; aesthetic values), streams and rivers within the state are assigned to one of four classes: Class AA (extraordinary), Class A (excellent), Class B (good), and Class C (fair).

Table 12. Summary of Data on Ambient Monitoring of Surface Water, WRIA 28 (Ehinger, 1993).

STATION NUMBER	STATION NAME	YEARS SAMPLED	PARAMETERS VIOLATED *
28A090	Columbia R. below Vancouver	1968-70	
28A165	Columbia R. at Warrendale	1973-79	
28A170	Columbia R. below Bonneville	1968-69, 1977	
28A175	Columbia R. at Bonneville Dam	1968-70, 1976	
28B070	Washougal R. at Washougal	1969-70, 1972-73, 1976-77, 1992	T
28B090	Washougal R. near Washougal	1962-70	
28C070	Burnt Bridge Cr. at Mouth	1973	
28C110	Burnt Bridge Cr. at Vancouver	1973	
28D070	Salmon Cr. at Salmon Cr.	1973	
28D110	Salmon Cr. near Battle Ground	1973	
28E070	Weaver Cr. near Battle Ground	1973	
28F070	Lake River near Ridgefield	1992	FC, T, Ph
286070	Gibbons Cr. near Washougal	1992	FC
29B070	White Salmon R. near Underwood	1960-70, 1972-73, 1976-83	

* DO = dissolved oxygen, T = temperature, FC = fecal coliform.

All streams and rivers within WRIA 28 are rated as Class A, and, under ideal conditions, should have water of sufficient quality for domestic uses, industry, agriculture, stock watering, wildlife habitat, recreation, and fish rearing or migration. Ehinger (1993) summarized the previous water-quality monitoring in WRIA 28 (Table 12). In 1994, Cusimano and Giglio (1995) analyzed the pollutant loading in Salmon Creek and its tributaries. Several streams failed to meet Class A criteria. The limitations on some streams, such as Salmon Creek, Burnt Bridge Creek, Lacamas Creek, the Washougal River, and the Bonneville tributaries, are so severe that they are included on the State's 303D list (a provision of the Clean Water Act) of significantly degraded streams (Table 13). While the causes of impairment vary by stream and affected reach, many of the water-quality problems are the result of agricultural and silvicultural practices, or urban stormwater runoff. General land development, construction, and nonpoint pollution sources also contribute significantly to the noted problems.

Table 13. Proposed 303(d) Listing of Impaired Water Bodies (Ecology, 1997).

WATER BODY	Dissolved Oxygen	Fecal Conform	Nutrients	PH	Temperature	Turbidity
Burnt Bridge Cr.	X	X		X	X	
China Creek	X	X		X	X	
Cougar Canyon Cr.						
Curtin Creek		X				
Fifth Plain Creek	X					
Gibbons Creek		X				
Lacamas Creek	X	X		X	X	
Lacamas Lake			Under restoration			
Lake River		X			X	
Matney Creek	X	X		X	X	
Mill Creek		X				
Salmon Creek		X			X	X
Shanghai Creek	X			X	X	
Vancouver Lake		Under restoration	Under restoration			

QUALITY OF GROUND WATERS

Ground-water quality in the Clark County portion of the study area has been extensively studied. Mundorff (1964) evaluated data from 12 wells in the southwest part of the area. Subsequent studies by Van Denburgh and Santos (1965), Ebert and Payne (1985), Turney (1990), and Clark Public Utilities (1995) have analyzed the more densely populated portions of Clark County.

Turney (1990) sampled 76 Clark County wells between April and May 1988 for major cations and anions, silica, nitrate, phosphorous, aluminum, iron, manganese, radon, and bacteria. He also sampled a subset of 20 wells for selected trace elements and organic compounds (Appendix F). Twelve of the sampled wells are completed in the regolith aquifer, 29 in the Troutdale gravel aquifer, 12 in the undifferentiated fine-grained unit, 5 in the Troutdale sandstone aquifer, and 18 in the older rocks.

Based on the classification scheme of Hem (1985), water throughout the Clark County portion of the study area is soft to moderately hard. For the wells sampled, dissolved solids concentrations were generally low, ranging from 12 to 245 mg/L, with a median concentration of 132 mg/L. The principal dissolved constituents included calcium, bicarbonate, and silica. In some samples from the older rocks, sodium is also prevalent (Turney, 1990). In the upper four hydrogeologic units, calcium-bicarbonate and calcium-magnesium-bicarbonate are the predominant water types. In the older rocks, sodium-calcium-bicarbonate and sodium-bicarbonate water types are also present.

The dissolved-solids concentration increases along regional flow lines (Turney, 1990). That is, concentrations in ground water in northeastern Clark County - the up-gradient recharge area - have lower dissolved solids concentrations than ground water in southwestern Clark County near discharge areas. This pattern is consistent with the expectation that total dissolved solids in ground water usually increase with increased residence time in the ground as a result of chemical weathering of minerals.

With exceptions for pH, turbidity, iron, manganese, and total coliform bacteria, all of the well water met the U.S. Environmental Protection Agency's (USEPA) drinking-water standards (ibid.; Appendix F). Elevated bacteria concentrations probably result from poor well construction or isolated conditions affecting individual wells. Elevated pH, turbidity, iron, and manganese concentrations likely result from natural hydrogeologic conditions.

Nitrate concentrations varied from less than 0.1 to 6.7 mg/L, with a median concentration of 0.18 mg/L (ibid.). Twenty wells produced water with nitrate concentrations greater than 1.0 mg/L, which may indicate ground-water contamination from septic systems and fertilizers. Most of the elevated nitrate concentrations were found in wells producing from the regolith aquifer and the Troutdale gravel aquifer near Vancouver. Based on an evaluation of 16 wells that were sampled at least twice during the period 1958 to 1988, nitrate concentrations might be increasing over time in the rural areas of Clark County where concentrations have historically been low. Conversely, in the urban southwest, which exhibited elevated nitrates in the earlier sampling, concentrations may be stable or decreasing slightly. Subsequent nitrate sampling by Clark Public

Utilities (1995) yielded similar results, although several wells produced water with nitrate concentrations greater than 5 mg/L (Figure 31).

Contaminated areas of very limited extent have been identified under Washington's Model Toxics Cleanup Act (MTCA) and the Federal Comprehensive Environmental Resource Cleanup Liability Act (CERCLA). These sites (Figure 32) are in various stages of analysis or cleanup.

FISH STOCKS AND HABITAT

ALTERATIONS TO HABITAT

The streams of the study area provide important spawning and rearing habitat for several anadromous and resident fish species, including chinook, coho, and chum salmon; summer and winter steelhead; sea-run and resident cutthroat trout; and rainbow trout.

Over time, many of the streams have been significantly altered by human activities. Decades of agriculture and urban development in the plains and lowlands, coupled with logging in the upper watersheds have contributed to the extreme reduction (estimated at 95%) in salmonid fish stocks and severely degraded habitat in several of the watersheds. The seriousness of the declines and extinctions have caused some stocks to be listed under the Endangered Species Act (ESA), and it is likely that more listings will occur. In March 1998, the National Marine Fisheries Service (NMFS) listed the wild steelhead of the lower Columbia River as threatened, or in grave danger of extinction.

Municipal and industrial pollution from the Vancouver and Camas-Washougal urban areas has chronically impaired the water quality of the Columbia River. Floodplain modifications, such as dikes and ditches, have altered flow patterns and access by fish. In the smaller watersheds, habitat alteration and destruction are primary factors in reducing fish populations (Columbia River Subbasin Plan, 1989).

In the Salmon Creek subbasin, residential development has resulted in fish passage barriers, high stream temperatures, low dissolved oxygen concentrations, poor water quality, and fine sediment deposition. Because of the large amount of development and subsequent water withdrawal, water quantity may also limit production of salmonids in the watershed (Washington Dept. of Ecology, 1997).

In many streams, low summer flow is a critical factor limiting the size of fish populations (Washington Dept. of Fisheries, 1975). Although summer flows are naturally low in some streams, they can be further reduced (in both quantity and duration) by human activities, ultimately resulting in increased water temperature, decreased dissolved oxygen concentrations, decreased insect drift, increased crowding and competition for available food, and less area in which to hide from predators. According to the Washington Dept. of Fish and Wildlife (1997), streams with low-streamflow problems are:

(1) Burnt Bridge, Dougan, Duncan, Gibbons, Greenleaf, Hamilton, Lacamas, Lawton, Matney, Mill (and 3 of its tributaries), Mud, Rock, Salmon (and one of its tributaries), Weaver, Whipple, and Wildboy Creeks and

(2) Little Washougal, East Fork Little Washougal, West Fork Washougal, and Washougal Rivers.

Maintaining and restoring fish passage to allow adult migration to upstream spawning areas, and juvenile emigration downstream, is a critical factor in assuring viable salmonid populations. While natural barriers such as waterfalls occur, along many of the Columbia Gorge tributaries, dams have also been built on Lacamas Creek, Duncan Creek, the Washougal River, and other tributaries to the Columbia. In many areas, improperly constructed or placed culverts have blocked fish passage to off-stream habitat and spawning areas. A number of the large lakes on the Columbia River floodplam have been diked and drained for agricultural use. Gibbons Creek was lost to fish use when the Columbia River dike was built in the vicinity of Lake Steigerwald National Wildlife Refuge. Recently, the U. S. Fish and Wildlife Service re-established fish passage by diverting the lower end of the creek through the dike.

SALMON DISTRIBUTION, ABUNDANCE, and STOCK STATUS

Two recently published studies regarding the health of salmonid stocks in Washington State were evaluated for this report: (1) "Pacific Salmon at the Crossroads: Stocks at Risk from California, Oregon, Idaho, and Washington," American Fisheries Society (AFS), 1991, and (2) "1992 Washington State Salmon and Steelhead Stock Inventory" (acronym "SASSI Report"), Washington Dept. of Fisheries, et al, 1992.

Table 14. Status of Anadromous Fish Stocks in WRIA 28 (Washington Dept. of Fisheries, et al., 1992).

WATER BODY	STOCK TYPE	STOCK ORIGIN	PRODUCTION TYPE	STOCK STATUS	SCREENING CRITERIA
Bonneville Tributaries	Coho	Mixed	Composite	Depressed	Chronically low
Hardy Creek (Bonneville Tributary)	Fall Chum	Native	Wild	Healthy	
Hamilton Creek Bonneville Tributary}	Fall Chum	Native	Wild	Depressed	Long-term negative trend, short-term severe decline
	Winter Steelhead	Native	Wild	Unknown	
Salmon Creek	Coho	Mixed	Composite	Depressed	Chronically low
“	Winter Steelhead	Native	Wild	Depressed	Chronically low
Washougal River	Coho	Mixed	Composite	Depressed	Chronically low
“	Fall Chinook	Mixed	Composite	Healthy	
“	Summer Steelhead	Native	Wild	Unknown	
“	Winter Steelhead	Native	Wild	Unknown	

West Fork Washougal River	Summer Steelhead	Native	Wild	Unknown	
“	Winter Steelhead	Native	Wild	Unknown	

The two fisheries reports differ in their respective approaches. The SASSI report examines the current status of fish stocks, while the AFS paper assesses the future risk of stock extinction. Accordingly, the reports appear to disagree substantially as to the condition of the stocks (Tables 14 and 15). On the other hand, the reports generally agree in their listings of stocks at risk. Runs of coho and fall chum salmon of the Bonneville tributaries, coho and winter steelhead in Salmon Creek, and coho salmon in the Washougal River are listed as depressed, or as having production below expected levels, based on the available habitat (Table 14 and Figure 33). None of the Lower Columbia stocks are listed as critical; however, several are listed as unknown, illustrating the need to collect information about these stocks - particularly if they have historically had small populations. In general, anadromous fish populations have been severely reduced by human activities.

Table 15. Conflicting Designations Between American Fisheries Society (AFS) and the Salmon and Steelhead Stock Inventory (Lufkin, 1993, unpublished).

WATER BODY	STOCK TYPES	AFS STATUS	SASSI STATUS
Washougal River	Fall Chinook	Extinct	Healthy
Washougal River	Coho	Extinct	Depressed
Washougal River	Chum	Extinct	Extinct or not verified

LOWER COLUMBIA STEELHEAD CONSERVATION INITIATIVE

The State of Washington currently is developing a statewide strategy to protect and restore wild steelhead runs and other salmon and trout species. In May of 1997, Governor Locke created the Joint Natural Resources Cabinet to provide leadership in developing and implementing coordinated statewide strategies to restore healthy salmon and trout populations by improving fish habitat. One important resulting activity is development of the Lower Columbia Steelhead Conservation Initiative (LCSCI) to address protection and recovery of steelhead in the lower Columbia River area. The goals of Washington's Department of Fish and Wildlife for this area include rebuilding wild stocks and restoring habitat diversity.

SUMMARY OF FINDINGS

HYDROGEOLOGY

The geology of the western half of Water Resource Inventory Area 28, Salmon-Washougal, consists of a structural basin filled with lacustrine and fluvial sediments. The geology of the eastern half consists largely of volcanic rocks comprising the foothills and peaks of the Cascade mountains. This section of the report discusses the western half almost exclusively because few wells have been drilled in the foothills and mountains and production rates are low.

Most of the ground water withdrawn from the western half of WRIA 28 comes from the coarser sedimentary facies. However, usable quantities of water can be obtained from the underlying bedrock units. The bedrock and basin-fill sediments have been subdivided into eight hydrogeologic units on the basis of their geology and water development potential including: (1) older rocks, (2) sand and gravel aquifer, (3) confining unit 2, (4) Troutdale sandstone aquifer, (5) confining unit 1, (6) Troutdale gravel aquifer, (7) unconsolidated sedimentary (or regolith, herein) aquifer, and (8) undifferentiated fine-grained unit.

Ground-water recharge occurs largely through infiltration of precipitation, discharge to septic drain fields, and runoff to drywells. Within the western two thirds of the study area, total recharge varies from 0 to 39 inches per year and averages 17 inches per year. Recharge from precipitation totals about 15.2 inches per year, while recharge from drywells and on-site waste disposal systems averages about 1.3 and 0.3 inches per year, respectively.

Ground water generally moves from upland recharge areas along the western flank of the Cascade range toward natural points of discharge along the Columbia River and its larger tributaries. In the uplands, heads decrease with increasing depth (hydraulic gradient oriented downward) indicating recharging conditions. In the lowlands, heads generally increase with increasing depth (hydraulic gradients oriented upward) indicating discharging conditions.

Ground water naturally discharges as spring flow or as seepage into streams and lakes. Substantial amounts of ground water are withdrawn through wells for industrial uses, public water supply, irrigation, and homes. Most of the ground water discharges to streams, with lesser amounts discharging to wells and springs.

CLIMATE

Precipitation records indicate that the study area has experienced cyclical wetter and drier periods since 1890. Overall, there is no trend toward either wetter or drier conditions, however, drier conditions have prevailed since around 1980.

EFFECTS OF GROUND-WATER USE ON THE HYDROLOGIC SYSTEM

Reductions in ground-water storage are the most thoroughly documented indication of the effects of ground-water withdrawals on the study areas aquifer system. Declining heads are readily apparent over large areas where ground water is withdrawn for public supply. The largest documented declines (15-25 feet) have occurred in the Troutdale gravel and unconsolidated sedimentary aquifers within the Burnt Bridge Creek and Salmon Creek drainages. Throughout western Clark County water levels have declined several feet.

Between 1949 and 1988, ground water discharge to springs along the Columbia River, between Vancouver and Camas, decreased by 10.5 cfs, or 42 percent. The cause of this decline appears to be pumping of wells in the uplands to the north, because the loss of spring flow corresponds closely in timing with the decline of heads in the aquifers that feed the springs.

For most streams and rivers in the study area, existing streamflow data is not sufficient to detect changes in discharge due to water use. The long-term streamflow data that have been collected are for sites upstream of substantial surface-water or ground-water usage. A predevelopment modeling simulation of the Portland Basin (Morgan and McFarland, 1994, p. 57) found that "streams and rivers throughout the basin received less ground-water discharge in 1987-88 than during predevelopment conditions. In some areas where the simulation shows that pumping has lowered the water table, streams may have stopped receiving discharge completely, or if they have sufficient flow, become a source of recharge to the shallow aquifers. Some river and stream reaches that contributed recharge to the ground-water system under predevelopment conditions, contributed more recharge after the water table was lowered by nearby pumping."

Despite severe declines in fisheries and recurring water-quality problems in the study area, and the documented reduction of ground-water storage, we do not have sufficient data to show what the effect streamflow reductions due to capture by wells has played in causing these conditions. We need to know what proportion of any reduction in seasonal flows is due to capture by wells at different times of the year before we can begin to judge the consequences of capture. Department of Ecology, Clark Public Utilities, and Clark County are committed to continue data collection to this end.

WATER DEMAND

The population of the study area is increasing steadily, pushing up the demand for water. As the cost of doing business in the Portland area rises, Clark County has become increasingly attractive to corporations. Low development costs and an abundant labor force have attracted a number of high-tech companies to the area. Clark County has been one of the fastest growing counties in the State for the past two decades, with an average annual population growth of 2.8% since 1970, compared to 1.6% for the State. The population increased by 126% from 1970 to 1995, more than three times the 36.5 percent statewide increase.

Surface-water and ground-water appropriations have increased steadily over the years, with a total authorized withdrawal of 1,235.5 cfs (Qi) and 78,470.6 acre-feet/yr (Qa) for surface water, and a total withdrawal of 295,677 gpm (Qi) and 273,103.8 acre-feet/yr (Qa) for ground water.

Applications for new water rights on file at Ecology total approximately 40.01 cfs and 1,420 acre-feet/yr for domestic supply, commercial, and fish propagation and irrigation purposes from surface waters, and approximately 18,118 gpm and 19,598.7 acre-feet/yr, for domestic supply, irrigation, mining, and municipal purposes from ground waters.

During 1987-88, the United States Geological Survey inventoried wells in the Portland Basin and estimated ground-water pumpage for the three major use categories of public supply, industrial, and irrigation. Their analysis showed that the estimated total average annual ground-water pumpage in the Salmon-Washougal watershed during 1987-88 was 88,280 acre-feet/yr, as compared to 262,964 acre-feet/yr, the amount issued for withdrawal under water-right certificates at the time.

We were not able to quantify the actual water use, but based on the findings of Collins and Broad (1993), the recorded water rights and claims greatly exceed actual consumptive water use. In addition, unauthorized use may also remove significant volumes of water from the streams and aquifers of the study area.

FISH STOCKS

Human activities have significantly altered many streams in the study area. Decades of agriculture in the plains and lowlands, urban development, and wholesale logging in the upper watersheds have continued to deplete remnant salmonid fish runs and degrade the riparian habitat. The water quality of the Columbia River has been chronically polluted by municipal and industrial discharge in the Vancouver and Camas-Washougal urban areas. In the Salmon Creek watershed, residential development has resulted in fish passage barriers, high stream temperatures, low dissolved oxygen concentrations, poor water quality, and fine sediment deposition. Water quantity may also limit production of salmonids.

During the summer and fall, low streamflow tends to increase water temperatures and to decrease dissolved oxygen. Low streamflow at any time of year reduces area suitable for fish to hide from predators. Because of these effects, low streamflow may be the critical factor limiting the size of fish populations in many streams. Although low streamflow is a natural phenomenon in all Washington streams, it is often exacerbated by reductions in ground-water recharge due to human activities or by withdrawal of ground water; both effects ultimately reduce the ground-water discharge to streams.

The coho and fall chum runs of the Bonneville area tributaries, the Salmon Creek coho and winter steelhead, and the Washougal coho have been listed as depressed, or as producing well below expected levels, based on available habitat. None of the Lower Columbia stocks have been listed as critical. However, the status of several of the Lower Columbia stocks has been listed as unknown, illustrating the need to collect more information, particularly if stocks have historically small populations.

WATER QUALITY

Several streams in the study area fail to meet all of the Class A criteria. The limitations on streams such as Salmon Creek, Burnt Bridge Creek, Lacamas Creek, the Washougal River, and the Bonneville tributaries are severe enough that they are included on the State 303D list of substantially degraded streams. While the causes of impairment vary by stream and by affected reach, many of the water-quality problems result from agricultural and silviculture practices or urban runoff. General land development, construction, and nonpoint-pollution sources also contribute significantly to the noted problems.

With exceptions for pH, turbidity, iron, manganese, and total coliform bacteria, all 76 of the wells sampled by Turney during 1988 produced water meeting the U.S. Environmental Protection Agency's (USEPA) drinking water standards. Elevated bacteria concentrations probably result from poor well construction or isolated conditions affecting individual wells. Elevated pH, turbidity, iron, and manganese concentrations likely result from natural hydrogeologic conditions.

Elevated nitrate concentrations were found largely in water samples collected from both the regolith aquifer and the Troutdale gravel aquifer within the southwestern part of the study area near Vancouver. Nitrate concentrations in ground water may be increasing over time in the rural areas of Clark County where concentrations have historically been low, although in the urban southwest, concentrations may be stable or decreasing slightly. Nitrate sampling by Clark Public Utilities identified several wells with nitrate concentrations greater than 5 mg/L.

CONCLUSIONS

Ground-water withdrawals within WRIA 28 has captured discharges from springs and streams and has drawn down ground-water levels over broad areas. To minimize the adverse effects of additional withdrawals, future high-capacity wells should be constructed within the tidally influenced lower reaches of streams or within the Columbia River alluvium. By restricting additional withdrawals to these reaches, ground-water discharge to the upper, non-tidal stream reaches will be substantially maintained. Continued ground-water development within the upland interior portions of WRIA 28 will result in decreased ground-water discharge to streams and additional declines in heads, eventually impairing senior water rights and degrading instream and riparian habitats. Strong efforts toward water conservation and re-use will help to reduce the growth in water demand which will tend to lead to these undesirable effects.

Water quality has been significantly degraded in many streams due to a variety of land-use practices and lack of proper waste disposal. Efforts to rehabilitate riparian corridors by fencing and bank restoration should continue. Compliance with regulations to prevent erosion from construction sites and forest practices must be encouraged and enforced.

A large volume of ground water is reserved for future public water supply but has not yet been allocated. Applications for new allocations from the reserve water must be approved through the usual process and so may be denied if the four tests for a water rights are not met. We cannot judge whether all the reserved water will be allocated because the current state of knowledge about the hydrologic system in WRIA 28 does not permit an accurate prediction of the effects of these future allocations on senior water rights, instream flows, and ground-water levels.

ADDITIONAL INFORMATION NEEDS

(1) DETAILED WATER-RIGHTS REVIEW AND ANALYSIS

Detailed compilations of active water rights and water usage are needed for individual watersheds, aquifers, and stream reaches. Additional field data are needed to tabulate and map all water rights or claims, to determine the amounts of water used for active rights and claims, and to search for unauthorized water usage. Compilations and maps of instream-flow requirements for individual water rights also are needed.

A GIS system should be used to produce maps of place-of-use, diversion locations, and well locations, based on digital linkages to the appropriate database files. This work can be coordinated with the Clark County assessor's office, which already has prepared ARC/INFO maps of land ownership.

(2) MONITORING AND ANALYSIS OF SURFACE-WATER CONDITIONS

Greatly expanded monitoring of streamflows and springs is needed to track conditions and to detect trends in water availability resulting from weather or usage changes. As with CPU and Clark County taking responsibility for some stream gaging, Ecology should encourage other agencies to participate in funding and operating gages. Volunteers could be used to periodically read staff gages.

Streamflow gages in the Washougal watershed should be re-activated due to the lack of current hydrologic information for that large watershed.

Streamflow gages on Salmon Creek and Burnt Bridge Creek should be continued indefinitely, with the exception of the Salmon Creek gage at Klineline Pond, which is not needed as long as the Northcutt residence gage is maintained. A new gage below the mouth of Cougar Creek, but just above the tidally influenced reach, would better reflect streamflow effects due to the use of CPU's well field in the Salmon Creek Park area. Staff gages on the major tributaries to Salmon Creek would give further indications of where changes may be occurring.

(3) PERIODIC WATER LEVEL MEASUREMENTS

Both Ecology and CPU measure water levels in observation wells in Clark County. These networks might be combined for efficient operation. A network of wells is needed in the Skamania County portion of the study area. The wells should be divided between those that reflect climatic changes and those that reflect the effects of ground-water withdrawals.

(4) FURTHER GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT

Access to data would be greatly enhanced by expanded use of ARC/INFO, the brand of GIS software adopted by the State's natural resources agencies, including the Department of Ecology. In addition, Clark Public Utilities, Clark County, and U. S. Geological Survey all use this software, in the process facilitating the exchange of data between agencies.

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Figures

Study Area Location

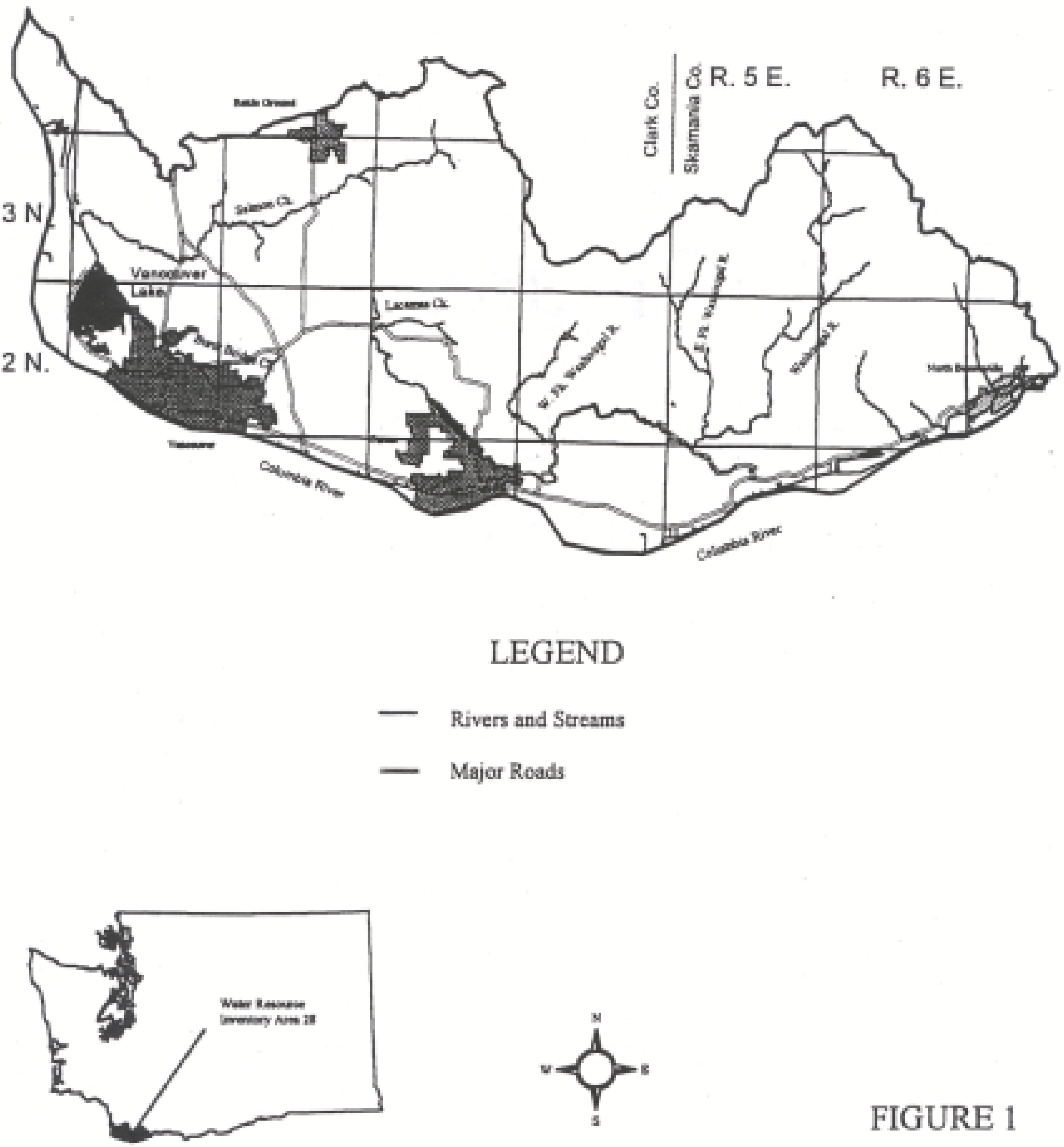


FIGURE 1

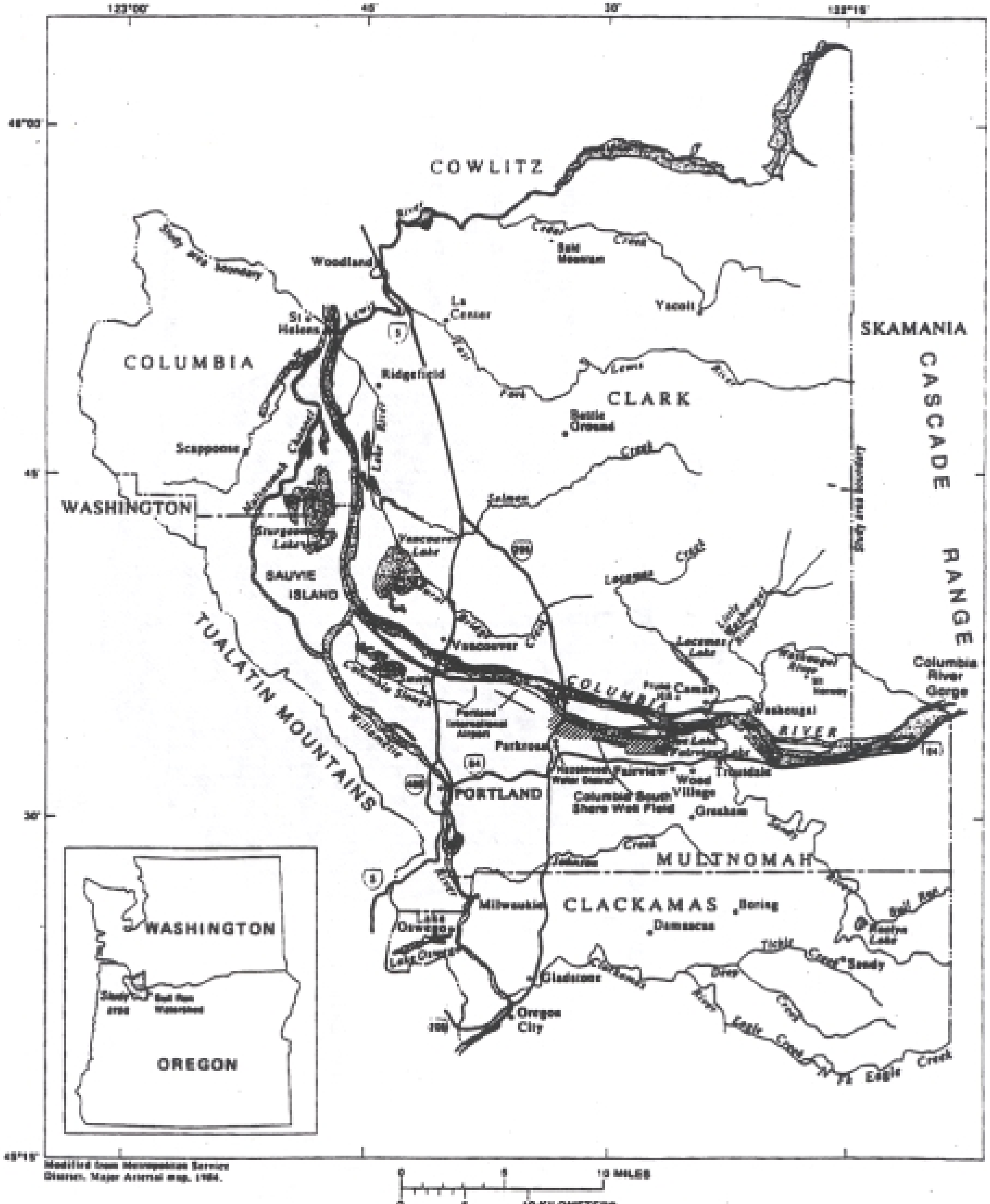


Figure 2. Location and general features of the Portland Basin study area (McFarland and Morgan, 1996)

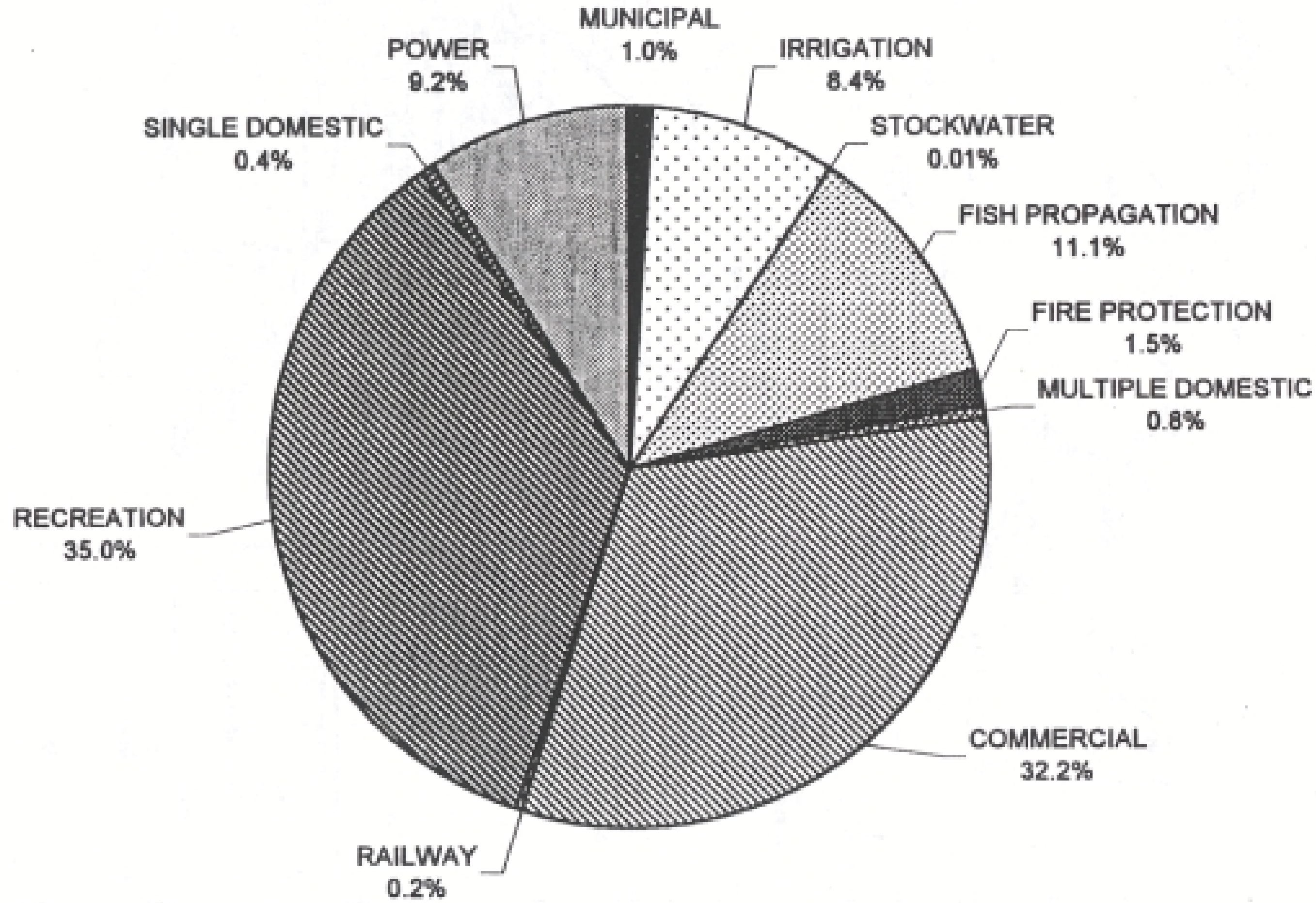


Figure 3. Surface-water Certificates, Primary Purpose of Use.

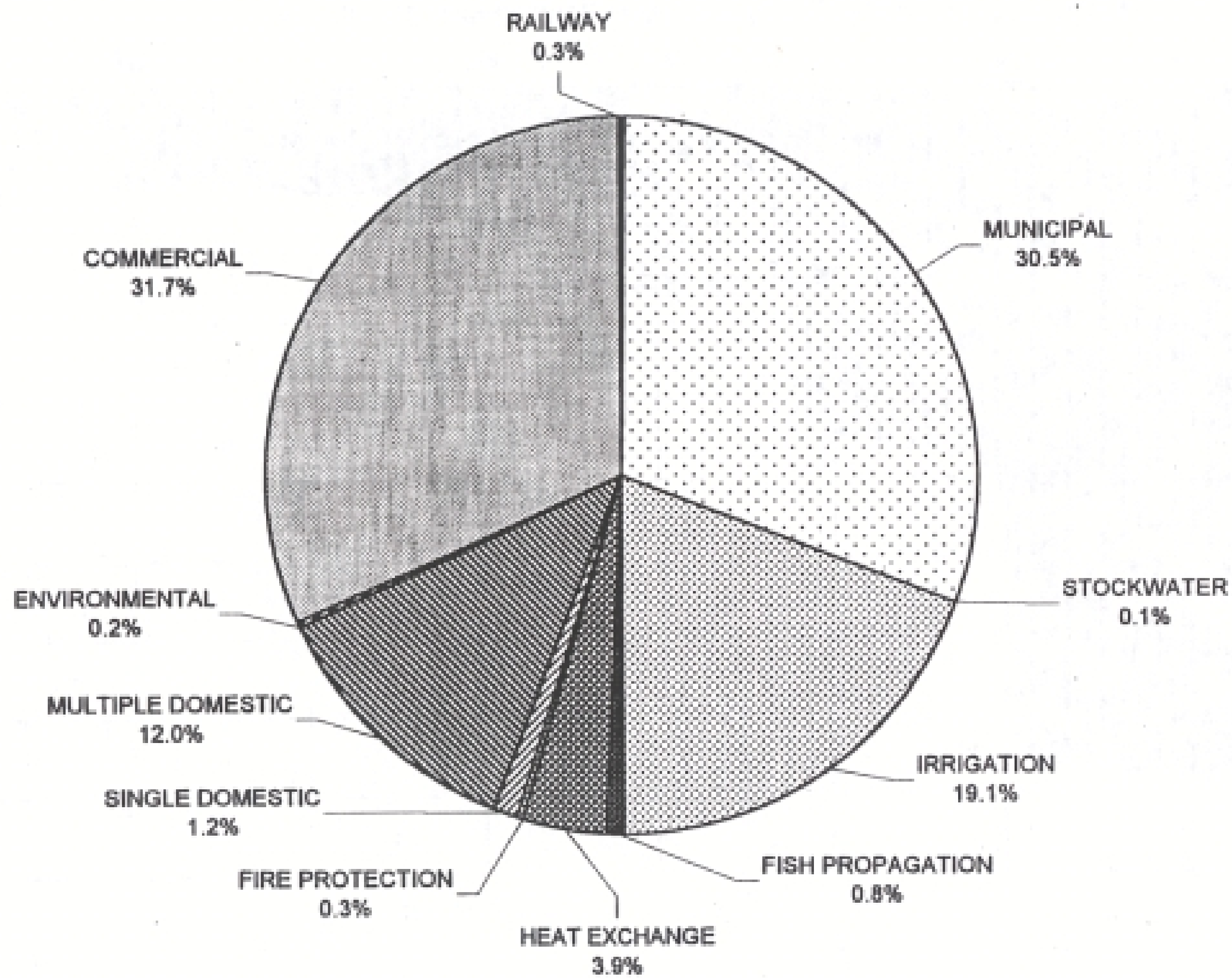


Figure 4. Ground-water Certificates, Primary Purpose of Use.

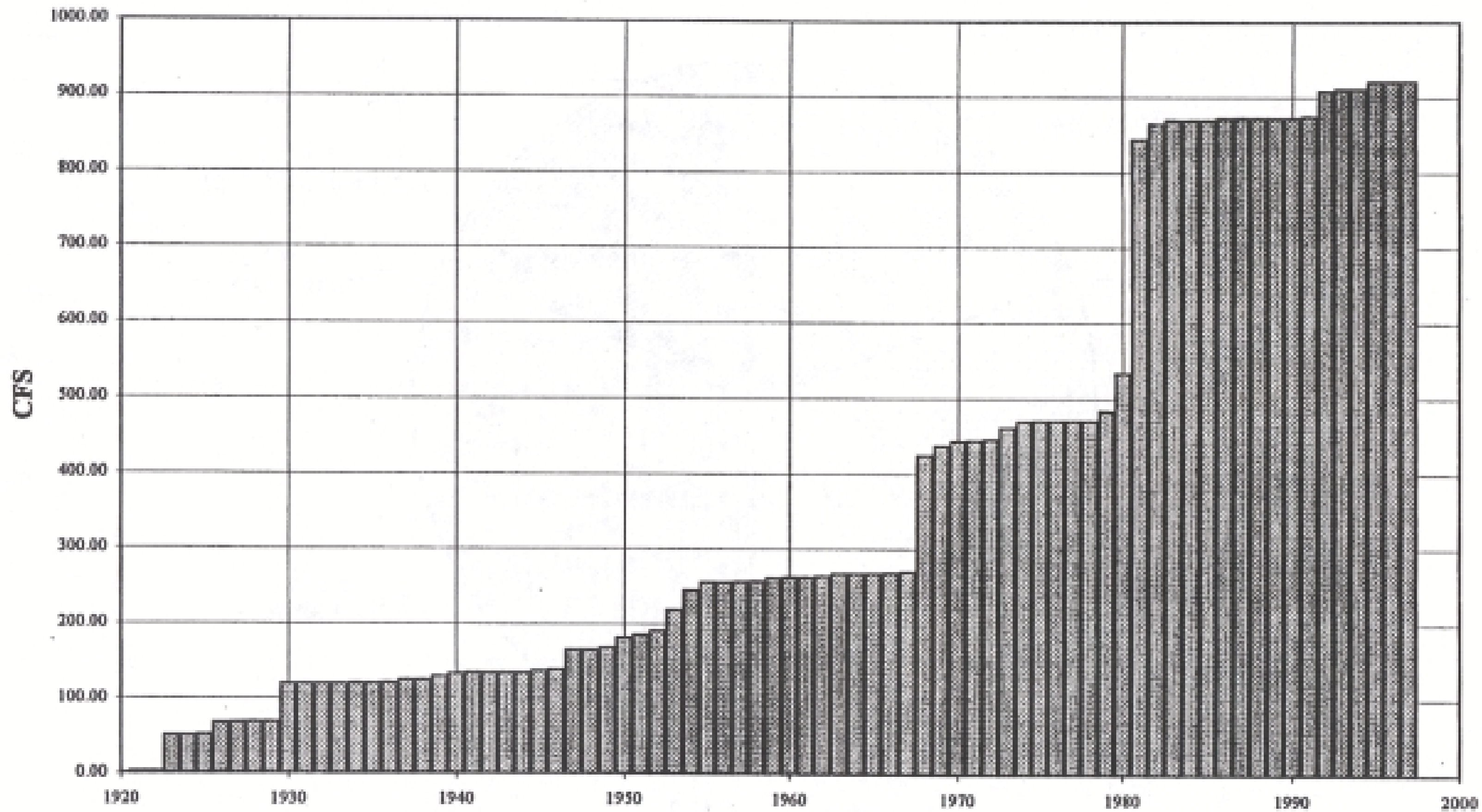


Figure 5. Growth of Surface-Water Appropriations in WRIA 28, Cumulative Annual Quantity.

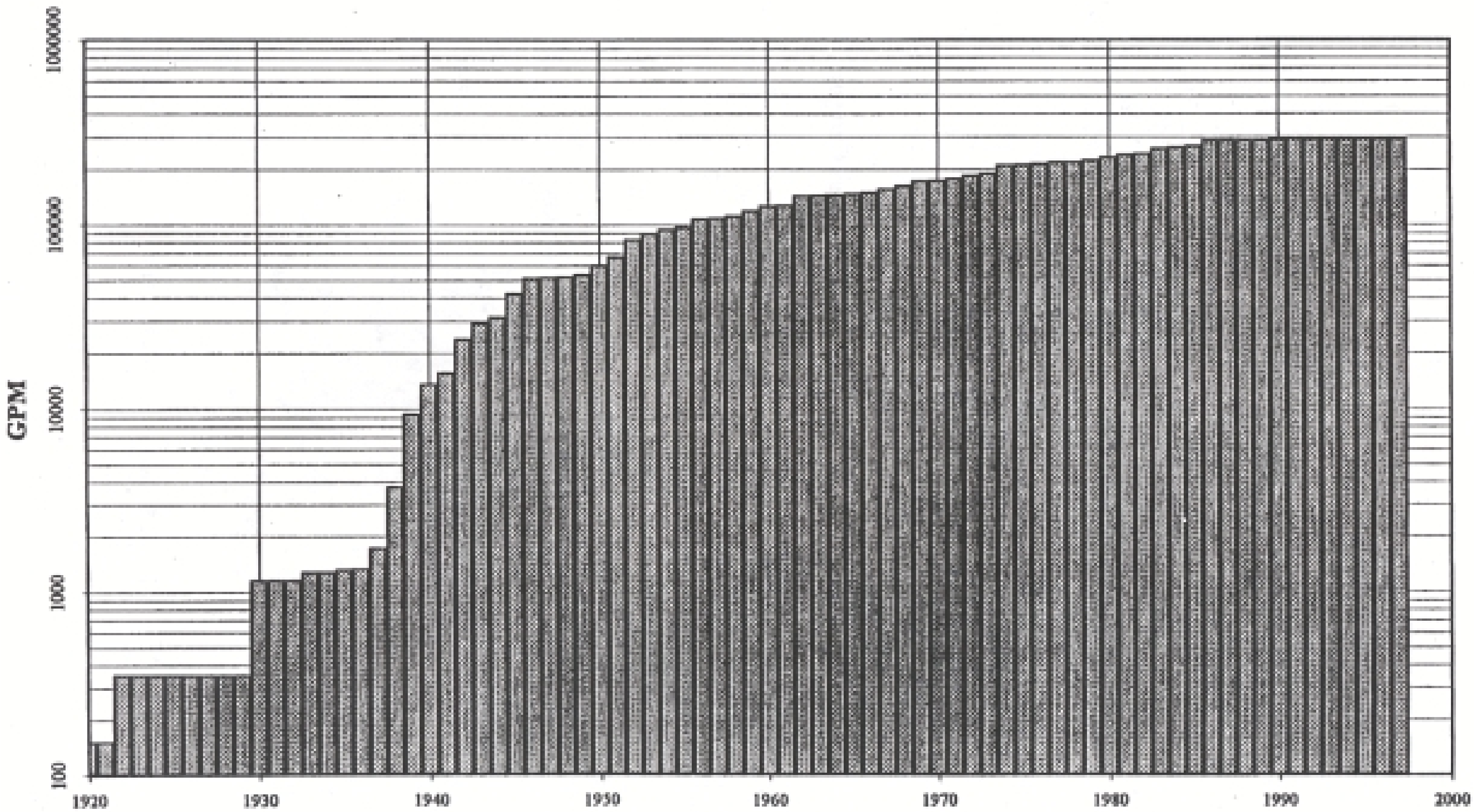


Figure 6. Growth of Ground-Water Rights in WRIA 28, Cumulative Instantaneous Quantity.

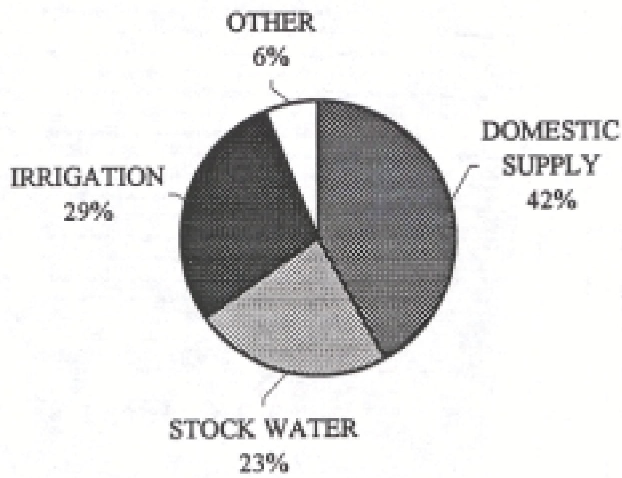


Fig. 7. Surface Water Claims by Use Category.

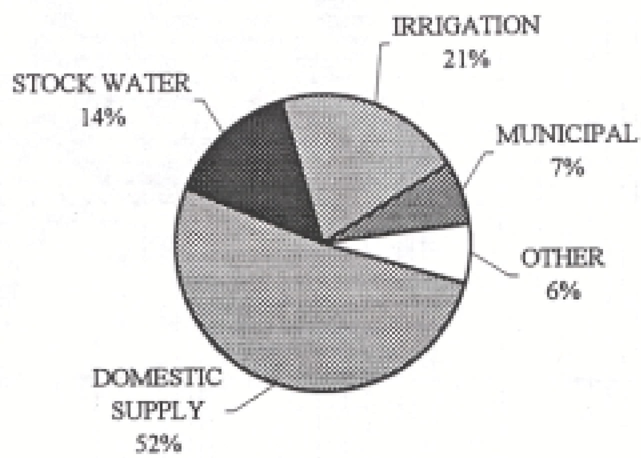


Figure 8. Ground Water Claims by Use Category.

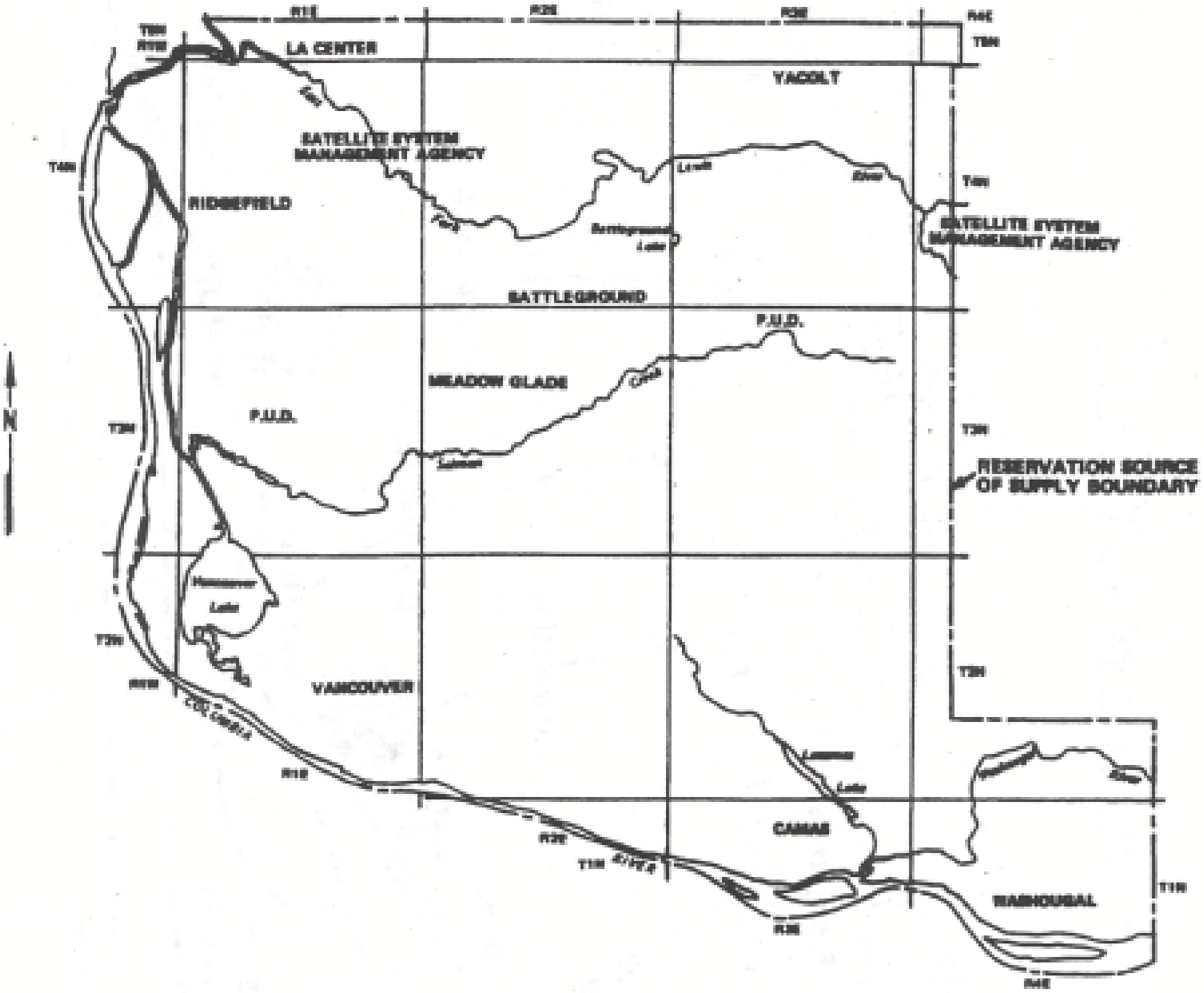


Figure 9. Clark County Reservation source of supply area boundary map (Washington Administrative Code 173-592-120)

THE WATER CYCLE

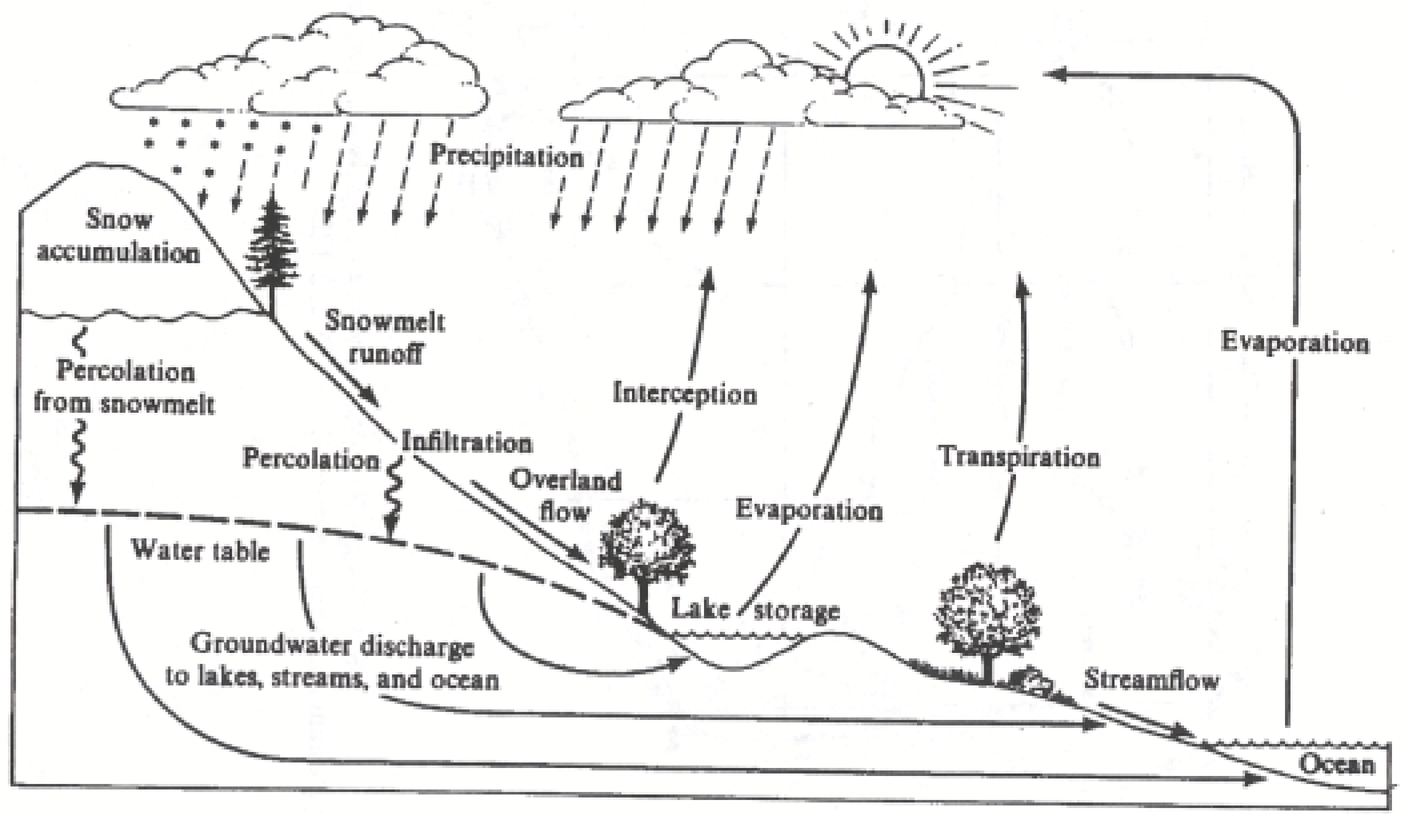
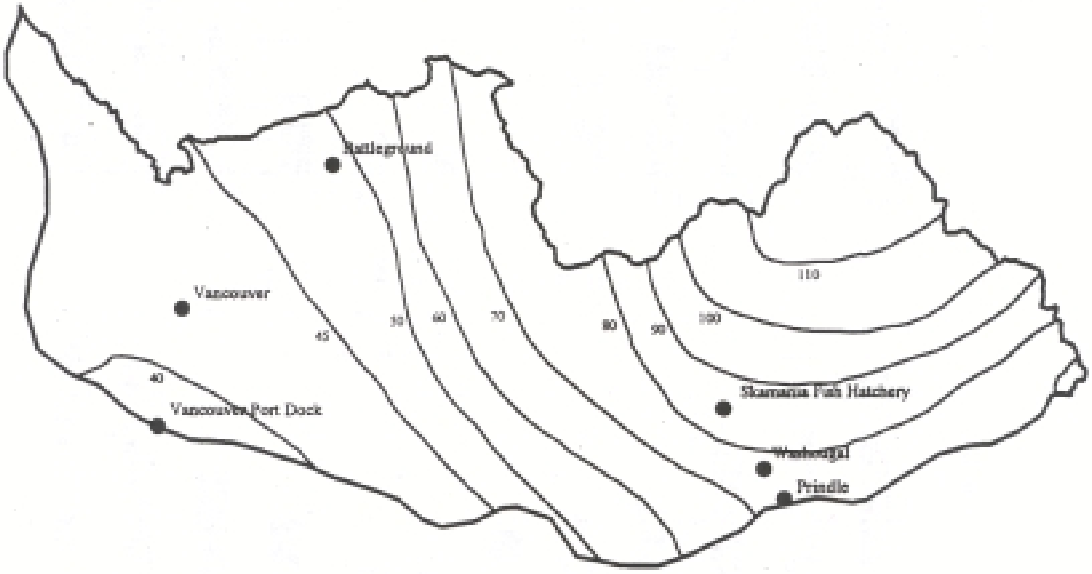


FIGURE 10. From Dunne and Leopold (1978)

National Weather Service Climate Stations and Distribution of Mean Annual Precipitation (Isohyets) for WRIA 28



LEGEND

STATION NAME (Period of Record)

Battleground (1948 to present)
Prindle (1948 to 1949)
Skamania Fish Hatchery (1965 to present)
Vancouver (1898 to present)
Vancouver Port Dock (1949 to 1959)
Washougal (1950 to 1964)

40 Isohyet Showing Mean Annual Precipitation (inches)

FIGURE 11

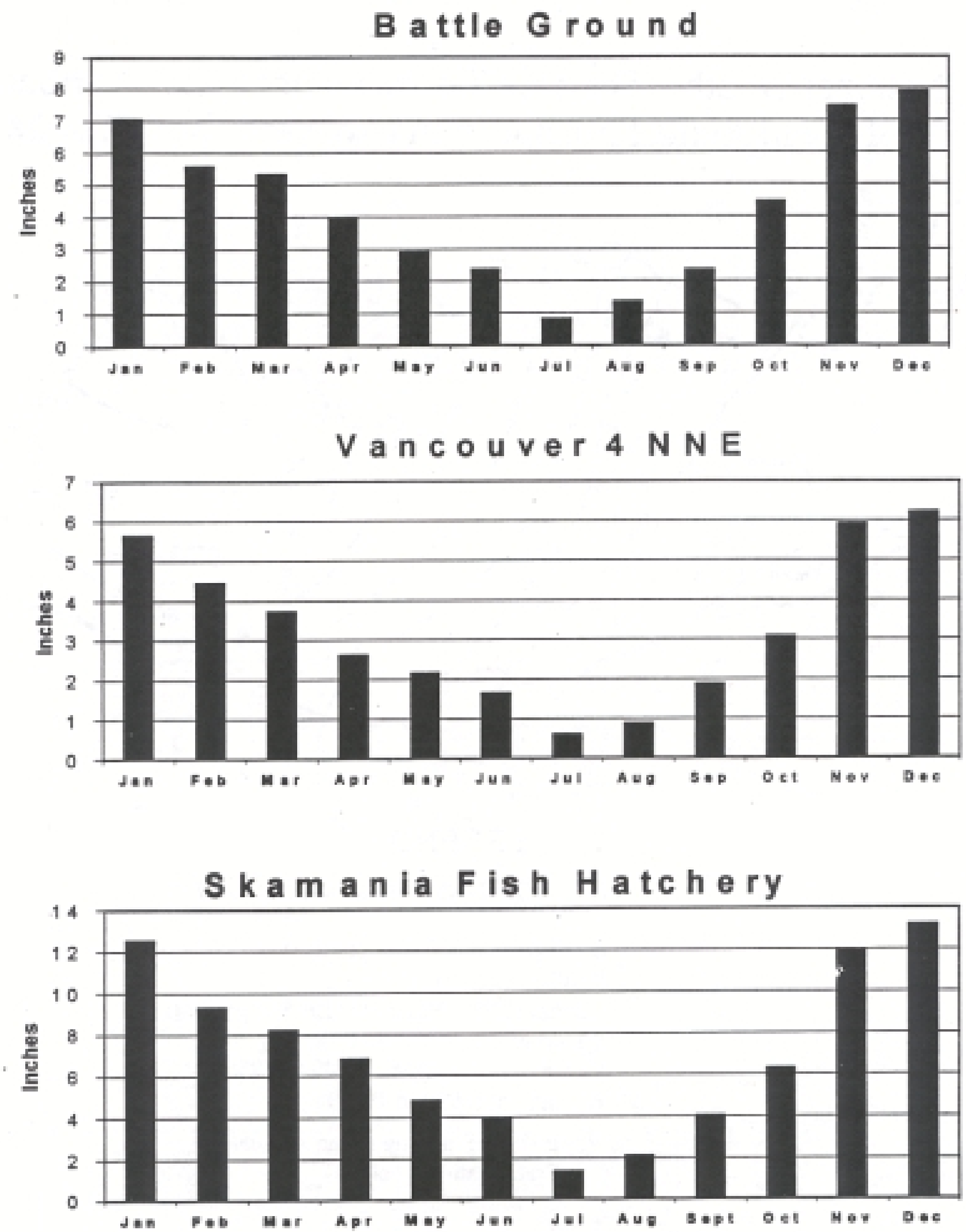


Figure 12. Average Monthly Precipitation at Three Weather Stations in WRIA 28.

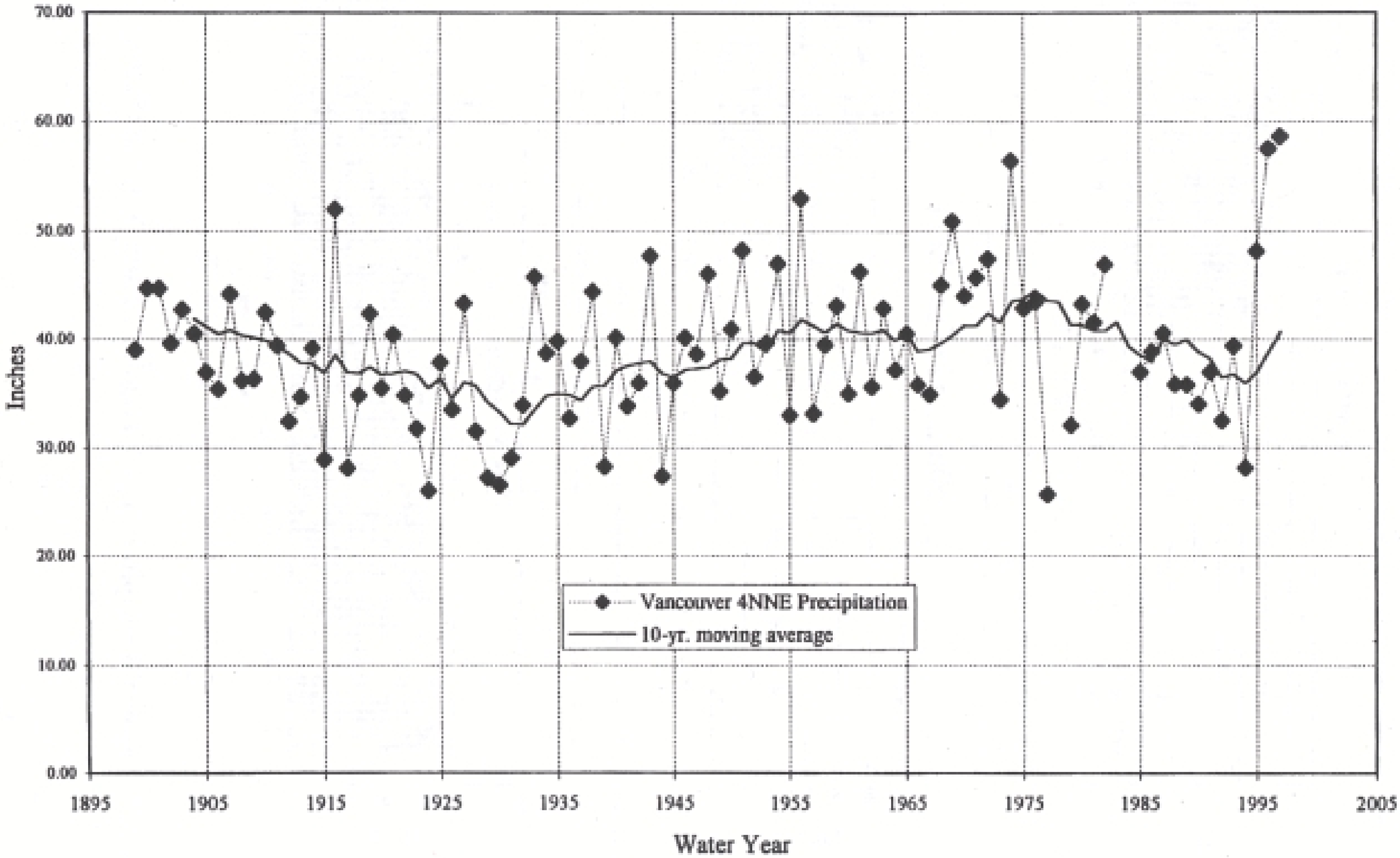


Figure 13. Precipitation Trends in Clark County.

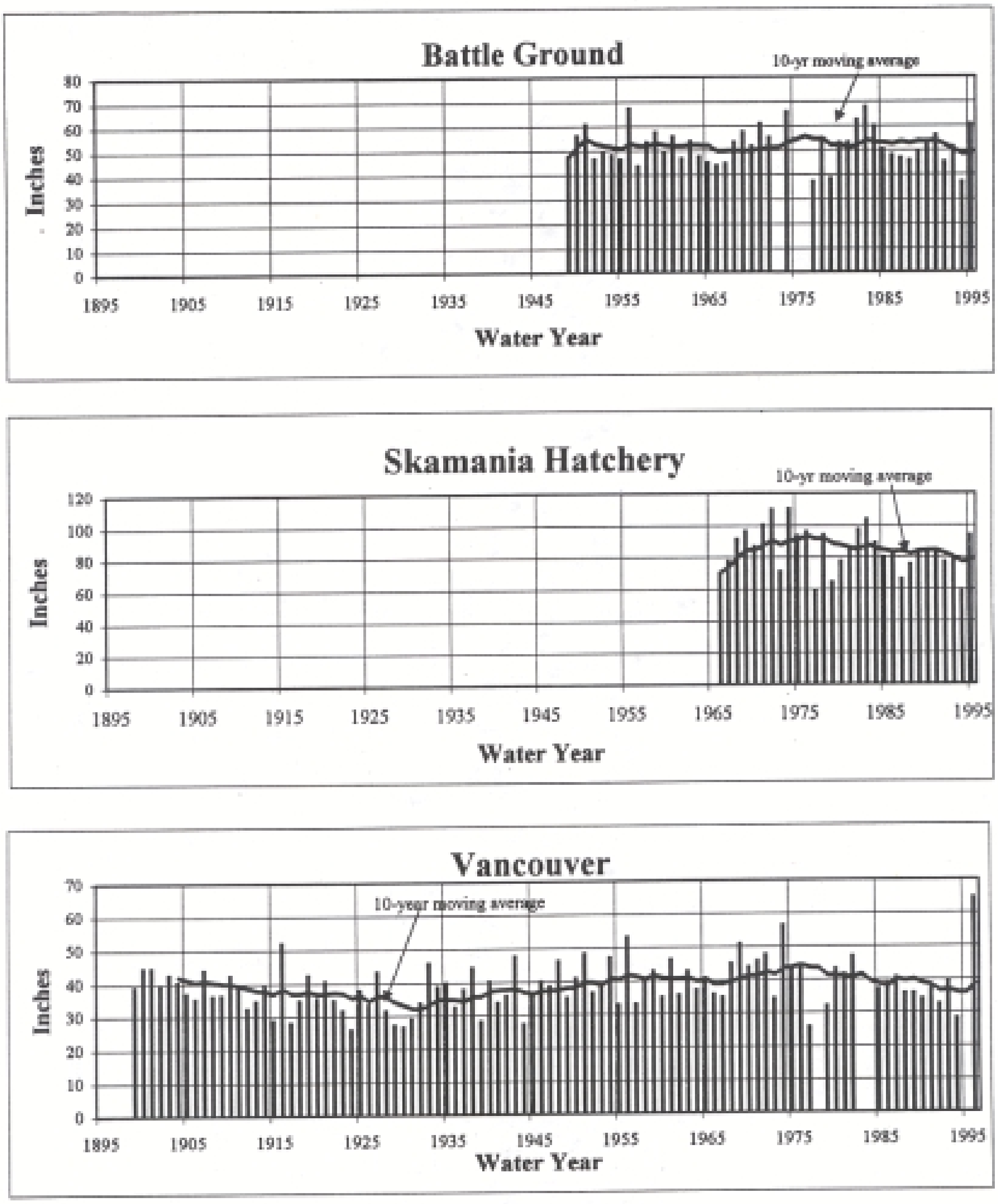


Figure 14. Annual Precipitation and Trends at Three Weather Stations, WRIA 28.

d:\wria28\climate\Figure14.xls\Fig. 14
4/24/98

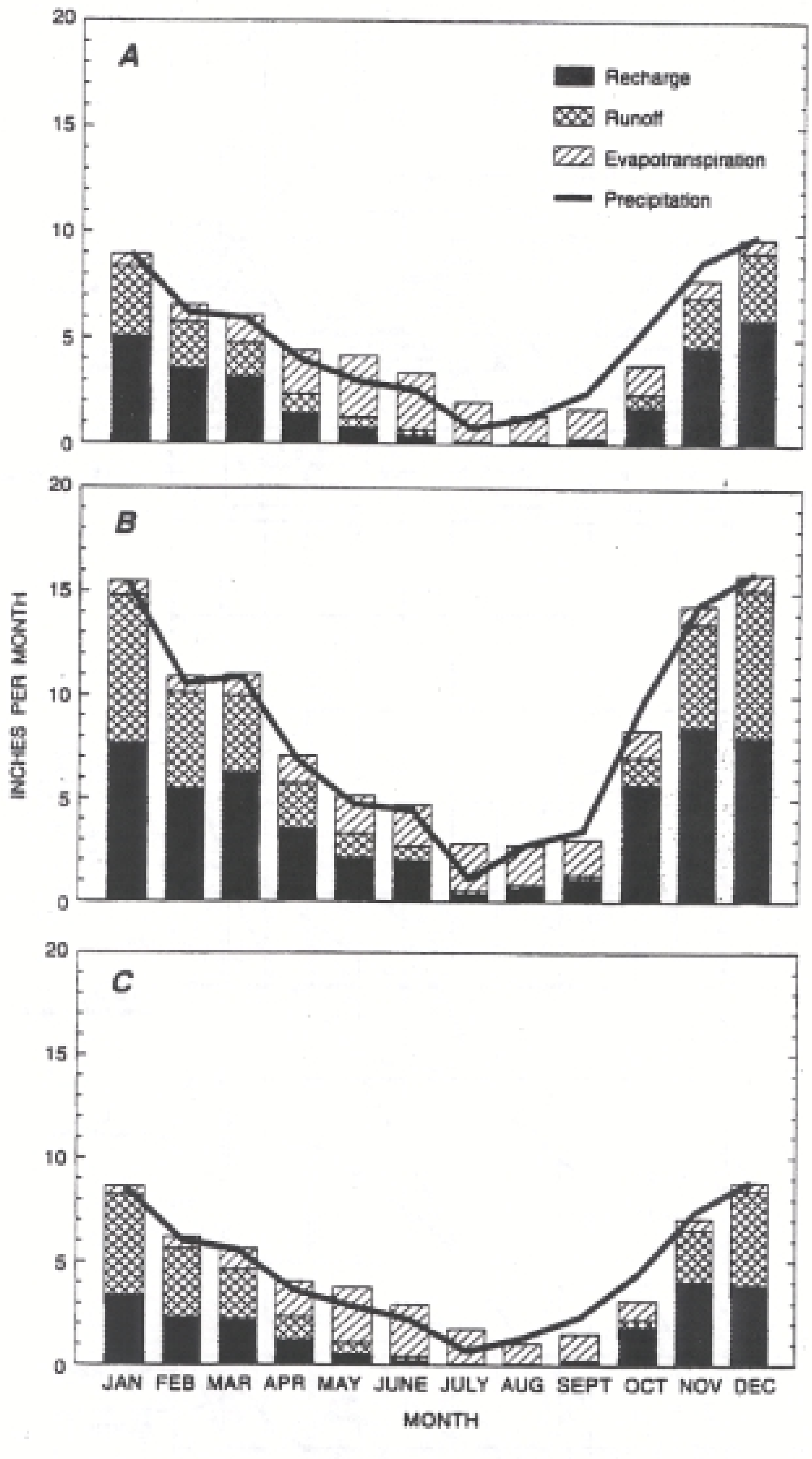


Figure 15. Average monthly water budget for (A) Salmon Creek Subbasin, 1949-74; (B) Cedar Creek Subbasin, 1952-69; and Johnson Creek Subbasin, 1949-83 (Snyder, et al., 1994)

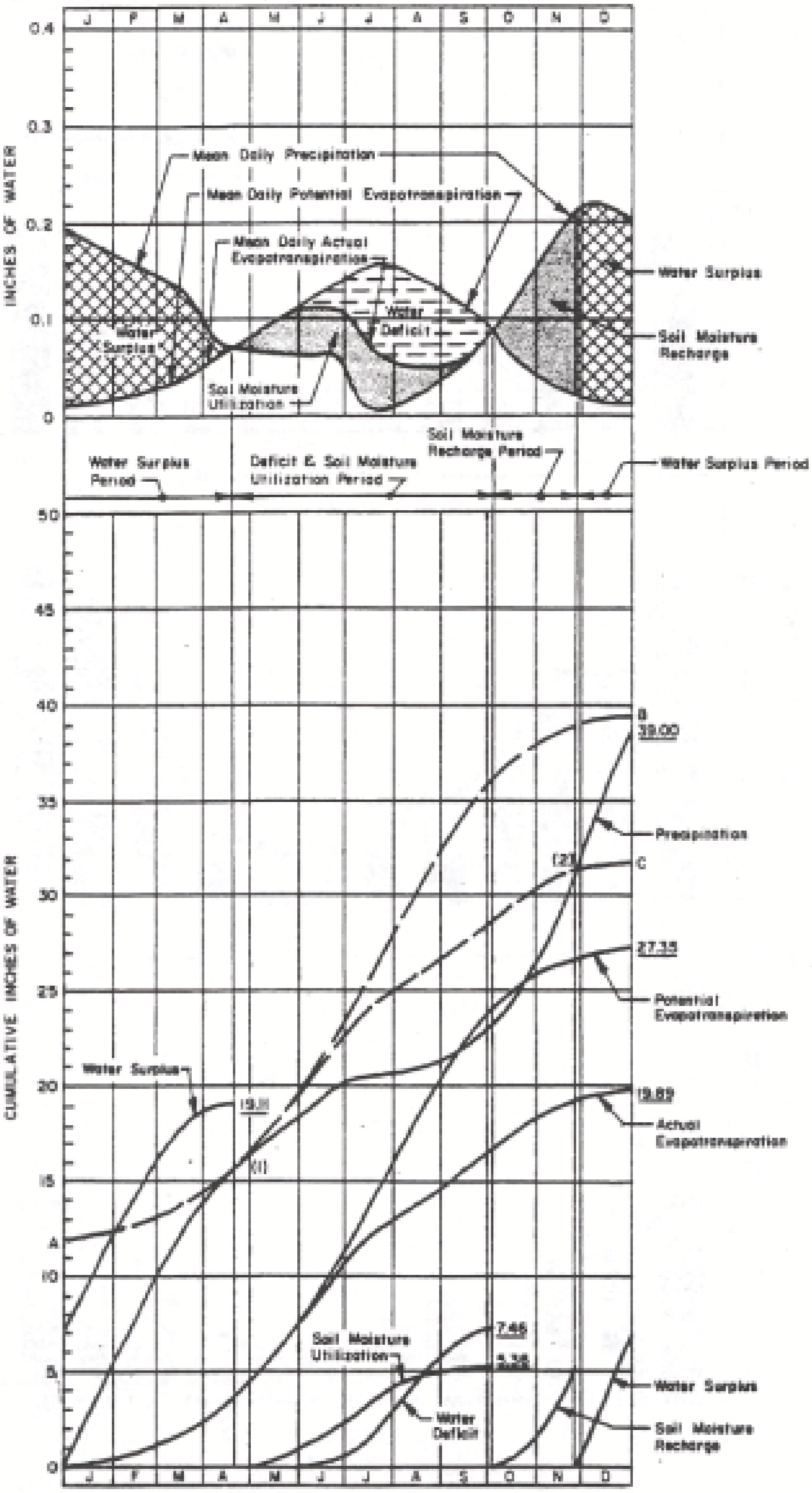


Figure 16. Mean annual soil water budget at Vancouver; root zone water capacity of 6 inches (U.S. Geological Survey, 1972)

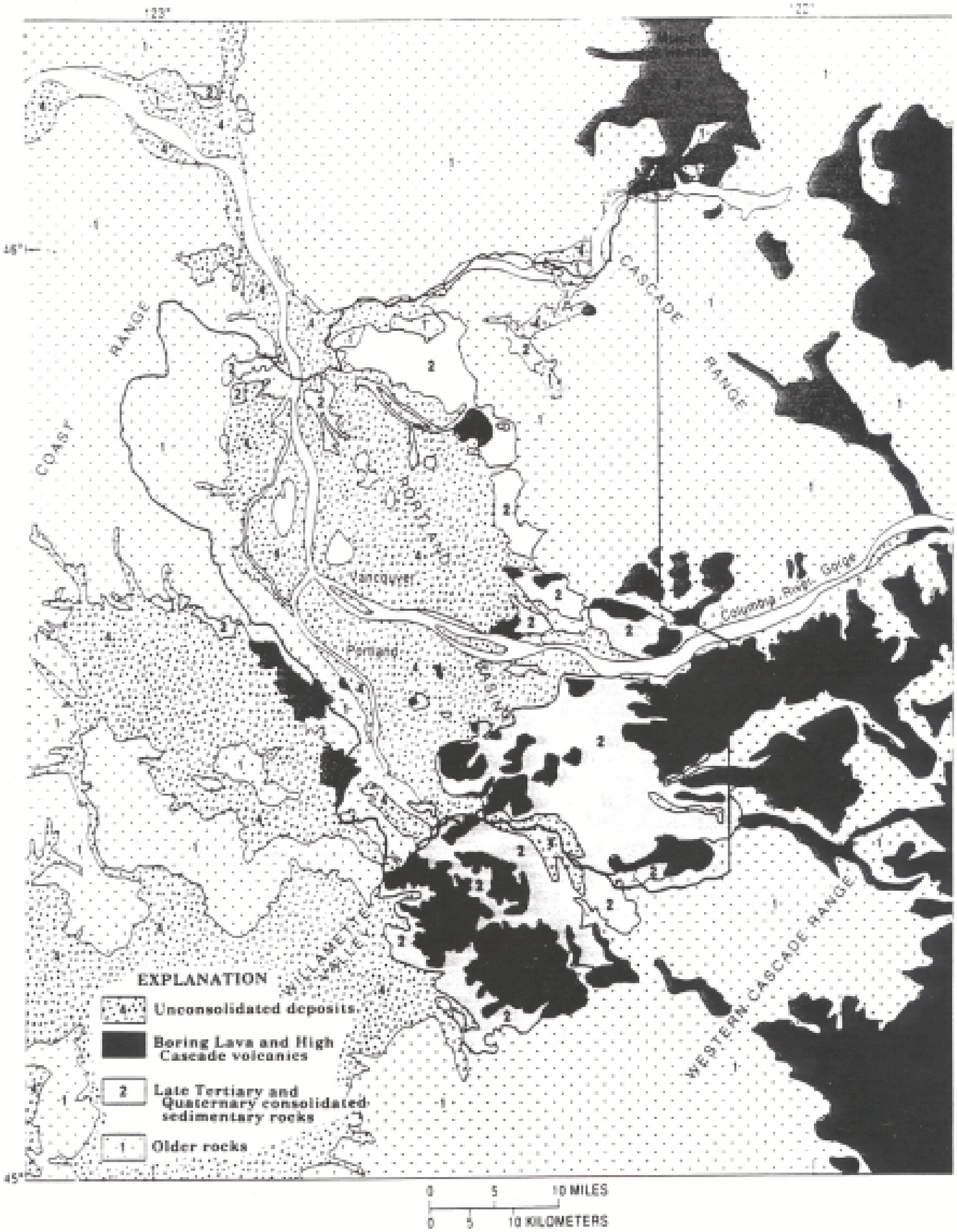


Figure 17. Regional geography of the Portland Basin (Swanson, et al., 1993)

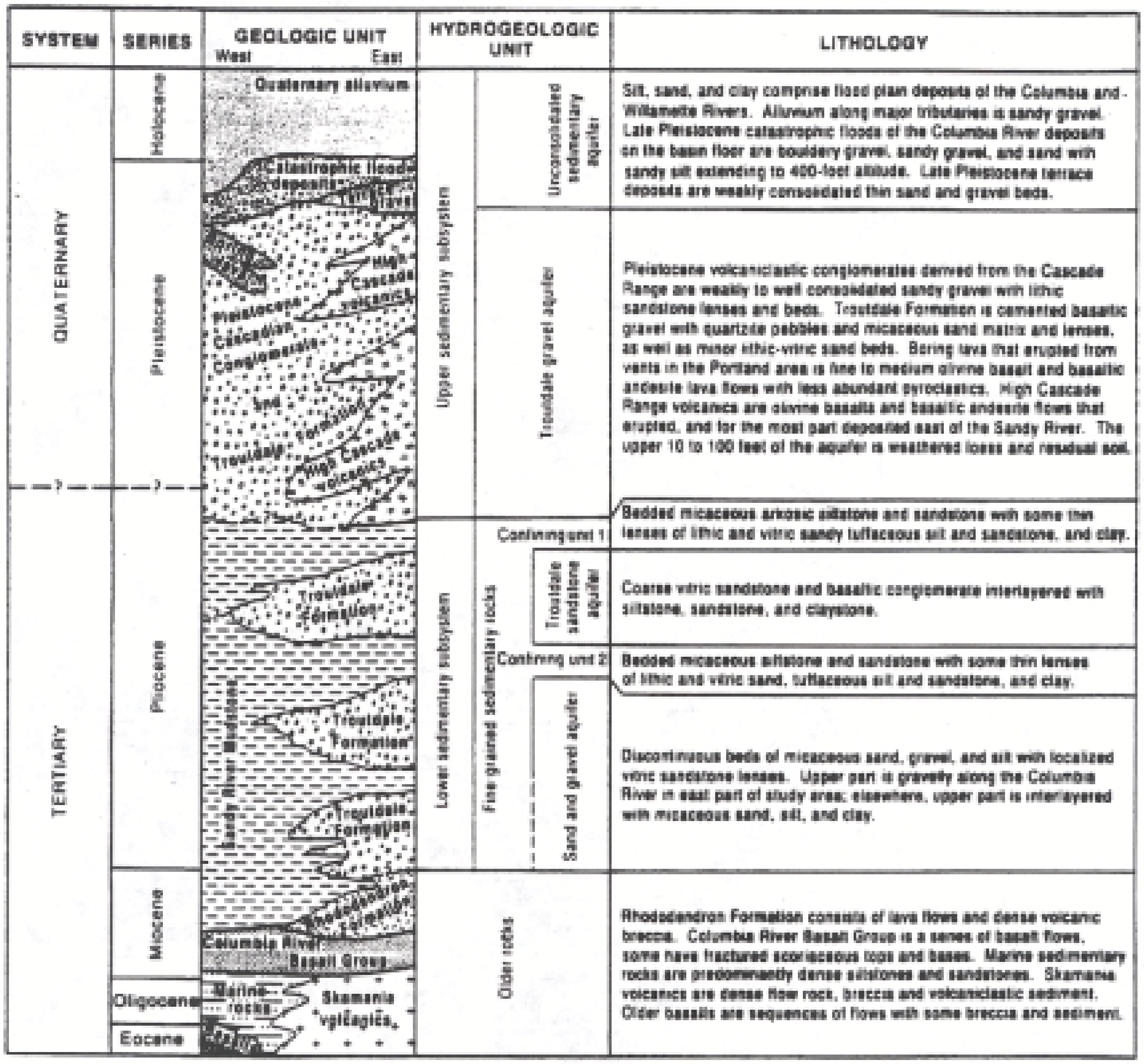


Figure 18. Summary of geologic and hydrogeologic units (Swanson, et al., 1993)

Distribution of Total Annual Recharge by Model Cell
(Snyder, et al, 1994)

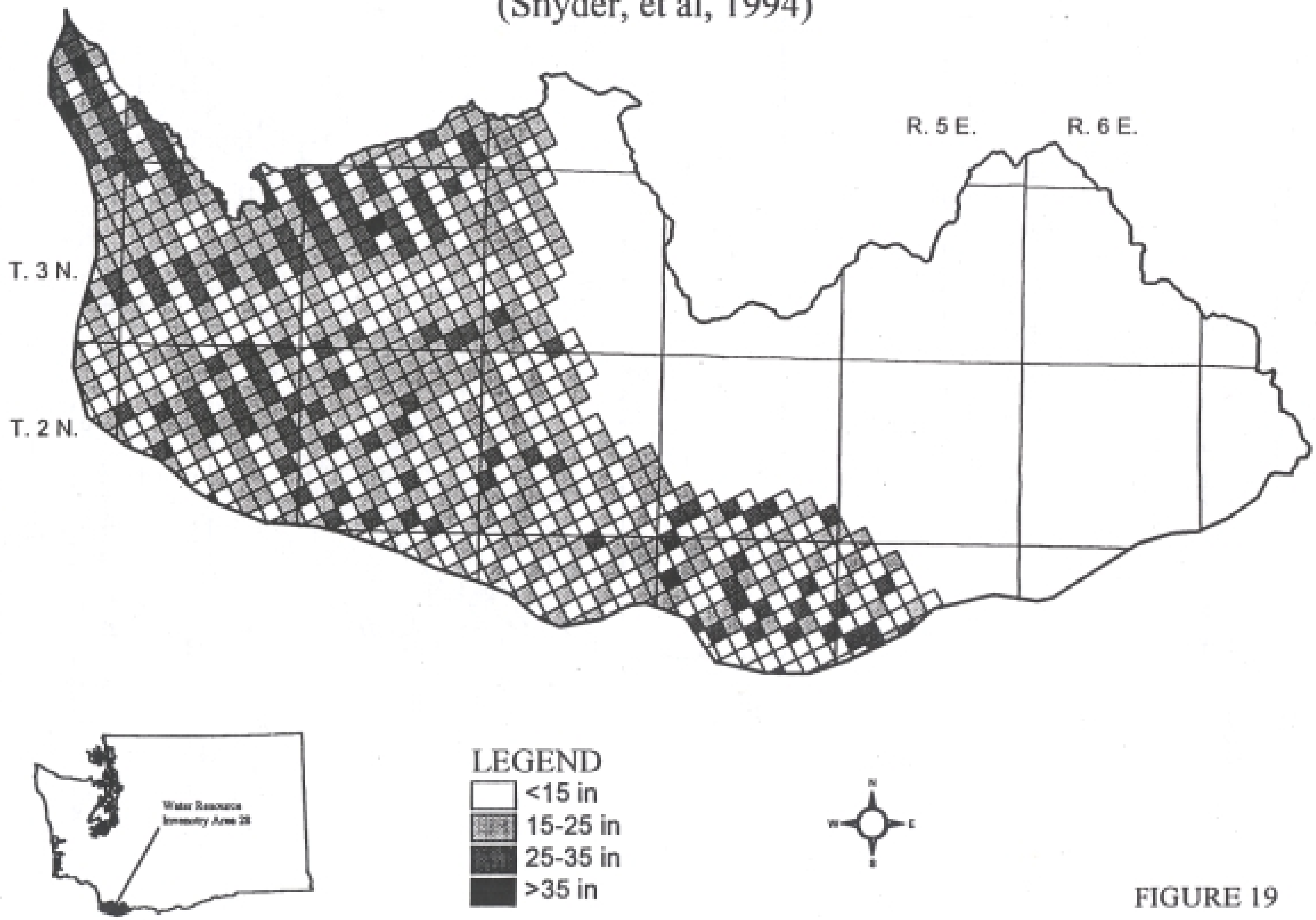


FIGURE 19

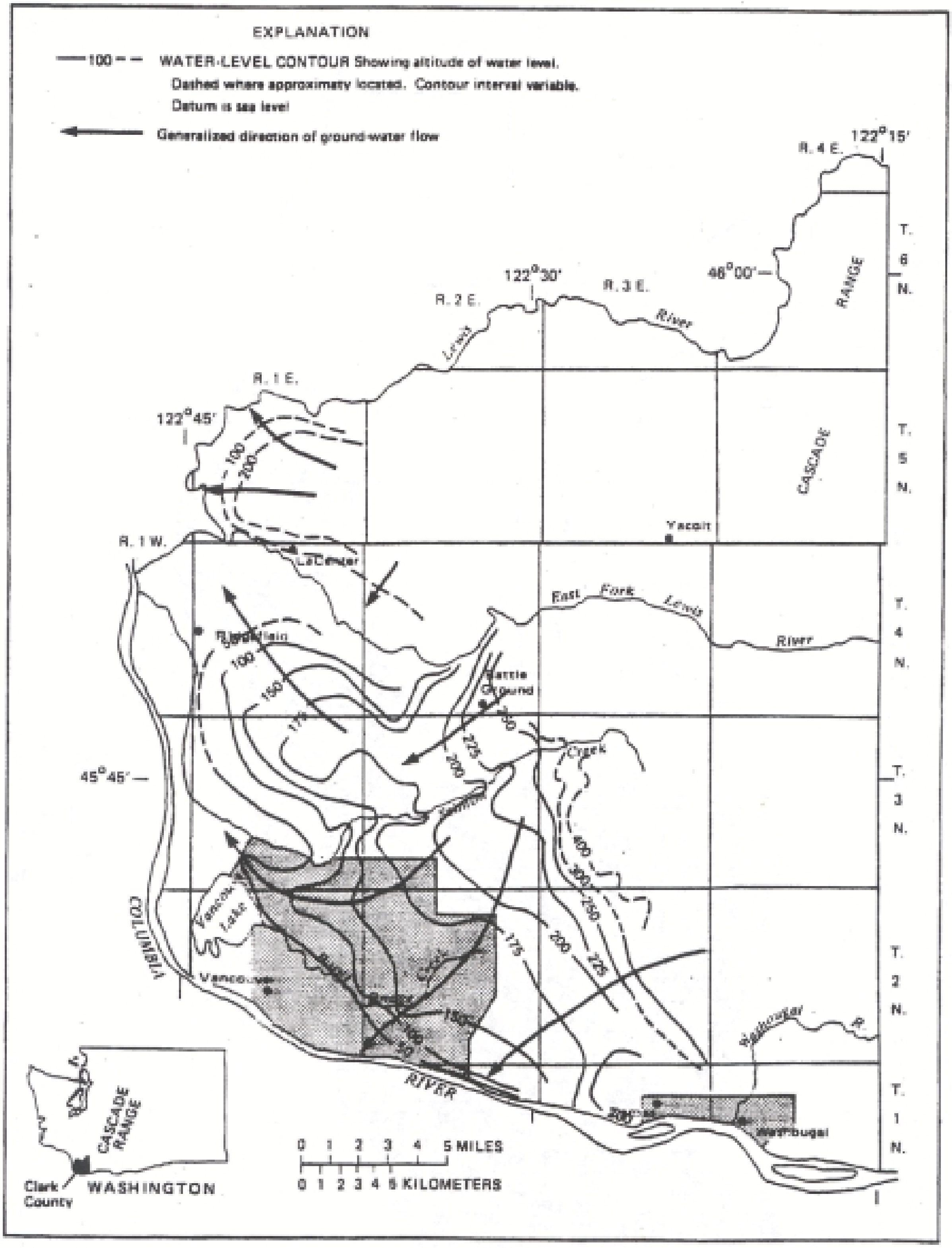


Figure 20. Water-level contours and generalized direction of ground-water flow in the Troutdale gravel aquifer (Turney, 1990)

Streamflow Measurement Sites for Estimating Seepage Gains and Losses
(McFarland and Morgan, 1997)

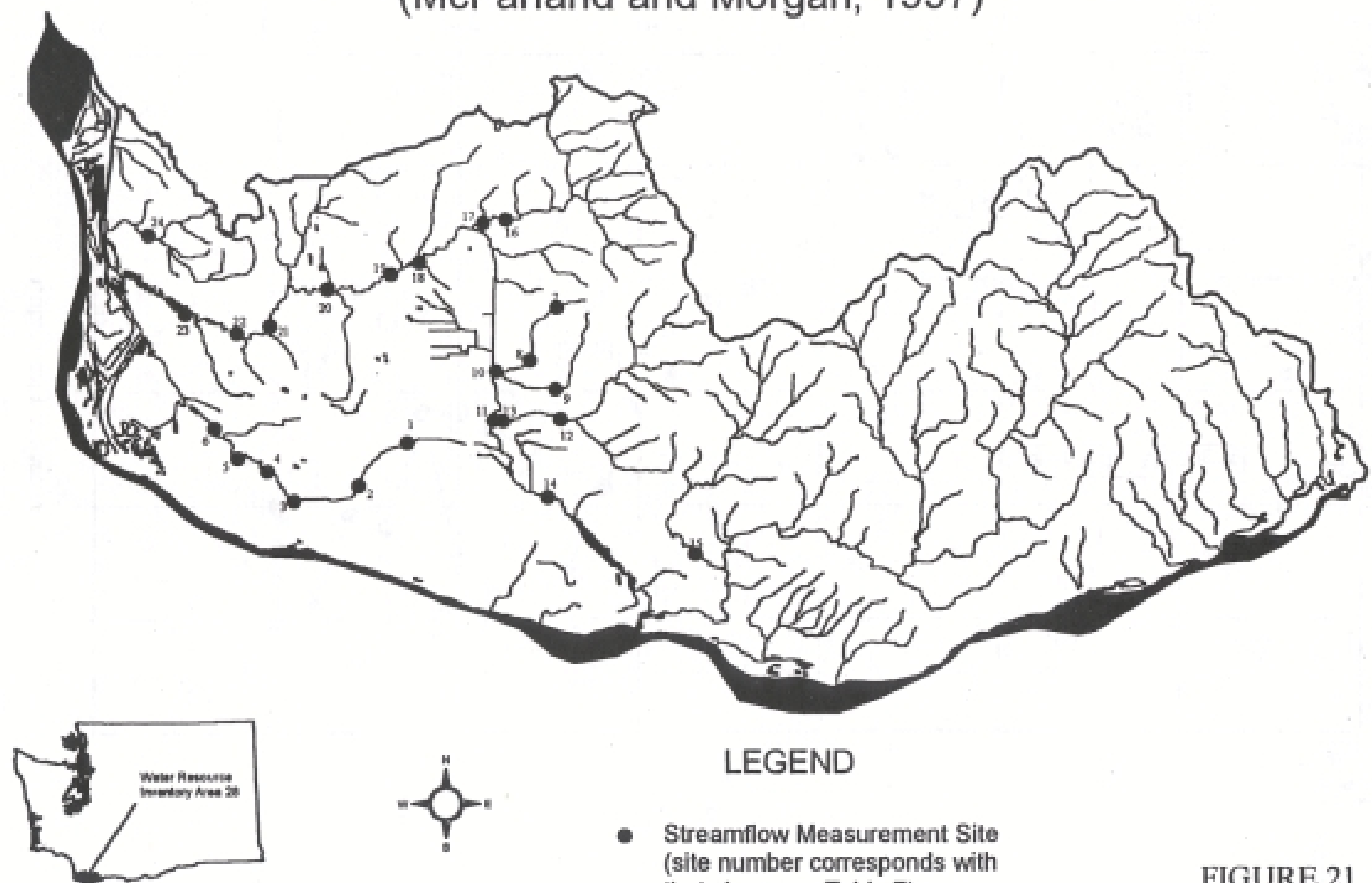


FIGURE 21

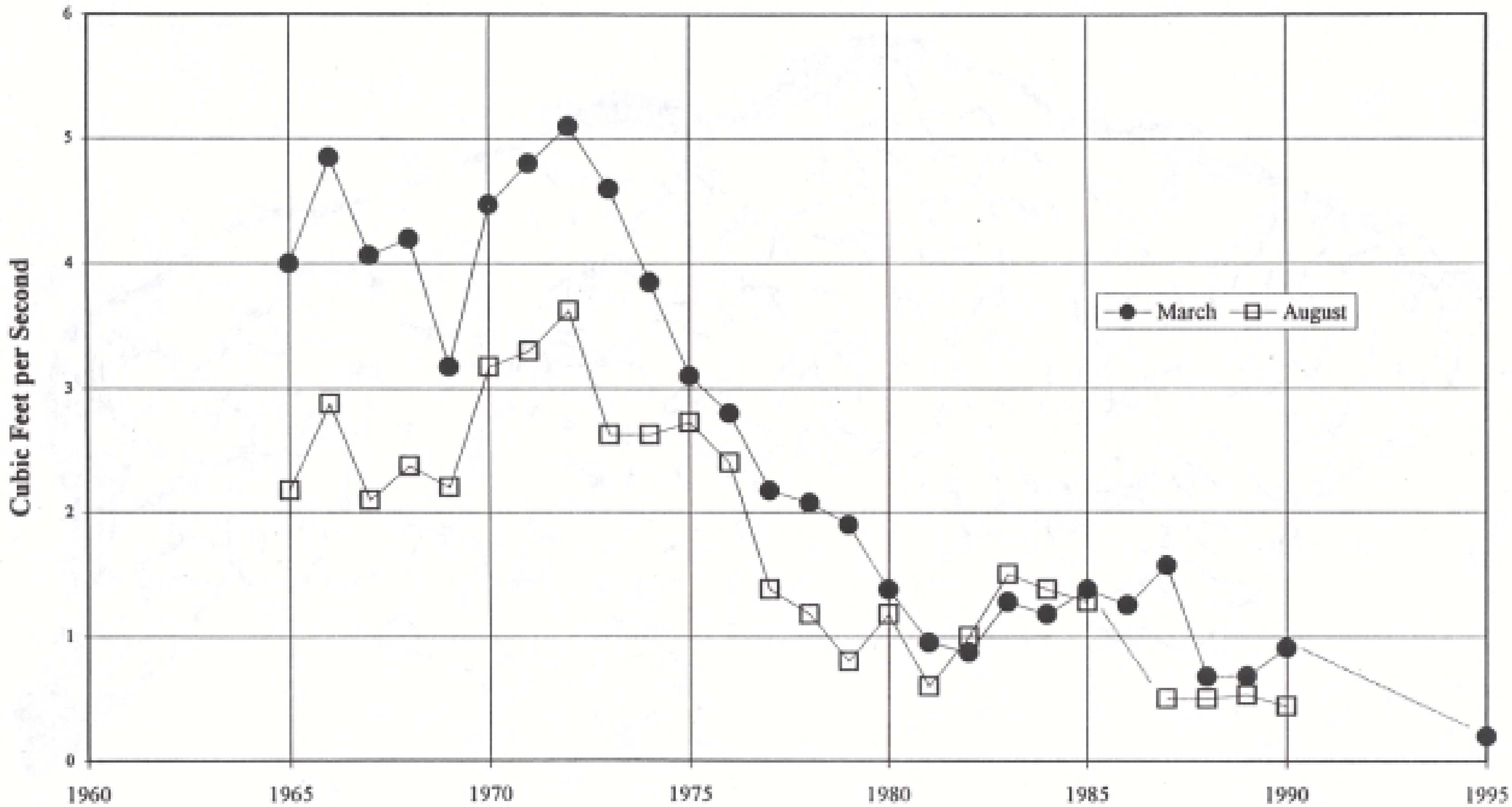


Figure 22. Fish Hatchery Spring Discharge, T1N/R2E-03ACC1

d:\wria28\springs\Vanhatch.xls\VanHatch chart
3/26/98

Measured Ground-Water Level Declines in Selected Monitoring Wells

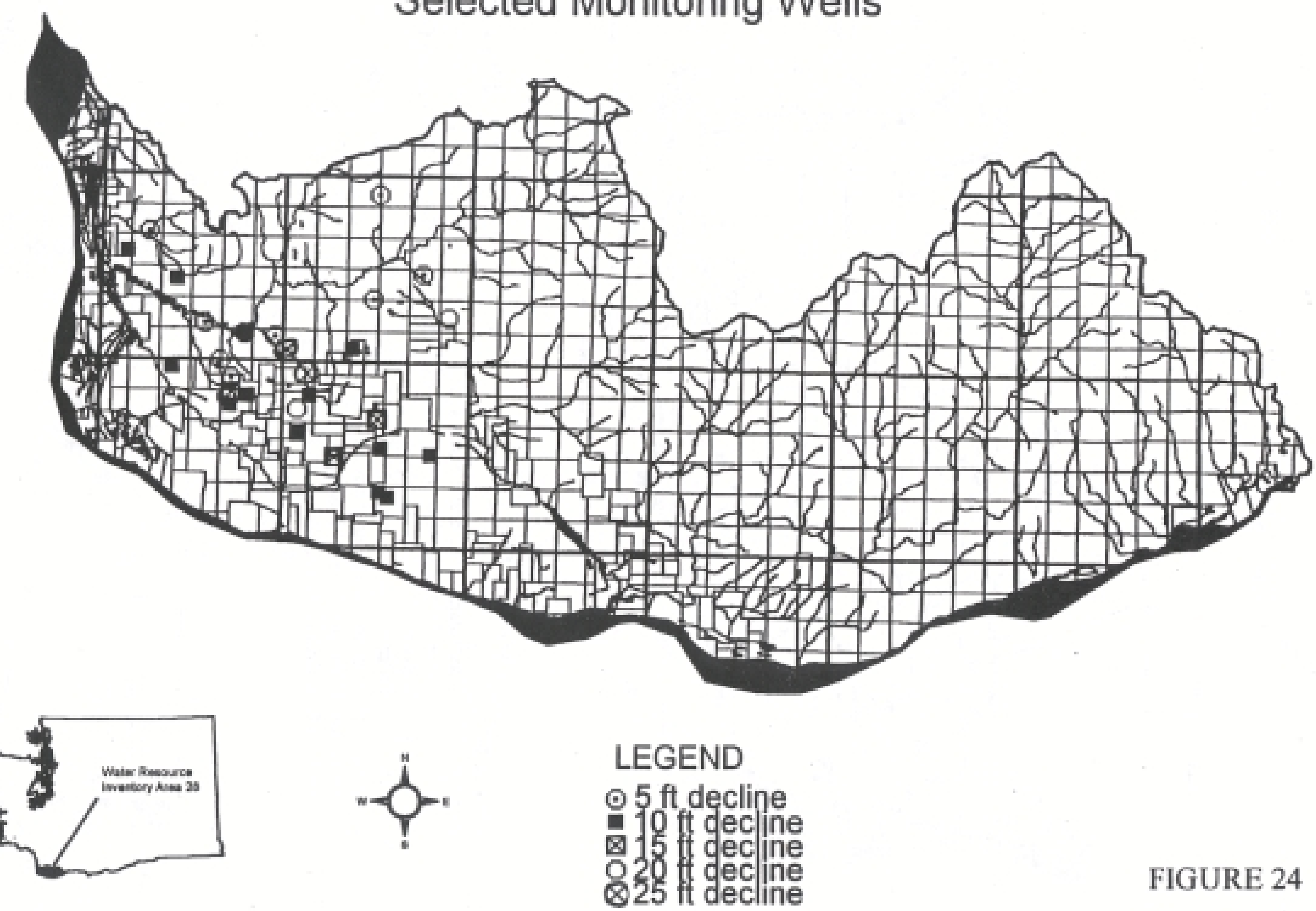
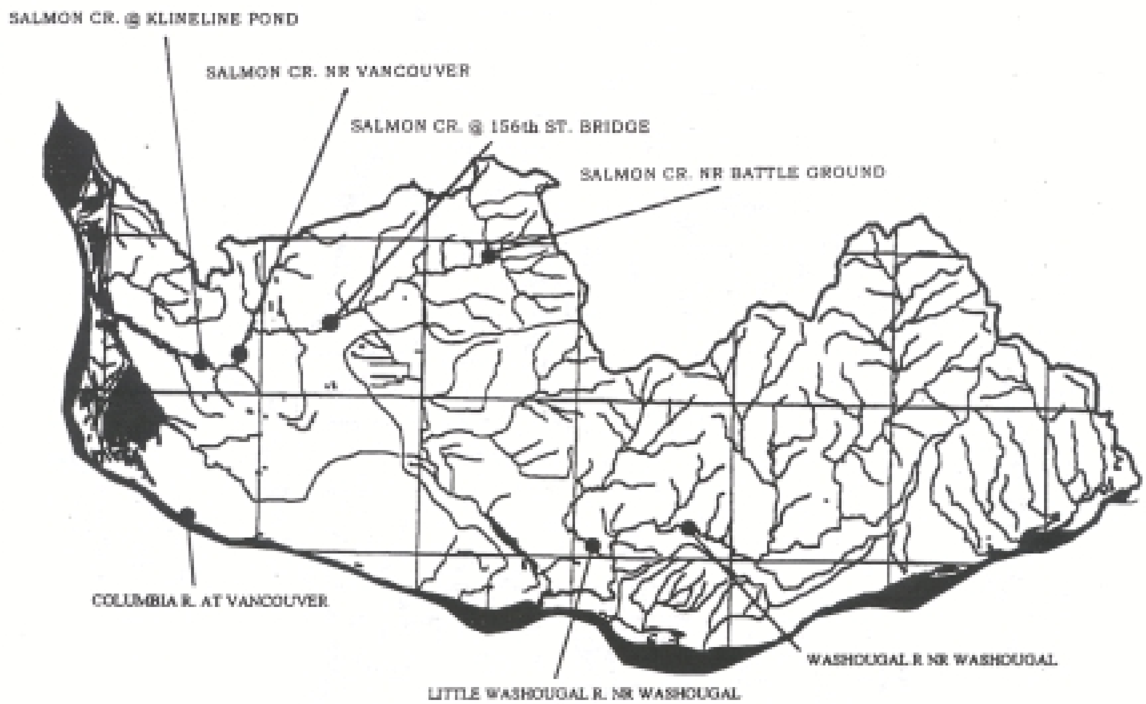


FIGURE 24

Location of Stream Gages



GAGING STATIONS

USGS#	;CPU#	
14143500;	----	Washougal R. near Washougal
14144000;	----	Little Washougal R. near Washougal
14144700;	----	Columbia R. at Vancouver
14212000;	S-01	Salmon Cr. near Battle Ground
14213000;	S-08	Salmon Cr. near Vancouver
------------;	S-04	Salmon Cr. at 156th St.
------------;	S-10	Salmon Cr. at Klineline Pond

LEGEND

- ● Stream Gage
- — Subbasin Boundary

FIGURE 25

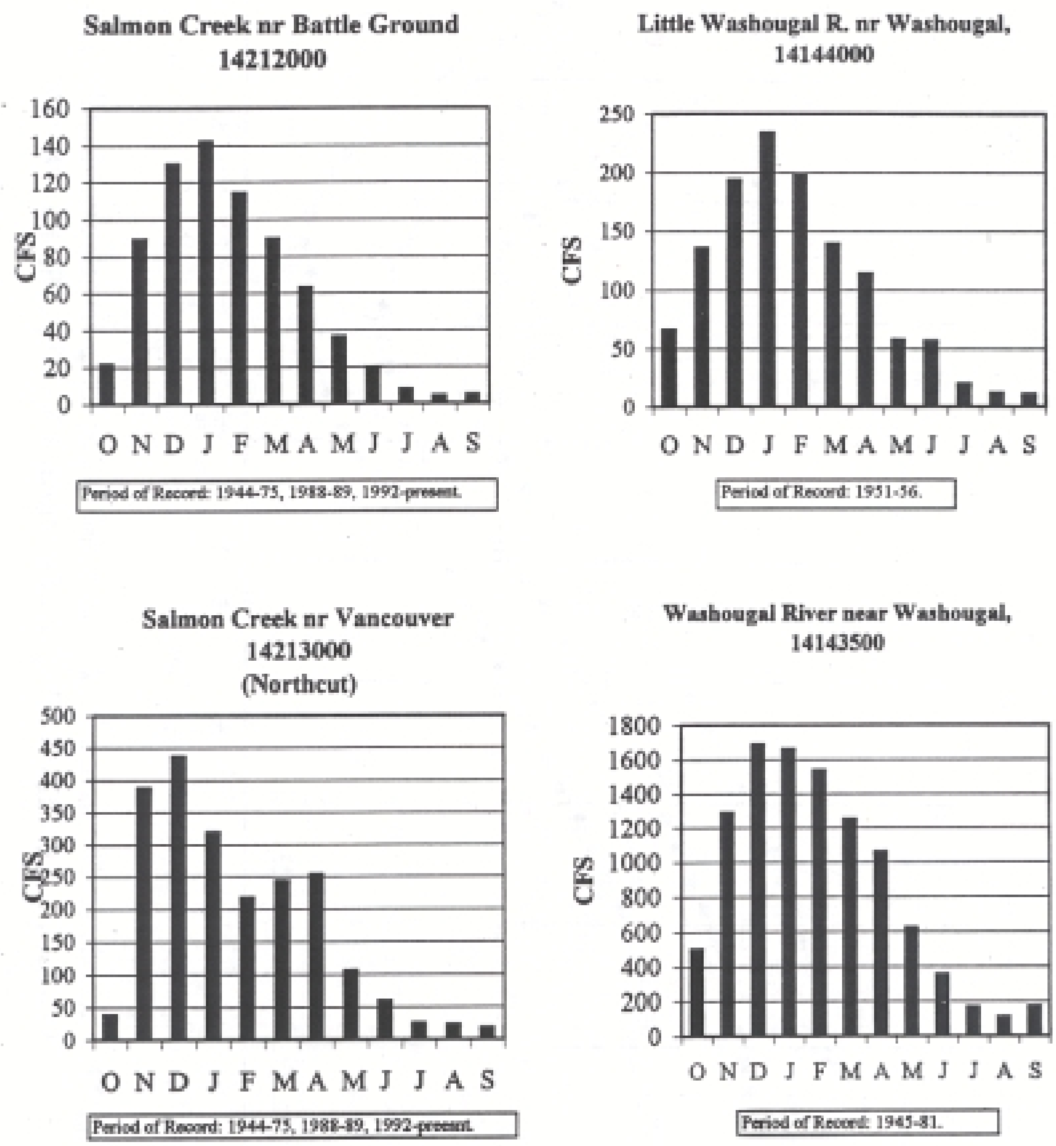


Figure 26. Mean Monthly Streamflow, Long-term Records

d:\wria28\stream.flo\allgrafs.xls\MeanMonChart
3/30/98

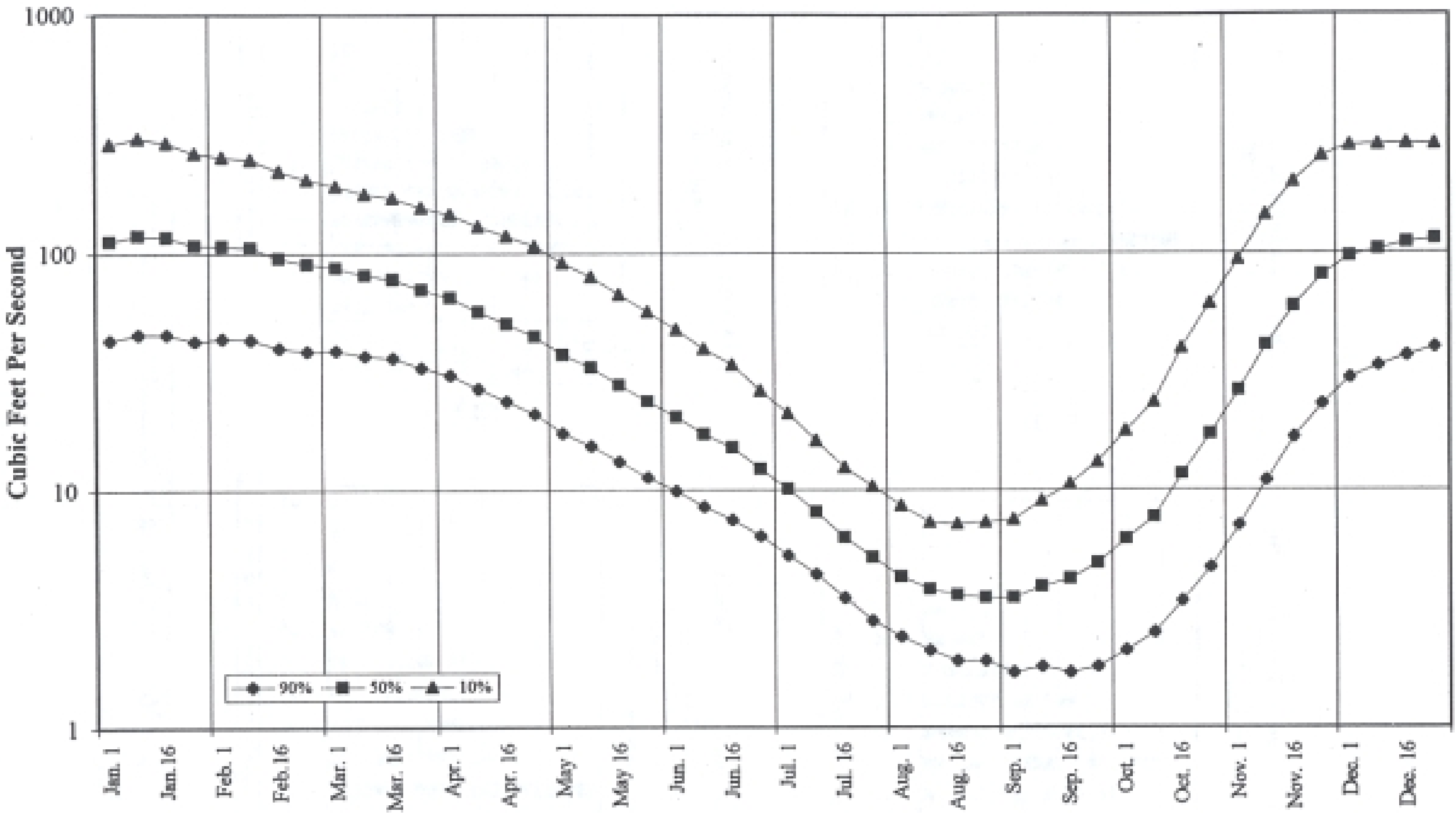


Fig. 27. Exceedence Probabilities for Streamflow, Salmon Creek near Battle Ground, USGS Gage 14212000, Period of Record: 1944-75, 1988-89, 1992-96.

d:/wria28/stream.flo/bg.s01/bg.xls/excd.chrt
5/1/98

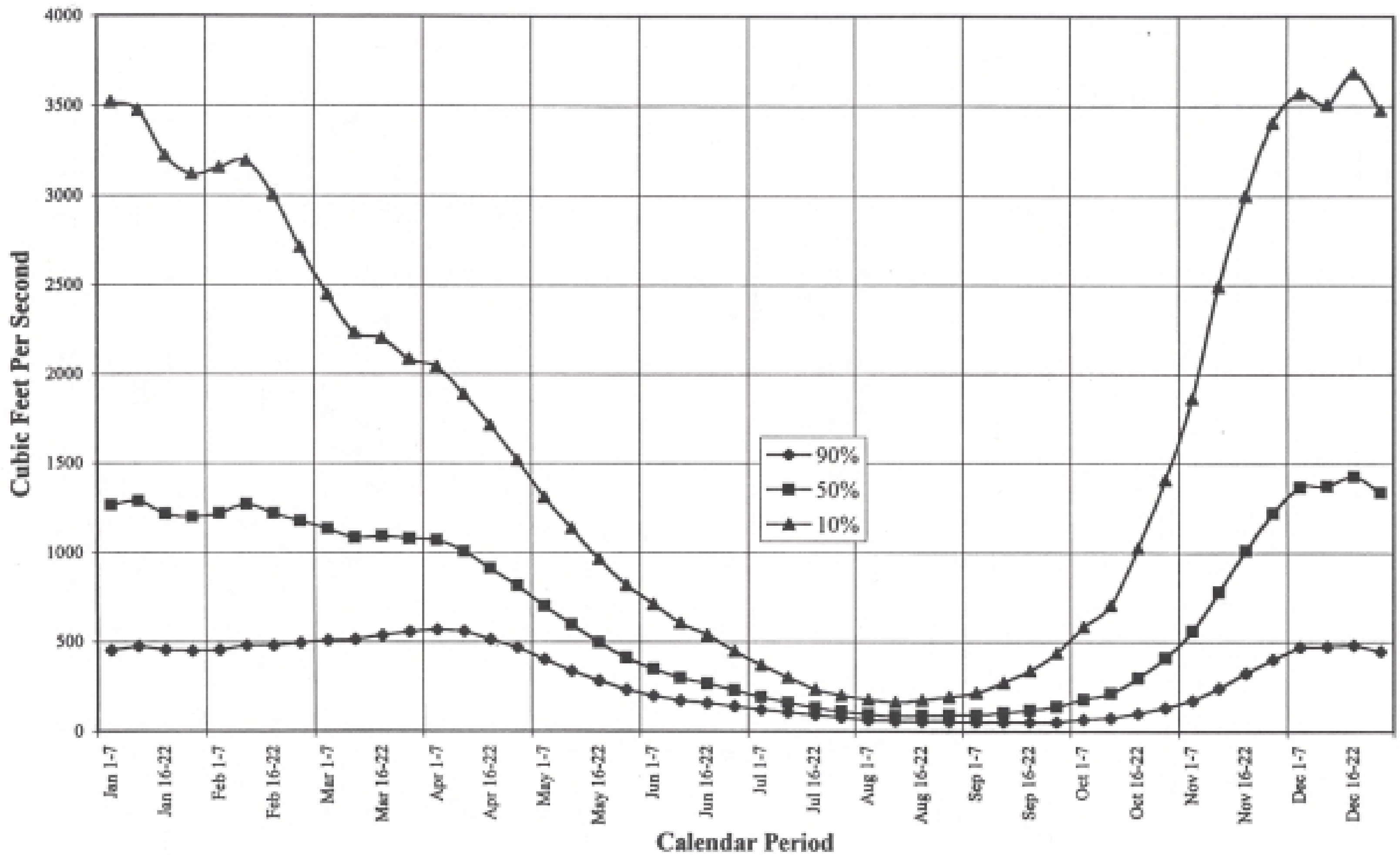


Fig. 28. Exceedence Probabilities for Streamflow, Washougal River near Washougal, USGS Gage 14143500, Period of Record 1945-81.

c:\wria28\stream.flo\washr\WASHTAB.xls\Excd chart
5/1/98

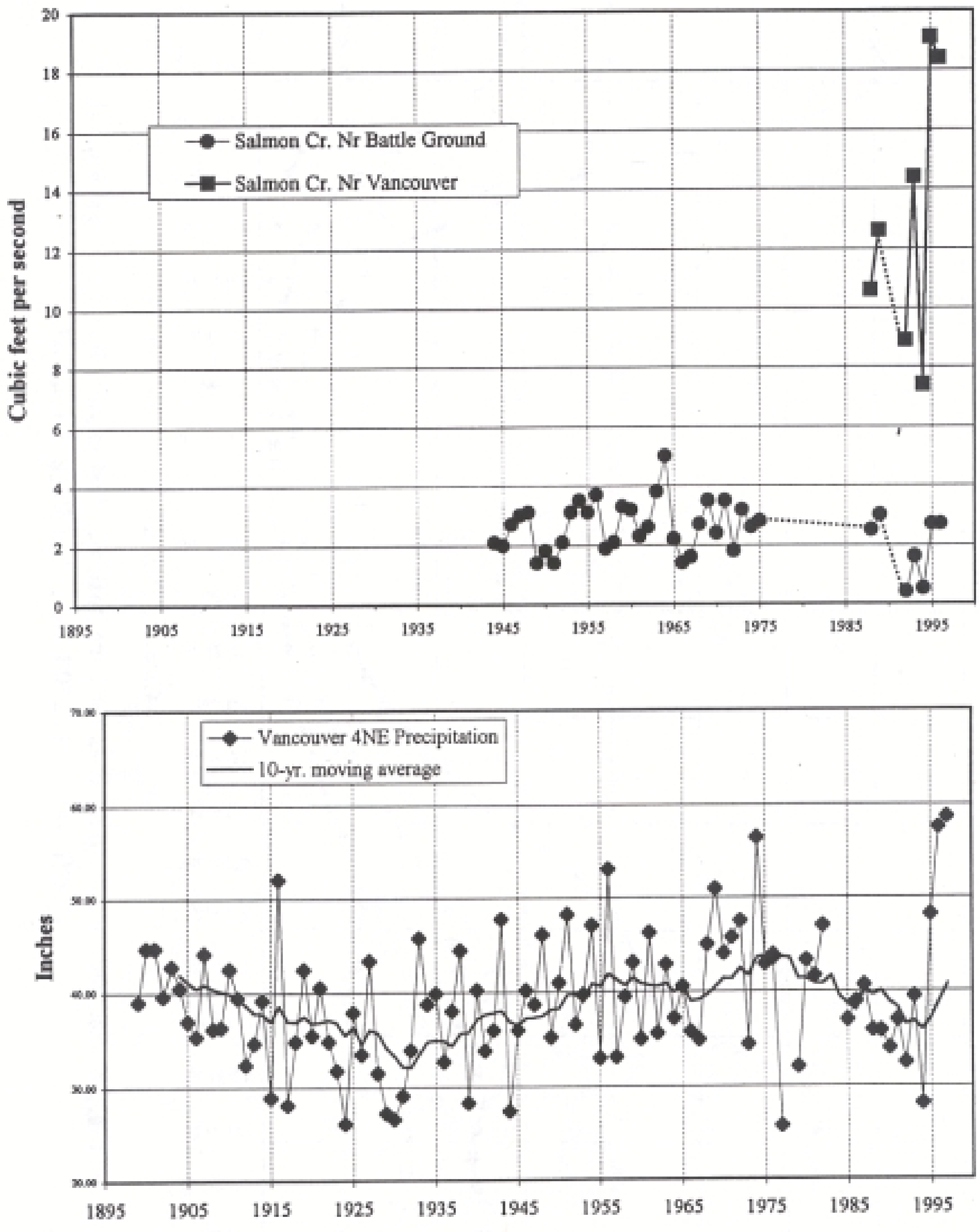


Figure 29. 7-day Low Flows versus Precipitation (by water year).

d:\wria28\stream.flo\allgrafs.xls\7d vs ppt. Chrt
5/1/98

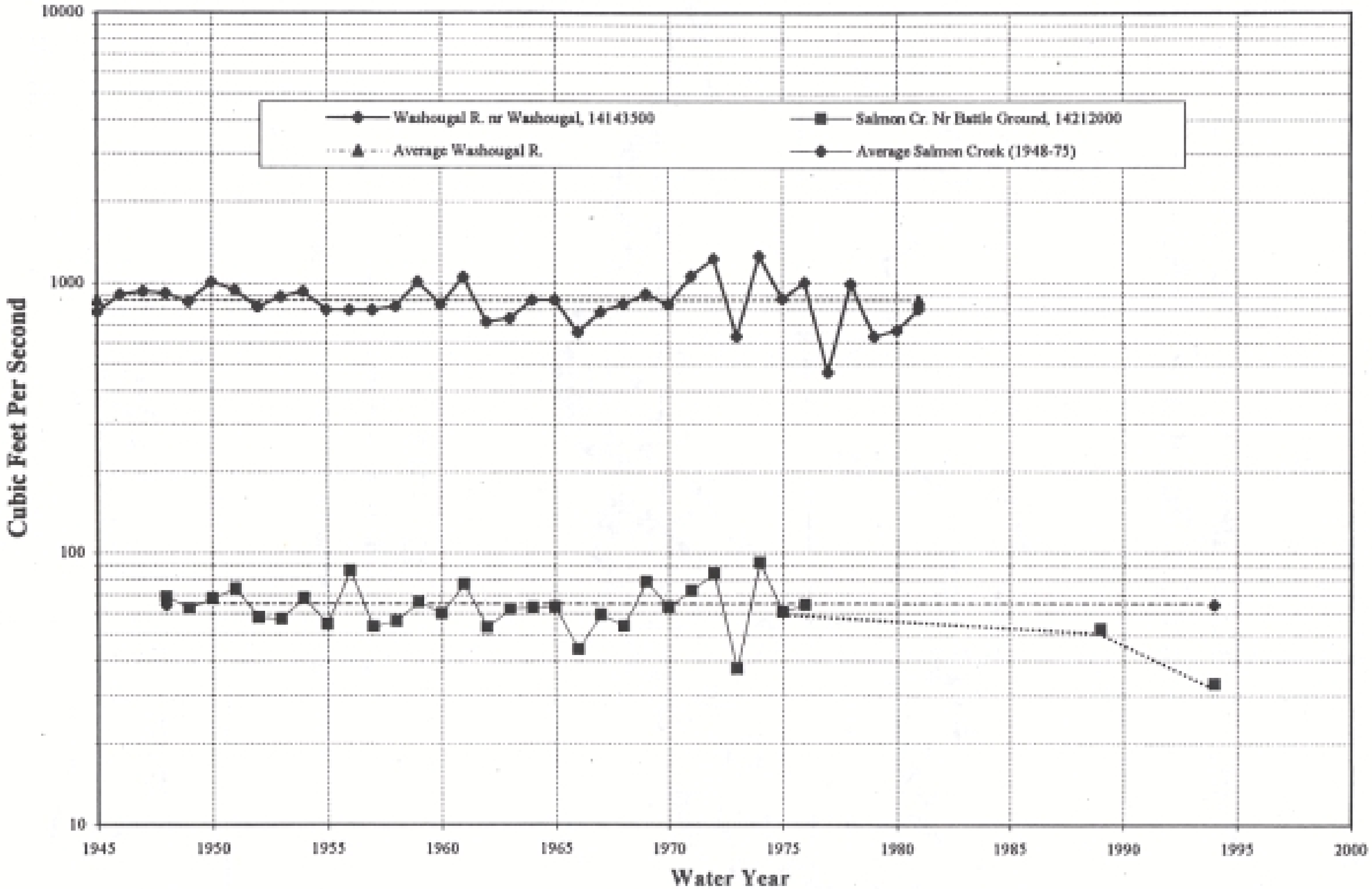
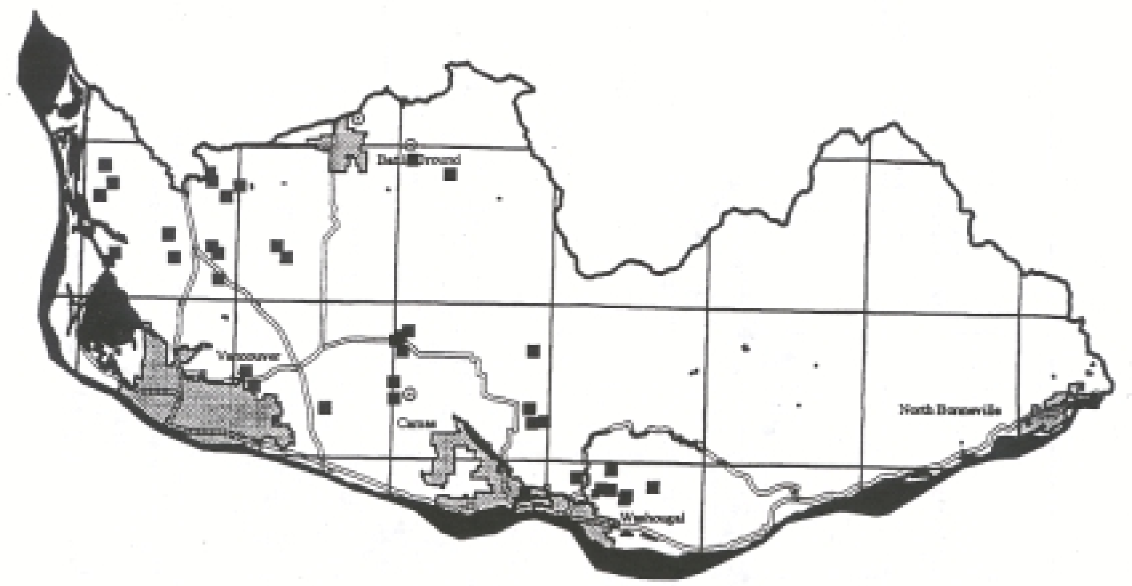


Fig. 30. Annual Mean Streamflow in WRIA 28.

d:\wria28\stream.flo\allgrafs.xls\Annual.chrt
3/30/98

Wells With Elevated Nitrate Concentrations
(Clark Public Utilities, 1995)



LEGEND

■ Wells With Nitrate Concentrations Between 5-10 mg/L

⊙ Wells With Nitrate Concentrations >10 mg/L

FIGURE 31

Location of MTCA and CERCLA Cleanup Sites

FIGURE 32

Streams With Depressed Anadromous Fish Stocks
(Washington Department of Fisheries, et al, 1992)

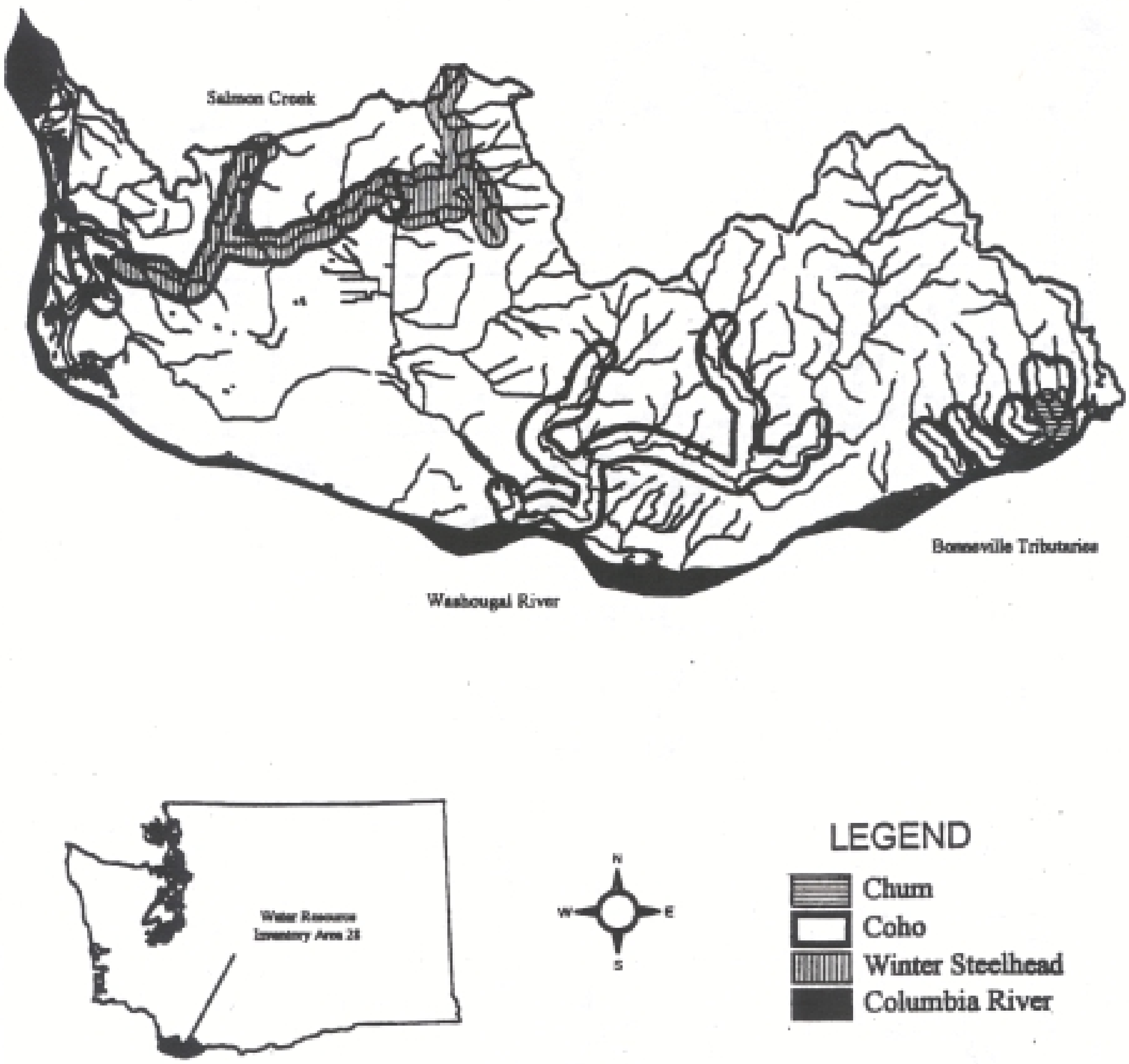


FIGURE 33

Appendix A.

Annual and Monthly Precipitation for Vancouver, Battle Ground, and Skamania Fish Hatchery

Station VANCOUVER 4 NNE
County CLARK
State WA
Id 8773
Elevation 210.00 ft

Precipitation
Record Count 96
Coverage % 99

Latitude 45:41:00
Longitude 122:39:00

Begin Date5/1898
End Date 6/1993

Summary of Precipitation, in inches

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Days Counted	2933	2654	2944	2850	2976	2848	2942	2945	2820	2945	2848	2902	34607
Daily Average	0.18	0.16	0.12	0.09	0.07	0.06	0.02	0.03	0.06	0.10	0.20	0.20	0.11
Months Counted	95	94	95	95	96	95	95	95	94	95	95	94	90
Maximum Monthly	12.84	10.52	8.38	7.72	4.49	4.02	3.75	5.11	4.88	7.25	12.92	15.04	56.59
Maximum Year	1970	1940	1916	1993	1945	1984	1983	1968	1911	1955	973	1933	1968
Minimum Monthly	0.29	0.17	0.70	0.39	0.16	0.00	0.00	0.00	0.00	0.05	0.58	1.64	23.88
Minimum Year	1985	1920	1911	1939	1947	01940	1984	1914	1975	1925	1936	1976	1929
Average Monthly	5.65	4.45	3.75	2.62	2.16	1.65	0.61	0.90	1.88	3.08	5.92	6.21	38.79
Monthly Standard Deviation	2.60	2.15	1.73	1.27	1.14	1.04	0.73	1.04	1.25	1.71	2.84	2.75	6.89
Monthly Skewness	0.50	0.45	0.54	0.88	0.42	0.42	1.97	1.66	0.53	0.44	0.38	0.65	0.16
Monthly Kurtosis	3.00	2.95	2.82	4.75	2.23	2.11	7.16	5.41	2.49	2.52	2.62	2.99	2.84

Station BATTLE GROUND Parameter Precipitation
County CLARK Record Count 46
State WA Coverage % 96
Id 482 Latitude 45:46:00 Begin Date 7/1948
Elevation 280.00 ft Longitude 122:32:00 End Date 6/1993

Summary of Precipitation, in inches

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Days Counted	1362	1227	1394	1347	1390	1286	1333	1364	1348	1395	1320	1363	16129
Daily Average	0.23	0.19	0.17	0.13	0.09	0.08	.03	0.04	0.08	0.14	0.25	0.26	0.14
Months Counted	44	43	45	45	45	43	43	44	45	45	44	44	38
Maximum Monthly	14.10	11.87	9.24	10.02	6.36	5.87	4.33	5.40	6.46	9.82	13.74	12.63	69.72
Maximum Year	1953	1949	1957	1993	1977	1981	1983	1968	1977	1950	1973	1980	1983
Minimum Monthly	0.36	0.76	0.75	1.11	0.29	.17	0.00	0.00	0.05	0.14	1.45	2.16	35.16
Minimum Year	1985	1993	1965	9156	1992	1951	1984	1967	1975	1987	1952	1960	1952
Average Monthly	7.07	5.57	5.34	3.98	2.92	2.38	0.83	1.35	2.36	4.47	7.45	7.91	51.99
Monthly Standard Deviation	3.56	2.30	1.96	1.89	1.50	1.39	0.86	1.24	1.61	2.52	3.01	2.92	7.97
Monthly Skewness	0.04	0.68 -	-0.28	1.02	0.43	.35	1.94	1.24	0.76	0.48	0.23	-0.23	0.22
Monthly Kurtosis	1.93	3.49	2.60	4.06	2.41	2.12	7.48	3.99	2.80	2.43	2.58	1.76	2.65

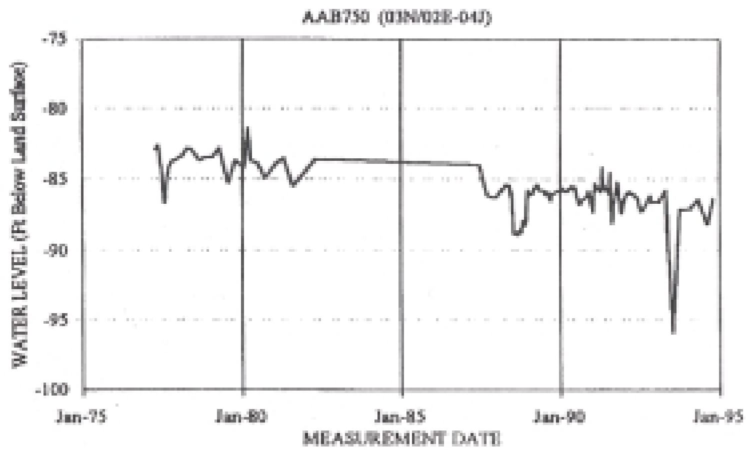
Station SKAMANIA FISH HATCHERY Parameter Precipitation
County SKAMANIA Record Count 29
State WA Coverage % 98
Station Id 7696 Latitude 45:38:00 Begin Date 2/1965
Elevation 440.00 ft Longitude 122:13:00 End Date 6/1993

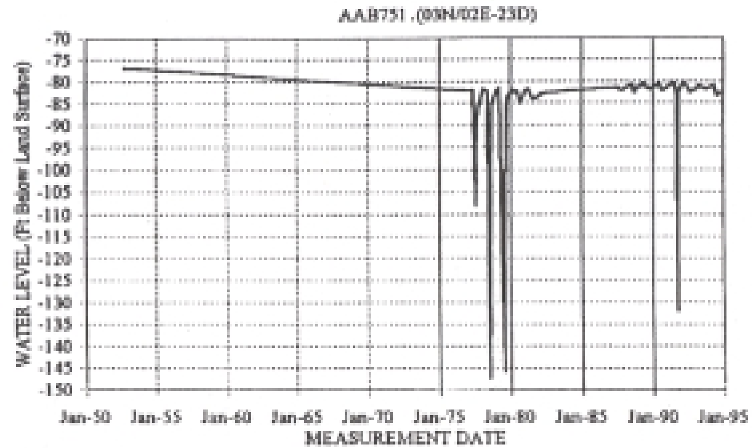
Summary of Precipitation, in inches

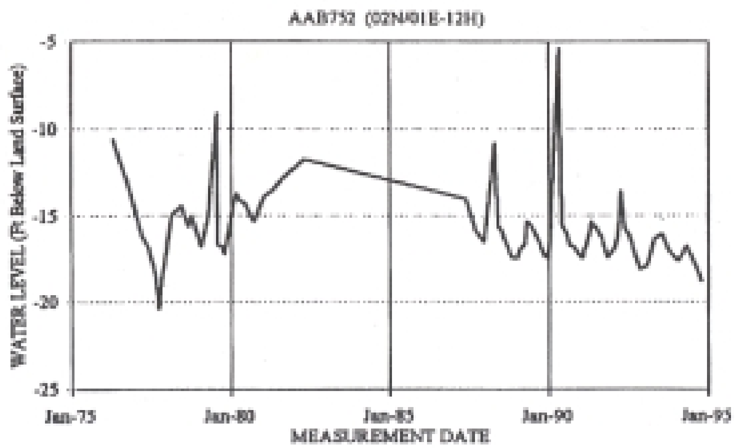
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
D Count	868	819	899	870	899	870	868	868	840	868	840	867	10376
D Avg	0.4	0.33	0.27	0.23	0.16	0.13	0.04	0.07	0.13	0.2	0.4	0.43	0.23
M Count	28	29	29	29	29	29	28	28	28	28	28	28	27
Max M	25.02	16.05	13.38	13.84	9.09	12.05	6.97	8.8	8.67	14.29	20.81	23.76	110.83
Maxyr	1970	1979	1974	1993	1977	1981	1983	1968	1986	1990	1984	1971	1971
Min M	0.19	1.24	1.75	2.8	0.75	0.9	0	0.04	0.03	0.12	2.77	3.61	63.59
Minyr	1985	1993	1965	1977	1992	1965	1984	1967	1975	1987	1976	1976	1976
Avg M	12.51	9.33	8.24	6.79	4.82	3.96	1.39	2.12	4.04	6.29	11.98	13.18	85.56
M Std	6.51	3.62	3.3	2.49	2.01	2.6	1.43	2.04	2.7	3.81	4.48	5.26	13.54
M Skw	0.02	0.17	-0.29	0.81	0.31	1.3	2.4	1.64	0.02	0.39	0.14	0.12	-0.07
M Kur	2	2.42	2.02	3.14	2.61	4.23	8.69	4.9	1.54	2.06	2.51	2.27	1.81

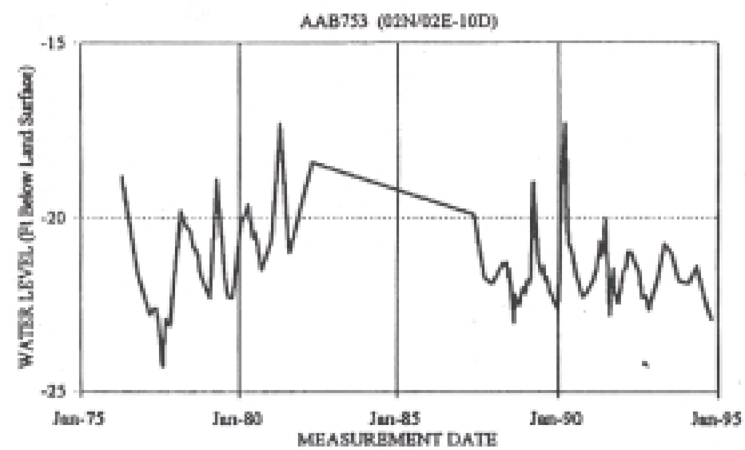
Appendix B.

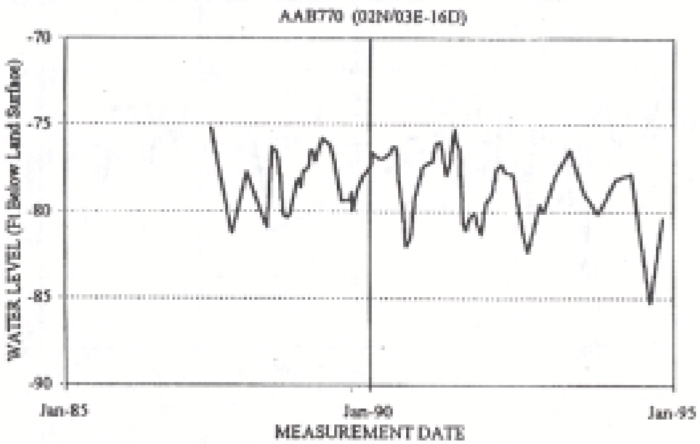
Selected Well Hydrographs

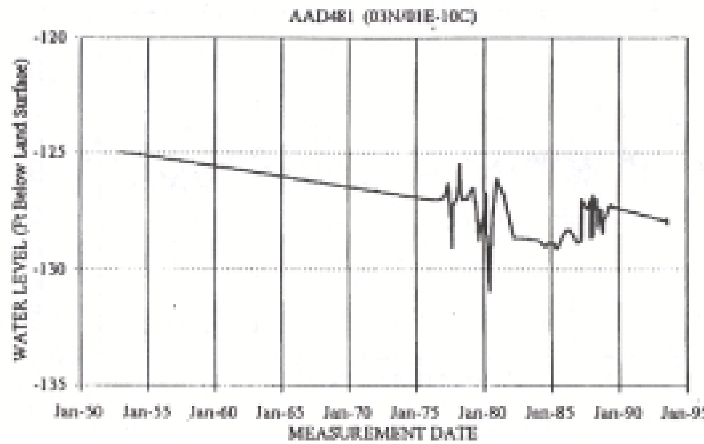

AAB750 (03N/02E-04J)
WATER LEVEL (Ft Below Land Surface)
-75
-80
-85
-90
-95
-100
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

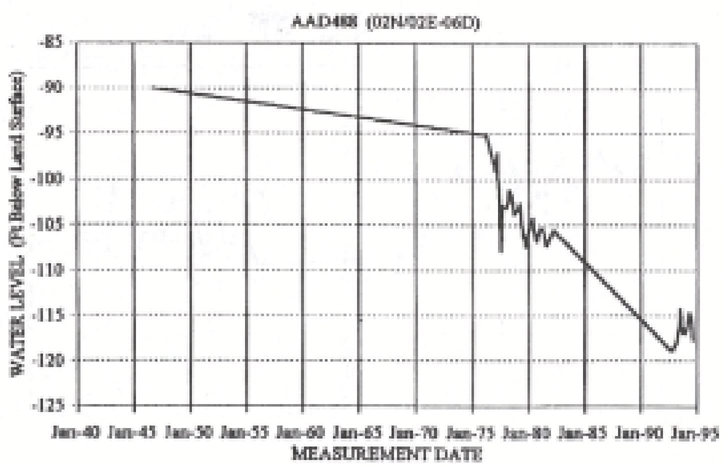

AAB751 (03N/02E-23D)
WATER LEVEL (Ft Below Land Surface)
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
-130
-135
-140
-145
-150
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

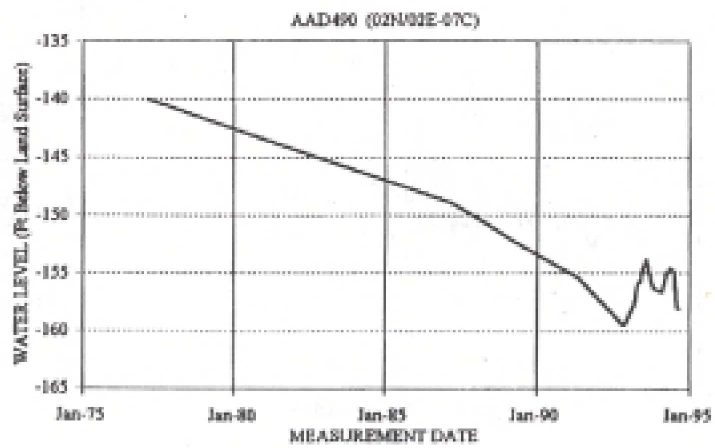

AAB752 (02N/01E-12H)
WATER LEVEL (Ft Below Land Surface)
-5
-10
-15
-20
-25
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


AAB753 (02N/02E-10D)
WATER LEVEL (Ft Below Land Surface)
-15
-20
-25
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

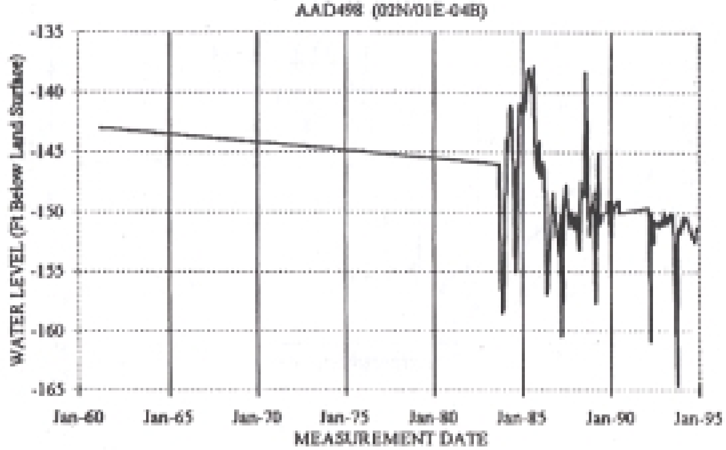

AAB770 (02N/03E-16D)
-70
-75
-80
-85
-90
WATER LEVEL (Ft Below Land Surface)
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


AAD481 (03N/01E-10C)
-120
-125
-130
-135
WATER LEVEL (Ft Below Land Surface)
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

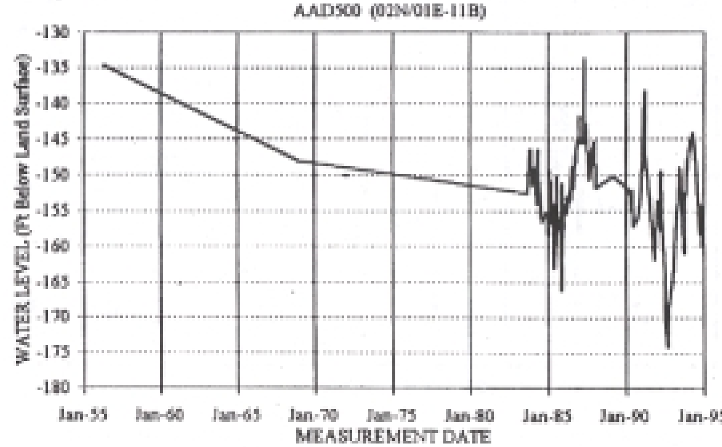

AAD488 (02N/02E-06D)
-85
-90
-95
-100
-105
-110
-115
-120
-125
WATER LEVEL (Ft Below Land Surface)
Jan-40
Jan-45
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


AAD490 (02N/02E-07C)
-135
-140
-145
-150
-155
-160
-165
WATER LEVEL (Ft Below Land Surface)
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

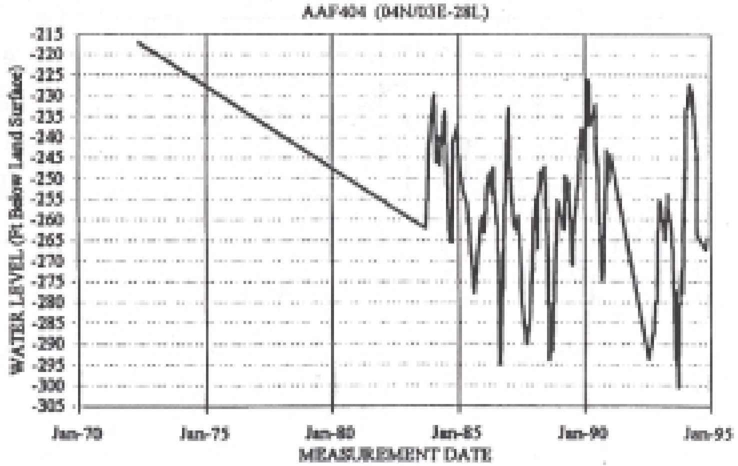
AAD498 (02N/01E-04B)



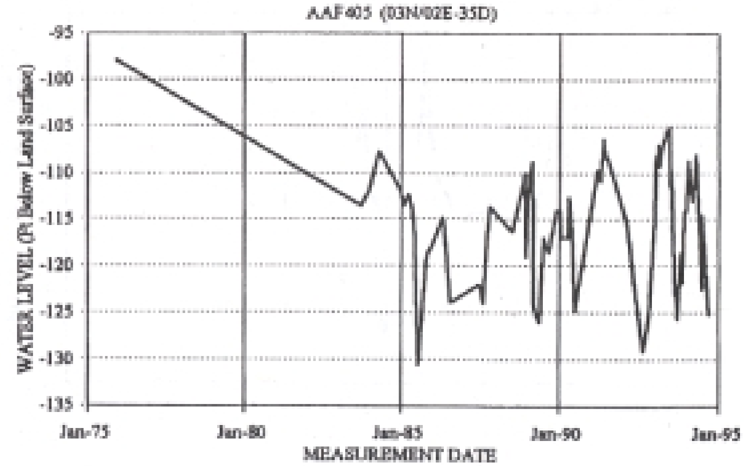
AAD500 (02N/01E-11B)



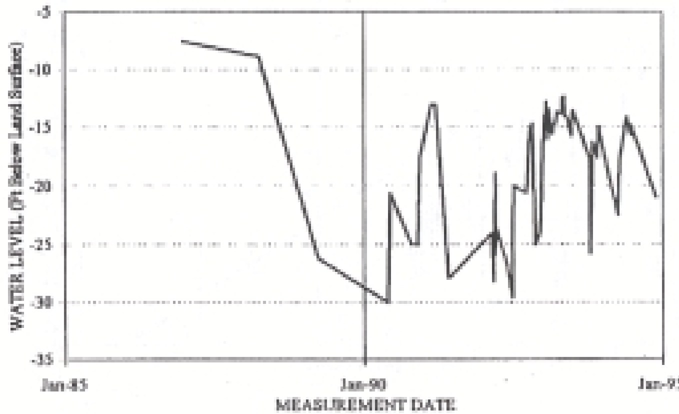
AAF404 (04N/03E-28L)



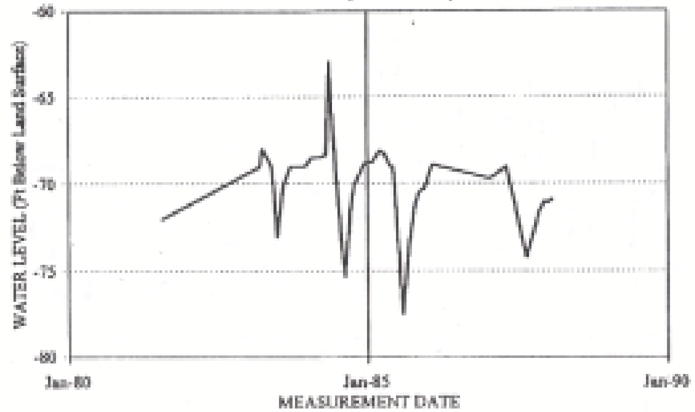
AAF405 (03N/02E-35D)



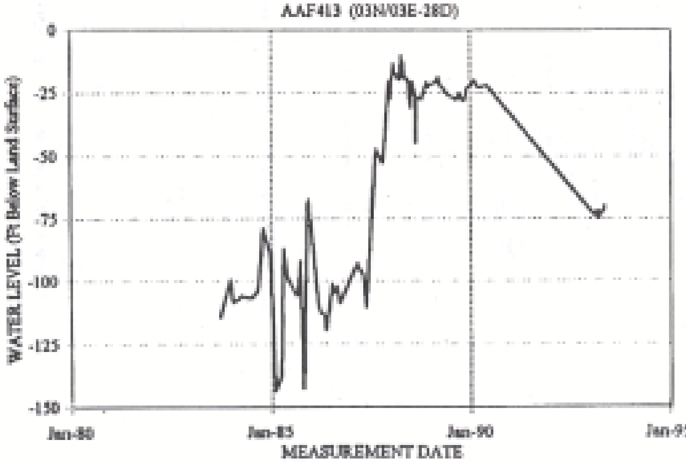
AAF407 (03N/03E-03P)



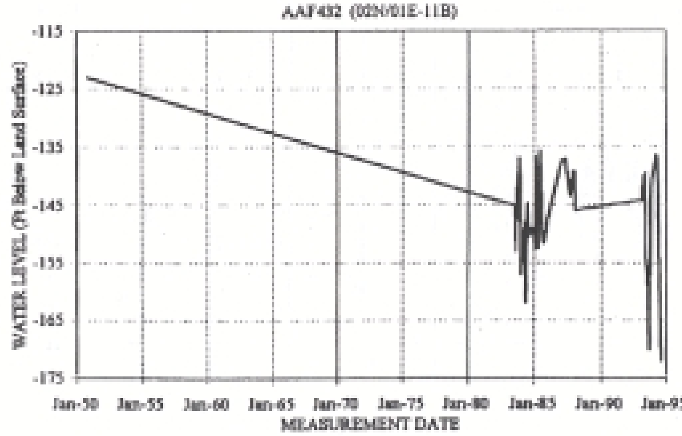
AAF411 (03N/02E-23C)



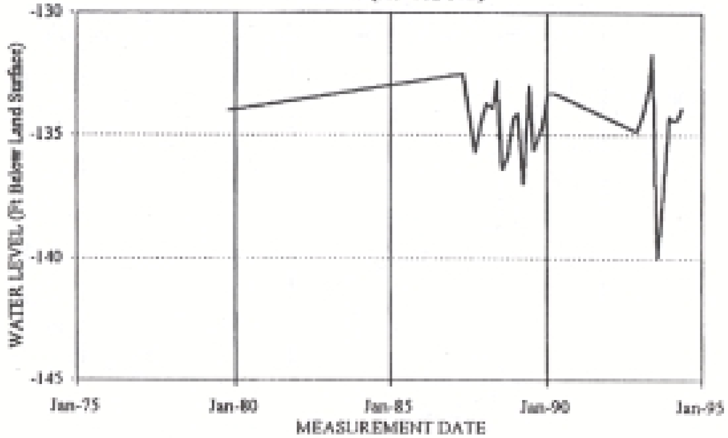
AAF413 (03N/03E-28D)



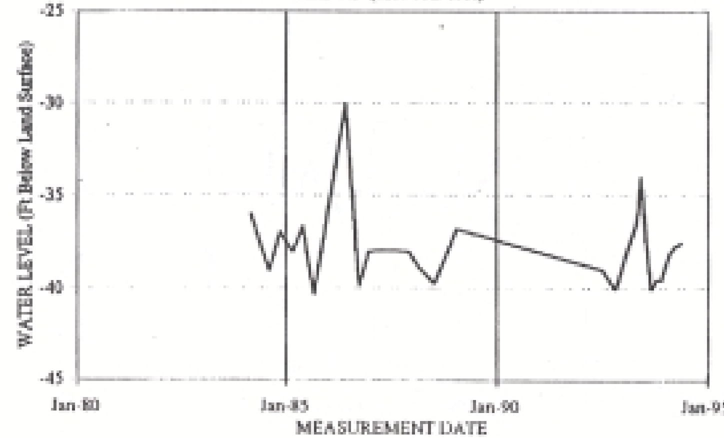
AAF432 (02N/01E-11B)



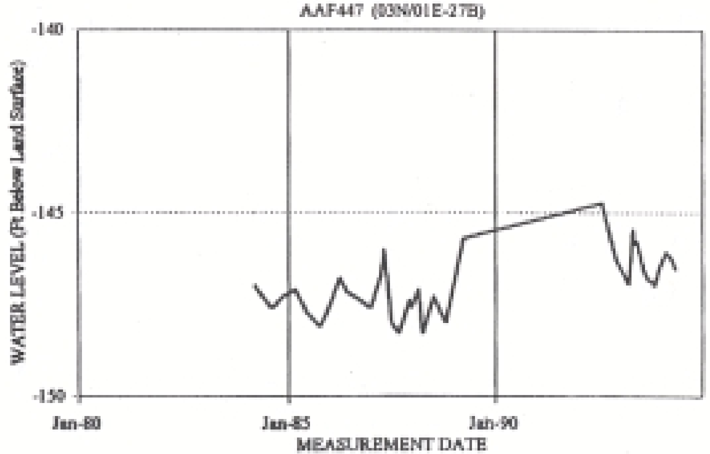
AAF444 (03N/01E-30D)



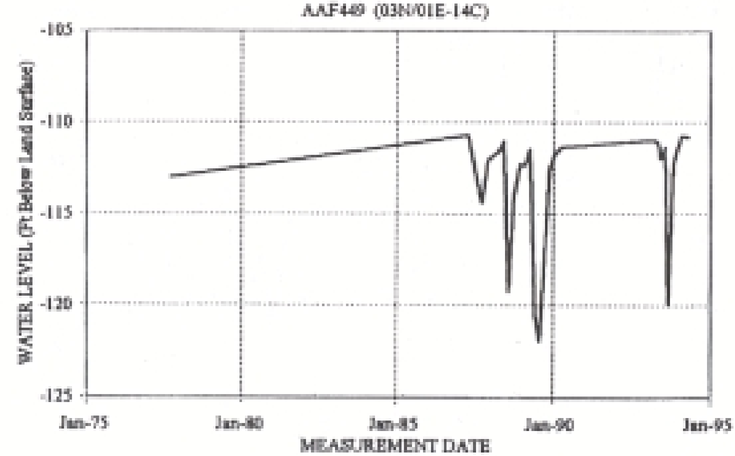
AAF445 (03N/01E-19A)

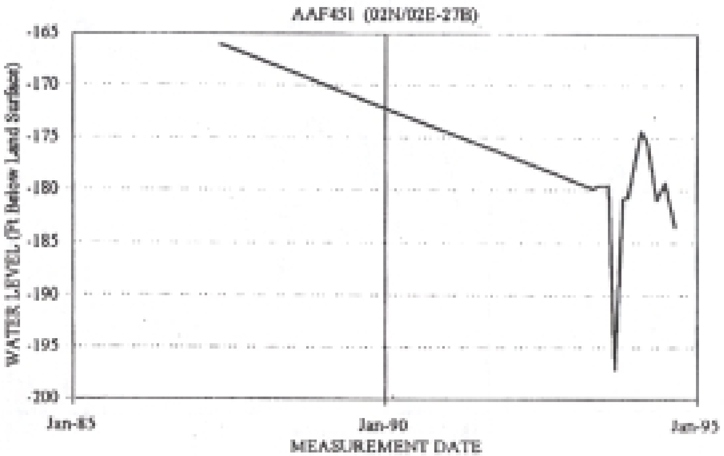


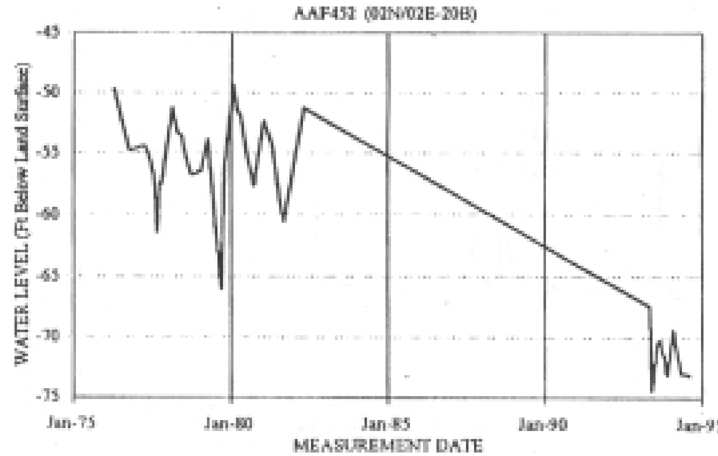
AAF447 (03N/01E-27B)

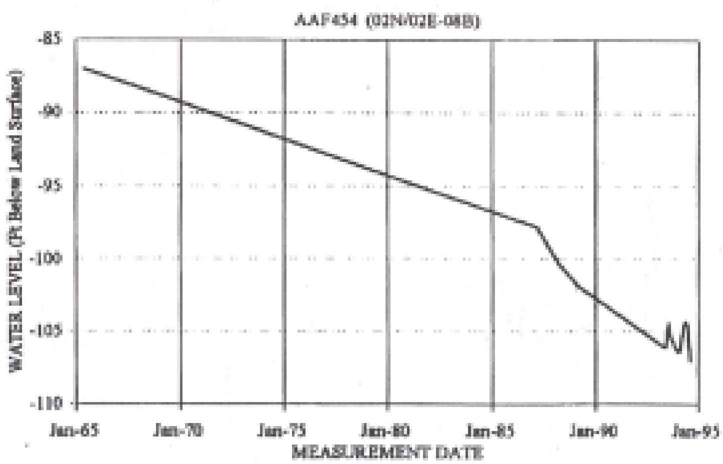


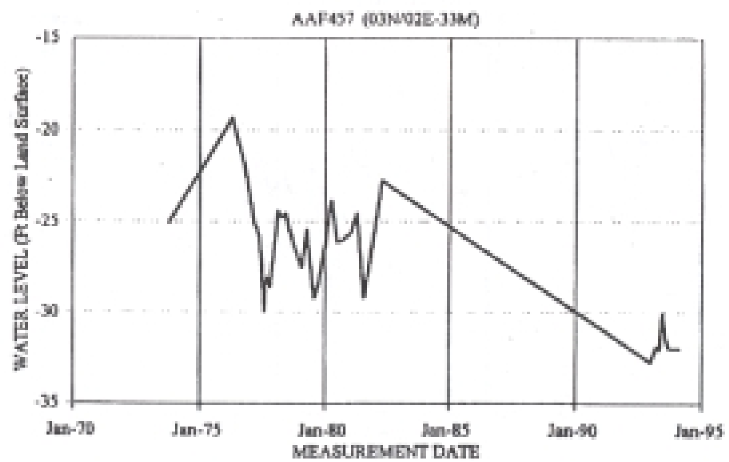
AAF449 (03N/01E-14C)

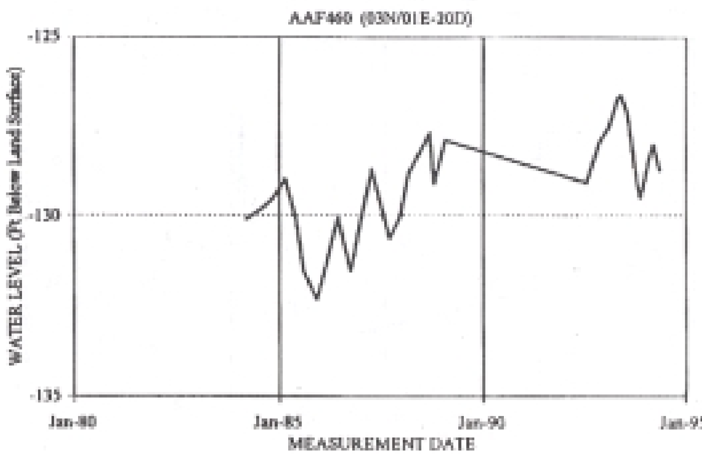


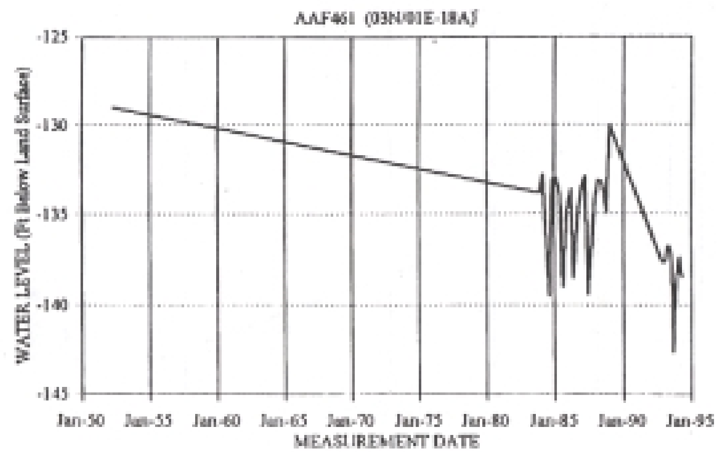

AAF451 (02N/02E-27B)
WATER LEVEL (Ft Below Land Surface)
-165
-170
-175
-180
-185
-190
-195
-200
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

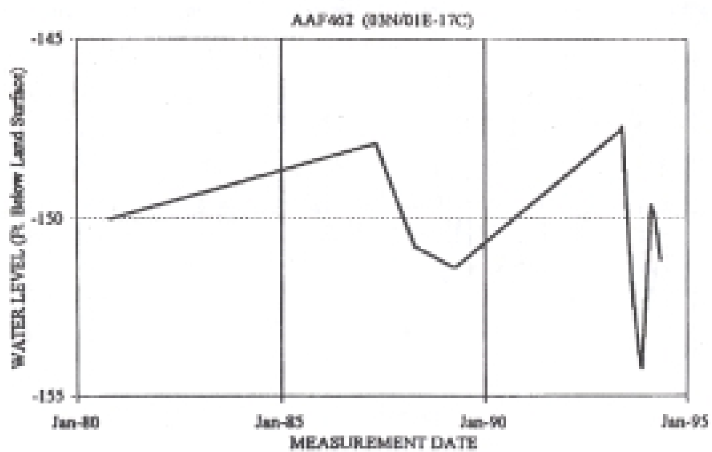

AAF452 (02N/02E-20B)
WATER LEVEL (Ft Below Land Surface)
-45
-50
-55
-60
-65
-70
-75
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

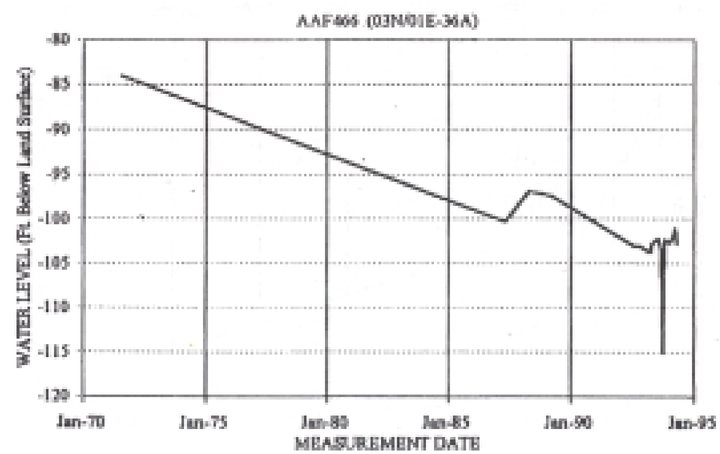

AAF454 (02N/02E-08B)
WATER LEVEL (Ft Below Land Surface)
-85
-90
-95
-100
-105
-110
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

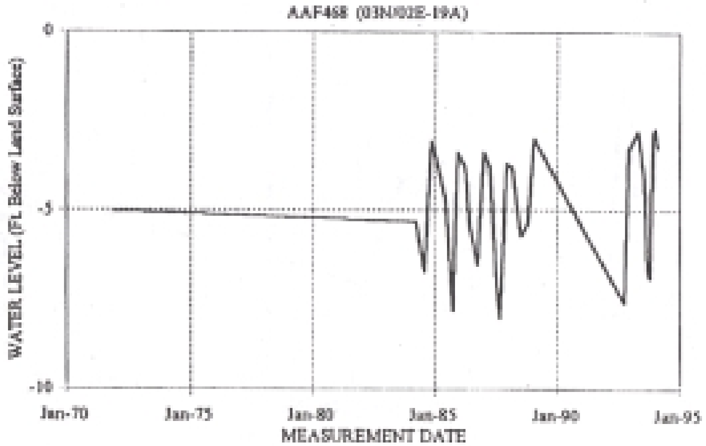

AAF457 (03N/02E-33M)
WATER LEVEL (Ft Below Land Surface)
-15
-20
-25
-30
-35
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

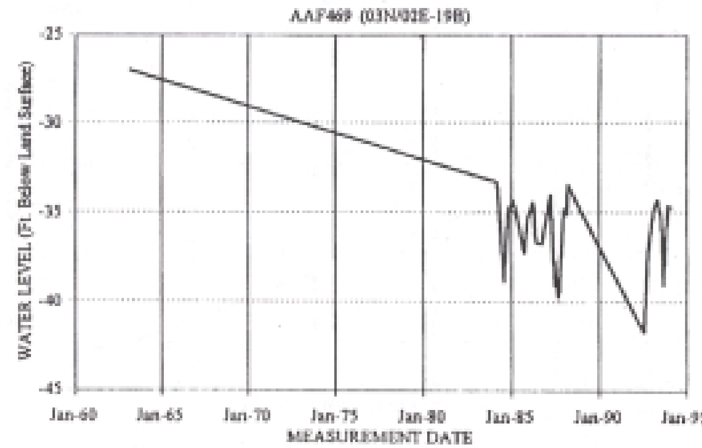

AAF460 (03N/01E-20D)
WATER LEVEL (Ft Below Land Surface)
-125
-130
-135
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

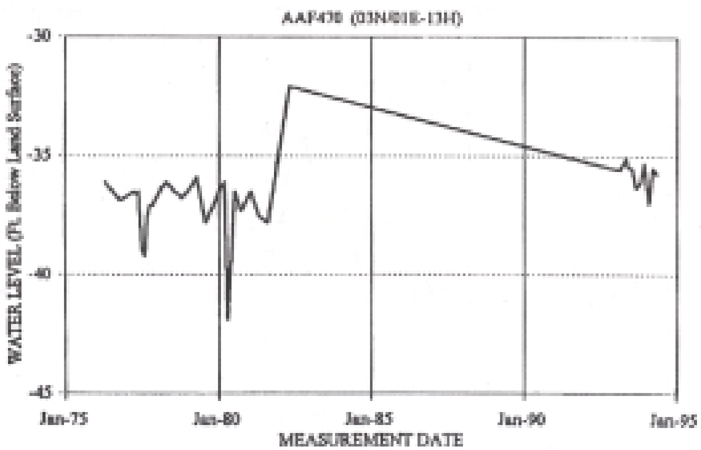

AAF461 (03N/01E-18A)
WATER LEVEL (Ft Below Land Surface)
-125
-130
-135
-140
-145
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

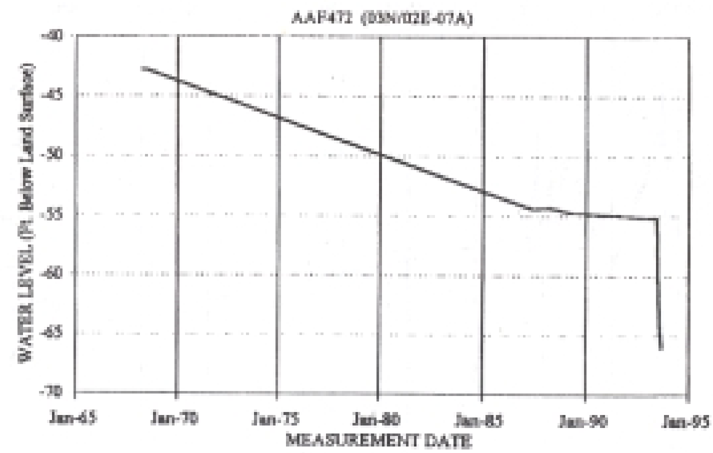

AAF462 (03N/01E-17C)
WATER LEVEL (Ft Below Land Surface)
-145
-150
-155
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

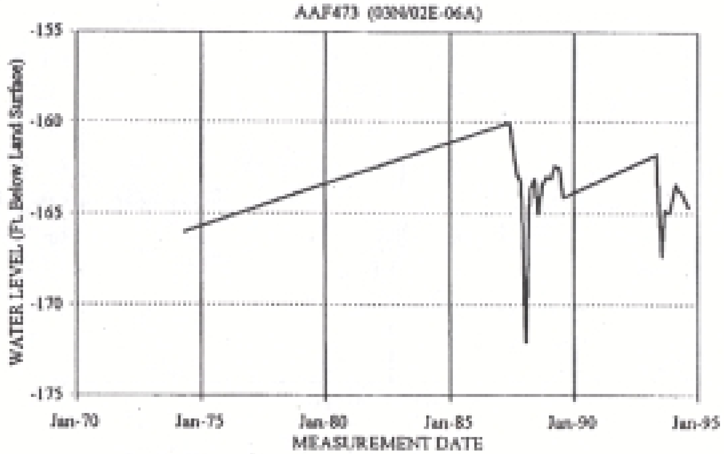

AAF466 (03N/01E-36A)
WATER LEVEL (Ft Below Land Surface)
-80
-85
-90
-95
-100
-105
-110
-115
-120
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

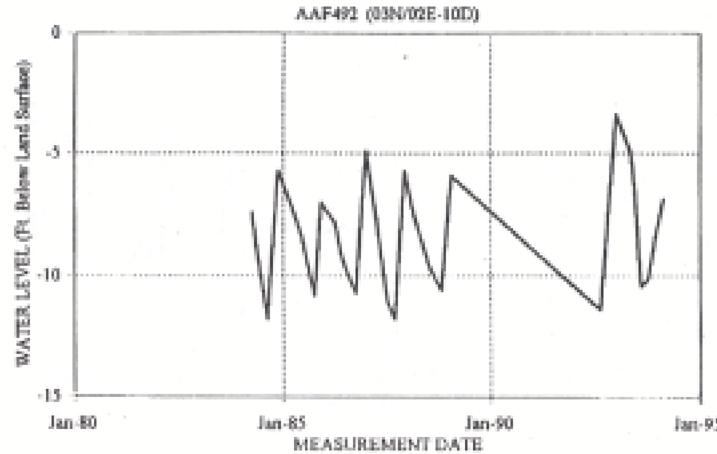

AAF468 (03N/02E-19A)
WATER LEVEL (Ft. Below Land Surface)
0
-5
-10
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

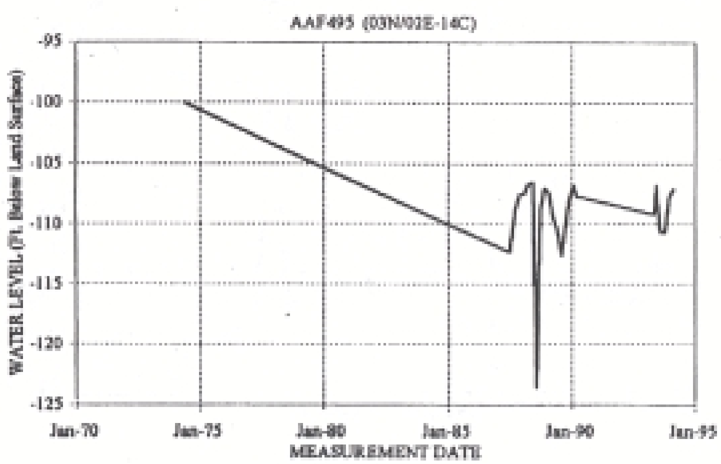

AAF469 (03N/02E-19B)
WATER LEVEL (Ft. Below Land Surface)
-25
-30
-35
-40
-45
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

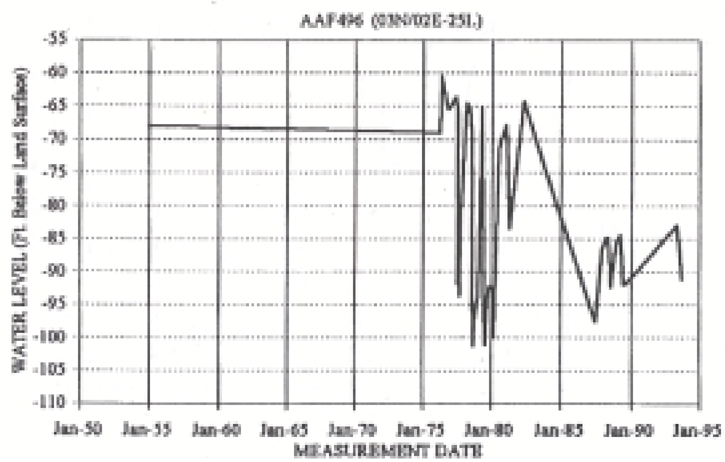

AAF470 (03N/01E-13H)
WATER LEVEL (Ft. Below Land Surface)
-30
-35
-40
-45
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


AAF472 (03N/02E-07A)
WATER LEVEL (Ft. Below Land Surface)
-40
-45
-50
-55
-60
-65
-70
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

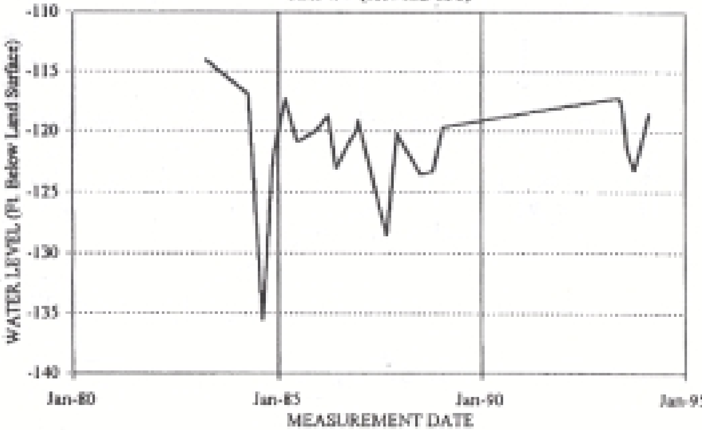

AAF473 (03N/02E-06A)
WATER LEVEL (Ft. Below Land Surface)
-155
-160
-165
-170
-175
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


AAF492 (03N/02E-10D)
WATER LEVEL (Ft. Below Land Surface)
0
-5
-10
-15
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

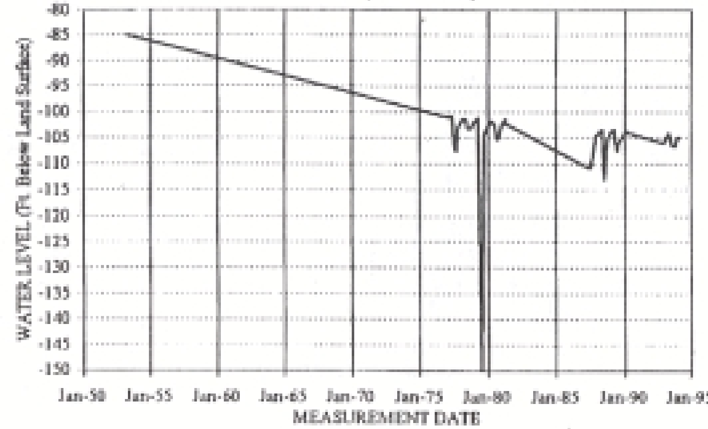

AAF495 (03N/02E-14C)
WATER LEVEL (Ft. Below Land Surface)
-95
-100
-105
-110
-115
-120
-125
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


AAF496 (03N/02E-25L)
WATER LEVEL (Ft. Below Land Surface)
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

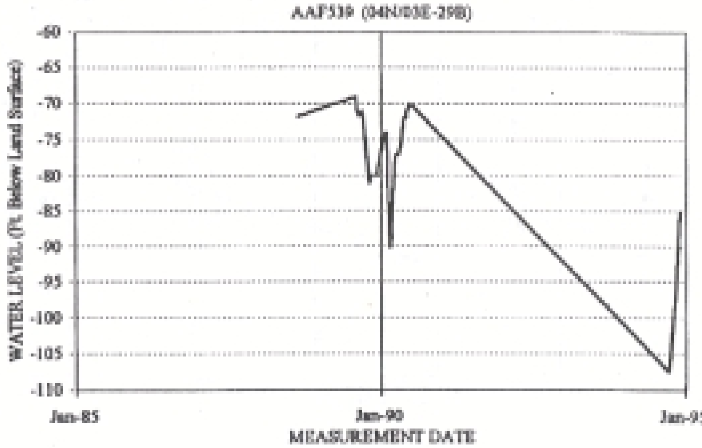
AAF497 (03N/02E-23C)



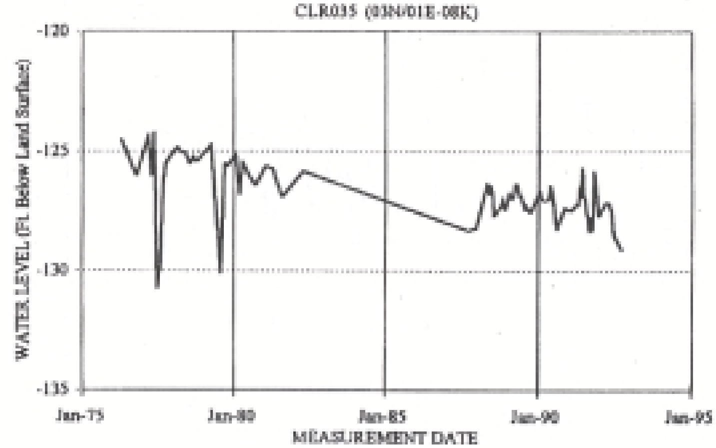
AAF505 (03N/02E-21K)

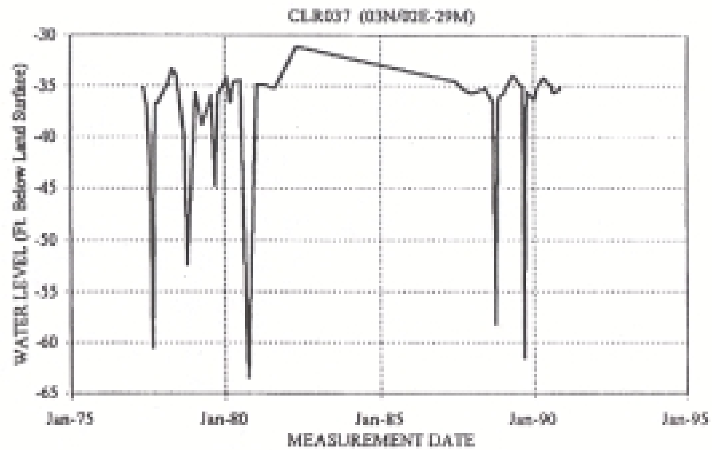


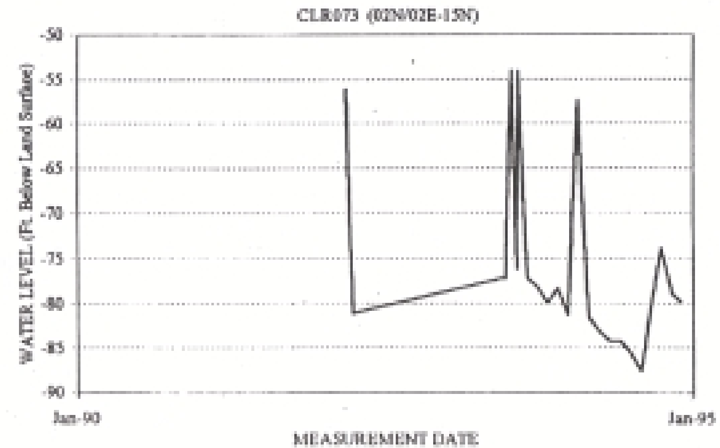
AAF539 (04N/03E-29B)

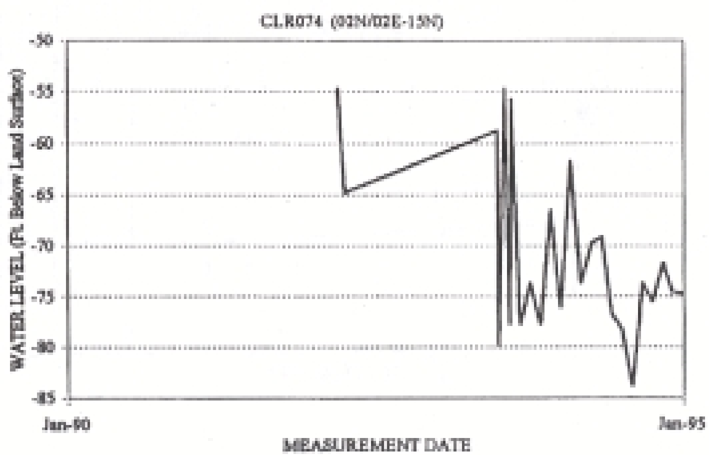


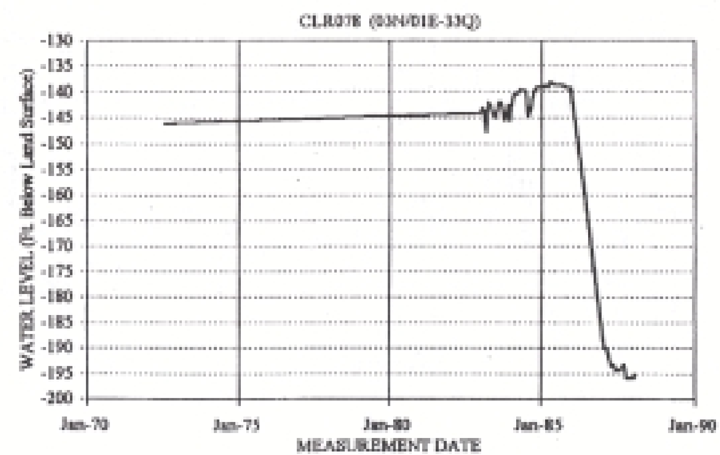
CLR035 (03N/01E-08K)

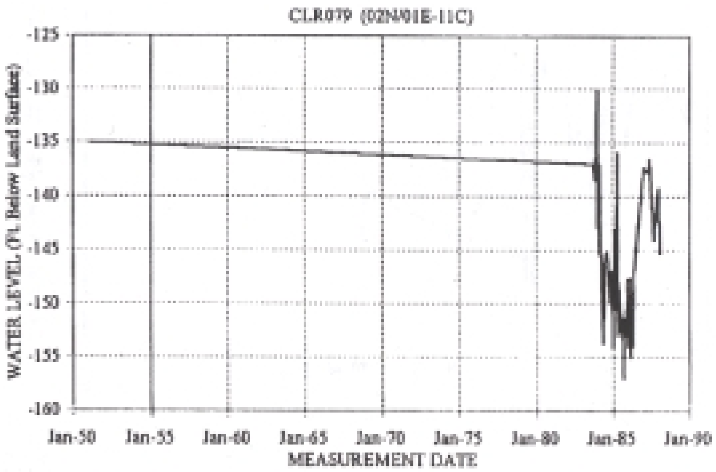


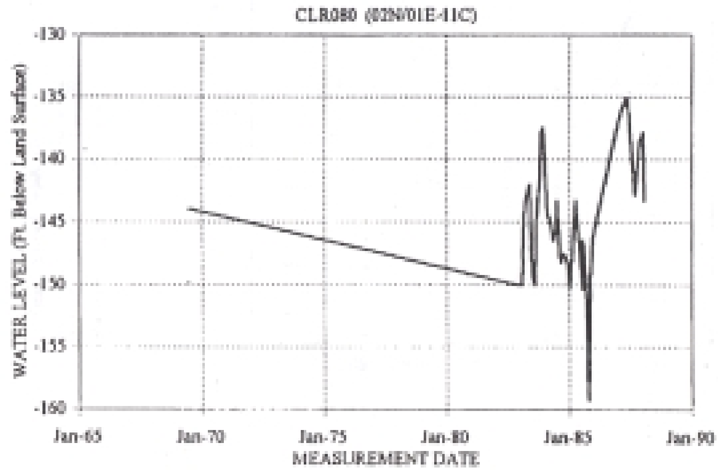

CLR037 (03N/02E-29M)
WATER LEVEL (Ft. Below Land Surface)
MEASUREMENT DATE
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95


CLR073 (02N/02E-15N)
WATER LEVEL (Ft. Below Land Surface)
MEASUREMENT DATE
Jan-90
Jan-95


CLR074 (02N/02E-15N)
WATER LEVEL (Ft. Below Land Surface)
MEASUREMENT DATE
Jan-90
Jan-95

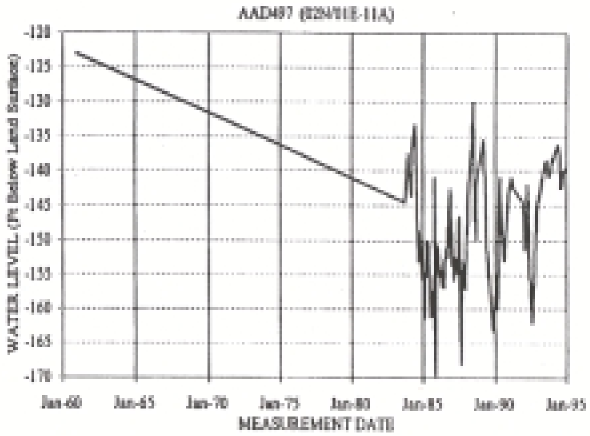

CLR078 (03N/01E-33Q)
WATER LEVEL (Ft. Below Land Surface)
MEASUREMENT DATE
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90

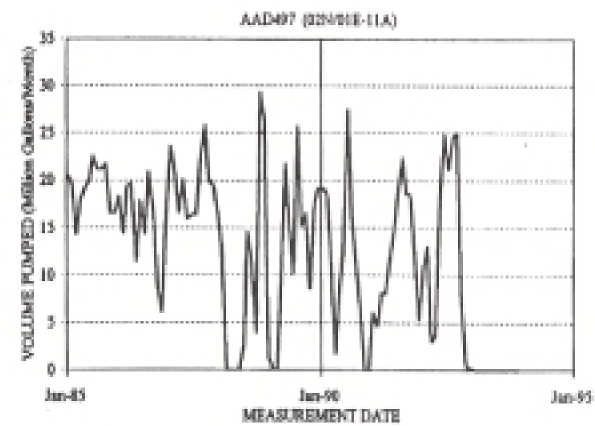

CLR079 (02N/01E-11C)
WATER LEVEL (Ft. Below Land Surface)
-125
-130
-135
-140
-145
-150
-155
-160
Jan-50
Jan-55
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
MEASUREMENT DATE

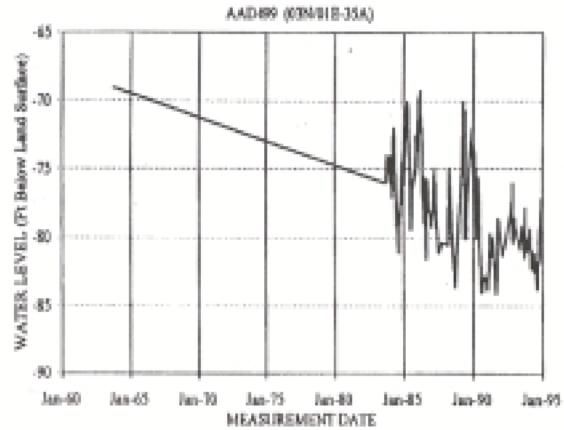

CLR080 (02N/01E-11C)
WATER LEVEL (Ft. Below Land Surface)
-130
-135
-140
-145
-150
-155
-160
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
MEASUREMENT DATE

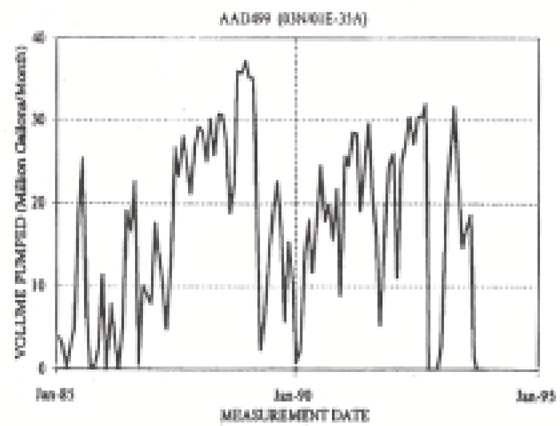
Appendix C.

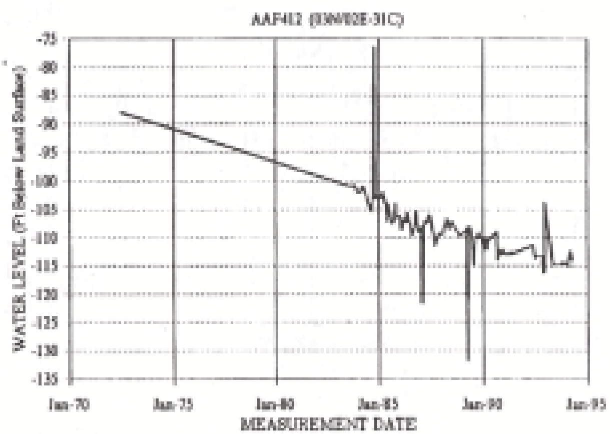
Selected Well Hydrographs and Pumpage

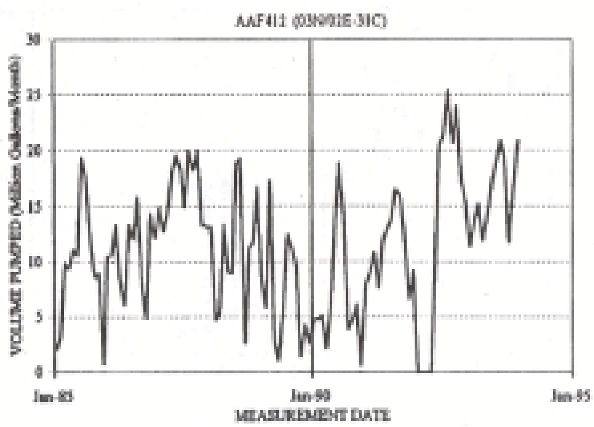

AAD497 (02N/01E-11A)
WATER LEVEL (Ft Below Land Surface)
-120
-125
-130
-135
-140
-145
-150
-155
-160
-165
-170
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

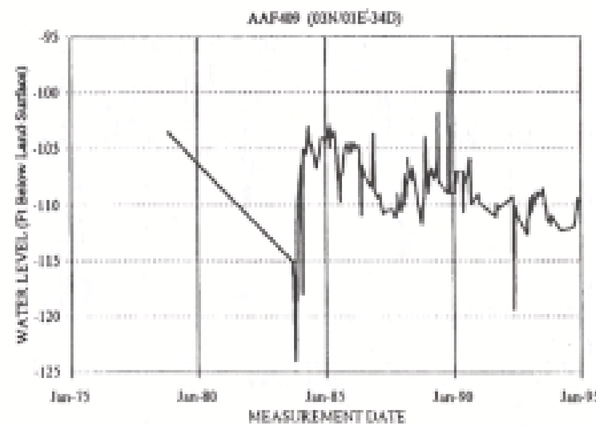

AAD497 (02N/01E-11A)
VOLUME PUMPED (Million Gallons/Month)
35
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

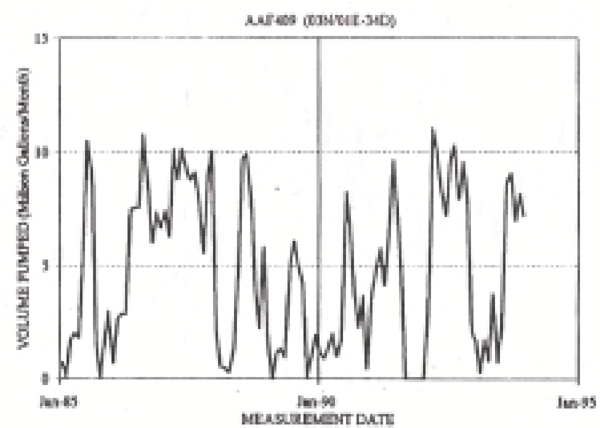

AAD499 (03N/01E-35A)
WATER LEVEL (Ft Below Land Surface)
-65
-70
-75
-80
-85
-90
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

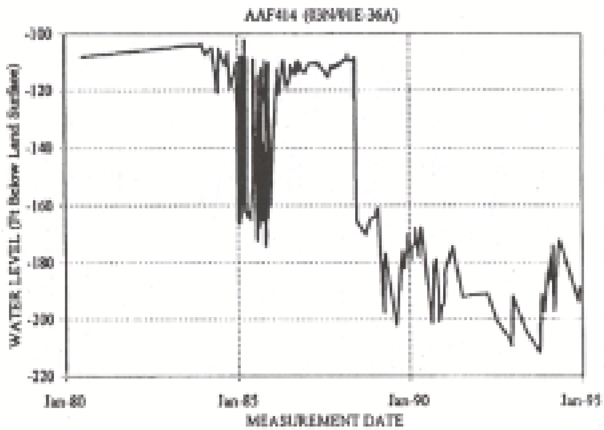

AAD499 (03N/01E-35A)
VOLUME PUMPED (Million Gallons/Month)
40
30
20
10
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

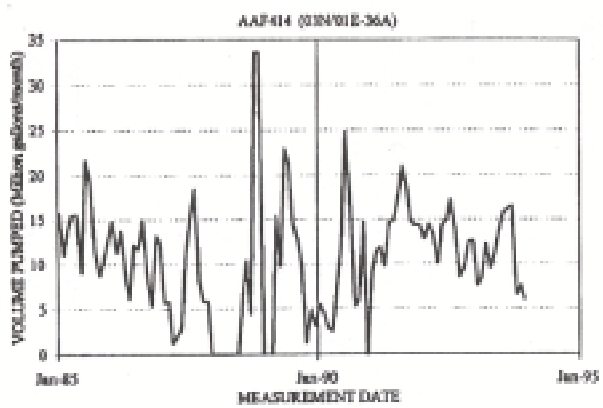

AAF412 (03N/02E-31C)
WATER LEVEL (Ft Below Land Surface)
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
-130
-135
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

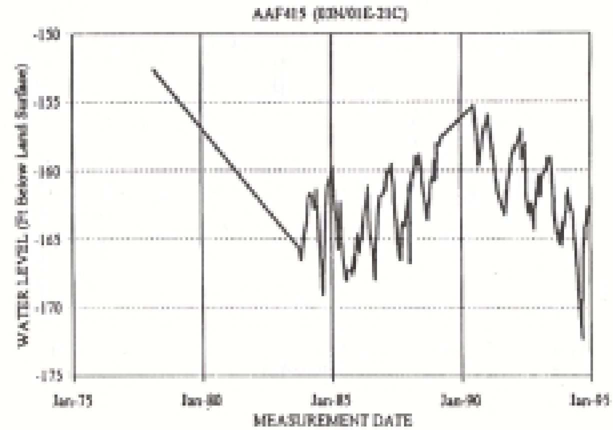

AAF411 (03N/02E-31C)
VOLUME PUMPED (Million Gallons/Month)
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

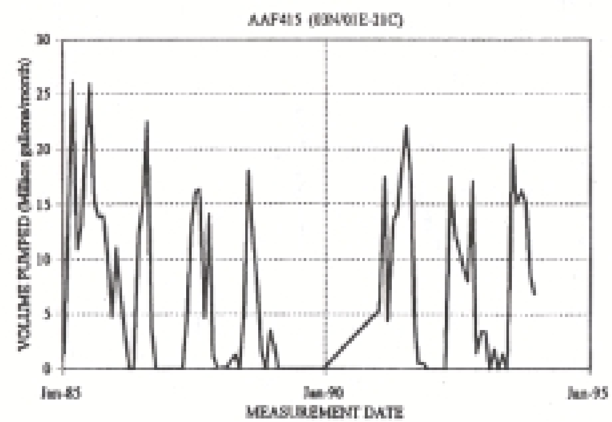

AAF409 (03N/01E-34D)
WATER LEVEL (Ft Below Land Surface)
-95
-100
-105
-110
-115
-120
-125
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

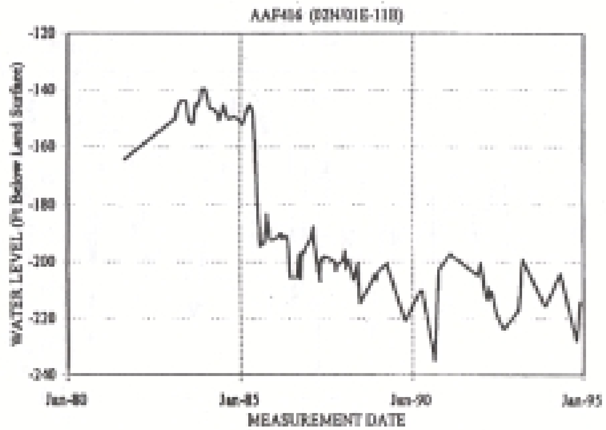

AAF409 (03N/01E-34D)
VOLUME PUMPED (Million Gallons/Month)
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

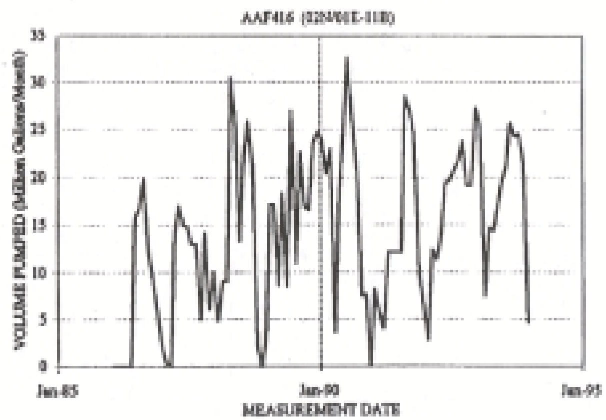

AAF414 (03N/01E-36A)
WATER LEVEL (Ft Below Land Surface)
-100
-120
-140
-160
-180
-200
-220
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

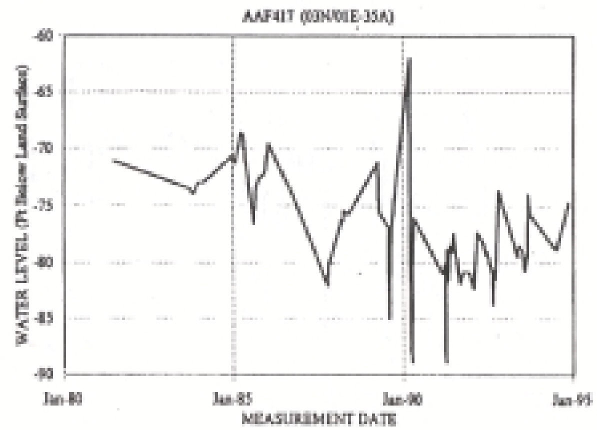

AAF414 (03N/01E-36A)
VOLUME PUMPED (Million gallons/month)
35
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

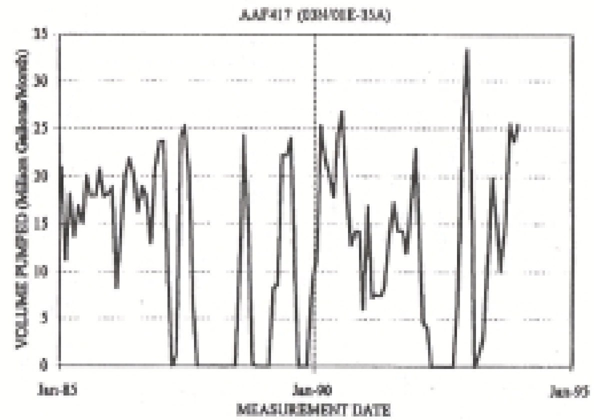

AAF415 (03N/01E-21C)
WATER LEVEL (Ft Below Land Surface)
-150
-155
-160
-165
-170
-175
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

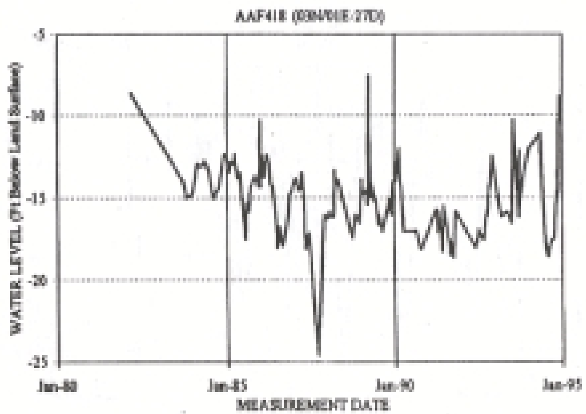

AAF415 (03N/01E-21C)
VOLUME PUMPED (Million gallons/month)
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

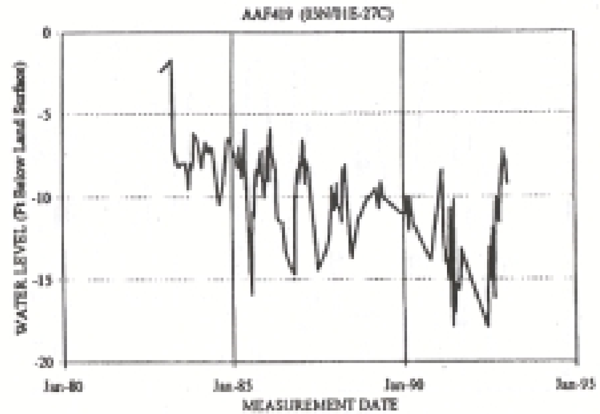

AAF416 (02N/01E-11B)
WATER LEVEL (Ft Below Land Surface)
-120
-140
-160
-180
-200
-220
-240
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

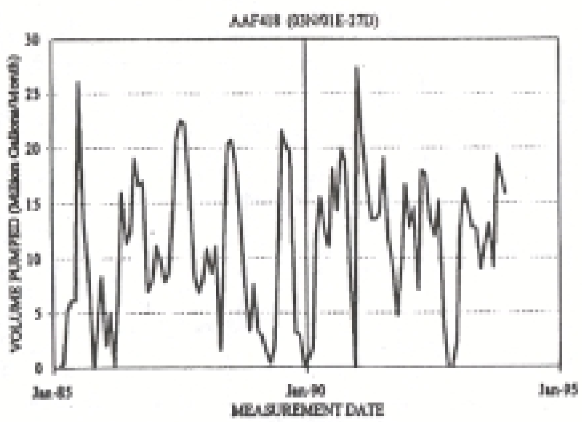

AAF416 (02N/01E-11B)
VOLUME PUMPED (Million Gallons/Month)
35
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

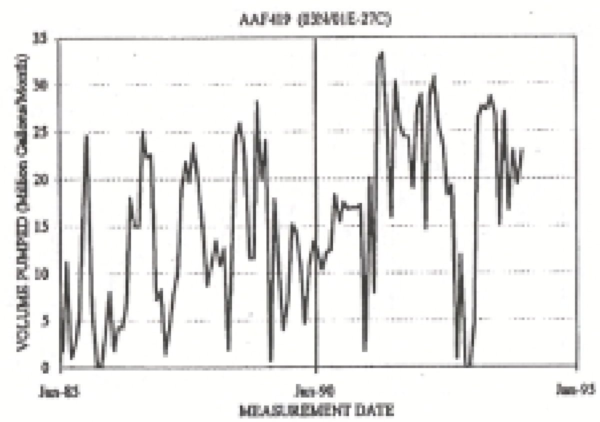

AAF417 (03N/01E-35A)
WATER LEVEL (Ft Below Land Surface)
-60
-65
-70
-75
-80
-85
-90
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

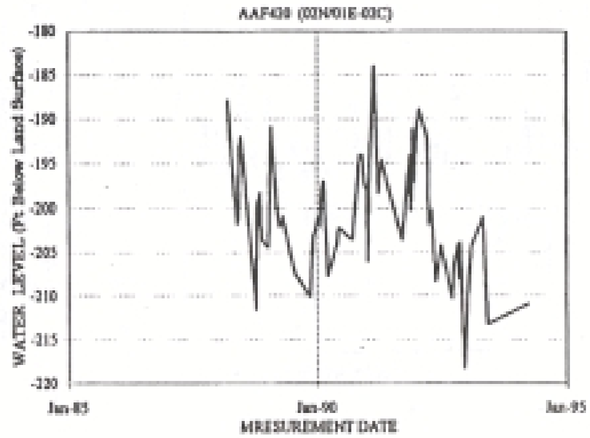

AAF417 (03N/01E-35A)
VOLUME PUMPED (Million Gallons/Month)
35
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

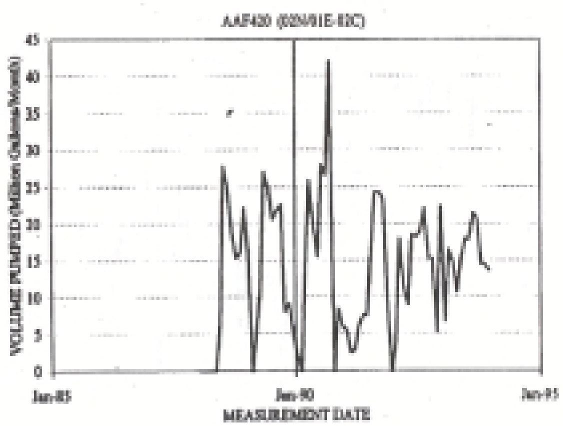

AAF418 (03N/01E-27D)
WATER LEVEL (Ft Below Land Surface)
-5
-10
-15
-20
-25
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

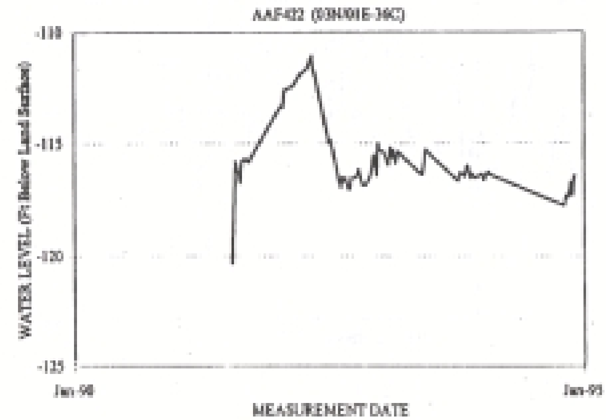

AAF409 (03N/01E-27C)
WATER LEVEL (Ft Below Land Surface)
0
-5
-10
-15
-20
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

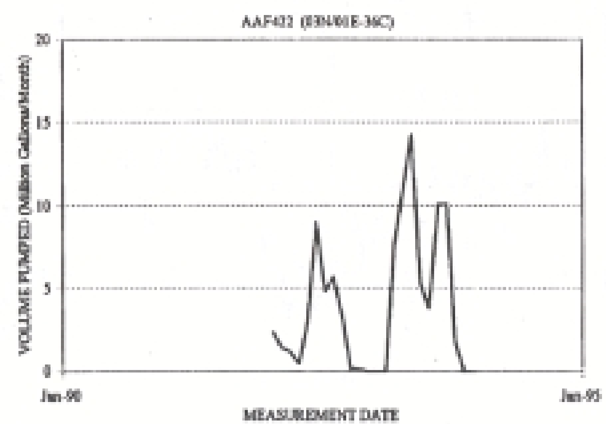

AAF418 (03N/01E-27D)
VOLUME PUMPED (Million Gallons/Month)
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

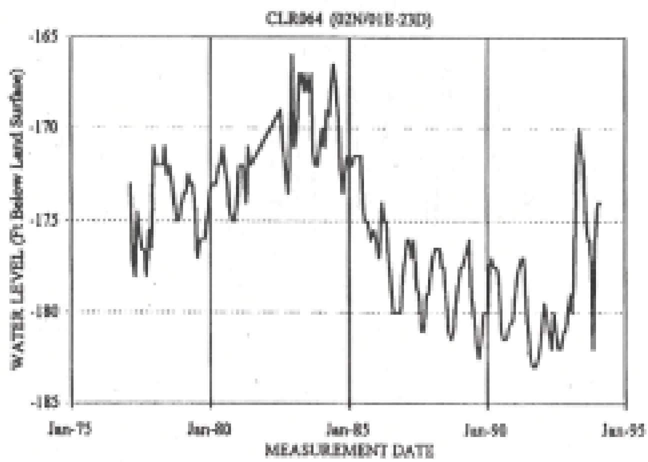

AAF409 (03N/01E-27C)
VOLUME PUMPED (Million Gallons/Month)
35
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

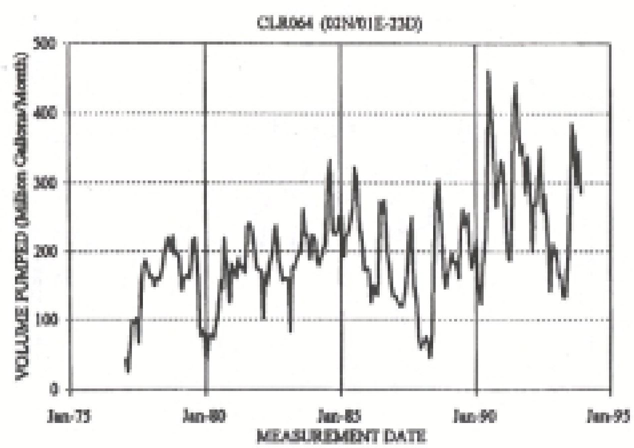

AAF420 (02N/01E-03C)
WATER LEVEL (Ft. Below Land Surface)
-180
-185
-190
-195
-200
-205
-210
-215
-220
Jan-85
Jan-90
Jan-95
MRESUREMENT DATE

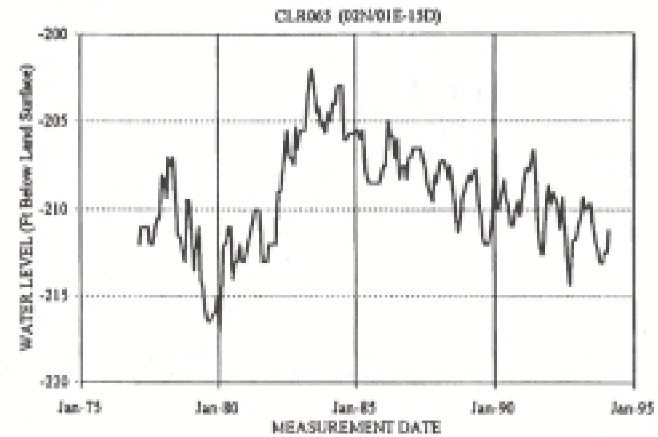

AAF420 (02N/01E-03C)
VOLUME PUMPED (Million Gallons/Month)
45
40
35
30
25
20
15
10
5
0
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

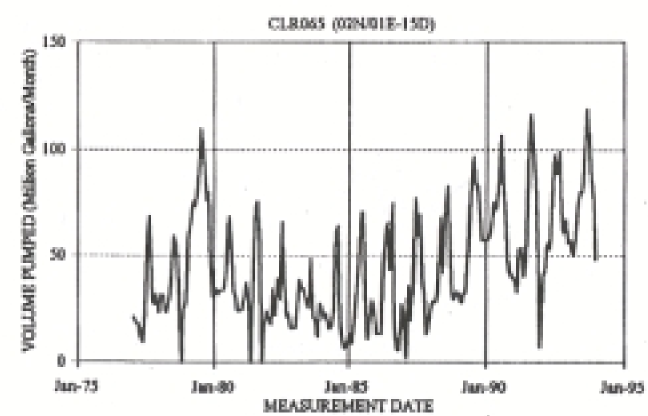

AAF422 (03N/01E-36C)
WATER LEVEL (Ft Below Land Surface)
-110
-115
-120
-125
Jan-90
Jan-95
MEASUREMENT DATE

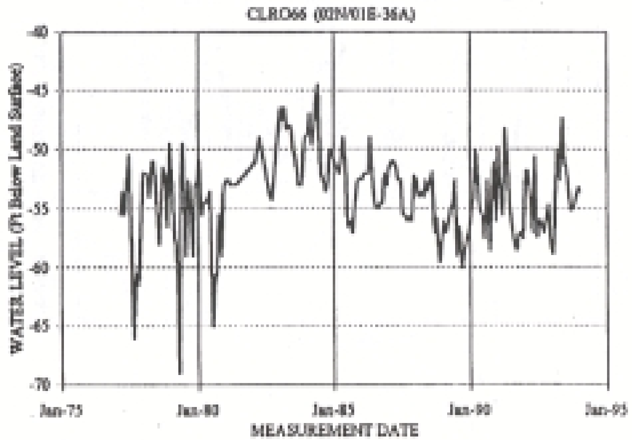

AAF422 (03N/01E-36C)
VOLUME PUMPED (Million Gallons/Month)
20
15
10
5
0
Jan-90
Jan-95
MEASUREMENT DATE

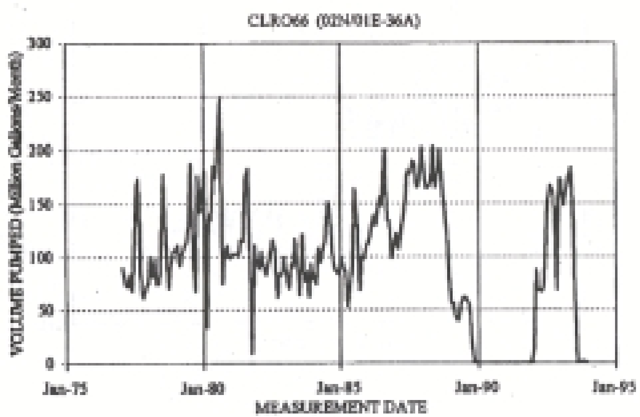

CLR064 (02N/01E-23D)
WATER LEVEL (Ft Below Land Surface)
-165
-170
-175
-180
-185
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

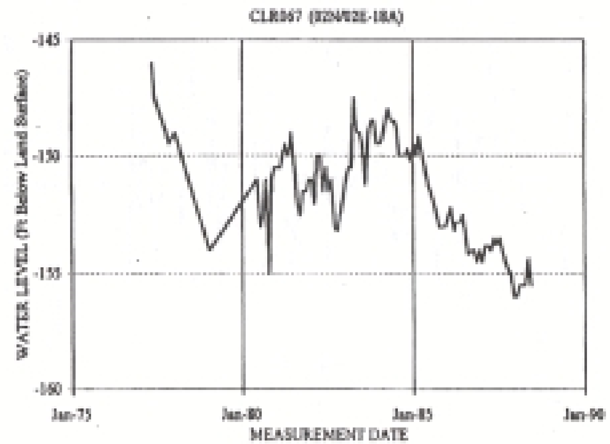

CLR064 (02N/01E-23D)
VOLUME PUMPED (Million Gallons/Month)
500
400
300
200
100
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

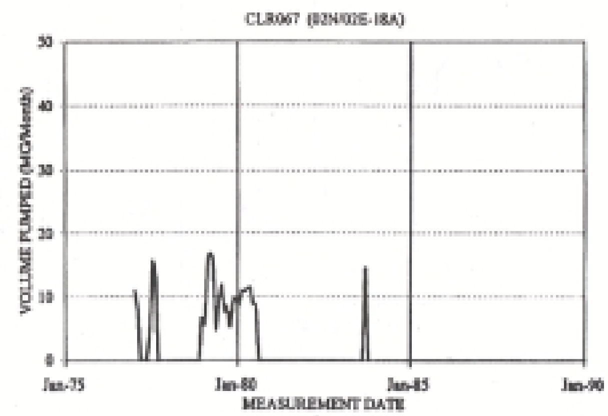

CLR065 (02N/01E-15D)
WATER LEVEL (Ft Below Land Surface)
-200
-205
-210
-215
-220
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

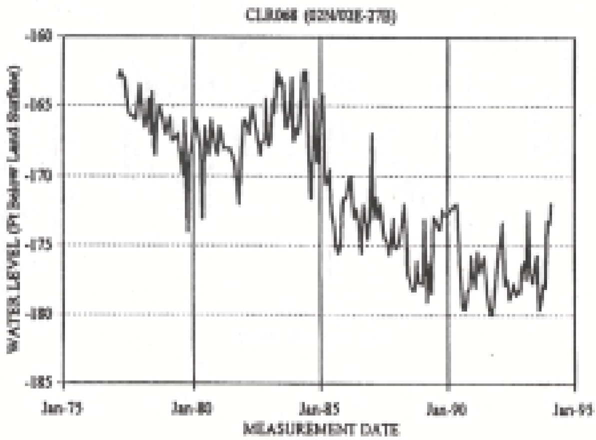

CLR065 (02N/01E-15D)
VOLUME PUMPED (Million Gallons/Month)
150
100
50
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

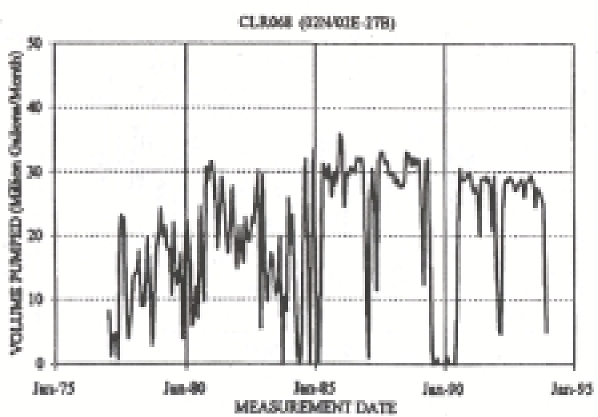

CLRO66 (02N/01E-36A)
WATER LEVEL (Ft Below Land Surface)
-40
-45
-50
-55
-60
-65
-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

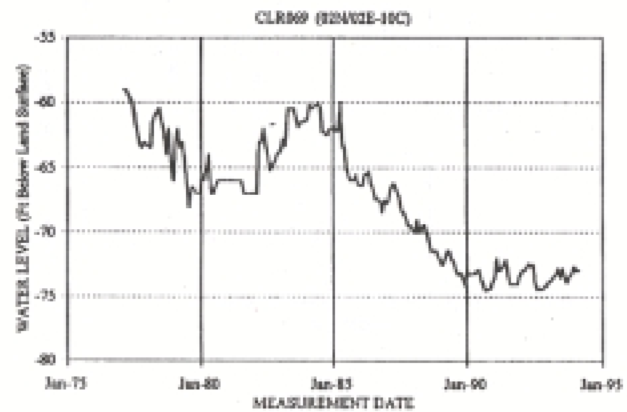

CLRO66 (02N/01E-36A)
VOLUME PUMPED (Million Gallons/Month)
300
250
200
150
100
50
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

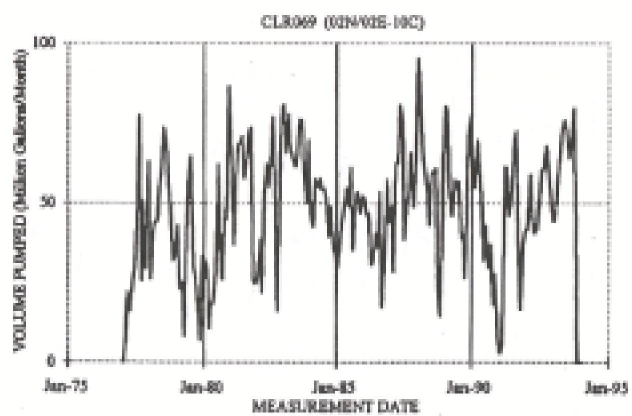

CLR067 (02N/02E-18A)
WATER LEVEL (Ft Below Land Surface)
-145
-150
-155
-160
Jan-75
Jan-80
Jan-85
Jan-90
MEASUREMENT DATE

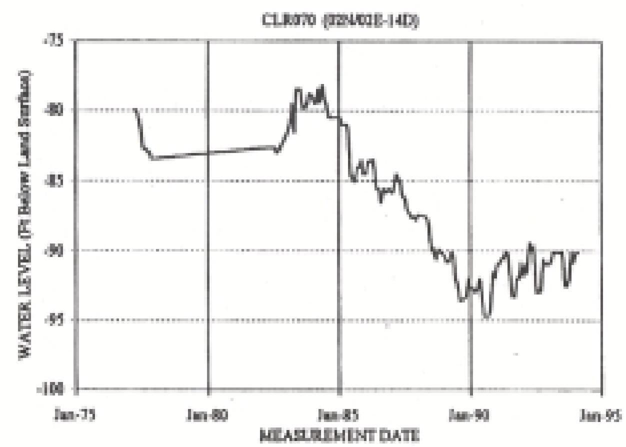

CLR067 (02N/02E-18A)
VOLUME PUMPED (MG/Month)
50
40
30
20
10
0
Jan-75
Jan-80
Jan-85
Jan-90
MEASUREMENT DATE

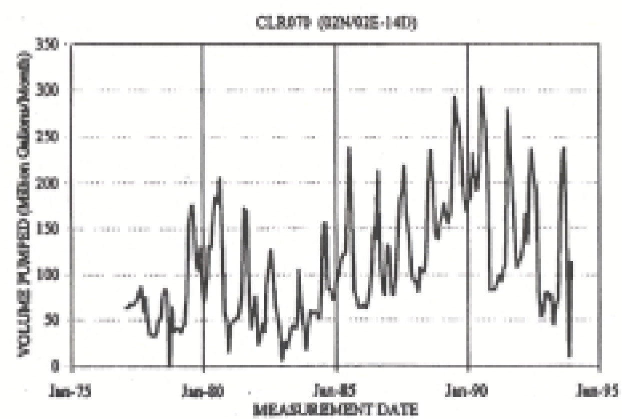

CLR068 (02N/02E-27B)
WATER LEVEL (Ft Below Land Surface)
-160
-165
-170
-175
-180
-185
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

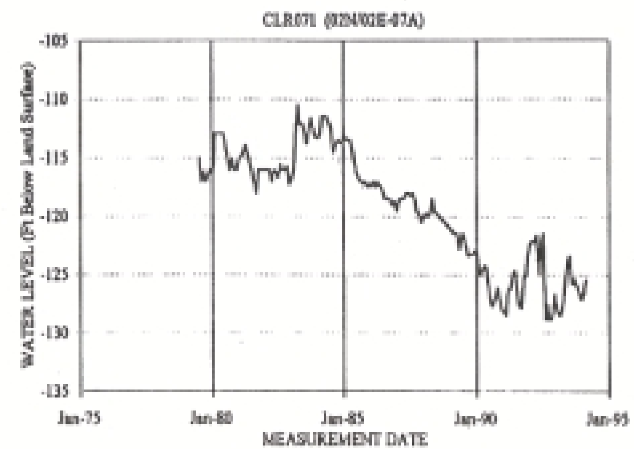

CLR068 (02N/02E-27B)
VOLUME PUMPED (Million Gallons/Month)
50
40
30
20
10
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

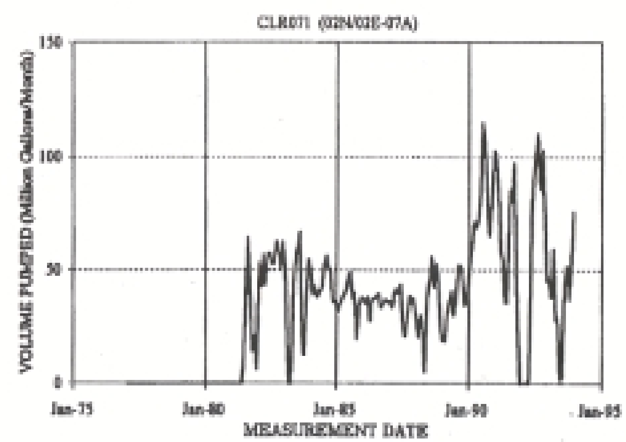

CLR069 (02N/02E-10C)
WATER LEVEL (Ft Below Land Surface)
-55
-60
-65
-70
-75
-80
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


CLR069 (02N/02E-10C)
VOLUME PUMPED (Million Gallons/Month)
100
50
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


CLR070 (02N/02E-14D)
WATER LEVEL (Ft Below Land Surface)
-75
-80
-85
-90
-95
-100
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


CLR070 (02N/02E-14D)
VOLUME PUMPED (Million Gallons/Month)
350
300
250
200
150
100
50
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


CLR071 (02N/02E-07A)
WATER LEVEL (Ft Below Land Surface)
-105
-110
-115
-120
-125
-130
-135
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE


CLR071 (02N/02E-07A)
VOLUME PUMPED (Million Gallons/Month)
150
100
50
0
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
MEASUREMENT DATE

Appendix D.

Streamflow for Salmon Creek Near Battleground, U.S. Geological Survey Gage 14212000, and for Washougal River At Washougal, U.S. Geological Survey Gage 14143500.

Monthly and Water-Year Mean Streamflow (in cubic feet per second), Salmon Creek near Battleground, Wa., U.S. Geological Survey Gage 14212000.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Annual Mean
1944	13.2	16.2	54.7	42.1	82.6	48.9	63.7	23.2	27.6	7.3	3.7	4.1	31.9
1945	4.5	36	46.7	121.7	110.3	125.9	79.1	82.1	18.1	5.5	3	5.3	52.9
1946	7.9	165.7	118.7	133.9	131.2	114.9	35.2	15.9	15.1	9.6	3.6	3.6	62.5
1947	32.8	142.4	206.8	115.3	104.8	60.1	81.4	16.9	14.8	6.2	3.8	3.6	65.5
1948	42	158.6	94.4	141.7	109.7	97.5	69.3	79.6	17	7	5.5	7.6	68.9
1949	11.4	109.6	213.3	41	257.6	58.9	26.6	35.1	6.6	3	1.7	2.2	62.6
1950	6.9	56.6	128.9	186.7	179	127.8	88	29.7	10.7	5	2.8	2.8	68.2
1951	32.7	168.4	173	214.3	125.9	109.2	26.3	22.1	8.7	4.3	2.3	3	74.0
1952	83.4	85.5	155	79.7	98.9	124.4	32.8	14.9	9	5.8	3.1	2.6	57.9
1953	2.4	3.2	41.8	285.6	121.4	80.8	41.8	57.8	34.8	8.2	5.5	4	57.1
1954	8.8	82.9	226.2	184.6	120.5	53.9	52.2	16	49	15.9	6.2		67.8
1955	10.6	74.7	94.7	98.2	98.9	81.1	133.9	31.1	17	12.5	5	5.6	54.9
1956	84.5	199.7	200.8	181.5	110.5	153.8	48.6	19.3	19.4	7	7.1	4.9	86.4
1957	48.7	70.8	113.3	51.5	106	139.2	70.7	21.3	14.9	5.6	3.3	2.2	53.7
1958	5	25.5	180.4	123.7	138	55.9	103.9	21.1	14.7	6.6	2.4	4.5	56.4
1959	5.9	121.7	117.5	170.4	121	74.8	52.6	58.8	48.4	12	4.2	9.1	66.0
1960	53.8	84.7	80.3	71.4	115.8	85.1	102.2	91.9	21.4	6.5	4.9	5	59.9
1961	16.2	203.2	55.6	95.1	248.6	151.8	76.2	67.7	13.7	5.4	2.9	3.7	77.0
1962	12.5	65.5	146.4	79.8	67	110.5	60.3	58.1	22.2	6.6	5.7	5	53.4
1963	16.3	164.4	82.2	56.8	119.3	91.6	114.8	71.5	13.8	13	5.8	5.5	62.3
1964	12.9	102.9	78.4	242.7	74.2	107.9	43	30.8	34	12.2	7.7	7.7	62.9
1965	8.5	65.9	228.2	243.4	109	31.1	30.9	21.9	8.6	4.5	4	3	63.3
1966	5.2	25.7	97.9	170.1	64.8	116.3	23.3	10.5	6.1	6.3	2.1	2.8	44.4
1967	9.1	53	157.5	198.4	103.4	93.5	60.9	21.1	10.1	3.9	1.9	2.2	59.5
1968	22.1	33.8	130.4	96.8	163.9	54.8	44	21.7	44.5	7.1	11.2	22.5	53.7
1969	82.4	125.5	196.1	212.9	138.3	52.9	34.2	29.9	36.2	20.8	6	12.3	78.8
1970	37.2	60.5	114.6	260.2	122.2	42.8	52.6	48.7	11.3	4.8	2.8	4.9	63.4
1971	11.6	64.9	155.7	274.8	107.7	137	63.3	15.7	19.3	10.2	4.3	8.1	72.8
1972	17.8	102.6	245.4	210.5	142	145.3	81.6	39.7	14.4	5.9	2.8	5.1	84.3
1973	3.7	32.6	148.1	85.7	31.8	62.5	33.5	19.8	14.5	6.9	4	5.8	37.6
1974	18.1	197.8	207.8	203.2	155.6	142	103	43.5	20.5	14.7	5.3	3.4	92.5
1975	3.4	63.7	154.8	206	101.2	97.9	41.7	34.8	10.4	5.3	6.3	4.3	60.8
1976	28.6	8.3											
1977													
1978													
1979													
1980													
1981													
1982													
1983													
1984													
1985													
1986													
1987													
1988					62.9	93.5	84.3	57.6	37.7	10.3	4.5	4.2	
1989	4.8	93.5	75.6	156.6	65.1	115.1	60.5	29	13.5	7.1	5.8	3.4	52.5
1990	4.7	36.7	66.8	149.5	195.1	71.1	37.9	12.5					
1991													
1992									3.7	3.3	1.4	2.8	
1993	7.2	56.2	117	76.2	34.5	84.6	156	73.6	35	9.8	0.2	1.2	54.4
1994	3.5	6.3	63.6	110	86.7	71.5	59.9	14.8	10.1	3.9	1	1.7	35.8
1995	27.7	109	165	8.6	20.5	56.6	76.9	54.6	20.3	8.8	4.6	7.1	46.8
1996	42.5	211	132	153	226	59.9	70.4	43.4				5.1	
MEAN	21.8	89.4	129.9	141.9	114.3	89.6	62.9	36.4	19.7	7.9	4.2	4.9	

Monthly and Water-Year Mean Streamflow (in cubic feet per second), Washougal River at Washougal, Wa., U.S. Geological Survey Gage 14143500.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Annual Mean
1945	137	874	584	1732	1597	1451	1370	1060	237	103	67	216	780
1946	149	1941	1714	1810	1681	1637	810	365	346	305	101	87	907
1947	724	2042	2598	1458	1254	815	1086	241	494	215	101	212	934
1948	1511	1737	1042	1517	1566	1031	1138	860	236	139	90	175	918
1949	456	1552	2065	330	2142	1529	1017	786	168	121	74	118	854
1950	457	1296	1605	1241	2519	2332	1472	771	257	123	78	102	1012
1951	1043	1926	1988	2132	1583	1003	790	409	183	90	64	143	943
1952	1677	1020	1612	660	1646	1269	1042	437	194	144	74	59	817
1953	54	79	930	4320	1913	1185	672	735	444	148	136	91	890
1954	251	1268	2920	1501	1837	880	1061	292	676	305	129	128	932
1955	390	1023	1143	1197	1134	953	1747	1046	452	253	127	160	799
1956	390	1023	1143	1197	1134	953	1747	1046	452	253	127	160	799
1957	921	888	1894	413	1547	1990	1093	342	257	127	87	59	798
1958	217	728	2364	1757	1844	704	1543	285	200	116	59	95	820
1959	294	2471	1842	1951	959	1351	1074	760	530	167	75	727	1015
1960	1342	985	910	623	1762	1296	1290	1104	355	132	127	127	834
1961	446	2474	891	1453	3224	2095	951	837	226	106	69	100	1056
1962	599	954	1805	1122	835	830	1127	731	258	114	101	146	719
1963	515	1790	1013	635	1348	902	1407	796	201	183	95	108	743
1964	313	1666	959	2519	1062	1347	919	629	465	184	174	176	867
1965	313	1666	959	2519	1062	1347	919	629	465	184	174	176	867
1967	384	1017	1670	2524	1264	1015	769	423	174	84	56	52	785
1968	933	715	1634	1126	2542	843	594	323	514	119	340	449	838
1969	1009	1642	1726	1501	683	1288	1246	737	477	262	104	251	913
1970	610	716	1358	3037	1529	864	843	631	181	95	67	136	837
1971	487	1287	1659	3226	1707	1621	1166	695	402	181	87	251	1062
1972	502	1510	2135	3041	2891	2229	1187	694	256	133	75	220	1235
1973	100	777	2196	1386	514	923	529	361	390	163	78	193	637
1974	467	2499	2733	2702	1781	1834	1461	770	463	275	110	72	1261
1975	64	844	2018	2861	1349	1242	719	677	222	136	193	156	874
1976	671	1534	2947	2240	1431	1095	1008	464	290	164	154	102	1009
1977	124	265	340	357	551	1468	728	612	477	112	136	457	468
1978	401	2450	3975	1102	1041	486	881	779	358	133	115	239	996
1979	118	671	1245	287	2160	1403	769	590	150	144	79	113	634
1980	306	498	1558	1421	1243	1026	929	318	341	173	91	117	667
1981	94	1166	2540	501	1646	543	1199	522	1071	225	97	96	801

Appendix E.

Quality of ground Water in Clark County: Summary of Values and Concentrations of Common Constituents, Trace Elements, and Cyanide (Turney, 1990).

Quality of Ground Water in Clark County
Summary of values and concentrations of common constituents (Turney, 1990)

[Concentrations in milligrams per liter (mg/L) unless otherwise noted. All are dissolved concentrations; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; µg/L, micrograms per liter; --, no U.S. Environmental Protection Agency (USEPA) drinking water standard]

Constituent	Concentrations			USEPA[a] drinking water standard	Number of wells sampled	Number of wells exceeding standard
	Minimum	Median	Maximum			
Specific conductance (µS/cm)	14	180	438	--	76	--
pH (standard units)	5.7	7.1	9.5	6.5 to 8.5*	76	7
Dissolved oxygen	.0	5.0	10.4	--	76	--
Turbidity (NTU)	.10	.30	75	1.0	76	18
Hardness as $CaCO_3$	3.0	73	190	--	76	--
Calcium	.57	17	52	--	76	--
Magnesium	.02	7.3	15	--	76	--
Sodium	1.1	7.6	70	--	76	--
Potassium	.10	1.8	6.6	--	76	--
Bicarbonate	6.0	97	247	--	76	--
Carbonate	0	0	22	--	76	--
Alkalinity as $CaCO_3$ (Field)	5.0	83	203	--	76	--
Sulfate	<.20	1.6	29	250*	76	0
Chloride	1.1	2.6	110	250*	76	0
Fluoride	.10	.20	2.0	4.0, 2.0*	76	0
Silica	8.4	47	68	--	76	--
Dissolved solids	12	132	245	500*	75	0
Nitrate	<.10	.16	6.7	10	76	0
Phosphorus	<.010	.070	.33	--	76	--
Aluminum (µg/L)	<10	<10	50	--	76	--
Iron (µg/L)	<3	5	7,700	*300	76	3
Manganese (µg/L)	<1	2	690	*50	76	13

[a]Primary drinking water standard unless noted with an asterisk, in which case the figure is a secondary drinking water standard.

Quality of Ground Water in Clark County
Summary of concentrations of trace elements and cyanide (Turney, 1990)

[Concentrations in micrograms per liter unless otherwise noted. All are dissolved concentrations; --, no U.S. Environmental Protection Agency (USEPA) drinking water standard]

Element	Concentrations			USEPA[a] drinking water standard	Number of wells sampled	Number of wells exceeding standard
	Minimum	Median	Maximum			
Antimony	<1	<1	13	--	20	--
Arsenic	<1	1	4	50	20	0
Barium	<2	7	30	1,000	20	0
Beryllium	<.5	<.5	<.5	--	20	--
Boron	<10	<10	40	--	20	--
Cadmium	<1	<1	<1	10	20	0
Chromium	<1	<1	3	50	20	0
Copper	<1	2	18	1,000*	20	0
Lead	<5	<5	<5	50	20	0
Mercury	<.1	<.1	.1	2	20	0
Molybdenum	<1	<1	3	--	20	--
Nickel	<1	1	4	--	20	--
Selenium	<1	<1	1	10	20	0
Silver	<1	<1	1	50	20	0
Thallium	<1	<1	<1	--	20	--
Vanadium	2	10	23	--	20	--
Zinc	<3	10	170	5,000*	20	0
Cyanide (milligrams per liter)	<.01	<.01	<.01	--	20	--

[a]Primary drinking water standard, unless noted with an asterisk, in which case the figure is a secondary drinking water standard.