SUMMARY OF WATER-RESOURCES ACTIVITIES OF THE U.S. GEOLOGICAL SURVEY IN WASHINGTON: FISCAL YEAR 1989

Compiled by Judith A. Wayenberg

U.S. GEOLOGICAL SURVEY

Open-File Report 90-180

Tacoma, Washington
1990

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

COVER PHOTOGRAPH:
Columbia River Gorge near Washougal, Washington;
view is upstream to the east.

For additional information
write to:

District Chief
U.S. Geological Survey
1201 Pacific Avenue, Suite 600
Tacoma, Washington 98402

Copies of this report can be
purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Building 810, Federal Center
Box 25425
Denver, Colorado 80225

CONTENTS

PLATE

[Plate is in pocket at end of report]

TABLE

The use of brand or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

SUMMARY OF WATER-RESOURCES ACTIVITIES OF THE U.S. GEOLOGICAL SURVEY IN WASHINGTON: FISCAL YEAR 1989

INTRODUCTION

Water-resources-related activities of the U.S. Geological Survey in Washington consist of collecting water-resources data and conducting interpretive hydrologic investigations and research. The water-resources data and the results of the interpretive investigations and research are published or released by the U.S. Geological Survey or by cooperating agencies. This report describes the data-collection activities and water-resources investigations in Washington for the 1989 fiscal year (October 1, 1988, to September 30, 1989).

In 1984, the Oregon and Washington Districts combined to form the Pacific Northwest District. The District Chief of the Pacific Northwest District is Garald G. Parker, Jr. The Pacific Northwest District office is located in Tacoma, Washington. The Washington State office is also in Tacoma, and Philip J. Carpenter was the State Chief in 1989. The Washington Office has three field offices located in Tacoma, Spokane, and Pasco, and the Cascades Volcano Observatory located in Vancouver. Requests for information should be addressed to:

District Chief
U.S. Geological Survey
Water Resources Division
1201 Pacific Avenue, Suite 600
Tacoma, Washington 98402
Telephone: (206) 593-6510

Tacoma Field Office
U.S. Geological Survey
Water Resources Division
1201 Pacific Avenue, Suite 520
Tacoma, Washington 98402
Telephone: (206) 593-6520

Pasco Field Office
U.S. Geological Survey
Water Resources Division
403 W. Lewis, P.O. Box 1344
Pasco, Washington 99301-1344
Telephone: (509) 547-2571

Washington Office Chief
U.S. Geological Survey
Water Resources Division
1201 Pacific Avenue, Suite 600
Tacoma, Washington 98402
Telephone: (206) 593-6510

Spokane Field Office
U.S. Geological Survey
Water Resources Division
Room 694, U.S. Court House
West 920 Riverside Avenue
Spokane, Washington 99201
Telephone: (509) 353-2633

Cascades Volcano Observatory
U.S. Geological Survey
Water Resources Division
5400 MacArthur Boulevard
Vancouver, Washington 98661
Telephone: (206) 696-7812

MISSION OF THE U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey was established by an act of Congress on March 3, 1879, in order to answer the need for a permanent government agency at the Federal level to conduct, on a continuing, systematic, and scientific basis, investigations of the "geological structure, mineral resources, and products of the national domain." Although a number of laws and executive orders have expanded and modified the scope of the Survey's responsibilities during its 110-year history, the Survey has remained principally a scientific and technical investigation agency, as contrasted with a developmental or regulatory one. Today the Survey is mandated to provide information for society to mitigate the impact of floods, earthquakes, landslides, volcanoes, and droughts; to monitor the Nation's ground- and surface-water supplies; to study the impact of man on the Nation's water resources; to provide mapped information on the Nation's landscape and land use; and to assess onshore and offshore energy and mineral resources. The Survey is the principal source of scientific and technical expertise in the earth sciences within the Department of the Interior and the Federal Government. The Survey's activities span a wide range of earth science research and services in the fields of geology, hydrology, and cartography, and represent the continuing pursuit of the long-standing scientific missions of the Survey.[1]

---

[1]Source: Adapted (and updated December 1984) from U.S. Geological Survey Yearbook for Fiscal Year 1983.

MISSION OF THE WATER RESOURCES DIVISION

The mission of the Water Resources Division, which supports the mission of the Geological Survey and the U.S. Department of the Interior, is to develop and disseminate scientific knowledge and understanding of the Nation's water resources. The activities carried out by the Water Resources Division fall into three broad categories: (1) resource assessment; (2) research; and (3) coordinating the activities and cataloging the products of numerous other entities involved in water research, data acquisition, or information transfer.

Resource Assessment. Resource assessment consists of:

- Collecting data on the quantity, quality, and use of surface water (rivers, streams, lakes, reservoirs, estuaries, and glaciers); the quantity, quality, and use of ground water (including water in the unsaturated zone); the quantity and quality of precipitation (as related to specific hydrologic investigations); and the quantities of evaporation, transpiration, and ablation.

- Storing and disseminating these data.

- Interpreting these data and publishing the results of these interpretations. This interpretation involves the inference of hydrologic causes, effects, and probabilities; and the extension, over space and time, of information contained directly in the data.

- Developing and applying new methods of hydrologic data collection, analysis, and interpretation.

- Conducting areally focused interpretive investigations and appraisals at national, regional, State, or local scales. These include characterizations of ground and surface waters and of precipitation chemistry; evaluation of natural hydrologic hazards; and studies of other water-related topics. Frequently, these investigations involve the development, testing, and application of mathematical models capable of predicting the hydrologic consequences of management actions, development plans, or natural phenomena. These investigations are carried out through specific Federal programs or in cooperation with State and local governments or other Federal agencies. Results are published in State, local, U.S. Geological Survey, or other Federal agency publications or in technical journals.

- Reporting to the Nation, on a regular basis, on the overall status of water resources and on hydrologic events and water-resource issues.

Research. The Division conducts research in a wide variety of scientific disciplines--geochemistry, ecology, geomorphology and sediment transport, water chemistry, ground-water hydrology, and surface-water hydrology--particularly as these disciplines relate to the quantity, flow, and quality of surface water and ground water and to other aspects of the hydrologic cycle. The research is intended to:

- Improve the overall understanding of the pathways, rates of movement, chemical processes, and biological processes in the hydrologic cycle.

- Improve the overall understanding of the hydraulic, chemical, and biological factors, both natural and anthropogenic, that affect the water resource.

- Provide new strategies of data collection, analysis, and interpretation, in the light of new knowledge and evolving scientific capabilities.

- Improve methods of predicting the response of hydrologic systems to stresses, whether hydraulic or chemical, and whether of natural or human origin.

Coordinating the Activities and Cataloging the Products of Other Entities Involved in Water Research, Data Acquisition, or Information Transfer. This function has four major components:

- The coordination of water-data acquisition activities of Federal agencies (as mandated by Office of Management and Budget Circular A-67).

- The acquisition of water-use data and development of State and national water-use data bases in cooperation with State governments.

- The operation of water information exchanges and centers, which provide all interested parties with indexing and access to many sources of water data and information.

- The administration of extramural water-resources research, technology, development, academic training, and information-transfer programs mandated by the Water Resources Research Act of 1984 (Public Law 98-424). The Act mandates research oriented to the environmental values associated with the resource. The research promoted by the Act involves many disciplines and activities other than those required in the assessment, research, and coordinating functions of the Water Resources Division.[2]

---

[2]Source: Mission statement by the Chief Hydrologist, September 18, 1984, updated to reflect recent additions.

COOPERATING AGENCIES

In Washington, many water-resources data-collection activities and interpretive hydrologic investigations are conducted in cooperation with Federal, State, and local agencies. The agencies cooperating with the U.S. Geological Survey during fiscal year 1989 were:

Washington Department of Ecology
Washington Department of Community Development
  Division of Emergency Management
Washington Department of Fisheries
Washington Department of Transportation
City of Bellevue
City of Pullman
City of Castle Rock
City of Kelso
City of Longview
City of Moscow, Idaho
City of Portland, Oregon
Municipality of Metropolitan Seattle
City of Seattle Light Department
Seattle-King County Department of Public Health
City of Tacoma Department of Public Utilities
City of Tacoma Department of Public Works
Chelan County Public Utilities District No. 1
Clark County Intergovernmental Resource Center
Cowlitz County
King County Department of Public Works
King County Planning Department
Kitsap County Public Utilities District No. 1
Lewis County Board of Commissioners
Pierce County Public Works Department
Pierce County Surface Water Management Utility
Skagit County Department of Public Works
Snohomish County Board of Commissioners
Thurston County Department of Public Works
Thurston County Health Department
Regional Water Association of South King County
University of Idaho
Washington State University
Confederated Tribes and Bands of the Yakima Nation
Hoh Indian Tribe
Makah Indian Tribe
Puyallup Tribe of Indians
Quinault Indian Business Committee
Tulalip Tribal Board of Directors
Umatilla Indians
Upper Skagit Indian Tribe
U.S. Department of Agriculture
     Forest Service
U.S. Department of the Army
     Corps of Engineers
U.S. Department of Commerce
     National Marine Fisheries Service

U.S. Department of the Interior
Bureau of Indian Affairs
Bureau of Land Management
Bureau of Reclamation
National Park Service
U.S. Department of Energy
Bonneville Power Administration
U.S. Environmental Protection Agency
U.S. State Department

COLLECTION OF WATER-RESOURCES QUANTITY AND QUALITY DATA

Hydrologic-data stations are maintained at selected locations throughout Washington and constitute a water-resources data network for obtaining records on stream discharge and stage, reservoir and lake stage and storage, ground-water levels, well and spring discharge, and the quality of surface and ground water (plate 1; table 1). Every year new stations are added to the network and other stations are terminated; thus, the U.S. Geological Survey has both a current and a historical file of hydrologic data. Most water-resources data are stored in the U.S. Geological Survey's WATSTORE (National Water Data Storage and Retrieval System) data base, and are available on request to water planners and others involved in making decisions affecting Washington's water resources. Most Washington water-resources data are stored in the Washington State Office's NWIS (National Water Information System) data base, and likewise are available to the public. These data can be retrieved in machine-readable form or in the form of computer-printed tables, statistical summaries, and digital plots. Local assistance in the acquisition of services or products from WATSTORE or NWIS can be obtained by contacting the Washington Office Chief in Tacoma, Washington.

Surface-Water Data

Surface-water discharge (streamflow), stage (water level), and surface-water-quality data are collected for general hydrologic purposes, such as assessment of water resources, areal analysis, determination of long-term trends, research and special studies, or for management and operational purposes. Data-collection platforms (DCP's), used for the transmission of satellite-telemetered river-stage information, have been installed at 107 sites throughout the State. Satellite-telemetry acquisition of the information is essential to many agencies for operating reservoirs, predicting river stage and flood conditions, and optimizing the availability and use of water resources. Data are received directly and in near real time from the U.S. Geological Survey ground-receive site located in Tacoma, Washington. After processing, the data are made available in near real time to other agencies.

Information from water-quality stations is used to monitor the quality of surface water in Washington. The frequency of sample collection can vary from continuous for selected constituents such as temperature, conductivity, and pH, to annual for data such as pesticide or radiochemical constituents. In addition to the water-quality data collected at recurring intervals, a variety of information is collected at miscellaneous sites as part of interpretive hydrologic studies. This information also is available from the U.S. Geological Survey files.

Periodic water-quality data (common ions, nutrients, and (or) trace metals) are obtained at 17 surface-water stations (see table 1). Eleven of these stations are part of a U.S. Geological Survey nationwide network known as NASQAN (National Stream Quality Accounting Network), and one is part of the nationwide Bench-Mark network that provides data used in the evaluation of trends in stream quality.

Table 1.--Water-resources data-collection stations in operation during fiscal year 1989, by station classification

Station classification	Number of stations
SURFACE WATER	
Streamflow:	
Discharge: Continuous record	191
Partial record	32
Stage only: Continuous record	6
Partial record	5
Real-time stage and discharge (data collection platforms)	107
Lakes and reservoirs:	
Stage and content	70
Water quality:	
Periodic chemical quality	17
Continuous or daily quality monitoring	17
Temperature	14
Specific conductance	5
pH	4
Suspended sediment:	
Daily or more often than weekly	6
Periodic	30
GROUND WATER	
Water level:	
Continuous	1
Long term	54
Short term	4
Water quality:	
Periodic chemical--monthly or more frequent	1
Periodic chemical--less than monthly	38
METEOROLOGICAL	
Precipitation	
Weekly quantity	20
Real-time quantity	9
Weekly quality	1

Water temperature is monitored continuously or daily at 14 sites, specific conductance at 5 sites, and pH at 4 sites. Automatic instruments measure the characteristic of interest continuously throughout each day, enabling the information to be summarized for the day as the daily maximum, minimum, and mean.

Suspended-sediment data are collected at 36 stations in Washington. Six stations are operated as daily stations, and of the 30 periodic stations, 17 are NASQAN stations. For the daily stations, concentrations of suspended sediment are determined for each daily sample, and particle size is determined in selected samples. For the periodic stations, both concentrations and particle size are determined for each sample collected.

Ground-Water Data

Data on ground-water levels, well and spring discharge, and ground-water quality are collected at a network of observation wells established throughout the State. The data are used to study the behavior of the major aquifer systems and to provide information used by water users and managers in making decisions about the management of their ground-water resources. Water levels were measured continuously at 1 well, on a long-term basis at 54 wells, and on a short-term basis at 4 wells. Periodic water-quality samples were taken monthly at 1 station and more frequently at 38 stations.

Meteorological Data

One station located in Washington is part of the nationwide NTN (National Trends Network) program to monitor long-term precipitation-quality changes. Composite samples are collected weekly by an observer who records precipitation quantities, measures pH and specific conductance of the composite sample, and submits the sample to the laboratory for chemical analysis.

Hourly quantity data are collected at four stations in relation to rainfall-runoff investigations in one county and at six sites in conjunction with the collection of flow data at stream-gaging stations.

INTERPRETIVE HYDROLOGIC INVESTIGATIONS

Forty interpretive hydrologic investigations were conducted during fiscal year 1989, in cooperation with 44 Federal, State and local agencies. Hydrologic investigations are being conducted that will provide information to answer hydrologic questions specific to the State's needs and scientific questions about hydrologic processes, as well as questions addressing statewide, multistate, and nationwide hydrologic problems. A summary of each investigation, including problem, objectives, approach, progress, and plans, follows.

PROJECT TITLE: Washington Water-Use Program

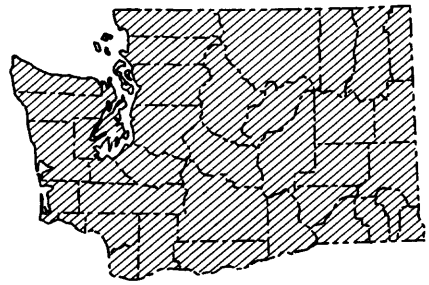
PROJECT NUMBER: WA-007

STUDY LOCATION: Statewide

COOPERATING AGENCY: State of Washington Department of Ecology

PROJECT CHIEF: Ronald C. Lane

PROJECT DURATION: Ongoing, beginning in 1978



PROBLEM: Water use in Washington has evolved in the past century from meager domestic and stockwater needs to the present complex requirements of large irrigation projects, municipalities, industrial plants, recreation, power generation facilities, waste dilution and transport, and aquatic habitat. Advances have been made in the ability to control, divert, and develop water, but accurate accounts have not been kept of the actual quantity of water used. With the ever-increasing competition for water (especially during periods of drought), accurate water-use information will be of considerable value in determining future water availability and making sound resource-management decisions.

OBJECTIVE: Beginning in fiscal year 1978, the State Department of Ecology, with assistance from the U.S. Geological Survey, began a water-use data-collection program appropriate for Washington. In succeeding years, the objective will be (1) to build the program to a level of data-collection and information that will accommodate the needs of all users in the State and Federal sectors; and (2) where possible, to relate withdrawals and diversions to specific sources--aquifer for ground-water supplies; specific stream reach or other location for surface-water supplies.

APPROACH: (1) Develop a local data-base system, based on and compatible with the National Water Use Data Base System (NEWSWUDS), that allows for storage, retrieval, and agregation of data by Water-Resource Inventory Area (WRIA), county, latitude-longitude, range-township, and (or) project identification number; and (2) develop and maintain an extensive data base for water-use information that will be accessible to all users at local, State, and Federal levels.

PROGRESS: An INFO-based version of NEWSWUDS, called New Info System (NIS), was developed to meet the requirements of approach 1. Data pertaining to statewide public-supply water use in 1988 were obtained from the Washington Department of Social and Health Services (DSHS) and entered into the INFO data base. Sites for about a third of the public water-supply systems have been reconciled with the USGS's National Water Information System. Work began to develop ARC-INFO coverages of the State to display the collected data on maps.

PLANS FOR FY 1990: The 1985 Washington water-use report and a water-use fact sheet will be completed and approved for publication. Reconciliation of the 1988 public-supply water-use data and the NWIS data base will be completed, and the NIS data system updated. The 1989 public-supply water-use data will be obtained from DSHS and processed. Assistance will be given to the USGS's water resources projects in collecting water-use data for their project areas. ARC-INFO capabilities will continue to be developed, and an ARC-INFO water-use data base will be developed, to replace the current INFO-based system.

PROJECT TITLE: Ground-Water Availability and Predicted Water-Level Declines Within the Basalt Aquifers of the Horse Heaven Hills, South-Central Washington

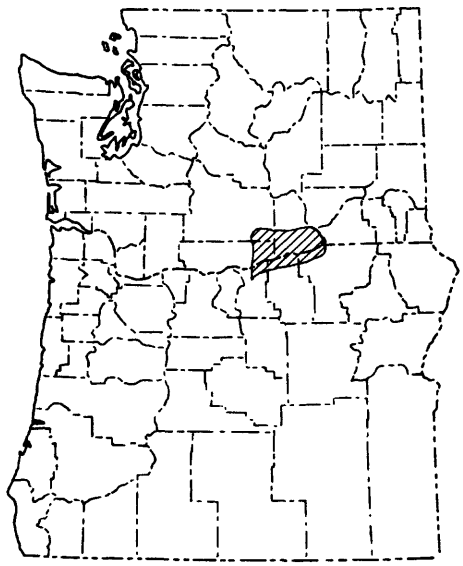
PROJECT NUMBER: WA-232

STUDY LOCATION: South-Central Washington

COOPERATING AGENCY: State of Washington Department of Ecology

PROJECT CHIEF: Frank A. Packard

PROJECT DURATION: Complete, except for report



PROBLEM: The Horse Heaven Hills area of south-central Washington contains about 10 percent of the potentially irrigable land of the State. Since 1970, surface water has been imported from the Columbia River to irrigate the southeastern parts of the area; a smaller quantity of irrigation water is also pumped from deep wells in the central part of the area. Recent deep-well drilling has been for the purpose of developing the remaining irrigable land. However, the State Department of Ecology is concerned about stresses being placed on these aquifers and the possibility that pumpage rates may exceed water availability now or in the near future.

OBJECTIVE: The purpose of this investigation is to determine the availability of ground water in the Horse Heaven Hills area and to develop a numerical model to simulate ground-water movement, for use as a management tool by the Department of Ecology.

APPROACH: Data collected during a 1977 study and data generated by subsequent development will be used to determine the extent to which the geohydrologic setting of the study area can be described. The study will be conducted in two phases. Phase I will include (1) definition of the ground-water-flow system from available and field-reconnaissance data; (2) construction of a preliminary numerical model to assist in determining the data-collection scheme; and (3) determination of the time and cost needed to collect the remaining information and construct a final model. Phase II will consist of collecting the data identified during phase I and refining and calibrating the numerical model.

PROGRESS: Report is being revised after technical review.

PLANS FOR FY 1990: Report will be published when approved.

PROJECT TITLE: Real-Time Hydrologic Data in the Pacific Northwest District and Alaska by Independent GOES Telemetry

PROJECT NUMBER: WA-241

STUDY LOCATION: Washington, Oregon, and Alaska

PROJECT CHIEF: Stewart A. Tomlinson

PROJECT DURATION: Ongoing, beginning in June 1980

PROBLEM: The use of GOES (Geostationary Orbiting Environmental Satellite) telemetry to relay remotely collected hydrologic data is now well established. The uses and demands for the data are increasing at a rapid rate, however. Cooperating agencies and WRD users want an accurate and reliable product they can use for a variety of purposes, including flood warning, control, and monitoring; power regulation; basic-records working; and special studies.

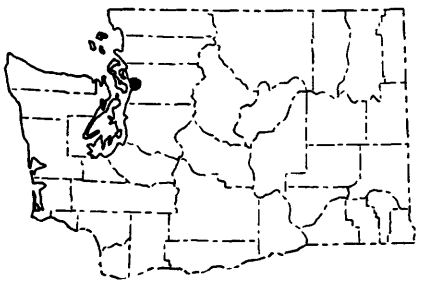
OBJECTIVE: (1) To maintain the Pacific Northwest District Independent GOES network and increase its reliability and efficiency; (2) to establish and encourage new uses of GOES data; and (3) to investigate the most economically effective way to manage and operate the Pacific Northwest District GOES System.

APPROACH: Two complete Direct Readout Ground Stations (DRGS) were installed in Tacoma, Washington, the first in FY 1982, the second in FY 1988, and both have been successfully operated and maintained. Two redundant dedicated computers for data compilation, storage, and cooperator relay on uninterruptable power systems (UPS's) are needed to increase system reliability. Hardware and software modifications will be made continually as current technology changes.

PROGRESS: A Data Collection Platform (DCP) network of telemetry stations for the Pacific Northwest District was established in the late 1970's and grew from 45 to about 200 stations from 1985 to 1989. The increased network growth is encouraged and is expected to continue through FY 1992. Cooperator-dedicated lines for receipt of DCP data were upgraded to 1200-band. U.S. Geological Survey-owned printers and modems were installed at dedicated cooperator sites for receipt of data to provide equipment standardization and to allow easy future system upgrades. ADAPS software, which includes satellite data processing, was installed. All DCP data software was moved to a PRIME 6350, which replaced the PRIME 9955 and PRIME 750. These system enhancements allow 96 to 98 percent of satellite data to be processed within 5 minutes of DCP transmission time, up from 60 to 70 percent in FY 1988. Twenty-two new DCP sites were added in FY 1989, bringing network size in the Pacific Northwest DRGS system to about 200. Conversion of cooperator data relay software to utilize ADAPS was begun.

PLANS FOR FY 1990: Finish conversion of cooperator data relay software to utilize ADAPS. Obtain an uninterruptable power supply for the PRIME 6350 to decrease down time during power outages or power inconsis-tencies. Add about 25 new DCP sites to the system in FY 1990.

PROJECT TITLE: Quantitative Evaluation of the Water Resources of the Tulalip Indian Reservation and Surrounding Areas, Snohomish County, Washington



PROJECT NUMBER: WA-244

STUDY LOCATION: Northwestern Washington

COOPERATING AGENCY: Tulalip Tribal Board of Directors

PROJECT CHIEF: William E. Lum II

PROJECT DURATION: Complete, except for report

PROBLEM: The population of the Tulalip Reservation doubled between 1960 and 1975, and growth has continued since 1975 with an additional influx of about 1,600 residents each summer. The well field established in 1975 is experiencing a water-level decline of about 1.5 feet per year, and has been estimated to have a remaining useful life of perhaps 15-20 years under present conditions. There is potential for industrial development, however, that would require additional water supply. Seawater intrusion has occurred in wells on the reservation, but is not yet a serious problem. Data from the ground-water phase of a 1975 study by the U.S. Geological Survey were not sufficient to answer these new questions because the study was limited to interpretation of data available from existing wells and two test holes drilled on the reservation.

OBJECTIVE: A comprehensive study is proposed to determine, in terms of areal distribution and quantity, the availability of ground water on the reservation from aquifers generally above sea level.

APPROACH: Quantification of the ground-water resources of the reservation requires mapping of aquifers in the unconsolidated deposits underlying the reservation, determining aquifer characteristics, and determining the hydraulic relations between the ground-water system and streams. The study may include modeling of ground-water flow in aquifers at or above sea level to quantify the available supply and ascertain the effects of future development.

PROGRESS: Report has been revised in response to technical review.

PLANS FOR FY 1990: Report will be submitted for Director's approval.

PROJECT TITLE: Sediment Transport--
Mount St. Helens

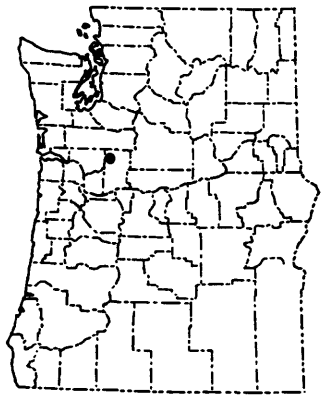
PROJECT NUMBER: WA-256

STUDY LOCATION: Western Washington, Oregon

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: John E. Costa

PROJECT DURATION: Ongoing, beginning in May 1981



PROBLEM: Extensive sediment deposition after the eruption of Mount St. Helens in 1980 drastically changed the sediment transport characteristics of the Toutle River system. As a result of the eruption and subsequent mudflow, the Toutle River has an annual sediment yield of 76,000 tons per square mile, which makes it the highest measured sediment-producing stream in the United States and possibly the world. Various sediment-modeling theories have been attempted or proposed to estimate future effects from the Toutle River basin on continual economic and ecological problems already created in the Cowlitz and Columbia Rivers. Testing the applicability of these models requires the monitoring of both suspended-sediment discharge and bedload.

OBJECTIVE: (1) To define the influence of suspended-sediment concentration on velocity distribution and sediment transport; (2) to define the influence of bedforms on velocity distribution, roughness, and sediment transport; (3) to study interaction between bedload and suspended load; and (4) to modify existing transport formulas to fit site-specific conditions.

APPROACH: Synoptic measurements in addition to sediment and discharge measurements at gaging stations will be made to define the sediment and hydraulic characteristics of the basin. As the detailed field data are collected, library and laboratory research on the mechanisms of erosion and sediment transport will be carried out. Transport formulas for both suspended sediment and bedload will be tested for application to conditions found in the Toutle River. Bedload formulas will be examined, accepted or rejected, and modified to fit the conditions found at each site. The results from each model will be compared with alluvial-channel data from other regions.

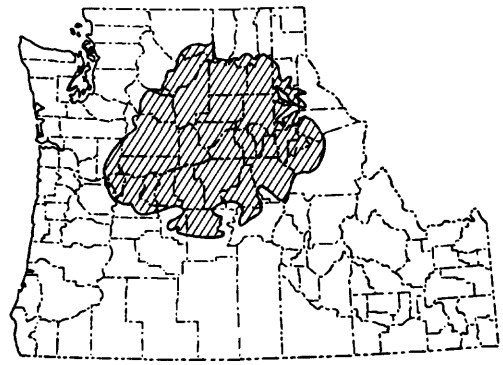
PROGRESS: Hydrologic data for computation of suspended-sediment discharge for the Toutle and North Fork Toutle Rivers near Mount St. Helens were compiled and published, and a comparison of different kinds of bedload samplers was completed. Final construction of a new walkway for the Kid Valley sediment research station was completed, and the basic form and characteristics of gravel bedforms at this site have been documented. Several different bedload equations have been tested against sampled bedload-transport field data. Cross sections downstream from the new U.S. Army Corps of Engineers sediment-retention structure on the North Fork Toutle River have been surveyed to monitor downstream channel and sediment changes in the river. A new instantaneous suspended-sediment sampling device has been developed, and field tests will begin shortly. Preliminary filming of a sediment-sampling video has begun.

PLANS FOR FY 1990: Reports on comparisons of the bedload samplers will be completed. Gravel-dune and bedform investigations will be expanded at Kid Valley, and several sediment and streamflow models will be tested using the Kid Valley data. Bedload data will be computed and compiled in a report. Investigations into the variance in suspended-sediment sampling will begin using the Kid Valley research station for rapid, intensive data collecting. Work will begin on a report comparing the experimental instantaneous suspended-sediment sampling equipment at Tower Road and Kid Valley with PS-69 and P-61 samplers.

PROJECT TITLE: Columbia Plateau Regional Aquifer-System Analysis

PROJECT NUMBER: WA-260

STUDY LOCATION: Southeastern and south-central Washington, northeastern Oregon, and northwestern Idaho



COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: John J. Vaccaro

PROJECT DURATION: Complete, except for reports

PROBLEM: The Regional Aquifer System Analysis (RASA) program of the U.S. Geological Survey began in FY78 to provide information, on a regional scale, on the major ground-water systems in the nation. This information includes the aquifer boundaries, description of the flow system, geohydrologic and hydraulic characteristics, and water quality. Flow models will be constructed to improve understanding of the ground-water-flow systems and to analyze the effects of stresses that have led to changes. The flow models also provide a means of assessing the effects of future development of the systems. The Columbia River Basalt Group (CRBG) in the Columbia Basin was selected as a RASA study that began in FY83.

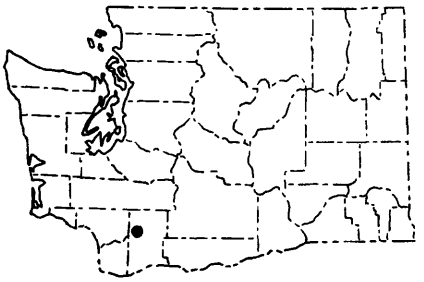
OBJECTIVE: To obtain a better understanding of the regional ground-water system of the CRBG aquifer by: (1) describing the geologic framework; (2) describing the geohydrologic characteristics of the system; (3) determining the water budget in the plateau; (4) determining water quality, flow paths, residence time, and water-rock interactions; (5) developing a data-base management and application system for water-use, water-quantity, and water-quality data; and (6) developing a regional flow model to improve understanding of the aquifer system, including the sensitivity of the hydraulic parameters, components of the water budget, geologic framework, and the hydrologic effects of proposed future development.

APPROACH: Data from drillers' logs, geophysical logs, and mass water-level measurements were stored in the Ground Water Site Inventory (GWSI) data base. They were used, along with pumpage data for crops, irrigated land, and pump efficiencies, in a recharge estimation model that calculates daily water budgets. A steady-state ground-water model for predevelopment and time-averaged 1983-85 conditions was conceptualized and calibrated. The model was operated to evaluate the effects of hypothetical ground-water development. In addition, water-quality characteristics of the major formations in the CRBG were described and a geochemical model was developed.

PROGRESS: Project is complete, except for a few reports. Twenty-two reports have been published.

PLANS FOR FY 1990: All remaining reports will be submitted for Director's approval and published when approved.

PROJECT TITLE: Volcanic Flood Hazards for Mount Rainier in Washington



PROJECT NUMBER: WA-264

STUDY LOCATION: Western Washington

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: Kevin Scott

PROJECT DURATION: Complete, except for report

PROBLEM: Mount Rainier is a dormant volcano. During Holocene times more than 55 lahars originated at Rainier. The 5,000-year-old Osceola mudflow, consisting of about 0.7 cubic mile of material, covered about 120 square miles. The 600-year-old Electron mudflow extended 30 miles down the Puyallup River valley. At present, similar or even smaller events could significantly affect Mount Rainier National Park, 19 towns, or any of the 5 dams and reservoirs, 3 power division canals, 3 Indian reservations, and many miles of highways now existing along major river systems. Even during quiescent periods, the potential for destructive and dangerous lahars, jökuhlhaups, and moraine-lake outburst floods is significant. Our ability to interpret various flow deposits, understand the hydrodynamics of different types of flows, and estimate possible magnitude of a disaster justify further evaluation of volcanic flood hazards and the extent of volcanic floods at and near Rainier.

OBJECTIVE: To examine the magnitude and potential effects of the various types of volcanic flood hazards at Mount Rainier and, for the foreseeable future, the probable extent and travel time of the most serious and most dangerous debris-flow events possible in each of the mountain's five major drainage basins.

APPROACH: Lahars and lahar runouts, sturzstroms, glacial outburst floods, and moraine-lake breakouts will be assessed. Consequential hazards from these events (such as valley damming and landslides from bank undercutting) will also be investigated. A thorough literature search will be conducted; a field reconnaissance of the entire mountain and surrounding valleys will identify post-hazard events and possible locations of future events. Hazard events will be categorized by type and basin, to decide which events are most serious and most dangerous and to determine additional field data needs, such as specific data on magnitudes for model calibration by surveying and mapping of the depth and extent of past flood events and downstream channel changes in rheology of the flows.

PROGRESS: The report has been submitted for Director's approval to publish. Field work continues to yield new data on lahar magnitude and frequency, which are incorporated in the report as radiocarbon and laboratory analyses are received. Some analyses are still in process, but all data should be received in time to be included in the final report draft.

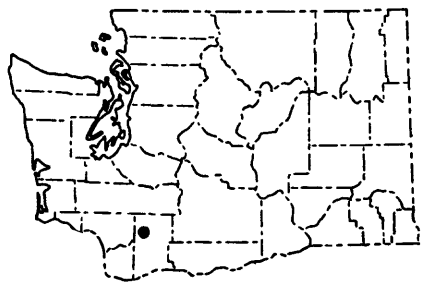
PLANS FOR FY 1990: The report will be published when approved.

PROJECT TITLE: Sedimentology of Lahars at Mount St. Helens

PROJECT NUMBER: WA-272

STUDY LOCATION: Southwestern Washington

COOPERATING AGENCY: None, U.S. Geological Survey funds only



PROJECT CHIEF: Kevin M. Scott

PROJECT DURATION: Ongoing, beginning in October 1981

PROBLEM: Mudflows and debris flows of volcanic origin (lahars) are recognized as major hazards to life and property. The river systems originating on Mount St. Helens--specifically, the Toutle River, Muddy River, Swift Creek, and Pine Creek--were affected by lahars after the eruption of May 18, 1980. The presence of recent and historical lahar deposits provides an opportunity for understanding the flow origin and processes and for developing criteria to define lahar deposits.

OBJECTIVE: Define the origins, sediment characteristics, and physical processes of lahar deposits. This research will help expand research conducted at other Cascade Range volcanoes and in other areas of volcanic activity worldwide. Results of this study will help in the development of techniques for hazard assessment and for control of volcanic debris.

APPROACH: Recent and historical lahar deposits will be studied. Analysis of grain composition may aid in dating older lahars, based on the presence or absence of certain rock types of known age. Measurement of grain size and analysis of grain spacing and orientation will be used to gain knowledge of transport mechanisms. Relations between texture, depth of flow, and thickness will be interpreted for an understanding of flow behavior.

PROGRESS: This project is the vehicle for a series of short-term sedimentology projects related to assessing lahar behavior and hyperconcentrated flow behavior that yield significant results for modest expenditures.

PLANS FOR FY 1990: The main activity of the project will be a joint report on volcanic and hydrologic hazards at Mount Rainier by the Water Resources Division and the Geologic Division of the U.S. Geological Survey. Other activities include continued work on the Three Sisters project in Oregon and possible international work in China (under protocol arrangement with the State Department), or a continuation of work in New Zealand in connection with the staff of Massey University at Palmerston North. Several journal papers are planned.

PROJECT TITLE: Mudflow/Debris Flow Rheology and Initiation

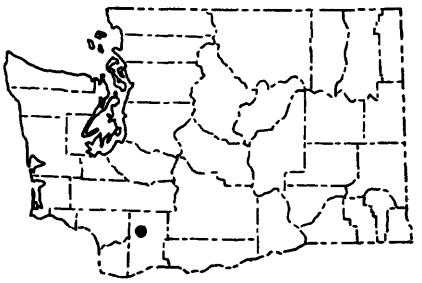
PROJECT NUMBER: WA-273

STUDY LOCATION: Topical research

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: Thomas C. Pierson

PROJECT DURATION: Ongoing, beginning in 1982



PROBLEM: Mudflows and debris flows are a significant and persistent worldwide volcanic/hydrologic hazard that can inflict catastrophic losses on societies. This was most recently demonstrated at Nevado del Ruiz volcano in Colombia, where more than 23,000 people were killed by such flows in 1985. Millions of people living on or near volcanoes capable of generating volcanic mudflows/debris flows are at risk. Other populations are at risk from such flows in steep, nonvolcanic terrain. A number of mathematical models (based primarily on theory and laboratory studies of fine-grained slurries) have been developed to predict flow behavior of mudflows/debris flows; in order to verify and calibrate such models (and to develop better models), data from real flows are needed. Only limited quantitative data are available on the flow dynamics, and no data exist on the rheological properties of full-scale mudflows/debris flows transporting coarse debris. Furthermore, triggering mechanisms of both volcanic and nonvolcanic mudflows/debris flows are poorly understood.

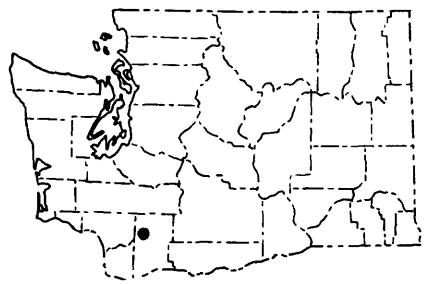
OBJECTIVE: (1) Document the kinematics and dynamics of actual debris flows and mudflows in the field; (2) measure rheological properties of mudflow/debris flow slurries in the field and in the laboratory; and (3) document and quantify the physical processes responsible for the mobilization of mudflows/debris flows.

APPROACH: The kinematic and dynamic properties of actual debris flows (mean velocity, velocity distribution, discharge, volume, shape and celerity of flood wave, hydraulic characteristics, and runout distance) will be determined by reconstruction of flow behavior from indirect measurements, eye-witness accounts, and stratigraphic studies, and direct measurement of moving flows. Flow characteristics will be related to material properties and channel variables. Rheologic parameters of coarse-grained mudflow/debris flow mixtures (viscosity, yield strength, development of excess pore pressures) will be measured in the laboratory using specially developed rotational viscometers. Appropriate rheologic models will be determined for these mixtures under different rates of shear and different water contents. Flow triggering and mobilization mechanisms will be deduced from geomorphic and stratigraphic studies in the field and from direct measurements of site variables at localities where flows have been or are expected to be triggered.

PROGRESS: Dynamic behavior and initiation mechanisms have been studied for volcanic debris flows at Mount St. Helens (events in 1980, 1982, and 1983) and at Nevado del Ruiz (1985), and for rainfall-induced nonvolcanic debris flows in Oahu, Hawaii. Direct measurements have been made or attempted on moving debris flows at Mount St. Helens (1981-1983), Wrightwood Canyon, California (1983), Rudd Canyon, Utah (1983-1984), and Mt. Sakurajima, Japan (1986-1987). Laboratory measurements of rheologic parameters have just begun. A detailed study of flow-initiation mechanisms (interaction of hot pyroclastic debris with snow and ice) was carried out at Nevado del Ruiz volcano (1985).

PLANS FOR FY 1990: Laboratory measurements on rheological properties of mudflow/debris flow slurries will continue.

PROJECT TITLE: Immediate and Long-Term Geomorphic Response to the 1980 Eruption of Mount St. Helens--The Toutle River Basin, Washington



PROJECT NUMBER: WA-274

STUDY LOCATION: Southwestern Washington

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: Richard J. Janda

PROJECT DURATION: October 1981 to September 1990

PROBLEM: The May 18, 1980, eruption of Mount St. Helens resulted in a massive avalanche that removed rock from the summit and northern flank, denuded forest land, and released lahars down all major streams draining the volcano. Hydrologic hazards resulting from this eruption still remain. Storm runoff and erodible sediment have greatly increased the threat of floods in downstream areas. Engineering and vegetative measures have been attempted to reduce potential flood threats, but the effectiveness of these measures depends on the rate of erosion of the avalanche deposit and the response of the stream channels to changed basin conditions. A study is needed in the Toutle River basin to expand our understanding of the geomorphic processes occurring in the basin.

OBJECTIVE: To develop sediment budgets for various parts of the Toutle River basin in order to identify the sediment-storage sites and transport processes that most influence sediment discharge. The project will attempt to identify which drainage basin and site conditions most control channel response. A secondary objective is to describe the changes in channel pattern, slope, and cross-sectional geometry that control hydraulics and aquatic habitat, where detailed measurements of erosion and channel changes will be made to obtain characteristic data for input to the digital model. Special measurement sites will be established on the Toutle avalanche deposits to compare prototype data with model outputs. After satisfactory calibration of the model, the individual and collective influences of major parameters on geomorphic processes will be varied.

APPROACH: Hillslope erosion data from the U.S. Forest Service and university groups will be compiled for the development of sediment budgets. Changes in channel geometry and sediment storage will be determined through repeated surveys of monumented channel cross sections, study of time-sequential aerial photographs, and comparison of photogrammetrically produced topographic maps. Greatest emphasis will be placed on the North Fork Toutle debris avalanche. Because of the unique character of the sediment deposits, the project will include considerable research on geomorphic processes, including those influencing preferential erosion, and development of a digital model of the geomorphic processes influencing sediment movement. An attempt will be made to identify the relative significance of the more important geomorphic factors.

PROGRESS: Emphasis this year was on archiving, reducing, and disseminating data collected between 1980 and 1986. Documentation of field locations, data files, and data analysis programs is now sufficient to allow access to any interested party. Thirty-five indicator cross sections were resurveyed; no aerial photography was obtained. Two Survey publications and one abstract were approved for publication. Invited lectures were presented at the Kagoshima International Conference on Volcanoes, the 20th Annual Meeting of the Japanese Erosion Control Engineering Society, and the Japanese Ministry of Construction's Public Works Research Institute. Rates of geomorphic change and sediment yield in the Toutle River basin remained high during the 1987 and 1988 water years, even though the basin was not disturbed by any major storms or volcanic activity. Potentially unstable lake blockages remain intact. An erratic trend toward reduced sediment yield and increased channel stability continued. Current sediment yields, however, are as much as 10 times greater than during the 1985 water year. Accruing data do not provide a conspicuous explanation for this seemingly erratic recovery from the 1980 eruption of Mount St. Helens.

PLANS FOR FY 1990: Formal reports on recent erosion of potentially unstable lake blockages, the response of Toutle River to increased sediment discharge, and a synthesis of landscape and ecosystem recovery from the 1980 eruption will be completed. The effect of any extreme flood or renewed volcanic activity on channel geometry of the Toutle River and its major tributaries will be documented.

PROJECT TITLE: Water Resources of the Lower Puyallup River Basin

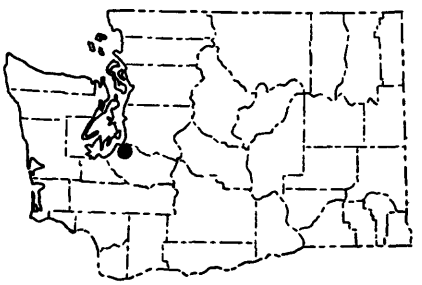
PROJECT NUMBER: WA-279

STUDY LOCATION: Western Washington

COOPERATING AGENCY: Puyallup Tribe of Indians

PROJECT CHIEF: Ronald C. Lane

PROJECT DURATION: Complete, except for report



PROBLEM: A comprehensive study of the water resources of the Puyallup Indian Nation requires an understanding of the Puyallup River system. The depth to bedrock in this area is unknown. The uppermost gravels are not an important source of water; the largest source of water may be the sequence of alternating fine- and coarse-grained materials underlying the marine deposits. Although preliminary evaluations of these aquifers have been made, water availability has not been determined quantitatively, and the water-quality characteristics of these aquifers have not been defined comprehensively, with emphasis on existing or potential problems.

OBJECTIVE: Determine the discharge characteristics of the Puyallup River and its tributaries within the boundary of the Puyallup Indian Reservation, and determine the significant factors that affect the discharge characteristics and quality. Within the Reservation boundaries, define the availability and quality of ground water in the Puyallup River valley, define the relation between the Puyallup River and the ground-water system, and, to the extent that available data allow, evaluate the short-term yields of aquifers in areas adjacent to the valley.

APPROACH: Using historical data, daily means for low and high flows and frequency of peak flows will be determined for the Puyallup River within the reservation. Discharge measurements and water-quality samples will be obtained at the locations of known waste-water input. The salinity distribution in the Puyallup River estuary will be determined at high and low tides for medium and low flows. Wells in the Puyallup River valley will be inventoried. Existing well data will be evaluated to define stratigraphy, head distribution, and ground-water quality. Recharge rates in the glacial till of adjacent uplands will be determined using centrifugation of cores and on-site neutron probe techniques. A model will be developed to simulate ground-water movement in the river valley and along the freshwater-saltwater interface.

PROGRESS: Work has continued on documentation of the ground-water model.

PLANS FOR FY 1990: The report will be submitted for approval and published when approved.

PROJECT TITLE: Ground-Water Pumpage in the Columbia Plateau

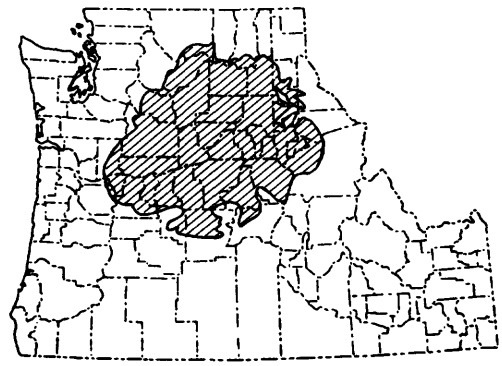
PROJECT NUMBER: WA-281

STUDY LOCATION: East-central and south-central Washington

COOPERATING AGENCY: State of Washington Department of Ecology

PROJECT CHIEF: Denzel R. Cline

PROJECT DURATION: Complete, except for report



PROBLEM: The Columbia Plateau, a major agricultural area of eastern Washington, is underlain by extensive basalt deposits. The ground-water system of these basalts is not well understood. Studies conducted during the 1960's have shown localized areas of severe ground-water decline. Further study is needed to gain an understanding of the distribution and rate of pumping, particularly in the Greater Odessa area of the Plateau.

OBJECTIVE: Define the distribution and rate of ground-water pumpage in the Columbia Plateau in Washington.

APPROACH: All large irrigation wells will be located and the efficiencies of selected wells will be measured. Pumpage data will be compiled for selected years from 1945 to 1984. Power records will be compiled for pumpage calculations in the core area. Satellite images will be used, along with crop-type information, to determine irrigated areas and pumpage. Metering data, reports, and other sources of data will also be used to compile pumpage information.

PROGRESS: The historical-pumpage report was revised in response to colleague review. The approved report on 1984 pumpage is being prepared for publication.

PLANS FOR FY 1990: Revised historical-pumpage report will be approved for publication; the report on 1984 pumpage report will be published.

PROJECT TITLE: Basalt Waste-Isolation Coordination

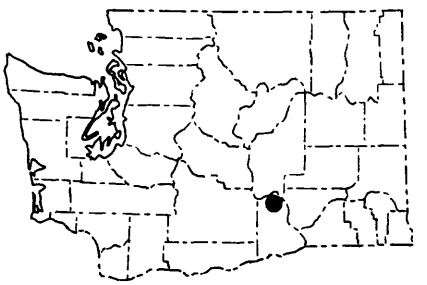
PROJECT NUMBER: WA-282

STUDY LOCATION: East-central and south-central Washington

COOPERATING AGENCY: Department of Energy

PROJECT CHIEF: William E. Lum II

PROJECT DURATION: Complete



PROBLEM: The interpretation of the ground-water-flow system in the Site Characterization Report being prepared by Department of Energy (DOE) contractors for evaluating the feasibility of burying high-level nuclear waste at the Hanford Reservation varies significantly from that of both the Battelle Pacific Northwest Laboratory and the U.S. Geological Survey. The Nuclear Regulatory Commission (NRC) believes that the hydrologic investigative work conducted by DOE's contractors needs more interaction with Battelle.

OBJECTIVE: To determine the differences between the contractors, Battelle Pacific NW Laboratory, and the Geological Survey concerning the conceptualization and modeling of the ground-water-flow system of the Columbia Plateau and the Pasco basin; and to attempt to resolve those differences.

APPROACH: The Survey will participate with the other concerned parties in a task force (the Interagency Hydrology Working Group, IHWG), whose purpose is to resolve differences in the conceptualization and definition of the ground-water-flow system of the Pasco basin, and will carry out computer and laboratory analyses and related studies as necessary for a complete analysis of the problem areas.

PROGRESS: On December 22, 1987, a revision to the National Waste Policy Act of 1982 was signed into law, mandating that all work on the Basalt Waste Isolation Project at the Hanford Reservation be terminated. The IHWG was one of those activities to be cut off. The Interagency Agreement that provided funding to the IHWG was revised to reflect an orderly shutdown of activities. Major accomplishments include permanent archiving of all computer programs and data sets associated with the ground-water-flow modeling activities in the IHWG and publication of a report to release all basic data collected for this project.

PROJECT TITLE: Sediment-Transport Model Development and Preliminary Application to the Columbia River

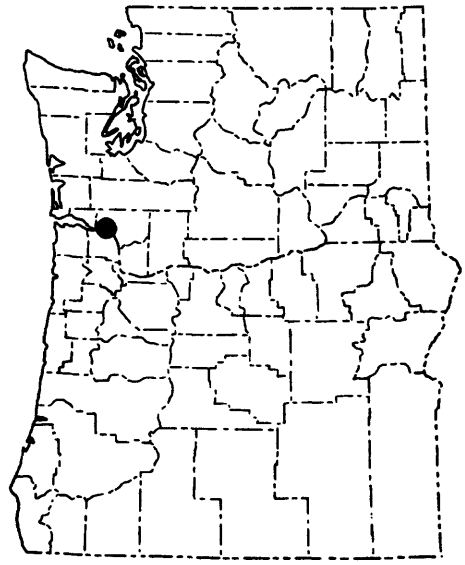
PROJECT NUMBER: WA-289

STUDY LOCATION: Southwestern Washington and northwestern Oregon

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: William G. Sikonia

PROJECT DURATION: Complete



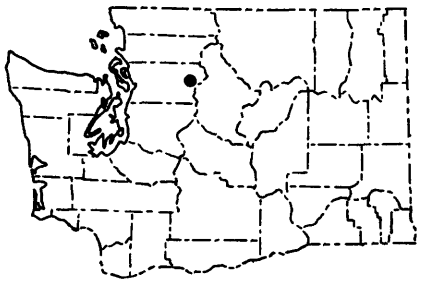
PROBLEM: The Pacific Northwest District needs the ability to model sediment transport, especially in view of the large-scale transport that is taking place from the slopes of Mount St. Helens. The state of the art in sediment transport modeling, however, is such that results are reliable only within an order of magnitude. The desired sediment transport model requires a good water-routing model; the routing of nonsteady-state flood phenomena; and the ability to handle complex geometries with constructions, expansions, tributaries, and distributaries.

OBJECTIVE: To develop a sediment transport model or set of compatible models that allow more comprehensive and accurate modeling than is now possible with existing models.

APPROACH: Existing models will be reviewed and their capabilities and limitations assessed by applying a select few to the lower Columbia River with input of a Cowlitz River mudflow. Desirable features from them will be used in constructing a more refined model suitable for District applications. We will use a finite-element setting and construct a two-dimensional model to provide detailed results, augmented by a one-dimensional channel model to provide more approximate results faster. The models will then be configured and calibrated to simulate conditions measured in the Toutle River and observed in recent mudflows and floods on the Toutle and Cowlitz Rivers. Results of this investigation will be documented in a published report.

PROGRESS: A report that describes the new mass-conserving method of characteristics for streamflow modeling has been published.

PROJECT TITLE: Background Water Quantity and Quality of the Goat Lake Watershed, Snohomish County, Washington



PROJECT NUMBER: WA-290

STUDY LOCATION: Western Washington

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: Norman P. Dion

PROJECT DURATION: Ongoing, beginning in October 1982

PROBLEM: In 1982, the Goat Lake watershed was selected by the U.S. Geological Survey as an "experimental watershed" to function as the focus for long-term studies on the effects of acidic precipitation on water resources. The reasons for selecting Goat Lake were: (1) the lake contains dilute water and is highly sensitive to acidic inputs from atmospheric deposition and streamflow; (2) during the rainy (winter) season, the lake is downwind of the Tacoma-Seattle-Everett industrial and urban area that emits sulfurous and nitrous oxides that combine with atmospheric moisture to produce acidic precipitation; (3) the lake is situated at high altitude and receives more than 150 inches of precipitation per year; (4) the lake is in a wilderness area, where land-use changes are unlikely; (5) the lake is relatively inaccessible and is unlikely to be affected substantially by man; and (6) the lake is typical of numerous lakes in the Cascade Range.

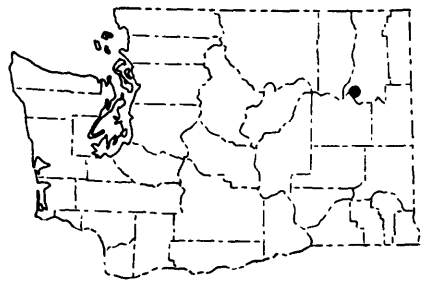
OBJECTIVE: The objective of the ongoing data-collection project at Goat Lake is to collect sufficient discharge and water-quality data at the inflow and outflow to enable a general assessment of the water-quality characteristics of the streams, especially with respect to those constituents that are sensitive to, or indicative of, acidic precipitation.

APPROACH: Samples from the outflow and principal inflow will be collected monthly. Specific conductance and pH will be measured in the field. The samples will be processed and prepared for analysis for calcium, magnesium, sodium, potassium, chloride, sulfate, nitrate, phosphate, fluoride, alkalinity, pH, specific conductance, iron, manganese, and aluminum. Samples for the determination of iron, manganese, and aluminum will be filtered through a 0.10-micron filter and acidified with ultra-pure nitric acid. A nonrecording gage that monitors precipitation quantity will be maintained just downstream of the lake outlet.

PROGRESS: The lake inlet and outlet were visited and sampled 2 and 12 times, respectively. The discharge of the lake outlet was monitored continuously. A report describing U.S. Geological Survey activities at Goat Lake and summarizing the discharge and water-quality data collected during the first 5 years of the study was approved for publication.

PLANS FOR FY 1990: Data collection will continue, including continuous monitoring of the lake outlet quantity, monthly sampling of the lake outflow, and periodic gaging and sampling of the principal lake inlet. Plans are being made to install a precipitation monitoring station and wet/dry precipitation collector near Monte Cristo, about 2 miles southeast of Goat Lake but at essentially the same altitude.

PROJECT TITLE: Investigation of Hydrologic Conditions at the Midnite Mine and Vicinity, Stevens County, Washington



PROJECT NUMBER: WA-296

STUDY LOCATION: Northeastern Washington

COOPERATING AGENCY: U.S. Bureau of Indian Affairs
U. S. Bureau of Land Management

PROJECT CHIEF: Steven S. Sumioka

PROJECT DURATION: Complete

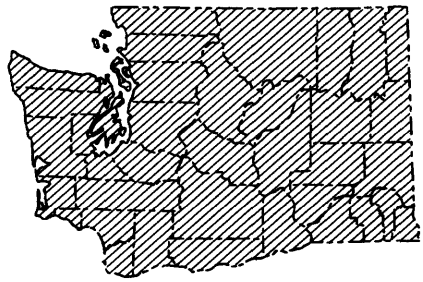
PROBLEM: Midnite Mine is an open-pit uranium mine near Spokane. Mining activity ceased in early 1982. Since that time, water has accumulated in the ore pits and now threatens to overflow from pit 4, near the north end of the mine. The quality of the water in the pit is unknown, and it is uncertain whether and when the pit will overflow. In 1980, water in seeps issuing from the bases of waste piles near the down-gradient end of the mine contained radium, uranium, and ammonia in potentially harmful concentrations, and had a low-pH. All water from Midnite Mine discharges to Blue Creek, tributary of Franklin D. Roosevelt Lake, and the Bureau of Indian Affairs and the Bureau of Land Management are concerned about the hazards posed by the mine drainage.

OBJECTIVE: Determine a monthly and annual water budget for the study area. Determine the pH of precipitation falling on the mine during the study period. Describe the quality of ground water draining from the alluvium in the study area into Blue Creek. Describe the quality at selected times of surface water in major pits and ponds, drainage into Blue Creek, and Blue Creek. Determine mean daily values of discharge and water temperature, specific conductance, and pH. Design a water-quality monitoring program that will allow the determination of the annual loads of selected chemical constituents discharged from the mine into Blue Creek. Assess the tracing agents and procedures best suited to examine ground-water flow paths in the lower part of the mine.

APPROACH: Monthly and annual water budgets will be calculated on the basis of precipitation, evaporation, surface-water outflow, and ground-water outflow. The pH of precipitation will be monitored by collecting precipitation in a wet/dry sampler and measuring pH of the composite sample weekly. The quality of ground water draining from the alluvium will be determined by collecting a monthly sample from a well at or near site 32 and analyzing it for water temperature, pH, specific conductance, and a suite of 38 water-chemistry constituents. The quality of surface-water bodies in the study area will be determined by sampling the major pits and ponds within the mine twice yearly and selected streams once per month. Continuous water-quality monitors will be used to measure and record water temperature, pH, and specific conductance at selected stream sites.

PLANS FOR FY 1990: Approved report will be published.

PROJECT TITLE: Hazardous-Waste Assessment in the State of Washington



PROJECT NUMBER: WA-297

STUDY LOCATION: Washington statewide

COOPERATING AGENCY: State of Washington
Department of Ecology

PROJECT CHIEF: Edmund A. Prych

PROJECT DURATION: Ongoing, beginning in October 1983

PROBLEM: The impact of hazardous-waste disposal is one of the most significant problems that affect our water resources. Public Law 94-580 provides that the Federal government promote the protection of health and environment through technical assistance to State agencies in the development of solid- and hazardous-waste management laws. Ten waste-disposal sites identified under the "Superfund Program" are located in Washington and 12 more have been recommended for inclusion in this program. In addition, nearly 200 other sites have been identified where less severe hazardous-waste problems exist. Leachate from almost all of these sites affects ground or surface waters. The State of Washington is now developing a major program to deal with this problem.

OBJECTIVE: To carry out a four-phase cooperative program to determine the present and future effects of hazardous waste on the water resources of Washington; to improve knowledge of the processes and technology that will have applications in the study area and other areas; and to develop a framework for hazardous-waste assessments that will provide a more consistent approach to the analysis of geohydrologic aspects. The four phases of the program are (1) characterization of hazardous-waste disposal sites, (2) research on processes, (3) characterization of areas for hazardous-waste disposal, and (4) technical support.

APPROACH: Where site characterization is undertaken, a wide array of analytic tools will be used, including (1) ground-water-system definition and modeling; (2) electric resistivity and other geophysical surveys; (3) use of U.S. Geological Survey auger to obtain drill and (or) core samples; and (4) determination of ground-water-flow direction from water-level data. Research proposals will be developed from each study undertaken in the first phase. Characterization of areas will involve assessment of such factors as soil thickness and permeability; lithology; type, age, and permeability of indurated rock; depth to zone of saturation; rainfall and natural recharge; and physiographic measurements.

PROGRESS: During the past year, work was done on six subprojects: (1) a review of an assessment of a proposed hazardous-waste burial site; (2) a review of published reports on the geohydrology and movement of leachate beneath a solid-waste landfill; (3) resampling of ground water in an area where organic chemicals are present, to resolve apparent discrepancies in previously collected data; (4) a statistical analysis of previously collected data on the concentrations of naturally occurring metals in soils; (5) sampling of ground water in the area of a gasoline and diesel oil spill

that occurred from 1979 to 1982. The data collected during this sampling are being published and compared with data collected during a project that was terminated in 1987; (6) defining the geohydrology of the South Tacoma Channel, which is the location of three hazardous-waste sites, several major municipal wells, and a proposed ground-water recharge project. A large solid-waste landfill is adjacent to the area.

PLANS FOR FY 1990: A survey will be conducted to determine concentrations of naturally occurring metals in soils over about 10 percent of the State. Work will also continue on defining the geohydrology of the South Tacoma Channel.

PROJECT TITLE: Puyallup River Flood-Capacity Study

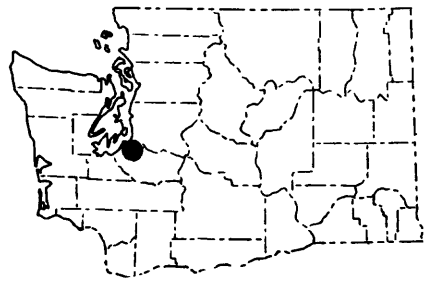
PROJECT NUMBER: WA-301

STUDY LOCATION: Western Washington

COOPERATING AGENCY: Pierce County Public Works Department and State of Washington Department of Ecology

PROJECT CHIEF: William G. Sikonia

PROJECT DURATION: Complete



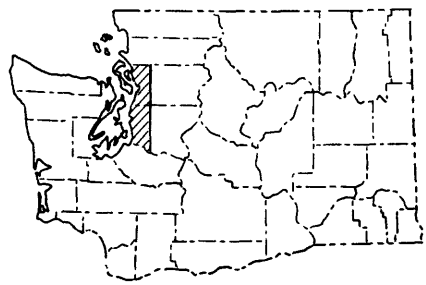
PROBLEM: Approximately 20 miles of the Puyallup River, 10 miles of the tributary White River, and 5 miles of the tributary Carbon River have been channelized and leveed for flood protection. Pierce County is responsible for maintaining the flood capacity of those channels, but the Puyallup Indian Tribe has obtained an injunction against the removal of vegetation from the channels and banks, to preserve fish habitat. It now appears that vegetation and accumulated sediment have increased to such an extent that channel maintenance may be necessary to reduce the risk that a major flood might top the levees, but the injunction effectively prohibits Pierce County from fulfilling its responsibilities. The major uncertainties are the exact flood capacities and whether the application of certain remedies for flooding would be detrimental to fish production.

OBJECTIVE: The U.S. Geological Survey will participate in studies to address these uncertainties, and to determine for the lower Puyallup, White, and Carbon Rivers (1) channel flood capacity and whether it is changing; (2) the effect of bank vegetation and sediment deposition on channel flood capacity; and (3) the effect on fish habitat of altering bank vegetation or streambed elevation and composition.

APPROACH: Determine present channel capacities by using step-backwater model to compute water-surface elevations corresponding to flood-peak discharges. Determine capacities for the channel in 1977 using the same methodology and cross-section data obtained then. Volume of sediment deposited or removed since 1977 will be calculated by using a subroutine of the step-backwater model that computes subsurface material volume. The effects of vegetation changes, sediment traps, and other mitigative measures on flood capacities and sediment transport will be evaluated with the step-backwater model with the Hydrologic Engineering Center-6 (HEC-6) model. Preferred fish habitat will be determined by using the Instream Flow Incremental Method (IFIM) and altered to reflect the effects of alternative mitigative measures.

PROGRESS: Report has been published.

PROJECT TITLE: Rainfall-Runoff Models for Small Basins in Metropolitan Areas of Western Washington



PROJECT NUMBER: WA-303

STUDY LOCATION: Northwestern Washington

COOPERATING AGENCY: King County, Snohomish County, Municipality of Metropolitan Seattle

PROJECT CHIEF: Richard S. Dinicola

PROJECT DURATION: Complete

PROBLEM: Most new population growth in King and Snohomish Counties is occurring in the mid- and upstream parts of small drainage basins. Land-use changes in upland areas and encroachment of development on natural marshes and wetlands have caused more frequent and costly flooding in the small basins. These changes also are having a negative effect on the anadromous fish resources, and accelerated bank erosion and the increase in fine-sediment load are reducing the quantity of good spawning habitat. There is a rapidly growing need to mitigate the effects of urbanization and runoff in these small, unincorporated basins.

OBJECTIVE: The purpose of this study was to characterize and simulate rainfall-runoff relations in five headwater drainage basins in western King and Snohomish Counties.

APPROACH: The characteristics of rainfall-runoff were hypothesized for the study area as a whole, using existing information. In undisturbed areas, Horton overland flow--runoff generated from rain falling at a greater rate than the infiltration rate of the soil--is not a significant mechanism. Shallow-subsurface flow from hillslopes mantled with glacial till, groundwater flow from glacial outwash deposits, and saturation overland flow from depressions, stream bottoms, and till-capped hilltops are the significant runoff mechanisms. In disturbed, primarily urbanized areas, Horton overland flow is a significant mechanism, along with overland flow from impervious surfaces.

PROGRESS: These hypothesized characteristics were incorporated into the Hydrologic Simulation Program-FORTRAN (HSPF) simulation model, and the model was calibrated concurrently at 21 stream-gage sites in the study area. Hydrologic data from the 1985-86 water years were used in this effort. The calibration resulted in 12 sets of generalized HSPF parameters, one set for each land-segment type with a unique hydrologic response. The generalized parameters can be used with HSPF to simulate runoff from most headwater basins within the study area.

The average standard errors of estimate for calibrated streamflow simulation at all 21 sites were 7.9 percent for annual runoff, 11.2 percent for winter runoff, 13.1 percent for spring runoff, 40.1 percent for summer runoff, 21.7 percent for storm peak discharge, 21.4 percent for storm runoff volume, and 42.3 percent for all daily mean discharges. High flows were simulated more accurately than were low flows.

The simulation errors were not large enough to reject the hypothesized rainfall-runoff relations. The simulation model will be validated at 12 additional stream-gage sites in a different set of drainage basins in the same physiographic region.

A report describing the model calibration effort was published. Model input for basins to be used for the model verification was prepared, and the 1987 streamflow, rainfall, and potential evaporation data were readied for use.

PLANS FOR FY 1990: The model will be verified using 1987-88 data, and the final project report will be written.

PROJECT TITLE: Crop Water Remote Sensing

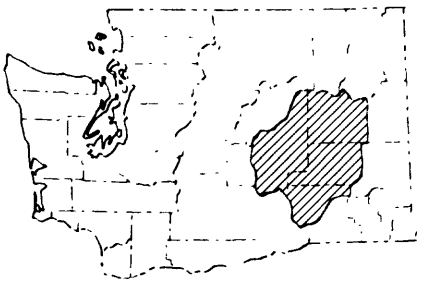
PROJECT NUMBER: WA-305

STUDY LOCATION: Southeastern Washington

COOPERATING AGENCY: State of Washington
Department of Ecology

PROJECT CHIEF: Peter C. Van Metre

PROJECT DURATION: Complete



PROBLEM: Estimates of ground-water use for crop irrigation on several thousand square miles of the Columbia River plateau in eastern Washington are not sufficiently accurate to meet present needs. Pumpage data for the State and for the Regional Aquifer-System Analysis study are being calculated from public utility district power records, with average pumpage efficiencies extrapolated from a scattering of measured efficiencies, and with total heads extrapolated from control in a scattered number of wells. Extrapolation of total head or of pump efficiency from one area to another introduces significant error into the pumpage calculation because of large local variations in specific capabilities of wells completed in basalt, in pumping lifts, and in pump system design and condition. A need exists to develop other methods that can be used to calculate pumpage with better overall accuracy and cost effectiveness. In addition, a more efficient method is needed for obtaining yearly totals and locations of acreage irrigated by ground water.

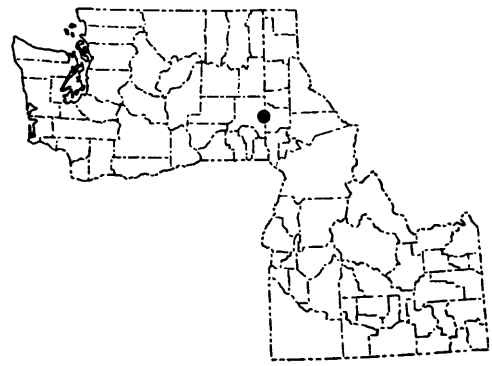
OBJECTIVE: Using available software, crop-identification ground truth, and Landsat imagery, crop types will be identified for the major ground-water-irrigated areas on the Columbia Plateau, including Lincoln, Grant, Adams, and Walla Walla Counties and the Horse Heaven Hills area. Using these results and a soil water budget, ground-water pumpage will be calculated and the calculated data will be compared with measured pumpage at selected sites.

APPROACH: There are two separate aspects to the study. The first is to identify crop type using Landsat-5 multispectral scanner scenes that cover the ground-water-irrigated areas of the Columbia Plateau. Crops will be identified in the field for the 1983 or 1984 growing season as ground truth for crop identification. The second aspect of the study is to calculate water use based on crop type using RASA software for estimating soil water budgets, and to compare this with measured pumpage at selected sites in the plateau. Data collection will be limited to five crop types: wheat, corn, alfalfa/hay, potatoes, and pasture. Three main independent variables--crop type, climate type, and soil type--will be varied to determine how they affect pumpage.

PROGRESS: Report has been approved.

PLANS FOR FY 1990: Approved report will be published.

PROJECT TITLE: Computer Simulation of Ground-Water Flow in the Pullman-Moscow Basin, Washington and Idaho



PROJECT NUMBER: WA-309

STUDY LOCATION: Southeastern Washington and northwestern Idaho

COOPERATING AGENCY: University of Idaho, Washington State University, and Cities of Moscow, Idaho, and Pullman, Washington

PROJECT CHIEF: William E. Lum II

PROJECT DURATION: Complete

PROBLEM: Virtually all water used in the Pullman-Moscow basin is derived from ground water contained within the basalts underlying the area. Four major users--the towns of Pullman, Washington, and Moscow, Idaho, Washington State University, and the University of Idaho-- use about 99 percent of the total water withdrawn from the basalts. Ground-water levels began to decline after pumping began. This decline not only has continued, but in recent years has accelerated. Surface water is not presently an alternative water source; as a result, the Pullman-Moscow area has been the subject of numerous ground-water investigations by the U.S. Geological Survey, in cooperation with the four major users.

OBJECTIVE: To quantify the ground-water system of the Pullman-Moscow basin in sufficient detail that the effect of existing and future stresses on it can be predicted.

APPROACH: The overall approach will be to refine the existing ground-water-flow model of the basin by: (1) using results of the Geological Survey's sodium study and the Regional Aquifer-System Analysis project to better quantify the geology and hydraulic properties of modeled units; (2) collecting additional field data, including ground-water levels and information on the interconnection between streams in the area and the ground-water system, to permit additional calibration and verification of the model; and (3) re-defining the model boundaries on the basis of field data, including observed water-level declines and seepage runs. The investigation will be conducted by the University of Idaho and the Survey.

PROGRESS: Report has been approved and published.

PROJECT TITLE: Effects of the Release from Spirit Lake on South Fork Coldwater Valley

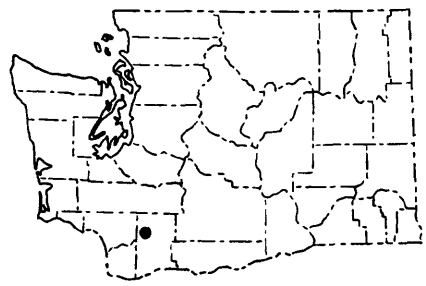
PROJECT NUMBER: WA-310

STUDY LOCATION: Southwestern Washington

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: David F. Meyer

PROJECT DURATION: Complete, except for report



PROBLEM: On April 27, 1985, the U. S. Army Corps of Engineers (COE) began to release water from Spirit Lake into South Fork Coldwater Creek through a tunnel constructed to control Spirit Lake levels and minimize the possibility of catastrophic breaching of the blockage. Release of Spirit Lake effluent will approximately double the discharge of South Fork Coldwater Creek. It is hypothesized that this will quadruple the erosive capacity of the channel and that increased sediment loads of the channel may have drastic effects downstream. Water discharge will be controlled by COE, and the tunnel effluent will be practically sediment free. Thus, this offers a unique opportunity to collect sediment transport data in a controlled environment. Proposed data collection and analysis will be useful in predicting the response of high-gradient streams to augmentation.

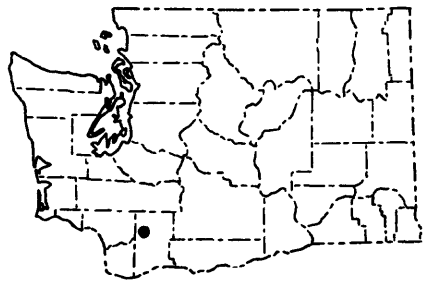
OBJECTIVE: (1) To make a detailed sediment budget of the erosion induced by the release from Spirit Lake into South Fork Coldwater Creek. This budget will relate rates of erosion to channel geometry (including but not restricted to slope, width, and depth), sediment transport, and bank mechanics. (2) To test existing and proposed models of channel development and sediment transport. (3) To assess the effects of the release from Spirit Lake into South Fork Coldwater Creek on the long-term stability of the Coldwater Lake blockage. (4) To document rates and types of sediment entrainment and selective transport and sorting that accompany the predicted erosion.

APPROACH: Discharge measurements (probably using salt- or dye-dilution techniques), sediment measurements (suspended and bedload), and both terrestrial and aerial photographic surveillance will be made. Through cooperation with the U.S. Forest Service, COE, and the contractor operating release of the lake, flows will be varied between 200 and 500 cubic feet per second, on a schedule yet to be determined. Water release will be interrupted periodically for 1 day. During that time, intensive field work will be undertaken involving at least two field parties of three who will survey nine cross sections grouped into three clusters, survey the longitudinal profile of the channel within the clusters, survey a grid of elevations on the lower South Fork Coldwater fan and delta in Coldwater Lake, and collect bathymetric data in front of the Coldwater delta.

PROGRESS: The report has been submitted for approval to publish.

PLANS FOR FY 1990: The report will be published when approved.

PROJECT TITLE: Mass-Movement Dynamics: Interaction With Ground Water and Streams



PROJECT NUMBER: WA-311

STUDY LOCATION: Southwestern Washington and northern California

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: Richard M. Iverson

PROJECT DURATION: October 1984 to September 1990

PROBLEM: Debris flows are a worldwide geologic and hydrologic hazard of sometimes catastrophic proportions, yet understanding of their basic physics remains incomplete. Most begin as hillside landslides, but little is known of how these mobilize into flows. This hazard could be mitigated, in part, if debris-flow-mobilization processes were better understood. Our success to date in gaining this understanding has been good but incomplete. Laboratory experiments have been successful, but limited in real-world applicability by the small size of laboratory apparatus. Field experiments can be done on a scale sufficiently large to simulate real-world phenomena, but are hindered by lack of rigorous experimental control, which is inherent in all field experiments.

OBJECTIVE: Collect and analyze data on debris-flow-mobilization processes. Develop a physically based mathematical theory that is consistent with the data.

APPROACH: Collect data on high-frequency pore-pressure fluctuations that occur as debris flows mobilize from landslides. Analyze the data using Fourier techniques and compare data with predictions of a physically based mathematical theory.

PROGRESS: As visiting scientists at the National Research Center for Disaster Prevention in Tsukuba, Japan, Richard Iverson and Richard LaHusen conducted a successful series of large-scale experiments on debris-flow initiation and pore-pressure fluctuations in shearing soil. Iverson was one of a team of specialists assisting the Survey's Hawaii District in investigations of the New Year's Eve debris flow and flood disaster in southeastern Oahu. The team identified the causes of debris flows and flooding and proposed future work aimed at hazard evaluation and mitigation.

PLANS FOR FY 1990: Work will continue on the role of dynamic pore-pressure fluctuations in landslides and debris flows. Significant progress is being made in the theoretical component of this work, so that the results of experiments can be predicted using rigorous, physically based theory. A new project emphasis will be on computational studies of the effect of ground-water-flow fields on topographically induced elastic stress fields in slopes. This work should provide new, fundamental understanding of how ground-water flow can lead to large-scale instability in mountain massifs and volcanic edifices.

PROJECT TITLE: Ground-Water Study for Benton and Franklin Counties

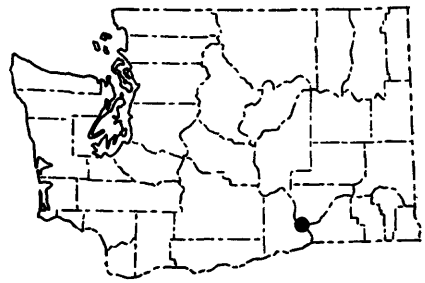
PROJECT NUMBER: WA-315

STUDY LOCATION: Pasco Basin, Washington

COOPERATING AGENCY: State of Washington
Department of Ecology

PROJECT CHIEF: Brian W. Drost

PROJECT DURATION: October 1985 to November 1990



PROBLEM: The area surrounding the Tri-Cities of Kennewick, Pasco, and Richland has been changing from rangeland and dryland farming to one of the major irrigated-agriculture areas of the Northwest. With the introduction of imported irrigation water, there is new concern about ground water--no longer is there enough, but rather, is there too much. There are rising water-table and seepage and ponding problems throughout the region; the magnitudes of individual causes of these water-level changes (applied irrigation, canal seepage, and base-level changes) have been difficult to ascertain. Water quality is also a major problem. Various agencies have documented the increase in concentrations of nitrate and other contaminants in local ground water, but the source and patterns of contaminant movement and migration can be identified only after the hydrology of the area is determined.

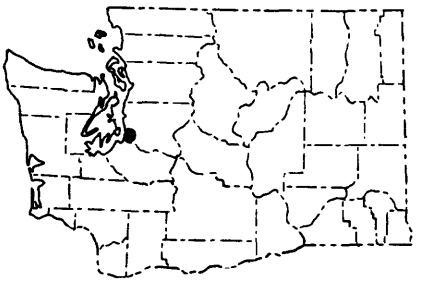
OBJECTIVE: Determine flow patterns of the ground-water system and quantities of movement, so that the effect of stresses on the system caused by artificial recharge and ground-water withdrawals can be documented; (2) test mitigation procedures; (3) determine the effects of various land uses and rising water levels on the quality of water; (4) determine if pesticides are present in ground water in and downgradient of areas of high pesticide usage; and (5) determine the movement of undesirable chemicals and (or) chemical concentrations under the present system and under suggested mitigation procedures.

APPROACH: A three-dimensional ground-water model will be constructed of the study area. This will require mapping the lithologic units that make up the unconsolidated deposits and making mass water-level measurements just before, during, and after irrigation. The model will simulate the movement of ground water in the unconsolidated deposits and the basalts, and simulate the response of the system to man-induced stresses. Concurrent with this effort will be a water-quality program to identify the nature, magnitude, and sources of water-quality problems.

PROGRESS: Two basic-data reports were approved and published. Mass ground-water samplings were conducted during February and September 1988. Approximately 150 wells were sampled during each mass sampling. Soil samples were collected from eight unfarmed sites and tested for nitrogen content, to determine if natural soils and conditions may be contributing nitrates to the ground water.

PLANS FOR FY 1990: Definition of geohydrologic units and mapping of hydrologic characteristics will be completed. Historical data (primarily water levels, water use, and water quality) will be compiled. Construction and calibration of the ground-water-flow model will continue. Land use (crop types, fertilizer and pesticide applications, and density of septic systems) will be inventoried for use in analyzing water-quality data. Water-quality data will be compiled, verified, and analyzed. Project staff will begin writing final reports for both the ground-water and water-quality phases of the study.

PROJECT TITLE: Evaluation of Ground-Water Resources in Southwest King County



PROJECT NUMBER: WA-318

STUDY LOCATION: Western Washington

COOPERATING AGENCY: State of Washington Department of Ecology, Regional Water Association of South King County, and Seattle-King County Department of Public Health

PROJECT CHIEF: Edwin H. McGavock

PROJECT DURATION: October 1985 to September 1989

PROBLEM: Southwest King County is one of several areas in the Puget Sound region with rapid growth in population and urban development, and therefore increased demands for water for public-supply, domestic, commercial, and industrial uses. Several municipalities are drilling additional public-supply wells in order to satisfy both normal and peaking water demands. The availability of ground water and the effects of well pumpage on lakes, springs, wetlands, and instream flows are important issues that need to be reconciled. Several serious water-quality problems related to industrial and waste-disposal practices have been recognized at sites in the study area; contamination and the potential for seawater intrusion can limit the ability of the aquifer system to provide water of adequate quality for the needed uses.

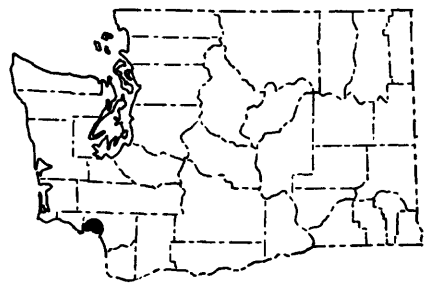
OBJECTIVE: (1) Define and quantify the ground-water system using available or readily collectible data; (2) determine the general water chemistry for the major aquifers from which water is being withdrawn; and (3) determine what additional data, if any, are required to sufficiently characterize the ground-water system in order to allow management decisions for developing further suppies.

APPROACH: (1) Map the Pleistocene and Holocene sediments; (2) inventory and measure water levels in about 1,000 wells; (3) correlate drillers' and geophysical logs to define aquifer and confining units, and draw structure and thickness maps; (4) make mass water-level measurements of 300-500 wells to map the flow system within each aquifer; (5) estimate recharge to the ground-water system; (6) estimate discharge from the ground-water system; (7) estimate the annual water budget for the Big Soos basin; (8) estimate the major pumpage and domestic well use; (9) determine water chemistry of the major aquifers; (10) design an observation well network to monitor water-level and water-quality changes; and (11) describe additional data and analyses needed to determine ground-water availability and ground water-surface water interaction.

PROGRESS: A report describing the results of the study is in technical review.

PLANS FOR FY 1990: The approved report will be published.

PROJECT TITLE: Influence of Sediment From the 1980 Mount St. Helens Mudflows on the Ground-Water System in the Lower Cowlitz River Valley, Washington



PROJECT NUMBER: WA-319

STUDY LOCATION: Southwestern Washington

COOPERATING AGENCY: Cowlitz County, Cities of Castle Rock, Kelso, and Longview, Washington

PROJECT CHIEF: Frank A. Packard

PROJECT DURATION: Complete, except for report

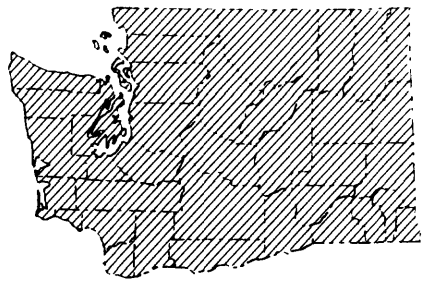
PROBLEM: Since the May 18, 1980, eruption of Mount St. Helens, ground-water levels in the Cowlitz River valley have risen, probably due to a rise of the Cowlitz River bed and stage after mudflow deposition. The sewer systems of the area are old, and apparently the rising ground water has destabilized the foundations of sanitary sewer and storm drain lines and caused pipes to crack and joints to pull apart. During a 75-year recurrence storm in February 1986, the pipes acted as ground-water drains as water levels rose above the pipes, possibly to historically high levels. Sediment around the broken sewers was carried into the pipes, and the displacement caused more than 34 collapse holes above sewer lines in Kelso and Longview alone. At some locations, collapse holes undermined roadways, resulting in substantial damage. Costs associated with repairing roadway damage from one collapse hole alone exceeded $300,000. In all, the February storm resulted in more than $1.8 million in damage.

OBJECTIVE: (1) To determine the relation between the river and adjacent ground-water system; (2) to determine if there has been sustained ground-water-level rise in the Cowlitz River since 1980; (3) if sustained rise has occurred, to determine the cause or causes; and (4) to document the relation between ground-water levels and collapse holes above the sewer lines.

APPROACH: Information on pre-eruption ground-water levels and seasonal fluctuations is available. A piezometer network was installed in the valley immediately after the eruption, and was measured for 1 1/2 years thereafter; but a recent survey has indicated that many of those wells have been lost or destroyed. The existing network will be expanded so that the present relation between the river and ground-water system can be identified. Water-borne seismic instruments will be used to determine if the mudflow deposits still exist in the Cowlitz River streambed. A longitudinal profile of the Cowlitz River streambed and stage will be made and compared to pre- and post-eruption information, to determine if changes have occurred since dredging by the U.S. Army Corps of Engineers. The location and extent of dredged materials will be mapped, and the position of the water table relative to these deposits will be determined. Precipitation records will be reviewed to determine if there has been an increase since 1980.

PLANS FOR FY 1990: The report will be published when approved.

PROJECT TITLE: Compilation of Miscellaneous Streamflow Measurements in Washington



PROJECT NUMBER: WA-324

STUDY LOCATION: Washington

COOPERATING AGENCY: State of Washington
Department of Ecology

PROJECT CHIEF: John R. Williams

PROJECT DURATION: Complete

PROBLEM: More than 2,500 streamflow measurements have been made at ungaged sites since 1960, when the last compilation of such measurements was published. The increasing need for data from small basins, particularly for low-head hydropower and planning models, makes it desirable to have the data readily available. Most of the data are published, but are scattered among more than 50 data and interpretive reports.

OBJECTIVE: Publish the data for all miscellaneous measurements made by the U.S. Geological Survey in Washington since the 1960 compilation. Enter all data into computer storage in format compatible with ARC/INFO.

APPROACH: Compile all data for 1961-85 water years into format used in Annual Data Report. About two-thirds of the data are included in previous data reports, but interpretive reports must be gleaned to obtain the remaining data.

PROGRESS: All data for the report were entered into computer storage and are now available for retrieval as tables. All previously published data from 1890 to 1961 have also been entered into the data base. The report has been published.

PROJECT TITLE: Fluvial Paleohydraulics and Paleohydrology

PROJECT NUMBER: WA-325

STUDY LOCATION: Topical research

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: John E. Costa

PROJECT DURATION: Ongoing, beginning in October 1986

PROBLEM: Planning for the utilization and preservation of streams and adjacent lands is often complicated by the problem of inadequate data to provide reasonable estimates of the magnitude and frequency of flows. Hydrologic conditions in small basins are especially difficult to characterize because there are so few flow records available. Paleohydrology is the study of the movement of water and sediment in channels and valleys before the time of continuous hydrologic records or direct measurements. The application of paleohydrology to develop the magnitude-frequency-response to extraordinary events in small basins is essential to further advance our knowledge of flood frequency, hazard analysis, sediment transport, landform evolution, and several other critical areas of interest to the U.S. Geological Survey.

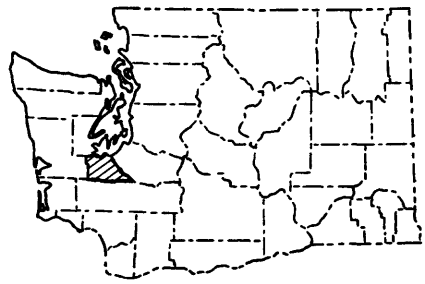
OBJECTIVE: Develop methods or techniques to estimate magnitude and frequency of large flow events in small basins; develop methods to identify flow processes occurring in small upland basins--debris flows, hyperconcentrated flow, or water floods; gain an understanding of the different hydraulics, geomorphic, and sedimentologic characteristics of flash-flood-producing processes, including excessive precipitation and dam failures; and develop methods to predict landform modifications and sedimentologic characteristics accompanying floods in different physiographic settings.

APPROACH: Compile information on the occurrence and location of the largest flows known in the United States and throughout the world and the meteorological, hydraulic, physiographic, and geomorphic data associated with each extraordinary flow. Resurvey selected watersheds from these locations, making indirect measurements as appropriate, and collect data at future locations of extraordinary flows. Develop morphologic and sedimentologic criteria for differentiating the sequence and characteristics of sediment-water flows in channels and computing critical values of velocity, depth, and concentrations of prehistoric flows. Use landform and sediment information in conjunction with dating techniques to identify and date the historic occurrence of extraordinary floods.

PROGRESS: An analysis of large floods from rainstorms and dam failures and a new technique to evaluate effective force in geomorphology were completed and published. Work continues on building a data base of landslide dams from around the world. Moraine dams continue to be investigated. The latest accomplishments include a bathymetric survey of Moraine Lake, at Broken Top in central Oregon, and calculation of paleohydrologic estimates of flood-peak discharge from the 1966 moraine-dam failure at selected locations downstream from Moraine Lake.

PLANS FOR FY 1990: Plans include continuation of data compilation for the landslide dam data base and preparation of a report on the 1966 failure of Moraine Dam at Broken Top.

PROJECT TITLE: Streamflow Simulation Models for Small Urban Drainage Basins in Thurston County



PROJECT NUMBER: WA-327

STUDY LOCATION: Southwest Washington

COOPERATING AGENCY: Thurston County Department of Public Works

PROJECT CHIEF: Steven N. Berris

PROJECT DURATION: January 1988 to September 1991

PROBLEM: Population in the north-central part of Thurston County is growing rapidly, and large areas of agricultural and forested lands are being developed for residential and commercial use. Thurston County planning agencies need a method for estimating the effects of different zoning and land-use practices on streamflow, ground-water recharge, and water quality.

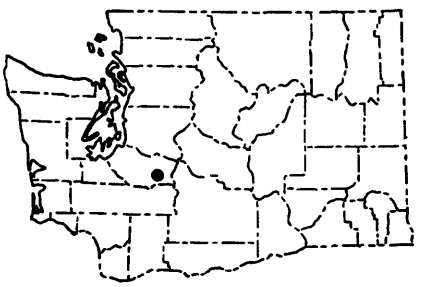
OBJECTIVE: To develop a method for estimating streamflow and ground-water recharge in small, ungaged basins in north-central Thurston County. Methodology will be based on the influence of physical basin characteristics on runoff and recharge, so that changes in those characteristics can be used to estimate the effects of land development. To expand knowledge of the influence of physical characteristics in the Puget Sound region by adding those characteristics unique to Thurston County to a base of characteristics determined from prior studies in two other counties. Will assist the county in developing deterministic models to simulate the effect of land use on runoff, and will transfer the ability to use these predictive hydrologic models to urban planners.

APPROACH: Develop numerical rainfall-runoff models using the Hydrologic Simulation Program-FORTRAN (HSPF) package of computer programs to estimate streamflows on three small drainage basins in north-central Thurston County. The models will be tested by comparing model-simulated streamflows with streamflows continuously observed over a 2-year period at recording gaging stations and intermittently at crest-stage gages in the three basins. The models will also produce estimates of ground-water recharge. County personnel will be trained in the techniques of model construction and use.

PROGRESS: Provisionally coded HSPF models with input data files were delivered to Thurston County personnel to use for estimating streamflows. Nearly 1 year of rainfall and runoff data has been collected. Model calibration using 1 year of observed runoff data should improve simulation accuracy substantially.

PLANS FOR FY 1990: Collection of rainfall and runoff data will continue at the 10 sites established in 1988 in the three basins. Rainfall and evaporation data will be used to run the models. Runoff data will be used to determine parameter values for unique soil-cover-slope complexes not previously modeled while assessing the validity of transferring the regional parameter values previously determined for King and Snohomish Counties.

PROJECT TITLE: Glacial Outburst Floods at Mount Rainier



PROJECT NUMBER: WA-328

STUDY LOCATION: Mount Rainier National Park, Washington

COOPERATING AGENCY: National Park Service
U.S. Geological Survey

PROJECT CHIEF: Joseph Walder

PROJECT DURATION: June 1988 through September 1992

PROBLEM: Glacial outburst floods (sometimes known by the Icelandic term jökulhlaups) are sudden discharges of water from glaciers, typically from either englacial storage or by draining of marginal, ice-dammed lakes. They present a serious hazard in Mount Rainier National Park, particularly because as they traverse the steep, narrow mountain streams, the flood waters entrain large amounts of rock debris and transform to debris flows. Aside from general correlations of flood occurrence with periods of either intense surface melting or heavy rain, little is known about the physical controls on outburst floods at Mt. Rainier. Because they occur with essentially no warning, hazard mitigation is difficult.

OBJECTIVE: By means of field and theoretical studies, basic data will be collected on the magnitude of glacial outburst floods at Mt. Rainier and the conditions that control the release of such floods, and the physics of water storage and release in temperate mountain glaciers will be analyzed. Guidelines will be provided to the National Park Service personnel at Mt. Rainier to assist them in flood-hazard mitigation.

APPROACH: Outburst floods occur most frequently on the southwest side of Mt. Rainier, particularly from South Tahoma Glacier, which drains into Tahoma Creek. At least nine outburst floods have occurred in Tahoma Creek since autumn 1986. For this reason and because of funding limitations, the field study will concentrate on South Tahoma Glacier. Monitoring of stream discharge and temperature, flood-induced seismicity, and photographic surveillance of both floods and areas likely to supply loose rock to form debris flows, will form the bulk of the field work, along with possible glaciological work (if conditions permit) to better define the three-dimensional glacier geometry and glacier hydrology.

PROGRESS: Instruments installed during summer 1988 were destroyed by a large flood in October 1988; reinstrumentation is beginning.

PLANS FOR FY 1990: Stage and temperature at Tahoma Creek will be monitored, along with photographic surveillance of lower glacier and upper reaches of stream, collection of meteorological data near the glacier, reconnaissance of glacier to determine viability of techniques such as dye tracing and radar sounding of glacier-bed topography, and seismic monitoring of floods. Stage and water temperature of the uppermost reach of South Puyallup River, where it drains the neighboring Tahoma Glacier, will be monitored to compare

with hydrology of a glaciated drainage in which outburst floods do not occur. Field work will be coupled with theoretical studies of water storage and release by temperate glaciers on steep beds. The likelihood of continued occurrence of outburst floods as the glacier's geometry changes due to thinning of the ice mass will be evaluated.

PROJECT TITLE: Hydrologic Hazards Related To Volcanism at Mount Hood, Oregon

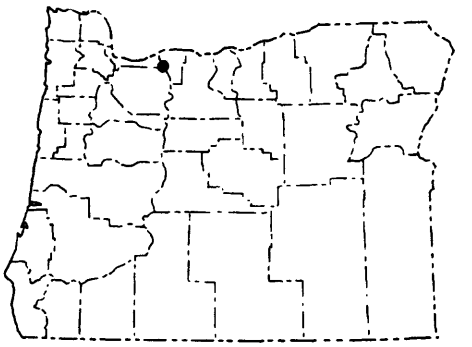
PROJECT NUMBER: WA-329

STUDY LOCATION: Northwestern Oregon

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: Thomas C. Pierson

PROJECT DURATION: January 1988 to September 1991



PROBLEM: Mount Hood is a recently active explosive-type volcano in northwestern Oregon, rising 11,235 feet above sea level. It is hazardous because: (1) it is a large mountain, with steep slopes rising thousands of feet above the surrounding terrain, and therefore any dislodged or ejected masses of rock, ice, or water would possess high potential energy; (2) much of the rock composing the upper part of the volcanic cone is fragmented and has been weakened by intense hydrothermal alteration, which renders the summit area more unstable than it would otherwise be; (3) its upper cone is mantled by 12.3 billion cubic feet of ice and snow, much of which could be melted or dislodged during an eruption; (4) it has a geologically recent record of large landslides (debris avalanches) and debris flows (lahars) extending down valleys many tens of miles away from the volcano; and (5) those same valleys are heavily populated at certain times of the year, and more development is planned. The frequency and magnitude of debris avalanches, debris flows, and floods that have extended beyond the base of the volcano (as well as smaller events on the volcano) have not been well documented. This information is crucial for land-use planning and risk assessment in lowland areas.

OBJECTIVE: The objectives of this project are (1) to determine the frequency and magnitude (depth of inundation and downstream extent) of sediment-water flows (debris avalanches, debris flows, and floods) extending beyond the lower flanks of the volcano; (2) to determine the causes for initiation wherever possible (particularly the relative proportion of eruption-triggered to non-eruptively triggered events); and (3) to estimate probable travel times, inundation depths, and downstream extents for future potential flows. This last objective will include the preparation of hazard maps.

APPROACH: The objectives will be accomplished by (1) stratigraphic, granulometric, mineralogic, and paleomagnetic analyses of deposits; (2) geologic mapping and absolute dating of deposits; and (3) flow simulation using computer flood-routing models. The study will begin with the Sandy River drainage basin, then proceed to the Hood River and White River drainages in turn. Documentation of hazard interpretations by the publication of scientific reports will precede release of hazard maps and reports.

PROGRESS: Geologic mapping and stratigraphic analysis of the deposits in the Sandy River basin are essentially completed. A previously unknown sequence of eruptively triggered lahars 400 to 600 years old (named the Zigzag eruptive period) has been identified. Most of the residential and commercial development in the Sandy and Zigzag River valleys is situated on lahar terraces that are less than 1,800 years old (and therefore vulnerable to future lahars). The last major lahar to flow down the Sandy River to the Columbia River occurred in 1782. In the last 12,000 years, the quiet intervals between eruptive periods have become progressively shorter (approximately 10,200, 900, and 130 years). It has been at least 124 years since the last eruption at Mount Hood.

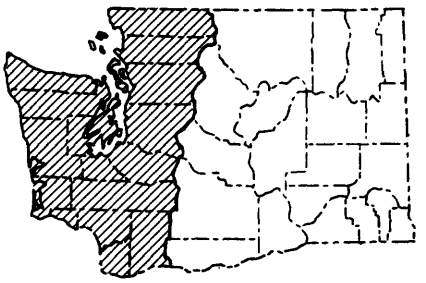
PLANS FOR FY 1990: Data reduction and writing of one or more journal articles on the results of the Sandy River basin study will be carried out. In the spring of 1990, we will begin field work in one of the other two basins.

PROJECT TITLE: Characteristics of Braided Channels

PROJECT NUMBER: WA-330

STUDY LOCATION: Western Washington

COOPERATING AGENCY: None, U.S. Geological Survey funds only



PROJECT CHIEF: Chris Paola

PROJECT DURATION: October 1988 to September 1993

PROBLEM: A braided stream is one that displays most of the following characteristics: (1) flow in several channels simultaneously; (2) low individual-channel sinuosity; and (3) frequent channel switching. Although a good deal of excellent work has been done on braided streams, most of it has been qualitative and nearly all has focused on specific small-scale phenomena that occur in individual braided channels. A quantitative predictive model is needed for river engineering and sedimentary geology problems.

OBJECTIVE: As a result of this study, the U.S. Geological Survey hopes to develop improved models for channel behavior, differential transport, and channel interaction, and thereby develop a combined stochastic/deterministic model for active river systems. Although the coupling of many channels together leads to highly chaotic behavior (more like real braided streams), the chaos is not completely random and statistical properties can be gleaned from the equations used to generate the models described above.

APPROACH: Equations describing motion and sediment transport in a natural coordinate system that incorporate bank curvature/width variations have already been formulated. Data on boundary sheer stress, vertical velocity profiles, bed elevation, flow depth, and sediment-transport rate of various size fractions will be needed to test individual-channel theories. But single-channel theory is already so complex that simply solving the equations for several channels simultaneously is almost certainly impractical; instead, a reduced set of equations, probably width-averaged, will be solved simultaneously. The main data source for the multichannel theory will be simultaneous measurements of flow and channel evolution in several channels by tracking surface floats with a helicopter-borne video camera.

PROGRESS: Major accomplishments include development of a new, physically based model for downstream fining by selective deposition in braided stream systems, and further development of our existing models for development of mid-channel bars, associated channel widening, and distribution of flow around fully developed and dissected bars. Extensive data have been collected from the North Fork Toutle River and Sunwapta River in Canada for testing and refining these models. These data include measurements of (1) flow around bars, both submerged and developed; (2) bank-erosion rates and near-bank structure; and (3) downstream grain-size changes and deposition rates in the delta of the North Fork Toutle Sediment Retention Structure. Existing Corps of Engineers data are also being used for the latter set.

PLANS FOR FY 1990: Detailed flow, shear stress, and sediment-transport measurements will be made in relatively inactive channels, and the measurements will be used to derive the required data from reduced measurements made during floods.

PROJECT TITLE: Ground-Water Quality of Clark County, Washington

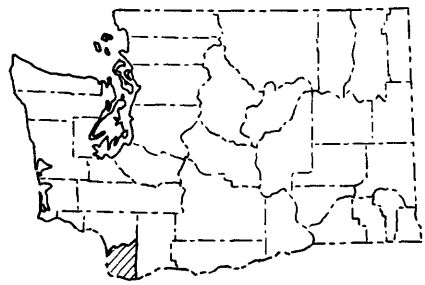
PROJECT NUMBER: WA-331

STUDY LOCATION: Southwestern Washington

COOPERATING AGENCY: Intergovernmental Resource Center of Clark County

PROJECT CHIEF: Gary L. Turney

PROJECT DURATION: March 1988 to June 1989



PROBLEM: Clark County, in southwestern Washington, is almost entirely dependent on ground-water resources for water supply, and has petitioned the State of Washington for designation of Clark County as a Ground-Water Management Area. Such designation will enable the county to receive State funds for development of a ground-water management plan, which includes a study of the physical and chemical characteristics of the ground water. To assist the county in developing the plan, the Oregon State Office of the U.S. Geological Survey has begun a cooperative study to identify hydrogeologic characteristics of the ground-water system, which ultimately will result in a ground-water-flow model to be used as a management tool. There is still a need, however, to characterize the quality of the ground water.

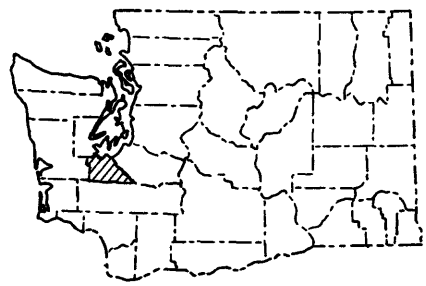
OBJECTIVE: Concentrations of inorganic and organic constituents in the ground water will be determined on a countywide scale. Variations in constituents as a function of area, depth, and aquifer will be defined. Constituent concentrations will also be used to try to verify generalized ground-water-flow paths as determined from water levels and to identify sources of constituents in ground water.

APPROACH: Existing well logs and water-quality data contained in files of the U.S. Geological Survey, Environmental Protection Agency, Washington Department of Ecology, and Clark County will be reviewed to select wells suitable for water-quality sampling. Samples will be collected from about 75 wells throughout the county. All samples will be analyzed for concentrations of major ions and other inorganic constituents and properties needed to characterize ground-water chemistry, and for selected bacteria and radon; samples from 20 wells will also be analyzed for pesticides, volatile organic compounds, radiochemical constituents, and dissolved metals. Resulting data will be tabulated and used in preparation of a statistical summary report. The report will also discuss relations between water chemistry and ground-water flow.

PROGRESS: An interpretive report addressing the chemistry of various aquifers and relations to geology and ground-water flow has been submitted for approval. Data have been forwarded to the cooperator and to individual well owners.

PLANS FOR FY 1990: The report will be published when approved.

PROJECT TITLE: Ground-Water Hydrology of North Thurston County, Washington



PROJECT NUMBER: WA-332

STUDY LOCATION: Thurston County, southwest Washington

COOPERATING AGENCY: Thurston County Health Department

PROJECT CHIEF: Norman P. Dion

PROJECT DURATION: April 1988 to September 1991

PROBLEM: Thurston County is undergoing rapid population growth, and the study area is served almost entirely by ground water for public supply, domestic use, industrial use, and irrigated agriculture. The city of Olympia obtains most of its water from McAllister Springs, which discharges about 15 cubic feet per second of water from glacial deposits. Although at present there are no significant, identifiable problems with ground-water quantity or quality, county and State officials are concerned about the potential for such problems in the future. Concerns about the availability of additional ground-water supplies stem from the recognition that ground-water withdrawals are increasing rapidly, little is known about the productivity of the deeper aquifers, and increased development could eventually affect the discharge and quality of McAllister Springs.

OBJECTIVE: The objectives of the cooperative ground-water study are: (1) to describe and quantify the ground-water system to the extent that existing or readily collectable data allow; (2) to describe the general water chemistry of the major aquifers and the regional patterns of pollution from septic tanks, agriculture, and other sources; (3) to evaluate the feasibility of constructing a three-dimensional, modular transient ground-water-flow model for the area; and (4) to design and propose monitoring networks for ground-water quantity and ground-water quality.

APPROACH: All existing ground-water data files (about 3,000) will be assembled, and 1,000-2,000 will be selected for field inventory and water-level measurement. The aquifer geometry will be mapped. Specific-capacity data will be used to calculate hydraulic conductivities. A water budget will be developed. Existing water-quality data will be assembled and reviewed along with land-use maps and other pertinent information available from the County Health Department. The feasibility of building a three-dimensional transient ground-water flow model will be based on how adequately the data can define the geometry and hydraulic characteristics of the aquifers.

PROGRESS: Approximately 800 wells were visited in the field, well schedules were prepared, and water levels were measured. ARC/INFO files were created to describe the principal physiographic features of the study area, including topography, drainage, and land nets. The task of correlating drillers' lithologic logs and of preparing geologic cross sections was begun

and is about 95-percent complete. The compilation of water-quality data was begun, as was a literature search of pertinent published and unpublished reports. A report describing the quality-assurance plan for the study was completed.

PLANS FOR FY 1990: Another 450 wells will be inventoried in the field; the data resulting from the entire well-inventory effort will be coded and entered into the GWSI data base. ARC/INFO files of selected cultural data will be developed, to include land ownership, land use, housing density, and areas of central water and sewer service. A complete outline of the expected final report will be written, as will the data-collection plan for the study. The construction of geologic cross sections will be completed, as will maps of the tops and thicknesses of the major aquifers and confining layers. A preliminary water-level map of the area immediately surrounding McAllister Springs will be completed. The aquifer from which each of the inventoried wells withdraws water will be determined, in preparation for the selection of wells for water-level monitoring and water-quality sampling. Water levels will be measured in about 35 observation wells on a monthly basis. In April, samples will be taken from 350 production wells finished in the principal aquifers, and will be analyzed for chemical characteristics and possible water-quality degradation. Major springs in the study area will be visited and inventoried, and if possible, discharge will be measured. An inventory of the quantities of water used for public-supply, domestic, industrial, stock, and irrigation purposes in calendar year 1988 will be made and the results tabulated by aquifer. Writing of the introductory part of the final report will begin.

PROJECT TITLE: Puget-Willamette Lowland Regional Aquifer-System Analysis

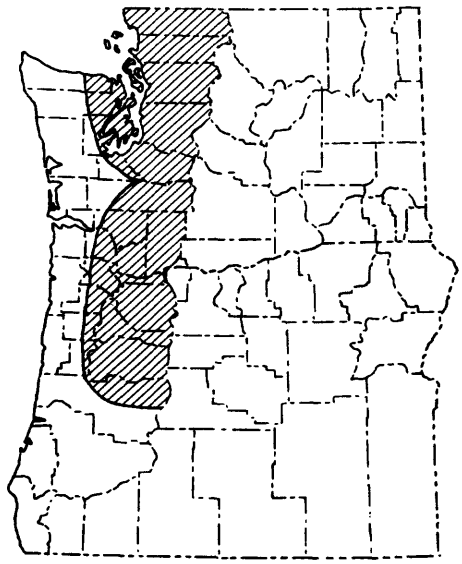
PROJECT NUMBER: WA-336

STUDY LOCATION: Western Washington and northwestern Oregon

COOPERATING AGENCY: None, U.S. Geological Survey funds only

PROJECT CHIEF: John J. Vaccaro

PROJECT DURATION: January 1989 to September 1994



PROBLEM: The Puget-Willamette Lowland regional aquifer system is one of the 28 regional aquifers chosen for study under the U.S. Geological Survey Regional Aquifer-System Analysis (RASA) program. The States of Washington and Oregon are interested in this study because more than 70 percent of their population resides within the study area boundaries. In the study area, such information as quantity and direction of ground-water flow, lengths of flow paths, locations of ground-water discharges, stream-aquifer interaction, relations with older rock materials, and continuity between aquifer units is largely unknown. All of these topics require better definition; lack of that information impairs the ability of managers to make knowledgeable decisions.

OBJECTIVE: The primary goal of this study is to obtain a better understanding of the regional ground-water system. To achieve this goal, the following objectives have been defined: (1) describe the geologic framework of the regional aquifer system; (2) describe the geohydrologic characteristics of the regional aquifer system; (3) describe the regional flow system; (4) estimate the water budget for selected areas of the aquifer system and use this information to describe the regional water budget; (5) determine the present water quality and variations of native water quality and water-rock interactions along selected ground-water-flow paths; and (6) use ground-water-flow models to synthesize the geohydrologic data and concepts on how the regional flow system operates.

APPROACH: The first year of effort will consist of a planning stage or "pre-RASA" study, during which it will be determined if the available information, including data on discharge, recharge, runoff, and hydraulic characteristics, and results from local studies allow construction of a conceptual model of ground-water flow. Existing data and studies will be compiled and analyzed. Available information will be mapped and analyzed on a regional scale. Trends and variations of hydrologic and water-quality information will be studied in conjunction with available geologic information. Areas where information on the regional system is lacking will be identified. A plan of study will be formulated by the project chief, identifying the time frame, manpower, costs, and steps to be taken for completion of the study.

PROGRESS: Project proposal was completed and approved.

PLANS FOR FY 1990: Available information will be mapped and analyzed on a regional scale. Existing data sets will be incorporated into a regional data base. A bibliography for the study area will be published. Conceptual models of ground-water flow will be tested with simple cross-sectional numerical models. Watersheds/basins will be defined for the Puget Sound region. Data collection will begin in selected basins.

PROJECT TITLE: Hazardous Waste, Hanford (CERCLA)

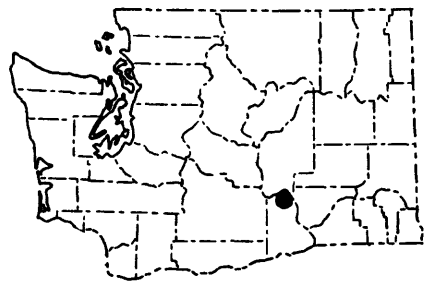
PROJECT NUMBER: WA-338

STUDY LOCATION: South-central Washington

COOPERATING AGENCY: U.S. Environmental Protection Agency

PROJECT CHIEF: Ward W. Staubitz

PROJECT DURATION: February 1989 to September 1993



PROBLEM: The U.S. Department of Energy's (USDOE) Hanford Nuclear Reservation was designed and operated to produce plutonium for nuclear weapons. As a result of plutonium processing and operation of nine nuclear reactors, large volumes of liquid wastes have been generated and discharged to the ground. These wastes include a wide variety of radionuclides and organic and inorganic chemicals contained in more than 1,400 waste storage, disposal, or spill sites. The degree of contamination is largely unknown. Although the USDOE has operated a long-term ground-water-monitoring program for selected radionuclides and inorganic constituents, sampling for a wider range of constituents has been limited; in recent sampling, several hazardous constituents have been detected in excess of the U.S. Environmental Protection Agency (USEPA) maximum contamination levels. The Hanford Site has been organized into 78 operable units, and the clean-up of each unit will entail a detailed site-characterization study to determine the nature and extent of contamination. USEPA has oversight responsibility for the remediation, and the USGS is providing technical assistance.

OBJECTIVE: The objective of the work is to review data-collection activities and evaluate all hydrologic and geologic data collected at Hanford CERCLA (Comprehensive Environmental Response Compensation and Liability Act) sites, and to use these data and additional information supplied by the USEPA and the USDOE to assess the hydrology and geology at the CERCLA sites.

APPROACH: The USGS will review and comment on each operable unit Remedial Investigation/Feasibility Study (RI/FS) work plan, concentrating on sections pertaining to geologic and hydrologic site characterization. The USGS periodically will review field data-collection activities and meet with representatives of the USEPA, USDOE, and their contractors to discuss and resolve disagreements on the technical approach and execution of the hydrologic investigations. The USGS then will evaluate data generated from the RI/FS and incorporate existing information to assess the geology and hydrology of each operable unit and define the extent of contamination and its potential for migration.

PROGRESS: Since the beginning of the project in February 1989, the USGS has reviewed RI/FS work plans for three operable units. We also have commented on drilling techniques, documentation of data-collection methods, quality-assurance and quality-control procedures, and the development of site-wide ground-water-flow models. All project personnel have completed radiation and hazardous-waste health and safety training and are currently enrolled in a medical monitoring program.

PLANS FOR FY 1990: The RI/FS work plans for three operable units will be approved by November 1, 1989. Field data-collection activities at these operable units will be inspected and the data will be evaluated when available. The RI/FS work plans for four new operable units will be reviewed, as will a multivolume Hanford data-collection-techniques manual. Additional effort will also be directed toward reviewing and discussing techniques for the characterization of soil hydraulic properties and the development and calibration of unsaturated and saturated ground-water-flow and solute-transport models.

PROJECT TITLE: Thurston County Ground-Water Model

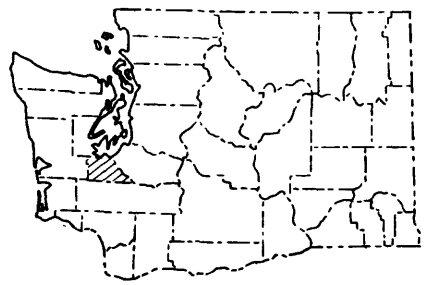
PROJECT NUMBER: WA-339

STUDY LOCATION: Western Washington

COOPERATING AGENCY: Thurston County Health Department

PROJECT CHIEF: W. E. Lum II

PROJECT DURATION: February 1989 to September 1992



PROBLEM: In Thurston County, at the southern end of Puget Sound, the metropolitan area of Olympia-Lacey-Tumwater is the fastest growing area in the State. The area is served almost entirely by ground water for public supply, industrial use, and irrigated agriculture. Recent State legislation requires local management of water resources. Ongoing cooperative studies in Thurston County are providing information on rainfall-runoff relations under various land useages and soil types, the geohydrologic framework of the area, current ground-water useage, and quality of water. The results of these studies will be used in the study to construct a ground-water-flow model that will provide a quantitative tool for managing ground-water resources. The ground-water model will help define ground-water recharge and discharge areas, long-term ground-water availability, movement of contaminents in ground water, and effects of land-use changes on the natural ground-water-flow system.

OBJECTIVE: (1) To gain a greater understanding of the flow system and quantify the ground-water-flow components in the study area by constructing, calibrating, and operating a three-dimensional ground-water-flow model; (2) to estimate possible areas of recharge, discharge, and ground-water-flow paths by constructing and operating a particle-tracking post processor to the flow model. Meeting these objectives will allow the following water-management objectives to be met: (1) to quantitatively assess how installing sanitary sewers in specific areas would affect ground-water quality, wetlands, and water-budget items; (2) to assess the effects of farming on ground-water quality; (3) to estimate locations of areas where degradation of ground-water quality will have a long-term effect on major sources of public or municipal water supply; and (4) to estimate the effects of large increases in pumpage on ground-water quality and water levels in all known aquifers in the study area.

APPROACH: To accomplish the stated objectives, a ground-water-flow model will be constructed and calibrated with the observed data. The model will provide information about how much water is moving through the ground-water system under the study area. A particle-tracking post processor will allow definition of flow paths in the ground-water system. The definition of specific groups of flow paths will allow (1) the mapping of recharge areas for specific discharge points of the ground-water system; (2) the mapping of probable pathways of contaminants from their source to points of discharge from the ground-water system; and (3) an estimate of the time-of-travel for a conservative-type contaminant through the ground-water system.

PROGRESS: Work has started on construction of a preliminary three-dimensional ground-water-flow model. Computerized files of the geohydrologic framework are nearly complete.

PLANS FOR FY 1990: An operational ground-water-flow model will be completed in the first quarter of FY90. A sensitivity analysis of this model will be used to plan data-collection activities in the project area that will continue for the remainder of FY90. In FY91, the model will be revised to reflect the newly collected data and calibrated to match observed conditions, and a report will be written documenting the results of the study.

PROJECT TITLE: Hydrologic Investigations at Hanford Nuclear Reservation

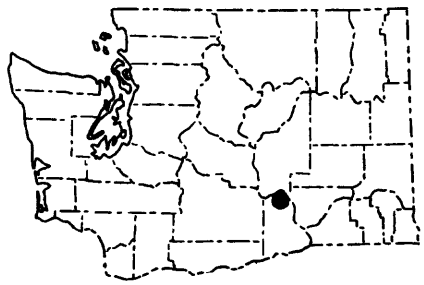
PROJECT NUMBER: WA-340

STUDY LOCATION: South-central Washington

COOPERATING AGENCY: U.S. Department of Energy

PROJECT CHIEF: Ward W. Staubitz

PROJECT DURATION: July 1989 to September 1994



PROBLEM: The U.S. Department of Energy's (USDOE) Hanford Nuclear Reservation was designed and operated to produce plutonium for nuclear weapons. As a result of plutonium processing and operation of nine nuclear reactors, large volumes of liquid wastes have been generated and discharged to the ground. These wastes include a wide variety of radionuclides and organic and inorganic chemicals. The degree of contamination is largely unknown. Although the USDOE has operated a long-term ground-water-monitoring program for selected radionuclide and inorganic constituents, sampling for a wider range of constituents has been limited; several hazardous constituents have been detected in recent samples in excess of U.S. Environmental Protection Agency (USEPA) maximum contamination levels. Despite extensive studies of the hydrology of the Hanford Reservation over the past 40 years, several processes important to site characterization and the development and implementation of remediation strategies are not well understood: (1) the quantity of natural recharge from precipitation on the reservation and its effect on migration of contaminants in the unsaturated zone; (2) the quantity of natural recharge from infiltration of surface-water runoff originating in the Cold and Dry Creek watersheds and its influence on the rate and direction of ground-water flow; and (3) the potential flooding of existing waste sites by runoff from Cold and Dry Creeks during extreme flood events.

OBJECTIVE: The objective is to provide site-wide hydrologic information and technical support to the USDOE for accurate characterization of the ground-water-flow system and effective development and implementation of remediation strategies at Hanford.

APPROACH: The USGS will interpret existing information and conduct hydrologic investigations to develop a refined understanding of the hydrology of the Hanford site. The USGS will participate in third-party technical review panels to evaluate ongoing site-wide hydrologic characterization and solute-transport and ground-water-flow model development being conducted under the performance assessment program. The USGS also will provide project proposals and conduct investigations to address specific hydrologic issues mutually agreed upon by the two agencies. Current projects include development of a rainfall-runoff model of the Cold and Dry Creek watersheds to estimate long-term discharge from these ephemeral streams and recharge to the unconfined aquifer underlying the Hanford Reservation, as well as a feasibility study for a paleoflood investigation of the Cold and Dry Creek basins.

PROGRESS: A third-party technical review was made of the Hanford performance assessment program in July. Review and comments were completed on the development and application of unsaturated and saturated ground-water-flow and solute-transport models. Construction of gaging stations and instrumentation of the Cold and Dry Creek watersheds was begun in mid-September.

PLANS FOR FY 1990: It is anticipated that additional third-party technical reviews of the performance assessment program will be done. The paleoflood feasibility study will be conducted, and if dateable slack-water deposits are found in Dry and Cold Creeks, a paleoflood investigation and flood-frequency analysis will be conducted. Instrumentation of the Cold and Dry Creek watersheds will be completed by December, and rainfall-runoff data collection will continue for at least 3 years.

PROJECT TITLE: Pierce County Rainfall-Runoff

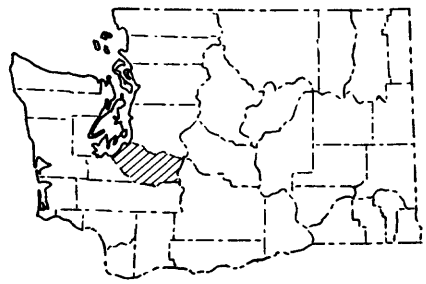
PROJECT NUMBER: WA-341

STUDY LOCATION: Western Washington

COOPERATING AGENCY: Surface Water Management Utility of Pierce County

PROJECT CHIEF: Mark C. Mastin

PROJECT DURATION: June 1989 to September 1990



PROBLEM: Pierce County is within the Puget Sound region, for which the U.S. Geological Survey has recently developed a regional version of the HSPF (Hydrologic Simulation Program-FORTRAN) rainfall-runoff model. The regional model was developed from data collected in small upland drainage basins in several areas adjacent to Pierce County. The newly formed Surface Water Management Utility of Pierce County is beginning the development of a comprehensive surface-water management plan for unincorporated areas of the county, and needs to determine the current and future runoff and streamflow characteristics of many upland drainage basins in the county as foundation for the plan. The regional HSPF model could be the tool of choice for such determinations by Pierce County, because the hydrologic and physical properties of upland basins in Pierce County are similar to those represented in the regional model, but the simulation accuracy of the regional model has not yet been tested in this county.

OBJECTIVE: This study is a preliminary application of the Puget Sound regional HSPF model for two small drainage basins in Pierce County to determine its accuracy in simulating streamflow that will be measured and recorded for 12 months at 12 sites in the two basins. If this modeling approach is accepted, the scope of the study will likely be expanded to include at least a second year of data collection and calibration to refine the regional parameters used in the model.

APPROACH: The model will be tested for applicability on the Clear Creek and Clarks Creek basins, which are tributary to the Puyallup River in Pierce County. These two basins typify the topographic, geologic, soil, and land-use characteristics found in many upland basins in the county, and they are also physiographically similar to those basins from which the regional model was developed. Three primary tasks will be performed for this study. First, a streamflow and rainfall data-collection network will be installed in the two basins and operated to obtain one complete year of record. Next, the topographic, geologic, soil, land-use, and hydraulic characteristics of the basins will be inventoried. Finally, the hydrologic data and basin characteristics will be incorporated into the regional HSPF model framework, and the model will be run to simulate the hydrology of the basins for the 1-year period of data collection.

PROGRESS: Four continuous-recording gages, eight crest-state gages, and two continuous-recording precipitation gages have been installed and are operating. Twenty-three reaches or subbasins have been delineated on mylar overlays at a scale of 1:4,800, and soil associations as defined by the regional HSFP model have been outlined on aerial photo prints at the same scale.

PLANS FOR FY 1990: Discharge measurements will be made throughout the water year to define the stage-discharge relations at all stream-gage sites. Stage data at all sites will be collected and processed to provide a record of storm-peak discharge at the crest-stage gages, continuous discharge at the continuous-recording stream-gage sites, and continuous precipitation at the two precipitation sites. Cross sections at all the stream reaches will be made to define the hydraulic characteristics needed for the model. The drainage subbasins, soil associations, and land use will be digitized on the ARC-INFO/GIS system in order to compute the size and distribution of the various land segments that will be put into the model. Along with the computed hydraulic and land-segment input, the regional hydrologic parameters developed from the previous HSPF model will be entered into the model. The model will be run and compared with the measured discharge at the stream-gaging stations.

PROJECT TITLE: Long-Term Evapotranspiration Network

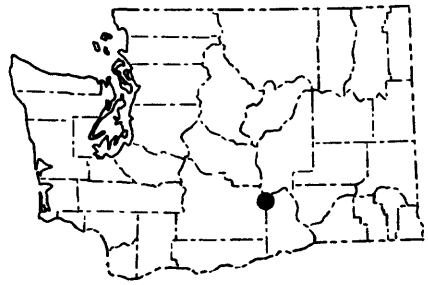
PROJECT NUMBER: WA-343

STUDY LOCATION: South-central Washington

COOPERATING AGENCY: State of Washington
Department of Ecology

PROJECT CHIEF: Stewart Tomlinson

PROJECT DURATION: July 1989 to September 1991



PROBLEM: Estimates of evapotranspiration (ET) are important for determining components of the water budget. Accurate estimates of water-budget components are, in turn, important for quantifying ground-water availability. However, both short-term and long-term ET estimates are lacking, and the few available estimates are for very short periods of time.

OBJECTIVE: Long-term ET sites need to be established. These sites would be located throughout Washington and would include important climate and plant regimes.

APPROACH: The U.S. Geological Survey will establish two sites in a basin. This basin also will be monitored for other hydrologic variables by Survey hydrologists. The sites will be a Bowen ratio site (provides data for calculating actual ET) and a Penman site (provides data for calculating potential ET). The first part of the study will be to assess equipment, intrabasin variability in climate parameters, and relation of Bowen ratio site to Penman site information. Thus, the feasibility of locally calibrating the Penman site potential ET data to the Bowen site actual ET data would be estimated. This would allow for future ET sites to consist of the more trouble-free Penman equipment. Those future sites then would need to be calibrated only periodically.

PROGRESS: One Bowman ratio site and one Penman site were installed in the Cold Creek watershed in eastern Washington, to monitor ET for a sagebrush-grassland cover in a semiarid climate regime. This watershed was selected for the first sites because it will also be instrumented with a neutron access tube, precipitation and streamflow gaging network for 3 years by the Survey as part of the work related to Environmental Protection Agency superfund activities at the Hanford Nuclear Reservation.

PLANS FOR FY 1990: ET equipment on loan from the Nevada District will be set up at a test site in Tacoma during October. This will allow for further training and familiarization with equipment and data collection. During the winter and spring, the district will purchase its own ET equipment and develop retrieval and analysis systems. Equipment installation and data collection will begin at the Cold Creek site in late spring or early summer. Data collection and preliminary data analysis will take place through summer and early fall.

AVAILABILITY OF WASHINGTON OFFICE REPORTS

Published reports are announced in the U.S. Geological Survey monthly periodical "New Publications of the Geological Survey."

U.S. GEOLOGICAL SURVEY: OPEN-FILE REPORTS are available only through:

U.S. Geological Survey
Books and Open-File Reports Section
Building 810, Federal Center
Box 25425
Denver, CO 80225

When ordering, please use the Open-File Report number and full title.

U.S. GEOLOGICAL SURVEY: WATER-RESOURCES INVESTIGATIONS REPORTS--Most are available through Books and Open-File Reports (same address as above). When ordering, please use the Water-Resources Investigations Report number and full title.

U.S. GEOLOGICAL SURVEY: WATER-RESOURCES DATA REPORTS for Washington and for the 1989 water year are available only from:

National Technical Information Service
U.S. Department of Commerce
Springfield, VA 22161

When ordering, please use the NTIS number.

U.S. GEOLOGICAL SURVEY: PROFESSIONAL PAPERS, BULLETINS, WATER-SUPPLY PAPERS, TECHNIQUES OF WATER-RESOURCES INVESTIGATIONS, CIRCULARS are available from:

U.S. Geological Survey
Books and Open-File Reports Section
Building 810, Federal Center
Box 25425
Denver, CO 80225

U.S. GEOLOGICAL SURVEY: WATER-RESOURCES INVESTIGATIONS OPEN-FILE REPORTS are listed in the U.S. Geological Survey monthly periodical "New Publications of the Geological Survey" in section Reports Available Only Through Certain Geological Survey Field Offices, and are available only from:

State Chief, Washington Office
U.S. Geological Survey
Water Resources Division
1201 Pacific Avenue, Suite 600
Tacoma, Washington 98402

U.S. GEOLOGICAL SURVEY: MAPS can be purchased by mail at:

Distribution Branch
U.S. Geological Survey
P.O. Box 25286, Federal Center
Denver, Colorado 80225

PROFESSIONAL PAPERS

383-A. Storage of ground water behind subsurface dams in the Columbia River Basalt, Washington, Oregon, and Idaho, by R.C. Newcomb. 1961.

383-C. Effect of tectonic structure on the occurrence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington, by R.C. Newcomb. 1969.

417-D. Chemical quality of the surface waters of the Snake river basin, by L.B. Laird. 1964.

422-A. Morphology and hydrology of a glacial stream--White River, Mount Rainier, Washington, by R.K. Fahnestock. 1963.

424-B. Short papers in the geologic and hydrologic sciences, Articles 1-146, by U.S. Geological Survey: Article 7, Distinctive characteristics of glacier runoff, by M.F. Meier and W.V. Tangborn, p. B14-B16; Article 86, Mass budget of South Cascade Glacier, 1957-60, by M.F. Meier, p. B206-211; Structural barrier reservoirs of ground water in the Columbia River Basalt, by R.C. Newcomb, p. B213-B215; Recent hydrologic trends in the Pacific Northwest, by W.D. Simons,p. B17. 1961.

424-C. Computation of the total flow of the Columbia River at the mouth, byH.M. Orem. 1961.

433-N. Radionuclides in transport in the Columbia River from Pasco to Vancouver, Washington, by W.L. Haushild, H.H. Stevens, Jr., I.L. Nelson, and G.R. Dempster, Jr. 1973.

450-C. Short papers in geology and hydrology, Articles 60-119, by U.S. Geological Survey; Article 107, Artificial recharge of basalt aquifers, Walla Walla, Washington, by A.A. Garrett, p. C116-C117. 1962.

450-E. Highly productive aquifers in the Tacoma area, Washington, by K.L. Walters, in Geological Survey Research, 1963, by U.S. Geological Survey, p. E157-E158. 1963.

475-B. Contamination by sea-water intrusion along the Puget Sound, Washington, an area having abundant precipitation, by G.E. Kimmel, in Geological Survey Research 1963, Short papers in geology and hydrology, by U.S. Geological Survey, p. B182-B185. 1963.

525-C. Stratigraphy of the upper part of the Yakima Basalt in Whitman and eastern Franklin Counties, Washington, in U.S. Geological Survey Research 1965, by J.W. Bingham and K.L. Walters. 1965.

525-D. Chemical distinction between ground water of four sedimentary units on the Kitsap Peninsula and adjacent islands, Washington, by A.S. Van Denburgh. 1965.

575-B. Movement and dispersion of fluorescent dye in the Duwamish River estuary, Washington, by J.R. Williams, in Geological Survey Research 1967, Chapter B, by U.S. Geological Survey, p. B245-B249, 1967.

575-D Prediction of salt-water intrusion in the Duwamish River estuary, King County, Washington, by J.D. Stoner, in Geological Survey Research 1967, by U.S. Geological Survey, p. D253-D255. 1967.

582-A. Methods for predicting dispersion coefficients in natural streams with applications to the lower reaches of the Green and Duwamish Rivers, Washington, by H.B. Fisher. 1968.

600-D. Glacier outburst floods in the Pacific Northwest, by Donald Richardson, p. D79-D86; A water-balance equation for the Rathdrum Prairie ground-water reservoir, near Spokane, Washington, by E.J. Pluhowski and C.A. Thomas, p.D75-D78, in Geological Survey Research 1968, by U.S. Geological Survey. 1968.

631. Analysis of a 24-year photographic record of Nisqually Glacier, Mount Rainier National Park, Washington, by F.M. Veatch. 1969.

650-B. Temperature analysis of a stream, by M.R. Collings, in Geological Survey Research 1969, Chapter B, by U.S. Geological Survey, p. B174-B179. 1969.

705-A. Inventory of glaciers in the North Cascades, Washington, by Austin Post, Donald Richardson, W.V. Tangborn, and F.L. Rosselot. 1971.

715-A. Combined ice and water balances of Gulkana and Wolverton Glaciers, Alaska, and South Cascade Glacier, Washington, 1965 and 1966 hydrological years, by M.F. Meyer, W.V. Tangborn, L.R. Mayo, and Austin Post. 1971.

715-B. Combined ice and water balances of Maclure Glacier, California, South Cascade Glacier, Washington, and Wolverine and Gulkana Glaciers, Alaska--1967 hydrologic year, by W.V. Tangborn, L.R. Mayo, D.R. Scully, and R.M. Krimmel. 1977.

717. Geology and ground-water characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington, by R.C. Newcomb, J.R. Strand, and F.J. Frank. 1972.

750-C. Plant nutrients and the estuary mechanism in the Duwamish River estuary, Seattle, Washington, by L.J. Tilley and W.A. Dawson, in Geological Survey Research 1971, Chapter C, by U.S. Geological Survey, p. C185-C191. 1971.

813-S. Summary appraisals of the nation's ground-water resources, Pacific Northwest Region, by B.L. Foxworthy. 1979.

917. A numerical model of material transport in salt-wedge estuaries, Part I. Description of the model, by H.B. Fischer; Part II. Model computation of salinity and salt-wedge dissolved oxygen in the lower Duwamish River estuary, King County, Washington, by J.D. Stoner, W.L. Haushild, and J.B. McConnell. 1975.

990. Numerical model of the salt-wedge reach of the Duwamish River estuary, King County, Washington, by E.A. Prych, W.L. Haushild, and J.D. Stoner. 1976.

1022-A. Assessment of increased thermal activity at Mount Baker, Washington, March 1975-March 1976, by David Frank, M.F. Meier, and D.A. Swanson. 1977.

1022-B. Water-quality effects on Baker Lake of recent volcanic activity at Mt. Baker, Washington, by G.C. Bortleson, R.T. Wilson, and B.L. Foxworthy. 1977.

1022-C. Postglacial volcanic deposits at Mount Baker, Washington, and potential hazards from future eruptions, by J.H. Hyde and D.R. Crandell. 1978.

1249. Volcanic eruptions of 1980 at Mount St. Helens, the first 100 days, by B.L. Foxworthy and Mary Hill. 1982.

1250. The 1980 eruptions of Mount St. Helens, Washington, edited by Peter W. Lipman and Donal R. Mullineaux. 1981.

1345. The effects of ground water, slope stability, and seismic hazard on the stability of the South Fork Castle Creek blockage in the Mount St. Helens area, Washington, by William Meyer, M.A. Sabol, H.X. Glicken, and Barry Voight. 1984.

1447-A. Lahars and lahar-runout flows in the Toutle-Cowlitz River system, Mount St. Helens, Washington--origins, behavior, and sedimentology, by Kevin M. Scott. 1988.

1447-B. Lahars and lahar-runout flows in the Toutle-Cowlitz River system, Mount St. Helens, Washington--magnitude and frequency of lahars and lahar-runout flows in the Toutle-Cowlitz River system, by Kevin M. Scott. 1989.

HYDROLOGIC INVESTIGATIONS ATLASES

313. Ground-water occurrence in the Goldendale area, Klickitat County, Washington, by J.E. Luzier. 1968.

385. Stream temperatures in Washington State, by M.R. Collings and G.T. Higgins. 1973.

617. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound region, Washington, by G.C. Bortleson, M.J.Chrzastowski, and A.K. Helgerson. 1980.

WATER-SUPPLY PAPERS

55. Geology and water resources of a portion of Yakima County, Washington, by G.O. Smith. 1901.

111. Preliminary report on the underground waters of Washington, by Henry Landes. 1905.

118. Geology and water resources of a portion of east-central Washington, by F.C. Calkins. 1905.

316. Geology and water resources of a portion of south-central Washington, by G.A. Waring. 1913.

339. Quality of the surface water of Washington, by Walton Van Winkel. 1914.

425-E. Ground water in Quincy Valley, Washington, Chapter E, in Contributions to the hydrology of United States, 1917, p. 131-161, A.T. Schwennesen and O.E. Meinzer. 1919.

889-B. Water-table fluctuations in the Spokane Valley and contiguous area, Washington-Idaho, Chapter B, in Contributions to the hydrology of the United States, 1941-43, p. B83-B138, by A.M. Piper and G.A. LaRocque, Jr. 1944.

968-B. Floods of the Puyallup and Chehalis River basins, Washington, by I.E. Anderson. 1948.

1135. Ground-water resources of Snohomish County, Washington, by R.C. Newcomb. 1953.

1220. Irrigation and streamflow depletion in the Columbia River basin above The Dalles, Oregon, by W.D. Simons. 1953.

1316. Compilation of records of surface waters of the United States through September 1950--part 12, by U.S. Geological Survey. 1955. (Earliest station records began in 1878 for the Columbia River near The Dalles, Oregon.)

1317. Compilation of records of surface waters of the United States through September 1950--part 13, by U.S. Geological Survey. 1956. (Earliest station records began in 1878 for the Columbia River near The Dalles, Oregon.)

1318. Compilation of records of surface waters of the United States through September 1950--part 14, by U.S. Geological Survey. 1958. (Earliest station records began in 1878 for the Columbia River near The Dalles, Oregon.)

1413. Geology and ground-water resources of Kitsap County, Washington, by J.E. Sceva. 1957.

1499. Water resources of the Tacoma area, Washington, Chapter B, in Water resources of industrial areas, p. B1-B99, by W.C. Griffin, J.E. Sceva, H.A. Swenson, and M.J. Mundorff. 1962.

1527. Floods in Skagit River basin, Washington, by J.E. Stewart and G.L. Bodhaine. 1961.

1539-I. Evaluation of bank storage along the Columbia River between Richland and China Bar, Washington, by R.C. Newcomb and S.G. Brown. 1961.

1594-A. Artificial recharge through a well tapping basalt aquifers, Walla Walla area, Washington, by C. E. Price. 1961.

1594-C. Artificial recharge in Oregon and Washington, 1962, by Don Price, D.H. Hart, and B.L. Foxworthy. 1965.

1595. Effects of hydraulic and geologic factors on streamflow of the Yakima River basin, Washington, by H.B. Kinnison and J.E. Sceva. 1964.

1598. Geology and ground-water resources of Ahtanum Valley, Yakima County, Washington, by B.L. Foxworthy. 1962.

1600. Geology and ground-water resources of Clark County, Washington, with a description of a major alluvial aquifer along the Columbia River, by M.J. Mundorff. 1964.

1655. Ground water in the Pullman area, Whitman County, Washington, by B.L. Foxworthy and R.L. Washburn. 1963.

1687. Magnitude and frequency of floods in the United States--Part 12, Pacific Slope basins in Washington and upper Columbia River basin, by G.L. Bodhaine and D.M. Thomas. 1964.

1688. Magnitude and frequency of floods in the United States--Part 13, Snake River basin, by C.A. Thomas, H.C. Broom, and J.E. Cummans. 1963.

1689. Magnitude and frequency of floods in the United States--Part 14, Pacific Slope basins in Oregon and lower Columbia River basin, by Harry Hulsing and N.A. Kallio. 1964.

1736. Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 12, by U.S. Geological Survey.1964.

1737. Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 13, by U.S. Geological Survey.1963.

1738. Compilation of records of surface waters of the United States, October 1950 to September 1960--Part 14, by U.S. Geological Survey. 1963.

1784. Quality of surface waters in the lower Columbia River basin, by J.F. Santos. 1965.

1798-H. Sediment transport by streams in the Chehalis River basin, Washington, October 1961-September 1965, by P.A. Glancy. 1971.

1839-J. Evaluation of seepage from Chester Morse Lake and Masonry Pool, King County, Washington, by F.T. Hidaka and A.A. Garrett. 1967.

1852. Water resources of King County, Washington, by Donald Richardson, J.W. Bingham, and R.J. Madison. 1968.

1868. Sediment transport by streams in the Walla Walla River basin, Washington and Oregon, July 1962-June 1965, by B.E. Mapes. 1969.

1869-F. Analysis of current-meter data at Columbia River gaging stations, Washington and Oregon, by John Savini and G.L. Bodhaine. 1971.

1873-A. Factors initiating phytoplankton blooms and resulting effects on dissolved oxygen in Duwamish River estuary, Seattle, Washington, by E.B. Welch. 1969.

1873-B. Estuarine studies in upper Grays Harbor, Washington, by J.P. Beverage and M.N. Swecker. 1969.

1873-C. Physical, chemical, and biological aspects of the Duwamish River estuary, King County, Washington, 1963-67, by J.F. Santos and J.D. Stoner. 1972.

1873-D. Measurement of salt-wedge excursion distance in the Duwamish River estuary, Seattle, Washington, by means of the dissolved oxygen gradient, by W.A. Dawson and L.J. Tilley. 1972.

1873-F. Determination of mass balance and entrainment in the stratified Duwamish River estuary, King County, Washington, by J.D. Stoner. 1972.

1899-C. Sediment transport by streams in the Palouse River basin, Washington and Idaho, July 1961 - June 1965, by P.R. Boucher. 1970.

1968. The hydrology of four streams in western Washington as related to several Pacific salmon species, by M.R. Collings, R.W. Smith, and G.T. Higgins. 1972.

1990. Annotated bibliography on artificial recharge of ground water, 1955-67, by D.C. Signor, D.J. Growitz, and William Kam. 1970.

1999-N. Quality of the ground water in basalt of the Columbia River Group, Washington, Oregon, and Idaho, by R.C. Newcomb. 1972.

2020. Subsurface waste disposal by means of wells--a selective annotated bibliography, by D.R. Rima, E.B. Chase, and B.M. Myers. 1971.

2029-B. Generalization of stream-temperature data in Washington, by M.R. Collings. 1973.

2036. Digital-simulation and projection of water-level declines in basalt aquifers of the Odessa-Lind area, east-central Washington, by J.E. Luzier and J.A. Skrivan. 1975.

2240. Estimation of nonpoint-source loadings of phosphorus for lakes in the Puget Sound Region, Washington, by R.J. Gilliam. 1983.

2250. National Water Summary 1983--Hydrologic events and issues, by the U.S. Geological Survey. 1984.

2265. The Spokane Aquifer, Washington: Its geologic origin and water-bearing and water-quality characteristics, by Dee Molenaar. 1988.

2300. National Water Summary 1985--Surface-water resources, by J.R. Williams. 1987.

2325. National Water Summary 1986--Ground-water quality, by S.S. Embrey. 1988.

CIRCULARS

109. Water resources of the Hamma Hamma, Duckabush, and Dosewallips Rivers, Washington, by F.F. Lawrence. 1952.

180. Evaluation of streamflow records in Yakima River basin, Washington, by H.B. Kinnison. 1952.

191. Floods in western Washington--frequency and magnitude in relation to drainage basin characteristics, by G.L. Bodhaine and W.C. Robinson. 1952.

356. Ground water in the Yelm area, Thurston and Pierce Counties, Washington, by M.J. Mundorff, J.M. Weigle, and G.D. Holmberg. 1955.

372. Water resources of the Portland, Oregon, and Vancouver, Washington, area, by W.C. Griffin, F.A. Watkins, Jr., and H.A. Swenson. 1956.

422. Availability of ground water at the border stations at Laurier and Ferry, Washington, by K.L. Walters. 1960.

850-B. Mudflows resulting from the May 18, 1980, eruption of Mount St. Helens, Washington, by J.C. Cummans. 1981.

850-C. Channel conditions in the lower Toutle and Cowlitz Rivers resulting from the mudflows of May 18, 1980, by R.E. Lombard, M.B. Miles, L.M. Nelson, D.L. Kresch, and P.J. Carpenter. 1981.

850-D. Effects of volcanism on the glaciers of Mount St. Helens, by M.M. Brugman and Austin Post. 1981.

850-E. Some chemical effects of the Mount St. Helens eruption on selected streams in the State of Washington, by J.M. Klein. 1984.

850-F. Toxicity of Mount St. Helens ash leachate to a blue-green alga, by D.M. McKnight, G.L. Feder, and E.A. Stiles. 1981.

850-G. Effects of Mount St. Helens eruption on selected lakes in Washington, by N.P. Dion and S.S. Embrey. 1981.

850-H. Effects of the Mount St. Helens eruption on the benthic fauna of the Toutle River, Muddy River, and Pine Creek drainage basins, Washington, by L.A. Fuste. 1981.

850-I. Emergency assessment of Mount St. Helens post-eruption flood hazards, Toutle and Cowlitz Rivers, Washington, by M.E. Jennings, V.R.Schneider, and P.E. Smith. 1981.

850-J. Characteristics of Columbia River sediment following the eruption of Mount St. Helens on May 18, 1980, by D.W. Hubbell, J.M. Laenen, and S.W. McKenzie. 1983.

850-K. Sediment deposition in the Columbia and lower Cowlitz Rivers, Washington-Oregon, caused by the May 18, 1980, eruption of Mount St.Helens, by F.P. Haeni, 1983.

WATER-RESOURCES INVESTIGATIONS REPORTS

9-73. Test-observation well near Paterson, Washington--Description and preliminary results, by H.E. Pearson. 1973.

11-73. The hydrology of ten streams in western Washington as related to several Pacific salmon species, by M.R. Collings and G.W. Hill. 1973.

39-73. Sediment transport by streams in the upper Columbia River basin, Washington, May 1969-June 1971, by L.M. Nelson. 1974.

42-73. Flood profiles and inundated areas along the lower Nisqually River, Washington, by J.E. Cummans. 1974,

62-73. Flood profiles and inundated areas along the Skokomish River, Washington, by J.E. Cummans. 1974.

8-74. Low-flow characteristics of streams in the Willapa Bay drainages, Washington, by M.R. Collings and F.T. Hidaka. 1974.

13-74. Flood profiles and inundated areas along the White River, Chelan County, Washington, by John Savini, V.F. Schneider, and D.E. LaFrance. 1974.

37-74. A method for the relative classification of lakes in the State of Washington from reconnaissance data, by G.C. Bortleson, N.P. Dion, and J.B. McConnell. 1974.

42-74. Water resources of the Toppenish Creek basin, Yakima Indian Reservation, Washington, by U.S. Geological Survey. 1975.

62-75. Evaluation of ground-water contamination from cleaning explosive-projectile casings at the Bangor Annex, Kitsap County, Washington--phase II, by J.V. Tracy and N.P. Dion. 1976.

77-62. Comparison of selected cultural, physical, and water-quality characteristics of lakes in Washington, by G.C. Bortleson and N.P. Dion. 1979.

77-94. Preliminary water-quality characterization of lakes in Washington, by G.C. Bortleson. 1978.

78-31. Progress report on water resources of the Tulalip Indian Reservation, Washington, by B.W. Drost. 1979.

78-44. Physical, chemical, and biological characteristics of Ross Lake, Snohomish County, Washington, by N.P. Dion. 1979.

78-64. Preferred and observed conditions for sockeye salmon in Ozette Lake and its tributaries, Clallam County, Washington, by G.C. Bortleson and N.P. Dion. 1979.

78-84. Flood profiles along the Cedar River, King County, Washington, by O.C. Hettick. 1979.

78-101. Water resources of the Nisqually Lake area, Pierce County, Washington, by H.E. Pearson and N.P. Dion. 1979.

78-112. Water resources of the Port Madison Indian Reservation, Washington, by W.E. Lum II. 1979.

78-130. Flood elevations for the Sooes River at proposed fish hatchery, Clallam County, Washington--A surface-water site study, by J.H. Bartells. 1979.

78-133. Sediment transport by the White River into Mud Mountain reservoir, Washington, June 1974-June 1976, by L.M. Nelson. 1979.

79-12. Water resources of the Swinomish Indian Reservation, Washington, by B.W. Drost. 1979.

79-33. Seepage study for unnamed tributary to Alder Creek, Stevens County, Washington, by P.J. Carpenter and B.W. Drost. 1979.

79-63. Environmental features, general hydrology, and external sources of nutrients affecting Wilderness Lake, King County, Washington, by N.P. Dion. 1979.

79-66. Water resources of the Port Gamble Indian Reservation, Washington, by W.E. Lum II. 1980.

79-81. Estimation of floods of various frequencies for the small ephemeral streams in eastern Washington, by W.L. Haushild, 1979.

79-82. Water resources of the lower Elwha Indian Reservation, Washington, by K.L. Walters, W.L. Haushild, and L.M. Nelson. 1979.

79-1530. Ground-water hydrology of the Sagebrush Flat area and possible relations to the discharge of Rattlesnake Springs, Grant and Douglas Counties, Washington, by K.L. Walters. 1980.

80-14. Submarine features and bottom configuration in the Port Townsend quadrangle, Puget Sound region, Washington, by M.J. Chrzastowski. 1980.

80-15. Water resources of the Makah Indian Reservation, Washington, by N.P. Dion, K.L. Walters, and L.M. Nelson. 1980.

80-955. Reconnaissance of water availability and quality in abandoned coal mines near Roslyn, Kittitas County, Washington, by F.A. Packard. 1981.

80-1124. Preliminary evaluation of lake susceptibility to water-quality degradation by recreational use, Alpine Lakes wilderness area,Washington, by R.J. Gilliom, D.P. Dethier, S.A. Safioles, and P.L. Heller. 1980.

80-1186. Ground-water availability on the Kitsap Peninsula, Washington, by A.J. Hansen, Jr., and E.L. Bolke. 1980.

80-1300. Digital-model simulation of the hydrologic flow system, with emphasis on ground water, in the Spokane Valley, Washington and Idaho, by E.L. Bolke and J.J. Vaccaro. 1981.

81-67. An engineering economic analysis of artificial recharge in a conjunction irrigation plan in the Columbia Basin Project, Washington, by M.R. Karlinger and A.J. Hansen, Jr. 1983.

81-425. Digital-model simulation of the Toppenish alluvial aquifer, Yakima Indian Reservation, Washington, by E.L. Bolke and J.A. Skrivan. 1981.

81-694. Modification of the Tangborn short-term hydrometeorological model, with trial results from the Baker River basin, Washington, by M.R. Karlinger and J.D. Wilson. 1981.

81-1021. Water resources of the Gig Harbor peninsula and adjacent areas, Washington, by B.W. Drost. 1982.

81-1182. Historical changes to Lake Washington and route of the Lake Washington ship canal, King County, Washington, by M.J. Chrzastowski. 1983.

82-508. Fluoride, nitrate, and dissolved-solids concentrations in ground waters of Washington, by W.E. Lum II and G.L. Turney. 1983.

82-561. Preliminary survey of ground-water resources for Island County, Washington, by D.R. Cline, M.A. Jones, N.P. Dion, K.J. Whiteman, and D.B. Sapik. 1982.

82-646. Simulation of streamflow temperatures in the Yakima River basin, Washington, April-October 1981, by J.J. Vaccaro. 1986.

82-648. Water resources of the Tulalip Indian Reservation, Washington, by B.W. Drost. 1983.

82-684. Lake-water quality and land-use relationships for selected lakes in the Port Townsend quadrangle, Puget Sound region, Washington, by R.J. Gilliom. 1983.

82-769. Evaluation of water-quality characteristics of part of the Spokane Aquifer, Washington and Idaho, using a solute-transport model, by J.J. Vaccaro and E.L. Bolke. 1983.

82-4010. Ground-water hydrology of the Toppenish Creek basin, Yakima Indian Reservation, Washington, by J.A. Skrivan. 1987.

82-4065. Numerical simulation of ground-water flow in lower Satus Creek basin, Yakima Indian Reservation, Washington, by E.A. Prych. 1983.

82-4125. Mudflow hazards along the Toutle and Cowlitz Rivers from a hypothetical failure of Spirit Lake blockage, by C.H. Swift III and D.L. Kresch. 1983.

83-4015. Phase I summary and phase II plan for comparing regulated with unregulated streamflow in the Yakima River at Union Gap, Washington, by C.H. Swift III. 1985.

83-4019. Occurrence, quality, and use of ground water in Orcas, San Juan, Lopez, and Shaw Islands, San Juan County, Washington, by K.J. Whiteman, Dee Molenaar, G.C. Bortleson, and J.M. Jacoby. 1983.

83-4057. General hydrology and external sources of nutrients affecting Pine Lake, King County, Washington, by N.P. Dion, S.S. Sumioka, and T.C. Winter. 1983.

83-4083. Flood elevations for the Soleduck River at Sol Duc Hot Springs, Clallam County, Washington, by L.M. Nelson. 1983.

83-4094. Impact of changes in land use on the ground-water system in the Sequim-Dungeness peninsula, Clallam County, Washington, by B.W. Drost. 1983.

83-4102. The quality of ground water in the principal aquifers of northeastern-north central Washington, by J.C. Ebbert. 1984.

83-4162. Quality of water, Quillayute River basin, Washington, by M.O. Fretwell. 1984.

83-4165. A reconnaissance of the water resources of the Shoalwater Bay Indian Reservation and adjacent areas, Pacific County, Washington, 1978-79, by W.E. Lum II. 1984.

83-4167. Sediment transport by irrigation return flows in four small drains within the DID-18 drainage of the Sulphur Creek basin, Yakima County, Washington, April 1978 to October 1981, by P.R. Boucher. 1984.

83-4178. Availability of water from the alluvial aquifer in part of the Green River valley, King County, Washington, by W.E. Lum II, R.C. Alvord, and B.W. Drost. 1984.

83-4185. Availability of ground water from the alluvial aquifer on the Nisqually Indian Reservation, Washington, by W.E. Lum II. 1984.

83-4197. Preliminary estimate of possible flood elevations in the Columbia River at Trojan Nuclear Power Plant due to failure of debris dam blocking Spirit Lake, Washington, by D.L. Kresch and Antonius Laenen. 1984.

83-4227. Water resources of Clallam County, Washington: Phase 1 report, by B.W. Drost. 1986.

83-4259. Test wells in central Washington, 1977 to 1979: Description and results, by W.E. Lum II and D.R. Cline. 1985.

84-4090. Principal surface-water inflow to Puget Sound, Washington, by J.R. Williams. 1984.

84-4093. The quality of water in the principal aquifers of southwestern Washington, by J.C. Ebbert and K.L. Payne.

84-4258. Quality of ground water in the Puget Sound region, Washington, by G.L. Turney. 1986.

84-4262. Quality of ground water in southeastern and south-central Washington, 1982, by G.L. Turney. 1986.

84-4279. Geologic, hydrologic, and cultural factors in the selection of sites for the land disposal of wastes in Washington, by N.P. Dion, R.C. Alvord, and T.D. Olson. 1986.

84-4293. Water-surface elevations for the high tide of December 15,1977, in the Puget Sound region, Washington, by L.M. Nelson. 1985.

84-4304. Geochemical controls on dissolved sodium in basalt aquifers of the Columbia Plateau, Washington, by P.P. Hearn, W.C. Steinkampf, G.C. Bortleson, and B.W. Drost. 1985.

84-4326. Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington, by B.W. Drost and K.J. Whiteman. 1986.

84-4351. A preliminary evaluation of hydrology and water quality near the Tacoma landfill, Pierce County, Washington, by W.E. Lum II and G.L. Turney. 1985.

84-4360. Maps showing ground-water levels in the Columbia River Basalt and overlying materials, spring 1983, southeastern Washington, by H.H. Bauer, J.J. Vaccaro, and R.C. Lane. 1985.

84-4361. Appraisal of ground-water conditions and potential for seawater intrusion at Tahola, Quinault Indian Reservation, Washington, by B.W. Drost. 1985.

85-4005. Occurrence of dissolved sodium in ground waters in basalts underlying the Columbia Plateau, Washington, by G.C. Bortleson and S.E. Cox. 1986.

85-4018. Reconnaissance of the water resources of the Hoh Indian Reservation and the Hoh River basin, Washington, by W.E. Lum II. 1986.

85-4046. Occurrence of ground water and potential for seawater intrusion, Island County, Washington, by M.A. Jones. 1985.

85-4048. Controls on ground-water chemistry in the Horse Heaven Hills, south-central Washington, by W.C. Steinkampf, G.C. Bortleson, and F.A. Packard. 1985.

85-4054. Impact on the Columbia River of an outburst of Spirit Lake, by W. G. Sikonia. 1985.

85-4080. Channel geometry, flood elevations, and flood maps, lower Toutle and Cowlitz Rivers, Washington, June 1980 to May 1981, by R.E. Lombard. 1986.

85-4151. Plan of study for the Regional Aquifer-System Analysis, Columbia Plateau, Washington, northern Oregon, and northwestern Idaho, by J.J. Vaccaro. 1986.

85-4232. Simulation of streamflow temperatures in the Yakima River basin, Washington, April-October 1981, by J.J. Vaccaro. 1986.

85-4254. Water quality of selected lakes in Mount Rainier National Park, Washington, with respect to lake acidification, by G.L. Turney, N.P. Dion, and S.S. Sumioka. 1986.

85-4274. Effects of coal mine drainage on the quality of small receiving streams in Washington, by F.A. Packard, E.L. Skinner, and L.A. Fuste. 1988.

85-4316. Effect of bank protection measures, Stehekin River, Chelan County,Washington, by L.M. Nelson. 1986.

85-4320. Quality of ground water in the Columbia Basin, Washington, 1983, by G.L. Turney. 1986.

86-4000. Quantity and quality of storm runoff from three urban catchments in Bellevue, Washington, by E.A. Prych and J.C. Ebbert. 1986.

86-4046. Ground-water levels in three basalt hydrologic units underlying the Columbia Plateau in Washington and Oregon, Spring 1984, by K.J. Whiteman. 1986.

86-4056. Effects of coal strip mining on stream water quality and biology, southwest- ern Washington, by L.A. Fuste and D.F. Meyer. 1987.

86-4154. Water quality in the lower Puyallup River valley and adjacent uplands, Pierce County, Washington, by J.C. Ebbert, G.C. Bortleson, L.A Fuste, and E.A. Prych. 1987.

86-4173. Geohydrologic reconnaissance of a ground-water contamination problem in the Argonne Road area near Spokane, Washington, by N.P. Dion. 1987.

86-4179. Flood characteristics for the Nisqually River and susceptibility of Sunshine Point and Longmire facilities to flooding in Mount Rainier National Park, Washington, by L.M. Nelson. 1987.

86-4198. Flood hazard assessment of the Hoh River at Olympic National Park ranger station, Washington, by D.L. Kresch. 1987

86-4326. The relation of streamflow to habitat for anadromous fish in the Stillaguamish River basin, Washington, by S.S. Embrey. 1987.

87-4006. Estimates of streamflow characteristics for selected small streams, Baker River basin, Washington, by J.R. Williams. 1987.

87-4045. Evaluation of available data on the geohydrology, soil chemistry, andground-water chemistry of Gas Works Park and surrounding region, Seattle, Washington, by M.A. Sabol, G.L. Turney, and G.N. Ryals. 1988.

87-4129. Flood-carrying capacities and changes in channels of the lower Puyallup, White, and Carbon Rivers in western Washington, by E.A. Prych. 1988.

87-4182. Ground-water resources and simulation of flow in aquifers containing freshwater and seawater, Island County, Washington, by D.B. Sapik, G.C. Bortleson, B.W. Drost, M.A. Jones, and E.A. Prych. 1989.

87-4237. Preliminary evaluation of the ground-water resources of Bainbridge Island, Kitsap County, Washington, by N.P. Dion, T.D. Olson, and K.L. Payne. 1988.

87-4263. Effects of the 1980 eruption of Mount St. Helens on the limnological characteristics of selected lakes in western Washington, by S.S. Embrey and N.P. Dion. 1988.

87-4268. Geohydrology and digital simulation of the ground water flow system in the Umatilla Plateau and Horse Heaven Hills area, Oregon and Washington, by A.D. Smith, E.L. Bolke, and C.A. Collins. 1987.

UNNUMBERED OPEN-FILE REPORTS

Anderson, D.G., and Bodhaine, G.L., 1956, Flood of 1956 in the Esquatzel Coulee area, Washington.

Anderson, H.W., Jr., 1969, Water supplies for Coulee Dam National Recreation area, Washington.

Bartells, J.H., and G.T. Higgins, 1966, Peak flows from small drainage areas in Washington--compilation, annual maximums through the 1965 water year.

Cline, D.R., 1969, Availability of ground water in the Federal Way area, King County, Washington.

_____, 1974, A ground-water investigation of the Lummi Indian Reservation area, Washington.

Collings, M.R., 1971, A proposed streamflow-data program for Washington State.

_____, 1973, Data on selected lakes in Washington, Part I.

_____, 1974, Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington.

Collings, M.R., Smith, R.W., and Higgins G.T., 1970, The hydrology of four streams in western Washington as related to several Pacific salmon species.

_____, 1972, The hydrology of four streams in western Washington as related to several Pacific salmon species--Humptulips, Elochoman, Green, and Wynoochee Rivers.

Cummans, J.E., and Nassar, E.G., 1975, Low-flow characteristics of streams in the Grays Harbor drainages, Washington.

Dion, N.P., 1974, A proposal for the investigation of possible ground-water contamination in the Bangor area, Kitsap County, Washington.

_____, 1974, Data from a reconnaissance of selected lakes in Washington.

Eakin, T.E., 1946, Ground water resources of the Waterville area, Douglas County, Washington.

Fisher, H.B., 1974, A numerical model of material transport in saltwedge estuaries: Part 1. Description of the model; Part 2. Model computation of salinity and saltwedge dissolved oxygen in the lower Duwamish River estuary, King County, Washington.

Foxworthy, B.L., 1972, Emergency ground-water supplies in the Seattle-Tacoma urban complex and adjacent areas, Washington.

Foxworthy, B.L., and Washburn, R.L., 1956, Reconnaissance investigation of ground water in the Wellpinit area, Stevens County, Washington,

Foxworthy, B.L., and Nassar, E.G., 1975, Flood hazards in the Seattle-Tacoma urban complex and adjacent areas, Washington.

Garrett, A.A., and Walters, K.L., 1960, The status of ground-water investigations in the State of Washington.

Garrett, A.A., and Londquist, C.J., 1972, Feasibility of artificially recharging basalt aquifers in eastern Washington.

Gregg, D.O., and Lum, W.E.II, 1973, Dry Creek exploration test well.

Harkness, R.E., Myers, D.A., and Bortleson, G.C., 1974, Water resources of the Colville Indian Reservation, Washington.

Hart, D.H., 1957, Feasibility of recharging basalt aquifers in the Walla Walla area, Washington.

_____, 1958, Artificial recharge to ground water in Oregon and Washington.

_____, 1958, Tests of artesian wells in the Cold Creek area, Washington.

Haushild, W.L., Perkins, R.W., Stevens, H.H., Jr., Dempster, G.R., Jr., and Glenn, J.L., 1966, Radionuclide transport in the Pasco-to-Vancouver reach of the Columbia River, July 1962 to September 1963.

Haushild, W.L., and Stoner, J.D., 1973, Predicted effects of proposed navigation improvements on residence time and dissolved oxygen of the salt wedge in the Duwamish River estuary, King County, Washington.

Haushild, W.L., Dempster, G.R., Jr., and Stevens, H.H., Jr., 1973, Distribution of radionuclides in the Columbia River streambed from the nuclear reactors, Hanford Reservation, to Longview, Washington.

Hidaka, F.T., 1972, Low-flow characteristics of streams in the Puget Sound region, Washington.

_____, 1972, Low flows and temperatures of streams in the Seattle-Tacoma urban complex and adjacent areas, Washington.

LaFrance, D.E., 1975, Low-flow characteristics of selected streams in north-eastern Washington.

Laird, L.B., and Walters, K.L., 1967, Municipal, industrial, and irrigation water use in Washington, 1965.

LaRocque, G.A., Jr., and Piper, A.M., 1938, Ground water in the Tacoma area, Washington, progress report No. 2.

La Sala, A.M., and Doty, G.C., 1971, Preliminary evaluation of hydrologic factors related to radioactive waste storage in basaltic rocks at the Hanford Reservation, Washington.

Liesch, B.A., 1955, Records of wells, water levels, and quality of ground water, Sammamish Lake area, King County, Washington.

Longfield, R.J., 1974, Floods of January 1974 in Washington.

Luzier, J.E., 1964, Ground-water supply for Mount Rainier National Park Headquarters site near Ashford, Washington.

Molenaar, Dee, and Cummans, J.E., 1973, Water resources of the Skokomish Indian Reservation, Washington.

Mundorff, M.J., 1953, Ground-water conditions in the Columbia Basin Project.

_____, 1953, Availability of ground water to supplement surface water irrigation supplies in the Yakima River basin, Washington.

Mundorff, M.J., Reis, D.J., and Strand, J.R., 1952, Progress report on ground water in the Columbia Basin Project, Washington.

Mundorff, M.J., and Bodhaine, G.L., 1954, Investigation of the rise in level of Soap Lake at Soap Lake, Washington.

Myers, D.A., 1972, Test-observation well near Davenport, Washington: description and preliminary results.

Myers, D.A., and Cummans, J.E., 1973, Water resources of the Nisqually Indian Reservation, Washington.

Nassar, E.G., 1965, Effects of wind and atmospheric pressure on storagemeasurements at Roosevelt Lake, Washington.

_____, 1973, Low-flow characteristics of streams in the Pacific Slope basins and lower Columbia River basin, Washington.

Nelson, L.M., 1971, Sediment transport by streams in the Snohomish River basin, Washington, October 1967-June 1969.

_____, 1972, Potential transport of sediment from Enloe Reservoir by the Similkameen and Okanogan Rivers, Washington.

_____, 1974, Sediment transport by streams in the Deschutes and Nisqually River basins, Washington, November 1971-June 1973.

Newcomb, R.C., 1947, Ground water of the South Bar area, Grays Harbor, Washington.

_____, 1948, Ground water in the Kennewick area, Washington.

_____, 1949, Geologic and ground-water data on the central part of the Walla Walla basin, Washington and Oregon.

_____, 1951, Preliminary report on the ground-water resources of the Walla Walla basin, Washington-Oregon.

_____, 1958, Ground water of the Columbia Basin.

_____, 1958, Repair of leaking artesian wells in upper Cold Creek Valley, Benton County, Washington.

Newcomb, R.C., Sceva, J.E., and Stromme, Olaf, 1949, Ground water resources of western Whatcom County, Washington.

Newcomb, R.C., and others, 1953, Seismic cross sections across the Spokane River valley and the Hillyard Trough, Idaho and Washington.

Pardee, J.T., 1931, Report on the occurrence of artesian water at the United States Navy Yard, Kitsap County, Washington.

Parker, G.G., Jr., 1971, Municipal, industrial, and irrigation water use in Washington, 1970.

_____, 1974, Public water supplies in the Seattle-Tacoma urban complex and adjacent areas, Washington.

_____, 1974, Urbanized areas served by sewers and septic tanks in the Seattle-Tacoma urban complex and adjacent areas, Washington.

_____, 1974, Surface-water investigations on the Lummi Indian Reservation, Washington.

Piper, A.M., 1930, Water supply of the United States penitentiary at McNeil Island, Washington.

Piper, A.M., Robinson, T.W., and Thomas, H.E., 1933, Ground water in the Walla Walla basin, Oregon-Washington.

Piper, A.M., and LaRocque, G.A., Jr., 1938, Ground water in the Tacoma area, Washington, progress report No. 1.

Piper, A.M., and Huff, L.C., 1943, Some ground-water features of Rathdrum Prairie-Spokane Valley area, Idaho-Washington, with respect to seepage loss from Pend Oreille Lake.

Richardson, Donald, 1962, Drainage-area data for western Washington.

_____, 1965, Effect of logging on runoff in upper Green River basin, Washington.

Robinson, J.W., 1946, Typical wells and springs of the Tacoma area, Washington.

Robinson, J.W., and Piper, A.M., 1942, Water levels in observation wells and stages of certain lakes of the Tacoma area, Washington.

Rorabaugh, M.I, and Simons, W.D., 1966, Exploration of methods of relating ground water to surface water, Columbia River basin, second phase.

Rorabaugh, M.I., Simons, W.D., Garrett, A.A., and McMurtrey, R.G., 1966, Exploration of methods of relating ground water to surface water, Columbia River basin, first phase.

Sceva, J.E., 1950, Preliminary report on the ground-water resources of south-western Skagit County, Washington.

Sceva, J.E., Watkins, F.A., Jr., and Schlax, W.N., Jr., 1949, Geology and ground-water resources of Wenas Creek valley, Yakima County, Washington.

Sceva, J.E., Wegner, D.E., and others, 1955, Records of wells and springs, water levels, and quality of ground water in central Pierce County, Washington.

Schlax, W.N., Jr., 1947, Preliminary report on ground-water resources of the central Chehalis valley, Washington.

Scott, W.R., 1969, Characteristics of streamflow in the Colville River basin, Stevens County, Washington.

Taylor, G.C., Jr., 1941, Summary of ground-water conditions in parts of the Columbia Basin Project area with respect to development of domestic livestock water supplies.

_____, 1944, Factual data pertaining to wells and springs in the Columbia Basin Project area, Washington.

_____, 1948, Ground water in the Quincy Basin, Wahluke Slope, and Pasco Slope subareas of the Columbia Basin Project, Washington.

U.S. Geological Survey, 1961-64, Surface water records of Washington. [published annually]

_____, 1964, Water quality records in Washington. [published annually]

_____, 1965-74, Water resources data for Washington, Part 1, Surface water records. [published annually]

_____, 1965-74, Water resources data for Washington, Part 2, Water quality records. [published annually]

_____, 1971, An evaluation of ground-water conditions in the vicinity of the Bel Bay development, Lummi Indian Reservation, Washington.

_____, 1976, Water resources data for Washington, water year 1975. [published annually]

_____, 1976, Hydrologic unit map--1974, State of Washington, scale 1:500,000.

_____, 1977-88, Water resources data for Washington, volume 2 Eastern Washington. [published annually]

_____, 1978, Water-resources investigations in Washington, 1978: U.S. Geological Survey folder.

Veatch, F.M., Kimmel, G.E., and Johnston, E.A., 1966, Surface- and ground-water conditions during 1959-61 in part of Flett Creek basin, Tacoma, Washington.

Waananen, A.O., 1965, Hydrology of the Willapa Bay area, Washington.

Walters, K.L,. 1965, Ground-water supply for a new Navy installation at Zelatched Point, Jefferson County, Washington.

_____, 1970, Water supplies for selected sites in Olympic National Park, Washington.

_____, 1972, Test-observation well near Almira, Washington: Description and preliminary results.

Walters, K.L., Cline, D.R., and Luzier, J.E., 1972, Test-observation well near Odessa, Washington: Description and preliminary results.

Washburn, R.L., 1954, Preliminary investigation of ground water in East Sound area, Orcas Island, San Juan County, Washington.

_____, 1957, Ground water in the Lummi Indian Reservation, Whatcom County, Washington.

Wegner, D.E., 1956, Preliminary investigation of ground water in the Grayland watershed, Grays Harbor and Pacific Counties, Washington.

Weigle, J.M., and Mundorff, M.J., 1952, Records of wells, water levels, and quality of ground water in the Spokane Valley, Spokane County, Washington.

Weigle, J.M., and Washburn, R.L., 1956, Records of wells and springs, water levels, and quality of ground water in Lewis County, Washington.

Williams, J.R., 1964, Drainage-area data for eastern Washington.

Wilson, R.T., and Fretwell, M.O., 1976, Table of data on quality of surface waters and of snowpack drainage to Baker River from Mount Baker, Washington.

NUMBERED OPEN-FILE REPORTS

74-336. Magnitude and frequency of floods in Washington, by J.E. Cummans, M.R. Collings, and E.G. Nassar. 1975.

75-19. A general outline of the water resources of the Toppenish Creek basin, Yakima Indian Reservation, Washington, by D.O. Greggs and L.B. Laird. 1975.

75-67. Reconnaissance study of sediment transport by selected streams in the Yakima Indian Reservation, Washington, 1974 water year, by P.R. Boucher. 1975.

75-155. Estimation of stream discharges preferred by steelhead trout for spawning and rearing in Washington, by C.H. Swift III. 1976.

75-344. Solid-waste disposal sites in relation to water resources in the Seattle-Tacoma urban complex and vicinity, Washington, by R.T. Wilson. 1975.

75-395. Flood profiles and inundated areas along the Deschutes River, Washington, by J.R. Williams. 1976.

75-518. Reconnaissance of the water resources of the upper Klickitat River basin, Yakima Indian Reservation, Washington, by D.R. Cline. 1976.

76-195. Table of data on water quality of Baker Lake near Mount Baker, Washington, by G.C. Bortleson and R.T. Wilson. 1976.

76-351. Availability of ground water in the area surrounding the Trident Submarine Construction Facility, Kitsap County, Washington, by A.J. Hansen, Jr., and Dee Molenaar. 1976.

76-382. Reconnaissance of ground-water resources of the Squaxin Island Indian Reservation, Washington, by W.E. Lum II and K.L. Walters. 1976.

76-415. Modeling coliform-bacteria concentrations and pH in the salt-wedge reach of the Duwamish River estuary, King County, Washington, by W.L. Haushild and E.A. Prych. 1976.

76-495. Preliminary assessment of the water resources of the Tulalip Indian Reservation, Washington, by B.W. Drost. 1977.

76-685. Water resources of the Satus Creek basin, Yakima Indian Reservation, Washington, by M.J. Mundorf, R.D. McNish, and D.R. Cline. 1977.

76-704. Low-flow characteristics of streams on the Kitsap Peninsula and selected adjacent islands, Washington, by J.E. Cummans. 1977.

76-808. Outline of the water resources of the Satus Creek basin, Yakima Indian Reservation, Washington, by Dee Molenaar. 1977.

77-128. Quality of surface and ground waters, Yakima Indian Reservation, Washington, by M.O. Fretwell. 1979.

77-308. Municipal, industrial, and irrigation water use in Washington--1975 by N.P. Dion and W.E. Lum II. 1977.

77-422. Preferred stream discharges for salmon spawning and rearing in Washington, by C.H. Swift III. 1979.

77-455. Test-well drilling in the upper Satus Creek basin, Yakima Indian Reservation, Washington, by H.E. Pearson. 1977.

77-647. Ground-water resources of the North Beach Peninsula, Pacific County, Washington, by J.V. Tracy. 1987.

77-704. Water resources of the Chehalis Indian Reservation, Washington, by H.E. Pearson and G.T. Higgins. 1979.

77-812. Low-flow characteristics of streams on the Olympic Peninsula, Washington, by W.L. Haushild and D.E. LaFrance. 1978.

77-829. Spokane Valley-Rathdrum Prairie Aquifer, Washington and Idaho, by B.W. Drost and H.R. Seitz. 1978.

78-167. Evaluation and design of a streamflow-data network in Washington, by M.E. Moss and W.L. Haushild, 1978.

78-291. Rainfall-runoff data for selected basins, Portland, Oregon, and Vancouver, Washington, 1973-77, by Antonius Laenen and G.L. Solin. 1978.

78-946. Sediment transport by irrigation return flows in the lower Yakima River basin, Washington, 1975 and 1976 irrigation seasons, by L.M. Nelson. 1979.

78-947. Sediment transport by irrigation return flows, on the Yakima Indian Reservation, Washington, 1975 and 1976 irrigation seasons, by L.M. Nelson. 1979.

79-333. Selected hydrologic data for Spokane Valley, Spokane, Washington, 1977-78, by E.L. Bolke and J.J. Vaccaro. 1979.

79-741. Hydrometeorological model for streamflow prediction, by W.V. Tangborn. 1979.

79-978. Analyses of trace metals associated with bottom material and biological communities in Salmon Creek basin, Clark County, Washington, by A.C. White and S.W. McKenzie. 1979.

79-1465. Reconnaissance data on lakes in the Alpine Lakes wilderness area, Washington, by D.P. Dethier, P.L. Heller, and S.A. Safioles. 1979.

80-328. Estimation of background loadings and concentrations of phosphorus for lakes in the Puget Sound region, Washington, by R.J. Gilliom. 1980.

80-430. Availability, distribution, and uses of data from wells, springs, and test holes in the Port Townsend quadrangle, Puget Sound region, Washington, by David Frank. 1980.

80-440. An analysis of reservoir storage contents for the proposed enlargement of Bumping Lake in Washington, by J.H. Bartells. 1981.

81-639. Low-flow characteristics of streams in the Deschutes River basin, Washington, by J.E. Cummans. 1981.

81-822. Sediment data for streams near Mount St. Helens, Washington, volume 1. 1980 water-year data, by R. L. Dinehart, J.R. Ritter, and J.M. Knott. 1981.

81-1007. Surface-water-quality data from selected sites in Washington affected by Mount St. Helens eruptions: March 27-September 30, 1980, by G.L. Turney and J.M. Klein. 1982.

81-1008. Irrigation-water quality in the Sulphur Creek basin, Yakima and Benton Counties, Washington, April 1976 through March 1977, by P.R. Boucher and M.O. Fretwell. 1982.

82-161. Estimation of nonpoint-source loadings of phosphorus for lakes in the Puget Sound region, Washington, by R.J. Gilliom. 1982.

82-172. Ground water-surface water relationships in the Bonaparte Creek basin, Okanogan County, Washington, 1979-80, by F.A. Packard, S.S. Sumioka, and K.J. Whiteman. 1983.

82-185. Chemical characteristics for western Washington rivers, 1961-80, by D.P. Dethier. 1982.

82-561. Preliminary survey of ground-water resources for Island County, Washington, by D.R. Cline, M.A. Jones, N.P. Dion, K.J. Whiteman, and D.B. Sapik. 1982.

82-627. Streamflow and sediment transport in the Quillayute River basin, Washington, by L.M. Nelson. 1982.

82-770. Spirit Lake dam-failure flood routing assessment, by D.L. Kresch. 1985.

82-771. Filling of Spirit Lake, Washington, May 18, 1980, to July 31, 1982, by William Meyer and P.J. Carpenter. 1983.

82-907. Lake phosphorus loading from septic systems by seasonally perched ground water, Puget Sound region, Washington, by R.J. Gilliom and C.R. Patmont. 1982.

83-205. Data supplement to: Quality of coal mine drainage in Washington, 1975-77, by L.A. Fuste, F.A. Packard, M.O. Fretwell, and D.P. Garland. 1983.

83-541. The Nisqually Glacier, Mount Rainier, Washington, 1857-1979: A summary of the long-term observations and a comprehensive bibliography, by C.C. Heliker, Arthur Johnson, and S.M. Hodge. 1984.

84-064. Data collected by the U.S. Geological Survey during a study of urban runoff in Bellevue, Washington, 1979-82, by J.C. Ebbert, J.E. Poole, and K.L. Payne. 1985.

84-144A. Streamflow statistics and drainage-basin characteristics for the Puget Sound region: Volume I. Western and southern Puget Sound, by J.R. Williams, H.E. Pearson, and J.D. Wilson. 1985.

84-144B. Streamflow statistics and drainage-basin characteristics for the Puget Sound region: Volume II. Eastern Puget Sound from Seattle to the Canadian border, by J.R. Williams, H.E. Pearson, and J.D. Wilson. 1985.

84-145A. Streamflow statistics and drainage-basin characteristics for the southwestern and eastern regions, Washington, Volume I. Southwestern Washington, by J.R. Williams and H.E. Pearson. 1985.

84-145B. Streamflow statistics and drainage-basin characteristics for the southwestern and eastern regions, Washington, Volume II. Eastern Washington, by J.R. Williams and H.E. Pearson. 1985.

84-614. Changes in channel geomorphology of six eruption-affected tributaries of the Lewis River, 1980-82, Mount St. Helens, Washington, by H.A. Martinson, S.D. Finneran, and L.J. Topinka. 1984.

85-412. Post-eruption changes in channel geometry of streams in the Toutle River drainage basin, 1980-82, Mount St. Helens, Washington, by D.F. Meyer, K.M. Nolan, and J.E. Dodge.1986.

85-496. A preliminary evaluation of the geohydrology and water quality of the Greenacres landfill area, Spokane County, Washington, by W.E. Lum II, G.L. Turney, and R.C. Alvord. 1986.

85-631. Channel geometry and hydrologic data for six eruption-affected tributaries of the Lewis River, Mount St. Helens, Washington, water years 1983-84, by H.A. Martinson, H.E. Hammond, W.W. Mast, and P.D. Mango. 1986.

85-632. Sediment data for streams near Mount St. Helens, Washington, volume 2. water years 1981-83, by R.L. Dinehart. 1986.

86-61. Data on snow chemistry of the Cascade-Sierra Nevada Mountains, by L.B. Laird, H.E. Taylor, and R.E. Lombard. 1986.

86-536. Documentation of a deep percolation model for estimating ground-water recharge, by H.H. Bauer and J.J. Vaccaro. 1987.

87-222. Subsurface transport of radionuclides in shallow deposits of the Hanford Nuclear Reservation, Washington--Review of selected previous work and suggestions for further study, by U.S. Geological Survey.
1987.

87-526. Documentation of a steady-state saltwater-intrusion model for three-dimensional ground-water flow, and user's guide, by D.B. Sapik. 1988.

88-116. U.S. Geological Survey ground-water studies in Washington, by F.A. Packard and H.E. Pearson. 1988.

88-182. Selected ground-water information for the Columbia Plateau Regional Aquifer System, Washington and Oregon, 1982-85: Volume I. Geohydrology, by R.C. Lane. 1988.

88-183. Selected ground-water information for the Columbia Plateau Regional Aquifer System, Washington and Oregon, 1982-85: Volume II. Water levels, by R.C. Lane. 1988.

88-312. National water quality assessment pilot program, by W.G. Wilber and W.W. Alley. 1988.

88-459. Geology in action--jokulhlaups on Mount Rainier, by C.L. Driedger. 1988.

89-38. Well data, surface-water discharge, and nitrate concentrations, February 1986-September 1987, in parts of the Pasco Basin, Washington, by B.W. Drost, K.M. Schurr, G.P. Ruppert, and S.E. Cox. 1989.

89-60. Surface-water quality assessment of the Yakima River basin, Washington: A pilot study, by S.W. McKenzie and D.A. Curtiss.

89-228. Well data, surface-water discharge, and nitrate concentrations, February 1986-September 1987, in parts of the Pasco Basin, Washington, by B.W. Drost, K.M. Schurr, G.P. Ruppert, and S.E. Cox. 1989.

MISCELLANEOUS INVESTIGATIONS SERIES MAPS

I-589. Geologic map and sections of parts of Grant, Adams, and Franklin Counties, Washingon, by M.J. Grolier and J.W. Bingham. 1971.

I-836. Map showing potential hazards from future eruptions of Mount Rainier, by D.R. Crandell. 1973.

I-851-A. Climatic factors related to land-use planning in the Puget Sound basin, Washington, by B.L. Foxworthy and Donald Richardson. 1973.

I-852-A. Map showing relative slope stability in part of west-central King County, Washington, by R.D. Miller. 1973.

I-852-B. Landslides and associated damage during early 1972 in part of west-central King County, Washington, by D.W. Tubbs. 1974.

I-582-E. Slope map of part of west-central King County, Washington, by U.S. Geological Survey. 1975.

I-853-A. Map showing spawning areas of anadromous fish in southern Hood Canal area, Washington, by J.D. Findley. 1973.

I-853-B. Relative susceptibility of lakes to water-quality degradation in southern Hood Canal area, Washington, by G.C. Bortleson and B.L. Foxworthy. 1974.

I-853-C. Streamflow in the southern Hood Canal area, Washington, as related to land-use planning, by Donald Richardson. 1974.

I-853-D. Geologic conditions related to waste-disposal planning in the southern Hood Canal area, Washington, by R.J. Carsons, Mackey Smith, and B.L. Foxworthy. 1975.

I-853-F. Relative slope stability of the southern Hood Canal area, Washington, by Mackey Smith and R.J. Carlson. 1977.

I-854-A. Map showing percolation rates of earth materials in western Whatcom County, Washington, by D.J. Easterbrook. 1973.

I-854-B. Geologic map of western Whatcom County, Washington, by D.J. Easterbrook. 1976.

I-854-C. Map showing slope stability in western Whatcom County, Washington, by D.J. Easterbrook. 1976.

I-854-D. Map showing engineering characteristics of geologic materials, Whatcom County, Washington, by D.J. Easterbrook. 1976.

I-1198-A. Map showing natural land slopes, Port Townsend quadrangle, Puget Sound region, Washington, by J.E. Frederick. 1980.

OTHER U.S. GEOLOGICAL SURVEY PUBLICATIONS

Bingham, J.W., and Grolier, M.J., 1966, The Yakima Basalt and Ellensburg Formation of south-central Washington: U.S. Geological Survey Bulletin 1224-G, p. G1-G15.

McGavock, E.M., Wiggins, W.D., Boucher, P.R., Blazs, R.L., Reed, L.L., and Smith, M.L., 1986, Water resources data, Washington, water year 1984: U.S. Geological Survey Data Report 84-1.

_____, 1987, Water resources data, Washington, water year 1985: U.S. Geological Survey Data Report 85-1.

_____, 1988, Water resources data, Washington, water year 1986: U.S. Geological Survey Data Report 86-1.

Skrivan, J.A., and Karlinger, M.R., 1980, Semi-variogram estimation and universal Kriging program: U.S. Geological Survey Computer Contribution, National Technical Information Service Accession # PB81 120560.

STATE OF WASHINGTON WATER-SUPPLY BULLETINS

1-6. Monthly and yearly summaries of hydrographic data in the State of Washington. Published 1921, 1923, 1924, 9129, 1935, and 1955, respectively.

7. Artificial recharge through a well tapping basalt aquifers, Walla Walla area, Washington, by C.E. Price. 1961.

8. Records of wells, water levels, and quality of ground water in the Columbia Basin Project area, Washington, by K.L. Walters and M.J. Grolier. 1960.

9. Geology and ground-water resources of Clark County, Washington, by M.J. Mundorff. 1964.

10A. Geology and ground-water resources of Thurston County, Washington, by E.F. Wallace and Dee Molenaar. 1961.

10B. Geology and ground-water resources of Thurston County, Washington, by J.B. Noble and E.F. Wallace. 1966.

11. A preliminary report on geology and ground-water resources of the Sequim-Dungeness area, Clallam County, Washington, by J.B. Noble. 1960.

12. Water resources of the Nooksack River basin and certain adjacent streams, by Washington Division of Water Resources. 1960.

13. Summary of snow survey measurements in the State of Washington, 1915-1960 inclusive, by Washington Division of Water Resources. 1960.

14. Lakes of Washington, Volume 1, Western Washington, by E.E. Wolcott. 1961; Volume 2, Eastern Washington, by E.E. Wolcott. 1964.

15. Monthly and yearly summaries of hydrographic data in the State of Washington, October 1953 to September, 1960, by Washington Department of Conservation. 1962.

16. Flowing artesian wells in Washington State, by Dee Molenaar. 1961.

17. Geology and ground-water resources of west-central Lewis County, Washington, by J.M. Weigle and B.L Foxworthy. 1962.

18. Water resources and geology of the Kitsap Peninsula and certain adjacent islands, by W.E. Garling, Dee Molenaar, and others. 1965.

19. Water resources of the Tacoma area, Washington, by W.C. Griffin, J.E. Sceva, H.A. Swenson, and M.J. Mundorff. 1962.

20. Geology and ground-water resources of northwestern King County, Washington, by B.A. Liesch, C.E. Price, and K.L. Walters. 1963.

21. Geology and ground-water resources of the Walla Walla River basin, Washington-Oregon, by R.C. Newcomb. 1965.

22. Ground-water occurrence and stratigraphy of unconsolidated deposits, central Pierce County, Washington, by K.L. Walters and G.E. Kimmel. 1968.

23. Miscellaneous stream-flow measurements in the State of Washington, 1890 to January 1961, by Washington Division of Water Resources. 1964.

24. Ground water in Washington: Its chemical and physical quality, by A.S. Van Denburgh and J.F. Santos. 1965.

25. Ground-water resources of Island County, Washington, by H.W. Anderson. 1968.

25. Pleistocene stratigraphy of Island County, Washington, by D.J. Easterbrook, 1968.

26. Reconnaissance of geology and of ground-water occurrence and development in Whitman County, Washington, by K.L. Walters and P.A. Glancy. 1969.

27. Ground-water resources and related geology of north-central Spokane and southeastern Stevens Counties, Washington, by D.R. Cline. 1969.

28. Geology and ground-water resources of southwestern King County, Washington, by J.E. Luzier. 1969.

29. Geology and related ground-water occurrence, southeastern Mason County, Washington, by Dee Molenaar and J.B. Noble. 1970.

30. Geology and ground-water resources of the lower Chehalis River valley and adjacent areas, Grays Harbor County, Washington, by P.A. Eddy. 1966.

31. Ground-water withdrawal in the Odessa area, Adams, Grant, and LincolnCounties, Washington, by A.A. Garrett. 1968.

32. Reconnaissance of seawater intrusion along coastal Washington, 1966-68, by K.L. Walters. 1971.

33. Hydrology of basalt aquifers and depletion of ground water in east-central Washington, by J.E. Luzier and R.J. Burt. 1974.

34. Water in the Okanogan River basin, Washington, by K.L. Walters. 1974.

35. Availability of ground water in western Cowlitz County, Washington, by D.A. Myers. 1970.

36. Ground-water survey, Odessa-Lind area, Washington, by J.E. Luzier, J.W. Bingham, R.J. Burt, and R.A. Barker. 1968.

37. Appraisal of ground-water availability and management projections, Walla Walla River basin, Washington and Oregon, by R.D. MacNish, D.A. Myers, and R.A. Baker. 1973.

38. Water in the Methow River basin, Washington, by K.L. Walters and E.G. Nassar. 1974.

39. Water in the Palouse River basin, Washington, by E.G. Nassar and K.L. Walters. 1975.

40. Digital-model study of ground-water hydrology, Columbia Basin Irrigation Project area, Washington, by H.H. Tanaka, A.J. Hansen, Jr., and J.A. Skrivan. 1974.

41. Data on selected lakes in Washington, Part 1, by M.R. Collings. 1973.

42. Data on selected lakes in Washington, Part 2, by G.C. Bortleson, G.T. Higgins, and G.W. Hill. 1974; Part 3, by G.C. Bortleson, G.T. Higgins, J.B. McConnell, and J.K. Innes. 1976; Part 4, by J.B. McConnell, G.C. Bortleson, and J.K. Innes. 1976; Part 5, by N.P. Dion, G.C. Bortleson, J.B. McConnell, and J.K. Innes; Part 6, by N.P. Dion, G.C. Bortleson, and J.K. Innes, 1980.

43. Reconnaissance data on lakes in Washington, Volume 1, Clallam, Island, Jefferson, San Juan, Skagit, and Whatcom Counties; Volume 2, King and Snohomish Counties; Volume 3, Kitsap, Mason, and Pierce Counties; Volume 4, Clark, Cowlitz, Grays Harbor, Lewis, Pacific, Skamania, and Thurston Counties; Volume 5, Chelan, Ferry, Kittitas, Klickitat, Okanogan, and Yakima Counties; Volume 6, Adams, Benton, Douglas, Franklin, Grant, Lincoln, Walla Walla, and Whitman Counties; Volume 7, Pend Oreille, Spokane, and Stevens Counties, by N.P. Dion, G.C. Bortleson, J.B. McConnell, and L.M. Nelson. 1976.

44. Digital simulation of a basalt aquifer system, Walla Walla River basin, Washington and Oregon, by R.D. MacNish and R.A. Barker. 1976.

45. Digital model of the gravel aquifer, Walla Walla River basin, Washington and Oregon, by R.A. Barker and R.D. MacNish. 1976.

46. Geology and water resources of the San Juan Islands, San Juan County, Washington, by Washington Department of Ecology, 1975.

47. Water in the Skagit River basin, Washington, by B.W. Drost and R.E. Lombard, 1978.

48. Computer simulation and geohydrology of a basalt aquifer system in the Pullman-Moscow basin, Washington and Idaho, by R.A. Barker 1979.

49. Primer on lakes in Washington, by N.P. Dion. 1978.

50. Geology and water resources of Klickitat County, by J.C. Brown. 1979.

51. Water in the Horse Heaven Hills, south-central Washington, by Dee Molenaar. 1982.

52. Hydrology of the upper Yakima River basin, Washington, by H.E. Pearson. 1985.

53. Water in the lower Yakima River basin, Washington, by Dee Molenaar. 1985.

54. Geology and ground-water resources of eastern Jefferson County, Washington, by Peder Grimstad and R.J. Carson. 1981.

55. Ground-water levels and pumpage in east-central Washington, including the Odessa-Lind area, 1967 to 1981, by D.R. Cline. 1984.

56. Seawater intrusion into coastal aquifers in Washington, 1978, by N.P. Dion and S.S. Sumioka. 1984.

57. Trophic classification of Washington lakes using reconnaissance data, by S.S. Sumioka and N.P. Dion. 1985.

OTHER PUBLICATIONS

Artim, E.R., 1976, Slope stability map of Thurston County, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources, Geologic Map GM-15.

_____, 1976, Relative ground settlement hazards of Thurston County, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources, Geologic Map GM-16.

Bennett, W.A.G., 1962, Saline lake deposits in Washington: Washington Department of Natural Resources, Division of Mines and Geology, Bulletin 49.

Brown, J.C., 1976, Well construction and stratigraphic information; Pullman test and observation well, Pullman, Washington: Washington State University College of Engineering, Research Report No. 76/15-6.

Bush, J.H., Jr., and others, 1972, Test-observation well near Mansfield, Washington; description, stratigraphic relationships, and preliminary results: Washington State University College of Engineering, Research Report No. 72/11-128.

_____, 1973, Test-observation well near Walla Walla, Washington; description, stratigraphic relationships, and preliminary results: Washington State University College of Engineering, Research Report No. 73/15-66.

Eddy, P.A., 1969, Ground-water data for Goldendale area, Klickitat County, Washington: Washington Department of Water Resources, Geohydrologic Monograph 2.

_____, 1973, Geohydrology of the Chehalis River valley, Elma to Oakville, Grays Harbor County, Washington: Washington Department of Ecology, Geohydrologic Monograph 3.

_____, 1976, Description, preliminary results, and pumping tests of test-observation well 13 near George, Washington: Washington Department of Ecology, WRIS Technical Bulletin No. 19.

Grolier, M.J., and Bingham, J.W., 1978, Geology of parts of Grant, Adams, and Franklin Counties, east-central Washington: Washington Division of Geology and Earth Resources, Bulletin 71.

Higgins, G.T., and Hill, G.W., 1973, Analysis and summary of temperatures of streams in Washington prior to 1968: Washington Department of Ecology, Miscellaneous Report 73-003.

Huntting, M.T., Bennett, W.A.G., Livingston, V.E., Jr., and Moen, W.S., 1961, Geologic map of Washington: Washington Division of Mines and Geology, 1:500,000, two sheets.

Jenkins, O.P., 1922, Underground water of the region about White Bluffs and Hanford: Washington Division of Geology, Bulletin 26.

Martin, L.J., 1981, Ground water in Washington: Washington Water Research Center, Pullman, Report No. 40.

Molenaar, Dee, 1968, A geohydrologic reconnaissance of northwestern Walla Walla County, Washington: Washington Department of Water Resources, Geohydrologic Monograph 1.

_____, 1975, The hydrologic cycle, as generally applicable to the Pacific Northwest: Washington Department of Ecology, Geohydrologic Monograph 4.

Molenaar, Dee, Grimstad, Peder, and Walters, K.L., 1980, Principal aquifers and well yields in Washington: Washington Department of Ecology, Geohydrologic Monograph 5.

Phinney, L.A., and Bucknell, Patrick, 1975, A catalog of Washington streams and salmon utilization, volume 2, coastal region: Washington Department of Fisheries, in sections by basin.

Smith, Mackey, 1976, Geologic factors affecting waste disposal practices, Gig Harbor peninsula, Pierce County, Washington: Washington Department of Natural Resources Division of Geology and Earth Resources, Geologic Map GM-19.

_____, 1976, Relative slope stability of Gig Harbor peninsula, Pierce County, Washington: Washington Department of Natural Resources Division of Geology and Earth Resources, Geologic Map GM-18.

_____, 1976, Relative potential for differential settlement, Gig Harbor peninsula, Pierce County, Washington: Washington Department of Natural Resources Division of Geology and Earth Resources, Geologic Map GM-17.

Tubbs, D.W., 1974, Landslides in Seattle: Washington Department of Natural Resources Division of Geology and Earth Resources, Circular 52.

Williams, R.W., Laramie, R.M., and Ames, J.J., 1975, A catalog of Washington streams and salmon utilization, Volume 1 Puget Sound region:Washington Department of Fisheries, in sections by basin.

DEPOSITORIES

Reports are available for examination at the following U.S. Geological Survey depositories:

District Office
Water Resources Division
U.S. Geological Survey
1201 Pacific Avenue, Suite 600
Tacoma, WA 98402

U.S. Geological Survey
Library
5400 McArthur Drive
Vancouver, WA 98661

Library
U.S. Geological Survey, MS 950
12201 Sunrise Valley Drive
Reston, VA 22092

Library
U.S. Geological Survey, MS 914
Denver Federal Center, Box 25046
Denver, CO 80225

Library
U.S. Geological Survey
Room 656
West 920 Riverside
Spokane, WA 99201

Library
U.S. Geological Survey, MS 55
345 Middlefield Road
Menlo Park, CA 94025

Public Inquiries Office
Documents Serial Section
504 Custom House
555 Battery Street
San Francisco, CA 94111

Public Inquiries Office
Room 7638 Federal Bldg.
300 N. Los Angeles Street
Los Angeles, CA 99012

Public Inquiries Office
Room 678 U.S. Courthouse Bldg.
West 920 Riverside Avenue
Spokane, WA 99201

U.S. Department of the Interior
Natural Resources Library
Gifts and Exchange Section
Washington, D.C. 20240

Regional Hydrologist, WR
U.S. Geological Survey MS 470
345 Middlefield Road
Menlo Park, CA 94025