MASTER

HYDROLOGIC BIBLIOGRAPHY OF THE
COLUMBIA RIVER BASALTS IN WASHINGTON
WITH SELECTED ANNOTATIONS

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August 1979

Prepared for Rockwell Hanford Operations,
A Prime Contractor to the U.S. Department of Energy,
Under Contract Number DE-AC06-77RL01030

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WATER RESOURCES INVESTIGATIONS
STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
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INTRODUCTION

This bibliography was prepared by the Department of Ecology (Washington State) for Rockwell Hanford Operations (Rockwell), Richland, Washington, a Prime Contractor to the U. S. Department of Energy under Contract Number DE-AC06-77RL01030. The objective of this compilation is to present a comprehensive listing of the published, unpublished, and open file references pertaining to the surface and subsurface hydrology of the Columbia River basalts within the State of Washington and is presented in support of Rockwell's hydrologic data compilation effort for the Basalt Waste Isolation Program.

A comprehensive, annotated bibliography of the Pasco Basin (including the Hanford Site) hydrology has been prepared for Rockwell as part of the Pasco Basin hydrology studies.* In order to avoid unnecessary duplication, no effort was made to include a complete list of bibliographic references on Hanford in this volume. Literature compiled for this bibliography was gathered by H. H. Tanaka and L. Wildrick. Annotations were performed by B. Pearson.

*W. K. Summers and G. E. Schwab, Bibliography of the Geology and Ground Water of the Basalts of the Pasco Basin, Washington, RHO-BWI-C-15, Rockwell Hanford Operations, Richland, Washington (June 1978).

LOCATION ABBREVIATIONS

At the end of each entry is either an abbreviation in parentheses or the full name of the location where a copy of the publication may be found. These abbreviations are as follows.

Battelle	Battelle, Pacific Northwest Laboratory, Richland, Washington (Library)
DOE	Department of Ecology (Washington State), Headquarters, St. Martin's College, Lacey, Washington (Library)
DOE,WRI	Department of Ecology (Washington State), Water Resources Investigations, Southwest Regional Office, Thurston Air-dustrial Park, Tumwater, Washington (Files)
GER	Geology and Earth Resources, Department of Natural Resources (Washington State), Olympia, Washington (Library)
EWU	Eastern Washington University, Cheney, Washington (Library)
RHO,DC	Rockwell Hanford Operations, Richland, Washington (Document Control)
RHO,BWIL	Rockwell Hanford Operations, Richland Washington (Basalt Waste Isolation Program Library)
USACE,SD	U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
UW,ENGR	University of Washington, Seattle, Washington (Engineering Library)
UW,FOR	University of Washington, Seattle, Washington (Forestry Library)
UW,GEOG	University of Washington, Seattle, Washington (Geography Library)
UW,SRR	University of Washington, Seattle, Washington (Science Reading Room, Suzzalo Library)
USGS	U. S. Geological Survey, Tacoma, Washington
WRC	Washington Water Research Center, Washington State University, Pullman, Washington
WSL	Washington State Library, Olympia, Washington
WSU	Washington State University, Pullman, Washington (Library)

- M. F. Adams, "Water resources of the State of Washington": Wash. (State) Institute of Tech. Bull. 237, Wash. State Univ., Pullman, Wash., 1957. (WSU)
- A. F. Agnew, "Interstate ground-water aquifers of the State of Washington, physical and legal problems--a preliminary assessment": Wash. (State) Water Res. Center, Wash. State Univ., Pullman, Wash., Report No. 8, Pt. A - The physical situation, 1971. (WRC)
- S. W. Ahlstrom, R. J. Serne, R. C. Routson, and D. B. Cearlock, "Methods for estimating transport model parameters for regional ground water systems": Battelle Northwest Labs, BNWL-1717, Richland, Wash., 26 p., 1974. (Battelle)
- I. D. Allison, "New version of the Spokane Flood": Geol. Soc. Am. Bull., v. 44, no. 4, p. 675-722, 1933. (UW,SRR)
- I. D. Allison, "Flint's fill hypothesis of the origin of the scabland": Jour. Geol., v. 49, p. 54-73, 1941. (UW,SRR)
- D. G. Anderson and G. L. Bodhaine, "Flood of 1956 in the Esquatzel Coulee area, Washington": U. S. Geol. Surv. Open-File Rept., Tacoma, Wash., 51 p, 1956. (USGS)
- H. W. Anderson, Jr., "Water supplies for Coulee Dam National Recreation Area, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 104 p., 1969. (USGS)
- R. C. Arnett, et al., "Conceptual and mathematical modeling of the Hanford ground-water flow regime": Atlantic Richfield Hanford Company, ARH-ST-140, Richland, Wash., 103p., Oct. 1976. (RHO,DC)
- Atlantic Richfield Hanford Company, "Water table measurement data maps--July 1975": H-2-38396 Hanford Reservation Water Table Map, Richland, Washington, 1975. (RHO,DC)
- Atlantic Richfield Hanford Company, "Water table measurement data maps--December 1975": H-2-38396 Rev. 1, Hanford Reservation Water Table Map, Richland, Wash., 1976. (RHO,DC)
- Atlantic Richfield Hanford Company, "Preliminary feasibility study on storage of radioactive wastes in Columbia River basalts": two volumes, Atlantic Richfield Hanford Company, ARH-ST-137, Richland, Wash., Nov. 1976. (RHO,BWIL)
- V. R. Baker, "Paleohydrology and sedimentology of Lake Missoula flooding in eastern Washington": Geol. Soc. Amer. Spec. Paper 114, 79 p., 1973. (UW,SRR)
- R. A. Barker, "Geohydrology and digital simulation of the basalt aquifer system in the Pullman-Moscow Basin, Washington and Idaho": Wash. (State) Dept. Ecology Water-Supply Bull. 48, 1979, (in press) (DOE,WRI)

R. A. Barker and R. D. MacNish, "Digital simulation of basalt system, Walla Walla River Basin, Washington and Oregon": Wash. (State) Dept. Ecology Water-Supply Bull. 44, 1976. (DOE)

R. A. Barker and R. D. MacNish, "Digital model of the gravel aquifer, Walla Walla River Basin, Washington and Oregon": Wash. (State) Dept. Ecology Water-Supply Bull. 45, 49 p., 1976. (DOE)

C. D. Becker, "Aquatic bioenvironmental studies in the Columbia River at Hanford, 1945-1971: A bibliography with abstracts": Battelle Pacific Northwest Lab., BNWL-1734 UC-48, Richland, Wash., 153 p., Feb. 1973. (DOE; Battelle)

W. A. G. Bennett, "Saline lake deposits in Washington": Wash. (State) Div. Mines and Geol. Bull. 49, Olympia, Wash., 129 p., 1962. (GER)

R. D. Bentley, "Parke Creek Ranch aquifers and artesian system-a geologic study, Kittitas Valley, Washington": consultant rept. for Parke Creek Ranch, Kittitas Co., Wash., 11 p., 1975. (DOE,WRI)

W. B. Betchart, "Model development and systems analysis of the Yakima River Basin, Water quality modeling": Wash. (State) Water Research Center, Wash. State Univ., Pullman, Wash., 50 p., Nov. 1974. (DOE; WRC)

W. H. Bierschenk, "Hydraulic characteristics of Hanford aquifers": Hanford Works, HW-48916, Richland, Wash., March 3, 1957. (Battelle)

W. H. Bierschenk, "The effect of ground-water mounds on the Purex operation": Hanford Works, HW-49728, Richland, Wash., April 18, 1957. (Battelle)

W. H. Bierschenk, "Fluctuations of Hanford water levels": Hanford Works, HW-53599, Richland, Wash., Nov. 14, 1957. (Battelle)

W. H. Bierschenk, "Hydrological aspects of radioactive waste disposal": Jour. Sanitary Engineering Div., Am. Soc. Civil Engineers, Proc. Paper No. 1835, v. 84, Nov. 1958. (UW,ENGR)

W. H. Bierschenk, "Aquifer characteristics and groundwater movement at Hanford": Hanford Atomic Products Operation, HW-60601, Richland, Wash., 81 p., June 9, 1959. (Battelle)

W. H. Bierschenk and M. W. McConiga, "Changes in the Hanford water table, 1944-1957": Hanford Atomic Products Operations, HW-51277, Richland, Wash., 21 p., 1957. (Battelle)

J. W. Bingham, "Basic ground-water data for the Columbia Basin Irrigation Project area, Washington, fiscal years 1959-64": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 375 p., 1965. (USGS)

* J. W. Bingham and M. J. Grolier, "The Yakima Basalt and Ellensburg Formation of south-central Washington": U. S. Geol. Survey Bull. 1224-G, p. G 1 - G 15, 1966. (USGS)

*Annotated

- * J. W. Bingham and K. L. Walters, "Stratigraphy of the upper part of the Yakima Basalt in Whitman and eastern Franklin Counties, Washington": U. S. Geol. Survey Prof. Paper 525-C, p. 87-90, 1965. (USGS)
- R. A. Bishop and R. A. Lee, "Spokane River cooperative water quality study": Wash. (State) Dept. of Ecology, Olympia, Wash., 72 p., 1972. (DOE)
- G. C. Bortleson, N. P. Dion, and J. B. McConnell, "A method for the relative classification of lakes in the State of Washington from reconnaissance data": U. S. Geol. Survey Water-Resources Inv. 37-74, 35 p., 1974. (USGS)
- G. C. Bortleson, G. T. Higgins and G. W. Hill, "Data on selected lakes in Washington, part 2": Wash. (State) Dept. Ecology Water-Supply Bull. 42, Part 2, Olympia, Wash., 145 p., 1974. (DOE)
- G. C. Bortleson, G. T. Higgins, J. B. McConnell and J. K. Innes, "Data on selected lakes in Washington, part 3": Wash. (State) Dept. Ecology Water-Supply Bull. 42, part 3, Olympia, Wash., 143 p., 1976. (DOE)
- P. R. Boucher, "Sediment transport by streams in the Palouse River Basin, Washington and Idaho, July 1961 - June 1965": U. S. Geol. Survey Water-Supply Paper 1899-C, 37 p., 1970. (USGS)
- P. R. Boucher, "Reconnaissance study of sediment transport by selected streams in the Yakima Indian Reservation, Washington, 1974 water year": U. S. Geol. Survey Open-File Rept. 75-67, Tacoma, Wash., 11 p., 1975. (USGS)
- J. H. Bretz, "The channeled scablands of eastern Washington": Geog. Rev., v. 18, p. 446-477, 1928. (UW,GEOG)
- J. H. Bretz, "Lake Missoula and the Spokane Flood" (abs.): Geol. Soc. Am. Bull., v. 41, p. 92-93, 1930. (UW,SRR)
- J. H. Bretz, "Washington's channeled scabland": Wash. (State) Div. Mines and Geol. Bull. 45, Olympia, Wash., 1959. (GER)
- J. H. Bretz, H. T. U. Smith and G. E. Neff, "Channeled scablands of Washington": Geol. Soc. Am. Bull., v. 67, p. 957-1049, 1956. (UW,SRR)
- D. J. Brown, "Correlation of sediments overlying the Columbia River Basalt in southeastern Washington": Hanford Atomic Products Operation, HW-SA-3343A, Richland, Wash., also in Prog. 1964 Ann. Meeting Rocky Mtn. Section Geol. Soc. Am., Moscow, Idaho, May 4-6, 1964. (Battelle)
- D. J. Brown, "Migration characteristics of radionuclides through sediments underlying the Hanford Reservation": Hanford Atomic Products Operation Unclassified ISO-SA-32, Isochem Inc., Richland, Wash., May 29, 1967. (Battelle)
- D. J. Brown and W. A. Haney, "The movement of contaminated ground water from the 200 areas to the Columbia River": Hanford Atomic Products Operation, HW-80909, Richland, Wash., 16 p., 1964. (Battelle)

*Annotated

D. J. Brown and W. A. Haney, "The role of geology in the disposal of radioactive wastes": Battelle Pacific NW Labs., BNWL-SA-57, Richland, Wash., 18 p., 1965. (Battelle)

D. J. Brown and V. L. McGhan, "Hanford wells": Hanford Atomic Products Operations, HW-44355, Rev. 2, Richland, Wash., 190 p., 1963. (Battelle)

D. J. Brown and J. R. Raymond, "Radiologic monitoring of ground water at the Hanford Project": Jour. Am. Water Works Assoc., v. 54, no. 10, p. 1201-1211, 1962. (UW, ENGR)

D. J. Brown and J. R. Raymond, "Ground-water temperature investigations": in "Hanford radiological sciences research and development annual report for 1962", Hanford Atomic Products Operation, HW-77609, Richland, Wash., p. 4.41-4.42, 1963. (Battelle)

J. C. Brown, "Well construction and stratigraphic information: Pullman test and observation well, Pullman, Washington": Wash. State Univ., College Eng. Res., Res. Rept. 76/15-6, 35 p., Jan. 1976. (WRC)

J. C. Brown, "Continuing study of ground-water availability in Klickitat County and Goldendale area": Wash. (State) Water Research Center, Wash. State Univ., Pullman, Wash., 1977. (WRC)

J. C. Brown, "Discussion of geology and ground-water hydrology of the Columbia Plateau, with specific analysis of the Horse Heaven, Sagebrush Flat, and Odessa-Lind areas, Washington": W.S.U., College of Eng. Res., Rept. 78/15-23, Pullman, Wash., 1978, 51 p. + appendix and plates. (WRC)

R. E. Brown, "The underground disposal of liquid wastes at the Hanford Works, Washington; an interim report covering the period up to January 1, 1950": Hanford Works Doc. HW-17-088, Richland, Wash., 1950. (Battelle)

R. E. Brown, "Well drilling - past performance and future plans": Hanford Works, HW-60284, Richland, Wash., May 14, 1959. (Battelle)

R. E. Brown, "Desirable new geologic research in support of radioactive waste disposal as indicated by Hanford experience": in Proc. IAEA Sci. Conf. on Disposal of Radioactive Wastes, Monaco, v. 2, p. 499-516, Nov. 16-21, 1959. (Battelle)

R. E. Brown, "Hydrologic inter-area relationships as indicated by rising heads in confining aquifers, Pasco Basin, Wash.": Battelle Pacific Northwest Laboratories, BNWL-SA-686, Richland, Washington, 1966. Also abstract in Program 1966 Ann. Meeting, Geol. Soc. Amer., Rocky Mtn. Section, Las Vegas, Nevada, May 11-14, 1966. Also Northwest Science, v. 41, 1966. (Battelle)

R. E. Brown, "The Yakima Basalt Formation and its relationship to the Columbia River in aquifer development": Battelle Pacific Northwest Lab., BNWL 481-3, Richland, Wash., p. 1-5, 1968. (Battelle)

R. E. Brown and W. H. Bierschenk, "Geologic and hydrologic guides to the ground containment and control of wastes at Hanford": Nuclear Eng. and Sci. Conf., Preprint 14, Session XVI, March, 1958. (Battelle)

R. E. Brown and D. J. Brown, "Geologic features and ground-water flow": Hanford Atomic Products Operation, HW-77609, Richland, Wash., p. 4.43-4.44, 1963. (Battelle)

R. E. Brown, et al. "Experience in the disposal of radioactive wastes to the ground at two production sites": Int'l. Conf. on Peaceful Uses of Atomic Energy, Geneva Paper 1767, Sept. 12, 1958. (Battelle)

R. E. Brown, N. W. McConiga and P. P. Rowe, "Geological and hydrological aspects of the disposal of liquid radioactive wastes": Hanford Works, Richland, Wash., Oct., 1956. (Battelle)

R. E. Brown and J. R. Raymond, "The measurement of Hanford's geohydrologic features affecting waste disposal": Hanford Atomic Products Operation, HW-SA-2260, Richland, Wash., 21 p., 1961. (Battelle)

R. E. Brown and H. G. Ruppert, "Underground waste disposal at Hanford Works; an interim report covering the 200-West area": Hanford Works Docs, HW-9-428 and HW-9-671, Richland, Wash., 1948. (Battelle)

R. E. Brown and H. G. Ruppert, "The underground disposal of liquid wastes at the Hanford Works, Washington. An interim report covering the period up to Jan. 1, 1950": Hanford Works, Contract #W-31-109 eng-52, unclassified, Richland, Wash., Feb. 1, 1950. (Battelle)

L. E. Brownell, R. E. Isaacson, J. P. Slaughter, and M. D. Veatch, "Moisture movement in soils of the Hanford Reservation": Atlantic Richfield Hanford Co., ARH-2068, Richland, Wash., April 1971. (RHO,DC)

J. Burt, "Horse Heaven Hills drainage area": U. S. Geol. Survey unpublished records, Tacoma, Wash., 12 p., 1970. (USGS)

* J. H. Bush, Jr., J. V. Anderson, J. W. Crosby, III and B. A. Siems, "Test-observation well near Mansfield, Washington: description, stratigraphic relationships, and preliminary results": Wash. State Univ., College of Eng. Res., Div. Res. Rept. No. 72, Pullman, Wash., p. 11-128, 1972. (WRC)

* J. H. Bush, Jr., J. A. Morton, J. V. Anderson, and J. W. Crosby, III, "Test-observation well near Walla Walla, Washington: description, stratigraphic relationships, and preliminary results": Wash. State Univ., College of Eng. Res., Div. Res. Rept. No. 73, Pullman, Wash., p. 15-66, 1973. (WRC)

W. R. Butcher, et al., "Long-run costs and policy implications of adjusting to a declining water supply in eastern Washington": Wash. (State) Water Res. Center Rept. no. 9, Wash. State Univ., Pullman, Wash., 106 p., 1971. (WRC)

*Annotated

- H. G. Byers and C. A. Ruddy, "The water resources of Washington": Wash. (State) Geol. Survey Ann. Rept. 1, Pt. 5, Olympia, Wash., p. 12-23, 1902. (GER)
- F. C. Calkins, "Geology and water resources of a portion of east-central Washington": U. S. Geol. Survey Water-Supply Paper 118, 96 p., 1905. (USGS)
- C. D. Campbell, "Geologic factors affecting Pullman water supply": presented before the Land Committee meeting, Nov. 1952. (DOE, WRI)
- D. B. Cearlock, "A systems approach of management of the Hanford ground-water basin": Ground Water, v. 10, #1, 1972. (Battelle)
- * D. B. Cearlock, et al., "Mathematical ground-water model of the Ahtanum-Moxee subbasins, Yakima County, Washington": implementation report for Wash. (State) Dept. Ecology by Battelle Pacific NW Labs., Richland, Wash., 36 p. + appendices, Aug. 1975. (Battelle)
- L. L. Chang, "Factors affecting ground-water recharge in the Moscow Basin, Latah County, Idaho": M. S. thesis, Washington State University, Pullman, Wash., 86 p., 1967. (WSU)
- C. Cline, "Newman well pumping test": Wash. (State) Dept. Ecology, Water Resources Invest. Section, Memo Rept., Olympia, Wash., 4 p., Jan. 1974. (DOE)
- * D. R. Cline, "Ground-water resources and related geology of north-central Spokane and southeastern Stevens counties, Washington": Wash. (State) Dept. Water Resources Water Supply Bull. 27, Olympia, Wash., 195 p., 1968. (DOE)
- * D. R. Cline, "Reconnaissance of the water resources of the Upper Klickitat River Basin, Yakima Indian Reservation, Washington": U. S. Geol. Survey Open-File Rept. 75-518, Tacoma, Wash., 54 p., 1976. (USGS)
- M. R. Collings, "Data on selected lakes in Washington, Part I": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 179 p., 1973. (USGS)
- M. R. Collins, "Generalization of stream-temperature data in Washington": U. S. Geol. Survey Water-Supply Paper 2029-B, 45 p., 1973. (USGS)
- M. R. Collins and G. T. Higgins, "Stream temperatures in Washington State": U. S. Geol. Survey Hydrologic Invest. Atlas HA-385, 2 plates, 1973. (DOE; USGS)
- Columbia Basin Interagency Committee, "Report on determination of historical flows at selected power sites, Columbia River basin": Water Management Subcommittee, Vancouver, Wash., 13 p., 1956. (WRC; DOE)
- Columbia Basin Interagency Committee, "Report on modified flows at selected power sites, Columbia River basin": Water Management Subcommittee, Vancouver, Wash., 1957. (WRC; DOE)

*Annotated

Columbia Basin Interagency Committee, "Extension of modified flows through 1958, Columbia River Basin": Water Management Subcommittee, Vancouver, Wash., June 1960. (WRC; DOE)

Columbia Basin Interagency Committee, "Report on extension of historical flows through 1958, Columbia River Basin": Water Management Subcommittee, Vancouver, Wash., May 1961 (WRC; DOE)

Columbia Basin Interagency Committee, "River mile index, Yakima River and tributaries": Hydrology Subcommittee, Vancouver, Wash., 39 p., 1964. (DOE)

Columbia Basin Interagency Committee, "River mile index Spokane River and tributaries": Hydrology Subcommittee, Vancouver, Wash., 24 p., April 1964. (DOE)

Columbia Basin Interagency Committee, "Summary of operations, Columbia River, 1964 flood": Water Management Subcommittee, Vancouver, Wash., 1965. (DOE)

Columbia Basin Interagency Committee, "River mile index: Klaskanine, Sandy, Hood, Umatilla, Walla Walla rivers, and minor left bank Columbia River tributaries, Columbia River Basin, Oregon and Washington": Hydrology Subcommittee, Vancouver, Wash., 18 p., 1966. (DOE; WRC)

Columbia Basin Interagency Committee, "River mile index; Cowlitz, Lewis, Klickitat, and minor right bank Columbia River tributaries, Columbia River Basin, Washington": Hydrology Subcommittee, Vancouver, Wash., 74 p., March 1967. (DOE)

Columbia Basin Interagency Committee, "Pacific Northwest daily streamflow records for ADP as of September 1966": Hydrology Subcommittee, Vancouver, Wash., 26 p., 1967. (DOE)

Columbia Basin Interagency Committee, "Report on streamflow depletion in the Columbia River Basin": Vancouver, Wash., May 1967. (DOE)

Columbia River Basalt Symposium, 2nd, "Proceedings of the second Columbia River Basalt Symposium": Eastern Washington State College, Cheney, Wash., March 21-23, 1969, EWSC Press, 333 p., 1970. (WSL)

Columbia River Water Management Group, "Columbia River water management report for water year 1971 (+)": Portland, Ore., annual. (DOE)

Columbia River Water Management Group, "Provisional report on modified flows at selected sites 1928 to 1968 for the 1970 level of development Columbia River and coastal basins": Portland, Ore., Feb. 1973, revised Aug. 1973. (DOE)

R. J. Condit, "Phosphorus and algal growth in the Spokane River": Northwest Science, v. 46, No. 3, p. 177-189, 1972. (DOE)

W. R. Conley, "Hanford Atomic Energy Plant - water supply": J. Amer. Water Works Assoc., V. 46, #7, p. 629-633, 1954. (UW, ENGR)

- * H. D. Copp and D. T. Higgins, "Model development and systems analysis of the Yakima River Basin: Hydraulics of surface water runoff": Wash. (State) Water Res. Center Rept. 178, Wash. State Univ., Pullman, Wash., 150 p., Nov. 1974. (DOE; WRC)

Cornell, Howland, Hayes, and Merryfield, "A report on an engineering investigation of the municipal water system, College Place, Washington": consultant report, Seattle, Wash., 124 p., July 1964. (DOE)

Cornell, Howland, Hayes, and Merryfield, "A report on an engineering investigation of the municipal water system, Walla Walla, Washington": consultant rept., Seattle, Wash., 111 p., June 1966. (DOE)

Cornell, Howland, Hayes, Merryfield/Hill, "Characterization of present water quality conditions, Yakima Basin water quality management plan": consultant report prepared for Wash. (State) Dept. Ecology, CH₂M/Hill, Bellevue, Wash., Jan. 1974. (DOE)

Cornell, Howland, Hayes and Merryfield/Hill, "Study well water supply": consultant report prepared for city of Yakima, Wash., CH₂M/Hill, Bellevue, Wash. (DOE)

Cornell, Howland, Hayes, and Merryfield/Hill, "Investigate well No. 3": consultant report for town of Wapato, Wash., CH₂M/Hill, Bellevue, Wash. (DOE)

- * J. W. Crosby, III, "Ground-water research in the Pullman-Moscow Basin": in "Engineering geology and soils engineering symposium, 4th Ann., Moscow, Idaho, 1966": Boise, Idaho, Idaho Dept. Highways, p. 215-236, 1966. (WRC; DOE)

J. W. Crosby, III, "Ground-water hydrology of the Pullman-Moscow Basin, Washington": in T. H. Campbell and R. O. Sylvester, eds., "Water resources management and public policy", Seattle, Wash., Univ. Wash. Press, p. 93-109, 1968. (UW, SRR)

- * J. W. Crosby, III and J. V. Anderson, "Some applications of geophysical well logging to basalt hydrogeology": Ground Water, v. 9, no. 5, 1971. (UW, ENGR)

- * J. W. Crosby, III and R. E. Cavin, "Geological investigation of the Moscow ground-water basin employing geophysical studies": Inst. Tech. Bull. 250, Wash. State Univ., College Eng., Pullman, Wash., 23 p., 1960. (WRC)

- * J. W. Crosby, III and R. E. Chatters, "Water-dating techniques as applied to the Pullman-Moscow ground-water basin": Inst. Tech. Bull. 296, Wash. State Univ., Coll. Eng., Pullman, Wash., 21 p., 1965. (WRC)

J. W. Crosby, III, and J. C. Mellott, "Physical characteristics of basalt aquifers": Wash. (State) Water Research Center, OWRR Project No. A-021-WASH, Wash. State Univ., Pullman, Wash., June 1973. (WRC)

*Annotated

J. E. Cummins, M. R. Collings and E. G. Nasser, "Magnitude and frequency of floods in Washington": U. S. Geol. Survey Open-File Rept. 74-336, Tacoma, Wash., 46 p., 1975. (USGS)

D. Cunningham and G. Rothwell, "Water quality report Walla Walla River, December 1970 - March 1971": Wash. (State) Dept. of Ecology, Office of Technical Services, Olympia, Wash., 23 p., Dec. 1971. (DOE)

John W. Cunningham and Associates, "Report on the water-supply systems of College Place, Washington, together with valuations and program of improvement": consultant rept. for City Council, College Place, Wash., 1948. (DOE)

C. E. Cushing and L. A. Rancitelli, "Trace element analyses of Columbia River water and phytoplankton": Northwest Sci., V. 46, No. 2, p. 115-121, 1972. (UW,SRR)

T. Dalrymple, "Flood peak runoff and associated precipitation in selected drainage basins in the United States": U. S. Geol. Survey Water-Supply Paper 1813, p. 360-382, 1965. (USGS)

Leo A. Daly Co., "Water study, 228 unit armed forces housing project, Geiger Field, Spokane, Washington": Consultant report for Procurement Office, 84th Fighter Group, Air Defense, U. S. Air Force, Geiger Field, Spokane, Wash., 13 p., Feb. 1958. (DOE,WRI)

J. J. Davis, "Dispersion of radioactive materials by streams": J. Amer. Water Works Assoc., V. 50, #11, p. 1505-1515, Nov. 1958. (Study in Pasco Basin) (WSL)

R. A. Deju, "Review of the hydrologic program and overall water management of the Hanford Project": Hanford AT(45-1)-2130, Richland, Wash., Nov. 1973. (Battelle)

R. A. Deju, "A comprehensive review of mathematical models constructed to describe the hydrology of the Hanford Reservation": Hanford AT(45-1)-2130, Richland, Wash., April 1974. (Battelle)

R. A. Deju, "Technical program review of the groundwater management program of the Hanford Reservation": Atlantic Richfield Hanford Co., ARHCO, v. 7, 603-11.1, Richland, Wash., 1976. (Battelle)

R. A. Deju, "Feasibility of storing radioactive wastes in Columbia River basalts": Atlantic Richfield Hanford Company, ARH-SA-281, Richland, Wash., Dec. 1976. (RHO,DC)

R. A. Deju, P. A. Eddy, M. W. Grutzeck, and C. W. Myers, "Environmental factors needed to establish the geotechnical feasibility of storing radioactive waste in Columbia River Basalts": Rockwell Hanford Operations, RHO-ST-8, Richland, Wash., September 1977. (RHO,DC)

R. A. Deju and R. E. Gephart, "Hydrologic management at the Hanford Nuclear Waste Facility": Hanford AT(45-1)-2130, Richland, Wash., May 1975. (RHO,DC)

R. A. Deju and W. K. Summers, "Transmissivity and hydraulic conductivity of saturated sedimentary rocks in the Hanford Reservation": Consultant report, R. A. Deju and Associates for Atlantic Richfield Hanford Co., Hanford AT(45-1)-2130, Richland, Wash., April 1975. (Battelle)

H. DeMotts and W. F. Miles, "Study of the Pullman artesian basin": Wash. State College highest honors thesis, 35 p., 1933. (WSU)

D. H. Denham, "Radiological status of the groundwater beneath the Hanford Project, July-Dec. 1968": Battelle Pacific NW Labs., BNWL-1047, Richland, Wash., 3 figs., 5 tables, May 1969. (Battelle)

D. H. Denham, "Radiological status of the groundwater beneath the Hanford Project, Jan.-June 1969": Battelle Pacific NW Labs., BNWL-1233, Richland, Wash., 3 figs., 5 tables, Nov. 1969. (Battelle)

D. H. Denham, "Radiological status of the groundwater beneath the Hanford Project, July-Dec. 1969": Battelle Pacific NW Labs., BNWL-1392, Richland, Wash., 3 figs., 5 tables, May 1970. (Battelle)

N. P. Dion, "Data from a reconnaissance of selected lakes in Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 228 p., 1974. (USGS)

N. P. Dion, G. C. Bortleson, J. B. McConnell, and J. K. Innes, "Data on selected lakes in Washington, part 5": Wash. (State) Dept. Ecology Water-Supply Bull. 42, part 5, Olympia, Wash., 125 p., 1976. (DOE)

N. P. Dion, G. C. Bortleson, J. B. McConnell, and L. N. Nelson, "Reconnaissance data on lakes in Washington, v. 5; Chelan, Ferry, Kittitas, Klickitat, Okanogan, and Yakima Counties, Washington": Wash. (State) Dept. Ecology Water-Supply Bull. 43, v. 5, Olympia, Wash., 264 p., 1976. (DOE)

N. P. Dion, G. C. Bortleson, J. B. McConnell, and L. N. Nelson, "Reconnaissance data on lakes in Washington, v. 6; Adams, Benton, Douglas, Franklin, Grant, Lincoln, Walla Walla, and Whitman Counties, Washington": Wash. (State) Dept. Ecology Water-Supply Bull. 43, v. 6, Olympia, Wash., 407 p., 1976. (DOE)

N. P. Dion, G. C. Bortleson, J. B. McConnell, and L. N. Nelson, "Reconnaissance data on lakes in Washington, v. 7; Pend Oreille, Spokane, and Stevens Counties, Washington": Wash. (State) Dept. Ecology Water-Supply Bull. 43, v. 7, Olympia, Wash., 267 p., 1976. (DOE)

H. R. Doerksen, "Regional analysis in the Pacific Northwest: Part A - Interstream flow needs, Part B - Basalt ground-water aquifers, Part C - Wild and scenic rivers": Wash. State Water Research Center, Pullman, Wash., Office of Water Research and Technology, Wash., D. C., 121 p., 1975. (WRC)

T. E. Eakin, "Ground water for additional public supply at Waterville": U. S. Geol. Survey Memo. Rept., Portland, Ore., 6 p., 1945. (USGS)

- * T. E. Eakin, "Ground-water resources of the Waterville area, Douglas County, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 36 p., 1946. (USGS)

Ebasco Services, Inc., "Supplemental water supply for the city of Moscow, Idaho; interior report, phase one: preliminary reconnaissance and consultation": consultant report, 22 p., Dec. 1958. (City of Moscow, Idaho)

- * P. A. Eddy, "Geohydrology of the Columbia Basin Project Area, Washington": Northwest Science, v. 43, no. 1, p. 35, 1969. (UW,SRR)

P. A. Eddy, "Ground-water data for Goldendale area, Klickitat County, Washington": Wash. (State) Dept. Water Resources, Geohydrologic Monograph 2, 21 p., 1 map sheet, Olympia, Wash., 1969. (DOE)

P. A. Eddy, "Geology and ground-water availability, Selah area, Washington": Wash. (State) Dept. Ecology, Water Resources Investigation Section, unpub. letter rept., Olympia, Wash., 7 p., Dec. 1970. (DOE,WRI)

P. A. Eddy, "Geology and ground-water resources of the Selah area, Yakima County, Washington": Wash. (State) Dept. Ecology, Water Resources Invest. Sect., unpublished letter rept., Olympia, Wash., 1971. (DOE,WRI)

P. A. Eddy, "Geohydrology and the digital model, Odessa area, Washington (abs.)": Northwest Scientific Assoc. Abs. of Papers presented at the 45th annual meeting. Northwest Science, Program and Abstracts (WSU)

P. A. Eddy, "Ground-water conditions in the vicinity of Plaza, Spokane County, Washington": Wash. (State) Dept. Ecology Water Resources Invest. Sect., unpub. letter rept., Olympia, Wash., 9 p., 1973. (DOE,WRI)

- * P. A. Eddy, "Description, preliminary results, and pumping tests of test-observation well 13, near George, Washington": Wash. (State) Dept. Ecology, Water Resource Information System Tech. Bull. 19, 43 p., 1976. (DOE)
- * P. A. Eddy and C. S. Cline, "A geohydrologic reconnaissance of the Dead Canyon area, Klickitat County, Washington": Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpub. letter rept., Olympia, Wash., 6 p., 1972. (DOE,WRI)

P. A. Eddy and J. R. Raymond, "Ground-water investigations of Washtucna Coulee near Kahlotus Lake, Washington": Wash. (State) Dept. Ecology, Water Resource Investigations Technical Bull. 16, Olympia, Wash., 20 p., 1975. (DOE)

C. E. Erdmann, "Report on geologic investigations of miscellaneous dam sites on the Walla Walla River, and the South Fork of the Walla Walla River in the vicinity of Milton-Freewater, Oregon": U. S. Geol. Survey Inter. Rept., Tacoma, Wash., 65 p., 1933. (USGS)

*Annotated

T. H. Essig, "Radiological status of the ground water beneath the Hanford Project, July-Dec. 1967": Battelle Pacific NW Labs, BNWL-835, Richland, Wash., June 1968. (Battelle)

T. H. Essig, "Radiological status of the ground water beneath the Hanford Project, Jan.-June 1968": Battelle Pacific NW Labs., BNWL-984, Richland, Wash., Jan. 1969. (Battelle)

T. H. Essig, "Radiological status of the ground water beneath the Hanford Project, Jan.-June 1970": Battelle Pacific NW Labs., BNWL-1539, Richland, Wash., Dec. 1970. (Battelle)

T. H. Essig, "Radiological status of the ground water beneath the Hanford Project, July-Dec. 1970": Battelle Pacific NW Labs., BNWL-1613, Richland, Wash., Sept. 1971. (Battelle)

C. M. Falter, et al., "Limnology of the lower Snake River Reservoirs - Idaho and Washington, Interim Report": U. S. Army Corps of Engineers, Walla Walla Dist., Walla Walla, Wash., 58 p., May 1977. (DOE)

Fenix and Scisson, Inc., "Basalt aquifer identification, correlation, and sampling program; well history DB-1-2-4-5-7": Hanford Works, Richland, Wash. (Battelle)

R. F. Flint, "Origin of the Cheney-Palouse scabland tract, Washington": Geol. Soc. Am. Bull., v. 49, p. 461-523, 1938. (UW,SRR)

S. Fortier, "Irrigation return flows and water quality in the Yakima River, the Columbia River Basin": U. S. Dept. Agriculture, Tech. Bull. No. 200, 1930. (UW,FOR)

R. F. Foster and R. E. Rostenbach, "Distribution of radioisotopes in Columbia River": J. Amer. Water Works Assoc., V. 46, No. 7, p. 633-640, 1954. (UW,ENGR)

- * J. D. Fox and D. D. Wooldridge, "Model development and systems analysis of the Yakima River Basin: Forest hydrology model": Wash. (State) Water Res. Center, Rept. 17E, Wash. State Univ., Pullman, Wash., 75 p., Nov. 1974. (DOE; WRC; WSL)

B. L. Foxworthy, "Ground water in the lower Ahtanum Valley, Washington and possible effects of increased withdrawal in that area": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 26 p., 1953. (USGS)

- * B. L. Foxworthy, "Results of pumping test, City Well Four, Pullman, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 15 p., 1957. (USGS)

- * B. L. Foxworthy, "Geology and ground-water resources of the Ahtanum Valley, Yakima County, Washington": U. S. Geol. Survey Water-Supply Paper 1598, 100 p., 1962. (USGS)

*Annotated

- B. L. Foxworthy and C. T. Bryant, "Artificial recharge through a well tapping basalt aquifers at The Dalles, Oregon": U. S. Geol. Survey Water-Supply Paper 1594-E, 84 p., 1967. (USGS)
- B. L. Foxworthy and R. L. Washburn, "Reconnaissance investigation of ground water in the Wellpinit area, Stevens County, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 14 p., 1956. (USGS)
- * B. L. Foxworthy and R. L. Washburn, "Ground water in the Pullman area, Whitman County, Washington": U. S. Geol. Survey Water-Supply Paper 1655, 71 p., 1963. (USGS)
- O. W. Freeman, "Grand Coulee and neighboring geological wonders": published by the author, 20 p., 1937. (WSL)
- M. O. Fretwell, "Quality of surface and ground waters, Yakima Indian Reservation, Washington, 1973-74": U. S. Geol. Survey Open-File Rept. 77-128, Tacoma, Wash., 225 p., 1977. (USGS)
- R. E. Fuller, "The aqueous chilling of basaltic lava on the Columbia River plateau": Am. Jour. Sci., v. 21, p. 281-300, 1931. (UW,SRR)
- A. A. Garrett, "Artificial recharge of basalt aquifers, Walla Walla, Washington": In Geol. Survey Res., Short Papers in Geology and Hydrology, U. S. Geol. Survey Prof. Paper 450-C, p. C116-C117, 1962. (USGS)
- * A. A. Garrett, "Ground-water withdrawal in the Odessa area, Adams, Grant, and Lincoln counties, Washington": Wash. (State) Dept. Water Resources Water-Supply Bull. 31, 84 p., 1968. (DOE)
- * A. A. Garrett and C. J. Londquist, "Feasibility of artificially recharging basalt aquifers in Eastern Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 42 p., 1972. (USGS)
- A. A. Garrett and K. L. Walters, "Washington": in C. L. McQuinness, "The role of ground water in the national water situation": U. S. Geol. Survey Water-Supply Paper 1800, 1963. (USGS)
- A. F. Gasperino and R. A. Soltero, "Phosphorus reduction and its effect on the recovery of Long Lake Reservoir": Battelle Pacific Northwest Laboratories, Richland, Wash., 100 p., June 1977. (DOE; Battelle)
- R. E. Gephart, "Hydrologic impact of Columbia Aqua Product waste disposal": Atlantic Richfield Hanford Co., ARH-LD-122 Informal Rept., Richland, Wash., Jan. 1976. (RHO,DC)
- * E. H. Gilmour and M. Bacon, "Ground-water resources and potential sewage pollution in southern Spokane County": Office of Water Research and Tech. Project Completion Rept., E. Wash. State College, 58 p., 1974. (EWU)
- J. S. Gladwell, "Study of certain aspects of the water resources of the State of Washington": Wash. (State) Water Res. Center Open-File Rept. 1, Wash. State Univ., Pullman, Wash., 60 p., 1966. (WRC)

J. S. Gladwell and A. C. Mueller, "Groundwater": in "An initial study of the water resources of the State of Washington, v. II, Water resources atlas of the State of Washington": Wash. (State) Water Res. Center, Rept. no. 2, p. VIII-1 to VIII-10 and Chart VIII-1, Wash. State Univ., Pullman, Wash., 1967. (WRC)

Gray and Osborne, "City of Goldendale, Klickitat County, Washington; engineering report on water supply and distribution system": consultant report, Yakima, Wash., Aug. 1962. (DOE)

- * D. O. Gregg and L. B. Laird, "A general outline of the water resources of the Toppenish Creek Basin, Yakima Indian Reservation, Washington": U. S. Geol. Survey Open-File Report 75-19, Tacoma, Wash., 37 p. 1975. (USGS)

- * D. O. Gregg and W. E. Lum, II, "Dry Creek exploration test well": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 9 p., 1973. (USGS)

D. H. Griswold, "Possibilities of developing ground water for irrigation on the Ross Farm south of Washtucna Coulee, Franklin Soil Conservation District, Washington": U. S. Dept. Agric. Soil Conserv. Ser. Letter Rept., 3 p., 1964. (DOE,WRI)

D. H. Griswold, "Ground water report vicinity Benge-Ralston": Wash. (State) Dept. Ecology, Water Resources Invest. Section, Unpublished letter report, Olympia, Wash., 2 p., Sept. 1964. (DOE,WRI)

D. H. Griswold, "Ground water report vicinity - Washtucna": Wash. (State) Dept. Ecology, Water Resources Investigations Section, Unpublished letter report., 3 p., Olympia, Wash., Dec. 1964. (DOE,WRI)

- * M. J. Grolier, "Geology of part of the Big Bend area in the Columbia Plateau, Washington": Johns Hopkins Univ., Ph. D. Thesis, 267 p., 1965. (DOE,WRI)

- * M. J. Grolier and J. W. Bingham, "Geologic map and sections of parts of Grant, Adams, and Franklin counties, Washington": U. S. Geol. Survey, Misc. Geol. Inv. Map I-589, Scale 1:62,500, 1971. (USGS)

M. J. Grolier and J. W. Bingham, "Geology and ground-water conditions in parts of Grant, Adams and Franklin counties, Washington": Unpublished U. S. Geol. Survey Prof. Paper, Tacoma, Wash., 435 p., 1971. (USGS)

M. J. Grolier and B. L. Foxworthy, "Geology of the Moses Lake North Quadrangle, Washington": U. S. Geol. Survey Invest. Map I-330, 1961. (USGS)

M. A. Hagood, D. E. Miller, and E. C. Larson, "Water-holding capacities of Columbia Basin Irrigation Project soils": Wash. (State) Agricultural Exp. Sta. Circular 517, Wash. State Univ., Pullman, Wash., 52 p. + map, 1970. (WSU)

*Annotated

- F. D. Hahn, "Report on water resources studies": consultant report for Wash. Water Resources Advisory Committee and presented to the Subcommittee on Agriculture and Natural Resources of the Wash. State Legislative Council, Section I, p. 6 and plate III, Nov. 30, 1962. (GER)
- B. F. Hajek, "Soil survey, Hanford Project in Benton County, Washington": Battelle Pacific NW Labs., BNWL-243, UC-51, Richland, Wash., 16 p., 5 tables, 1 fig., April 1966. (Battelle)
- A. A. Hammer, "Rattlesnake Hills Gas Field": Northwest Oil and Gas World, v. 2, nos. 5, 6, 7, 8, and 9, 1931. (USGS)
- E. R. Hampton and S. G. Brown, "Geology and ground-water resources of the upper Grande Ronde River basin, Union County, Oregon": U. S. Geol. Survey Water-Supply Paper 1597, 99 p., 1964. (USGS)
- D. W. Hanlon, "Columbia Basin Project return flow study 1970 and 2020 levels of development": U. S. Bonneville Power Administration, Portland, Ore., 36 p., 1973. (DOE)
- R. E. Harkness, D. A. Myers, and G. C. Bortleson, "Water resources of the Colville Indian Reservation, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 149 p., 1974. (USGS)
- * D. H. Hart, "Feasibility of recharging basalt aquifers in the Walla Walla area, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 35 p., 1957. (USGS)
- * D. H. Hart, "Tests of artesian wells in the Cold Creek area, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 21 p., 1958. (DOE; USGS)
- * D. H. Hart, "Artificial recharge to ground water in Oregon and Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 55 p., 1958. (USGS)
- * D. H. Hart and F. J. Frank, "Aquifer evaluation tests in the Gable Mountain area Hanford Reservation, Washington": U. S. Geol. Survey, unpublished report (subject to revision), Ground-Water Branch, Portland, Ore., April, 1954. (USGS)
- H. T. Hart, "Pumping tests on Wells 3000F and 3000G near North Richland, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 1959. (USGS)
- M. Hastay, et al., with summary by J. S. Gladwell, "The Columbia River as a resource (a preliminary evaluation of the consequences of a diversion)": Wash. (State) Water Research Center, Rept. 5, Wash. State Univ., Pullman, Wash., 66 p. + appendices, 1971. (WRC)
- * W. L. Haushild, G. R. Dempster, Jr., and H. H. Stevens, Jr., "Distribution of radionuclides in the Columbia River streambed from the nuclear reactors, Hanford Reservation to Longview, Washington": U. S. Geol. Survey Prof. Paper 433-0, 35 p., 1975. (USGS)

*Annotated

- W. L. Haushild, R. W. Perkins, H. H. Stevens, Jr., G. R. Dempster, Jr., and J. L. Glenn, "Radionuclide transport in the Pasco-to-Vancouver reach of the Columbia River, July 1962 to September 1963": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 188 p., 1966. (USGS)
- * W. L. Haushild, H. H. Stevens, Jr., J. L. Nelson, and G. R. Dempster, Jr., "Radionuclides in transport in the Columbia River from Pasco to Vancouver, Washington": U. S. Geol. Survey Prof. Paper 433-N, 43 p., 1973. (USGS)
- F. T. Hidaka, "Water resources": in "Mineral and water resources of Washington": Committee on Interior and Insular Affairs, U. S. Congr., 89th, 2nd Sess., Com. Print., p. 311-355, 1966. (WSL)
- G. T. Higgins and G. W. Hill, "Analysis and summary of temperatures of streams in Washington prior to 1968": Wash. (State) Dept. Ecology Misc. Rept. 73-003, Olympia, Wash., 141 p., 1973. (DOE)
- J. Hileman, R. Cunningham, and V. Kollias, "Columbia River nutrient study 1972": U. S. Environmental Protection Agency, Region X, Surveillance and Analysis Div., Seattle, Wash., 81 p., July 1975. (DOE)
- G. M. Hogenson, "Geology and ground water of the Umatilla Basin, Oregon": U. S. Geol. Survey Water-Supply Paper 1620, 1964. (USGS)
- J. F. Honstead, "Movement of radioactive effluents in natural waters at Hanford": in Scientific Conf. on the Disposal of Radioactive Wastes, Monaco, Nov. 16-21, 1959, Atomic Energy Agency, Vienna, Proc. v. 2, p. 385-399, 1960. (Battelle)
- J. F. Honstead, et al., "Gable Mountain ground-water tests": Hanford Works, HW-34532, Richland, Wash., Jan. 21, 1955. (Battelle)
- J. F. Honstead, R. E. Brown, and D. J. Brown, "Hanford wells": Hanford Works, HW-44355, Richland, Wash., July 19, 1956. (Battelle)
- J. J. C. Hsieh, A. E. Reisenauer and L. E. Brownell, "Study of soil water potential and temperature in Hanford soils": Battelle Pacific Northwest Lab., BNWL-1712, Richland, Wash., 1973. (DOE; Battelle)
- M. T. Huntting, W. A. G. Bennett, V. E. Livingston, Jr., and W. S. Moen, "Geologic map of Washington": Wash. (State) Div. Mines and Geology, single sheet, Olympia, Wash., 1961. (GER)
- International Columbia River Engineering Board, "Water resources of the Columbia River basin: A preliminary report to the International Joint Commission": Ottawa, Canada, 77 p., Oct. 1945. (WSL)
- * W. H. Irvin and R. P. Ahrens, "Geology and groundwater hydrology of the South Dam, Columbia Basin project, Washington (abs.)": Geol. Soc. Am. Bull., v. 57, no. 12, p. 1207-1208, Dec. 1946. (UW; SRR)
- R. E. Isaacson, "The Hanford Experiment Deep Well": ARH-SA-47, Atlantic Richfield Hanford Co., Richland, Wash., July 16, 1969. (Battelle)

- N. C. Jannsen, "Ground-water conditions in the State of Washington": consultant rept., Wash. State Planning Council, Div. Water Resources, Olympia, Wash., 76 p., May 1937. (GER)
- O. P. Jenkins, "Underground water supply of the region about White Bluffs and Hanford": Wash. (State) Div. Geol. Bull. 26, Olympia, Wash., 41 p., 1922. (GER)
- O. P. Jenkins and H. H. Copper, "Geological investigation of Grand Coulee Reservoir": Wash. (State) Dept. of Conservation and Development unpub. letter rept., Olympia, Wash., 5 p., 1921. (DOE)
- M. C. Jensen and C. A. Pettibone, "Water resources and utilization area of city of Pullman, Washington": prepared for the Pullman City Council, 9 p., Jan. 1959. (City of Pullman, Washington)
- R. W. Jones and S. H. Ross, "Moscow Basin ground-water problem: 'How long will the water last?' ": in Proc. 7th Ann. Symp. Eng. Geol. and Soils Eng., Boise Idaho, p. 62-83, 1969. (WRC)
- * R. W. Jones and S. H. Ross, "Moscow basin ground-water studies": Idaho Bureau Mines and Geology Pamphlet 153, 95 p., 1972. (WRC)
- H. B. Kinnison, "Evaluation of streamflow records in Yakima River Basin, Washington": U. S. Geol. Survey Circ. 180, 38 p., 1952. (USGS)
- * H. B. Kinnison and J. E. Sceva, "Effects of hydraulic and geologic factors on streamflow of the Yakima River Basin, Washington": U. S. Geol. Survey Water-Supply Paper 1595, 134 p., 1963. (USGS)
- K. L. Kipp, Jr., "Radiological status of the ground water beneath the Hanford Project, Jan.-June 1971": Battelle Pacific NW Labs., BNWL-1649 Special Distr., Richland, Wash., 6 tables, April 1972. (Battelle)
- K. L. Kipp, Jr., "Radiological status of the ground water beneath the Hanford Project, July-Dec. 1971": Battelle Pacific NW Labs., BNWL-1680 Special Distr., Richland, Wash., 6 tables, Jan. 1973. (Battelle)
- K. L. Kipp, Jr., "Radiological status of the ground water beneath the Hanford Project, Jan.-June 1972": Battelle Pacific NW Labs., BNWL-1737, Special distr., Richland, Wash., 9 tables, May 1973. (Battelle)
- K. L. Kipp, Jr., "Radiological status of the ground water beneath the Hanford Project, July-Dec. 1972": Battelle Pacific NW Labs., BNWL-1752, Special distr., Richland, Wash., 9 tables, 3 figs., Aug. 1973. (Battelle)
- K. L. Kipp, Jr., V. L. McChen and D. W. Damschen, "Hanford wells": Battelle Pacific NW Labs., BNWL-1739, UC-70, Richland, Wash., 111 p., June 1973. (Battelle)
- K. L. Kipp and R. D. Mudd, "Selected water table contour maps and well hydrographs for the Hanford Reservation, 1944-1973": Battelle Pacific NW Labs., BNWL-B-360, Richland, Wash., 5 p. + maps, 16 figs., 1974. (Battelle)

- * C. A. Ko, "Geology and groundwater resources of the Hangman Creek Drainage Basin, Idaho-Washington": Ph. D. Dissertation, Wash. State Univ., Geol. Dept., Pullman, Wash., 1974. (WSU)
- Kramer, Chin, and Mayo, "Ellensburg water-supply development": consultant report prepared for Ellensburg, Wash., KCM, Seattle, Wash., 1970. (DOE)
- D. E. Lafrance, "Low-flow characteristics of selected streams in north-eastern Washington": U. S. Geol. Survey Open-File Report, Tacoma, Washington, 22 p., 1975. (USGS)
- L. B. Laird, "Chemical quality of the surface waters of the Snake River Basin": U. S. Geol. Survey Prof. Paper 417-D, 47 p., 1964. (USGS)
- L. B. Laird and K. L. Walters, "Municipal, industrial, and irrigation water use in Washington": U. S. Geol. Survey Open-File Rept., 13 p., 1967. (USGS)
- Henry Landes, "Preliminary report on the underground waters of Washington": U. S. Geol. Survey Water-Supply Paper 111, 85 p., 1905. (USGS)
- H. Landes, "The water resources of Washington": Jour. Geog., v. 14, p. 323-331, 1916. (UW, GEOG)
- F. B. Laney, V. R. D. Kirkham, and A. M. Piper, "Ground-water supply at Moscow, Idaho": Idaho (State) Bureau of Mines and Geology Pamphlet No. 8, Boise, Idaho, 13 p., 1923. (GER)
- A. M. LaSala and G. C. Doty, "Preliminary evaluation of hydrologic factors related to radioactive waste storage in basaltic rocks at the Hanford Reservation, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 68 p., 1971. (USGS)
- A. M. LaSala, Jr. and G. C. Doty, "Geology and hydrology of radioactive solid waste burial grounds at the Hanford Reservation, Washington": U. S. Geol. Survey Open-File Rept. 75-625, Tacoma, Wash., 70 p., 1975. (USGS)
- A. M. LaSala, Jr., G. C. Doty, and F. J. Pearson, Jr., "A preliminary evaluation of regional groundwater flow in south-central Washington": U. S. Geol. Survey Administrative Rept., Tacoma, Wash., p. 55, 1972. (DOE; USGS)
- R. K. Ledgerwood and R. A. Deju, "Hydrology of the uppermost confined aquifers underlying the Hanford Reservation": Atlantic Richfield Hanford Co., ARH-SA-253, Richland, Wash., March 5, 1976. (DOE; Battelle)
- P. Lee, D. Glantz, and R. Pine, "Water quality assessment, Yakima River Basin": Wash. (State) Dept. Ecology, Olympia, Wash., unpub. rept., 183 p., Oct. 1976. (DOE)
- R. A. Lee, "Limnological studies of selected Washington State lakes": Wash. (State) Water Pollution Control Commission, Tech. Rept. 69-2, Olympia, Wash., 55 p., 1969. (DOE; WRC)

- * C. L. Lin, "Factors affecting ground-water recharge in the Moscow Basin, Latah County, Idaho": M. S. Thesis, Wash. State Univ., Pullman, Wash., 1967. (WSU)

- Al J. Lings, "Bacteriology and algal assays - Lower Snake River reservoirs, Idaho and Washington": U. S. Corps of Engineers, Walla Walla Dist., Walla Walla, Wash., 37 p., May 1977. (DOE)

- G. T. Lobdell and J. C. Brown, "Geophysical investigations of Washington's ground-water resources, annual report 1976/1977": Wash. State Univ., College Eng. Res. Rept. 77/15-76, Dec. 1977. (WRC)

- R. J. Longfield, "Floods of January 1974 in Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 13 p., 1974. (USGS)

- * J. E. Luzier, "Ground-water occurrence in the Goldendale area, Klickitat County, Washington": U. S. Geol. Survey Hydrol. Inv. Atlas, HA-313, 1969. (USGS)

- * J. E. Luzier, J. W. Bingham, R. J. Burt, and R. A. Barker, "Ground-water survey, Odessa-Lind area, Washington": Wash. (State) Dept. Water Resources Water-Supply Bull. 36, Olympia, Wash., 31 p., 1968. (DOE)

- * J. E. Luzier and R. J. Burt, "Hydrology of basalt aquifers and depletion of ground water in east-central Washington": Wash. (State) Dept. Ecology Water-Supply Bull. 33, Olympia, Wash., 53 p., 1974. (DOE)

- * J. E. Luzier and J. A. Skrivan, "Digital simulation and projection of water-level declines in basalt aquifers of the Odessa-Lind area, east-central Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 56 p., 1973. (USGS; DOE)

- R. D. MacNish, "Mathematical model of an aquifer system in the Columbia River Basalt Group in southeastern Washington and northeastern Oregon, (abs.)": Geol. Soc. Amer. Abs. Prog., v. 8, no. 3, p. 391-392, 1976. (UW,SRR)

- * R. D. MacNish and R. A. Barker, "Digital simulation of a basalt aquifer system, Walla Walla River Basin, Washington and Oregon": Wash. (State) Dept. Ecology Water-Supply Bull. 44, Olympia, Wash., 51 p., 1976. (DOE)

- R. D. MacNish, D. A. Myers, and R. A. Barker, "Appraisal of ground-water availability and management projections, Walla Walla River Basin, Washington and Oregon": Wash. (State) Dept. Ecology Water-Supply Bull. 37, Olympia, Wash., 25 p., 1973. (DOE)

- * G. E. Maddox, "A proposed structural control of surface and ground water in the eastern portion of the Columbia River Basalt, Washington (abs.)": Geol. Soc. Amer. Abs. with Programs, v. 8, no. 3, p. 392, 1976. (UW,SRR)

- H. E. Malde, "Evidence in the Snake River plain of a catastrophic flood from Pleistocene Lake Bonneville": U. S. Geol. Survey Prof. Paper 400-B, p. B295-B297, 1960. (USGS)

- B. E. Mapes, Sediment transport by streams in the Walla Walla River Basin, Washington and Oregon, July 1962 - June 1965": U. S. Geol. Survey Water-Supply Paper 1868, 32 p., 1969. (USGS)
- * B. W. Mar and W. R. Butcher, "Model development and systems analysis of the Yakima River Basin: Macro model simulation": Wash. (State) Water Research Center, Rept. 17A, Wash. State Univ., Pullman, Wash., Nov. 1974. (WRC)
- M. W. McConiga, "Changes in the Hanford ground-water table, 1944-1955": Hanford Works, HW-40469, Richland, Wash., Dec. 1, 1955. (Battelle)
- J. B. McConnell, G. C. Bortleson and J. K. Innes, "Data on selected lakes in Washington, part 4": Wash (State) Dept. Ecology Water-Supply Bull. 42, part 4, Olympia, Wash., 1976. (DOE)
- C. C. McDonald and H. C. Riggs, "Annual runoff in Columbia River Basin in percent of the mean, 1928-45": U. S. Geol. Survey Circ. 36, 20 plates, Oct. 1948. (USGS; UW,SRR)
- D. M. McGaughy, "Yakima River water quality report, Dec. 1970-Sept. 1971": Wash. (State) Dept. Ecology, Olympia, Wash., 87 p., 1973. (WSL)
- E. H. McGavock, "Field inspection of potential sites for exploratory wells in the upper Yakima basin": U. S. Geol. Survey Memo to the record, Tacoma, Wash., 3 p., 1977. (USGS)
- V. L. McGhen, D. A. Meyers and D. W. Danschen, "Hanford wells": Battelle Pacific NW Labs., BNWL-1981, Richland, Wash., 1976. (Battelle)
- J. G. McMacken, "Geological implications of wells in Spokane - Rathdrum Valleys - permafrost (abs.)": NW Science, v. 33, no. 1, p. 37-38, Feb. 1949. (GER; UW,SRR)
- C. L. McQuinness, "Role of ground water in the national water situation with state summaries based on reports by district offices of the ground-water branch": U. S. Geol. Survey Water-Supply Paper 1800, p. 906-928, 1963. (USGS)
- * J. C. Mellott, "Preliminary ground-water flow system analysis in the Columbia River Basalts": M. S. Thesis, Wash. State Univ., Geol. Dept., Pullman, Wash., 1973. (WSU)
- * R. T. Milhous, "A natural flow model of the Yakima River": presented at PNW meeting Am. Geophysical Union, Richland, Wash., 21 p., Oct. 1974. (DOE)
- * J. L. Mogg, "Aquifer test No. 4, Clarkston, Washington": consultant report by A. A. Durand and Son, 11 p., March 1958. (DOE,WRI)
- D. Molenaar, "Memorandum describing the ground-water resources in the Ellensburg area": Wash. (State) Dept. of Conservation, Olympia, Wash., unpub. letter rept., 3 p., 1956. (DOE)

- * D. Molenaar, "Flowing artesian wells in Washington State": Wash. (State) Div. Water Resources Water-Supply Bull. 16, Olympia, Wash., 115 p., 1961. (DOE)
- * D. Molenaar, "A geohydrologic reconnaissance of northwestern Walla Walla County, Washington": Wash. (State) Dept. Water Resources Geohydrologic Monograph 1, Olympia, Wash., 1968. (DOE)
- D. Molenaar, "The hydrologic cycle, as generally applicable to the Pacific Northwest": Wash. (State) Dept. Ecology Geohydrologic Monograph 4, Olympia, Wash., 1 Pl., Multicolor, 1975. (DOE)
- * D. Molenaar, "Outline of the water resources of the Satus Creek Basin, Yakima Indian Reservation, Washington": U. S. Geol. Survey Open-File Rept. 76-808, Tacoma, Wash., 34 p., 1977. (USGS)
- S. B. Morris, "Ground-water, a vital national resource - Pacific coast problems (abs.)": Annot. Bibliography Econ. Geol. 1943, v. 15, no. 2, p. 251, Dec. 1943. (UW,SRR)
- * M. J. Mundorff, "Ground-water conditions in the Columbia Basin Project": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 26 p., 1953. (USGS)
- * M. J. Mundorff, "Availability of ground water to supplement surface-water irrigation supplies in the Yakima River Basin, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 11 p., 1953. (USGS)
- M. J. Mundorff and G. L. Bodhaine, "Investigation of the rise in level of Soap Lake at Soap Lake, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 57 p., 1954. (USGS)
- * M. J. Mundorff, R. D. MacNish and D. R. Cline, "Water resources of the Satus Creek Basin, Yakima Indian Reservation, Washington": U. S. Geol. Survey Open-File Rept. 76-685, Tacoma, Wash., 102 p., 1977. (USGS; DOE)
- * M. J. Mundorff, D. J. Reis and J. R. Strand, "Progress report on ground water in the Columbia Basin Project, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 229 p., 1952. (USGS)
- * D. A. Myers, "Test-observation wells near Davenport, Washington: description and preliminary results": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 23 p., 1972. (USGS)
- D. A. Myers, J. J. Fix and J. R. Raymond, "Environmental monitoring report on the status of ground water beneath the Hanford site, January-December 1976": Battelle Pacific Northwest Laboratory, Richland, Wash., 31 p., April 1977. (DOE; Battelle)
- E. G. Nassar, "Effects of wind and atmospheric pressure on storage measurements at Roosevelt Lake, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 35 p., 1965. (USGS)

*Annotated

- E. G. Nassar, "Low-flow characteristics of streams in the Pacific Slope basins and lower Columbia River Basin, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 68 p., 1973. (USGS)
- * E. G. Nassar and K. L. Walters, "Water in the Palouse River Basin, Washington": Wash. (State) Dept. Ecology Water-Supply Bull. 39, Olympia, Wash., 246 p., 1975. (DOE)
- L. M. Nelson, "Potential transport of sediment from Enloe Reservoir by the Similkameen and Okanogan rivers, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 21 p., 1972. (USGS)
- L. M. Nelson, "Sediment transport by streams in the upper Columbia River Basin, Washington, May 1959-June 1971": U. S. Geol. Survey Water-Resources Investigation 39-73, 69 p., 1974. (USGS)
- R. W. Nelson, "Electrical analog simulation of the Hanford ground-water flow system": Hanford Atomic Products Operation Rept. HW-77609, Richland, Wash., p. 4.28-4.33, 1963. (Battelle)
- R. W. Nelson and W. A. Harey, "Analog simulation of Hanford ground-water flow": in "La Retention et la migration des ions radioactifs dans les sols," p. 131-138, 3 figs., 1 table, 1962. (Battelle)
- * R. C. Newcomb, "Ground water in the Kennewick area, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 15 p., 1948. (USGS; DOE)
- * R. C. Newcomb, "Geologic and ground-water data on the central part of the Walla Walla basin, Washington and Oregon": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 50 p., 1949. (USGS; DOE)
- * R. C. Newcomb, "Preliminary report on the ground-water resources of the Walla Walla River Basin, Washington-Oregon": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 203 p., 1951. (USGS)
- * R. C. Newcomb, "Ground water of the Columbia Basin": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 7 p., 1958. (USGS)
- R. C. Newcomb, "Repair of leaking artesian wells in upper Cold Creek Valley, Benton County, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 8 p., 1958. (USGS)
- * R. C. Newcomb, "Some preliminary notes on ground water in the Columbia River Basalt": Northwest Sci., v. 33, no. 1, p. 1-8, 1959. (UW,SRR)
- * R. C. Newcomb, "Storage of ground water behind subsurface dams in the Columbia River Basalt, Washington, Oregon, and Idaho": U. S. Geol. Survey Prof. Paper 383-A, A1-A15, 1961. (USGS)
- * R. C. Newcomb, "Structural barrier reservoirs of ground water in the Columbia River Basalt": U. S. Geol. Survey Prof. Paper 424B, p. 213-215, 1961. (USGS)

*Annotated

- * R. C. Newcomb, "Geology and ground-water resources of the Walla Walla River Basin, Washington-Oregon": Wash. (State) Div. Water Resources Water-Supply Bull. 21, 151 p., 1965. (DOE)
- * R. C. Newcomb, "Effects of tectonic structure on the occurrence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington": U. S. Geol. Survey Prof. Paper 383-C, p. C1-C33, 1969. (USGS; DOE)
- * R. C. Newcomb, "Geologic map of the proposed Paterson Ridge pumped-storage reservoir, south-central Washington": U. S. Geol. Survey Misc. Geologic Inv. Map I-653 (Open-File), Portland, Ore., 1971. (USGS)
- * R. C. Newcomb, "Tectonic structure of the main part of the basalt of the Columbia River Group, Washington-Oregon-Idaho": U. S. Geol. Survey Misc. Geol. Invests., Map I-587, (Open-File) Portland, Ore., 1970. (USGS)
- R. C. Newcomb, "Geology and ground-water characteristics of the Hanford Reservation of the U. S. Atomic Energy Commission, Washington": U. S. Geol. Survey Open-File Rept., Portland, Ore., 260 p., Nov. 1970 (USGS)
- R. C. Newcomb, "Quality of the ground water in basalt of the Columbia River Group, Washington, Oregon and Idaho": U. S. Geol. Survey Water-Supply Paper 1999-N, 71 p., 1972. (DOE; USGS)
- * R. C. Newcomb, "Some characteristics of aquifers in the Columbia River Basalt, (abs.)": Geol. Soc. Amer. Abs. Prog., v. 8, no. 3, p. 399-400, 1976. (UW, SRR)
- R. C. Newcomb and S. G. Brown, "Evaluation of bank storage along the Columbia River between Richland and China Bar, Washington": U. S. Geol. Survey Water-Supply Paper 1539-I, p. I-1 - I-13, 1961. (USGS; DOE)
- R. C. Newcomb, et al., "Seismic cross section across the Spokane River Valley and the Hillyard Trough, Idaho and Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 16 p., 1953. (USGS)
- R. C. Newcomb, J. R. Strand and F. J. Frank, "Geology and ground-water characteristics of the Hanford Reservation of the U. S. Atomic Energy Commission, Washington": U. S. Geol. Survey Prof. Paper 717, 78 p., 1973. (USGS)
- T. M. Olsen, et al., "Geology, groundwater and water quality of part of southern Spokane County, Washington": Wash. (State) Dept. Ecology Water Resource Information System Technical Bull. no. 15, Olympia, Wash., July, 1975. (DOE)
- * T. M. Olson, "The geology and ground-water resources of part of the Hangman and Marshall creeks drainage basins, Spokane County, Washington": Eastern Wash. State College M. S. thesis, Cheney, Wash., 70 p., 1975. (EWU)
- H. M. Orem, "Computation of the total flow of the Columbia River at the mouth": U. S. Geol. Survey Prof. Paper 424C, p. C148, 1961. (USGS)

L. L. Oriard, "Ground water for City of Cheney test well": consultant report for Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpublished letter rept., Olympia, Wash., 1959. (DOE,WRI)

- * L. L. Oriard, "Ground-water studies, City of Cheney, Washington": consultant rept., for City of Cheney, Wash., 4 p. (DOE,WRI)

Pacific Northwest River Basins Commission, "Columbia-North Pacific region comprehensive framework study": Vancouver, Wash., 17 vol., 1969-71. (DOE; WRC)

Pacific Northwest River Basins Commission, "Columbia-North Pacific region comprehensive framework study - Appendix V: Water resources": Columbia - North Pacific technical staff, Pacific Northwest River Basins Commission, Vancouver, Wash., v. 1-2, 1022 p., April 1970. (USGS; DOE; WRC)

Pacific Northwest River Basins Commission, "River mile index, mainstem, Columbia River": Hydrology and Hydraulics Committee, Vancouver, Wash., 26 p., 1972. (DOE)

Pacific Northwest River Basins Commission, "Yakima Basin Level B study": Wash. State Study Team, Vancouver, Wash., 235 p., May 1977. (DOE)

M. Palko, "Water quality report, Yakima River, summer 1970": Wash. (State) Dept. Ecology, Olympia, Wash., unpub. letter rept., 25 p., 1971. (DOE; WRC)

J. T. Pardee, "Geology of reservoir sites near Washtucna and Kahlotus, Washington": Wash. (State) Dept. of Conservation, Olympia, Wash., unpub. letter rept., 1928. (DOE)

- * G. G. Parker, Jr., "Municipal, industrial and irrigation water use in Washington, 1970": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 21 p., 1971. (USGS)

G. G. Parker, Jr. and A. M. Piper, "Geologic and hydrologic features of the Richland area, Washington, relevant to the disposal of wastes at the Hanford directed operations of the Atomic Energy Commission": U. S. Geol. Survey WP, v. 7 (GEH-15,045), 101 p., 1949. (USGS)

G. L. Parker and L. Lee, "Summary of hydrometric data in Washington, 1878-1919": U. S. Geological Survey Water-Supply Paper 492, 363 p., 1923. (USGS; UW,SRR)

G. L. Parker and F. B. Storey, "Water powers of the Cascade Range, Part III, Yakima River Basin": U. S. Geol. Survey. Water-Supply Paper 369, 165 p., 1916. (USGS)

R. M. Parsons Co., "Horse Heaven Project development plan": Prepared for Horse Heaven Study Committee and Klickitat County Public Utility District, under contract with Benton Co. Pub. Utility Dist. no. 1, 71 p., 1968. (WSL)

*Annotated

- * H. E. Pearson, "Test-observation well near Paterson, Washington - description and preliminary results": U. S. Geol. Survey Water Resources Investigations 9-73, 23 p., 1973. (USGS)
- * H. E. Pearson, Test well drilling in the Upper Satus Creek Basin, Yakima Indian Reservation, Washington": U. S. Geological Survey Open-File Rept. 77-455, Tacoma, Wash., 14 p., 1977. (USGS)
- R. W. Perkins, "Effect of a reactor fuel element failure on the Columbia River radionuclide concentrations at Pasco, Washington": Hanford Atomic Products Operation Rept. HW-77609, p. 3.68, 1963. (Battelle)
- A. M. Piper, "Ground-water problems in the Pacific Northwest (abs.)": Geol. Soc. Am. Bull., v. 51, no. 12, pt. 2, p. 2029, Dec. 1940. (UW,SRR)
- A. M. Piper, "Adequacy of public water supplies in the Hanford Barracks and Richland Village areas of the Hanford Engineer Works, Hanford, Washington: Hanford Works, GEH-20490, Richland, Wash., May 3, 1944. (Battelle)
- A. M. Piper and L. C. Huff, "Some ground-water features of Rathdrum Prairie-Spokane Valley area, Idaho-Washington, with respect to seepage loss from Pend Oreille Lake": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 13 p., 1943. (USGS)
- A. M. Piper and G. A. Larocque, Jr., "Water-table fluctuations in the Spokane River Valley and contiguous area, Washington-Idaho": U. S. Geol. Survey Water-Supply Paper 889B, p. 83-139, 1944. (USGS)
- * A. M. Piper, T. W. Robinson and H. E. Thomas, "Ground water in the Walla Walla Basin, Oregon-Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 99 p., 1933. (USGS)
- E. J. Pluhowski and C. A. Thomas, "A water-balance equation for the Rathdrum Prairie ground-water reservoir, near Spokane, Washington": U. S. Geol. Survey Prof. Paper 600D, p. D79, 1968. (USGS)
- C. E. Price, Jr., "Artificial recharge of a well tapping basalt aquifers, Walla Walla area, Washington": Wash. (State) Div. Water Resources Water Supply Bull. 7, 50 p., 1960. (DOE)
- * C. E. Price, Jr., "Artificial recharge of a well tapping basalt aquifers, Walla Walla area, Washington": U. S. Geol. Survey Water-Supply Paper 1594-A, p. A1-A33, 1961. (USGS)
- * D. Price, D. H. Hart, and B. L. Foxworthy, "Artificial recharge in Oregon and Washington, 1962": U. S. Geol. Survey Water-Supply Paper 1594-C, p. C1-C65, 1965. (USGS)
- S. M. Price and L. L. Ames, "Characterization of actinide-bearing sediments underlying liquid waste disposal facilities at Hanford": in "Transuranium nuclides in the environment", IAEA, Vienna, Austria, p. 191-211, 1976. (Battelle)

*Annotated

W. J. Purvis, "Stratigraphic control of the ground water through Spokane Valley": M. S. thesis, Wash. State Univ., Dept. of Geol., Pullman, Wash., 213 p., 1969. (WSU; DOE)

J. R. Raymond, "An electrical technique for ground-water velocity measurement": Hanford Works, HW-36217, Richland, Wash., April 11, 1955. (Battelle)

J. R. Raymond, "A Pumping System for ground-water aquifer evaluation tests": Hanford Works, HW-51171, Richland, Wash., June 25, 1957. (Battelle)

J. R. Raymond and W. H. Bierschenk, "Hydrologic investigations at Hanford": Trans. Am. Geophys. Union, v. 38, no. 5, p. 724-729, 1957. (UW, SRR)

J. R. Raymond and D. J. Brown, "Ground-water exchange with fluctuating rivers": Hanford Works, HW-SA-3198, Richland, Wash., 26 p., 1963. (Battelle)

J. R. Raymond and D. D. Tillson, "Evaluation of a thick basalt sequence in south-central Washington": Battelle Pacific Northwest Laboratories, BNWL-776, Richland, Wash., 120 p., 1968. (Battelle)

J. Q. Ressler, "Graphic display of water rights and water resource information for the Yakima River Basin as an aid to decision making": Central Wash. State College, Dept. Geog., Ellensburg, Washington, Project Completion Report OWRT A-075-WASH, 98 p., Oct. 1976. (DOE)

F. Roberts, "Ground water in the Quincy-Winchester area": consultant rept. by Robinson, Roberts and Associates, Inc. for Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpublished letter rept., Olympia, Wash., 2 p., May 10, 1947. (DOE, WRI)

F. B. Roberts, "Brief report on investigation of water surface in College Place and surrounding area": consultant rept. for town of College Place, Wash., Robinson, Roberts, and Associates, Tacoma, Wash., 1947. (DOE, WRI)

* M. Robinette, "Geophysical investigations of Washington's ground-water resources, 1974/75": Wash. State Univ., College of Eng., Res. Div. Rept. 75/15-24, Pullman, Wash., 1975. (WRC)

M. S. Robinette and M. J. Robinette, "Geophysical investigations of Connell City Well no. 7": Wash. State Univ., Coll. Eng. Res., Res. Rept. 76/15-31, 4 p., July 1976. (WRC)

M. S. Robinette, M. J. Robinette, and J. C. Brown, "Geophysical investigations of Washington's ground-water resources, annual report, 1975/1976": Wash. State Univ., College of Eng. Res., Res. Rept. 77/15-6, 56 p., Jan. 1977. (DOE, WRI)

J. W. Robinson, "Additional water supply for Eastern State Hospital and Lakeland Village": consultant rept. by Robinson, Roberts and Associates, Inc. for Wash. (State) Div. Eng. and Architecture, Olympia, Wash., 16 p., Oct. 1966. (DOE, WRI)

- Robinson, Roberts and Associates, "Hydrology of the Garden Springs area, Spokane County, Washington": consultant report for the Wash. (State) Highway Commission, Olympia, Wash., March 1963. (DOE)
- M. I. Rorabaugh and W. D. Simons, "Exploration of methods of relating ground water to surface water, Columbia River Basin, second phase": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 99 p., 1966. (USGS; DOE; WRC)
- M. I. Rorabaugh, E. D. Simons, A. A. Garrett and R. G. McMurtrey, "Exploration of methods of relating ground water to surface water, Columbia River Basin, first phase, with section on direct computation of ground-water outflow by electric analog, by B. J. Bermes": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 124 p., 1966. (USGS; DOE; WRC)
- S. H. Ross, "Contributions to the geohydrology of Moscow Basin, Latah County, Idaho": Idaho Bur. Mines and Geol. Open-File Report, 119 p., 1965. (USGS)
- C. A. Ruddy, "The water resources of Washington: artesian water": Wash. (State) Geol. Survey Ann. Rept. 1, pt. 5, Olympia, Wash., p. 12-23, 1902. (GER)
- I. C. Russell, "A geological reconnaissance in central Washington": U. S. Geol. Survey Bull. 108, p. 11-108, 1893. (USGS)
- I. C. Russell, "A geological reconnaissance of southeastern Washington": U. S. Geol. Survey Water-Supply Paper 4, 96 p., 1897. (USGS)
- I. C. Russell, "Geology and water resources of Nez Perce County, Idaho": U. S. Geol. Survey Water-Supply Paper 53 and 54, 1901. (USGS)
- I. C. Russell, "Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon": U. S. Geol. Survey Water-Supply Paper 78, 53 p., 1903. (USGS)
- R. H. Russell, "Artificial recharge of a well at Walla Walla, Washington": American Water Works Assoc. Journal, v. 52, no. 11, p. 1427-1437, 1960. (DOE)
- R. H. Russell, "Water-level decline in Medical Lake area, Spokane County, Washington": Wash. (State) Dept. Ecology letter to W. E. Thompson and Assoc., Olympia, Wash., 3 p., Jan. 1971. (DOE, WRI)
- R. H. Russell, "A geohydrologic evaluation of four proposed solid waste disposal sites, Garfield County, Washington": Wash. (State) Dept. Ecology Memo Rept., Olympia, Wash., 5 p., 1971. (DOE)
- R. H. Russell and P. A. Eddy, "Geohydrologic evaluation of Aeneas Lake - Horse Springs Coulee area, Okanogan County, Washington": Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpublished letter rept., Olympia, Wash., 14 p., Jan. 1972. (DOE, WRI)

- J. F. Santos, "Quality of surface water in the lower Columbia River Basin": U. S. Geol. Survey Water-Supply Paper 1784, 73 p. 1965. (USGS)
- John Savini and G. L. Bodhaine, "Analysis of current-meter data at Columbia River gaging stations, Washington and Oregon": U. S. Geol. Survey Water-Supply Paper 1869-F, 59 p., 1971. (USGS)
- J. E. Sceva, "Ground water in the vicinity of Geiger Field, Spokane County": U. S. Geol. Survey unpublished rept., Tacoma, Wash., 25 p., 1953. (USGS)
- J. E. Sceva, "Geohydrologic evaluation of streamflow records in the Yakima River Basin, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 129 p., August 1954. (USGS; DOE)
- * J. E. Sceva, F. A. Watkins and W. N. Schlax, Jr., "Geology and ground-water resources of the Wenas Creek Valley, Yakima County, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 81 p., 1949. (USGS)
- W. Schmidt and R. Cleary, "Regional temperature reporting network 1968 field reconnaissance survey, a function of the Columbia River thermal effects study": U. S. Federal Water Pollution Control Administration, NW region, Portland, Ore., Working Paper 62, 97 p., 1969. (DOE)
- * A. T. Schwennesen and O. E. Meinzer, "Ground water in Quincy Valley, Washington": U. S. Geol. Survey Water-Supply Paper 425-E, p. 131-161, 1918. (USGS; DOE)
- W. R. Scott, "Characteristics of streamflow in the Colville River Basin, Stevens County, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 31 p., 1969. (USGS)
- C. R. Showen and O. O. Williams, "Index to water quality data available from the U. S. Geological Survey in machine readable form to December 31, 1972, Western Region": U. S. Geol. Survey Water-Resources Invest. 24-73, 516 p., June 1973. (DOE; USGS)
- * B. A. Siems, "Surface to subsurface correlation of Columbia River Basalt using geophysical data, in parts of Adams and Franklin Counties, Washington": Wash. State Univ., College of Eng. Bull. 331, Pullman, Wash., 1973. (WRC)
- * B. Siems, "Stratigraphic identification and correlation of basalt aquifers using geophysical and chemical techniques": Wash. State Univ. College of Eng. Res. Rept. #74/15-90, Pullman, Wash., 1974. (WRC)
- * B. A. Siems, J. W. Crosby, III, J. V. Anderson, J. H. Bush and T. L. Weber, "Final Report 1972/73, geophysical investigations of Washington's ground-water resources": Wash. State Univ., College of Eng., Res. Div. Res. Rept. 73/15-58, Pullman, Wash., 1973. (WRC)

*Annotated

B. A. Siems, J. W. Crosby, T. L. Weber, J. V. Anderson, and G. B. Lane, "Geophysical investigation of Washington's ground water resources": Wash. (State) Dept. of Ecology, completion report, project no. 74-025B, July 1, 1973-June 30, 1974, 4 p., 1974. (DOE,WRI)

L. E. Signs, "Ahtanum Creek ground-water supply": consultant rept. for the Federal Land Bank of Spokane, Spokane, Wash., 9 p., May 1960. (DOE,WRI)

L. E. Signs, "Wenas Creek ground-water supply, Yakima County, Washington": consultant report for the Federal Land Bank of Spokane, Spokane, Wash., 8 p., July 1960. (DOE,WRI)

* Jan Silar, "Ground-water structures and ages in the eastern Columbia Basin, Washington": Wash. State Univ., College of Eng. Bull. 315, Pullman, Wash., 165 p., 1969. (WRC)

W. D. Simons, et al., "Spokane - Coeur d'Alene River Basin, Washington-Idaho": in "The physical and economic foundation of natural resources, Part 4, Subsurface facilities of water management and patterns of supply - type area studies": U. S. Cong., House of Rep., Interior and Insular Affairs Committee, p. 162-185, 1953. (GER)

W. D. Simons, "Irrigation and streamflow depletion in the Columbia River Basin above The Dalles, Oregon": U. S. Geol. Survey Water-Supply Paper 1220, 126 p., 1953. (USGS)

W. D. Simons, "Recent hydrologic trends in the Pacific Northwest": U. S. Geol. Survey Prof. Paper 424B, p. B17, 1961. (USGS)

R. T. Skrinde, "Quality of ground water in the Columbia Basin Project": in "Water quality in the Columbia River Basin": Proc. Water Quality Conference, Nov. 28-30, 1960, Wash. State Inst. Tech., Pullman, Wash., p. 95-110, 1960. (GER)

G. O. Smith, "Geology and water resources of a portion of Yakima County, Washington": U. S. Geol. Survey Water Supply Paper 55, 68 p., 1901. (USGS)

D. Sokol, "Interpretation of short term water level fluctuations in the Moscow Basin, Latah County, Idaho": Idaho Bur. Mines Geol. Pamph. 137, Boise, Idaho, 27 p., 1966. (WRC)

J. K. Soldat, "A compilation of basic data relating to the Columbia River": Hanford Works, HW-69369, Richland, Washington, 1962. (DOE; Battelle)

G. Sorlie, "A review of the water resources of the Wenatchee Basin": Wash. (State) Dept. Ecology, Water Resources Analysis and Information Section Office Rept. no. 40, Olympia, Wash., 43 p., 1976. (DOE)

P. R. Stevens, "Ground-water problems in the vicinity of Moscow, Latah County, Idaho": U. S. Geol. Survey Water-Supply Paper 1460-H, p. 325-358, 1960. (USGS)

Stevens and Thompson, Inc., "Water works improvements for Washington State University": consultant engineering rept., 1962. (WSU)

J. R. Strand and D. H. Hart, "Preliminary report on the aquifer evaluation test in the 100-K Area, AEC Hanford Reservation, Wash.": U. S. Geol. Survey, unpublished report, Ground Water Branch, Portland, Oregon, October 1952. (USGS)

W. K. Summers and R. A. Deju, "A preliminary review of the regional hydrology of the Hanford Reservation": CA-168-RAD-4, consultant rept., R. A. Deju Assoc., Richland, Wash., June 1974. (DOE; Battelle)

W. K. Summers, P. A. Weber, and G. E. Schwab, "A survey of the ground-water geology and hydrology of the Pasco Basin, Washington": for Rockwell Hanford Operations, RHO-BWI-C-41, Richland, Wash., 125 p., Oct. 1978 (RHO,BWIL)

D. A. Swanson, R. D. Bentley, G. R. Byerley, J. N. Gardner, and T. L. Wright, "Preliminary reconnaissance geologic maps of the Columbia River basalt group in parts of eastern Washington and northern Idaho": U. S. Geol. Survey Open-File Rept. 79-534, 25 p., 1979. (USGS)

R. O. Sylvester, "Research and investigation on the quality of water of the Columbia River and effects on the fisheries resources": consultant report prepared for U. S. Fish and Wildlife Service, 204 p., 1957. (UW,ENGR)

R. O. Sylvester, "Water quality studies in the Columbia River Basin": U. S. Fish and Wildlife Service, Spec. Scientific Rept. Fisheries No. 239, Wash., D. C., 134 p., 1958. (DOE)

R. O. Sylvester, "A report on Lower Columbia River basin water quality data analysis for the year 1960": Univ. of Wash., Seattle, Wash., 94 p., 1961. (WSL)

* H. H. Tanaka, "Pumping test on the DNR well in Horse Heaven Hills": Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpublished letter rept., Olympia, Washington, 3 p., Oct. 1976. (DOE,WRI)

* H. H. Tanaka, "Warden aquifer test": Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpub. letter rept., Olympia, Wash., 2 p., July 1977. (DOE,WRI)

* H. H. Tanaka, "Aquifer test of well 18/25-15E in Grant County, Washington": Wash. (State) Dept. Ecology, Water Resources Invest. Section, unpublished letter rept., Olympia, Wash., 3 p., 1977. (DOE,WRI)

H. H. Tanaka and A. J. Hansen, Jr., "Hydrologic situation north of Snipes Mountain near Sunnyside, Yakima County, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Wash., 12 p., 1970. (USGS)

* H. H. Tanaka, A. J. Hansen, Jr. and J. A. Skrivan, "Digital-model study of ground-water hydrology, Columbia Basin Irrigation Project area, Washington": Wash. (State) Dept. Ecology Water-Supply Bull. 40, Olympia, Wash., 60 p., 1974. (DOE)

H. H. Tanaka and W. E. Lum, "Water-level altitudes in deeper basalt aquifers and shallow gravel aquifers in March 1973 in Columbia Basin Irrigation Project area, Washington": U. S. Geol. Survey Open-File Maps, 2 sheets, 1973. (USGS)

- * G. C. Taylor, "Summary of ground-water conditions in parts of the Columbia Basin Project area with respect to development of domestic and livestock water supplies": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 8 p., 1941. (USGS)
- * G. C. Taylor, "Factual data pertaining to wells and springs in the Columbia Basin Project area, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Wash., 85 p., 1944. (USGS)
- * G. C. Taylor, Jr., "Ground water in the Quincy Basin, Wahluke Slope and Pasco Sub-slopes areas of the Columbia Basin Project, Washington": U. S. Geol. Survey Typewritten Report, Tacoma, Wash., 182 p., 1948. (USGS)

H. E. Thomas, "Ground-water regions of the United States - their storage facilities": in "The physical and economic foundation of natural resources - Part 3, Ground-water regions of the United States": U. S. Cong., House of Rep., Interior and Insular Affairs Committee, p. 15, 17, 22, 23, 31-34, 1952. (GER)

G. T. Thompson, "Model development and systems analysis of the Yakima River Basin, irrigated agricultural water use": Wash. (State) Water Res. Center, Rept. 17C, 80 p., Sept. 1974. (WRC)

D. D. Tillson, D. J. Brown and J. R. Raymond, "River water - ground water relationships along a section of the Columbia River Valley": ASCE National Meeting on Water Resources Engineering, New Orleans, Louisiana, Feb. 3-7, 1969, Meeting Reprint 823, 27 p., 1969. (UW,ENGR)

Neil Twelker and Assoc., "Ben Franklin Dam, Hanford Works, analysis and prediction of groundwater": consultant rept., Seattle, Wash., June 24, 1966. (Battelle)

S. N. Twiss, "Report on ground water in Ahtanum Valley, Yakima County, Washington": Soil Conservation Service, 1943. (UW,SRR)

R. G. Tyler, "Water Resources of Washington": Wash. State Univ. Eng. Exp. Sta. Rept. 4, Pullman, Wash., p. 8-9, June 1938. (UW,SRR)

U. S. Army Corps of Engineers, "Review report on Columbia River and tributaries. Appendix K: Minor tributaries below Yakima River, Appendix L: Columbia River below Yakima River, Appendix R: Inventory of projects and investigations - bibliography": North Pacific Division, Portland, Oregon, October 1, 1948. (DOE)

U. S. Army Corps of Engineers, "Water-resources development of the Columbia River Basin": U. S. 81st Cong., 2nd. Sess., Rev. House Doc. 531, v. 1, 396 p., 1958. (USACE,SD)

- U. S. Army Corps of Engineers, "Report on water resource development of the Columbia River Basin": Board of Engineers for Rivers and Harbors, Portland, Oregon, 3 volumes, 1959. (USACE,SD)
- U. S. Army Corps of Engineers, "Water surface fluctuation studies - Mid 1980 conditions": U. S. Army Corps of Engineers, North Pacific Div., Columbia River and Tributaries Review Study, Portland, Oregon, Jan. 1977. (USACE,SD)
- U. S. Army Corps of Engineers, "Yakima Valley Regional Water Management Study", U. S. Army Corps of Engineers, Seattle District, Vol. II, Water Quality 103 p.; Vol III Water Budget, 72 p.; Vol IV, Geology and Ground Water, 46 p., July 17, 1978. (DOE)
- U. S. Bureau of Reclamation, "The Columbia River; A comprehensive departmental report on the development of the water resources of the Columbia River Basin for review prior to submission to the Congress - Vol. 1": p. 188, 212-214, 223-224, 226, 228, 254, 289, 304, 306, Feb. 1947. (GER)
- U. S. Bureau of Reclamation, "Data on water and land resource development in Washington": Region I, Upper Columbia Development Office, Spokane, Wash., 53 p., May 1968. (DOE)
- U. S. Dept. of Health, Education and Welfare, "Biological investigation Yakima River": 1961. (DOE)
- U. S. Environmental Protection Agency, "Water quality assessment - lower Snake River": U. S. E. P. A. Region X, Seattle, Wash., 1976. (DOE)
- U. S. Environmental Protection Agency, "Report on Banks Lake, Grant and Douglas Counties, Washington": Office of Research and Development, National Eutrophication Survey Working Paper No. 865, Washington, D. C., 12 p., July 1977. (DOE)
- U. S. Environmental Protection Agency, "Report on Medical Lake, Spokane County, Washington": Office of Research and Development, National Eutrophication Survey Working Paper No. 871, Washington, D. C., 12 p., July 1977. (DOE)
- U. S. Environmental Protection Agency, "Report on Moses Lake, Grant County, Washington": Office of Research and Development, National Eutrophication Survey Working Paper No. 872, Washington, D. C., 20 p., July 1977. (DOE)
- U. S. Environmental Protection Agency, "Report on lower Granite Reservoir, Garfield and Whitman Counties, Washington": Office of Research and Development, National Eutrophication Survey Working Paper No. 876, Washington, D. C., 111 p., July 1977. (DOE)
- U. S. Geological Survey, "Summary of records of surface waters of Washington, 1919-35": U. S. Geol. Survey Water-Supply Paper 870, 456 p., 1940. (USGS; UW,SRR)
- U. S. Geological Survey, "Waterlevel measurements in Columbia Basin": unpublished records, Tacoma, Wash., 1949-1955. (USGS)

U. S. Geological Survey, "Well records and logs from representative wells in the Ahtanum Valley": unpublished records, Tacoma, Washington, 1957. (USGS)

U. S. Geological Survey, "Columbia Basin Irrigation Project basic data, 1959-1960 fiscal years": unpublished records, Tacoma, Wash., 1960. (USGS)

U. S. Geological Survey, "Summary of snow survey measurements in the State of Washington, 1915-1960 inclusive": Wash. (State) Div. Water Resources, Water-Supply Bull. 13, Olympia, Wash., 111 p., 1960. (USGS)

U. S. Geological Survey, "Magnitude and frequency of floods in the United States, Part 12-14": Water-Supply Papers 1687-89, 1964. (USGS; UW,SRR)

U. S. Geological Survey, "Mineral and Water Resources of Washington": Report prepared for Senate Committee on Interior and Insular Affairs, Washington, D. C., 436 p., 1966. (USGS)

U. S. Geological Survey, "Annual summary of water quality data for selected sites in the Pacific Northwest, October 1971 to September 1972": Northwest Water Resources Data Center, Portland, Ore., 35 p., Nov. 1972. (WRC)

U. S. Geological Survey, "Water-level altitudes in sedimentary and shallow aquifers and in deeper basalt aquifers, March 1973, in Columbia Basin Irrigation Project area": U. S. Geol. Survey Open-File Maps. (USGS)

* U. S. Geological Survey, "Water resources of the Toppenish Creek Basin, Yakima Indian Reservation, Washington": U. S. Geol. Survey Water Resources Investigations 42-74, Tacoma, Wash., 144 p., 1975. (DOE; USGS)

U. S. Geological Survey, "Water resources data for Washington - water year ____": annual 1971-74, "Part I: Surface Water", "Part II: Water Quality"; also V. 1, 1975; and V. 2, "Eastern Washington", 1976, Tacoma, Wash. (USGS; UW,SRR)

U. S. Geological Survey, "Quality of surface water of the United States": annual, Water-Supply Papers (WSP). Listed as follows by year of record and WSP number: (USGS; UW,SRR)

1941, WSP 942	1951, WSP 1200	1961, WSP 1786, 1885
1942, WSP 950	1952, WSP 1253	1962, WSP 1945
1943, WSP 970	1953, WSP 1293	1963, WSP 1951
1944, WSP 1022	1954, WSP 1353	1964, WSP 1959
1945, WSP 1030	1955, WSP 1403	1965, WSP 1966
1946, WSP 1050	1956, WSP 1453	1966, WSP 1996
1947, WSP 1102	1957, WSP 1523	1967, WSP 2016
1948, WSP 1133	1958, WSP 1574	1968, WSP 2100
1949, WSP 1163	1959, WSP 1645	1969, WSP 2150
1950, WSP 1189	1960, WSP 1745	1970, WSP 2160

*Annotated

U. S. Geological Survey, "Surface water supply of the United States": annual for 1897-1970, Water-Supply Papers (WSP). Listed as follows by year of record and WSP number: (USGS; UW,SRR)

1897, WSP 16	1921, WSP 532-34	1943, WSP 982-84
1898, WSP 28	1922, WSP 552-54	1944, WSP 1012-14
1899, WSP 38	1923, WSP 572-74	1945, WSP 1042-44
1900, WSP 51	1924, WSP 592-94	1946, WSP 1062-64
1901, WSP 66, 75	1925, WSP 612-14	1947, WSP 1092-94
1902, WSP 85	1926, WSP 632-34	1948, WSP 1122-24
1903, WSP 100	1927, WSP 652-54	1949, WSP 1152-54
1904, WSP 135	1928, WSP 672-74	1950, WSP 1182-84
1905, WSP 177-78	1929, WSP 692-94	1951, WSP 1216-18
1906, WSP 214	1930, WSP 707-09	1952, WSP 1246-48
1907-8, WSP 252	1931, WSP 722-24	1953, WSP 1286-88
1909, WSP 272	1932, WSP 737-39	1954, WSP 1346-48
1910, WSP 292	1933, WSP 752-54	1955, WSP 1396-98
1911, WSP 132	1934, WSP 767-69	1956, WSP 1446-48
1912, WSP 332	1935, WSP 792-94	1957, WSP 1516-18
1913, WSP 362	1936, WSP 812-14	1958, WSP 1566-68
1914, WSP 392-94	1937, WSP 832-34	1959, WSP 1936-38
1915, WSP 412-14	1938, WSP 862-64	1960, WSP 1716-18
1916, WSP 442-44	1939, WSP 882-84	Summary through 1950, WSP 1316-18
1917, WSP 462-64	1940, WSP 902-04	Oct. 1950 to Sept. 1960, WSP 1736-38
1918, WSP 482-84	1941, WSP 932-34	1961-65, WSP 1932-34
1919-20, WSP 512-14	1942, WSP 962-64	1965-70, WSP 2133-35

U. S. Geological Survey, "Water levels and artesian pressures in observation wells in the United States in _____ - part 5, northwestern states": various authors, Water-Supply Papers (WSP), listed as follows by year of record and WSP number: (USGS; UW,SRR)

1935, WSP 777	1946, WSP 1075	1961-65, WSP 1845
1936, WSP 817	1947, WSP 1100	1966-70, WSP 1980
1937, WSP 840	1948, WSP 1130	
1938, WSP 845	1949, WSP 1160	
1939, WSP 886	1950, WSP 1169	
1940, WSP 910	1951, WSP 1195	
1941, WSP 940	1952, WSP 1225	
1942, WSP 948	1953, WSP 1269	
1943, WSP 990	1954, WSP 1325	
1944, WSP 1020	1955, WSP 1408	
1945, WSP 1027	1956-60, WSP 1760	

U. S. Public Health Service, "Columbia River Basin project for water supply and water quality management, introductory report": Region 9, 26 p., March 1961. (DOE)

A. S. Van Denburg and J. F. Santos, "Ground water in Washington, its physical and chemical quality": Wash. (State) Dept. Conservation, Div. Water Resources, Water-Supply Bull. 24, Olympia, Wash., 93 p., 1965. (DOE)

Walton Van Winkle, "Quality of the surface water of Washington": U. S. Geol. Survey Water-Supply Paper 339, 105 p., 1914. (USGS)

E. F. Wallace, "Investigation of possible interference between two wells in Section 34, Township 12 N., Range 29 E, W. M. in Franklin County": Wash. (State) Dept. Conservation, Water Resource Div., unpub. letter rept. 4 p., 1961. (DOE)

L. Wallick, et al., "Draft final report study area VI-C, Columbia River": consultant report, Parametrix, Inc., Seattle, Washington, prepared for National Commission on Water Quality, 137 p., May 1975. (DOE)

- * K. L. Walters, "Water resources of the White Salmon area, Klickitat County, Washington": U. S. Geol. Survey Memo. for the files, Tacoma, Washington, 17 p., 1967. (USGS)

K. L. Walters, "Test-observation well near Odessa, Washington": U. S. Geol. Survey unpublished report., Tacoma, Wash., 27 p., 1971. (USGS; DOE; WRI)

- * K. L. Walters, "Test-observation well near Almira, Washington: description and preliminary results": U. S. Geol. Survey Open-File Report, Tacoma, Washington, 20 p., 1972. (USGS)

K. L. Walters, "A summary of rehabilitation work on the Odessa oil-test well": U. S. Geol. Survey Memo. Rept., Tacoma, Washington, 8 p., 1973. (USGS)

K. L. Walters, "Water in the Okanogan River Basin, Washington": Wash. (State) Dept. Ecology, Water-Supply Bull. 34, Olympia, Washington, 136 p., 1974. (DOE)

- * K. L. Walters, D. R. Cline and J. E. Luzier, "Test-observation well near Odessa, Washington--description and preliminary results": Wash. (State) Dept. Ecology, Olympia, Washington, and U. S. Geol. Survey Open-File Report, Tacoma, Washington, 25 p., 1971. (DOE; USGS)

- * K. L. Walters and P. A. Glancy, "Reconnaissance of geology and of ground-water occurrence and development in Whitman County, Washington": Wash. (State) Dept. Water Resources Water Supply Bull. 26, 169 p., 1969. (DOE)

K. L. Walters and M. J. Grolier, "Records of wells, water levels, and quality of ground water in the Columbia Basin project area, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Washington, 494 p., 1959. (USGS)

- * K. L. Walters and M. J. Grolier, "Geology and ground-water resources of the Columbia Basin Irrigation Project area, Washington, v. 1": Wash. (State) Dept. Conservation, Div. Water Resources Water-Supply Bull. 8, Olympia, Washington, 542 p., 1960. (DOE)

K. L. Walters and E. G. Nassar, "Water in the Methow River Basin, Washington": Wash. (State) Dept. Ecology, Water-Supply Bull. 38, Olympia, Washington, 73 p., 1974. (DOE)

G. A. Waring, "Geology and water resources of a portion of south-central Washington": U. S. Geol. Survey Water-Supply Paper 316, 46 p., 1913. (USGS; DOE)

C. R. Warren, "Course of the Columbia River in south-central Washington": Am. Jour. Sci., v. 239, no. 3, p. 209-232, 1941. (UW,SRR)

Washington (State) Department of Conservation, "Monthly and yearly summaries of hydrometric data in the State of Washington to Sept., 1933": Washington (State) Div. Water Resources, Water-Supply Bull. 5, 201 p., 1935. (DOE)

Washington (State) Department of Conservation and Development, "Monthly and yearly summaries of hydrographic data in the State of Washington to Sept. 1953": Wash. (State) Dept. Conservation, Div. Water Resources Water-Supply Bull. No. 6, Olympia, Wash., 824 p., 1955. (DOE)

Washington (State) Department of Conservation, "Monthly and yearly summaries of hydrographic data in the State of Washington, Oct. 1953 to Sept. 1960": Wash. (State) Dept. Conservation, Div. Water Resources Water-Supply Bull. No. 15, Olympia, Wash., 378 p., 1962. (DOE)

Washington (State) Department of Conservation, "Miscellaneous streamflow measurements in Washington, 1890-1961": Wash. (State) Dept. Conservation, Div. Water Resources, Water-Supply Bull. 23, Olympia, Wash., 292 p., 1964. (DOE)

Washington (State) Department of Ecology, "Water quality report Spokane River and Little Spokane River; December 1970 - March 1971": Olympia, Wash. 28 p., December 1971. (DOE)

Washington (State) Department of Ecology, "Water quality report Spokane and Little Spokane Rivers; July 1971 - September 1972": Olympia, Wash., 28 p., August 1972. (DOE)

Washington (State) Department of Ecology, "State of Washington water quality assessment report": Olympia, Washington, 2 vols., Rept. 75-8, June 1975. (DOE; WSL)

Washington (State) Department of Ecology, "Water quality assessment, Yakima River, summer 1970": Olympia, Washington, 25 p., August 1971. (DOE)

Washington (State) Department of Ecology, "Reconnaissance data on selected lakes in Washington: Vol. 5 - Chelan, Kittitas, Klickitat, Okanogan, Yakima, and Ferry Counties; Vol. 6 - Adams, Benton, Douglas, Franklin, Grant, Lincoln, Whitman, and Walla Walla Counties; Vol. 7 - Pend Oreille, Spokane, and Stevens Counties": Dept. Ecology Water-Supply Bull. 43, Olympia, Wash., 1976. (DOE)

Washington (State) Department of Water Resources, "Ground water resources and related geology, north-central Spokane and southeastern Stevens counties": Olympia, Washington, 195 p., 1969. (DOE)

Washington (State) Division of Mines and Geology, "Mineral and water resources of Washington": Reprint no. 9, Olympia, Washington, 436 p., 1966. (GER)

Washington (State) Legislature, "Ground water code relating to the regulation and control of certain ground waters within the State and rights to the use thereof, Chapter 263 of Session Laws, 1945": Wash. (State) Dept. Conservation and Devel., Div. Water Resources, Olympia, Washington, 1945. (DOE)

Washington (State) Office of Program Planning and Fiscal Management, "Washington's water resources": Olympia, Washington, 82 p., 1971. (WSL)

Washington (State) Pollution Control Commission, "Comprehensive pollution control program for the Yakima River Basin (Basin No. 25)": Olympia, Wash., 24 p., March 1952, Revised 1954. (UW; DOE; WRC)

Washington (State) Pollution Control Commission, "Quality of surface waters June 1959-July 1960": Olympia, Washington, 97 p., 1961. (WRC; DOE)

Washington (State) Pollution Control Commission, "Interim report, physical and chemical data for lower Columbia River, Feb. 1964 - Nov. 1965": Olympia, Washington, 95 p., 1966. (WSL)

Washington State University, "Water quality in the Columbia River Basin": Institute of Technology, Div. Industrial Res., proceedings of the Water Quality Conference, Nov. 28-30, 1960, Pullman, Washington, p. 95-110, 1960. (WSU)

Washington (State) Water Research Center, "An initial study of the water resources of the State of Washington; Vol. I - A first estimate of future demands for water in the State of Washington; Vol. II - Water resources atlas of the State of Washington": Pullman, Washington, Feb. 1967. (WRC; DOE)

Washington (State) Water Research Center, "Long-run costs and policy implications of adjusting to a declining water supply in eastern Washington": Rept. 9, Pullman, Washington, 106 p., Oct. 1971. (DOE)

D. G. Watson, et al., "Cycling of radionuclides in Columbia River biota (with discussion)": in "Trace Subst. Environ. Health, Proc., no. 4, p. 144-157, 1971. (Battelle)

J. M. Weigle and M. J. Mundorff, "Records of wells, water levels, and quality of ground water in the Spokane Valley, Spokane County, Washington": U. S. Geol. Survey Open-File Report, Tacoma, Washington, 102 p., 1952. (USGS)

A. E. Weissenborn, et al., "Geology": in "Mineral and water resources of Washington": Senate Committee on Interior and Insular Affairs, U. S. Congr., 89th, 2nd. Sess., Committee Print, U. S. Govt. Prtg. Off., p. 13-46, 1966. (DOE)

J. F. Williams, "Well report, Basalt Explorer": Development Assoc., Inc., Spokane, Wash., 1960. (WRC)

J. R. Williams, "Drainage-area data for eastern Washington": U. S. Geol. Survey Open-File Report, Tacoma, Washington, 197 p., 1964. (USGS)

W. D. Williams, "Application of mathematical models for analysis of Yakima River water quality: The role of data acquisition": Univ. of Wash., Masters thesis, Seattle, Washington, 174 p., 1973. (DOE)

E. E. Wolcott, "Lakes of Washington, V. 2, eastern Washington": Wash. (State) Dept. Conservation, Div. Water Resources, Water Supply Bull. 14, Olympia, Washington, 650 p., 1964. (DOE)

V. W. Wood, "A Summary of Columbia River hydrographic information pertinent to Hanford Works, 1894-1954": Hanford Works, HW-30347, Richland, Washington, February 24, 1954. (Battelle)

C. C. Wright, "Surface and subsurface waters of the Yakima and Klamath reclamation projects": Wash. (State) Agr. Exper. Sta. Bull. 228, Wash. State Univ., Pullman, Washington, 1928. (WSL)

L. Young, "Paterson Ridge pumped-storage site, Washington": U. S. Geol. Survey Open-File Rept., Tacoma, Washington, 37 p., 1967. (DOE)

Bingham, J. W. and M. J. Grolier. The Yakima Basalt and Ellensburg Formation of south-central Washington. Washington, D.C., U.S. Geological Survey, 1966. 15p. (Bulletin 1224-G)

The uppermost part of the Yakima Basalt--herein assigned to the Columbia River Group--has the following largely conformable units (from oldest to youngest): lower basalt flows; the Vantage Sandstone Member; the Frenchman Springs Member, which locally includes the Squaw Creek Diatomite Bed; the Roza Member; the Priest Rapids Member, which locally includes the Quincy Diatomite Bed; and the Saddle Mountains Member. Sedimentary deposits of the Ellensburg Formation interfinger with basalt flows of the youngest member of the Yakima Basalt.

The maximum thickness of the Yakima Basalt is not known, but the formation is about 4,500 feet thick at a test well drilled in the Odessa area, and is probably much thicker toward the center of the Columbia Plateau. The part described herein has a composite thickness of about 1,200 feet above the Vantage Sandstone Member. The overlying and interfingering Ellensburg Formation is as thick as 2,000 feet in the type area, and the Beverly Member, which represents the lower part of the Ellensburg in the Sentinel Gap area, is as thick as 300 feet.

The Yakima Basalt is late Miocene and early Pliocene in age, as determined from the flora and fauna in the underlying Mascall Formation in Oregon, the intrabedded sedimentary rocks and the interbedded and overlying Ellensburg Formation.

Bingham, J. W. and K. L. Walters. Stratigraphy of the upper part of the Yakima Basalt in Whitman and eastern Franklin counties, Washington. Washington, D.C., U.S. Geological Survey, 1965. p. 87-90 (Professional Paper 525-C)

A stratigraphic sequence in basalt, similar to that described by Mackin (1961)^{1/} near Sentinel Gap, was measured in two places on the Columbia Plateau, about 70 and 130 miles east of the gap. This sequence is in the upper part of the Yakima Basalt, and consists of the nonporphyritic Priest Rapids Member at the top, the porphyritic Roza Member in the middle, and the sparsely porphyritic Frenchman Springs Member at the base. The existence of the sequence at widely spaced localities in central and eastern Washington suggests that it is continuous and mappable over large areas of the plateau.

^{1/} Mackin, J. H., 1961. A stratigraphic section in the Yakima Basalt and the Ellensburg Formation in south-central Washington: Washington Div. Mines and Geology Report Invest. 19, 45p.

Bush, J. H., Jr., J. V. Anderson, J. W. Crosby, III, and B. A. Siems.
 Test-observation well near Mansfield, Washington: Description,
 stratigraphic relationships and preliminary results. Pullman,
 Washington, Washington State University, College of Engineering,
 1972. (Research Report No. 72/11-128)

A 760-foot test-observation well drilled near Mansfield, Washington by the Washington State Department of Ecology is one of several drilled to date (1972). These test wells provide information on ground-water conditions where data from existing wells are incomplete and fail to provide adequate guidance for management of the ground-water resources of the area.

The Mansfield well penetrates 135 feet of post-Vantage Yakima Basalt and 490 feet of pre-Vantage Yakima Basalt and interflow sediments. Two major interbeds of sand, silt and clay occur between depths of 475 and 592 feet and between depths of 690 and 755 feet. The well bottoms in granitic rocks. Regional stratigraphic relationships show that flow sequences thin in the Mansfield area and that the well is located near the edge of basining during basalt extrusion.

Three important aquifers were encountered. The top aquifer occurs within the basalt sequence between 380 and 400 feet. The other two aquifers occur within the two previously mentioned interbeds. Pump tests and geophysical logs indicate that these three aquifers are capable of high production. However, due to the nature of the aquifers, drilling and development costs would be high. The lateral extent of each aquifer is not known, but it is suspected that they only receive recharge from precipitation over the northern portion of the Waterville Plateau.

Due to caving conditions, piezometer tubes used for monitoring the aquifers and water-bearing zones have not been installed. The well, however, is in an excellent location for determining long-term ground-water changes in the northeastern portion of the Waterville Plateau, and it is believed that additional information will become available by installing piezometer tubes to each of the encountered aquifers.

Bush, J. H., Jr., J. A. Morton, J. V. Anderson, and J. W. Crosby, III.
 Test-observation well near Walla Walla, Washington: Description,
 stratigraphic relationships, and preliminary results. Pullman,
 Washington, Washington State University, College of Engineering,
 1973. (Research Report No. 73/15-66)

A 1,308-foot test-observation well drilled near Walla Walla, Washington by the Washington State Department of Ecology and the U.S. Geological Survey is one of several drilled to date (1973). These test wells provide information on ground-water conditions where data from existing wells are incomplete and fail to provide adequate guidance for management of the ground-water resources of the area.

The Walla Walla well lies approximately in the center of the Walla Walla Basin. The well penetrated, from top to bottom, 260 feet of "Pleistocene?" gravel, 490 feet of "Pleistocene?" clay and 558 feet of Columbia River Basalt. Chemical analyses suggest that most of the basalt sequence belongs to the middle Yakima Formation. Correlation of units within the clay and basalt sequences to nearby wells using geophysical techniques aided in understanding the configuration and origin of the Walla Walla Basin.

Two important basalt aquifers were encountered, one between 710 and 740 feet and one between 1,260 and 1,309 feet. Pump tests showed that the upper aquifer is capable of high production in excess of 1,400 gallons per minute (gpm), with less than 100 feet of drawdown. The potential of the lower aquifer is not known.

Piezometer tubes were installed in each of the important aquifers and a thermal-measurement tube the entire depth of the well. The data obtained during drilling and the data expected from the tubes will be useful in management of the ground-water resources of the area.

Cearlock, D. B., C. R. Cole, H. P. Foote, R. W. Wallace. Mathematical ground-water model of the Ahtanum-Moxee subbasins, Yakima County, Washington. Implementation report. Richland, Washington, Battelle, Pacific Northwest Laboratory, 1975. 36p.

A digital computer model was developed for the multiaquifer ground-water system of the Moxee-Ahtanum subbasins located in southeastern Washington near Yakima. The model was developed to serve as a management tool for this ground-water system which is becoming highly stressed due to increasing demands of agricultural irrigation.

This study was performed by Battelle-Northwest (BNW) in conjunction with the Washington State Department of Ecology (DOE). DOE was responsible for data collection and BNW worked with DOE to interpret the field data.

For model development, the area was considered as two independent subbasins divided by the Yakima River which acts as the ultimate ground-water discharge body for each subbasin. Each subbasin consists of three hydrologic units: (1) an unconfined water table aquifer, gravel (QAL); (2) an underlying confined aquifer, the Ellensburg formation; and (3) the lowest unit a confined aquifer consisting of basalt flows, the Yakima Basalt.

Only the steady-state versions of the digital model were calibrated and verified because time histories were not sufficient to calibrate the transient model. The Ahtanum Subbasin Model was calibrated using 1951 data taken by Foxworthy (USGS WSP-1598) and verified with data collected in 1973 by the DOE. The Moxee subbasin was calibrated with 1973 DOE data. Comparisons of model-predicted potentials with observed data indicate that the model reasonably simulates the ground-water system. Further data collection and model verification studies would improve the

accuracy of the model, but in its present state it is an efficient management tool for predicting the effect of proposed new pumping on the aquifer system.

Cline, D. R. Ground-water resources and related geology of north-central Spokane and southeastern Stevens counties of Washington. Olympia, Washington, Washington State Department of Water Resources, 1968. 195p. Prepared in cooperation with U.S. Geological Survey. (Water-Supply Bulletin No. 27)

The project area of 450 square miles, which includes the northern part of the city of Spokane, lies in a basin surrounded by low mountains and contains several basalt-capped mesas. Most of the project area is drained by the Little Spokane River, which joins the Spokane River at the southwest edge. Precipitation ranges from about 15 to 25 inches in the study area and is as much as 49 inches in the adjacent mountains.

Granitic and metamorphic basement rocks of pre-Tertiary age underlie the basin and form the surrounding mountains. Many wells tapping these rocks yield small amounts of water, up to about 35 gpm, sufficient for domestic and stock use; however, many other wells yield no water. Shale, clay, and sand of the Latah Formation and, locally, interbedded lavas of the Yakima (?) Basalt overlie the basement rocks in much of the project area. Most wells tapping aquifers in the Tertiary formations yield enough water for domestic and stock use. Yields from these rocks are generally less than 35 gpm.

Unconsolidated Quaternary materials such as landslide debris, loess, dune sand, alluvium, and morainal, glaciolacustrine, and glaciofluvial deposits overlie the consolidated rocks throughout much of the basin. These deposits are at least several hundred feet thick in the Spokane Valley, the Hillyard Trough, and the lower part of the Little Spokane River Valley. In those valleys, wells tapping the unconsolidated materials commonly yield several thousand gallons per minute with only a few feet of drawdown. On the mesas, wells tapping the unconsolidated deposits generally yield less than 20 gpm; elsewhere, the range in yield is from 5 gpm to as much as 600 gpm.

Water levels in most wells in the project area are less than 100 feet below land surface. In the Hillyard Trough, levels in some wells exceed 200 feet. Under the mesas, more than one water level occurs, the deepest known being about 550 feet below land surface.

Recharge to the ground-water reservoir in the Little Spokane River Basin probably amounts to about one-fifth of the precipitation that falls on the basin, or about 160,000 acre-feet per year. The ground water moves generally toward the river and discharges into it.

In 1964 about 9 billion gallons were pumped from wells in the project area. This quantity is equivalent to less than 10 percent of the average September flow of the Little Spokane River near its mouth. About 90 percent of the pumpage comes from unconsolidated deposits in the Spokane

metropolitan area. The large ground-water withdrawals in the Spokane area have not affected the regional water level.

Ground water in the project area in 1964 was used for industrial purposes (48 percent), public supplies (39 percent), irrigation (8 percent), and rural domestic and stock supplies (about 5 percent). Although most of the water is pumped from wells, many springs are also used. Ground-water withdrawals probably will be one-half again as large by 1980 as in 1964, probably mostly in the metropolitan Spokane area. Sufficient water is available to meet these needs.

Most of the wells yield a hard or moderately hard calcium magnesium bicarbonate water that is generally of good quality, except in some places where iron concentrations are excessive. Most of the ground-water temperatures are between 8 and 12 degrees Celsius, or between 47 and 54 degrees Fahrenheit (°F).

Cline, D. R. Reconnaissance of the water resources of the Upper Klickitat River Basin, Yakima Indian Reservation, Washington. Tacoma, Washington, U.S. Geological Survey, 1976. 54p. (Open-File Report 75-518)

The upper Klickitat River basin, covering 749 square miles in the Yakima Indian Reservation, Washington, lies immediately east of the crest of the southern Cascade Range and is dominated on its western margin by 12,276-foot Mount Adams, a glacier-mantled volcano. The Klickitat River, which flows south to the Columbia River, discharges an annual flow of about 1,200 cubic feet per second (cfs) at the point where it leaves the reservation; probably about 60 percent of this is ground-water discharge. Several streams provide irrigation water to about 5,600 acres in the Camas Prairie-Glenwood area. About 12,000 acre-feet of the water were delivered by Hellroaring Ditch in 1974. The area around Mount Adams yields considerably more water per square mile than the remainder of the basin because an average of 140 inches of precipitation falls on the upper slopes of this mountain, mostly as snow. Less than 30 inches fall in the southern part of the basin along the Klickitat River. Ground water in large quantities (more than 400 cfs in the fall of 1974 and mostly from the Mount Adams area) discharges into the Klickitat River canyon in a 13-mile reach in the southern part of the reservation; about one-half of the water is discharged from large springs. The largest spring discharges about 40 cfs.

Copp, H. D. and D. T. Higgins. Model development and systems analysis of the Yakima River Basin: Hydraulics of surface water runoff. Pullman, Washington, Washington Water Research Center, 1974. 150p. (Report No. 178)

A computer model is described that is an accounting of water quality in the Yakima River that flows from upper watershed areas into and through

predefined stream reaches to the watershed outlet. The model adds tributary streams at confluences, and subtracts withdrawals from the stream. The model is deterministic; water quantities must be specified. However, with: (1) separate analyses to define water runoff at various levels of probability; and (2) model use with these runoff quantities, future probabilistic events and their consequences can be analyzed. Model development recognized the flexibility which water planning must have. Accordingly, the user has considerable freedom in establishing (1) watershed description, (2) the stream system, (3) quantities of flow in the streams, (4) positions and quantities of withdrawals and/or return flows, (5) location and operation rules of storage-reservoirs, and (6) flow quantities needed to meet above-mentioned requirements. The model is thus capable of simulating many water management plans, existing or envisioned, and a wide range of water quality regimes.

Crosby, III, J. W. "Ground-water research in the Pullman-Moscow Basin." In: Engineering geology and soils engineering symposium. Proceedings of the 4th annual . . . symposium, held at Moscow, Idaho, April 19-21, 1966. Boise, Idaho, Idaho Department of Highways, 1966. p. 215-236.

During the past 50 or 60 years, piezometric levels of the basaltic aquifers of the Pullman-Moscow basin have been declining at rates varying from 1 to 5 feet per year. The indicated withdrawals from storage in the basin and the apparent deterioration of municipal water quality at Moscow have been subjects of increasing concern. Research studies of the ground-water basin have been conducted for many years, principally, by the USGS, the University of Idaho and Washington State University. In the past few years, these efforts have been expanded because of the establishment of water research centers at both universities. A cooperative program is being conducted to determine the mechanisms of natural recharge to the basin. Although the studies are being coordinated, each university is approaching the problem independently and most of the findings are in substantial agreement, though there are some points on which data appear to be contradictory.

Washington State University has conducted a series of seismic studies in the Moscow subbasin utilizing both refraction and reflection techniques. Studies were directed toward determining the configuration of the pre-Tertiary drainage system and the stratigraphic relationships between the basalts and the Latah Formation. The ground-water system has been investigated by both carbon-14 and tritium dating techniques. Results obtained thus far indicate these methods may be a valuable hydrologic research tool in basaltic terranes. Much of the present ground-water body appears to have been in storage by the closing phases of the glacial period. Ground-water levels apparently declined until the post-glacial thermal maximum. With the advent of more humid conditions the reservoir slowly filled to its earliest known level in the 1890's.

The hydrogeology of the Pullman-Moscow area is complex and not readily treated by standard analytical measures. The nature of the water-bearing zones in the basalts and their modes of hydraulic interconnection are known in general, but obscure in detail. Standard pump-testing techniques frequently lead to results which are difficult to analyze and suggest a need for investigating other methods of determining aquifer characteristics. Carbon-14 water-dating techniques appear to offer considerable promise for investigating the hydrology of basaltic terranes, and studies should include determination of $^{13}\text{C}/^{12}\text{C}$ ratios on all samples. Seismic studies have proven to be a valuable tool for gaining subsurface information in the Moscow subbasin. Refraction and reflection techniques, used conjunctively, give the best results. Using drill logs and seismic data, it has been possible to reconstruct the surface topography of the basement complex and the surface of the upper basalt with considerable confidence. Success of seismic operations in the Moscow subbasin depends in large measure upon alternating basalts and Latah sediments. It is doubtful that comparable results could be obtained in basaltic areas where the stratigraphic column was lacking in sedimentary interbeds.

Crosby, III, J. W. and J. V. Anderson. "Some applications of geophysical well logging to basalt hydrogeology." Ground Water. Vol. 9, No. 5. p 12-20. 1971.

The application of borehole geophysics to study of basalt hydrogeology has been pursued at Washington State University for the past six years. Throughout this period, much effort has been directed to redesign of commercial geophysical system components and development of expanded downhole capabilities. It has been demonstrated that composite logging techniques can be used to define the hydraulic regime of a well constructed in basalt. Certain of the logging measures, with further study, may become powerful tools for identifying anomalous conditions associated with pollutant dispersion in an aquifer. Positive correlations of basalt with the logging methods have not yet been made over distances greater than 20 miles. However, as improved logging density permits intermediate points of correlation to be established, further extensions are anticipated. Both major and minor log features of the basalts display varying degrees of lateral persistence. Because driller's logs are generally inadequate in describing subtleties of basalt geology, subsurface correlations are best made with geophysical logs. In areas with extensive surficial cover, the geophysical methods may prove to be a very practical method of determining basalt stratigraphy. Geophysical well logging offers to agencies charged with ground-water management many opportunities for gaining new knowledge which have been largely neglected. Reprinted by permission of the Water Well Journal Publishing Co., C. 1971. All rights reserved.

Crosby, III, J. W. and R. E. Cavin. Geological investigation of the Moscow ground-water basin employing geophysical studies. Pullman, Washington, Washington State University, College of Engineering, 1960. 23p. (Institute of Technology Bulletin No. 250)

Water levels in wells of the Moscow, Idaho area have been declining at a slow, but continual rate for many years. During the past decade, the water table has dropped at an increasing and alarming rate, causing much concern to the residents of Moscow and their city officials. In order to do something to alleviate the problem, a Mayor's Water Resources Committee was appointed to investigate the many phases involved.

Although many water wells have been drilled in the Moscow area, few are sufficiently deep to give much help to the geologist in defining the lower portion of the stratigraphic section. Some of the wells have been reported to have penetrated the granite or quartzite, but in these instances the wells are either reasonably shallow or there is reason to question the driller's log. Therefore, the depth to and the configuration of the granitic surface has always caused much speculation. If such information were put at the disposal of the geologist, it would help immeasurably in predicting the most favorable sites to drill wells.

Washington State University's Division of Industrial Research became interested in the possible application of the reflection seismograph to studies of structural and stratigraphic problems in the northwest. As virtually no reflection seismology had ever been attempted, possible applications of the equipment to local research problems appeared to be unlimited.

Crosby, III, J. W., and R. E. Chatters. Water-dating techniques as applied to the Pullman-Moscow ground-water basin. Pullman, Washington, Washington State University, College of Engineering, 1965. 2lp. (Institute of Technology Bulletin No. 296)

Carbon-14 dating techniques as applied to ground waters show great promise as an inventory technique and as a means of contributing to basic knowledge of ground-water accumulation and movement.

In a detailed study of the Pullman-Moscow ground-water basin of eastern Washington and western Idaho, over 50 samples of well waters were collected and analyzed for ^{14}C and/or tritium. The data indicate that the ground waters are distinctly stratified and display a well-defined relationship between water age and elevation of the productive zone.

The bulk of the ground water appears to have been placed in storage by the closing phases of the Pleistocene glaciation. Some additional recharge has been occurring in the Pullman subbasin since the thermal maximum about 6,500 years ago.

The ^{14}C data indicate that there has been no measurable recharge in the Moscow area in recent times. However, recharge in the Pullman subbasin is estimated to be 108 million gallons per year, or about 10 percent of the present pumpage rate.

Eakin, T. E. Ground-water resources of the Waterville area, Douglas County, Washington. Tacoma, Washington, U.S. Geological Survey, 1946. 36p. Prepared in cooperation with Washington State Department of Conservation and Development and the City of Waterville. (Open-File Report)

This report evaluates the potential sources of ground-water supply in the vicinity of Waterville, Washington. It gives the results of a brief investigation made by the U.S. Geological Survey in cooperation with the Washington State Department of Conservation and Development and the City of Waterville. The area concerned includes a part of the Waterville Plateau which lies between the Badger Mountains on the south and the Columbia River on the north and west. The report gives estimates of available water. The estimates are based on records of only a few months' duration and are, therefore, only rough approximations.

The character, succession, and water-bearing properties of the rocks are discussed and records of certain wells and springs in the area are noted.

Eddy, P.A. "Geohydrology of the Columbia Basin Project area, Washington." Northwest Science. Vol. 43, No. 1. p. 35. 1969.

The permeability of the basalt ranges from 10 to 40 gpd/ft²; specific yield ranges from .001 to .010. Permeable zones represent about 10 to 25 percent of total thickness, and have little hydraulic connection.

Unconsolidated sedimentary material overlying the basalt ranges from a few feet to about 900 feet. Permeabilities vary from 100 gpd/ft² in fine-grained material to over 10,000 gpd/ft² in sand and gravel. Specific yield ranges from .01 in fine-grained material to .20 in sand and gravel.

Ground-water flow is controlled primarily by regional geologic structures, and the hydrologic properties of the material above the basalt. Reprinted by permission of the Northwest Scientific Association, c. 1969. All rights reserved.

Eddy, P. A. Description, preliminary results, and pumping tests of test-observation well 13 near George, Washington. Olympia, Washington, Washington State Department of Ecology, 1976. 43p. (WRIS Information Bulletin No. 19)

A 975-foot deep test-observation well was drilled near the town of George, Washington by the Washington State Department of Ecology in cooperation with the U.S. Bureau of Reclamation. The well is the tenth drilled to date under the State of Washington's test-observation well drilling program. Information on the stratigraphy of the rocks and ground-water conditions was obtained and analyzed in order to establish

adequate guidelines for the management of the ground-water resource in the "Sand Dune Area."

The George well penetrated four major water-bearing units which are: (1) the glacial-fluvial material; (2) the Ringold Formation; (3) the upper 200 feet of the Yakima Basalt; and (4) Yakima Basalt below the upper 200 feet. The shallow aquifer, which consists of glacial-fluvial deposits, is designated as being within the upper 100 to 200 feet in wells in the "Sand Dune Area" and yields domestic and stock water. The Ringold Formation, generally, does not produce large quantities of water except where gravel sequences within the formation are intercepted, in which case, yields as large as 1,000 gpm have been obtained. The upper Yakima Basalt yields between 500 and 1,000 gpm and the deep basalt yields, in places, in excess of 2,100 gpm. For management purposes, anything above 200 feet into the Yakima Basalt is considered to be the shallow aquifer and everything below is the deep aquifer, regardless of the material or inter-aquifers.

A pump test was conducted on the deep aquifer which consists of several water-yielding interflow zones. The well was pumped in excess of 2,100 gpm for approximately 24 hours; this resulted in a maximum drawdown of 27 feet. Calculations using these data determined a value of 300,000 gallons per day per foot (gpd/ft) for the transmissivity and a storage coefficient of between 1.6×10^{-4} and 2.0×10^{-5} based on an assumed effective radius of the pumped well.

The well is favorably located for determining the long-term ground-water changes of the deep basalt in the "Sand Dunes Area" near George. At present, a Stevens A35 recorder is installed and future plans call for another pumping test after additional observation wells have been drilled into the shallow and deep basalt aquifer near the test-observation well.

Eddy, P. A. and C. S. Cline. A geohydrologic reconnaissance of the Dead Canyon area, Klickitat County, Washington. Olympia, Washington, Washington State Department. of Ecology, 1972. 6p. (Water Resources Investigation Section, unpublished letter report.)

The Dead Canyon lies about 30 miles south of Prosser in the northeast corner of Klickitat County and covers about 150 square miles. It is flanked by Alder Creek and Tule Canyon with a projected line to Glade Creek on the west, the Columbia River to the south and Glade Creek to the north and east. The northern part of the area is approximately 4 miles wide and slopes from an elevation of 1,300 feet to an elevation of 600 feet. The stream pattern is trellis and consists primarily of intermittent streams flowing in a southeasterly direction to the Columbia River.

The area has one major lithologic unit which is very significant to the occurrence of ground water, consisting primarily of basalt flows which have interfingered lake and river sediments consisting of shales, sandstone and clays or claystones. It lies on the gently inclined south limb of a primary anticlinal structure with an east-west-tending axis.

It appears that a secondary synclinal structure is also present in the study area. The trellis stream drainage pattern of Alder Creek indicates a gentle southeastward dip and the drainage of Glade Creek shows a southwestward control. As a result of this secondary geologic feature, the heads in wells close to the axis of the syncline are high and heads eastward and westward are significantly lower. The artesian conditions in the study area appear to be associated with one or two aquifer zones which are 600 feet or more below land surface.

A total of 8 wells which provided varying amounts of data and detail was used in this study. Most of the wells are large-production wells and are suitable for irrigation purposes. Data indicate that wells in the study area are capable of yielding large quantities of water.

It is felt by the authors and others that the present production rates are near the area recharge capacity at the present time and that increased production in excess of the calculated amount of recharge may cause decreases in the artesian head in the area.

Fox, J. D., and D. D. Wooldridge. Model development and systems analysis of the Yakima River Basin: Forest hydrology model. Pullman, Washington, Washington State University, 1974. 75p. (Water Research Center Report No. 17E)

The basic concepts of watershed modeling are explored and a working model is developed for the forested zone areas in the Yakima River Basin of Washington. The model follows the general approach developed by Fordam at the Desert Research Institute, Reno, Nevada. Precipitation and temperature information are translated into estimates of snowpack, snow melt, ground-water storage and, finally, overland and ground-water flows. A FORTRAN program, calibrated for Yakima Basin conditions, is used to estimate changes in total runoff and seasonal patterns. A particular application is made to changes in runoff following clearcut timber harvesting over various proportions of the watershed surface.

Foxworthy, B. L. Results of pumping test, city well four, Pullman, Washington. Tacoma, Washington, U.S. Geological Survey, 1957. 15p. Unpublished records, subject to revision. (Open-File Report)

Measurements of water level on city well 4 and on nearby wells were made by the U.S. Geological Survey. Results of the pumping test are described in this report, and tabulations of water-level measurements, hydrographs, and descriptions of pertinent wells are included.

To determine water-level trends and fluctuations under essentially normal conditions of summertime pumping, measurements were made in 6 wells to compare with similar measurements during and following the pumping test on well 4. All the wells listed tap artesian basalt aquifers, and are in the same general area.

Sufficient data are at hand so that, with the collection of a small increment of additional information during, say, the next 2 or 3 years, an evaluation of the overall effects of pumping of well 4 probably can be made at that time.

Foxworthy, B. L. Geology and ground-water resources of the Ahtanum Valley, Yakima County, Washington. Washington, D.C., U.S. Geological Survey, 1962. 100p. (Water-Supply Paper No. 1598)

The Ahtanum Valley covers an area of about 100 square miles in an important agricultural district in central Yakima County, Washington. Because the area is semiarid, virtually all crops require irrigation. Surface-water supplies are inadequate in most of the area, and ground water is being used increasingly for irrigation. The purpose of this investigation was the collection and interpretation of data pertaining to ground water in the area as an aid in the proper development and management of the water resources.

The occurrence and movement of ground water in the Ahtanum Valley are directly related to the geology. The valley occupies part of a structural trough (Ahtanum-Moxee subbasin) that is underlain by strongly folded flow layers of a thick sequence of the Yakima Basalt. The upper part of the basalt sequence interfingers with, and is conformably overlain by, sedimentary rocks of the Ellensburg Formation which are as much as 1,000 feet thick. These rocks are in turn overlain unconformably by cemented basalt gravel as much as 400 feet thick. Unconsolidated alluvial sand and gravel, as much as 30 feet thick, form the valley floor.

Although ground water occurs in each of the rock units within the area, the Yakima Basalt and the unconsolidated alluvium yield about three-fourths of the ground water currently used. Wells in the area range in depth from a few feet to more than 1,200 feet and yield from less than 1 to more than 1,000 gpm.

Although water levels in water-table wells usually are shallow--often less than 5 feet below the land surface--levels in deeper wells tapping confined water range from somewhat above the land surface (in flowing wells) to about 200 feet below. Wells drilled into aquifers in the Yakima Basalt, the Ellensburg Formation, and the cemented gravel usually tap confined water, and at least 12 wells in the area flow or have flowed in the past. Ground-water levels fluctuate principally in response to changes in stream levels, variations in the flow of irrigation ditches and in rates of water application, variations in local precipitation, and seasonal differences in withdrawals from wells. Annual fluctuations of levels generally are less than 10 feet except in localities of heavy pumping. Periodic measurements of water levels in two observation wells in the area indicate, locally at least, a persistent decline in artesian pressures in confined basalt aquifers, although the record is too short to show whether withdrawal by pumping has reached, or is nearing, an optimum balance with recharge.

The aquifers are recharged by precipitation, by infiltration from streams, and by ground-water underflow into the area. Ground water is discharged by seepage to streams, by evapotranspiration, by springs and seeps at the land surface, and, artificially, by withdrawal from wells. It is estimated that the seepage discharge to the Yakima River from the area studied may range from about 20,000 to 25,000 acre-feet per year. The consumptive waste of ground water by phreatophytes probably exceeds 4,000 acre-feet per year and may represent a large reclaimable source of water in the area. The annual withdrawal of ground water from wells in the area for domestic, industrial, irrigation, public, and stock supplies is estimated to be 6,300 acre-feet.

The chemical quality of the ground water generally is satisfactory for most purposes, although the water from many wells is harder than is desirable for domestic use.

Foxworthy, B. L. and R. L. Washburn. Ground water in the Pullman area, Whitman County, Washington. Washington, D.C., U.S. Geological Survey, 1963. 71p. (Water-Supply Paper No. 1655)

This report presents the results of an investigation of the ground-water resources of the Pullman area, Whitman County, Washington. The investigation was made in cooperation with the Washington State Department of Conservation Division of Water Resources to determine whether the 1959 rate of ground-water withdrawal exceeded the perennial yield of the developed aquifers, and if so, (1) whether additional aquifers could be developed in the area, and (2) whether the yield of the developed aquifers could be increased by artificial recharge.

The Pullman area includes the agricultural district surrounding the city of Pullman, in southeastern Whitman County, and the western two-thirds of the Moscow-Pullman basin, which extends into Latah County, Idaho. The mapped area comprises about 250 square miles.

The area is in a region of smooth, rolling hills formed by erosion of thick deposits of loess, which cover a dissected lava plain. The loess (Palouse Formation of Pleistocene age) ranges in thickness from less than 1 foot to more than 150 feet. The underlying lava flows, part of the Columbia River Basalt of Tertiary age, are nearly horizontal and form bluffs and low cliffs along the major streams. The total thickness of the basalt sequence in the area is not known, but it may be considerably greater than 1,000 feet beneath the city of Pullman. The basalt sequence is underlain by a basement mass of granite, granite gneiss, and quartzite of pre-Tertiary age.

The most productive aquifers in the area are in the Columbia River Basalt. They consist of the permeable zones, commonly occurring at the tops of individual lava flows, which may contain ground water under either artesian or water-table conditions. Two such permeable zones have produced more than 95 percent of the ground water used in the Pullman area, or as much as 870 million gallons per year (1957). These

two zones are hydraulically connected and lie at depths ranging from about 50 to 170 feet below the land surface at Pullman.

The area receives about 21 inches of precipitation annually, about two-thirds of it from October through March. Only a fraction of the precipitation reaches the aquifers; the remainder is returned to the atmosphere by evapotranspiration or leaves the area as surface runoff. The basalt is recharged mainly by infiltration from streams and downward percolation from the overlying loess.

The ground water moves generally westward. However, most water in the artesian aquifers tapped by wells in the vicinity of Pullman may move toward the city of Pullman, which is the center of major pumping. The rate of movement ranges from extremely slow in the loess and the massive basalt to very rapid in the permeable zones of basalt.

The principal modes of discharge from the artesian aquifers are seepage to streams and pumpage from wells. The amount of natural discharge is unknown, but the pumpage ranged from about 340 to 870 million gallons per year, and during 1949-59 it averaged about 800 million gallons (2,500 acre-feet) per year.

For about the last 25 years at least, the piezometric surface of the artesian zones has declined each year, indicating that the annual ground-water discharge from the artesian aquifers (including pumpage and natural discharge) has exceeded the recharge in the Pullman area. An analysis of the relation of pumpage to the decline in artesian level indicates that during 1952-59 an average of about 65 million gallons per year was removed from storage. Although the decline in artesian pressures has resulted in an increase in the recharge to the aquifers, the present rate of pumping may be equal to or even exceed the perennial yield of the artesian aquifer in the report area under natural conditions.

Geologic and hydrologic conditions seem favorable for the existence of potentially good aquifers below those which are now extensively developed. The deep aquifers seem to have only a slight hydraulic connection with the overlying artesian basalt aquifers.

The best possibility for artificially recharging the artesian aquifers seems to be through the injection of water from streams into one or more wells that penetrate the artesian zones. In such an arrangement, the well could be used alternately for recharge and pumping. One perennial and several intermittent streams are possible sources of recharge water. The stream water is similar in chemical quality to that from the artesian aquifers and so would be suitable for recharge, but removal of sediment would be required prior to injection.

Garrett, A. A. Ground-water withdrawal in the Odessa area, Adams, Grant, and Lincoln counties, Washington. Olympia, Washington, Washington State Department of Water Resources, 1968. 84p. Prepared in cooperation with U.S. Geological Survey. (Water-Supply Bulletin No. 31)

Before 1960, in the 670-square-mile project area near Odessa, Washington, ground water was used only for public supply and for individual farmsteads. Since 1960, irrigation of wheat with ground water has become common and withdrawals have greatly increased. In 1963, 66 irrigation wells pumped a total of about 11,400 acre-feet of water. In 1965, 94 wells pumped about 22,000 acre-feet. More irrigation wells are being drilled and still others are planned in the near future.

Ground-water supplies are being developed non-uniformly within the project area and, as a result of intensive localized development, ground-water levels are declining in some areas. The withdrawal of more than 4,000 acre-feet of water from the north-central part of the area in 1965 caused a 2- to 20-foot decline in water level throughout one area of about 45 square miles. On the other hand, the withdrawal during 1965 of a few thousand acre-feet of water from the east-central part of the study area resulted in a slight decline in level only locally. Withdrawal of more than 4,100 acre-feet from the southern part of the area reportedly did not affect water levels.

Most wells in the area are pumped nearly continuously during 7 months of the year and are idle during the other 5. Some of the wells are not idle long enough for water levels to recover completely before the next pumping season begins. This cyclic pumping pattern could produce successive yearly increments of residual drawdown.

In many parts of the project area, water levels in shallow aquifers (those less than about 300 feet below land surface) are different in altitude from those in the deeper aquifers tapped by many large-yield irrigation wells. Nonetheless, pumping of some of the deeper irrigation wells produces water-level declines in shallow wells. Simultaneous pumping of several wells has resulted in declines of as much as a foot in shallow wells as far as 3 miles distant.

This report shows: (1) the amount of ground water pumped from the Odessa area during 1963-64; (2) the parts of the area where the pumping is taking place; (3) the effects of that pumping as of year-end 1965; and (4) the possible future trends.

Garrett, A. A. and C. J. Londquist. Feasibility of artificially recharging basalt aquifers in Eastern Washington. Tacoma, Washington, U.S. Geological Survey, 1972. 42p. Prepared in cooperation with the Washington State Department of Ecology. (Open-File Report)

This study was made to evaluate artificial recharge as a means of augmenting natural recharge to partly offset the effects of intensive pumping of ground water in parts of eastern Washington.

Water spreading is not considered a feasible method of recharge in eastern Washington, and only the potential of recharge through wells was evaluated. Because the overdraft is so widespread and the movement of

ground water so slow, a single source of water could not be used effectively as a means of augmenting the natural recharge. Therefore, water sources were sought close to each center of intensive withdrawal.

Direct injection of stream water into wells does not appear to be feasible because streams in most coulees in eastern Washington have intermittent and extremely flashy flows and are heavily laden with suspended solids. Ground water in alluvial fill in the coulees is considered the most suitable source of water for artificial recharge. This shallow ground water, replenished periodically by surface flow, is likely to contain little sediment and dissolved air, which have been clogging agents in previous injection operations.

Of 22 township-size areas where overdraft is evident or may be starting, only 3 were considered technically suited to an artificial recharge program, and 10 were considered unsuitable because of a lack of an adequate source of recharge water. Nine of the areas were considered as possible sites for a recharge program, but data are not available, and further field work is suggested to more clearly evaluate the possibilities for recharge. Pending further study, the ground water in alluvium adjacent to Crab Creek near Odessa is considered to be the only source of enough water of suitable quality for effective artificial recharge. However, use of this ground water would decrease the flow of Crab Creek, which already is fully committed to the U.S. Bureau of Reclamation. Thus, artificial recharge with ground water from this source would involve the diversion of water which at present is legally appropriated for other use.

For the use of water from Crab Creek valley, the estimated cost of artificial recharge ranges from about \$6 per acre-foot for recharging 2,000 acre-feet per year to about \$4 per acre-foot (1970 values) for recharging 6,000 acre-feet per year if the source and injection sites were both on the valley floor (the most favorable situation). An installation requiring transport of the water could increase costs greatly. In a case where about 4.6 miles of pipeline would be required to transport water from the valley to the nearest possible injection site on an adjacent upland, the estimated cost ranges from about \$17 per acre-foot for recharging 2,000 acre-feet per year to about \$11 per acre-foot for 7,000 acre-feet per year. These costs would make the artificially recharged water very expensive for irrigation.

Gilmour, E. H. and M. Bacon. Ground-water resources and potential sewage pollution in southern Spokane County. Cheney, Washington, Eastern Washington State College, 1974. 58p. (OWRT Project Completion Report)

Most of the ground-water withdrawal in the study area of southern Spokane County is derived from wells that penetrate five basalt interflow aquifers. These aquifers consist of the weathered and fractured upper and lower portions of the basalt flows as well as permeable interflow sediments when present. Several of these aquifers extend throughout most of the

study area. In uncased wells, the continual flowing of water downhole from upper aquifers to the lower aquifers has reduced the quantity of water in the upper aquifers. This condition has caused several homeowners to deepen existing wells and will require more wells to be deepened in the future. Water samples from ponds, shallow and deep wells, shallow boreholes in meadows, and a municipal sewage lagoon system located in the study area were tested for fecal coliforms (FC), total coliforms (TC), fecal streptococci (FS), and asparagin-sufficient, oxidase-positive *Pseudomonas* spp. (ASP). FC, TC, and FS counts for the pond samples were low and apparently derived from non-human sources. Higher counts occurred in the boreholes. For both shallow and deep wells, little or no immediate fecal pollution was shown, but potential pollution by fecal bacteria may be indicated by the presence of ASP in 80 percent of the samples.

Gregg, D. O. and L. B. Laird. A general outline of the water resources of the Toppenish Creek Basin, Yakima Indian Reservation, Washington. Tacoma, Washington, U.S. Geological Survey, 1975. 37p. (Open-File Report 75-19)

An accounting of the overall availability of water on the Yakima Indian Reservation broadly outlines the water resources of the Toppenish Creek Basin. Precipitation averages about 20 inches a year over the basin, but only about 2 inches fall during the April-September growing season. However, diversions from the Yakima River make the Toppenish Creek Valley one of the best agricultural areas in the state. Ground water in the basin occurs in three distinct units; the basalt, old valley fill deposits, and young valley fill deposits. Each unit is capable of yielding more than 1,000 gallons per minute to properly constructed wells. Water levels in wells tapping the young valley fill are higher under present (1974) irrigation conditions than they were in the past, but some water-level declines have occurred in the old valley fill in response to pumping. Water levels in the basalt wells in some areas have been lowered as much as 80 feet by pumping during the past 15 years. Some additional pumping in these areas can be allowed without lowering the water level more than a few feet. The young valley fill in the eastern part of the lower valley is the best source of ground water in the basin. The zones of coarse sand and gravel to depths of about 150 feet in this area can produce large quantities of water. Irrigation water from the Yakima River seeps into the ground and builds up this ground-water supply. About 120,000 acre-feet of water goes into temporary storage each irrigation season in the young valley fill.

Gregg, D. O. and W. E. Lum, II. Dry Creek exploration test well. Tacoma, Washington, U.S. Geological Survey, 1973. 9p. (Open-File Report)

The Dry Creek test well was drilled as an exploratory well to 698 feet to determine the potential for obtaining irrigation water in the basin.

Three major water-bearing zones were penetrated. The two upper zones (235 to 308 feet and 358 to 444 feet) may be connected, as the water level in both zones stands at about 141 feet below land surface. The third and lowest zone (544 to 574 feet) had a water level of 201 feet. The water flowed down the well bore from the two upper zones at a rate of about 65 gpm, resulting in a composite water level of 184 feet.

Results from a pump test indicated the well yielded about 250 gpm with 90 feet of drawdown or about 2.8 gpm per foot of drawdown. Based on these results, a single well tapping the same section of rocks could pump 500 gpm with a drawdown of about 200 feet or a total pumping lift of 380 feet. The water is moderately hard, but suitable for irrigation, stock, and domestic uses.

Grolier, M. J. Geology of part of the Big Bend area in the Columbia Plateau, Washington. Baltimore, Maryland. The Johns Hopkins University, 1965. 267p. (Ph.D. Dissertation, Geology.)

The southwestern part of the Big Bend area in eastern Washington is in the central part of a great structural basin which corresponds to the field of extrusion of immense lava flows. The environment in which geologic events of the region took place has always been continental. Lavas welled up from fissures in the earth and flowed either on land or into shallow lakes. Volcanism in the region produced layered lava flows, but all landforms and all rocks younger than the congealed lava flows are due to processes normally active on emerged land. Climate, fluvial and lacustrine processes, glaciation, and tectonic activity are the factors against which sedimentation and erosion are weighed in describing present landforms and explaining the geologic history of the region.

The area is underlain by the Yakima Basalt, of middle Miocene to Pliocene age, the Beverly Member of the Ellensburg Formation of Pliocene age, the Ringold Formation of early Pleistocene age, and a variety of fluvial, lacustrine and eolian deposits ranging in age from Pleistocene to Recent. The economic incentive for this regional geologic study is the determination of the existing ground-water supply. The Yakima Basalt, being the principal reservoir of ground water, is studied in greater detail than other stratigraphic units. The stratigraphic nomenclature employed for the members of the Yakima Basalt is that proposed by Mackin (1961), slightly modified. The members of the Yakima Basalt, so defined, consist of flows or groups of flows that are mapped throughout the area. Formations other than the Yakima Basalt are not subdivided stratigraphically, and only their principal lithofacies are described and mapped.

Subsidence of the lava field, local folding and faulting, and presumably deformation due to arching of the Cascade Range have affected to a varying degree the rocks of Miocene to Recent age. The principal landforms are those determined by tectonic activity, fluvial processes, mass wasting, and wind action.

Grolier, M. J. and J. W. Bingham. Geologic map and sections of parts of Grant, Adams, and Franklin counties, Washington. Washington, D.C., U.S. Geological Survey, 1971. 6 sheets. (Miscellaneous Geologic Investigations, Map I-589)

Scale 1:62,500. Sheets 1-5 are geologic maps of the Columbia Basin area; sheet 6 shows sections of each of the 5 parts of the basin covered.

Hart, D. H. Feasibility of recharging basalt aquifers in the Walla Walla area Washington. Tacoma, Washington. U.S. Geological Survey, 1957. 35p. Prepared in cooperation with the Washington State Division of Water Resources. For administrative use only. (Open-File Report)

The object of this report is to assemble all pertinent data and to present it in such form that it can be used effectively by interested officials in making decisions as to the feasibility of a program of ground-water recharge using city well 3 as an injection well.

Data now available lead to the following conclusions.

1. Part of the recharge water injected into city well 3 could be recovered by subsequent pumping of that well and wells 1 and 2, and part would move downgradient beyond the area of pumping depression produced by pumping those wells. Part of the recharge water probably would be available for recovery by existing wells located closer to, and within, the city of Walla Walla.
2. Water-level measurements indicate that the static water level in well 3 will be such that a positive head of 174-179 feet could be maintained during injection of recharge water, allowing injection at a possible rate of several thousand gallons per minute.
3. Waters from Mill Creek and from city well 3 are of identical chemical type; no deleterious chemical reaction is likely to occur.
4. Mill Creek water from the pipeline probably would be nearly saturated with dissolved air. If no additional air were entrapped during injection, the recharge water probably would be less saturated with respect to existing physical conditions after it passed into the aquifer, and troublesome bubbles would not be likely to form in the aquifer.
5. No data are available at present concerning the biological character of the Mill Creek water.

6. It is unlikely that the concentration of sediment in the water from the Mill Creek pipeline is great enough to reduce aquifer permeability to the extent that it could not be restored by subsequent pumping of the recharge well.
7. Mill Creek water in amounts sufficient to allow recharge at the rate of 1,000 gpm probably would be available each year from October through April, and at least part of September.
8. Any final decision to enter into a program of ground-water recharge rests with the officials concerned with the efficient operation of the city's public-supply system. Although a recharge program for the Walla Walla area appears to have a good chance of success, certain risks are inherent wherever ground-water recharge is undertaken for the first time in a given area. It should be considered as an experimental venture for which plans for continuation should depend on results obtained during the initial stages of the experiment.
9. During and after each period of recharge, careful measurements and tests should be made to detect any possible deterioration of aquifer permeabilities and to evaluate the overall results of the recharge experiment.

Hart, D. H. Tests of artesian wells in the Cold Creek area, Washington. Tacoma, Washington, U.S. Geological Survey, 1958. 21p. (Open-File Report)

Cold Creek Valley is in the south-central part of Washington State, about 40 miles east of Yakima. The area of artesian wells occurs near the mutual corner of Townships 12 and 13 N., Ranges 24 and 25 E.W.M. The 6 wells involved are in an area about 3 miles long and 0.5 mile wide in the upper half of the valley. Rectangular weirs having end contractions were designed for each well from theoretical flow calculations. Each weir was placed on a timber foundation and leveled, and vertical tape gages were fastened to one side of the weir boxes approximately 5 feet back from the weir plate. The gages were adjusted to read zero when the water was level with the crest of the weir plate.

Two of the wells having static water levels considerably below the land surface were used as observation wells during the tests. A Stevens automatic water-level recorder and a Fries automatic water-level recorder were placed in operation on these wells, and the discharge measurements were started after measurements of shut-in pressure had been made at all the flowing wells and the recorders started on the observation wells.

Each well in succession was allowed to flow separately for 24 hours. During the test of each well, readings in feet above land surfaces were made of the shut-in pressure in the other 3 wells. From 15 to 30 minutes after each well had been opened, the flow stabilized and remained fairly constant throughout the test. Only one well showed any great variation

in discharge, probably due to the leakage flowing from a casing break, reported to be about 50 feet below the surface.

After the end of the individual tests, all the wells were opened together and allowed to flow simultaneously for 48 hours. The measurements show that a slight decline in flow discharge occurred in each well during the 48-hour test. Toward the end of the 48-hour test, the discharge of the wells apparently was still subsiding slightly.

Hart, D. H. Artificial recharge to ground water in Oregon and Washington. Tacoma, Washington, U.S. Geological Survey, 1958. 55p. Preliminary records, subject to revision. (Open-File Report)

Nine installations in Oregon and Washington have recently practiced the artificial recharging of ground water in order to replenish the supply, to conserve physical characteristics of the water, or to dispose of excess uncontaminated water. Five of these installations are in Oregon, at Pine Flat, Springfield, Portland (two), and St. Helens; four are in Washington, at Vancouver, Snohomish, Tacoma, and Richland. The Richland public-supply system utilizes the largest amount of recharged water.

Each year about 100 acre-feet of field drainage are recharged into irrigation wells at Pine Flat, about 200 acre-feet of river water are recharged to augment the pumpage from nearby wells of the Springfield public-supply system, and about 311 acre-feet of exhaust water from 2 heat-pump installations are recharged at Portland. For several years approximately 43 acre-feet of excess spring water were recharged annually to a public-supply well at St. Helens. Nearly 384 acre-feet of exhaust water are recharged each year from a heat pump at Tacoma and 160 acre-feet at Vancouver. About 160 acre-feet of cooling water are recharged annually to 2 wells at the Snohomish substation. The Richland city system annually utilizes about 12,000 acre-feet of recharge water, of which 2,200 acre-feet are pumped from the Columbia River and the remainder is diverted by canal from the Yakima River.

The Richland system uses recharge ponds; all the other operations use recharge wells. The data show that little chemical change has occurred in the quality of the water as a result of its recharge and recovery. All the artificial recharge has been essentially successful in accomplishing the effects desired; however, one well at the Oregonian Building in Portland was unsatisfactory as to both yield and intake. The success to date indicates that the process will find greater use in the future.

The operators have found that some problems arose from insufficient records of the amounts of water recharged and withdrawn and of the chemical and physical quality of the water. The study indicates that future users of artificial recharge will find it advisable to record such data regularly.

Hart, D. H. and F. J. Frank. Aquifer evaluation tests in the Gable Mountain area, AEC Hanford Reservation, Washington. Portland, Oregon, U.S. Geological Survey, April 1954. 12p. (USGS unpublished report, Ground-Water Branch) Subject to revision.

To provide information as part of certain effluent discharge studies being carried out in the area, wells were constructed and tests were run to evaluate the glacial outwash aquifer adjacent to the north side of Gable Mountain.

A coefficient of transmissibility of 1,430,000 gpd/ft, determined from the observation well recovery data, should be of the correct order of magnitude and representative of the area influenced by the test, but may not necessarily be representative of the entire outwash terrace lands north of Gable Mountain. The average coefficient of storage of 0.03 obtained from the test data may be too low. Possibly, if observation wells had been available or if the pumped well had been located at a greater distance from the geologic barrier, a more reliable and perhaps larger value might have been obtained. The geologic character of the aquifer appears to be that of an old glacial channel with the barrier, found early in the test, explained as a silt blanket deposited along the side of an inner channel which was later filled with outwash sand and gravel.

Haushild, W. L., G. R. Dempster, Jr., and H. H. Stevens, Jr. Distribution of radionuclides in the Columbia River streambed from the nuclear reactors, Hanford Reservation to Longview, Washington. Washington, D.C., U.S. Geological Survey, 1975. 35p. (Professional Paper 433-0)

Until all the eight reactors at Hanford Reservation, Washington, cooled by once-through flow of treated Columbia River water, were shut down in 1971, their cooling-water effluent was the main source of dissolved and particulate radionuclides in the Columbia River. The distribution and quantities of radionuclides accumulated in the riverbed were investigated. Chromium-51 and scandium-46 usually had a greater affinity for fixation to fine sediment, relative to coarse sediment, than did zinc-65 or cobalt-60. Radionuclide concentrations in both coarse sediment and fine sediment did not vary significantly (95 percent confidence level) within relatively long river reaches. In June 1965, 28,900 curies of radionuclides were estimated to be in the Columbia River streambed from the reactors to the ocean; 20,200 curies in the riverbed and 8,700 curies in the estuary bed. A predominance of chromium-51 over zinc-65 in the estuary bed and an opposite predominance in the riverbed indicate less seasonal variation in the accumulation of radionuclides (especially chromium-51) in the estuary bed than in the riverbed.

Haushild, W. L., H. H. Stevens, Jr., J. L. Nelson, and G. R. Dempster, Jr.
Radionuclides in transport in the Columbia River from Pasco to
Vancouver, Washington. Washington, D.C., U.S. Geological Survey,
1973. 43p. (Professional Paper 433-N)

Radionuclides in the Columbia River originated in discharges of cooling-water effluent from the reactors on the U.S. Atomic Energy Commission Reservation at Hanford, Washington. All the contributing reactors were shut down by 1971. A progressive decrease in the concentrations and discharges of many radionuclides during the study period was attributable to the decrease in the number of operating reactors. Concentrations and discharges of the radionuclides also varied seasonally in patterns that were used to categorize the particulate and dissolved radionuclides into five classes. Concentrations of radionuclides in Classes 1, 2, and 4 varied seasonally in dissolved parent materials in the cooling water. Concentrations of Class 3 radionuclides varied with dilution of a source with constant strength. Concentrations of Class 5 radionuclides varied with the seasonal variation in water discharge. Specific activities of zinc-65 and chromium-51 at Vancouver varied inversely with concentration of suspended sediment. The hydrodynamic and sedimentation characteristics of the Columbia River and the chemical characteristics of the radionuclides were important factors affecting the disposition of the radionuclides discharged at Pasco.

Irvin, W. H. and R. P. Ahrens. Geology and groundwater hydrology of the South Dam, Columbia Basin Irrigation Project, Washington. Geological Society of America Bulletin. Vol. 57, No. 12. p. 1207-1208. December 1946.

The South Dam, a feature of the Columbia Basin Irrigation Project, will extend across the southern end of the Upper Grand Coulee near Coulee City, Washington. The reservoir area is underlain chiefly by basalt flows with a slight regional dip to the southwest; exposures of Colville granite occur in the northern section of the proposed reservoir. The Coulee monocline borders the lower end of the reservoir on the northwest and crosses it obliquely about 2 miles north of the damsite. The monocline is faulted where it crosses the reservoir and is flanked on the southeast by an open syncline with axis plunging to the northeast beneath the Hartline Basin.

As the reservoir is filled, the adjacent ground-water tables will rise, and some ground water, now tributary to the reservoir area, will be diverted to areas below the dam. Seepage losses from the reservoir through and beneath the earth dam will move toward the Dry Falls area and Lower Grand Coulee. Estimated losses beneath and through the dam will be relatively small and will be dissipated largely by evaporation and transpiration. In view of the relatively small seepage losses anticipated, grouting may be limited to the shallow depths required to seal the upper weathered and permeable zone of the foundation rock. An extensive program of ground-water and surface-water observations has been started to determine the effect of the filling of the reservoir on

ground-water levels and movements and to aid in locating paths of seepage. Reprinted by permission of the Geological Society of America. c. 1946. All rights reserved.

Jones, R. W. and S. H. Ross. Moscow basin ground-water studies. Boise, Idaho, Idaho Bureau of Mines and Geology, 1972. 95p. (Pamphlet 153)

Moscow Basin covers an area of about 58 square miles in Latah County, Idaho on the eastern edge of the Columbia Plateau physiographic province. The principal water users, City of Moscow and University of Idaho, depend exclusively on ground water obtained from wells that reach three zones of artesian aquifers in the basalt flows and sedimentary interbeds of the Columbia River Basalt Group of Miocene age. The three artesian zones are designated the upper, middle, and lower artesian zones. The Columbia River Basalt Group is overlain by surficial sediments in which water generally occurs under water-table conditions. It is underlain by a basement of crystalline rocks of pre-Tertiary age that also crops out beyond the limits of the basalt and forms the mountains that rim the basin on three sides. Where exposed at the surface, the crystalline basement contains water under water-table conditions. Neither the surficial sediments nor the crystalline basement will yield large amounts of water; the rocks of the Columbia River Basalt Group are the only source of water for public supplies. All ground water originates as precipitation that falls within the borders of the Moscow Basin; natural discharge of ground water is by underflow to the west.

Prior to 1960, the entire public supply was obtained from wells reaching the upper artesian zone. The quality of water was unsatisfactory because of excessive amounts of iron and moderate hardness. Between 1960 and 1965, wells were drilled into the middle and lower artesian zones, and by 1965, nearly all water pumped for public supplies was obtained from the middle and lower artesian zones, water from which contains only moderate amounts of iron and is relatively soft.

In 1896, water levels in wells in the upper artesian zone were at or slightly above land surface, but declined continuously thereafter, and by 1960 static levels were nearly 120 feet below the surface in the vicinity of the City of Moscow wells. This decline led to suggestions that ground-water recharge in the Moscow Basin was insufficient to balance pumpage. Following the phasing out of heavy pumpage of the upper artesian zone in 1960-1965, water levels rose and recovered to within 65 feet of the surface in 1969.

Two lines of investigation indicate that pumpage was not in excess of recharge during the period 1896-1960. The pumpage and water-level records of the public supply wells were analyzed using a mathematical model aquifer that utilizes the theory of image wells and assumes that there is no recharge to the basin. The results indicate that the decline of water levels in the upper artesian zone was actually much less than it would have been if pumpage was greatly in excess of recharge. Long-term records of water level fluctuations in observation wells in the

basin were also studied. The water table in the surficial aquifers remained stable during the time that the water levels in the upper artesian zone declined. The decline of the water levels in the upper artesian zone is attributed to barrier boundary effects rather than to lack of recharge. Results of studies support the views of previous workers who estimate ground-water recharge to the basin by use of the equation of hydrologic equilibrium. All such estimates indicate that recharge is in excess of pumpage sufficient to meet the demands of the basin through the year 2000.

Mathematical model aquifers were used to estimate the total water in ground-water storage in the Moscow Basin and to predict the decline in water levels that would occur by the year 2000. Although these figures are based on an assumption that was rejected--no recharge to the basin--they do represent the smallest amount of water and the largest amount of drawdown to be expected. The study indicates that the middle and lower artesian zones would meet the anticipated 1965-2000 demand of 50.1 billion gallons and still have as much as 299.4 billion gallons remaining in storage in the year 2000. Water levels would be from 50 to 80 feet lower in 2000 than they were in 1965. This study indicates that ground water can supply the anticipated needs of the Moscow Basin well into the 21st century regardless of whether the water is derived from ground water storage or from recharge.

If need for water should exceed natural recharge at some time in the future, artificial recharge utilizing water from sources in and near the Moscow Basin could furnish more than 1 billion gallons of additional water annually. During a normal year, spring runoff from intermittent streams in the Palouse Range can provide about 900 million gallons over a 90-day period during February through May. The Moscow Waste Water Treatment Plant now discharges about 300 million gallons annually; the discharge should increase to about 1 billion gallons by the year 2000. The effluent could be further treated, then recycled by artificial recharge. Mathematical model studies show that the existing wells in the upper artesian zone can accept artificial recharge at rates of 1,000 to 2,000 gpm, for as many as 100 consecutive days without the cone of impression reaching the surface. Cost of artificial recharge probably is less than the cost of long-distance importation of water.

The waters of the surficial aquifers are relatively soft, averaging 87 parts per million (ppm), hardness as CaCO_3 , and are relatively low in dissolved solids, averaging 127 ppm. As the waters move into the upper artesian zone, average hardness increases to 135 ppm, and average dissolved solids increases to 190 ppm, probably as the result of solution of magnesium from magnesium-rich minerals in the basalts. As the waters move through the middle artesian zone and into the lower artesian zone, average hardness decreases to 84 ppm, but average dissolved solids increases to 286 ppm; the decrease in hardness probably is the result of base exchange of sodium for calcium.

Calcium and bicarbonate are the dominant ions in most of the ground waters of the Moscow Basin, but calcium and sulfate or sodium plus calcium and bicarbonate are the dominant ions in a few of the waters. Excessive amounts of iron are moderately common in waters from the

surficial aquifers and very common in waters from the upper artesian zone. The iron originates in high-iron clay deposits in the surficial aquifers on the outer margin of the recharge area of the artesian aquifers. The high-iron waters move laterally from the clay deposits into the upper artesian zone. Waters from the middle and lower artesian zones contained only moderate amounts of iron when the aquifers were first placed into use. Continued pumpage could induce the high-iron waters to move into the middle and lower artesian zones. Silica also is somewhat high for ground waters and the origin of the silica probably is related to the origin of the iron. Some of the waters in the surficial aquifers contain relatively high amounts of nitrates and chlorides that indicate possible contamination from septic tanks, fertilizers, and barn-yard wastes.

Kinnison, H. B. and J. E. Sceva. Effects of hydraulic and geologic factors on streamflow of the Yakima River Basin, Washington. An evaluation of streamflow records as an index to basin runoff. Washington, D.C., U.S. Geological Survey, 1963. 134p. (Water-Supply Paper No. 1595)

The Yakima River Basin, in south-central Washington, is the largest single river system entirely within the confines of the state. Its waters are the most extensively utilized of all the rivers in Washington.

The river heads high on the eastern slope of the Cascade Range, flows for 180 miles in a generally southeast direction, and discharges into the Columbia River. The western part of the basin is a mountainous area formed by sedimentary, volcanic, and metamorphic rocks, which generally have a low capacity for storing and transmitting water. The eastern part of the basin is formed by a thick sequence of lava flows that have folded into long ridges and troughs. Downwarped structural basins between many of the ridges are partly filled with younger sedimentary deposits, which at some places are many hundreds of feet thick. The Yakima River flows from structural basin to structural basin through narrow water gaps that have been eroded through the anticlinal ridges. Each basin is also a topographic basin and a ground-water subbasin. A gaging station will measure the total outflow of a drainage area only if it is located at the surface outlet of a ground-water subbasin and then only if the stream basin is nearly coextensive with the ground-water subbasin. Many gaging stations in the Yakima Basin are so located. The geology, hydrology, size, and location of 25 ground-water subbasins are described.

Since the settlement of the valley began, the development of the land and water resources have caused progressive changes in the natural regimen of the runoff of the basin. These changes have resulted from diversion of water from the streams, the application of water on the land for irrigation, the storage and release of flood waters, the pumping of ground water, and other factors. Irrigation in the Yakima Basin is reported to have begun about 1864. In 1955 about 425,000 acres were under irrigation.

During the past 60-odd years, many gaging stations have been operated at different sites within the basin. Only stations in the upper reaches, such as those below Keechelus, Kachess, or Cle Elum lakes, give discharge records which are an accurate measure of the natural outflow of the drainage area. Farther downstream, as the utilization of water becomes more extensive, the records at a gaging station show the discharge passing a particular point, but they do not reflect the natural outflow of the basin. Large canals divert water for use on lands above a station or carry it around a station for irrigation downstream. The deep sedimentary deposits within subbasins and the overlying alluvial gravels permit down-valley movement of large subsurface flows which bypass the gaging stations, except in the near vicinity of the water gaps. At the water gaps, ground water rises to the surface, becoming streamflow, and can be accurately measured. The location of gaging stations within each subbasin is important, therefore, in determining whether the flow measured represents the total down-valley outflow or whether it is merely the surface-water component.

Surface and subsurface factors that may affect the discharge records at each gaging station in the Yakima River Basin include a description of upstream diversions, surface return flows, bypass canals, storage reservoirs, subsurface bypass flows, ground-water withdrawals, and other items. The available data are not sufficiently complete to permit a quantitative determination of the total basin yield at most gaging stations. However, data on the existing bypass channels, such as canals and drainage ditches, and on related subsurface movement of water provide valuable information necessary for proper use and interpretation of the streamflow records.

Ko, C. A. Geology and groundwater resources of the Hangman Creek drainage basin, Idaho-Washington. Pullman, Washington, Washington State University, 1974. 150p. (Ph.D. Dissertation, Geology)

The Hangman Creek Basin is an erosionally and depositionally modified, synclinal structural basin on the flank of a broad anticlinal uplift of belt strata, which comprises most of Kootenai County and the northern part of Benewah County, Idaho. Stratigraphic units identified in the basin include: (1) Precambrian Belt strata; (2) Cretaceous granitic rocks; (3) Tertiary sedimentary and volcanic rocks; (4) Quaternary eolian deposits; and (5) Recent alluvial deposits. Among these rock units, only the Tertiary rocks are significantly related to the occurrence of ground water in the basin.

Three distinctive basalt units, lower, middle, and upper, were identified in the study basin. These units are separated by interbeds of sandy and clayey deposits. In the Tertiary sedimentary sequence, two distinct lithologic units, upper Latah clays and lower Latah sands, were recognized. These units were deposited at different times and in different depositional environments. Contrary to earlier findings, the lower Latah sands were found to be capped entirely by the oldest basalt unit in the basin, and only the upper Latah clays are interfingering in places with basalt flows.

Water resources of the Hangman Creek Basin are in a state of equilibrium with long-term climatic, hydrologic, and geologic conditions. Stream runoff evaluated by empirical equations indicates that about 72,000 acre-feet of surface water are discharged annually from the basin. More than three-fourths of this water is discharged during the period November-May, and only one-fourth during the remaining months.

Three principal artesian aquifers were identified in the basin. These are: (1) the lower portion of the upper Latah clays; (2) the upper portion of the lower basalt unit; and (3) the lower Latah sands. The lateral extent of the different aquifers is variable and, therefore, the principal aquifer differs from place to place within the study basin. The average depth to the aquifers is about 160 feet from ground surface and the average piezometric head of the artesian water in these aquifers stands about 110 feet above the confining member. Aquifer tests indicate that the basalt aquifer has the highest transmissivity value of about 7×10^4 gpd/ft, where the lowest value of about 3×10^3 was associated with the lower Latah sands. The storage coefficient, on the other hand, was highest in the lower Latah sands and lowest in the basalt aquifer. The storage coefficients of these aquifers are 1.1×10^{-3} and 3.5×10^{-4} , respectively. The storage coefficient and other geologic and hydrologic properties indicate that the lower Latah sands probably have the highest potential for ground-water development in the basin.

It is estimated that aquifers in the basin receive about 1.5 percent of the total precipitation annually as ground-water recharge. About 24.3 percent of the precipitation flows from the basin as surface runoff, and the remaining 74.2 percent returns to the atmosphere as evapotranspiration. These estimates indicate that the amount of surface water which would ideally be available for use in the basin is 72,000 acre-feet and that of ground water, 4,300 acre-feet. Not all of these quantities are actually usable in the basin because of unavoidable losses of water during processes of storage, pumping, and transmission from point to point. However, much of the water could be utilized under conditions of adequate development, storage, and proper management.

Surface water and ground water of the study basin are, in general, suitable in chemical and physical qualities for irrigation use. However, they have moderate-to-high hardness and contain sufficient silica and iron to stain plumbing fixtures and laundry. Removal of iron may be required in order to make some of the ground water suitable for use for domestic purposes.

Lin, C. L. Factors affecting ground-water recharge in the Moscow Basin, Latah County, Idaho. Pullman, Washington, Washington State University, 1967. 86p. (M.S. Thesis, Geology)

The depleting ground-water reservoir reflected by long-term declines in the piezometric surface creates a critical problem in the Moscow basin. Results of climatological, hydrological, and geological studies indicate that (1) low intensity of precipitation, (2) frozen ground, (3) high

evaporation potential, (4) thickness, extent, and clay content of the Palouse loess and Latah Formation, (5) interflow zones, (6) fracture zones, and (7) presence of ancient drainage channels are the primary factors affecting ground-water recharge in the basin.

Fluorescent dye-dilution techniques have been used to detect stream losses near the margins of the plateau basalts. Results of these measurements verify other studies and indicate that this method is a sensitive tool in measuring the low flow of a stream. By applying this method, it can be shown that a portion of the surface flow joins the underflow in areas of low gradient and again rejoins the surface stream in reaches of steep gradient along Crumarine Creek.

A portion of the underflow or component of surface flow eventually recharges the basin. Vertically and laterally recharged water migrates toward the ancient buried drainage channels of past geologic times and is carried out of the basin as underflows. Total current recharge is not sufficient to meet the demands of the city indicated by recent pumpage data. Eventually, additional sources of water will be necessary.

Luzier, J. E. Ground-water occurrence in the Goldendale area, Klickitat County, Washington. Washington, D.C., U.S. Geological Survey, 1969. 1 sheet. (Hydrologic Investigations Atlas, HA-313)

Ground water occurrence in the Goldendale area of Klickitat County, Washington is shown by a 1-sheet hydrologic atlas consisting of a geohydrologic map scaled 1:6,250, drillers logs of representative wells, water level graphs, a precipitation map, and hydrographs of springs and creeks. Selected well records and chemical analyses are tabulated. Most ground water in the area occurs in permeable basalts. Most ground water use is for domestic and stock purposes. Springs are the chief sources of public supply, and surface waters are used for irrigation.

Luzier, J. E., J. W. Bingham, R. J. Burt, and R. A. Barker. Ground-water survey, Odessa-Lind area, Washington. Olympia, Washington, Washington State Department of Water Resources, 1968. 3lp. (Water-Supply Bulletin No. 36)

The significance of ground water and the farmer's awareness of the importance of that vital resource has rapidly increased during the last few years in the Odessa-Lind area. Large grain yields, once only dreamed of on dryland farms, have become a reality with irrigation. Even at that, ground water cannot meet the demand to irrigate all the suitable lands in the Odessa-Lind area.

As of spring 1968, water levels in the Odessa-Lind area have declined, but have not undergone a general decline of great magnitude. Even if

the yearly increase in pumping is brought to a halt, however, the established areal trend of declining water levels will continue for several years. If pumping continues to increase, the water-level decline will inevitably accelerate over an area of ever-increasing size. The problem involves not only the areas of declining water levels, but adjacent areas as well, as pumping from the nearby lands removes water that might normally flow into the area of decline and lessen lowering of the water level.

The cooperative investigation of the ground-water system in the Odessa-Lind area by the Washington State Department of Water Resources and the U.S. Geological Survey is being continued with the following goals:

1. Monitor the pumpage and response of the system;
2. Amplify present knowledge of the geologic controls on the system;
3. Develop a mathematical model of the system.

The mathematical model is a representation, by computer, of the characteristics of the ground-water system. When the model is tested and verified to produce reliable results, it may be used to test many different combinations of pumpage and the response of the ground-water system. Thus, the computer model becomes an excellent management tool for the optimum development and management of the ground-water system.

The cooperative investigation is being pressed forward toward the three goals as rapidly as possible within the limits of funds and manpower. When completed, the investigation should provide the Washington State Department of Water Resources with facts needed to establish a permanent policy for the optimum development of the ground-water resources in the Odessa-Lind area.

Luzier, J.E. and R. J. Burt. Hydrology of basalt aquifers and depletion of ground water in east-central Washington. Olympia, Washington, Washington State Department of Ecology, 1974. 53p. Prepared in cooperation with U.S. Geological Survey. (Water-Supply Bulletin No. 33)

Ground water available for large-scale withdrawal in east-central Washington occurs principally in a thick sequence of basalt flows known as the Columbia River Basalt Group. Permeable flow-contact zones within the sequence form the major aquifers of the region, and their slight regional dip to the southwest partly controls the general direction of ground-water movement. Ground water in the flow-contact zones normally is confined by dense basalt of low permeability, and the heads in the basalt sequence generally decrease with increasing aquifer depth.

Uncased well bores, 500-1,000 feet deep, interconnect a series of aquifers that otherwise are poorly connected hydraulically. Water from upper

aquifers, used chiefly for domestic and stock supplies, drains continuously in most areas through the uncased irrigation wells into deeper aquifers having lower artesian pressures. This short-circuiting effect has contributed to the declines of water levels in upper aquifers, especially in the intensively pumped Odessa area.

Basalt aquifers throughout most of east-central Washington are capable of yielding water to wells at high rates, but store only a small volume per unit volume of rock. The median specific capacity determined for 342 multi-aquifer wells is about 12 gpm per foot of drawdown. Storage coefficients, computed by volumetric analyses of large seasonal pumping depressions in the potentiometric surfaces in two areas near Odessa, range from 0.002 to 0.006.

Pumpage from basalt aquifers in the study region increased from about 44,000 acre-feet in 1963 to about 149,000 acre-feet in 1968. At least half the increase was in a 1,100-square-mile area near Odessa, where ground-water levels have been declining at rates of 2 to more than 10 feet per year since about 1965. Water-level declines predicted for deeper aquifers in the Odessa area, for the period 1967-77, range from 8 to 18 feet per year, if annual pumpage is maintained at the 1967 rate of about 53,000 acre-feet.

In wells tapping basalt aquifers in the immediate vicinity of Pullman, water levels have declined progressively as much as 100 feet since 1913. Annual rates of decline, averaging about 2 feet for many years, have increased to about 3 feet during 1965-69. The accelerated decline at Pullman probably is due not only to increased pumpage at Pullman, but also to pumping from deep basalt aquifers at nearby Moscow, Idaho. Based on historical water-level trends, the net projected decline in artesian head at Pullman may total 30 feet or more during 1970-80.

In most other parts of the study region where there is sizable pumpage from the basalt, water-level declines have begun, but long-term trends are not defined. In areas of intensive pumping, varying water-level declines and well interference are anticipated, depending on the local geohydrologic conditions.

Conditions that have led to depletion of ground water in basalt aquifers of the region include: (1) high rates of pumping withdrawal for consumptive use; (2) dense well spacing; (3) the small storage capacity and low vertical permeability of the basalt; (4) little recharge from precipitation; (5) leakage through uncased well bores; and (6) the presence of impermeable hydraulic boundaries. Early evaluation of the local aquifer systems and determination of optimum sustained yields are necessary for effective management of the ground water in the basalt.

Luzier, J. E. and J. A. Skrivan. Digital simulation and projection of water-level declines in basalt aquifers of the Odessa-Lind area, east-central Washington. Tacoma, Washington, U.S. Geological Survey, 1973. 56p. (Open-File Report)

A digital computer program using finite-difference techniques simulates an intensively pumped, multilayered basalt-aquifer system near Odessa, Washington. The aquifers now developed are in the upper 1,000 feet of a regionally extensive series of southwesterly dipping basalt flows of the Columbia River Basalt Group. Most of the aquifers are confined. Those in the depth range of about 500 to 1,000 feet are the chief source of ground water pumped from irrigation wells. Transmissivity of these aquifers ranges from less than 2,700 square feet per day to more than 40,000 square feet per day, and storage coefficients range from 0.0015 to 0.006. Shallower aquifers are generally much less permeable, but they are a source of recharge to deeper aquifers with lower artesian heads; vertical leakage occurs along joints in the basalt and down uncased wells, which short circuit the aquifer system. For model analysis, the deeper, pumped aquifers were grouped and treated as a single layer with drawdown-dependent leakage from an overlying confining layer. Verification of the model was achieved by closely matching observed pumpage-related head declines ranging from about 10 feet to more than 40 feet over the 4-year period from March 1967 to March 1971. Projected average annual rates of decline during the 14-year period from March 1967 to March 1981 are: from 1 to 9 feet per year if pumpage is maintained at the 1970 rate of 117,000 acre-feet per year; or, from 3 to 33 feet per year if 1970 pumpage is increased to 233,000 acre-feet per year, which includes 116,000 acre-feet per year covered by water-right applications held in abeyance.

MacNish, R. D. and R. A. Barker. Digital simulation of a basalt aquifer system, Walla Walla River Basin, Washington and Oregon. Olympia, Washington, Washington State Department of Ecology, 1976. 51p. (Water-Supply Bulletin No. 44)

A digital (mathematical) model utilizing an alternating-direction implicit procedure simulates the hydraulic response to 72 years of pumping stress of a basalt aquifer system underlying the 1,758-square-mile Walla Walla River Basin in Washington and Oregon. The modeled aquifer system is sandwiched between an underlying basalt-aquifer zone and an overlying aquifer zone composed of gravel and clay in the central lowland part of the basin and of basalt elsewhere.

A water budget of the aquifer system before pumping stress began in about 1900 was computed by steady-state simulation. For this simulation, the aquifer received 132,000 acre-feet of water per year, with 114,000 acre-feet entering from the principal recharge area, the Blue Mountains, on the southeastern border of the basin. Annual discharge rates were 97,500 acre-feet laterally to the Snake and Columbia rivers and 34,500 acre-feet to adjacent aquifers, which also eventually drain to the two rivers.

By 1945, pumping stress had reached about 5,000 acre-feet per year. A large increase in irrigation demand over the next 20 years increased the pumpage to 20,000 acre-feet per year and caused declines of as much as 135 feet from the 1900 water levels. Simulation of the effects of

pumping indicated that by 1972 the water budget of the basalt aquifer system showed a net increase of flow from the recharge areas (6,500 acre-feet per year) and reduction in both lateral outflow (8,500 acre-feet per year) and discharge to adjacent aquifers (12,500 acre-feet per year).

As calibrated, the model appears to have simulated the response of the aquifer system to the historical record of stress in the central lowland part of the basin with reasonable accuracy, and it could be used to project the effects of present and moderate additional stresses in the near future in this area. A shortcoming of the model is that an empirical method is used to approximate vertical fluxes to and from the aquifer.

Maddox, G. E. "A proposed structural control of surface and ground water in the eastern portion of the Columbia River Basalt, Washington." Geological Society of America. Abstracts with Programs. Vol. 8, No. 3. p. 392. 1976.

Discontinuous surface-water drainage, radical changes in drainage direction, and a rapid decrease in ground-water yield, all indicate a possible structural lineament transversing Benton, Franklin, Adams, Lincoln, Stevens, and Pend Oreille counties, Washington. The proposed lineament, which strikes approximately north 42 degrees east, first appears in Washington near the town of Patterson in Benton County. A change in the course of the Columbia River west of Patterson, the abrupt termination of the east end of Badger Mountain, changes in the direction of flow of surface water in the Michigan Prairie-Rattlesnake Flat area, the separation of the flow of Crab Creek and Cow Creek, and rapid changes in the direction of flow of the Spokane and Pend Oreille rivers are all indicative of the trend of the proposed lineament. Water wells drilled on either side of the proposed lineament indicate markedly different coefficients of transmissivity of the basalt aquifer, with the east side having the lower value. Additional economic significance of the proposed lineament is its possible control of the location of a small natural gas field in Benton County, and the distribution of ore deposits in northeastern Washington and northern Idaho. Reprinted by permission of the Geological Society of America. c. 1976. All rights reserved.

Mar, B. W. and W. R. Butcher. Model Development and systems analysis of the Yakima River Basin: Macro model simulation. Pullman, Washington, Washington State University, 1974. 93p. (Water Research Center Report No. 17A)

Simple simulation (MACRO) models that contain a few parameters and that provide a gross representation of a river basin in space and time have the advantages of rapid construction and a transparent development process. These attributes are valuable when synthesizing and examining major linkages between more detailed models of various sectors of a

river basin. The construction, theory, and application of MACRO models to integrate and evaluate the system analysis of the Yakima River Basin are presented and their utility demonstrated.

Mellott, J. C. Preliminary ground-water flow system analysis in the Columbia River basalts. Pullman, Washington, Washington State University, 1973. 63p. (M.S. Thesis, Geology)

A preliminary ground-water model of the Washington-Idaho portion of the Columbia River basalts is presented. A map of the potentiometric surface based on collected data and data assembled from unpublished sources is presented. Composite suites of borehole geophysical data are used to develop relative vertical permeability distributions. The relative vertical permeability distributions are used as input data to a digital computer solution to the model, and a series of subsurface potential maps is calculated. The results compare favorably with existing knowledge. This type of presentation would be useful to those individuals interested in exploiting, managing, or administering the water supply of the state. The lower cost of borehole geophysical data as compared to pump tests should appeal to most investigators.

Milhous, R. T. "A natural flow model of the Yakima River." Paper presented at American Geophysical Union, Pacific Northwest Regional Meeting, Richland, Washington, October 17-18, 1974. 21p.

The Yakima River is a well developed river located in central Washington, and is one of the most productive irrigated basins in the United States. The total area of the basin is 6,155 square miles, of which 790 square miles (505,000 acres) are irrigated.

Appropriation of the waters of the river almost depleted the flow of the river during the summer when gaging stations were established in the basin. Consequently, the natural flow of the river cannot be determined accurately from existing records. Using estimates of the annual depletion and measurements of the flow from the well-watered part of the basin into the arid areas, an estimate of the natural flow of the river was made. The total average annual flow from the basin under natural conditions would be approximately 3,581,000 acre-feet. The actual flow is 2,340,000 acre-feet. The average annual diversions within the Yakima Basin are 2,365,000 acre-feet. Consequently, the efficiency of water use is 48 percent. (That is, 48 percent of the water diverted from the surface and ground waters of the basin is consumed). The results show the impact of development and the importance of irrigation return flows in the system.

Mogg, J. L. Aquifer test no. 4, Clarkston, Washington. A. A. Durand and Son, 1958. 11p. (Consultant Report)

This test was conducted primarily to check interference calculations and to verify aquifer data obtained from previous tests. The 32-day test showed hydrologic boundaries are present in the basalt aquifers, and for this reason it is difficult to obtain correct aquifer coefficients. Analysis of the pump data shows that about 25 million gallons per day could safely be pumped from the basalt aquifer for a period of 90 days, with total interference for the 7 wells ranging from 65 to 75 feet.

Molenaar, D. Flowing artesian wells in Washington State. Olympia, Washington, Washington State Division of Water Resources, 1961. 115p. (Water Supply Bulletin No. 16)

The compilation of informative data on flowing artesian wells was initiated to determine the availability of uncontaminated ground-water supplies in the event that local or statewide power failures preclude the use of water available only by electrically operated pumping facilities. It may also be of assistance to drillers as an indication of areas where artesian zones may be penetrated. The tabulation of wells was composed of data from existing reports on ground-water conditions, and from well drillers' logs filed in conjunction with the processing of ground-water rights. No field work was conducted to determine the present day flows of wells listed in earlier reports. In many cases, wells have been altered or plugged and no longer exist, or their flows have either diminished considerably or ceased entirely conversely. Many new wells have been drilled which tap artesian zones, but have never been reported for recording. Also, existing reports deal primarily with areas where agricultural, industrial, and municipal growth accentuated the need for information on local ground-water conditions and supply.

Data tabulated in this report include location of wells, owner or tenant of property, altitude of land surface, description of the water-bearing zone, amount of flow or shut-in pressure and date of measurement, and occasional remarks which may include drawdown, depths of casing perforations or screens, water temperature, odor, hardness, etc.

Molenaar, D. A geohydrologic reconnaissance of northwestern Walla Walla County, Washington. Olympia, Washington, Washington State Department of Water Resources, 1968. 1 sheet (Geohydrologic Monograph 1)

The construction of hydroelectric power and flood-control dams on the Columbia and lower Snake rivers has provided the setting for future industrial, agricultural, residential, and recreational development in the areas adjacent to the large reservoirs. Should water in large quantities be pumped directly from the reservoirs for irrigation, there may be need for ground water of good quality for a parallel growth of

industries and communities. Because of such anticipated need for ground water, this preliminary study was made of the occurrence, availability, and present development of the ground water resources of the area.

The study, made in March 1963, included a 2-week field reconnaissance of surficial geology, a canvass of wells, and a compilation of drillers' records where available. Because most of the wells were drilled many years ago and chiefly for domestic supplies, few were recorded by water-right filings, and very few well records are now available. Most of the data on these domestic wells were obtained from scanty records retained by drillers or from their memory of wells drilled many years ago. Information on more recently drilled wells was from drillers' logs submitted in water-right filings with the Washington State Department of Water Resources. Because some water levels reported in drillers' logs were recorded prior to the filling of Lake Wallula behind McNary Dam, these probably have risen since to about reservoir level. In some cases, these early wells have been inundated by the lake.

The area of study lies in the eastern part of the Pasco Basin. No previous geohydrologic studies have been made in this area.

The ground-water reservoir underlying the study area generally is found associated with the fracture and rubble zones at the tops and bottoms of most basalt flows, and with interbeds of coarse sand and gravel. These water-bearing zones are recharged by seasonal precipitation that percolates from the land surface. Because this natural recharge is greatly limited by the low annual precipitation across the area, and because the deeply cut valleys of the Columbia and Snake rivers form a low "base level" for the main water table, wells at higher altitudes in the study area must be drilled deeply to intersect and tap the ground-water reservoir. The only places where large supplies of ground water at relatively shallow depth are assured are those near the shorelines of the reservoirs where coarse and highly permeable sand and gravel and fractured basalt are in zones of saturation.

The direction of ground-water flow through the basalt underlying the study area and the slope of the main water table were not determined from data gathered during this study. They probably are toward Lake Sacajawea on the north and Lake Wallula on the southwest. Locally, perched ground-water bodies occur within alluvial deposits that underlie intermittent stream channels and are in hydraulic continuity with these streams.

Molenaar, D. Outline of the water resources of the Satus Creek Basin, Yakima Indian Reservation, Washington. Tacoma, Washington, U.S. Geological Survey, 1977. 34 p. (Open-File Report 76-808)

On the Yakima Indian Reservation, Washington, only about 5 percent of the Satus Creek Basin--in the relatively flat eastern lowland adjacent to and including part of the Yakima River lowland--is agriculturally developed, mostly through irrigation. Because the streams of the basin

do not contain adequate water for irrigation, most irrigation is by canal diversion from the adjoining Toppenish Creek Basin. Irrigation application of as much as 9.25 acre-feet per acre per year, combined with the presence of poorly drained silt and clay layers in this area, and the natural upward discharge of ground water from deeper aquifers (water-bearing layers), has contributed to a waterlogging problem, which has affected about 10,500 acres, or about 25 percent of the irrigated area. In the upland of the basin, a large average annual base flow of about 30 cubic feet per second in Logy Creek indicates the presence of a potentially highly productive aquifer in young (shallow) basalt lavas underlying the higher western parts of the upland. This aquifer may provide a reservoir from which stream flow may be augmented by ground water pumping or, alternatively, it may be used as a source of ground water for irrigation of upland areas directly.

Mundorff, M. J. Ground-water conditions in the Columbia Basin Project. Tacoma, Washington, U.S. Geological Survey, 1953. 26p. (Open-File Report)

Water is now being supplied to the Columbia Basin Irrigation Project area from the Columbia River. About 450,000 acres will be irrigated under the current program, and the project is planned to irrigate ultimately more than a million acres of land. Although the water used for irrigation of project lands is entirely from the Columbia River, about 20,000 acres within the boundaries of the project have been irrigated in the past with ground water, and much will continue to be irrigated with ground water. As irrigation of the project builds up the water table, additional ground-water supplies will be developed for lands within the area, but not included in the project. However, the chief importance of ground water in the area is for domestic, municipal, and industrial use; at the present time, almost all domestic supplies are obtained from wells. In the next 20 to 25 years, an additional 15,000 to 20,000 families will need water for domestic use. Many community and cooperative water systems will supply a few to a score or more families from a single well, but even so several thousand new wells will be required for rural use. It is estimated that ultimate development will increase the population by nearly a quarter of a million. With rapid development of the area, many new industries are being established, most of which require ground-water supplies.

Not only is utilization of ground water important in the area, but the effect of irrigation on ground-water conditions in the area also is important. Many drainage problems will arise, and the distribution and timing of return flow from the project are important questions.

Measurement of water levels in a number of wells was begun in 1940 and has continued without interruption to the present time. This program of measuring water levels in observation wells was considerably expanded in 1949. With this background of previous water-level records, changes in water levels are already becoming apparent. The ground-water conditions in any area are closely related to the character of the rocks, their

structure, and their distribution, and to the land forms which these rocks exhibit at the surface. That is, ground water conditions in the area are dependent upon the geology and physiography of the area, as well as on the climate.

The area both structurally and physiographically is essentially a single, broad, shallow basin underlain by a great sequence of basalt lava flows. The basalt was folded and faulted to form several large subbasins separated by east-trending structural ridges. Lake and stream deposits consisting of clay, silt, sand, and gravel partially fill these basins. Thus, it is seen that the Columbia Basin Irrigation Project actually consists of several basins or parts of basins separated by folds or faults in the underlying strata.

Mundorff, M. J. Availability of ground water to supplement surface-water irrigation supplies in the Yakima River Basin, Washington. Tacoma, Washington, U.S. Geological Survey, 1953. 11p. (Open-File Report)

This report outlines general ground water conditions in the Yakima River Basin with particular reference to the possibility of ground-water development to supplement surface-water supplies for irrigation in the Kittitas and Roza divisions of the Yakima Irrigation Project.

Analysis of the ground-water potentialities in the Yakima River Basin involves consideration of both geology and hydrology. The basin consists of a number of structural basins and subbasins in which topography is largely controlled by the structure. The chief basins pertinent to this discussion include three along the main stem, the Kittitas, Upper Yakima and Lower Yakima basins. Each is separated from the others by structure and topography so that they are separate ground-water areas. Withdrawal or recharge of ground water in one basin will not affect ground-water conditions in other basins, except possibly to the extent it would affect downstream flow of the Yakima River. Each of the three basins is underlain by three important aquifers or groups of aquifers. These are, in order from the surface downward: (1) unconsolidated or semi-consolidated alluvial sand and gravel; (2) sandstone and conglomerate strata in the Ellensburg Formation; and (3) porous zones in the Yakima Basalt. The first two units are thickest and most important as aquifers toward the centers of the basins. Both irrigation divisions concerned are on higher lands toward the margins of the basins, so that the alluvial deposits and the Ellensburg Formation are of somewhat limited value as a source of ground water in these two irrigation divisions. The basalt, which is generally not utilized toward the centers of the basins because of its considerable depth, is much nearer the surface toward the margins of the basins. Potentially, it is a very important aquifer.

In evaluating the ground-water resources of a basin, the effect of ground-water withdrawals on surface-water discharge should be considered. To a certain extent, it is true that utilization of ground water reduces the amount of surface water available. However, use of ground water

nearly always increases the total utilizable supply because, generally, a large part of the ground-water withdrawal is from storage which is replenished during periods (winter and spring) when the surface water is, to a large extent, wasted.

Mundorff, M. J., R. D. MacNish, and D. R. Cline. Water resources of the Satus Creek Basin, Yakima Indian Reservation, Washington. Tacoma, Washington, U.S. Geological Survey, 1977. 102p. (Open-File Report 76-685)

The Satus Creek Basin lies on the east flank of the Cascade Range in south-central Washington. The basin is entirely within the Yakima Indian Reservation and is bordered and drained on the east by the Yakima River. Average annual precipitation ranges from about 35 inches in the western upland to less than 10 inches in the eastern lowland. This amounts to a yearly total of about 562,000 acre-feet, most of which falls in the upland. Much of the precipitation falls as snow, and the stream flow from the upland reflects this fact, having a high sustained runoff during the snowmelt months of April, May, and June. In 1973 about 176,000 acre-feet of water were carried by canals for irrigation of about 19,000 acres in the lowland; of this quantity, about 173,000 acre-feet were imported from the adjoining Toppenish Creek Basin. This high application rate of about 9.25 acre-feet of water per acre is largely responsible for severe waterlogging problems in many parts of the lowland. Relieving artesian heads by pumping, combined with reduced application and improved drainage, could alleviate the waterlogging, and free water for use in the irrigation of presently non-irrigated parts of the basin. Young volcanic rocks (basalt) in the southwestern, upland part of the basin receive nearly 70,000 acre-feet a year in recharge from precipitation and, although much of this water is what sustains the high base flows of the streams draining the rocks, the remaining water offers potential for development as a high-altitude source for irrigation water.

Mundorff, M. J., D. J. Reis, and J. R. Strand. Progress report on ground water in the Columbia Basin Project, Washington. Tacoma, Washington, U.S. Geological Survey, 1952. 229 p. (Open-File Report)

This report is supplementary to the report by Taylor, Jr., G. C., 1948, "Ground water in the Quincy Basin, Wahluke Slope, and Pasco Slope sub-areas of the Columbia Basin Project, Washington." U.S. Geological Survey Typewritten Report, Tacoma, Washington, 182p. By the U.S. Geological Survey as a mimeographed report.

The Columbia Basin Irrigation Project area includes approximately 3,900 square miles in Grant, Adams, and Franklin counties and lies east of the Columbia River on the semiarid low plateaus of central Washington.

The area both structurally and topographically is essentially a single, broad, shallow basin, but is partially separated into subbasins by east-trending structural ridges. Underlying the entire area is a great sequence of basalt lava flows with a known thickness of nearly 5,000 feet. Overlying the basalt are a few feet, to about 600 feet, of lake- and stream-deposited clay, silt, sand, and gravel. These overlying materials occur as filling in the centers of the subbasins and as more or less isolated patches in marginal areas.

The occurrence of ground water and the shape and slope of the water table are very largely controlled by geologic structures. Recharge to the water table occurs chiefly in areas where the basalt crops out at higher elevations, as in the north, east, and west margins of the basin. The water table slopes generally southward and southwestward, with the dip of the basalt, toward the Columbia River. All of the ground-water discharge from the area is into the Columbia and Snake rivers.

The basalt lavas are aquifers everywhere within the area, and more than half of the wells in the area obtain water from them. Yields range from a fraction of a gallon per minute to about 2,000 gpm. In general, the yields obtained correlate fairly well with depth of well drilled below the water table and the average yield is about 1.5 gpm for each foot drilled below the water table.

The sand, clay, and silt of the lake deposits generally are not prolific aquifers. Yields generally do not exceed 50 to 75 gallons a minute, except in the southwest part of the area where these deposits are thicker and coarser grained. Yield per foot of depth below the water table generally averages about 0.5 gpm.

The glaciofluvial outwash gravel, when saturated, is the most prolific aquifer in the area. Reported yields range up to 7,000 gpm. Of 106 wells in the gravel for which yields were reported, 10 percent yield 1,000 gpm or more and 80 percent yield 100 or more gpm.

Recharge to aquifers in the area is derived from precipitation on the area, surface inflow, and underground inflow. Annual precipitation on the area averages about 1,650,000 acre-feet, of which only a small percentage reaches the water table. Surface inflow averages nearly 70,000 acre-feet, most of which reaches the water table, and underground inflow probably is about 60,000 acre-feet annually.

Approximately 60,000 acre-feet of ground water are used annually for irrigation, of which about 36,000 acre-feet are consumed, the remainder returning to the water table. Other uses in the area probably consume about 10,000 acre-feet annually. Surface outflow averages about 30,000 acre-feet annually, and underground outflow may be roughly 60,000 acre-feet annually.

The quality of ground water almost without exception is satisfactory for all ordinary uses. Mineral content is moderately low and total hardness generally ranges from 100 to 200 ppm. Iron content of most samples was less than 0.3 ppm. Almost all samples tested were satisfactory for irrigation use with respect to percent sodium and boron content.

Temperatures of ground water range from 53 to 72°F.

Irrigation in the area, planned eventually to include over 1,000,000 acres, will raise the water table close to the land surface in almost the entire area. It is probable that many lakes and swamps will be formed and drainage problems may be serious. As the ground water saturates permeable zones now dry, wells will be shallower and less expensive to construct.

Myers, D. A. Test-observation wells near Davenport, Washington: Description and preliminary results. Tacoma, Washington, U.S. Geological Survey, 1972. 23p. Prepared in cooperation with Washington State Department of Ecology. (Open-File Report)

The 750-foot test-observation well drilled near Davenport, Washington is one of several drilled to date (1972) to provide information on ground-water conditions in selected areas of the state. The well provides information on aquifer characteristics in this area which are not available from existing deep irrigation wells. The well was drilled by air-rotary methods and penetrates eight aquifer zones (A through H); the upper 75 feet of the well are cased, and the remainder of the hole is open in basalt.

Test pumping during drilling showed that the well had specific capacities of: (1) 4.8 gpm per foot of drawdown when at the 255-foot depth and open to aquifers A through D; (2) 5.6 gpm per foot of drawdown when at the 640-foot depth and open to aquifers A through G; and (3) 76.5 gpm per foot of drawdown when at the full 750-foot depth and open to all eight aquifers. The tests indicate that most of the water available to the well is from the deepest aquifer (zone H).

Borehole geophysical logging supplemented the driller's log of the well and provided information on natural gamma radiation, water temperature and resistivity, and borehole diameter. In the completed well, each aquifer zone is isolated by cement seals, and piezometer pipes installed to zones B through H allow a basis for defining the vertical hydraulic gradient and ground-water movement in the area. The pipes also permit chemical-quality monitoring of water in the various aquifer zones. An additional pipe, installed for providing thermistor access, allows recording of the geothermal gradient in the well which provides a basis for estimating vertical ground-water movement in the area.

Nassar, E. G. and K. L. Walters. Water in the Palouse River Basin, Washington. Olympia, Washington, Washington State Department of Ecology, 1975. 246p. (Water-Supply Bulletin No. 39)

Surface-water supplies are inadequate for irrigation in much of the Palouse River Basin in eastern Washington, and dryland wheat farming

characterizes much of the area. Along the valleys where farms are irrigated from streams, upstream diversions during the low-flow period have sometimes depleted stream flow to the detriment of downstream irrigators. However, suitable sites for reservoirs for storage of winter and spring stream flows for summer irrigation are scarce; also, the large quantity of sediment deposited by streams in the basin would limit the usefulness of reservoirs.

A study directed toward defining low-flow characteristics of the streams could provide valuable information to water management agencies in the basin. A major ground-water problem exists in the heavily populated area of Pullman, where extensive pumping from wells for municipal supplies has lowered the artesian pressures to such an extent that wells that once flowed freely no longer do so. Any plan for continued development of the ground-water resource should include a wide spacing of new wells and a careful monitoring of water levels until the capacity of the local aquifers has been determined. Artificial recharge of aquifers may not be practical in the Palouse River Basin because of the limited availability of surplus surface water to serve for recharge, and because the high-sediment load in the surface water would require extensive treatment of the recharge water.

Newcomb, R. C. Ground water in the Kennewick area, Washington. Tacoma, Washington, U.S. Geological Survey, 1948. 15p. (Open-File Report)

The lowest part of the vast inland plateau area encompassed in the "Columbia Basin Irrigation Project Area" lies along the north flank of the Horse Heaven Hills and is commonly known as the Pasco Basin. This district consists of a system of broad sloping stream terraces which descend successively from the slopes of the boundary bedrock uplands to the present channel of the Columbia River. That district lying south of the Columbia River and bounded on the south by the slopes of the Horse Heaven uplift is known as the Kennewick area and is the principal concern of this investigation.

There is imminent need for a good potable water supply of 150,000 to 300,000 gpd for the Kennewick Irrigation District domestic system, and a summer, or standby, supply of an additional 100,000 to 250,000 gpd for the Pacific Power and Light Water District. Also, new connections soon may place new demands as high as 300,000 gpd; these may fall largely on the system of the irrigation district. In all, about 500,000 gpd may be needed for the irrigation district system and an additional 250,000 by the Pacific Power and Light system.

Ground water to meet these needs is available beneath the area in sufficient quantity from either of two zones, the "shallow" gravels overlying the basalt bedrock, or the basalt itself. Four to 6 properly constructed "shallow" wells of dug- or large-diameter-drilled-type would furnish the 500,000 gpd needed for the irrigation district and 2 or 3 such wells should yield the 250,000 gpd needed for the Pacific Power and Light system. Softening and, possibly, chlorination of the water might be necessary.

Three or possibly 4 wells drilled 400 or 500 feet into the basalt should supply the additional 500,000 gpd per day needed for the irrigation district domestic water system. One or two additional wells of this type should provide sufficient water to meet the needs of the Pacific Power and Light system. Water of the basalt zone is of excellent mineral quality and should not require treatment.

Newcomb, R. C. Geologic and ground-water data on the central part of the Walla Walla Basin, Washington and Oregon. Tacoma, Washington, U.S. Geological Survey, 1949. 50p. Unpublished records, subject to revision. (Open-File Report)

The end of the upland segment of the Blue Mountains slope that extends westward to Walla Walla is called Prospect Point. The upland extension, named Prospect Point Ridge, is probably bounded on the north and south by normal faults.

Above the basalt bedrock of this ridge, and in the adjacent valley sections, there is a thick stratum of old gravels (Pleistocene) that is known to extend westward from the vicinity of the topographic descent in Sec. 24 and 25, T7N, R36EWM. A cover of Palouse soil lies upon this gravel locally on the Prospect Point Ridge and, in turn, is overlain by old terrace deposits and, at the western end, by a thin mantle of "Touchet beds" material. The stratum of old gravels (Pleistocene) thickens to the west where it overlies and fingers into a thick zone of clays in the Walla Walla synclinal basin.

The old gravel (Pleistocene) is largely compact, "cemented" gravel of a moderately low-average permeability, but does have streaks and zones of loose gravel with high permeability. These permeable zones are not known to occur regularly in either the lateral or vertical direction. The static level of ground water in the gravels is usually near that of the surface streams. In the Russell Creek Valley, the ground-water level in the gravels is similar to that in the underlying basalt, but in the Mill Creek Valley it is higher than that in the basalt.

Newcomb, R. C. Preliminary report on the ground-water resources of the Walla Walla River Basin, Washington-Oregon. Tacoma, Washington, U.S. Geological Survey, 1951. 203p. (Open-File Report)

The Walla Walla River Basin, about 1,330 square miles in area, lies astride the Washington-Oregon boundary and drains westward to empty into the Columbia River. It slopes from the 5,000-foot crest of the Blue Mountains through a structural and topographic basin to the terraced lands adjoining the Columbia River at an altitude of about 300 feet. The main lower valley floor slopes from about 1,300 to 500 feet altitude.

The streams in the Blue Mountains flow in rockbound canyons from which they pass over the alluvial fans and through the terrace lands of the Milton-Freewater-Walla Walla area. Average annual precipitation varies from more than 40 inches on the higher uplands to less than 10 inches in the lower parts of the basin. The stream flow is highly seasonal and typical of drainage from a maturely dissected upland. In consequence of the low rainfall in summer, the stream flow is far short of irrigation requirements in the late summer months.

The only consolidated rock occurring in the basin is the Columbia River Basalt, whose accordantly layered flows form the bedrock exposed in the canyons and covered by the unconsolidated materials. The basalt dips westward from the Blue Mountains, southward down the "Touchet slope," northward from the Horse Heaven upland, and eastward from a rimrock ledge in the lower valley into a synclinal trough whose bedrock surface reaches to below sea level beneath the valley floor 10 miles west of Walla Walla. In places, faults intersect the even slopes that predominate in the basalt over most of the basin. The basalt is overlain by several unconsolidated deposits of Pleistocene and Recent age. The largest of these deposits consists of the old clays, up to 500 or more feet thick, that fill the Walla Walla synclinal trough and are interfingered by the old gravels that descend in a tabular stratum from the mouths of the canyons. Minor, and successively younger, deposits--the Palouse soil, deposits of the upper valley terraces, the Touchet beds, and the Recent alluvium--in places overlie the basalt and the old clays and gravels (Pleistocene).

The significant ground-water resources occur in two rock units--in the old gravels, which in places have a hydraulically continuous Recent alluvium mantle, and in the basalt. The regimen of the ground water in the two materials is considerably different. The ground water in the gravel is largely recharged by infiltration from the surface streams (and from water spread for irrigation) and travels rapidly down the fan slopes to its discharge points in spring zones, that in the interflow strata of the basalt recharges in the mountain, foothill, and upper-fan-slope zones around the edge of the valley floor area. It is confined beneath the old clays in the central valley floor area. Its downgradient progress is interrupted in places by structural barriers such as faults and sharp folds. Most of the ground water in the old gravels is unconfined, but that in the basalt is largely under conditions that are technically called confined.

Annually, about 38,800 acre-feet of ground water from the gravels and 9,000 acre-feet from the basalt are beneficially used. In the down-valley part of the old gravels, a minor amount of ground water in storage is available for development. A good deal more ground water can be developed from the basalt. Plans for development of that additional water from the basalt should provide for proper dispersement of well draft and the utilization of geologic and hydrologic knowledge to obtain the maximum benefits.

Newcomb, R. C. Ground water of the Columbia Basin. Tacoma, Washington, U.S. Geological Survey, 1958. 7p. (Open-File Report)

Part of the water that infiltrates from the surface reaches a zone of saturation whence it percolates toward the outlet and thereby is delayed in its course to the sea. This ground water is one form of natural storage which has different degrees of effect on stream flow in different segments of the Columbia River Basin. As a whole, the Columbia River receives a substantial part of its base flow from the discharge of ground water. The inflow from ground water differs materially in each of the following general terrain areas.

1. Interior Plateaus of Canada and the Rocky Mountain area of Montana, Washington, and Idaho are composed predominantly of crystalline metamorphic and igneous bedrocks of relatively low permeability, overlain in the valley areas by widespread deposits of unconsolidated and semiconsolidated sedimentary materials of relatively high permeability.
2. The Snake River plains and adjacent plateaus of southern Idaho, Utah, and Nevada are largely underlain by permeable and moderately permeable rocks, mostly lavas, and by semipermeable lake beds, although there are present other types of rocks as well as much recent alluvium.
3. The large plateau area, which comprises much of central, southeastern, and south-central Washington and north-central Oregon, is underlain by a thick accumulation of basaltic lavas that are only moderately permeable.
4. The central Oregon mountains and the Coast Range of Oregon and Washington are similar in that they are composed of rocks of relatively low permeability, do not contain sizable bodies of permeable alluvium, and have steep topography with quick runoff.
5. The Cascade Range in Oregon, and to lesser extent in southern Washington, is capped by an extensive deposit of highly permeable volcanic materials, the most permeable deposits occurring on the eastern slopes of the range.
6. The part of the Puget-Willamette Trough drained by the Columbia River possesses somewhat different ground-water features north and south of the main stem. To the north, the Lewis and Cowlitz rivers gather runoff mainly from the Tertiary rocks, which form the west side of the Cascade Range and flow across hilly lowlands cut mostly in Tertiary sedimentary rocks of low permeability. To the south, in the Willamette Valley, the strong rivers from the western slope of the Cascade Range have built fans and terraces of relatively coarse-grained alluvium along the eastern side of the valley.

The chemical and physical quality of the ground water is, in general, good or excellent.

Newcomb, R. C. "Some preliminary notes on ground water in the Columbia River Basalt." Northwest Science. Vol. 33, No. 1. p 1-8. 1959.

Ground water in the Columbia River Basalt occurs mostly in the tabular interflow zones. Some of these interflow, water-bearing zones consist only of a few small interconnected cracks; others are zones of fragmental rock so porous as to resemble rubble or loose breccia. At some places, the interflow zones may be buggy, but cavernous conditions rarely are found. Of the several hundred well logs collected from drillers, only a few show that even small caverns were encountered in the Columbia River Basalt.

The interbasalt sedimentary deposits, with a few exceptions, are not water-bearing. In general, the Latah Formation, the tuffaceous lower Ellensburg, and the many other interbedded clays and tuffs do not yield water in important amounts. The permeability and transmissibility of the interflow zones differ from place to place, and non-permeable rock is present at intervals between the places where the interflow zones are permeable. Stratigraphic discontinuities--the pinching out, overlapping, and fusion of flows and interflow zones--are present, but few of these are known to form a complete barrier to the passage of ground water.

The water-bearing zones are commonly identified in wells as more easily drilled parts of the basalt sequence. Changes in the static water levels, as different aquifers are penetrated during the drilling of wells, are further evidence of the tabular separation of the permeable zones in the basalt. In some districts, perched water has been observed to drain into lower porous zones during the drilling. The rise or fall of as much as 100 feet in the water level during a few feet of drilling through the massive confining parts of successive flows is common.

Thus, the fundamental pattern of aquifers in the Columbia River Basalt is that of separate tabular zones, each of which is interrupted in many places, but nevertheless is of rather widespread lateral extent. In some places, cubical, or "brickbat," and other types of fractured basalt allow hydraulic continuity between nearby permeable zones. Also, locally, the water in some aquifers is completely isolated vertically by impermeable, massive parts of the lava flows. Reprinted by permission of Northwest Scientific Association, c. 1959. All rights reserved.

Newcomb, R. C. Storage of ground water behind subsurface dams in the Columbia River Basalt, Washington, Oregon, and Idaho. Washington, D.C., U.S. Geological Survey, 1961. 15p. (Professional Paper No. 383-A)

The Columbia River Basalt, a thick sequence of accordantly layered lava flows, forms the bedrock beneath about 50,000 square miles in Washington, Oregon, and Idaho.

The rubbly rock at the top and bottom of some of the flows is permeable and transmits water laterally between the flows. Where the strata are

displaced vertically by faults, barriers to movement of the water are common. Where these barriers are transverse to the dip of the basalt layers, ground-water reservoirs are formed. Many such reservoirs are present in mountainous areas or on the flanks of mountain uplands, and their water has been little used to date.

Properly designed and constructed test wells are suggested as a means of determining the feasibility of withdrawing water from these reservoirs during the winter and spring. Benefits from such a practice may be especially great in stream valleys where water is needed in the late summer.

Newcomb, R. C. "Structural barrier reservoirs of ground water in the Columbia River Basalt." In: Short papers in the geologic and hydrologic sciences. Washington, D.C., U.S. Geological Survey, 1961. p. 213-215. (Professional Paper No. 424B)

A thick sequence of dark-colored lava flows, the Columbia River Basalt of Miocene and early Pliocene(?), extends beneath about 50,000 square miles of the Columbia Plateau and adjacent areas of the Pacific Northwest. In the central part of its vast areal extent, the total thickness of the basalt is more than 5,000 feet and may exceed 10,000 feet. At its margins, it tapers out against the pre-basalt slopes: the Okanogan Highlands at the north; the Rocky Mountains at the east; the mountains of central Oregon at the south; and the Cascade Range at the west, although it crosses through the Cascade Range at a few places. The individual lava flows range in thickness from about 5 to 150 feet, and average about 50 feet.

The basalt is a dense gray or black rock, composed of microcrystals in a glassy groundmass, that solidified in near-horizontal position from highly fluid lava that rose along fissures. Cooling joints cracked the rock into sets of vertical, columnar, and cubical blocks and into less prominent horizontal sheeting slabs. Except for the cooling joints, most flows are rather monolithic; little breccia or fragmental lava is present. Few sedimentary interbeds are present, except around the edges of the basalt unit. Most individual flows are dense and tight in their center parts, but some are vesicular, rubbly, and porous near their tops. Water percolates mainly along the porous tops of some of the lava flows. Tabular separation of the aquifers is common, and the hydraulic conditions of such occurrences vary from place to place.

The basalt has been tectonically warped into broad open folds with local areas of intense deformation. Infiltrated water moves down the dip of inclined porous flow tops so that the downwarped areas are sites of ground-water accumulation.

Locally, structural deformation has sheared and crushed the rock along faults and along tight folds in which the porous tops of the flows were crushed during the interflow slippage. These zones of crushed rock obstruct the tabular percolation of ground water and cause impounding

back to points of discharge. These ground-water reservoirs which updip from structural barriers occur in and near some of the valleys and in the uplands. Notable among the barrier reservoirs now in use is one underlying the Upper Cold Creek Valley northwest of Pasco, Washington and one under the Walla Walla Valley plain at College Place west of Walla Walla, Washington.

The impounded water is best tapped by wells at the barrier end of the reservoir. The perennial yield would be determined by the annual recharge and would differ from reservoir to reservoir. Withdrawals from reservoirs where flowing streams cross the intake area may decrease the stream flow; however, calculations on theoretical examples suggest this deduction in stream flow, at its maximum in late summer, would equal only a small part of the water drawn from otherwise unused storage.

Newcomb, R. C. Geology and ground-water resources of the Walla Walla River Basin, Washington-Oregon. Olympia, Washington, Washington State Division of Water Resources, 1965. 15lp. Prepared in cooperation with the U.S. Geological Survey, the Office of the State Engineer of Oregon, and the Board of County Commissioners of Walla Walla County, Washington. (Water-Supply Bulletin No. 21)

The Walla Walla River, whose drainage basin of about 1,330 square miles lies astride the Washington-Oregon boundary, drains westward to empty into the Columbia River. The basin slopes from the 5,000-foot crest of the Blue Mountains through a structural and topographic basin to the terraced lands adjoining the Columbia River at an altitude of about 340 feet. The main unit of the topographic basin is the valley plain, commonly called the Walla Walla Valley, which descends from about 1,500 feet at the foot of the mountain slopes to about 500 feet in altitude where the river cuts through the bedrock ridge near Divide. In the Blue Mountains, the streams flow in rockbound canyons. Beyond the canyons, near Milton-Freewater and Walla Walla, they pass onto the broad alluvial fans and the terrace lands of the valley.

The growing season is long and the climate dry, but equable. The average annual precipitation ranges from more than 40 inches on the higher uplands to less than 10 inches on the lower parts of the basin. The storm runoff is highly seasonal and typical of drainage from a maturely dissected upland. In consequence of the small amount of rainfall in summer, the stream flow is far short of irrigation requirements in the late summer months. Storage is a prime water problem; aside from some short-term storage as snow, ground water supplies the only storage of water within the basin.

The only consolidated rock in the basin is the Columbia River Basalt. These accordantly layered lava flows are the bedrock exposed in the canyons and other declivities. Beneath the valley plains, the bedrock is covered by unconsolidated sedimentary deposits. The basalt dips westward from the Blue Mountains, southward down the "Touchet slope," northward from the Horse Heaven ridge, and eastward from a divide ridge

in the lower valley. These dips converge into a synclinal trough whose bedrock surface extends below sea level in at least two places west of Walla Walla. In places, faults cut the basalt and cause displacements in the even slopes that characterize the basalt of most of the basin.

The basalt is overlain by unconsolidated deposits of Pleistocene and Recent age. The oldest, thickest, and most extensive unit of these deposits consists of the old clay, up to 500 feet or more thick, that partly fills the Walla Walla synclinal trough. The old clay is inter-fingered with the old gravel which descends in a tabular stratum from the mouths of the canyons. Successively younger deposits--the Palouse Formation, the deposits of the upper valley terraces, the Touchet beds, and the Recent alluvium--in places overlie the basalt as well as the old gravel and clay of Pleistocene age.

Significant ground-water storage occurs in two rock units--in the old gravel, which in places has a mantle of water-bearing alluvium of Recent age, and in the basalt. The regimen of the ground water in the two materials is considerably different. The ground water in the gravel is recharged directly by the infiltration of precipitation, by water from the surface streams, and by water infiltrated from irrigation; it percolates down-valley below the surface of the alluvial fans to its discharge points in springs and seepage areas. The ground water in the permeable parts of the basalt is recharged through the outcrops of permeable rock and by percolation of water from the overlying sedimentary deposits.

Most of the ground water in the old gravel is unconfined, but that in the basalt is largely confined (artesian). The water in the top part of the basalt is confined beneath the old clay in the central part of the valley. In its downgradient progress, the ground water in the basalt is dammed in places by impermeable zones along structural barriers created by faults and sharp folds.

Annually about 48,000 acre-feet of ground water from the gravel and 16,000 acre-feet from the basalt are taken for irrigation, industry, domestic, or public use. The annual basin-wide recharge to the aquifers is much greater than the present ground-water withdrawal, but overdrafts now occur locally.

Largely to appraise the size of the ground-water resources of the river basin, some estimates of recharge and storage are made. The average annual total basin-wide recharge to the ground water is about 300,000 acre-feet of water--125,000 acre-feet of this is recharged in the Blue Mountains and discharges to the streams. An estimated 500,000 acre-feet of water stored are in the old gravel and in the top-saturated 100 feet of the basalt. The pumping lift is commonly less than 200 feet.

In the down-valley part of the old gravel, some additional ground water in storage is available for use. Much greater use can be made of the space ready for storing water in the old gravel. More water than is now used can be developed from the basalt. Plans for development of large quantities of additional water from the basalt should provide for proper dispersment of well draft and the utilization of geologic and hydrologic knowledge to obtain the optimum benefits.

Newcomb, R. C. Effects of tectonic structure on the occurrence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington. Hydrology of volcanic-rock terranes. Washington, D.C., U.S. Geological Survey, 1969. 33p. (Professional Paper No. 383-C)

The 620-square-mile-area studied lies across the boundary of the Cascade Range and Columbia Plateau. The rubbly tops of some of the lava flows and the brecciated flows within the sequence form aquifers that yield large to small amounts of water to wells and springs. The yield of the aquifers depends on the hydrologic conditions and structural situation. Ground water in the basalt aquifers occurs mainly under three situations: (1) beneath the regional, or main, water table near river level; (2) perched at intermediate altitude near base-leveled secondary streams; and (3) perched at high levels near the top of the basalt in the uplands. Tectonic structure affects ground-water conditions in the basalt by the inclination of the aquifers, by formation of barriers to lateral percolation, by creation of avenues for some vertical movement, and by production of inlets for recharge and outlets for discharge. Together with stratigraphic discontinuities, the structural barriers have caused the impoundment of ground water in the basalt above the main water table. The levels of the outlets around barriers determine the uppermost level to which the obstructed ground water rises. The close relation between the tectonic structure and the occurrence of ground water in the basalt can be used to make better predictions of drilling results. The structural criteria for ground-water storage can be projected elsewhere in the basalt region. An accurate map of the geology, and particularly of the geologic structures, has been found imperative to the interpretation of the ground-water occurrences.

Newcomb, R. C. Geologic map of the proposed Paterson Ridge pumped-storage reservoir, south-central Washington. Portland, Oregon, U.S. Geological Survey, 1971. 1 sheet and text. Scale: 1:31,680. (Miscellaneous Geologic Investigations, Map I-653)

The area described here was proposed as a site for a multipurpose reservoir to store water pumped from the Columbia River. This investigation concerns largely the factors governing water tightness of the reservoir. The requirement for water tightness is considerably more rigid in a pumped-storage operation than it would be in an on-stream reservoir. For want of any specified limits, the author considered a total of 5 cfs per 1 million acre-feet stored to be the maximum leakage desirable and 10 cfs per 1 million acre-feet stored to be an excessive amount of leakage.

Summarized, the records of ground water show: (1) the top basalt flow is non-water-bearing or may have permeability in places for only very small quantities of water near its base in the lowest parts of the synclinal basin; (2) the second basalt flow in places has low to moderate permeability near its top and base; (3) the interbedded three sedimentary units are non-water-bearing and either perch ground water on their tops

or depress the level of confined ground water that occurs below their bases; and (4) permeability sufficient to yield large quantities of water to wells in the basalt occurs only at depths greater than 500 feet below the top of the basalt--a situation also found in this rock sequence across the Columbia River in Oregon.

Newcomb, R. C. Tectonic structure of the main part of the basalt of the Columbia River Group, Washington-Oregon-Idaho. Portland, Oregon, U.S. Geological Survey, 1970. 1 sheet. Scale: 1:500,000. (Miscellaneous Geologic Investigations, Map I-587)

This map was compiled to show the areas in which geologic structure favors the accumulation and storage of ground water in the basalt of the Columbia River Basalt Group of Miocene and Pliocene age. Published and unpublished sources of data were used, supplemented in places by field reconnaissance. In addition to folds and faults in the basalt, the map includes a few structures in rocks older than the basalt, where those structures affect the position and water-bearing capabilities of the nearby basalt.

Newcomb, R. C. "Some characteristics of aquifers in the Columbia River Basalt." Geological Society of America. Abstracts with Programs. Vol. 8, No. 3. p. 399-400. 1976.

The parts of this accordantly layered volcanic sequence that yield water to wells and springs consist of distinctive parts of the basalt. The principal water-yielding and transmissive parts consist of: (1) cooling-shattered parts of some flow tops; (2) pillow lava; and (3) flow breccia.

These permeable zones were discontinuously formed in a minor number of the lava flows; consequently, their distribution is irregular both vertically and horizontally. Their possible presence within a given depth at any one place can be expressed as a statistical probability. Among other uses, this type of probability may best express the possibility of long-distance water-pressure transfer from sites where natural or artificial recharge can take place. Reprinted by permission of the Geological Society of America. c. 1976. All rights reserved.

Olson, T. M. The geology and ground-water resources of part of the Hangman and Marshall creeks drainage basins, Spokane County, Washington. Cheney, Washington, Eastern Washington State College, 1975. 70p. (M.S. Thesis.)

The geology and ground-water resources of approximately 290 square miles lying immediately south of Spokane were studied in order to evaluate the

ground-water potential of the various units. The area includes smooth, rolling hills formed by erosion of thick, Pleistocene loess deposits overlying a Miocene-Pliocene basaltic lava plateau. Numerous pre-Tertiary plutonic and metamorphic rocks occur as steep toes and mountainous regions, and extensive areas are covered by a relatively thin mantle of windblown silt, ash, marsh, glacial, and Spokane Flood deposits. The total thickness of loess and/or glacial-related deposits is generally less than 100 feet. Maximum basalt thickness is unknown, but it exceeds 650 feet.

Wells up to 150 feet deep in glacial flood deposits or basalt usually satisfy domestic use requirements by producing 5 to 19 gpm. Wells tapping only loess or pre-Tertiary bedrock average only 1 to 3 gpm, with some holes being considered dry. Large-diameter wells, several hundred feet deep in the basalt, can produce over 1,000 gpm. Numerous wells located on the Hangman and Marshall creeks lowlands are also capable of producing several hundred gallons per minute.

The area receives approximately 17 inches of precipitation annually. Approximately 0.47 inch of this reaches the aquifers; the remainder is returned to the atmosphere by evapotranspiration or leaves the area as surface runoff. Recharge occurs mainly by infiltration from streams and downward percolation through the sediments.

Significant ground-water storage occurs in three geologic units--the unconsolidated sand and gravel deposits, the marsh and meadow deposits, and the basalt. The ground water in the gravel and marsh deposits is recharged directly by the infiltration of precipitation and by the water from surface streams as well as from any surface application such as irrigation. The basalt is recharged through outcrops of permeable rock and by percolation of water through the overlying sediments. Annual recharge to the sediments amounts to approximately 22 acre-feet per square mile of exposure. Annual recharge to the bedrock is calculated at the rate of about 3 acre-feet per square mile. In the southern part of the study area, the annual recharge is calculated to be 44 acre-feet per square mile. Total recharge for both aquifer systems for the entire area is 6,187 acre-feet per year.

Because annual withdrawals from all aquifers are calculated to be approximately 5,000 acre-feet, more water than is now used, particularly from the basalt aquifers, could be developed. Although annual basin-wide recharge is greater than the present withdrawal, overdraft and well interference will quickly develop if optimum well spacing is not considered.

Oriard, L. L. Ground-water studies, City of Cheney, Washington.
Washington State Division of Water Resources, not dated. 4p.
(Report of Investigations)

An investigation was made of the geophysical and geologic conditions pertaining to the potential water supply of the City of Cheney, Washington. On the basis of this field work, it was determined that the watershed

supplying Cheney lies generally to the north. An ancient valley lies between granitic rocks. Later, the Columbia River Basalt flows partly filled this valley. Subsequent glacial activity, water, and other agents have eroded the surface to its present shape. The aquifer in this case is the large mass of basaltic rocks, and the basin is provided by the old granitic valley system.

On the basis of the field studies, general geologic principles, what is known of the characteristics of these basalts, and supported by the well logs, it is probable that the water table lies above the granite surface and that a substantial water supply is available from these basalts. A third well about 0.25 mile away, north or east of the present wells, would not seem too great a risk.

Parker, Jr., G. G. Municipal, industrial and irrigation water use in Washington, 1970. Tacoma, Washington, U.S. Geological Survey, 1971. 21p. (Open-File Report)

This report contains data which give an accurate assessment of municipal, industrial, and irrigation water use in Washington in 1970, and projections of water use to 1985. Municipal and industrial water-use data are tabulated by month and source for the 39 counties. Total municipal water use was 331 billion gallons. Industry used 388 billion gallons, of which 170 billion gallons were from the municipal systems and 218 billion were self-supplied. Of the 549 billion gallons of water used for municipal and industrial supplies, 162 billion gallons were ground water, 373 billion gallons were fresh surface water, and 14 billion gallons were saline surface water. A compilation of statewide industrial use as categorized by the Standard Industrial Classification (SIC) shows that about 70 percent of the total water use in this compilation was by SIC 26 (Paper and Allied Products Industry) and 30 percent was used by the other 14 classifications listed.

Annual irrigation water used and acreage watered are listed by source (whether ground water or surface water) and by county. In 1970, 6.29 million acre-feet of water (2,050 billion gallons) were applied to 1.40 million acres. This water was 94 percent surface water and 6 percent ground water. More than 97 percent of the irrigation water was applied east of the Cascade Range to nearly 94 percent of the irrigated acreage in the state.

Pearson, H. E. Test-observation well near Paterson, Washington: Description and preliminary results. Tacoma, Washington, U.S. Geological Survey, 1973. 23p. Prepared in cooperation with Washington State Department of Ecology. (Water-Resources Investigations No. 9-73)

Initial irrigation development in the Horse Heaven Hills area started near the towns of Paterson and Plymouth along the Columbia River and has

relied on surface water from the river. The first stages of irrigation of land farther from the river created a need for more complete data on ground-water conditions than that provided from the few existing irrigation wells in the area. For this reason, an 860-foot test-observation well, 10 to 6 inches in diameter, was drilled in the Horse Heaven Hills about 8 miles north of Paterson, in the valley of the East Branch of Glade Creek. The test well is one of several drilled since 1970 to provide information on ground-water conditions in areas for which little or no information has been available.

The well, drilled by the air-rotary method, penetrates productive aquifer zones at the 735- and 860-foot depths. Test pumping showed specific capacities of 58 gpm per foot of drawdown at the 735-foot depth and 148 gpm per foot of drawdown at the 860-foot depth. The aquifer tests indicate that large amounts of water occur only at these--and possibly greater--depths.

Data from the well, including results of the pump tests of the aquifers and chemical analyses of the water, and that obtained from geophysical logs will provide valuable guidance in management of the ground-water resources of the area.

Pearson, H. E. Test-well drilling in the Upper Satus Creek Basin, Yakima Indian Reservation, Washington. Tacoma, Washington, U.S. Geological Survey, 1977. 14p. Prepared in cooperation with the Yakima Tribal Council. (Open-File Report 77-455)

Two test wells were drilled in the upper Satus Creek Basin of the Yakima Indian Reservation, Washington using the air-rotary method. At site 1, the well penetrated a young basalt and 175 feet of the Yakima Basalt; at site 2, the well penetrated the young basalt. The well at site 1 was drilled to a depth of 350 feet. Tests for drawdown and yield indicated a specific capacity of about 11 gpm per foot of drawdown. The potential yield of this well may be about 1,000 gpm. The well at site 2 was drilled to a depth of 500 feet. Only a small quantity of water was encountered and no test for yield was made. Data from these wells, including chemical analysis of the water from the well at site 1, will provide information useful in the development and management of the ground-water resources in this part of the Yakima Indian Reservation.

Piper, A. M., T. W. Robinson, and H. E. Thomas. Ground water in the Walla Walla Basin, Oregon-Washington. Tacoma, Washington, U.S. Geological Survey, 1933. 99p. Advance data, subject to revision. (Open-File Report)

The area described in this report comprises parts of Umatilla County, in northeastern Oregon, and parts of Walla Walla County, in southeastern Washington, and covers 295 square miles. It covers the central part of

the drainage basin of the Walla Walla River, which is an interstate stream and a minor tributary of the Columbia River.

The objectives of this investigation were to establish the relation between the Walla Walla River and the body of ground water which supplies the irrigation wells and certain perennial springs on the valley plain in the vicinity of Milton-Freewater, and to ascertain the general ground-water conditions of the area insofar as they might influence that relation.

A reconnaissance of the area was made in August 1932 when the potential investigation was conceived as a basis for a comprehensive allocation of all the surface-water and ground-water resources of the area. At that time, 13 observation wells were selected in key locations and measurements of the depth to water were made. In November and December of that year, 25 additional observation wells were selected and levels were run to all 36 wells. Measurements of the depth to water in these observation wells were made at irregular frequency until the following April. On May 1, 1933, when the cooperative investigation was undertaken in its limited scope, a geologic map of the basin and a study of hydrologic features were begun. Intensive field work was terminated in August 1935, but routine observations of wells and springs are being continued.

Price, Jr., C. E. Artificial recharge of a well tapping basalt aquifers, Walla Walla area, Washington. Washington, D.C., U.S. Geological Survey, 1961. 33p. (Water-Supply Paper No. 1594-A)

Declining water levels in part of the Columbia lava plateau, owing to pumping, have caused concern for several years. Therefore, the U.S. Geological Survey in cooperation with the Washington State Department of Conservation carried out an experiment to determine the feasibility of artificial recharge to halt the decline of water levels in part of the Walla Walla Basin, Washington. During the experiment, 71.3 acre-feet (23 million gallons) of surface water were injected into basalt through Walla Walla city well 3 at rates ranging from 630 to 670 gpm. The chemical and bacteriological quality of the injected water was excellent, and the water contained only 2 ppm of suspended sediment. The injected water probably was nearly saturated with air when it entered the top of the well and may have entrained some additional air as it fell into the well.

The water injection caused a rise of the water level and, hence, increased the amount of ground water in storage in the local area. However, the subsequent yield and specific capacity of the well were impaired. The data obtained during the tests suggest that hydraulic boundaries limit the lateral movement of water. The tests indicate also that the coefficient of transmissibility of the basalt is about 400,000 gpd/ft and that the coefficient of storage is about 0.0002.

Price, D., D. H. Hart, and B. L. Foxworthy. Artificial recharge in Oregon and Washington, 1962. Washington, D.C., U.S. Geological Survey, 1965. 65p. (Water-Supply Paper No. 1594-C)

Since 1950, artificial recharge has become an increasingly common practice in Oregon and Washington to augment the natural ground-water supply, to conserve desirable physical characteristics of water, and to dispose of excess water. Prior to 1950, there was little artificial recharge in the two states and by 1956, only 9 artificial-recharge installations were known to have been in operation. By 1961, when 2- and 3-well systems had been successfully used to furnish and dispose of water for heating and cooling of buildings and demand for additional municipal water supplies had increased, the number of current and former artificial-recharge operations had grown to 23, including 2 test operations and 1 standby installation.

Natural recharge to basalt, sand, and gravel aquifers in the 2 states was augmented by more than 17,000 acre-feet of artificially recharged water in 1961. The largest single artificial-recharge operation is a surface-spreading operation at Richland, Washington, where as much as 12,000 acre-feet of water, diverted from the Columbia and Yakima rivers, infiltrate each year to shallow aquifers tapped by municipal-supply wells.

Artificial-recharge tests at Walla Walla, Washington, in 1957-58 and at The Dalles, Oregon, in 1960-61 have demonstrated that recharge of basalt aquifers by the injection method is technically feasible and could be used more widely to supplement natural recharge in areas of similar volcanic terranes.

The general success of most artificial-recharge operations in the two states indicates that such operations can be a profitable means of conservation and that they will be used more widely in the future. However, improper design of systems and uncontrolled or indiscriminate recharge practices, such as injecting water of inferior quality under ground, can cause undesirable changes in both the ground water and the water-bearing capacity of the aquifers.

The successful design of an artificial-recharge system depends largely on collection and proper evaluation of background data on the chemical and physical character and biota of the waters involved, the subsurface geology, the natural ground-water regimen, and the existing uses of the waters involved. Successful operation of the system depends also on continued collection and proper evaluation of such data as quantities and rates of recharge and ground-water withdrawals, chemical and physical character and biota of both the recharge and ground water, sediment content of the recharge water, type and amount of treatment of the recharge water, and effects of recharge on ground-water levels. Early recognition and evaluation of problems that arose during operation of several existing artificial-recharge systems in Oregon and Washington were hampered because those data were not available or were inadequate.

Robinette, M. Geophysical investigations of Washington's ground-water resources, 1974/75. Pullman, Washington, Washington State University, College of Engineering, 1975. (Report No. 75/15-24)

This report expands the correlation efforts of the Lower/Middle Yakima contact in the central Columbia Basin area. Newly derived elevations substantiate the predicted map of Siems (1974) with only few variations which are shown in the individual correlation lines. A new map was not prepared because conflicting data do not change it significantly. One general area in T19N, R33EWM is suggestive of a 200-foot discrepancy in contact location, but until chemical data become available for the area, the results must be considered tentative and not sufficiently definitive to change the map.

A recently drilled deep hole (Sec. 8, T19N, R33EWM) which penetrates "Zone C" in the Odessa area has provided new information about the deep aquifer system. Correlations between this well and Basalt Explorer Well (Sec. 10, T21N, R31EWM) approximately 18 miles away, give preliminary indications about the variations and lateral extent of water-bearing zones. Chip samples from the well in Sec. 8, T19N, R33EWM have been described and are currently being analyzed for 10 elements as an aid to the stratigraphic identification of the Odessa area basalts.

Where aquifer correlations have been attempted, they have been made on the basis of neutron porosity data. Some correlation lines are based upon natural radioactivity logs because a gamma marker is present or the correlation line spans a large distance. Lithologic data are used whenever available to assist in log correlations and to determine major stratigraphic breaks. An attempt has been made to keep all correlations consistent with previous work and to use all available log information in establishing the correlation for an area. Two of the correlation lines cover areas for which there are very little geophysical data. These correlations should be considered tentative until more information becomes available.

Sceva, J. E., F. A. Watkins, and W. N. Schlax, Jr. Geology and ground-water resources of the Wenas Creek Valley, Yakima County, Washington. Tacoma, Washington, U.S. Geological Survey, 1949. 81p. (Open-File Report)

The Wenas Creek Valley is a plunging synclinal trough which extends from the eastern foothills of the Cascade Range to the Yakima River near Selah, Washington.

Precipitation decreases downstream from the moderate rain and snowfall of the headwaters area to the semiarid conditions prevalent in the Yakima Valley.

The lowland part of the valley is underlain by the clastic sediments of the Ellensburg Formation and the upper slopes of the valley sides by the Columbia River Basalt formation. A basaltic constriction separates the valley into an upper and a lower segment.

Ground-water development at present is chiefly in the lower valley. There, the principal aquifers have been found in the lower strata of the Ellensburg Formation. Permeability and areal extent of the aquifers are highly variable, resulting in erratic yields and pumping levels, although the ground-water levels in these aquifers show a rather uniform downstream gradient. Ground water moving down-valley is carried to considerable depths in the synclinal, basin-like structure of the lower valley. The water emerges at the lower end of the valley, where the water-bearing strata again rise to the surface.

The water resources of the valley that are now utilized are considerably less than those needed to service the readily irrigable land. This present study of ground-water occurrence and pumping levels in the light of the use being made of the water indicates that a wiser distribution of surface and ground-water resources might be affected.

One hundred sixty-one wells and 22 springs are described in the tables; 48 field analyses and 7 complete chemical analyses show the quality of the water to be good for most uses.

Schwennesen, A. T. and O. E. Meinzer. Ground water in Quincy Valley, Washington. Washington, D.C., U.S. Geological Survey, 1918. p. 131-161. (Water-Supply Paper No. 425-E)

The Quincy Valley is a 600-square-mile-area bounded on the north by the Badger Hills, on the south by Frenchman Hills, on the west by Babcock Ridge and other swells along the Columbia River gorge, and on the east by high land east of Moses Lake. Various crops in the valley are irrigated with surface and ground water. It is estimated that as much as 15,000 acres can be irrigated in the basin each year with water from the basalt, lake beds, and glacial outwash deposits.

Siems, B. A. Surface to subsurface correlation of Columbia River Basalt using geophysical data, in parts of Adams and Franklin counties, Washington. Pullman, Washington, Washington State University, College of Engineering, 1973. 65p. (College of Engineering Bulletin No. 331)

Stratigraphic work in the Columbia River Basalt has utilized differences in outcrop and petrographic characteristics. However, the northeastern part of the plateau has limited outcrop, and seems well suited for an attempt to extend surface mapping into the subsurface using geophysical logs of deep wells. Emphasis has been placed on the natural gamma and neutron-epithermal neutron logs. The neutron-epithermal log has been found to be valuable for locating flow contacts. Two marker features were recognized on the gamma logs: a gradual increase in natural radioactivity with depth in the upper 150-250 feet of the Frenchman Springs Member; and a marked high gamma spike at the probable stratigraphic

position of the Quincy diatomite. Correlations using these features, the known geology and the Ti_{02} analyses, suggest the existence of 530 feet of Frenchman Springs basalt in one well. This is about 130 feet less than is recognized on well logs from 2 boreholes in the Hanford Reservation (now Hanford Site) and 40 feet more than exists near the mouth of Devils Canyon, south of Kahlotus. Natural gamma correlations also indicate an increase in southerly dip just north of Cunningham, possibly the continuation of the Frenchman Hills anticline to the west.

Siems, B. A. Stratigraphic identification and correlation of basalt aquifers using geophysical and chemical techniques. Pullman, Washington, Washington State University, College of Engineering, 1974. (Research Report No. 74/15-90)

Since 1967, the Geohydrology Section of Washington State University has been collecting geophysical data from wells penetrating the upper part of the Columbia River Basalt in Washington. Beginning about 1971, enough data became available so that correlations between wells could be attempted. Using geophysical data, Crosby and Anderson (1971) made stratigraphic correlations and identified the major aquifers in wells in the vicinity of Pullman, Washington. Later work discussed relationships noted between geophysical logs and stratigraphic units in the basalt in other areas. The current report describes the results of the most recent efforts to relate stratigraphic units to the physical features reflected on the logs. Much of this work is preliminary and should be regarded as such. There are two areas discussed: an area in the Walla Walla Valley; and a large area approximately included by lines connecting Davenport, Cheney, Colfax, Ritzville, Lind, Washtucna, Kahlotus, Othello, Moses Lake, and Almira. The latter area is referred to as the Odessa area.

Siems, B. A., J. W. Crosby, III, J. V. Anderson, J. H. Bush, and T. L. Weber. Final Report 1972/73, geophysical investigations of Washington's ground-water resources. Pullman, Washington, Washington State University, College of Engineering, 1973. (Research Report No. 73/15-58)

Since 1967 the Geohydrology Section at Washington State University has been acquiring geophysical log data from irrigation wells on the Columbia Plateau. The data collection was accelerated around July 1971, allowing very complete coverage of some areas to become available. Stratigraphic interpretation of the logs in certain areas has become relatively straightforward, and advances toward recognition of persistent features in other areas are being made.

This report is essentially a status report, aimed at enabling the reader to access available geophysical data from Washington State University

files and to understand to some degree what the data mean. For that purpose, a nearly complete listing of wells logged, by county and legal description, is given in the appendix to the report. An additional list of wells logged this fiscal year (1973) using Washington State Department of Ecology funds is presented at the end of the text.

The Instrumentation Improvements section discusses the data treatment facility as it now exists. Methods of data treatment currently in use are presented, along with a discussion of their advantages.

In general, the newer the data, the more complete they are. The oldest log suites contain only natural gamma, spontaneous potential, wall rock resistivity, caliper, and neutron-neutron logs. In more recent work, the following additional logs have been collected: temperature; fluid resistivity; neutron-gamma; and gamma-gamma logs. Most available log suites will contain nearly all of the above logs, because the largest volume of data is recent. Vertical flow meter logs were collected intermittently from about January 1972 to early 1973; since that time, most suites have flow meter data. The flow meter tool is briefly described at the end of the Instrumentation Improvements section.

Stratigraphic features from various areas are discussed in the section on stratigraphy. Selected wells are used to give the reader an indication of those features recognized as locally or regionally significant at the present time.

Silar, Jan. Ground-water structures and ages in the eastern Columbia Basin, Washington. Pullman, Washington, Washington State University, College of Engineering, 1969. 165p. (College of Engineering Bulletin No. 315)

This paper summarizes the results of research work on ground-water structures in the eastern part of the Columbia Basin in the State of Washington. The aim of the work was to determine the applicability of radiocarbon dating to the ground-water conditions of the Columbia River Basalt lava flows in the regional ground-water research and, if possible, to get some basic data on ground-water flow for the design of artificial ground-water recharge.

The work was concentrated in the area where a large amount of ground water is pumped for irrigation. It was estimated that the amount of ground water pumped per square mile exceeds by several times the unit yield of ground water.

The investigated area consists of a sequence of basalt lava flows that is more than 10,000 feet thick. The lava flows poured on an uneven pre-Tertiary surface of metamorphic and granitic rocks. The basalt flows are subhorizontal with a gentle dip toward the southwest. The surface of the basalt is covered with a layer of Palouse loess that was partially washed out and removed during large Pleistocene floods. The bare surface of the basalt has been eroded and dissected into the so-called scablands.

The area is crossed from the northeast to the southwest by a system of shallow canyons known as coulees.

The ground water occurs in fissured zones at the tops and at the bottoms of individual lava flows and in highly permeable layers of pillow lava. The system of aquifers is permeable in the horizontal direction. The storage capacity as well as the permeability are irregular in individual zones and depend on the development of the flows. The ground-water circulation is influenced by the surface morphology. The deeper valleys in the eastern part of the investigated area form a natural drainage system for the aquifers.

The ground water is of the calcium bicarbonate type, with some few exceptions.

Forty-four samples of ground water were taken from wells and evaluated. The method of J. W. Crosby and R. M. Chatters (1965) was used for sampling; i.e., the bicarbonates from water were trapped on a strongly basic ion exchanger. The samples were processed, counted, and the ages calculated in the Radioisotopes and Radiations Laboratory of Washington State University.

The ages of the evaluated samples are in the range from modern up to $16,275 \pm 1,465$ years before present. The bulk of samples lies between 0 and 6,000 years old. Relationships have been examined between the ground-water ages and surface morphology, which seem to be the controlling factors in the ground-water regime in a monotonous sequence of lava flows. Samples were classified according to the morphology of the area surrounding the well and frequency of ages was expressed for each of the categories.

The following conclusions could be established.

Ground water in the plateau areas is predominantly younger than 6,000 years before present; i.e., post-glacial (post-Wisconsin). Modern age is rather an exception. This indicates the ground water originated when the present relief was already in existence. It indicates, too, a slow circulation below the plateau and the isolation from the surface.

The variation in ground-water ages from wells in valleys ranges from modern to 8,700 years and indicates a more intensive ground-water circulation along depressions and their probable drainage effects on ground water of the various aquifers and ages.

The variation of ground-water ages along the edges of valleys, on valley slopes, and on surface elevations, with frequent modern ages, indicates an intensive ground-water circulation in morphologically dissected areas and a communication of aquifers with the surface.

A considerable variation of ground-water ages, but excepting modern, has been established in artesian wells with overflow, thus indicating a slow motion in aquifers isolated from the surface.

No significant correlations between age and depth, or between age and altitude of aquifer, have been established so far.

It is evident that there is no uniform system of ground-water circulation within the investigated depth range between 0 and 300 feet and probably even more. The ground-water circulation in the investigated zone is considerably influenced by morphology, and is outside the zone of the profound regional ground-water flow.

A conclusion follows from the mentioned facts that the aquifers within the studied depth range cannot be used for a uniform ground-water recharge of the Columbia Basin and that artificial replenishment must be accomplished in individual, partial ground-water structures of the basin in the areas of water consumption.

Valley depressions and scabland areas with suitable potential conditions seem to be favorable as ground-water recharge areas.

Suggestions are given for completing basic data that are necessary for ground-water recharge design.

Tanaka, H. H. Pumping test on the DNR well in Horse Heaven Hills. Olympia, Washington, Washington State Department of Ecology, Oct. 1976. 3p. (Water Resources Investigation Section, unpublished letter report)

A pumping test in September, 1976 in Sec. 16, T6N, R23EWM, Klickitat County was made to determine the hydraulic properties of the basalt aquifer in order to compute long-term pumping interference at the Andrews #3 well, 7,100 feet away. The transmissivity and storage coefficients averaged 285,000 gpd/ft and 1.4×10^{-4} . Based on these values and an assumed pumping rate of 3,000 gpm, the well interference at the Andrews #3 well is calculated to be about 6, 8, or 11 feet in 10, 100, or 1,000 days of continuous pumping.

Tanaka, H. H. Warden aquifer test. Olympia, Washington, Washington State Department of Ecology, July 1977. 2p. (Water Resources Investigation Section, unpublished letter report)

The pumping schedule of two municipal wells at Warden were utilized in an aquifer test in June 1977. Municipal well 4 was pumped at a rate of 1,250 gpm for 21 hours and allowed to recover for 6.5 hours. Meanwhile, drawdown and recovery measurements were made on the pumped well and on municipal well 5, 690 feet away. The average values of transmissivity and storage were computed to be 80,000 gpd/ft and 3.0×10^{-5} for the basalt aquifer.

Tanaka, H. H. Aquifer test of well 18/25-15E in Grant County, Washington. Olympia, Washington, Washington State Department of Ecology, 1977. 3p. (Water Resources Investigations Section, unpublished letter report)

Well 18/25-15E in Grant County was test pumped at 2,400 gpm for 3 days in March 1977. Drawdown and recovery measurements were made on 9 observation wells ranging in distance from 60 feet to 4.5 miles from the pumped well. The computed transmissivity averaged 160,000 gpd/ft, and the storage coefficient averaged 8.0×10^{-4} .

Tanaka, H. H., A. J. Hansen, Jr., and J. A. Skrivan. Digital-model study of ground-water hydrology, Columbia Basin Irrigation Project area, Washington. Olympia, Washington, Washington State Department of Ecology, 1974. 60p. (Water-Supply Bulletin No. 40)

In the Columbia Basin Irrigation Project area in eastern Washington, ground-water levels generally have risen because of rapid increases in ground-water inflow, outflow, and storage from irrigation. Quantitative analyses of ground-water inflow and outflow by means of digital computer models represent three major areas--Quincy Basin, Pasco Basin, and Royal Slope. The digital computer models were designed to simulate the hydraulic-head response to natural or man-made stresses in the two-aquifer system underlying the area. The two-aquifer system is an unconfined upper aquifer (clay, silt, sand, and gravel in varying amounts) overlying a confined lower aquifer (basalt), separated by a leaky confining layer. The steady-state model analyzes conditions before irrigation (1952) when inflow and outflow to the aquifer system were essentially in balance and the transient model analyzes conditions during the first 16 years of irrigation (1952-67) when rapid hydrologic changes were taking place in the aquifer system. For the Quincy Basin model, annual inflow and outflow from both aquifers totaled 105,000 acre-feet, and average annual recharge from precipitation to both aquifers was 11,000 acre-feet. For the Pasco Basin model, inflow and outflow from both aquifers totaled 28,700 acre-feet, and average annual recharge from precipitation to both aquifers was 5,200 acre-feet. For the Royal Slope model, annual inflow and outflow from the lower aquifer totaled 14,800 acre-feet and average annual recharge from precipitation to the lower aquifer was 1,300 acre-feet. Cumulative storage of water between 1952-69 for the Quincy model was about 2.17 million acre-feet in the upper aquifer and about 29 thousand acre-feet in the lower aquifer. For the Pasco Basin model, it was about 3.8 million acre-feet in the upper aquifer and about 23 thousand acre-feet in the lower aquifer. For the Royal Slope model, it was about 750 thousand acre-feet in the upper aquifer and about 14 thousand acre-feet in the lower aquifer.

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

livestock water supplies. Tacoma, Washington, U.S. Geological Survey, 1941. 8p. (Open-File Report)

This summary was prepared for use by the planning agencies of the Columbia Basin Joint Investigations as a general guide in estimating the cost of domestic water supply systems in the areas of early development. It pertains to the three subdivisions of the project area that have thus far been covered in reconnaissance fashion: (1) the Quincy Basin in the northwestern part of the area; (2) the Wahluke Slope in the west-central part of the area; and (3) the Pasco Slope in the extreme southern part of the area.

Reliable estimates of the probable depth and water-yielding capacity of wells not yet constructed must rest on a base of facts known from existing wells and from geologic features of the area. Factual data concerning wells in the Quincy Basin are fairly comprehensive, but only scant data on wells in the Wahluke and Pasco slopes areas are available.

Taylor, G. C. Factual data pertaining to wells and springs in the Columbia Basin Project area, Washington. Tacoma, Washington, U.S. Geological Survey, 1944. 85p. Unpublished records, subject to revision. (Open-File Report)

This report assembles the basic factual data gathered in connection with the initial stage of an investigation of the ground-water features of the Columbia Basin Irrigation Project area by the U.S. Geological Survey and the Washington State Department of Conservation and Development. The initial or reconnaissance stage of the investigation began in August 1940 and sought to determine the general availability of ground water for the domestic and public supplies that will be needed as the area is settled. In the further stages of the investigation, the contemplated objectives are an estimate of the yields naturally and perennially available from the several ground-water bodies for all potential uses, including withdrawals for irrigation on outlying or isolated lands; also, a preliminary appraisal of the effects of extensive and continuing irrigation with respect to losses of water from reservoirs and canals, ultimate waterlogging of arable lands, and potential increases in ground-water yields.

The area under study covers about 3,900 square miles of the Columbia Plateau in east-central Washington including most of Franklin and Grant counties and the western part of Adams County. Except for local, small diversions from the Columbia River, Crab Creek, and Moses Lake for irrigation, wells and springs are the only present sources of water for all uses in the project area. As the project lands are settled and developed, wells and springs will remain the principal sources for year-long uses of water, as for domestic and industrial purposes. Thus, a reliable appraisal of ground-water resources of the area is essential if settlement is to be directed in an orderly and prudent manner.

Included in this report are three tables that respectively describe some 80 percent of the active or potentially active wells in the area and those abandoned wells for which pertinent factual data are now available, that describe the principal springs, and that give chemical analyses of representative natural waters.

Altogether, this report includes descriptive records for 1,072 wells and 36 springs or spring groups, also chemical analyses of 25 natural waters. About 800 of the wells have not been described previously. The wells described are distributed over 101 townships or approximately 90 percent of the area.

The known yields of active wells in the area range from less than 1 gpm to 7,000 gpm. These yields are not proportional to the depths of the wells, but are controlled largely by the perviousness and thickness of water-bearing zones, features of well construction, and the capacities of pumps.

The depth is known for essentially all the wells described, and ranges from 5.5 feet to 2,280 feet.

Among the 36 springs and spring groups listed, the Drumheller group, Lind Coulee group, and the Rocky Ford Springs each discharges more than 1,000 gpm. The greatest known discharge of the Rocky Ford Springs, the most productive in the area, is about 90 second-feet or 40,000 gpm.

Taylor, Jr., G. C. Ground water in the Quincy Basin, Wahluke Slope, and Pasco sub-slopes areas of the Columbia Basin Project, Washington. Tacoma, Washington, U.S. Geological Survey, 1948. 182p. Unpublished records, subject to revision. (Open-File Report)

This preliminary report gives in part the results of three months of field work in the Columbia Basin of central Washington during the autumn of 1940 and the spring of 1941. Especially considered in this report are: (1) the general geologic features of the project area in relation to the occurrence of ground water; (2) preliminary information regarding depth to water, source and movement of ground water, and depth and yields of wells in the Quincy Basin, Wahluke Slope, and Pasco Slope subareas of the Columbia Basin Irrigation Project area; and (3) general conclusions regarding the availability of ground-water supplies for domestic and municipal use in these three subareas.

The report contains three tables that give information on: (1) about 80 percent of the active or potentially active wells in the area and those abandoned wells for which pertinent data are now available; (2) the principal springs in the area; and (3) chemical analysis of representative natural waters. Records are included for 1,072 wells and 36 springs or spring groups, also chemical analyses of 25 natural waters. The wells described are distributed over approximately 90 percent of the area. The known yields of active wells in the area range from less than 1 gpm to about 7,000 gpm. The yields are not proportional to the depths of

the wells, but are controlled largely by the perviousness and thickness of water-bearing zones, features of well construction, and the capacities of pumps.

U.S. Geological Survey. Water resources of the Toppenish Creek Basin, Yakima Indian Reservation, Washington. Tacoma, Washington, U.S. Geological Survey, 1975. 144p. Prepared in cooperation with the Yakima Tribal Council. (Water Resources Investigations 42-74)

About 94 percent, or 655,000 acre-feet per year, of water used for irrigation in the Toppenish Creek Basin of the Yakima Indian Reservation is diverted from the Yakima River, the eastern boundary of the reservation. The flows of Toppenish Creek and its tributaries are small in comparison, but they are vital to irrigation of areas upslope from the irrigation canals. About 17.5 acre-feet per year of ground water from a basalt aquifer and about 3.5 acre-feet per year from young and old valley-fill aquifers also are used for irrigation in the basin. Each aquifer is capable of yielding more than 1,000 gpm to efficiently constructed wells. Owing to seepage from canals and irrigated lands, and ground-water level in the young valley fill, the aquifer is higher at present (1974) than in the past, but some water-level declines have occurred in the old valley fill and basalt aquifers. Water levels in wells tapping the basalt aquifer have been lowered in some places as much as 80 feet during the past 15 years. The young valley fill aquifer in the eastern part of the basin is the best source of ground water.

Walters, K. L. Water resources in the White Salmon area, Klickitat County, Washington. Tacoma, Washington, U.S. Geological Survey, 1967. 17p. (Memorandum for the files)

A reconnaissance of the White Salmon area was made to briefly evaluate the ground-water system, the present and potential water use, and the need for a formal ground-water investigation in this area. A brief analysis of the stream flow records for this area has been made, particularly in relation to low-flow characteristics.

The local people report that there are about 12,000 acres in the area that could be profitably irrigated. They have raised some funds locally for study of the area and have organized the Skamania-Klickitat Water Development Committee, and have plans to do some exploratory drilling on their own.

The stratigraphy of the area seems fairly simple. The Columbia River Basalt is overlain locally by the Simcoe Volcanics. Occurrence of sediments between the two basalts seems somewhat limited. The interbeds are probably important as aquifers only in the Little White Salmon Valley and in the upper reaches of the White Salmon Valley. There are a great many major structural features and faults known in the area.

Walters, K. L. Test-observation well near Almira, Washington: Description and preliminary results. Tacoma, Washington, U.S. Geological Survey, 1972. 20p. (Open-File Report)

A 750-foot test-observation well drilled near Almira, Washington, is one of several drilled to date (1971) in selected areas of the state. The test wells provide information on ground-water conditions where large-scale pumping from wells is rapidly increasing or is expected to increase, but where data available from existing wells are incomplete and fail to provide adequate guidance for management of the ground-water resources of the area.

The upper 60 feet of the Almira well has a 10-inch casing; below this depth, the well is uncased in basalt. Four major aquifer zones are penetrated by the well. Geophysical logging during drilling provided data on hole diameter, water resistivity (mineralization) and temperature, and natural radiation of the rock units. These data supplemented the driller's log as a basis for final selection of the aquifers to be monitored. Two pumping tests showed that: (1) when the well was 546 feet deep and was pumped at a rate of about 510 gpm for 9.5 hours, the specific capacity was 92 gpm per foot of drawdown; and (2) at the final 750-foot depth, with all 4 aquifers contributing water and the well being pumped at a rate of 525 gpm for 24 hours, the specific capacity was 96 gpm per foot of drawdown. Water from the well when drilled to its final depth of 750 feet is slightly warmer and somewhat more mineralized than when the well was only 546 feet deep.

Four piezometer pipes were installed in the well so that each reflected the head in a specific aquifer zone that is hydraulically isolated from the other aquifer zones by cement seals. The maximum difference in water levels between the uppermost and lowermost aquifers after the zones were isolated was 180 feet; the difference may increase somewhat as the heads in the aquifers continue to adjust after isolation. An access pipe also was provided for an instrument to measure the geothermal gradient.

The data that have been obtained from the test-observation well and that which will be available from it in the future are expected to provide invaluable guidance for management of the ground-water resources.

Walters, K. L., D. R. Cline and J. E. Luzier. Test-observation well near Odessa, Washington--Description and preliminary results. Tacoma, Washington, U.S. Geological Survey, 1971. 25p. Prepared in cooperation with Washington State Department of Ecology. (Open-File Report)

The test-observation well drilled near Odessa, Washington, provides information on the aquifer characteristics of the area which is not otherwise available from existing deep irrigation wells. The information is of value to the Washington State Department of Ecology in its management decisions in this area where heavy ground-water withdrawals have resulted in increasing annual water-level declines.

The 10-inch well is 750 feet deep and penetrates 6 aquifer zones (A through F) in basalt. The upper 60 feet of the well are cased, while the remainder of the hole is open in the basalt. The well was test pumped during drilling and showed specific capacities of: (1) 0.65 gpm per foot of drawdown when at the 258-foot depth and open to aquifers A and B; (2) 0.62 gpm per foot of drawdown when at the 540-foot depth and open to aquifers A through D; and (3) 22 gpm per foot of drawdown when at the full 750-foot depth and open to all 6 aquifers.

To supplement the driller's log of the well, borehole geophysical logging provided information on natural gamma radiation, water temperature and resistivity, down-hole movement (via flow meter) of the water, and borehole diameter (via caliper log). Upon completion of the well, each aquifer zone was isolated from the others by cement seals, and piezometer pipes were installed to each zone to allow definition of the vertical hydraulic gradient and an estimate of the vertical ground-water movement in the area, along with chemical-quality sampling of the various zones and monitoring of any changes in water quality with time. The initial measurements of water levels showed that the levels generally decrease with aquifer depth, with about 200 feet of head difference existing between the uppermost and lowermost aquifer zones. Another pipe, installed for providing thermometer access, permits recording the geothermal gradient with depth in the well, and provides another basis for estimating vertical ground-water movement in the area.

Prior to isolation of the various aquifer zones, the composite water level was recovering from the cessation of pumping at the end of the 1970 irrigation season. On April 6, 1971, this composite water level had begun declining, presumably as a result of pumping of an irrigation well 1 mile to the northwest. By May 6, after the aquifer zones had been isolated and piezometer pipes installed, water levels in aquifers E and F had declined 11 feet in 15 days, in response to pumping for irrigation in the area. Water levels in aquifers B, C, and D declined somewhat, but mostly in response to the draining of these aquifers to deeper aquifers down the many deep-well boreholes in the area.

Walters, K. L. and P. A. Glancy. Reconnaissance of geology and of ground-water occurrence in Whitman County, Washington. Olympia, Washington, Washington State Department of Water Resources, 1969. 169p. Prepared in cooperation with U.S. Geological Survey. (Water-Supply Bulletin No. 26)

Whitman County covers about 2,200 square miles in southeastern Washington, adjacent to the Washington-Idaho boundary. Average annual precipitation in the county ranges from about 14 to 20 inches. Agriculture is the principal industry--chiefly dry-land wheat farming, although some pasture and hay crops are irrigated. Much of the county is underlain by a thick sequence of basalt flows mantled by loess. Locally, older non-basaltic crystalline rocks are exposed, principally in the eastern part of the county.

The crystalline rocks normally contain very little water. Where they are fractured, however, they may contain enough water to meet domestic needs. Elsewhere, deposits of coarse-grained materials weathered from crystalline rocks may yield several hundred gallons per minute to individual wells.

Basalt of the Columbia River Basalt Group is the principal consolidated rock exposed in Whitman County. The Picture Gorge Basalt is exposed in the area south of Uniontown; elsewhere in the county only the Yakima Basalt is exposed. The maximum total thickness of basalt in the county is not known, but probably exceeds 5,000 feet. In this study, only the Roza Member of the Yakima Basalt was differentiated. The yield of large-diameter wells that penetrate several hundred feet of basalt in Whitman County is about 125 to 200 gpm for every 100 feet of saturated basalt penetrated.

Adequate yields of water for domestic and stock supplies are commonly obtained from loess or from the contact between the loess and the underlying basalt. Pleistocene gravel deposits and Recent alluvium characteristically yield little water. Locally, however, yields of several hundred gallons per minute are obtained from wells that penetrate the gravel, or the alluvium in the Snake River Valley.

Hydrographs of wells in the Pullman area indicate a continuing decline in water level. Elsewhere in the county, water levels fluctuate primarily in response to cyclic climatic conditions; they indicate no long-term change in ground-water storage.

The quality of ground water in Whitman County generally is acceptable for domestic, agricultural, and most common industrial purposes.

More ground water is used for irrigation than for any other purpose in the county. All public supplies are obtained from ground-water sources, and these constitute the second largest use. The amount of ground water used in Whitman County during 1963 was about 16,000 acre-feet.

Walters, K. L. and M. J. Grolier. Geology and ground-water resources of the Columbia Basin Irrigation Project area, Washington. Vol. 1. Olympia, Washington, Washington State Division of Water Resources, 1960. 542p. (Water-Supply Bulletin No. 8)

The investigation in which the data presented here were collected covers an area of about 3,900 square miles of the semiarid Columbia River Plateau of central Washington, including parts of Grant, Franklin, and Adams counties. The area includes lands being developed or considered for development under the U.S. Bureau of Reclamation's Columbia Basin Irrigation Project, plus an additional 200 square miles northwest of Ephrata which is hydrologically related to, but not a part of, the reclamation project. The area lies north and east of the Columbia River in the reach from Trinidad to the confluence with the Snake River near Pasco.

The basalt bedrock and coarse-grained sedimentary deposits in the sub-basins constitute the important sources of ground water in the area. The basalt ridges that separate the subbasins also are important to the occurrence of ground water, in that they may act as ground-water barriers retarding the movement of ground water from one subbasin to the other.

This report represents the first phase of a program designed to: (1) determine the availability and suitability of ground water for municipal supply, farm use, and industry within the Columbia Basin Irrigation Project; (2) delineate areas that might eventually become waterlogged as a result of irrigation; (3) interpret chemical quality and chemical changes of ground water, if any; and (4) evaluate the possibility of pumping ground water for irrigation and/or drainage purposes.

Volume I contains factual data for hundreds of wells drilled within the project boundary and a brief summary of water level changes that have occurred as a result of project irrigation. It is not designed to delineate problem areas or recommend a remedial program, but will serve as a valuable reference for farmers, irrigation districts, and other agencies actively engaged with the problems associated with the rising water table.

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