

Summary of Research Completed on the Moscow-Pullman Basin Hydrology

March 1999

**Compiled by,
Bill Belknap, University of Idaho**

This work represents an ongoing effort to compile and summarize research efforts past, present and future on the Pullman-Moscow Basin hydrology and water resources.

1. Baines, Clifford A., 1992, Determination of Sustained Yield For The Shallow Basalt Aquifer In The Moscow Area, Idaho. University of Idaho, M.S. thesis, 60 p.

Using pumping data from the University of Idaho and City of Moscow wells completed in the Wanapum Formation aquifer and drawdown measurements in a U.S.G.S. observation well, Baines calculates a sustainable yield for the shallow system of the Moscow Basin. Employing both the Hill method and the zero water level change method, Baines calculates a sustained yield of 500-520 million gallons per year for the Wanapum formation. Other observations include:

1. Much of the increased pumpage during the 1950's was balanced by reduced downward leakage to the Grande Ronde Formation.
2. The estimated sustained yield of 500 million gallons per year is probably 50 to 70 million gallons less than annual recharge assuming a 5-mile radius of influence.
3. Variable pumping rates result in variable estimates for sustained yield with higher pumpage resulting in higher yield values and vice versa.

2. Barker, R. A., 1979, Computer Simulation and Geohydrology of a Basalt Aquifer System in the Pullman-Moscow Basin, Washington and Idaho. Washington Department of Ecology Water Supply Bulletin 48, 119 p.

Barker constructs a geologic foundation for mathematical ground water modeling using well log data, potentiometric surface data and geophysical investigations. This data was then used to simulate ground water flow in the deeper primary system only. An attempt was made to delineate the observed ground water boundary in the southwestern portion of the basin near Union Flat Creek using geophysical techniques but the results were nonconclusive. It is suspected that a crystalline basement rock topographic high feature exists near Union Flat Creek, possibly as a result of western subsidence resulting in a hinge point feature with faulting or dike swarms. The resulting ground water flow direction is in a northwesterly direction out of the Pullman-Moscow Basin. A computer model was constructed using computer code written by Pinder (1971) using iterative, alternating-direction implicit procedure to solve finite-difference approximations of the nonlinear, partial differentiation equations describing two-dimensional ground-water flow.

Computer model results indicated that continued water level declines would occur if current pumpage rates were maintained or increased. A maximum of 55 feet of additional decline was projected if pumpage rates were nearly tripled during 1976-1999. The model also indicated that the rate of water-level decline would be reduced to less than 0.2 feet per year if pumping rates were stabilized near present-day averages of 6,600 acre-feet/yr.

3. Bockius, Samuel H., 1985, Geophysical Mapping of the Extent of Basaltic Rocks in the Moscow Groundwater Basin, Latah County, Idaho. University of Idaho, M.S. Thesis, 83 p.

Using magnetometer readings along twenty-seven line segments crossing the estimated contact zone between the crystalline basement rocks and the Miocene basalt flows, Bockius geophysically maps the contact. Bockius finds that there is adequate contrast between the crystalline rock and the basalts to allow detection between geologic units and that magneometric surveys are an economical and accurate method of geophysical detection in the Moscow Basin and other sites that are similar.

4. Brown, Paul A., 1998, Spore, Microsphere, and Encapsulated Sphere Transport in a Heterogenous Aquifer. University of Idaho, M.S. Thesis 137 p.

By conducting slug tests, multiple well pump test and multiple tracer tests using spores, mirospheres and bromide, Brown characterizes flow in the shallow alluvial aquifer system at the University of Idaho Plant Science Site. Brown found that hydraulic conductivity varied between wells by up to an order of magnitude. He also concluded that preferential flow paths and porosity exclusion effects controlled tracer migrations in addition to vertical and lateral heterogeneities of the geologic material. Spore transport characteristics most closely represented the conservative behavior of the bromide tracer. Also determined was that replicate tracer test were not ideally reproduced showing potential biofouling or other aquifer alterations between tests.

5. Brown, William G., 1991, Sensitivity Analysis of a Numerical Model of Ground Water Flow in the Pullman-Moscow Area. University of Idaho, M.S. Thesis, 93 p.

Brown completes a sensitivity analysis on the numerical ground water model created by Lum and others (1990) to determine the response to changes in recharge, discharge and boundary parameters. Brown finds that maximum responses of three to four feet of additional drawdown after twenty years of pumping (1% annual increase) were observed in the model when recharge and or seepage were doubled or halved. This shows very small responses to very large modifications to the model inputs and may represent deficiencies in the current model. Larger responses, two to six feet of additional drawdown after twenty years (1% annual increase) were observed when constant head boundaries were changed to constant flux boundaries. Brown concludes that a more complex model may be necessary to accurately represent the basin flow system. Modifications should include using head dependent drains for Snake River Canyon seepage, a multi-layer representation of the Grande Ronde formation and modification of the no-flow boundary with respect to the Palouse River since flow beneath the river probably occurs within the Grande Ronde Formation.

6. Bush, John, The Geologic History of Moscow and a Model for Moscow's Ground Water Recharge.

Using non-referenced data Bush creates a theoretical conceptual model to describe the hydrogeologic setting of the Moscow basin. Bush postulates that much of the current groundwater resources in the deeper Grande Ronde basalts may have been introduced during the Miocene basalt flow events that repeatedly dammed streams and drainages creating large lakes and flood events. These fluvial events now eliminated by city flood control and prevention measures cause rapid water runoff preventing much deep percolation from occurring. Bush believes current recharge introduction must be occurring along basalt-crystalline basement interface zones where sufficiently permeable sediments are present allowing recharge to reach the upper Wanapum aquifer, with much lesser amounts reaching the deeper Grande Ronde formation.

7. Crosby, James W., Chatters, Roy M., 1965, Water Dating Techniques as Applied to the Pullman-Moscow Ground-Water Basin. Washington State University College of Engineering Bulletin no. 296, 21 p.

Using carbon-14 dating techniques, Crosby and Chatters age date the waters of the shallow aquifer in attempt to determine the amount of recharge occurring to the shallow Wanapum system. Results indicate that only limited recharge is occurring on the Pullman side of the Basin with non-detectable recharge on the Moscow side. This may be attributable to infiltration of the Latah Sands on the eastern side of the basin with water being carried out of the Moscow area as lateral flow within these formations. It appears that we are pumping the shallow system at rates that far exceed current recharge. Crosby recommends that future municipal drilling be directed to the deeper system which is expected to contain greater reserves than the shallow system.

8. Crosby, J.W., Cavin, R.E., 1960, Geologic Investigation of the Moscow Ground Water Basin Employing Geophysical Studies. Washington State Institute of Technology Bulletin 250

Using seismic reflection and well log data, Crosby and others work to prepare a preliminary delineation of the crystalline basement topography in order to create a better understanding of the hydrogeologic system present in the basin. They find that in many sites absent of thick loess coverage, seismic reflection is an accurate and applicable tool in geophysical investigations in basaltic environments. Crosby found that a paleo topographical surface does exist within the basin with deeply entrenched drainage patterns. Crosby concludes that further research should be conducted to improve techniques for using seismic reflection in basaltic settings and towards reducing the economic costs of the technique.

9. Duncan, Chris H., 1998, Geology of Potlatch and Palouse 71/2 Minute Quadrangles, Idaho and Washington. University of Idaho M.S. Thesis, 58p.

Using area well logs, surface investigations and previous research, Duncan creates 71/2-minute geologic bedrock maps of two quadrangles that boarder the Moscow basin to the North and Northwest. He describes the subsurface geology using a series of cross-sections, structural contours and isopatch maps providing a geologic basis from which to investigate the area hydrology. Isopatch maps of the Priest Rapids member of the Wanapum basalts show an average thickness of 180 feet with thinning of the unit towards the basin margins. Also shown on structural contour maps is the lowering of the base of the Priest Rapids member to the west near the city of Potlatch, suggesting a structural high near the Viola Ridge. The Latah Formation sediments occur between the Grande Ronde and Priest Rapids units and appear to be continuous laterally east to west through the Palouse River basin with fluvial stream depositions in the Palouse area and mixed fluvial and lacustrine deposits near Potlatch. Holocene alluvium patterns suggest the inflowing basalts controlled sedimentation and streams have yet to equilibrate.

10. Duncan, David C., 1998, A Hydrogeologic Characterization and Modeling of The Shallow Alluvial Aquifer at The Plant Science Farm University of Idaho, Moscow Idaho. University of Idaho M.S. Thesis

Using a combination of slug and multiple-well pump tests and geologic data from multiple well logs, Duncan characterizes the Dinoseb-contaminated shallow alluvial ground-water system present at the University of Idaho Plant Science Farm. Using this data, Duncan then constructs a three-dimensional ground-water model of the system and plume movement. Insitu remediation of the Dinoseb contamination is also briefly evaluated. The data shows that a ground-water plume approximately 80 by 160 feet exists at the site and that average values for transmissivity and storativity were calculated to be $0.15 \text{ ft}^2/\text{min}$ and 0.0015 respectively. It appears retardation effects are limiting plume migration and currently presents no danger to human health. It is anticipated that retardation factors and natural attenuation will likely result in plume stabilization on site.

11. Foxworthy, B.L., Washburn, R.L., 1962, Groundwater in The Pullman Area Whitman County, Washington. Geologic Survey Water-Supply paper 1655, United States Government Printing Office, 1962

This was one of the early ground-water surveys in the Pullman area of Whitman County providing a preliminary delineation of the basin hydrogeology. It was initially thought that the communities of Moscow and Pullman were drawing from two separate systems with a common ground-water boundary between the two. At this time Pullman city wells had only recently been completed into the deeper Grande Ronde basalt unit and it was noted to have only a weak connection with the shallower Wanapum basalts with almost the same piezometric surface elevation. It was also estimated that at this time pumpage exceeded recharge by about 85 million gallons per year. Water levels at this time were showing a constant head decline of about 1-2 feet per year. Artificial recharge potentials

were investigated and potential source waters were located. Direct recharge by well injection was determined to be the most feasible option. An assessment of several local streams for water quality compatibility and sediment load content showed that water chemistry was believed to be compatible but settlement ponds or filtering would be required to prevent well plugging. An alternating scenario of injection and pumpage was recommended to minimize loss of well efficiency and maintenance costs.

12. Hawthorn, W. E., Barber, M. E. 1994, Hydrogeologic Boundary Assessment for the Pullman-Moscow Basin. Clearwater Consultants, Ltd. Project Completion Report

Using the model created by Lum and others (1990) Hawthorn and Barber examine the boundary conditions thought to exist in the Pullman-Moscow basin and complete an assessment and modification to the Lum model in attempt to increase it's accuracy. In particular they examine the presence of the preconceived barrier condition thought to exist in the area of Union Flat Creek. By incorporating such a boundary into the Lum model Hawthorn and Barber are able to explain many of the unique hydrologic behaviors observed in the area. Hawthorn and Barber conclude that if pumpage rates are stabilized, the Pullman-Moscow area should have adequate water resources for the future.

13. Heineman, Ronald, 1994, The Relationship between Streams and Ground-Water Flow Systems within the Pullman-Moscow Area of Washington and Idaho: University of Idaho, M.S. thesis, 58 p.

Employing well log and water level data, stream temperature and flow measurements and regional geologic structure information, Heineman describes the relationship between regional ground-water flow and the area's six major stream systems. Heineman concludes as follows:

1. Streams flow primarily on the Wanapum Formation
2. The upper reaches of the North Fork of the Palouse River and the central portion of Union Flat Creek receive significant ground-water discharge from Wanapum formation aquifers while Four Mile and Paradise Creeks receive lesser amounts of discharge.
3. The identified areas of discharge correlate to stream down-cutting through sedimentary deposits located along the eastern terminus of the Rosa member of the Wanapum formation.
4. Ground-water loss due to seepage along the Snake River Canyon walls is believed to be less due to a perceived northwest flow within the Grande Ronde Formation away from the river.
5. A geologic structure within the Grande Ronde Formation such as a buried syncline is thought to control ground-water flow in the Wilcox area creating ground-water discharge to occur west of Wilcox.

14. Hemud, Abdulm R., 1971, Geophysical Investigations of the Moscow Landfill Site,. Latah County, Idaho. University of Idaho, M.S. Thesis 59 p.

Hemud uses electrical sensitivity geophysics to determine the extent of contamination in the shallow aquifer and the extent of the crystalline rock contact below the site. Hemud was able to detect a small contaminant plume following the largest hydrologic drainage south of the landfill site and the crystalline basement depth. Site contamination appeared minimal and migration potential also appeared limited.

15. Johnson, Gary S., Bloomsburg, George, Ralston, Dale R., 1996, Evaluation and Modification of The Pullman-Moscow Ground-Water Flow Model. University of Idaho, Idaho Water Resource Research Institute Report, 41 p.

Johnson and others evaluated the previous mathematical model of the ground-water flow system of the Pullman-Moscow basin presented by Smoot (1987) and Lum (1990) to determine the reliability and accuracy of several assumptions and variables used in the model. The model was also converted from a mainframe system to a more convenient and economical personal computer based MODFLOW-EM program format. Following is a list of the variables evaluated:

1. Previous models treated the Grande Ronde Formation as a single stratigraphic unit due to difficulties in distinguishing different geologic boundaries. Johns and others divide the Grande Ronde formation into three units based upon magnetic orientation within the flows. The three units consist of up to 10 individual basalt flows each and vary from 500-900 feet in thickness. The result is a five layered model instead of the previous three layer model
2. Snake River Canyon wall seepage is also modified. Previous models had difficulties in treating the seepage as head-dependent and instead used a constant flux representation. By dividing the Grande Ronde into separate layers Johnson and others were able to establish head-dependent drains within the model.
3. The actual quantity of water lost due to seepage at the Snake River Canyon is unknown so reduced seepage values were evaluated with widely varying unrealistic results. This indicates that other parameters of the aquifer may be not well understood including the possibility of a low permeability material between the canyon and the cities.

Johnson and others conclude that increasing the complexity of the model does not necessarily increase the accuracy and reliability of the model and future efforts should be directed at gaining a better understanding of the actual system including:

1. The vertical conductivity between the Grande Ronde and Wanapum basalts.
2. The connection between Grande Ronde and surface water systems.
3. Transmissivity and storativity of the Grande Ronde.
4. Recharge and discharge systems and lateral boundaries of the aquifer.

16. Jones, R.W., Ross, S.H., Detailed Ground Water Investigation of Moscow Basin. Water Resources Research Institute Technical Completion Report, June 1969.

Using data from over 230 wells in the area, believed to be 80% of those present at the time of the study, Jones and Ross attempt to characterize the basin. Operating under the assumption of no recharge occurrence Jones and Ross create a mathematical model of the basin and predicate that water resources will be adequate for about 100 years. Values of transmissivity of 1.0×10^{-6} to 4.0×10^{-7} gallons per day per foot and values for storativity of 1.0×10^{-3} . These values are unusually high but necessary to match modeled values to those observed in the field assuming a no recharge system.

17. Kaal, Ayad S., 1978, Analysis of Hydrogeologic Factors for the Location of Water Wells in the Granitic Environment of Moscow Mountain, Latah County, Idaho. University of Idaho, M.S. Thesis 76 p.

Kaal characterizes the granitic Moscow Mountain area to describe the varying water producing rates of wells completed in this area and to provide a guide for the sighting of future wells using aerial photographs, well surveys and tests and geologic research. Kaal finds that fracture patterns and degree of weathering dominantly control the productivity of wells in this granitic environment. Aerial delineation of fracture lines and patterns are difficult to detect due to thick overlayers, abundant vegetation coverage and irregular fracture patterns. Kaal finds a very low well-yield potential, transmissivity and decreasing water production with depth. A high percentage of precipitation is lost to run-off due to topography and low permeability of surface materials.

18. Kopp, William Paul, 1994, Hydrogeology of The Upper Aquifer of The Pullman-Moscow Basin at The University of Idaho Aquaculture Site. University of Idaho, M.S. thesis, 192 p.

Kopp studied the upper Wanapum basalt formation and the underlying sediment deposits for development as a source of water for the University of Idaho's Aquaculture Research Laboratory site. The first Aquaculture well was screened within two specific fracture intervals in the basalt, but failed to produce the 150 gallons/min that the Laboratory required. Two additional wells were installed and completed within the underlying sediments to fulfill the lab's water needs. Two distinct unconsolidated sand bodies were found to exist in the upper 100 feet of the sediment deposit and were found to be hydraulically connected to the W Fracture at the University of Idaho Groundwater Research Site. Kopp calculated a long-term maximum yield of 240 gallons per minute for a well completed in the lower sand unit and 450 gallons per minute for the well completed within both sand units.

19. Larson, Kathryn R., 1997, Stable Isotopes in the Pullman-Moscow Basin, Eastern Washington and North Idaho: Implications for the Timing, Magnitude and Distribution of Groundwater Recharge. Washington State University, M.S. Thesis 85 p.

Larson uses stable oxygen isotopes to age-date the water resources in the shallower Wanapum formation and the deeper Grande Ronde formation of the Pullman-Moscow basin. Using Oxygen isotope ratios to determine the environmental conditions of deposition of water within the basalt aquifers, Larson is able to determine the relative age of the water deposition and the stratigraphic age layering present within the basin. This information is very helpful in determining the recharge processes present in basin and in considerations of long-term water resource use and conservation. Results of the study indicate the deeper Grande Ronde groundwater was recharged under much cooler climate conditions during the Pleistocene. The Wanapum formation and shallow Grande Ronde formations indicate deposition within the Holocene indicating much more recent recharge. Mixing between the two systems appears to be limited with the connection or flow pathways between the two systems unknown.

20. Li, Tong. 1991, Hydrogeologic Characterization of a Multiple Aquifer Fractured Basalt System. University of Idaho, PhD. Thesis, 307 p.

Using borehole geophysics, slug test, multiple-well pump tests and surface water and well hydrographs, Li characterizes the hydrology of the University of Idaho Groundwater Research Site. Using the previously mentioned methods Li describes the relationship between two distinct fracture systems at the Groundwater Research Site and their connection to the nearby Paradise Creek and shallow alluvial system.

21. Lin, Cang-Lu, 1967, Factors Affecting Ground-Water Recharge in The Moscow Basin, Latah County, Idaho. Washington State University, M.S. thesis, 86 p.

Lin postulates the presence of paleo-stream channels incised into the crystalline basement rock underlying the Moscow area. These paleo-stream channels were infilled by the subsequent Columbia River Basalt flows with sediment interbeds being deposited between flows as stream systems were dammed by the different events. Many of these basalt flows never achieved a complete contact to the topographic high crystalline bodies, allowing a sediment connection between the interbedded sediments and land surface near the basalt-basement boundary.

Through well log data, shallow basalt aquifer piezometric surface data and geologic mapping information, Lin maps these channels. Lin concludes that precipitation event percolation through these avenues constitutes the majority of recharge to the basin with smaller contributions coming from localized stream loss and infiltration through the Palouse Loess Formation. Lin also conducts a tracer dilution test on several reaches of Crumarine Creek and determined that stream-loss was occurring to an undefined extent.

22. Lockwood, Paul Jr., 1996, Analysis of Downhole Dissolved Oxygen Measurements in Shallow Aquifers Near Moscow, Idaho. University of Idaho, M.S. thesis, 125p.

Using a YSI model 50 dissolved oxygen and temperature meter, Lockwood measured down-hole dissolved oxygen levels of various wells upon University of Idaho property. Using clean and contaminated waters to evaluate the effectiveness of down-hole dissolved oxygen data as an indicator of subsurface conditions. Lockwood found that dissolved oxygen contents were useful indicators in deeper sedimentary aquifer systems. The technique is somewhat less effective in basaltic systems possibly due to chemical reactions involving iron and sulfide phases present in the basalt.

23. Lum, W.E., Smoot, J. L., Ralston, D.R., 1990 Geohydrology and Numerical Analysis of Ground-Water Flow in the Pullman-Moscow Area, Washington and Idaho. U.S. Geological Survey Water-Resources Investigations Report 89-4103, 73 p.

Using water level measurements, pumpage rates and geologic data on the Pullman-Moscow basin, Lum and others construct a three-dimensional groundwater flow model of the aquifer. The completed model is then compared to the previous Barker (1979) model and checked for historic water-level accuracy. The model created by Lum and others differs from that of Barker in several respects, but both show fairly accurate representations of water-levels for the 1896-1975 period but differ greatly in projected water-level declines for beyond 1975.

Barker's model predicted water-level declines of up to 40 feet by the year 2000 at a 3% annual increase in pumpage, while Lum's model predicts drawdown as high as 96 feet for the same time period. The three major differences between models are the annual amount of recharge assumed to reach the Grande Ronde, the source from which the pumped water originates and the size of the area modeled. In the Barker study the annual recharge to the Grande Ronde is calculated at 0.67 inches/yr while the Lum model calculates 2 inches/yr. In the Barker model recharge was modeled as a head-dependent "leakage" while the Lum treats it as a constant flux. Also in the Barker study 90% of pumped water was assumed to be from storage while the Lum study calculates that 9-15% will come from storage. Finally, the aerial size of the modeled area is much larger in the Lum model compared to the Barker model.

24. Nimmer, Robin E., 1998, Ground Water Tracer Tests in Columbia River Basalt. University of Idaho, M.S. Thesis 148 p.

Using bromide, veratryl alcohol, fluorescein, spores and microbeads, Nimmer examines the effectiveness of various types of tracers in a basaltic environment. Bromide, veratryl alcohol and fluorescein appear to act as conservative tracers and show satisfactory results for use in such environments. Of the spores and microbeads injected 99.999% were never recovered showing poor applicability in fractured basalts. Microbeads are thought

to have been lost as a result of filtration and density effects while the spores also suffered from sorption and predation. Curve matching results were unsatisfactory and probably resulted from the heterogeneous and anisotropic nature of the fractured rock.

25. O'Brien, R., Keller, C.K., Smith J.L., Multiple Tracers of Shallow Groundwater Flow and Recharge in Hilly Loess. Ground water vol. 34, no. 4, July-August 1996

Using three environmental tracers, chloride, nitrate and tritium, O'Brien and others estimate yearly recharge flux and velocity through the Palouse Formation Loess deposits that blanket the Pullman-Moscow basin. Analyzing these three tracers through various slope positions and depths, O'Brien and others calculate a yearly recharge average of 1.76 cm with an average recharge velocity of 4.3 cm/yr. The greatest recharge amounts and velocities were observed in the mid-slope positions with values of 3 cm and 8 cm/yr respectively. These values are of particular interest due to the fact that the averages of this study are 2-10 times smaller than previous estimates.

26. Pardo, Begona Garcia, 1993, Relationship Between Groundwater and Surface Water at The University of Idaho Groundwater Research Site. University of Idaho, M.S. thesis, 127 p.

Pardo compiled several years of hydrograph data of the wells present at the University of Idaho Groundwater Research Site and Paradise Creek that flows closely by the site. There are two distinct fracture systems within the Wanapum Formation that several of the wells are completed within at the research site, the E fracture and the W fracture. In addition several shallow alluvium wells are present throughout the site. Hydrograph data show very close correlation between stream levels, precipitation events and the shallow and E fracture wells. There appears to be a close relationship between the Creek and the E fracture with a possible variable recharge-discharge relationship between the two. The wells completed in the W fracture appear to have a weak connection to the E fracture and smaller responses to precipitation events and stream flows. It appears there is another recharge source associated with the W fracture that is not well understood.

27. Petrich, Christian R., 1995, Microsphere and Encapsulated Cell Transport in a Heterogeneous Subsurface Environment. University of Idaho, PhD. Thesis 260 p.

Using bromide, Polystyrene microspheres and argose-encapsulated cells, Petrich studies the hydraulic transport properties of preferential flow paths in the shallow alluvial aquifer at the University of Idaho Plant Science Site through multiple tracer tests. Petrich found the initial arrival times for the bromide and the polystyrene microspheres were generally similar with the bromide peak concentrations occurring after those of the microspheres. The peak of the microspheres represents the high conductivity paths while the peak in the bromide concentration represents a composite of both high and low conductivity paths. The low conductivity paths represent the largest total percentage of aquifer thickness at

the site. Argose-encapsulated cell transport showed significant retardation suggesting interaction with aquifer materials and/or particle filtration. A combination approach to tracer studies proved to be a valuable tool in characterization of preferential flow paths and the aquifer in general.

28. Pierce, Jack L., 1998, Geology and Hydrology of the Moscow East and Robinson Lake Quadrangles, Latah County, Idaho. University of Idaho, M.S. Thesis 60 p.

Through field studies and well Log data, Pierce describes the composition and distribution of geologic units and water levels of the Moscow East and Robinson Lake quadrangles. Pierce finds that the sediments of Bovill of the Latah Formation contain various lithologic and depositional characteristics that are distinguishable from the Palouse loess. The hydraulic properties of the sediments of Bovill are different enough from those of the loess that they should be treated as a separate hydrologic unit. The sediments of Bovill in the Moscow area are commonly characterized by unconsolidated coarse sand and gravel in stream valleys, and topographic high clay deposits. It is likely that the sediments of Bovill play an important role in recharge to the basin along its eastern extent where they overlay major paleo-channels. Pierce also notes that rapid recharge may be occurring in the eastern fringe of the basin since wells in that area completed within the Priest Rapids Member of the Wanapum Formation show significant fluctuations in water levels.

29. Provant, Andrew P, 1995, Geology and Hydrogeology of the Viola and Moscow West Quadrangles, Latah County, Idaho and Whitman County, Washington. University of Idaho, M.S. thesis, 116 p.

Using well log data, water level measurements, visual geologic outcrop surveys and previous geologic research, Provant creates a detailed local geologic map to provide a better understanding of the shallow aquifer, Wanapum Formation, recharge, discharge and ground water flow present within that system. A primary focus for this work is the Latah and Bovill sediment formations and how they influence recharge and ground water movement along with a better determination of the crystalline bedrock boundary.

Provant's findings are as follows:

1. The sediments of Bovill should be considered as a distinct unit separate from the Palouse loess due to their very different hydraulic conductivities.
2. Investigations into a cross-sectional view of the geology below Moscow reveal potential paleo-stream channels of faulted sections of basalt that could influence ground-water movement. Also the basalt gradients between Moscow and Pullman show less than 0.1 degrees of slope.
3. Water levels in wells of the eastern portion of the basin show significant seasonal water-level change while those toward the west show little response.
4. Recharge is believed to be dominated by infiltration through the Palouse loess and Bovill sediments in valleys where overlay of the basalt is thin with lesser contributions through stream loss and basin margin infiltration.

5. Only about 3% of the valley's margins are believed to have the conditions to allow surface recharge to occur.

30. Ralston, Dale R., Smoot, John L., 1989, Ground Water in the Moscow Pullman Area: A Water Resource for the Future? Idaho Water Resources Research Institute

Reviewing the results of the Smoot (1987) Pullman-Moscow Basin model and other research conducted regarding the basin water resources, Ralston and Smoot state steps needed to ensure the continued existence of abundant ground-water resources. These include limiting increased pumpage rates, increased conservation measures, recharge enhancement, use of treated waste water and use of water from the Wanapum Basalts when possible. The conclusion of the model was that at pumpage rates of up to double 1985 levels the water levels should after a short period stabilize. Continually increasing pumpage would result in continual drawdown of the aquifer to an undetermined extent.

31. Ralston, Dale R., 1972 Guide for Location of Water Wells in Latah County. Idaho Bureau of Mines and Geology Information Circular 23, 14p.

Ralston provides an overall geological sketch of Latah County to provide information regarding the placement of water wells in the area. Ralston sub-divides the County into five sub-areas to address the water resources characteristics of those specific areas to aid in well placement and design.

32. Ralston, Dale R. 1982, Well no. 9 Construction Report City of Moscow, Idaho

Ralston served as advisor to the site selection, construction and completion of Moscow City Well no. 9 and documented the process in this report. Valuable information regarding the geology at the selected site and the hydrologic properties of the completed well is recorded as well as the construction process history. This well was intended to, and did, fully penetrate the basalt sequences within the Moscow Basin to a depth of over 1,200 feet. Several pump tests were conducted with response being monitored in several nearby wells owned by the city and the University of Idaho. Transmissivity values for the aquifer are estimated to be 2.2×10^{-6} gpd/ft with storativity values estimated to be $1.9-2.5 \times 10^{-4}$. Well yield was calculated to be 115 gpm per foot of drawdown after 24 hours of pumping with pumping tests being conducted at 2,800 gpm resulting in 24.5 feet of drawdown after 1 day.

33. Ross, Sylvia Y.H., 1965, Contributions to the Geohydrology of Moscow Basin, Latah County, Idaho. University of Idaho, M.S. Thesis 108 p.

Ross completed this early study in response to growing concerns over water resource issues of water availability and quality. Using water-level measurements, water chemistry studies and local geology, Ross constructs an initial framework sketch of the Moscow Basin geology and water resources.

34. Seitz, Harold R., 1971, The Effect of a Landfill on a Hydrogeologic Environment. University of Idaho, M.S. Thesis, 90 p.

Using water samples obtained around the historic Moscow Landfill site, Seitz analyzed for hardness, ammonia, nitrates, chemical oxygen demand, tannin and lignin, conductivity, iron, alkalinity, chlorides and pH. Seitz found that groundwater in direct contact with landfill leachate became grossly polluted but that area conditions controlled contaminant migration and maintained contaminant levels below critical levels due to low permeability, high filtering capacity, high cation exchange capacities and soil bacterial processes.

35. Smoot, John Leach, 1987, Hydrogeology and Mathematical Model of Ground-Water Flow in The Pullman-Moscow Region, Washington and Idaho. University of Idaho, M.S. thesis, 118 p.

Smoot uses a three-dimensional groundwater model in conjunction with the U.S.G.S. to model the groundwater system of the Pullman-Moscow basin. Using a accompanying Magnetotelluric study to define the crystalline basement-basalt contact throughout the basin, observed well head values, stream flow rates and calculated recharge based upon aerial precipitation infiltration through the loess, Wanapum and Grande Ronde formations Smoot comes to the following conclusions:

1. Basalt thickness ranges from 1,300 feet in Moscow and 2,000 feet in Pullman to over 3,000 feet northwest of Pullman.
2. Results of recharge modeling suggest an average rate of 3.6 inches annually with only 1.9 inches reaching the Wanapum formation and 0.9 inches reaching the Grande Ronde Formation.
3. Most discharge from the basin is assumed to be in varying stream base flow and seepage along the Snake River Canyon Walls.
4. Computer models show that at constant pumpage rates of up to 200% of 1985 value of 7,600 acre-feet/year result in stabilizing water levels within 10-15 years. While increasing rates varying from 1%-2% annually result in continual decreasing water levels of 1-3 feet annually with no stabilization. Modeled increasing pumpage of 3% annually depicted water level decreases of up to 30-40 feet per decade.
5. Values used in the model are as follows:
 - a. Horizontal hydraulic conductivity = 0.6-15.0 feet/day varying upon location
 - b. Vertical hydraulic conductivity = 0.0001-0.0075 feet/day varying upon location
 - c. Storativity = 0.0001

Smoot concludes that continued data collection to improve model parameters including better definition of recharge and discharge locations and quantities is needed to improve the model accuracy.

36. Sokol, Daniel, 1968, Interpretation of Short Term Water Level Fluctuations in the Moscow Basin Latah County, Idaho. Idaho Bureau of Mines and Geology pamphlet 137.

Continuous water level recorders were installed in deep wells not in use during November 1963 and May 1965 to detect and attempt to analyze water level fluctuation data. Water level measurements were also obtained from the City of Moscow from the city's water supply pumping wells. It was found that the upper basalt aquifer is very weakly connected to the lower aquifer with seasonal responses present within the upper aquifer and limited response within the lower.

37. U.S. Geological Survey, 1996, Nitrate Concentrations in Ground Water of the Central Columbia Plateau. Open-file Report 95-445.

Sampling 573 wells located in the Central Columbia Plateau, including 30 on the Palouse, the U.S.G.S. conducts a survey of nitrate levels present in the Columbia Plateau ground water. Results indicate that land practices are the dominant influence over the distribution and concentration of nitrate in ground water. The Palouse subunit concentration results show that 6% of wells sampled exceed the MCL of 10 mg/L, 29% show concentrations between 3.1-9.9 mg/L, 19% contain concentrations between 1.1-3.0 mg/L and 46% between 0-1.0 mg/L.

38. U.S. Geological Survey, 1996, Are Agricultural Pesticides in Surface Waters of the Central Columbia Plateau? Fact Sheet 241-95.

Sampling several major surface water drainages for agricultural pesticides, the U.S.G.S. detected 45 out of the 85 compounds selected for analysis. While no detections exceeded the drinking water MCLs, several exceeded freshwater-chronic criteria for protection of aquatic life. The Palouse River near Hooper showed Diazinon and Triallate contamination above the aquatic life protection threshold.

39. U.S. Geologic Survey, 1996, Organochlorine Pesticides and PCBs in Aquatic Ecosystems of the Central Columbia Plateau. Fact Sheet 170-96.

Sampling both sediments and fish, the U.S.G.S. surveyed the Columbia Plateau for the presence of organochlorides and PCBs. In the Palouse River Basin PCBs were detected in fish and sediments at urban sites near Pullman and Moscow showing a residual effect from historical use. While hexachlorobenzene was detected in dryland farm areas. The report states that the most effective technique to prevent contaminant transport is erosion prevention.

40. U.S. Geological Survey, 1996, Pesticides and Volatile Organic Compounds in Ground and Surface Water of the Palouse Subunit, Washington and Idaho. Fact Sheet 204-96.

Analyzing both surface water and ground water samples for pesticides and organic compounds, the USGS characterizes water quality of the Palouse subunit. Six pesticides, one breakdown product and five VOCs were detected in samples from ground water. While 29 pesticides or their breakdown products were detected in surface-water samples. Pesticides or VOCs were detected in 25 percent of ground water samples and pesticides were detected in 97 percent of surface-water samples. While the detection rate was high no concentrations within water supply wells exceeded drinking-water standards.

41. U.S. Geological Survey, 1996, Pesticides in Public Supply Wells of the Central Columbia Plateau. Fact Sheet 205-96.

The USGS conducted a wide spread sampling of public water supply wells for the presence of pesticides in drinking water. Results show that 66% of all wells sampled had more than one pesticide detected. Shallow wells had the highest rate of detections and elevated nitrate levels. There were over nine pesticide detections in the Palouse area, with none exceeding the drinking-water standards.

42. Williams, Roy E., Allman, David W., Factors Effecting Infiltration and Recharge In a Loess Covered Basin. Journal of Hydrology, no. 8 1969 p.265-281

Williams and Allman studied loess infiltration by monitoring a series of shallow piezometers, precipitation records and local stream hydrographs. They found that there exists a shallow groundwater flow system within the loess. Water levels and precipitation event responses within the loess system mirrors that of the local streams. There also appears to be a flow gradient from these shallow loess systems to the streams. A large factor in determining the rate at which the precipitation infiltrates is the presence of deeply penetrating, over 30 feet, tubular openings of unknown origin. These bioturbations increased the long-term infiltration rates from only 1-1.5 inches per hour to over 4-5 inches per hour. Also studied was the effect of crop cultivation upon infiltration rates. It was found that grasses had the highest infiltration capacity with cultivated soils possessing the least. These finely cultivated soils posed a significant barrier to infiltration of the upper most depth within the loess and even when these cultivated soils overlie loess formations containing no tubular openings the cultivated soils still present the limiting factor.

43. Winter, Gerry, George, Dekan, Moscow Basin Ground Water Quality Study North Central Idaho. Ground water Quality Technical Report no. 7, Idaho DEQ, 1995

The investigation into the water quality of the Moscow Pullman Basin collected samples from 28 different wells of different depths throughout the basin. The samples were analyzed for common anions and common pesticides used within the basin. The study concluded the following:

1. Background nitrate concentrations of the basin were determined to be

0.005 mg/L.

2. No contamination as a result of routine use of pesticides was found, but elevated levels of nitrates were detected in relatively few shallow alluvium based wells.

3. Elevated nitrate levels resulted possibly from fertilizer use, septic system discharges and livestock activities.