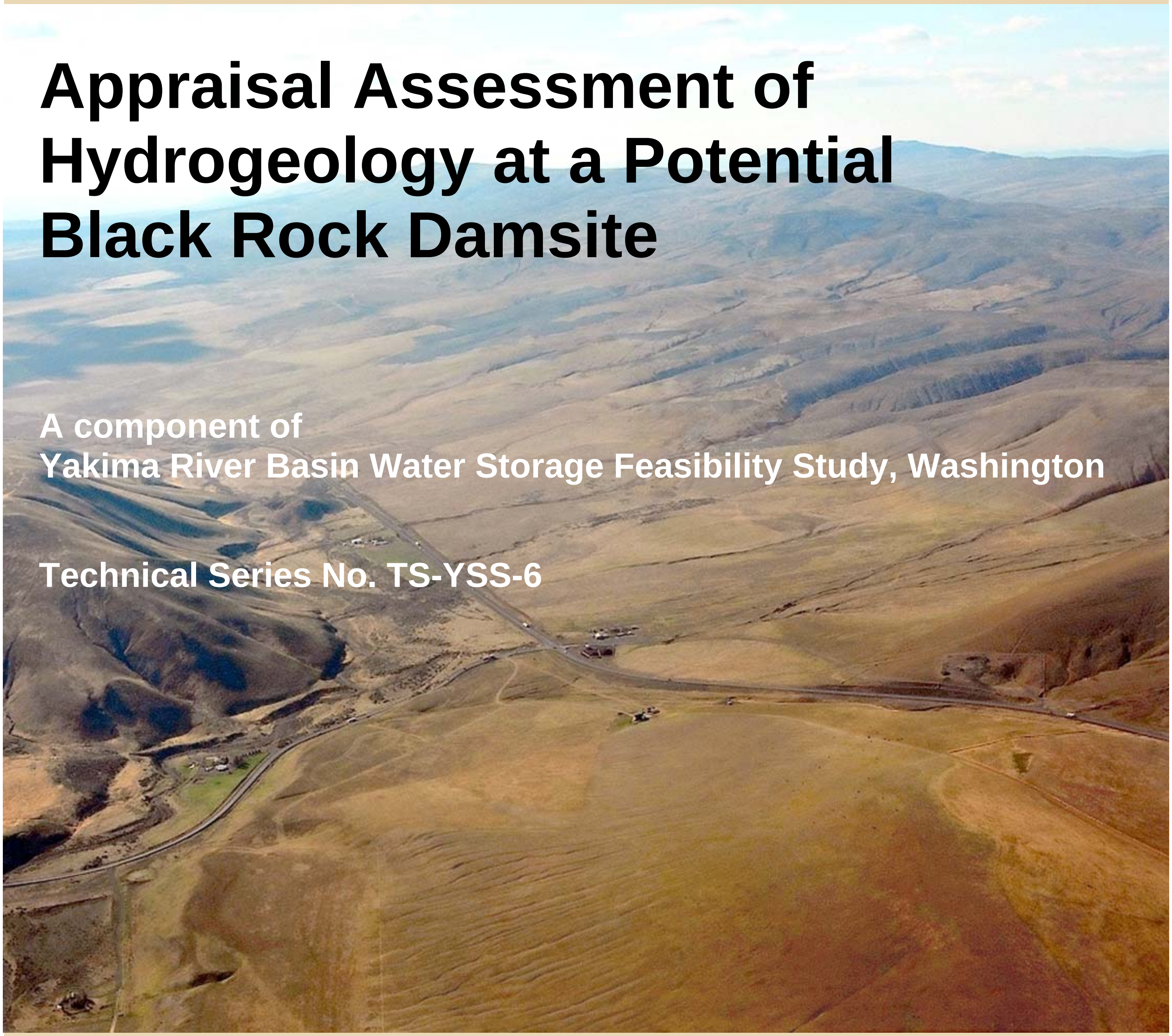
RECLAMATION
Managing Water in the West

Appraisal Assessment of Hydrogeology at a Potential Black Rock Damsite

A component of
Yakima River Basin Water Storage Feasibility Study, Washington

Technical Series No. TS-YSS-6



Black Rock Valley

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region

December 2004

Preface

Congress directed the Secretary of the Interior, acting through the Bureau of Reclamation (Reclamation), to conduct a feasibility study of options for additional water storage for the Yakima River basin. Section 214 of the Act of February 20, 2003, (Public Law 108-7) contains this authorization and includes the provision "… with emphasis on the feasibility of storage of Columbia River water in the potential Black Rock Reservoir and the benefit of additional storage to endangered and threatened fish, irrigated agriculture, and municipal water supply."

Reclamation initiated the *Yakima River Basin Water Storage Feasibility Study* (Storage Study) in May 2003. As guided by the authorization, the purpose of the Storage Study is to identify and examine the viability and acceptability of alternate projects by: (1) diversion of Columbia River water to the potential Black Rock reservoir for further water transfer to irrigation entities in the lower Yakima River basin as an exchange supply, thereby reducing irrigation demand on Yakima River water and improving Yakima Project stored water supplies, and (2) creation of additional storage within the Yakima River basin. In considering the benefits to be achieved, study objectives will be to modify Yakima Project flow management operations to most closely mimic the historic flow regime of a Yakima River system for fisheries, provide a more reliable supply for existing proratable water users, and provide additional supplies for future municipal demands.

State support for the Storage Study was provided in the 2003 Legislative session. The capital budget included a $4 million appropriation for the Department of Ecology (Ecology) with the provision the funds "… are provided solely for expenditure under a contract between the department of ecology and the United States bureau of reclamation for the development of plans, engineering, and financing reports and other preconstruction activities associated with the development of water storage projects in the Yakima river basin, consistent with the Yakima river basin water enhancement project, P.L. 103-434. The initial water storage feasibility study shall be for the Black Rock reservoir project."

Reclamation's Upper Columbia Area Office in Yakima, Washington, is managing and directing the Storage Study. Pursuant to the legislative directives, Reclamation has placed initial emphasis on Black Rock alternative study activities. These study activities are collectively referred to as the Black Rock Alternative Assessment (Assessment).

The Assessment has three primary objectives. First, it provides the emphasis directed by Federal and State legislation. Second, it builds upon prior work and studies to provide more information on the configuration and field construction cost of the primary components of a Black Rock alternative. It examines legal and institutional considerations of water supply and use, and identifies areas where further study is needed. Third, it is a step forward in identifying the viability of a Black Rock alternative.

This technical document, prepared by Reclamation's Pacific Northwest Region, is one of a series of documents prepared under the Storage Study. This particular document is a component of the Assessment reporting on preliminary hydrogeologic investigations conducted in 2004 at the alternate Black Rock damsite. Information and findings of this technical document are included in the Assessment Summary Report.

Further Consultations

The information available at this time is necessarily preliminary, has been developed only to an appraisal level of detail, and is therefore subject to change if this alternative is investigated further in the course of the Yakima River Basin Storage Feasibility Study (Storage Study). Finally, economic, financial, environmental, cultural, and social evaluations of the Black Rock alternative have not yet been conducted.

The policy of the Bureau of Reclamation (Reclamation) requires non-Federal parties to share the costs of financing feasibility studies and the eventual construction of Federal reclamation projects. In light of this policy, the preliminary cost estimates presented in the Assessment Summary Report, and current Federal budgetary constraints, Reclamation is not reaching a decision at this time as to whether the Black Rock alternative will be carried forward into the next phase of the Storage Study or dropped from further consideration. Rather, Reclamation will consult with the State of Washington (which is cost sharing in the Storage Study), the Yakama Nation, the potential water exchange participants, project proponents, and other interested parties before making a decision in this regard. It is anticipated that a decision will be reached by the fall of 2005.

If the Congress provides further funding for the Storage Study, all technically viable alternatives would be compared and an alternative(s) selected for further analyses in the feasibility phase. (Whether the Columbia River-Yakima River water exchange concept in the form of the Black Rock alternative is included will depend upon whether Reclamation, after these additional consultations, decides to carry that alternative forward into the plan formulation phase of the Storage Study.) The selected alternative(s) would then be subject to detailed evaluation in the feasibility phase in terms of engineering, economic, and environmental considerations, and cultural and social acceptability. This feasibility phase would be the last phase of the Storage Study. Preparation of the Feasibility Report/Environmental Impact Statement would be a part of this final phase.

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Prepared by: Kayti Didricksen, Hydrogeologist

U. S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Regional Resource & Technical Services
Boise, Idaho

December 2004

U.S. Department of the Interior
Mission Statement

The Mission of the U.S. Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

Bureau of Reclamation
Mission Statement

The Mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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SUMMARY AND CONCLUSIONS

Hydrologic testing of boreholes located at the potential Black Rock Dam was conducted from April 1 to June 9, 2004. The purpose of this initial hydrogeologic assessment was to determine the hydraulic properties of selected hydrogeologic units, identify hydraulic boundaries and assess the capacity for vertical communication (leakage) between units. In addition, groundwater samples were collected for hydrochemical and isotopic analyses and hydraulic head information was examined to determine hydraulic relationships between the hydrogeologic units at this location. These studies contribute to our understanding of the Black Rock valley hydrogeology and help assess the potential impact that seepage from a reservoir could have on local and adjacent off-site groundwater conditions.

Reclamation procured the expertise of Dr. Frank Spane through a contract with Pacific Northwest National Laboratory to assist in the hydrologic testing program. Dr. Spane performed the hydrologic test analyses and provided comparisons between the data gathered during this test program and data from previous hydrologic testing at the adjacent Hanford site.

The unsaturated zone includes all of the overburden sediments and the upper-most basalt flow (Pomona Basalt). There are no perched or unconfined aquifer systems at the site. The first groundwater was encountered at a depth of 254 feet, at the base of the Pomona Basalt / top of the Selah interbed. The upper water-bearing unit consists of the Selah interbed and Esquatzel Basalt flow top. This hydrogeologic unit is semi-confined and has a static water level of about 194 feet below ground surface.

Five vadose zones and two groundwater zones were successfully characterized using a suite of hydrologic test methods and analyses. Saturated hydraulic conductivity values for sedimentary intervals in the vadose zone range between 0.04 to 2.8 ft/day. These values fall within the lower range reported for the Hanford Site for comparable hydrogeologic units (Spane, 2004). Hydraulic conductivity values for the Selah/ Esquatzel unit range between 1.3 and 8.1 ft/day, with a best estimate average value of about 2.69 ft/day. Tests in the Mabton interbed indicate a much lower hydraulic conductivity value of about 0.03 ft/day. These values similarly fall within the lower range commonly cited for Ellensburg sedimentary interbeds on the Hanford Site (Spane, 2004).

Groundwater samples collected from the Selah and Mabton interbeds at DH-04-02 have similar major inorganic chemistries and hydrochemical characteristics as displayed by groundwaters within the Ellensburg Formation/Saddle Mountains Basalt at the Hanford Site and surrounding Pasco Basin (Spane, 2004). The groundwater samples from DH-04-02 appear to be relatively young and not altered by a long residence time within the groundwater flow system. This may indicate that groundwater recharge to the Saddle Mountains Formation is from relatively local sources and not from deeper basalt aquifers.

Hydrologic testing at DH-04-02 did not identify any faults or discontinuities within about 300 feet of the borehole. The mapped Horsethief Mountain thrust fault is located about 1000 feet from the tested well.

Leakage was pervasive through the Esquatzel and Umatilla basalt members during hydrologic testing. Based on the leakage response and on similar hydrochemical characteristics, the Selah/Esquatzel flow top and the Mabton interbed are considered to comprise a single groundwater-flow system.

The Pomona Basalt flow interior may inhibit large quantities of vertical leakage if preferential pathways are not present. However, where the interflow zones and interbeds are exposed or thinly veiled by shallow sediments on the adjacent anticlinal ridges, large amounts of reservoir leakage could occur.

<u>Recommendations for future investigations</u>:

- Hydrologic testing of upper abutment areas to evaluate potential reservoir leakage at damsite and along reservoir rim.

- Hydrologic testing of the Pomona Basalt to determine if it is a hydraulic barrier and to verify the lateral extent of the unit across the reservoir basin.

- Additional hydrologic testing to further define the vadose zone and aquifer characteristics and potential leakage between aquifers in the foundation of the dam. The testing should include the hydraulic interaction between the Saddle Mountains Formation and the underlying Priest Rapids Basalt of the Wanapum Formation.

- Hydrologic testing along the Horsethief Mountain thrust fault to determine whether the fault zone is a groundwater barrier or a conduit for reservoir seepage.

- Evaluate potential impacts from reservoir seepage and groundwater flow towards the Hanford site by using or modifying existing models developed by Pacific Northwest National Laboratory. This is envisioned to be a cooperative effort with PNNL and DOE.

INTRODUCTION

The Columbia River Basalt Group (CRBG) and interbedded sedimentary units of the Ellensburg Formation underlie the potential Black Rock Dam and reservoir. These geologic units compose the framework of a three-dimensional groundwater flow system. An understanding of the principle features of the groundwater flow system and the hydraulic properties of the aquifers is essential in determining the occurrence and movement of groundwater and the impact that the proposed reservoir could have on groundwater conditions.

Many previously published reports describe the geology and hydrogeology of the Columbia Plateau regional aquifer system and the Yakima area. Examples include those by Kirk and Mackie (1993), Whiteman and others (1994), Campbell (1998), Vaccaro (1999), and Gephart and others (1979). The reader is referred to these references for a detailed description of the hydrogeologic framework of the region.

This assessment report includes a summary description of the site hydrogeology, followed by a description and discussion of the hydrologic borehole tests completed during spring 2004. The hydrologic tests were conducted to determine the hydraulic properties of selected hydrogeologic units, identify hydraulic boundaries and assess the capacity for vertical communication (leakage) between units.

A series of pressure permeability tests were conducted during the initial damsite investigation in 2002 by Washington Infrastructure Services, Inc. (WIS, 2003). The pressure tests were conducted in four boreholes, above and below the water table, in sediment and rock, using essentially the same procedures and analysis methods for all of the tests. They used a double-packer assembly and often had leakage around the packer(s) and "wash-outs" in the tested intervals. By their own account, the results of their permeability testing have limited value and "should not be overused" (WIS, 2003).

A testing plan was developed for this study that was mindful of the problems that WIS had experienced at the site and one that could be tailored for the specific conditions encountered with depth in the borehole. A "toolbox" of testing methods is available and the type of test chosen for a specific interval depends on the hydrogeologic conditions of that interval and the preferred scale of examination (near borehole or extending further into the aquifer). Reclamation procured the expertise of Dr. Frank Spane through a contract with Pacific Northwest National Laboratory. Dr. Spane assisted in developing the Black Rock testing plan, provided on-site direction throughout the field work and completed the hydrologic test analyses (Spane, 2004). For a detailed account and explanation of analytical methods and diagnostic plots, the reader is referred to his letter-report.

The geologic variability within the basin constrains the results from these tests to the proximity of the borehole site. Different conditions and hydraulic properties are expected to be found on the dam abutments or adjacent to a tectonic fault. Nevertheless, the tests conducted at DH-04-02 provide representative data for the hydrogeologic units that were tested and the results from this phase of testing will help direct future investigations. Additional testing and characterization is necessary to answer the greater question about how leakage from a reservoir impoundment will affect underlying or off-site groundwater conditions.

SITE HYDROGEOLOGY

The proposed dam and reservoir site is underlain by the following geologic units: Recent loess and alluvial deposits, Pliocene Ringold Formation fluvio-lacustrine deposits, and Miocene Columbia River Basalts with interbedded Ellensburg Formation sediments. The CRBG has been divided into a series of formations (regionally mappable units) based on their unique physical, chemical and paleomagnetic properties. There are three basalt formations underlying the Black Rock area. These formations are, from youngest to oldest, the Saddle Mountains Basalt, Wanapum Basalt, and Grande Ronde Basalt. The basalt formations have been further subdivided into members and flow units (Figure 1). Sediments were deposited during the long periods of time between lava outpourings and are interbedded with the basalt flows in the CRBG. These interbeds are assigned to the Ellensburg Formation. Ancient river and lake systems and volcanic eruptions in the Cascade Range were the primary sources for these sediments.

Hydrogeologic units are the aquifers and confining beds that compose the framework of the groundwater flow system. They are not always synonymous with the geologic unit divisions because they are primarily defined by the material's hydraulic properties. Within basalt formations, the primary water-bearing zones are generally limited to the flow tops (rubbly, vesicular areas) and interflow zones (contact zone between adjacent basalt flows). The flow tops have relatively high lateral hydraulic conductivity, whereas the dense flow interiors have very low lateral conductivity but generally contain vertical cooling joints and tectonic fractures that could accommodate vertical groundwater movement. Vertical groundwater flow within the basalts is contingent on the connectivity of the fractures through the flows and the degree of in-filling with secondary mineralization and clay. Other geologic conditions that could be conducive to vertical flow include basalt flow margins and tectonic features. Where a basalt flow thins or pinches out, sedimentary interbeds merge and are in hydrologic communication with each other. Structural folds and faults may impede groundwater flow or act as vertical flow pathways, depending on the physical characteristics of the feature.

Hydraulic properties of the vadose (unsaturated) zone are important at the Black Rock site since heterogeneities within and between the distinctive unsaturated materials in the

Figure 1. Stratigraphic section of geologic units in the Black Rock area.

reservoir basin will result in complex flow paths, including variable downward migration and lateral flow of infiltrated water. Alternating layers of fine-grained and coarse-grained sediments create anisotropic conditions that tend to enhance lateral spreading. At the hydrologic test site, the vadose zone includes the upper-most basalt member, the Pomona Basalt.

Kirk and Mackie (1993) describe two aquifers within the Saddle Mountains Formation in the Black Rock and Moxee valleys; an upper unconfined system in the Elephant Mountain Basalt and stratified sediments of the Rattlesnake Ridge interbed, and a lower confined system that includes the underlying Saddle Mountains basalt and interbed layers. They delineate the two aquifers based on the dissimilar performance of wells completed in the upper versus the lower units in reaction to declining head conditions. It should be noted that nearly all of their study wells were located in the Moxee valley.

During the current investigations, no unconfined or perched water table conditions were found. Water was first encountered during drilling of DH-04-02 at a depth of 254 feet, in the Selah interbed that underlies the Pomona basalt. The water level rose in the well to about 194 feet below ground surface (bgs). Artesian conditions often occur in the synclinal valleys of the Yakima Fold Belt because most of the recharge to the water-bearing zones occurs where they are exposed at higher elevations along the anticlinal ridges. The interflow zones are inclined towards the valleys (synclines) and the groundwater flow direction is influenced by the structural dip. In the synclines these water-bearing zones are usually confined by overlying basalt flows, thereby producing the artesian condition.

DRILLING OF HYDROLOGIC TEST WELL

The drilling and testing of DH-04-02 occurred between April 1 and June 9, 2004. Prior to the drilling of the test well, a separate core hole, DH-04-01, was drilled. The drill core was thoroughly examined and geologically logged (Stelma, 2004), a geophysical log was run, then the borehole was completed as a piezometer isolated in the Selah interbed / Esquatzel Basalt flow top for subsequent water level monitoring. Drill holes DH-04-01 and -02 are located about 34 feet apart from each other and about 230 feet north of State Highway 24 (Figure 2).

DH-04-02 was drilled using air rotary methods for the purpose of hydrologic testing. The rock cuttings were not logged in detail; relying instead on the geologic and geophysical logs of DH-04-01 for specific geologic contact information. The drill logs, geophysical logs and as-built drawing for both holes, DH-04-01 and DH-04-02, are included in Appendix A.

At the site, about 30 feet of loess and alluvium overlie 60 feet of fluviolacustrine derived silt, sand and clay with gravel and cobbles of the Ringold Formation. Underlying the Ringold are Rattlesnake Ridge sediments and “rafted” sediments from the Selah interbed consisting of clay and fine-grained sand with pumice and basalt fragments. These

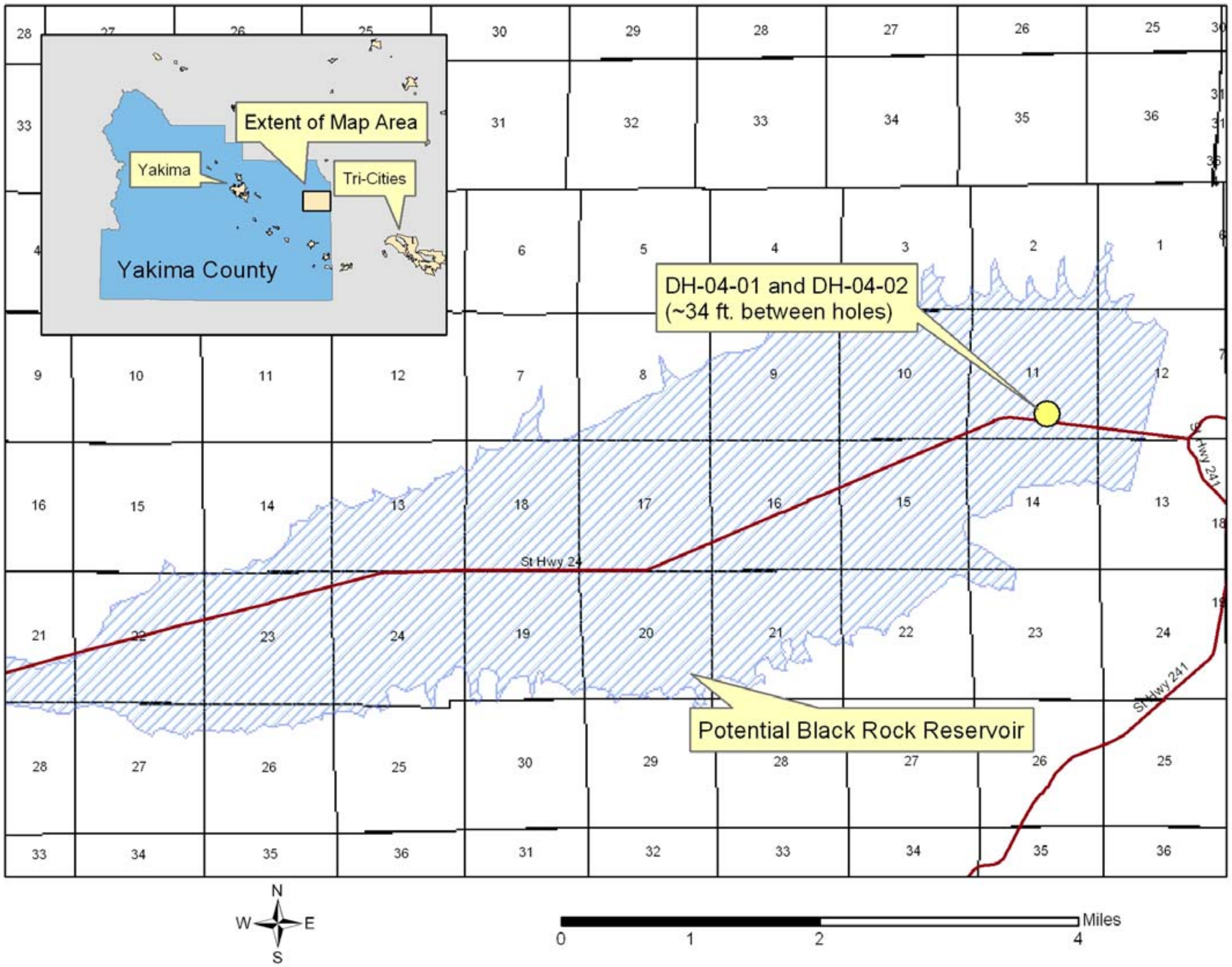


Figure 2. Location of Hydrogeologic Investigations

overburden materials are currently dry but would become saturated with leakage from the Black Rock reservoir. The top of the Pomona Basalt in DH-04-02 was encountered at 144 feet bgs. The Pomona is underlain by the Selah sedimentary interbed at a depth of 249 feet. Groundwater was first encountered in the Selah and the static water level is about 194 feet bgs.

The Selah is about 30 feet thick and underlain by the Esquatzel and Umatilla basalt flows. The contact between the Esquatzel and Umatilla flows was not definitive in the DH-04-01 drill core. The Mabton sedimentary interbed defines the base of the Saddle Mountains Formation and overlies the Wanapum Formation. The Mabton was found in DH-04-01 from 467 feet bgs to about 556 feet bgs and is composed of siltstone, tuffaceous sand and clay. DH-04-02 was terminated in the Mabton interbed at a depth of 530 feet.

Drilling in the basalts was generally fast and trouble-free however, the sedimentary interbeds tended to cave-in and a layer of heaving sand was encountered in DH-04-02 from 515 to 520 feet bgs in the Mabton. In order to complete the hydrologic testing, the borehole required slotted casing or screen through the interbeds to provide borehole stability.

HYDROLOGIC SITE INVESTIGATION

Three complementary techniques were used to characterize the variability of the hydraulic properties within and between aquifers at the study site: hydrologic borehole testing, hydrochemical analysis and hydraulic head information.

Hydrologic Borehole Testing

The hydraulic properties and storativity of an aquifer system determine the transmission and storage capability of the water-bearing unit. These characteristics directly affect the seepage potential of the proposed reservoir. Hydraulic conductivity varies both horizontally and vertically. It is dependent on the connectivity and degree of in-filling of joints and fractures in the basalts and the gradation and physical characteristics of the interbedded sediments. The primary technique to determine hydraulic conductivity is to perform a series of hydrologic borehole tests in which a stress is applied and the response data are compared with theoretical models of test responses. Comparison to the appropriate model can also be used to determine if leakage between units or other hydraulic conditions exist.

Test intervals within DH-04-02 were selected based on the detailed core analysis and borehole geophysical information obtained previously from DH-04-01. The hydrologic tests were conducted as the drill hole progressed ("drill and test" procedure). Throughout the drilling and testing of DH-04-02, a pressure transducer was also recording head data in piezometer DH-04-01. Examining the hydrologic responses at DH-04-01 (completed in the Selah interbed/Esquatzel basalt flow top) provided quantitative data to estimate the hydraulic communication (leakage) between hydrogeologic units at the site.

During this investigation, constant-head injection (gravity) tests, slug and slug interference tests, airlift and pumping tests were used to characterize the various hydrogeologic units. Table 1 lists the type of test, depth interval, geologic unit and date for each test conducted in DH-04-02.

The pressure transducer in DH-04-01 was an In-Situ model PTX-161, 10 psi range. The transducers used in the stress well, DH-04-02, were In-Situ model PXD-261, 250 psi range. An eight channel, Hermit 3000 data logger collected the pressure data and also recorded barometric readings. The data were downloaded in the field to a laptop computer after each testing sequence.

Table 1. Hydrologic Test Intervals in DH-04-02

Type of Test	Depth of Test Interval (feet)	Geologic Unit	Date(s) of test
constant head gravity	27-31	Alluvium	4/02/04
constant head gravity	77-81.7	Ringold	4/05/04
constant head gravity	117-137	Rattlesnake Ridge/Ellensburg sediments	4/06/04
constant head gravity	148-168	Pomona Basalt flow top	4/08/04
constant head gravity	148-230	Pomona Basalt	4/09/04
slug injection	236-290	Selah Interbed / Esquatzel flow top	4/13/04
step-drawdown	254-294	Selah Interbed/Esquatzel	5/12/04
constant rate pumping	254-294	Selah Interbed/Esquatzel	5/13/04 - 5/14/04
slug interference	254-294	Selah Interbed/Esquatzel	5/15/04
attempted slug tests – unable to isolate test zone with packer	356-405 & 381-405	Umatilla Basalt	5/19/04
airlift/constant drawdown	453-526.7	Mabton Interbed	6/03/04 – 6/04/04
pneumatic slug tests	453-526.7	Mabton Interbed	6/05/04

Vadose Zone Testing

Methods

Constant-head gravity tests were conducted in the unsaturated zone to provide estimated in-situ saturated hydraulic conductivity values for the intervals tested. Performance and analysis of the tests largely followed procedures outlined in the Reclamation Earth Manual (USBR, 1990) and Groundwater Manual (USBR, 1995). The steps followed are listed below:

1. Drill hole to a prescribed depth below the 8-inch drill casing,

2. Remove the drilling tool assembly to provide an open unsaturated borehole section,

3. Place a pressure transducer near the bottom of the borehole to monitor pressure response,

4. Rapidly fill the borehole/casing to the prescribed level (near top of the casing),

5. Maintain a uniform fluid level within the borehole and monitor the injection rates during the entire injection period.

6. Continue test until relatively uniform injection rates are established (i.e., pseudo-steady state conditions). Normally, constant head injection testing was completed within 2-hours.

7. End injection and monitor pressure response during recovery to pre-test condition.

Five vadose zones were tested: an interval within the Quaternary alluvium (depth 27 – 31 ft), an interval in the Ringold Formation (depth 77 – 82 ft), an interval of Rattlesnake Ridge and undifferentiated sediments of the Ellensburg Formation (depth 117 – 137 ft), a twenty-foot interval at the top of the Pomona Basalt flow (depth 148 – 168 ft) and a composite interval of Pomona Basalt (depth 148 – 230 ft).

Results

Calculated saturated hydraulic conductivity values for the vadose zone tests are listed in Table 2 (from Spane, 2004). For a complete description of the methods of analysis and equations used, please refer to Dr. Spane's report. Table 2 also lists comparative values from tests conducted at the Hanford site during previous investigations (see table footnotes for referenced reports).

Table 2. Analysis Summary for Vadose Zone Test Intervals, DH-04-02
(from Spane, 2004)

Test/Depth Interval ft bgs[a]	Test Formation	Test Date	Time/Test Duration hours, PDT (min)	Saturated Hydraulic Conductivity, K ft/day	
				DH-04-02	Hanford Site Values
27 – 31	Surficial Quaternary Alluvium	4/2/04	1124 - 1320[b] (116)	0.85	Range: 0.20 - 2.20[c]
77 - 82	Ringold	4/5/04	1001 - 1201 (120)	2.64	Range: 0.05 - 210[d] Geometric Mean: 8.43
117 - 137	Rattlesnake Ridge Interbed/Undifferentiated Ellensburg Formation	4/6/04	1116 - 1317 (121)	0.80	Range: 0.06 - 25.6[e] Geometric Mean: 2.36
148 - 168	Pomona Basalt Flow Top	4/8/04	0858 - 1059 (121)	0.04	10^{-2} to 10^{3} [f]
148 - 230 (148-183)	Composite Pomona Basalt Flow	4/9/04	1124 - 1405 (161)	0.04	10^{-2} to 10^{3} [f]

(a) ft bgs: feet below ground surface
(b) Time: Pacific Standard Time, PST for this test interval; Pacific Day-Light Time, PDT for all other vadose zone tests
(c) Saturated hydraulic conductivity estimates determined from laboratory permeability core tests for the Early Palouse soils and fine-grained sequence within the Hanford Formation, as reported in Connelly et al. (1992)
(d) Results for 38 Ringold Formation test sites within the central Hanford Site, as reported in Spane et al. (2001a, 2001b, 2002, 2003) and Spane and Newcomer (2004)
(e) Results for 22 Rattlesnake Ridge interbed test sites within the Hanford Site, as reported in Spane and Vermeul (1993) and Spane and Webber (1995)
(f) Results for Saddle Mountains Basalt flow tops and interflow zones, as reported in DOE (1988)

Saturated Zone Testing

Two water-bearing zones; the composite Selah interbed/Esquatzel flow top and the Mabton interbed, were successfully tested and characterized. A hydrologic test of an interval within the Umatilla basalt flow interior was attempted but was unsuccessful due to the inability to isolate the test section with the downhole packer.

Hydraulic property values for the saturated zones tested are listed in Table 3 (from Spane, 2004). For a complete description of the analysis methods and diagnostic plots, please refer to Dr. Spane's letter-report.

Test Zone - Selah Interbed/Esquatzel basalt flow top

The composite Selah interbed/Esquatzel flow top interval was tested in two phases. Initially, the borehole had been drilled through the selected test zone to a depth of 290 feet. A pneumatic packer was seated in an overlying, dense section of Pomona basalt. The packer assembly was built by Baski, Inc. specifically for the Black Rock tests (Figure 3). It includes an access port valve (shut-in tool) below the packer and accommodations for pressure transducers that permit monitoring of the isolated test interval as well as the open borehole above the packer. Prior to active testing, the integrity of the packer seal was checked by comparing the pressure response from the two transducers while the annulus above the packer was filled with water.

A series of six slug tests was completed under the first testing phase however; during the testing, a portion of the open borehole section below the packer assembly collapsed to a depth of approximately 273 feet. After several attempts to re-open and conduct additional tests, the borehole was re-drilled to a depth of 294 feet and a perforated casing was set from 254 - 294 feet. The remaining Selah/Esquatzel tests (phase two) were conducted in the perforated casing interval.

Slug Injection Tests - Slug tests are short-duration tests that provide initial estimates of hydraulic properties of the near-well aquifer. They are also used to evaluate drilling induced borehole damage ("skin effects"). A slug test consists of measuring the head response in a well after an abrupt water level change in that well. To conduct this test, a known volume of water is instantaneously added (slug injection) or removed from (slug withdrawal) the test interval.

To conduct the slug injection tests in DH-04-02, the 2-1/2 inch "drop" pipe (above the packer and access port valve) was filled with a specified quantity of water or to a specified head level; the access port valve was opened and the pressure response over time was recorded using the transducer and datalogger system. Six slug injection tests, under varying stress levels, were conducted during the first phase of testing in the Selah/Esquatzel flow top test zone.

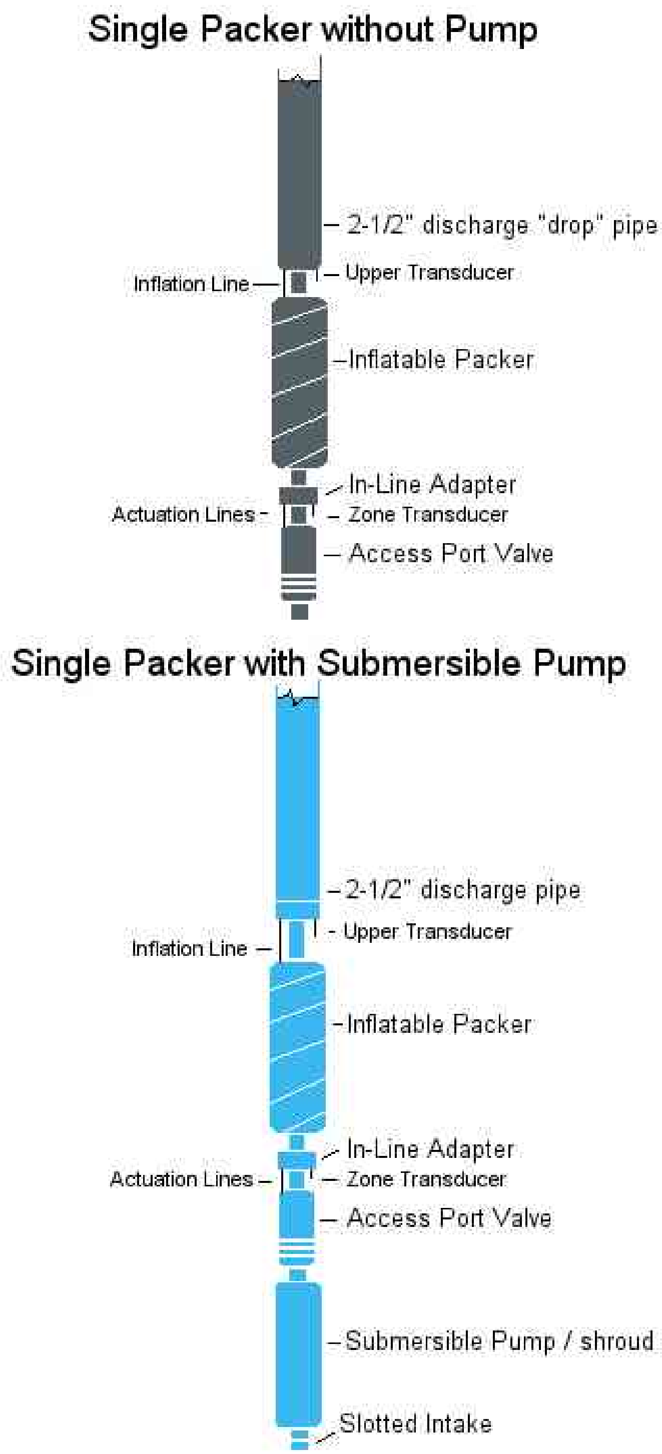


Figure 3. Packer assembly for hydrologic borehole tests.

Results - The hydraulic conductivity estimates for the Selah interbed ranged between 2.13 and 2.69 ft/day. Slug injection test #5 was considered to represent the best estimate value for the test interval and the calculated hydraulic conductivity was 2.69 ft/day and storativity was 1.0E-6 (Spane, 2004).

Constant-rate Pumping Test - During constant-rate pumping tests, water is withdrawn from the test interval at a constant, uniform rate. The pressure response within the borehole is monitored during the active pumping phase and during the subsequent recovery period. Because these tests are run for a longer period of time and the stress level is greater than during slug tests, the pressure response can be monitored at farther distances from the stress well (i.e. at surrounding observation wells). The larger scale of the test provides estimated hydraulic properties for a larger area of the aquifer and determination of other hydraulic conditions such as wellbore storage, presence of boundaries and leakage.

A constant-rate pumping test was conducted in DH-04-02 during the second phase of testing in the Selah/Esquatzel flow top test zone. A 1.5 hp Grundfos submersible pump (model 22SQ/SQE15-220) was housed in the pump shroud at the bottom of the packer assembly (refer to Figure 3). A slotted pipe section below the pump shroud allowed water to enter the assembly beneath the submersible motor and the access port valve was maintained in the closed position during pumping. The pressure response in the well was monitored by a transducer placed approximately five feet above the pump and a second transducer recorded pressure response data in piezometer DH-04-01. Data from both transducers were recorded on the Hermit 3000 datalogger. The discharge rate was monitored with an in-line instantaneous/totalizer flow meter and verified with 5-gallon bucket readings at the end of the discharge line.

A brief step-drawdown test was conducted prior to the constant-rate test to determine the optimum pumping rate. After recovery to static conditions, the constant-rate test was initiated and a discharge rate of approximately 7.5 gallons per minute (gpm) was maintained throughout the 30-hour test. Water samples were collected for hydrochemical analysis after pumping for 165 minutes during the step-drawdown test on 5/12/04 and after 98 minutes of pumping during the constant-rate test on 5/13/04. Due to a malfunction in the datalogger (low battery), only the first 15 min of pressure recovery measurements were recorded following termination of pumping. This limited the analysis of the constant-rate pumping test to only the drawdown phase.

Results - Examination of the diagnostic plots for the piezometer response indicates that leakage effects were evident within the piezometer data after about 30 minutes into the test and became predominant after about 400 minutes. The early-time data, prior to when leakage became evident (≤30 min), was analyzed using a non-leaky aquifer model (Spane, 2004). The early-time data set matched the type-curve and derivative plots reasonably well, providing an estimated hydraulic conductivity of about 8.1 ft/day and a storativity of $5x10^{-4}$. This analysis should be considered a scoping level calculation because of the probable influence of leakage on the results.

Leakage effects were also evident within the stress well data. The leakage was exhibited earlier at the stress well than at the piezometer, as would be expected due to greater drawdown and vertical head gradients in the stress well. More variability and turbulence obscures the data trends from pumping well DH-04-02. Because of these conditions, a non-leaky analysis approach was not attempted for the pumping well test data.

Slug Interference Test – A slug interference test is simply a slug test administered at a greater stress level so that the response can be monitored at a distance away from the stress well (i.e., at the near-by piezometer). Two slug withdrawal tests were conducted in DH-04-02 following the recovery to static conditions after the constant-rate pumping test. These tests were implemented to provide additional corroboration for hydraulic properties estimates that were obtained from the slug injection tests and constant-rate test. The submersible pump that was used during the constant-rate test was also used to withdraw water for the slug withdrawal interference tests. During the first test, 12.6 gallons of water were removed during 40 seconds of pumping. A small response was observed at the piezometer so a second test with a higher stress was initiated. The second test withdrew 36.2 gallons of water during 2 minutes of pumping. The data from the second test were analyzed to estimate hydraulic and storage property values

Results - A lower hydraulic conductivity and storativity were estimated from these tests than from the preceding constant-rate test: K = 2.43 ft/day and $S = 6.5x10^{-5}$. Again, a leakage response is evident in the test data and is visible in the diagnostic plots (Figures 5 and 6).

Test Zone – Mabton Interbed

While drilling through the Mabton sedimentary interbed, it became apparent that the borehole would not remain open throughout a series of hydrologic tests due to borehole instability. In addition, isolating a test zone with the pneumatic packer in the overlying Umatilla basalt had been unsuccessful; therefore a packer probably would not have isolated the Mabton interbed from the overlying units. To maintain borehole stability (and provide for future monitoring), a 50-foot interval (depth 477 – 527) in the Mabton was screened with 3-inch I.D., 0.020-inch slot PVC screen and isolated from overlying units by sealing around the PVC riser to ground surface with cement and bentonite.

Constant-Drawdown/Airlift Test - The Mabton interbed in DH-04-02 was tested using an airlift pumping system to withdraw water from the isolated interval. Size restrictions in the well (3-inch PVC screen and riser) precluded use of the available submersible pump. During an airlift test, a constant withdrawal rate is difficult to maintain but the pumping level is essentially constant (constant-drawdown). A 0-250 psi range pressure transducer monitored pressure response in the test well. Throughout the test, piezometer DH-04-01 was monitored to detect any cross-formational response in the overlying Selah interbed/Esquatzel Basalt flow top, located approximately 190 ft above the Mabton interbed test interval.

The airlift test was run for 22.4 hours on June 3 and 4 with a discharge rate of approximately five gallons per minute. The water was directed by hose to a baffled settlement tank to dispel the discharge pressure. A v-notch weir on the downstream end of the tank permitted measurements of the average flow rate.

Results – Pressure recovery was monitored for about 22 hours following termination of airlift pumping. A plot of the recovery data indicates a heterogeneous formation condition that can be produced when a higher permeability zone develops in the area immediately surrounding the well, and which transitions to an outer zone having a significantly lower permeability. This commonly occurs in wells that are screened within unconsolidated aquifers when fines in the surrounding formation are removed by pumping (i.e., during the airlift test).

The calculated hydraulic conductivity value for the recovery analyses is estimated at 0.025 ft/day. This value is representative of the outer-zone formation characteristics and not reflective of the altered/higher permeability zone surrounding the test well. This value falls within the lower range of those listed for the Mabton unit on the Hanford Site.

No significant leakage response is indicated in the recovery plot. This may be attributable to the location of the Mabton test interval (477 -527 ft) within the larger Mabton interbed thickness (467 - 556 ft); where the test interval is situated away from the interbed boundary margins. Not including the full thickness of the interbed may diminish the effects of overlying/underlying formation leakage during testing.

Cross-formational leakage was indicated, however, by the response of the piezometer DH-04-01 (Figure 7).

Pneumatic Slug Tests – Following recovery to static conditions after the airlift test, and to corroborate the results obtained by the airlift testing, two slug withdrawal tests were conducted in the Mabton interbed using compressed gas to apply the "slug". The top of the 3-inch PVC was fitted with a sealed and valved pipe manifold that included a fitting to inject the compressed gas and accommodations for two pressure transducers. One transducer was placed down hole to monitor the hydraulic pressure response and the other was at the top of the well to monitor the borehole air pressure. Compressed gas was added to the borehole until the pressure stabilized then the valves were opened to instantaneously release the pressure and initiate a water level change in the test interval.

Results – A hydraulic conductivity value of 1.03 ft/day and storativity value of $1.5\text{x}10^{-5}$ were obtained for this test analysis and are reflective of the higher permeability zone around the screened interval of the well.

Table 3. Analysis Summary for Saturated Zone Intervals, DH-04-02
(from Spane, 2004)

Test/Depth Interval[a] ft bgs	Test Formation	Test Date	Hydraulic Properties		Comments
			T ft^2/d	K[b] ft/d	
236- 290 (236 -271)	Selah Interbed	4/13/04	48.5	2.69	
254- 294	Composite Selah Interbed/Esquatzel Basalt Flow Top	5/12 - 15/04	75.4	2.43	
362 -405	Umatilla Flow Interior	5/19/04	-	-	Test failed; test zone could not be isolated with packer
477-527	Mabton Interbed	6/3 - 5/04	1.24	0.025	

(a) **ft bgs**: feet below ground surface
(b) **K** = T/b; assumed contributing, b, = test interval length

Hydrochemistry and Isotope Analysis

Vertical communication between individual aquifers can be assessed by analyzing the hydrochemistry differences between the units. Hydrochemical data gathered from the site also provides information about the background characteristics of the groundwater underlying the Black Rock valley. The hydrochemical and isotopic signature of Columbia River water may be distinctly different than basalt groundwater. Therefore, if a reservoir at this location is filled with water pumped from the Columbia River, the hydrochemical data may provide a means of distinguishing reservoir leakage from native groundwater and a way to define the extent of leakage from the reservoir.

Physical properties of the water samples (temperature, pH, oxidation-reduction potential, and specific conductance), concentrations of dissolved constituents and isotope ratios were determined for groundwater samples collected from DH-04-02. Samples were sent to the Reclamation PN Region water laboratory for analysis of common ions, nutrients and trace elements and to the University of Waterloo, through the USGS Water Quality Laboratory (Tacoma), for stable isotope, carbon isotope and tritium analyses.

Sample Collection and Processing

The water samples were collected from a valve on the pump discharge pipe or from the v-notch weir discharge of the baffle-tank used during airlift testing (Mabton unit). Final sampling from the Mabton interbed unit was accomplished using a Grundfos Redi-Flo submersible pump. A 0.45–micrometer filter was used on the flexible tygon sampling tube to provide filtered samples for common ion and alkalinity determination. Two 250-mL poly-bottles were filled for ion analysis; the sample for cation analysis and trace metals was preserved with nitric acid to maintain a pH less than 2. Samples for stable isotopes (deuterium and ^{18}O) were collected from raw water discharged to clear glass sample bottles equipped with poly-cone seals. Tritium and carbon isotope (^{13}C and ^{14}C) samples were collected from raw water discharged to amber glass sample bottles; the carbon sample bottles were sealed with poly-cone caps. Dissolved gases (helium, methane and excess nitrogen) were sampled from the Mabton test interval by inserting the flexible sampling tube to the bottom of a submerged serum bottle to prevent atmospheric contact. All of the samples were packed on ice and refrigerated prior to analysis. A summary table of the sampling plan that lists the parameters measured and collection methods is included in Appendix B.

Field measurements of temperature, pH, and specific conductance were made with a Hanna HI 991300 meter. The probe was calibrated for pH using two-point calibration procedures and calibrated for specific conductance using a manufacturer-supplied standard solution. Oxidation-reduction potential was field measured with a portable Hach ORP tester. Dissolved-oxygen concentration was measured with a YSI 57 field meter. The dissolved-oxygen probe was calibrated using air-saturated water corrected to ambient atmospheric pressure. Alkalinity was determined in the field by incremental titration using a Hach digital titrator and an Orion 250A pH meter that was calibrated using two-point calibration procedures. A summary of the field measured parameter results is shown in Table 4.

Sample Analysis

Inorganic ions and nutrients were analyzed at the Reclamation Water Quality Laboratory in Boise, Idaho (Table 5). The constituents were analyzed following procedures outlined in the lab's Quality Assurance document (Reclamation, 2004). The analyses for stable isotope and tritium characterization of the Mabton water samples were analyzed by the Environmental Isotope Lab of the University of Waterloo, through an agreement with the USGS, Water Resources Division.

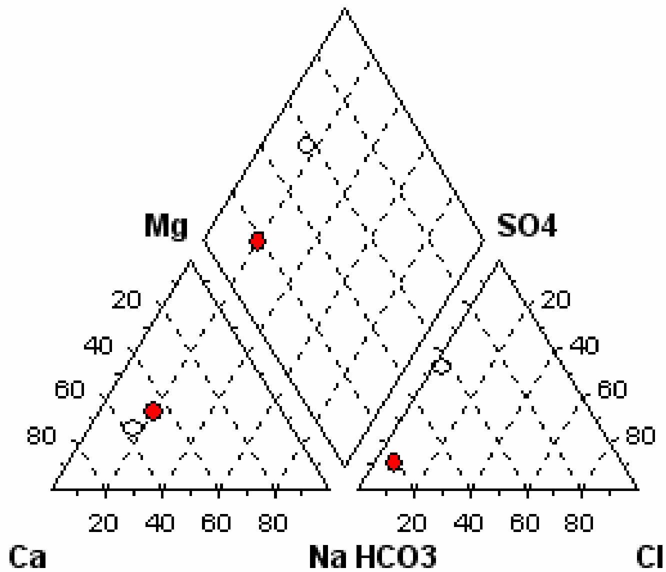
The groundwater samples from the Selah and Mabton interbeds at DH-04-02 exhibit similar major inorganic chemistries. Relatively high levels of sulfate and calcium were measured in the Mabton water. These results are likely due to the chemical influence of the Cal-Seal (a gypsum cement), that was placed above the sand filter pack surrounding the screened Mabton interval.

The samples from DH-04-02 have similar hydrochemical characteristics as displayed by groundwater within the Ellensburg Formation/Saddle Mountains Basalt at the Hanford Site and Pasco Basin (Figure 4, Spane, 2004). The groundwater from DH-04-02 appears to be relatively young and not altered by a long residence time within the groundwater flow system.

All waters have distinctive "fingerprints" of naturally occurring isotopes that provide information about their origin. Two of the most useful are the ratios of oxygen-18 to oxygen-16 ($^{18}O/^{16}O$) and hydrogen-deuterium to hydrogen (D/H). These ratios can be used to determine recharge location and to discriminate between naturally occurring groundwater and seepage from a surface water reservoir. The $^{18}O/^{16}O$ and D/H ratios were measured in water samples from the Mabton interbed. Data from one test well alone, is not sufficient to answer questions about seepage and recharge but the database will be appended with additional isotopic data from future groundwater samples if the project continues to feasibility level studies.

Tritium is a radioactive isotope of hydrogen that decays to 3-helium with a half-life of 12.43 years. Tritium was added to the atmosphere and natural precipitation as a result of atmospheric nuclear-bomb testing during the mid-1950's and early 1960's. The quantity of tritium (tritium/helium ratio) that is found in modern groundwater can be used to define the time elapsed since the water was isolated from the atmosphere following recharge. Tritium was not detected in water samples from the Mabton interbed (results were below the lab's detection limit of 0.8 TU), indicating that groundwater from the Mabton is at least 40 years old.

(a)



(b)

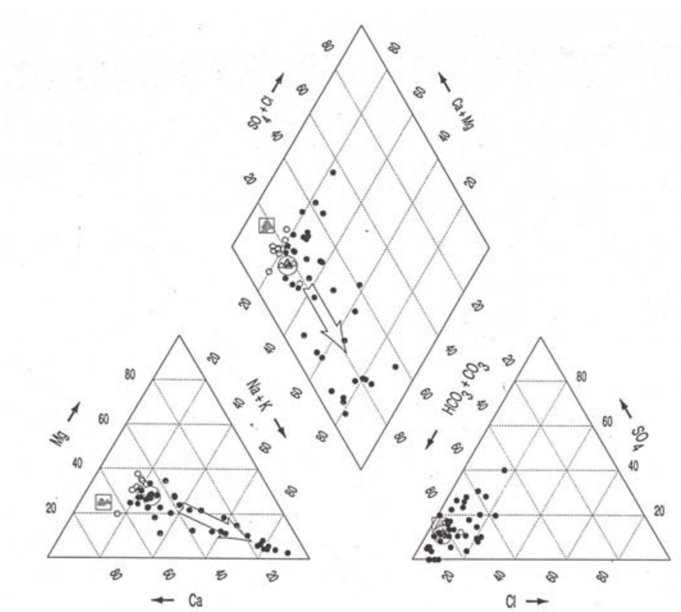


Figure 4. Tri-linear diagram that (a) compares chemical composition between Selah (red symbol) and Mabton (white symbol) interbeds and (b) Hanford site-Pasco Basin Upper-Saddle Mountains Basalt / Ellensburg Formation groundwaters (from Spane, 2004)

Table 4. Field Measured Parameters - Groundwater Samples from DH-04-02

Test Interval	Date	Time (hour, PST)	Elapsed pumping time (min)	Q (gpm)	Temp (C)	pH (SU)	Specific Conductance (uS/cm)	ORP (mV)	DO (mg/L)	Alkalinity (mg/L as CaCO3,)
Selah/Esquatzel flow top Step- drawdown test	5/12/04	1220	25 min into step 1	7	16.3	7.89	289	77	--	--
		1305	10 min into step 2, 70 min total	9.1	16.8	7.83	--	--	10.5	--
		1330	35 min into step 2, 95 min total	9.1	16.5	7.63	285	35	10.5	--
		1440	45 min into step 3, 165 min total	12.35	16.8	7.94	288	83	7.2	--
Selah/Esquatzel flow top constant-rate pump test	5/13/04	1000	45	7.5	16.6	7.63	283	29	6.7	120.1
		1130	135	7.5	17.0	7.63	283	--	--	--
		1330	255	7.5	17.1	7.63	268	116	7.75	--
		1630	435	7.5	17.1	7.63	284	130	7.35	--
		1915	600	7.5	16.7	7.63	284	95	7.65	--
		2230	795	7.5	16.3	7.63	284	95	7.7	--

Table 4 (con't).										
Test Interval	**Date**	**Time (hour, PST)**	**Elapsed pumping time (min)**	**Q (gpm)**	**Temp (C)**	**pH (SU)**	**Specific Conductance (uS/cm)**	**ORP (mV)**	**DO (mg/L)**	**Alkalinity (mg/L as CaCO3,)**
Selah/Esquatzel flow top,Constant -rate pumping	05/14/04	0516	1201	7.5	16.0	7.73	285	--	6.2	--
		0605	1250	7.5	15.9	7.63	286	--	6.0	--
		0655	1300	7.5	16.1	7.63	286	--	7.6	--
		0735	1340	7.5	16.8	7.77	284	--	7.3	--
		0911	1436	7.5	16.9	7.86	286	139	7.6	112.7
		1455	1780	7.5	17.5	7.62	284	18	8.3	--
Mabton Airlift/Constant Drawdown	06/03/04	1725	335	5.5	20.6	8.53	511	--	--	--
	06/03/04	1732	342	5.5	20.4	8.57	511	--	--	--
	06/04/04	0940	1295	5.5	21.4	8.25	316	--	--	--
Mabton Pumping	06/09/04	0925	75	3 gpm for 45 min then <1	21.4	7.4	580	--	0.3	138

Table 5. Physical properties and concentrations of dissolved constituents in DH-04-02 groundwater

Sample Date (Time, PST)	Hydro geologic Unit	Temp C	Field pH SU	ORP mV	Specific Conductance uS/cm	Dissolved Oxygen mg/L	Field Alkalinity mg/L as CaCO3	NO3/ NO2 mg/L	CO3 mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L
5/12/04 (1440)	Selah – step test	16.8	7.9	83	288	7.2	--	1.44	0	146	16.8	6.9
5/13/04 (1053)	Selah – pump test	16.6	7.6	29	283	6.7	120	1.46	0	145	16.6	6.9
6/ 3/04 (1732)	Mabton – airlift	20.6	8.5	--	511	--	--	0.31	2.45	171	130	6.8
6/ 4/04 (0940)	Mabton – airlift	21.6	8.4	--	320	--	--	0.36	2.45	171	57.2	7
6/ 9/04 (0925)	Mabton – pump	21.4	7.4	--	580	0.3	138	0.12	0	175	172	6.9

Sample Date	Hydro geologic Unit	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Hardness mg/L	SAR	Alkalinity mg/L	Lab pH SU	Lab EC uS/cm	Fl mg/L	Fe-Diss ug/L	Mn-Diss ug/L
5/12/04 (1440)	Selah – step test	26.2	11.9	13	4.1	114	0.5	120	7.7	290	0.37	100	10
5/13/04 (1053)	Selah – pump test	26.1	11.9	12.8	4.1	114	0.5	119	8	285	0.37	140	< 10
6/ 3/04 (1732)	Mabton – airlift	60.8	15.8	22.1	8.2	217	0.7	144	8.4	514	0.46	20	20
6/ 4/04 (0940)	Mabton – airlift	37.3	14.8	21.6	8.1	154	0.8	144	8.4	394	0.36	20	20
6/ 9/04 (0925)	Mabton – pump	70.4	20.3	22.3	8.4	259	0.6	144	7.8	610	0.28	120	80

Leakage Response

Analysis of the hydraulic head/pressure response monitored in piezometer DH-04-01 allowed a qualitative assessment of leakage (vertical hydraulic communication) between hydrogeologic units at the site. The pressure response in DH-04-01 was monitored throughout the drilling and testing of DH-04-02. To facilitate the recognition of leakage, the effects of barometric pressure were removed from pressure measurements at the piezometer. Based on a visual examination of the corrected pressure record at DH-04-01, the following observations can be concluded concerning leakage at the site (Spane, 2004):

- No cross-formational response due to leakage was detected at DH-04-01 during vadose zone testing or during the drilling of DH-04-02 to a depth of 230 ft. bgs within the Pomona Basalt flow interior

- Multi-well interference tests conducted within the composite Selah interbed/Esquatzel flow top exhibited leakage response in DH-04-01 (Figures 5 and 6)

- Cross-formational response due to leakage was detected at DH-04-01 during the drilling and testing of the Mabton interbed in DH-04-02 (Figure 7)

Based on information gathered to date, it appears that the cross-formational leakage response monitored during the field testing is due to hydraulic pathways (i.e., fractures) within the Esquatzel/Umatilla Basalt.

Confined and unconfined aquifers respond differently to changes in atmospheric pressure. In confined aquifers, the transmission of barometric change is instantaneous and the magnitude of the water level and formation pressure change is a function of the "barometric efficiency" (based on the degree of confinement, rigidity of the aquifer matrix and the specific weight of the groundwater). In unconfined aquifers, there is a time-delayed response to the water table within the aquifer because air must move into or out of the vadose zone to transmit the pressure change. These differences result in specific, diagnostic response patterns that allow identification of the aquifer type from the way in which it responds to barometric change over time. A leaky confined aquifer is indicated by a transition pattern between the confined and unconfined response models.

Figure 8 shows the response patterns exhibited by DH-04-01 and DH-04-02. Both wells exhibit a leakage response pattern and depart from the horizontal, confined aquifer model response. This information corroborates the leakage response indicated by the hydrologic testing.

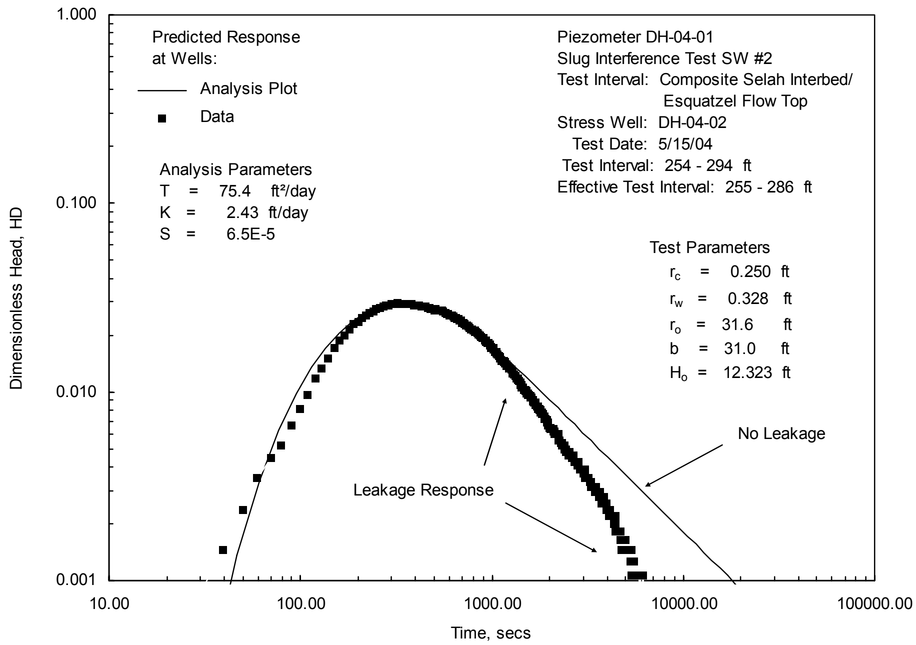


Figure 5. Type-Curve Analysis Plot for Slug Withdrawal Interference for Piezometer DH-04-01: Composite Selah Interbed/Esquatzel Basalt Flow Top (from Spane, 2004)

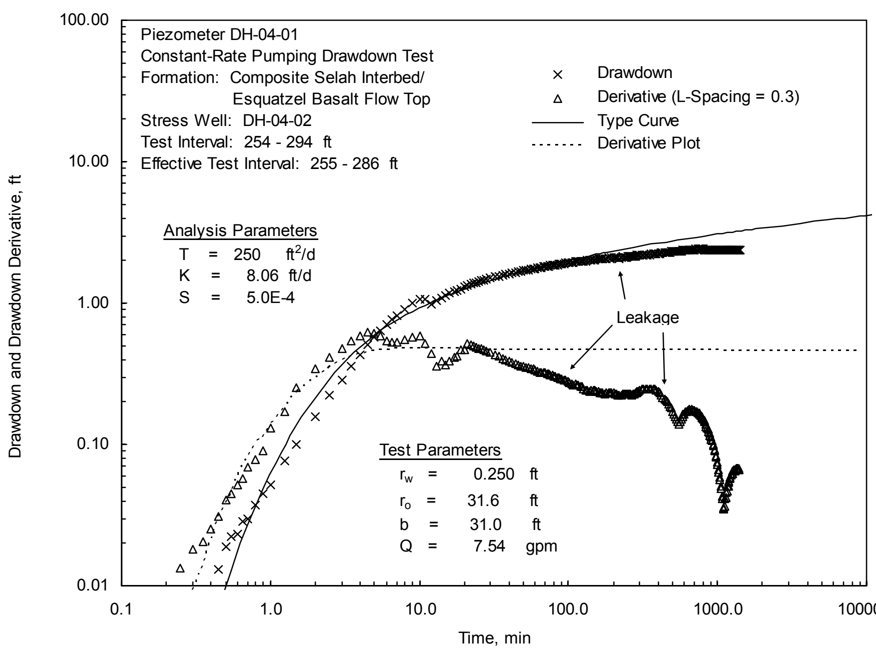


Figure 6. Type-Curve and Derivative Plot Analysis of Constant-Rate Pumping Test Drawdown Data for Piezometer DH-04-01: Test Interval 254 - 294 ft. (from Spane, 2004)

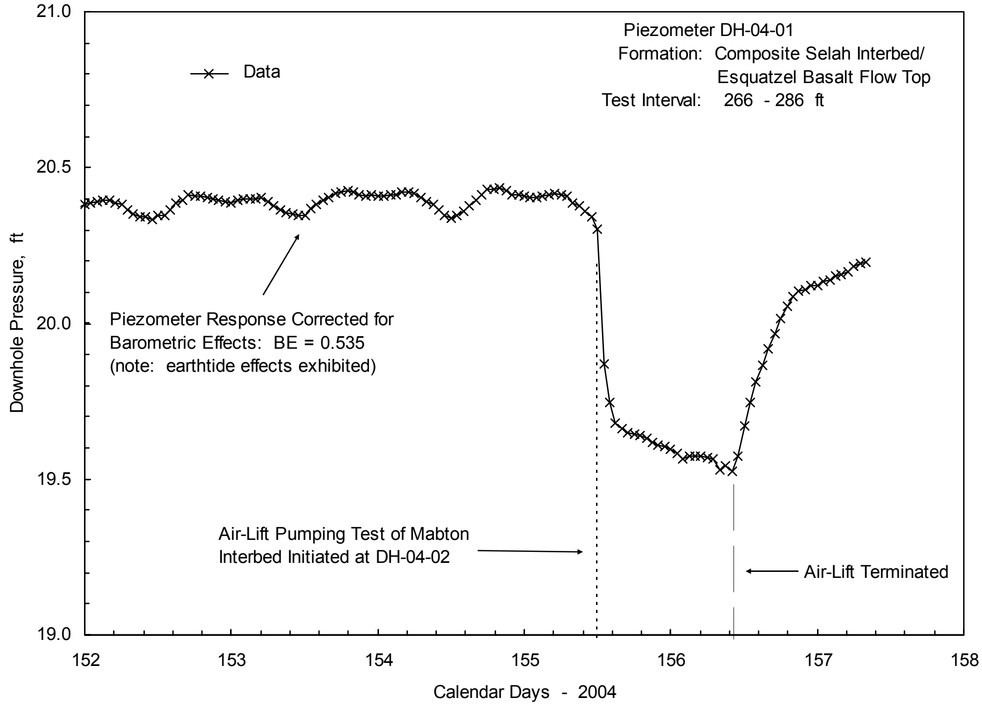


Figure 7. Piezometer DH-04-01 Baseline Monitoring Response Indicating Cross-Formational Leakage During Air-Lift Pumping Test of the Mabton Interbed at Test Well DH-04-02 (from Spane, 2004)

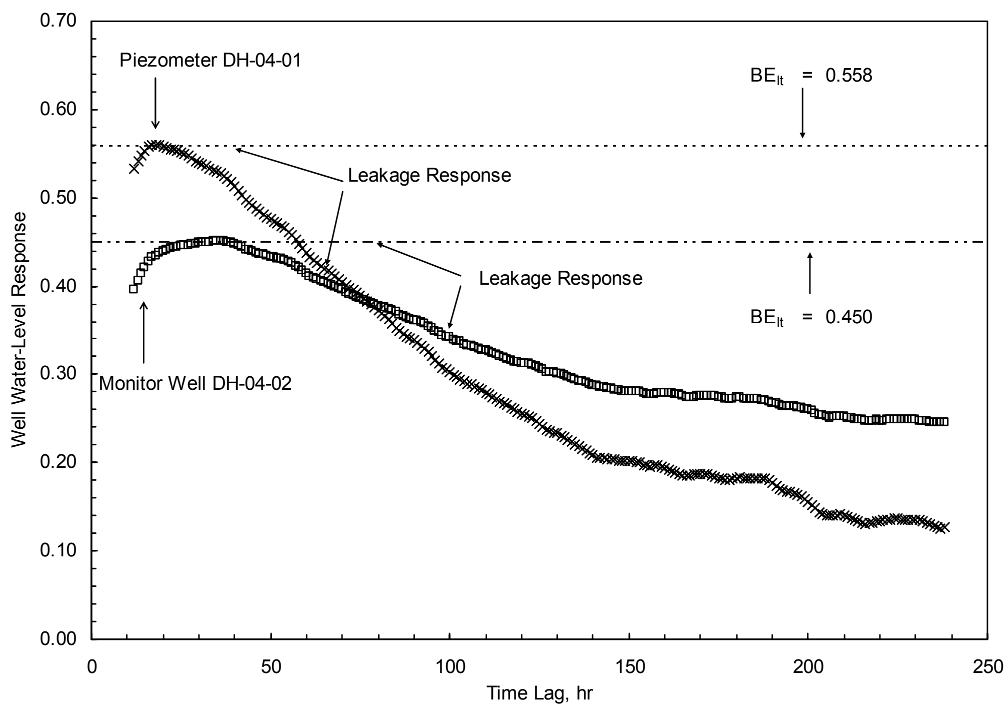


Figure 8. Comparison of DH-04-01 and DH-04-02 Barometric Response Plots (from Spane, 2004)

Hydraulic Head Information

At the Black Rock site, there may be a significant head drop from the Saddle Mountains aquifer to the Wanapum aquifer. The Mabton sedimentary interbed that separates the two basalt formations has low vertical conductance, creating an aquitard and inhibiting vertical flow. During the drilling of DH-04-01, all of the drill fluid was lost once the Mabton interbed was fully penetrated and the Priest Rapids Basalt of the Wanapum Formation was encountered.

Within the Saddle Mountains units, the Selah and Mabton water bearing zones have essentially the same head (as measured in DH-04-01 and DH-04-02). This finding is in agreement with Kirk and Mackie's (1993) report which states: "The flow interiors of the Lower Saddle Mountains Aquifer have sufficient vertical conductivity to maintain a similar head within the interflow zones during non-stressed conditions".

Kirk and Mackie (1993) used water level measurements in wells to interpret how structural features (i.e., folds and faults) have compartmentalized the basalt aquifers in the Moxee and Black Rock valleys. The Hog Ranch-Naneum Anticline trends north-south and separates the Moxee valley (to the west) from the Black Rock valley (to the east). It acts as a hydraulic barrier within the Wanapum aquifer. To the west of the anticline, the aquifer is confined but to the east the aquifer is unconfined and is unsaturated in the upper part of the formation. They further describe the Hog Ranch–Naneum Anticline as a hydraulic divide within the Saddle Mountains aquifer. Groundwater drains to the east in the Black Rock valley.

Kirk and Mackie describe the Yakima Ridge and Rattlesnake Ridge (Horsethief Ridge) as hydraulic barriers to north-south flow of groundwater within the Saddle Mountains aquifer. The Saddle Mountains basalt has been removed by erosion and the underlying Wanapum basalt is exposed at the surface of the ridges, therefore there can be no groundwater flow across the ridges within the Saddle Mountains aquifer. The Wanapum Formation is continuous across the anticlines and the ridges are hydraulic divides within the Wanapum aquifer.

Horsethief Fault, mapped along the lower edge of the south abutment, is also characterized as a hydraulic barrier (Kirk and Mackie, 1993). If sedimentary interbeds are recharged by reservoir seepage along the upper south abutment/reservoir rim and if the fault prevents normal drainage to the valley, elevated pore pressures within the south abutment could instigate landslides in the low-strength sediment layers. Future investigations should determine the fault's hydraulic significance by monitoring head response on either side of the fault during stressed and non-stressed conditions.

Baseline Hydraulic Head Monitoring

After the hydrologic testing was completed, hydraulic head monitoring continued at both wells; DH-04-01 monitors the composite Selah interbed/Esquatzel basalt flow top and DH-04-02 monitors the Mabton interbed. Figure 9 compares the water level fluctuations and trend in each well for the time period August 5 through September 24, 2004. The calculated water-level trend is -0.00193 ft/day for DH-04-01 and -0.00380 ft/day for DH-04-02 for the 50-day measurement period. The slight downward trends are consistent with expected seasonal recharge and discharge patterns of the aquifer.

To define groundwater flow conditions more accurately, the barometric effects must be accounted for and applied to the observed head to obtain total head. Figure 10 shows the total hydraulic head difference between DH-04-02 and DH-04-01. Positive values indicate an upward head gradient while negative values indicate a downward head gradient. The head difference between the two wells is relatively small (-0.05 to +0.15 ft) and a slight upward head gradient is exhibited over much of the 50-day measurement period.

Baseline monitoring will continue to provide additional information concerning response characteristics over time for the Saddle Mountain Formation and will provide additional hydrologic information for assessing offsite impacts.

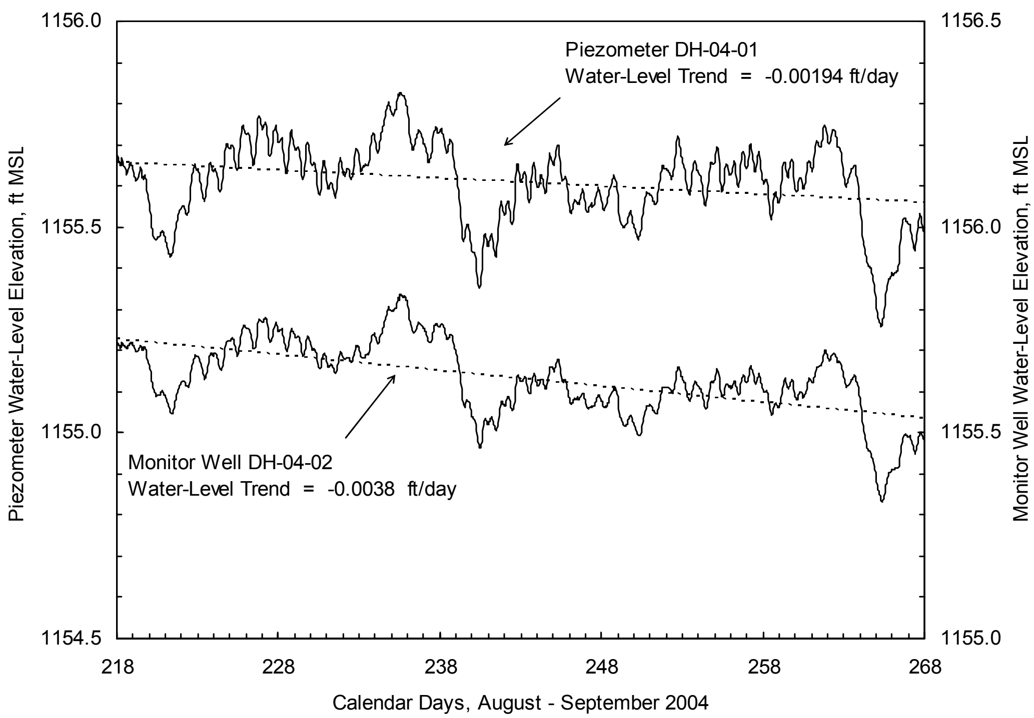


Figure 9. Comparison of Baseline Water Level Fluctuations for DH-04-01 and DH-04-02, August 5 – September 24, 2004 (from Spane, 2004)

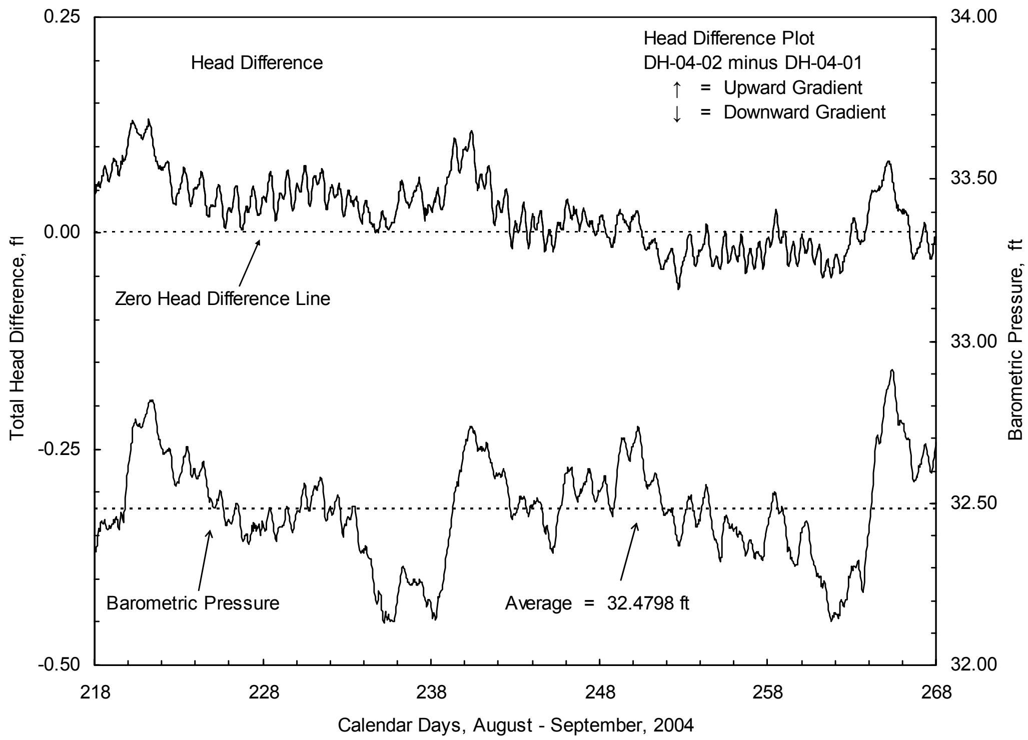


Figure 10. Total Head Difference Between DH-04-01 and DH-04-02, August 5 – September 24, 2004 (from Spane, 2004)

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