June 29th, 2010

Technical Memorandum
Update on Groundwater Level Gauging Project
Lower Lake Roosevelt Watershed, Lincoln County, Washington

To: WRIA 53 Planning Unit and
Lincoln County Planning Department

From: Eugene N.J. St.Godard, R.G., L.Hg.
Water & Natural Resource Group, Inc.
P.O. Box 28755, Spokane, WA 99228

Subject: FY 2010 Groundwater Level Gauging Update – Lower Lake Roosevelt Watershed (WRIA 53): Ecology Grant G-0800258

1.0 INTRODUCTION

The WRIA 53 – Lower Lake Roosevelt Watershed initiated a groundwater level gauging program during its Phase 2 Level 2 watershed planning process. This program was initiated in order to better understand the groundwater elevations and fluctuations in the three major aquifers within the WRIA 53 watershed, primarily located in northern Lincoln County as shown in Figure 1. The watershed encompasses approximately 326,164 acres, or approximately 509.63 square miles. The Columbia River bisects the watershed with 118,730 acres (185.52 square-miles) located north of the Columbia River, primarily within the boundaries of the Colville Indian Reservation, and 207,432 acres (324.11 square miles) located south of the Columbia River, that area which iss the primary focus of this assessment. In general, the watershed encompasses that portion of the Columbia River and it is tributaries between the confluence of the Spokane River to the east and the location of Grand Coulee Dam to the west.

The Groundwater Level Gauging Program was initiated in July 2009. The project consisted of:

1) Developing an informational flyer that was sent out to all property owners in the watershed to request participation of landowners in the groundwater gauging program;
2) Preparing a Quality Assurance Project Plan for the groundwater gauging program;
3) Conducting additional personal outreach to landowners to solicit their participation in the project;
4) Researching well logs and well construction attributes to determine if a well which was volunteered for gauging would be suitable for the project;

5) Performing an on-site inspection of each well to determine if access to the wells would not be restricted;
6) Preparing and signing an access agreement with each of the participating landowners;
7) Gauging the wells on a six to eight week frequency; and
8) Preparing periodic updates to the WRIA 53 Planning Unit.

Tasks 1 through 6 were completed from July through December 2009. Gauging of some wells began in late December 2009 and early January 2010. It should be noted that throughout the project, additional outreach to potential landowners was ongoing, and additional wells were added as the project progressed. Some wells were also dropped from the gauging program due to access problems.

2.0 GOALS AND OBJECTIVES

The Groundwater Level Gauging Project is funded by a watershed grant from the Washington State Department of Ecology (Ecology) for the 2010 FY, under grant number G0800258. The overall general objective of the Gauging Project is to develop a database of groundwater levels in the three distinctive aquifers that WRIA 53 can use on a long-term basis for scientifically-based water resource management and planning activities. Specific objectives include refining hydrogeologic models, identifying local groundwater flow systems, and quantitatively evaluating regional-scale and local-scale groundwater occurrence, movement, recharge, and discharge. Data can subsequently be used for future land use management decisions based on availability of groundwater resources.

The Goals for the project was to gauge 50 to 75 wells throughout the watershed for a minimum of one year. Distribution of wells throughout the three distinct aquifers was attempted, with the majority of wells within the basalt aquifer, which is the most regional aquifer and the primary water source for most water users in the watershed.

3.0 PROCEDURES AND RESPONSIBILITIES

The WNR Group, supported by its primary subcontractor GSI, is acting as the lead investigators for the Groundwater Level Gauging Project under the direction of the WRIA 53 Planning Unit and contracted through Lincoln County. The Lincoln County Conservation District (LCCD) are conducting the field activities under their MOU with Lincoln County and the supervision of Gene St.Godard, L.Hg., and Dr. Kevin Lindsey, L.Hg. Gene St.Godard is acting as the project manager and principal investigator for the consultant team. Mr. St.Godard is responsible for seeing that quality assurance goals on the Project are met and as project manager reports to Mr. Jim DeGraffenreid, Director of Lincoln County Planning and subsequently to the WRIA 53 Planning Unit. Mr. Jim DeGraffenreid of Lincoln County Planning has overall fiscal oversight and contract management responsibility under WRIA 53 grant contract with Ecology. For LCCD, the district manager, Mr. David Lundgren coordinates the field technicians for the field gauging program. LCCD staff under the direction of Mr. David Lundgren are conducting data collection activities described in the QAPP prepared for this project.

Key overall project responsibilities of each of the project participants are defined below:

1. WRIA 53 Management: Mr. Jim DeGraffenreid, Director of Lincoln County Planning, Lincoln County Board of County Commissioners
   a. Responsible for oversight of all WRIA 53 projects.
   b. Responsible for the decision and policy making process which guides project activities and day-to-day operations of the WRIA 53 Groundwater Level Gauging Project.
   c. Responsible for overall project budget tracking and periodic reporting to Ecology.

2. WNR Group & GSI
   a. Lead investigator in charge of project organization
   b. Prepare sampling plans, including the QAPP.
   c. Assist in development of spreadsheet databases in which data collected for the project is stored, perform data entry.
   d. Plan and conduct oversight activities of the hydrogeologic data collection.
   e. Conduct evaluation, and data validation activities as determined by the project scientific team.
   f. Oversee the progress of data collection, evaluation, and database compilation; provide project oversight; and check data validity.
   g. Prepare Technical Memorandum's updating the Planning Unit on the data collected.
3. LCCD
   a. Conduct field data collection.
   b. Notify WRIA 53 Management regarding unplanned activities or unforeseen circumstances affecting project data collection.
   c. LCCD field staff were trained by WNR Group and GSI and will work under sampling plans prepared by the project hydrogeologists (St.Godard and Lindsey).

In addition to these formal roles and responsibilities, the WRIA 53 project team is in regular communication with Ecology staff to share data and insights into the hydrogeology of WRIA 53 and surrounding area. While Ecology staff members are not a formal part of the WRIA 53 team, we anticipate continued discussions with them, to include but not be limited to, data sharing and peer review.

3.1 Schedule

The project schedule for the Groundwater Level Gauging Project began with in July 2009 with the public outreach portion to locate potential landowners for gauging of their groundwater wells. This activity will continue through December 2010. Field data collection began in December 2009 and is scheduled through June of 2011, depending on the continued availability of Ecology watershed funding. The actual project schedule will be dictated by data collection needs associated with watershed planning efforts, actual conditions encountered in the field, and new information and insights into the WRIA 53 groundwater conditions as the work proceeds.

3.2 Project Documents

Project documents are maintained at the Lincoln County Planning Department GIS office and the LCCD offices in Davenport, Washington. Specific Documents include:

1) Quality Assurance Project Plan for WRIA 53 – Lower Lake Roosevelt Watershed Groundwater Level Gauging Program: Northern Lincoln County, Washington, dated December 28th, 2009, completed by the WNR Group and GSI Water Solutions. This document is located within all project team members' offices, and kept on the WRIA 53 web-site and the Lincoln County Planning Department offices. A copy is also with each field technician measuring the wells.
2) Landowners access agreements. These documents are maintained at the LCCD offices in Davenport, Washington. Each field technician also has a copy of the access agreements while in the field.
3) Logs of wells being monitored. These logs were retrieved from the Ecology Water Well Log Database, and are kept within the LCCD office and the Lincoln County Planning Department offices in Davenport, Washington. Field copies are also with the field technicians sampling the wells.
4) Groundwater level databases. Draft databases and maps are compiled by the LCCD staff and sent to the Lincoln County Planning Department and WNR Group. Interpretation of field data is conducted by the WNR Group and final databases maintained at their office and the Lincoln County Planning Department office.

4.0 LOCATION OF AQUIFERS IN LOWER LAKE ROOSEVELT WATERSHED

The surficial geology of WRIA 53 is summarized in Stoffel et al. (1991), Waggoner (1990), Hansen et al. (1994), Whiteman (1994) and St.Godard (2009). The WRIA 53 watershed lies within the northern extent of the Columbia Basin. This section presents a brief review of the geologic framework of the aquifers found within the WRIA 53 area. Potable groundwater in WRIA 53 is found predominantly in: 1) Pleistocene Cataclysmic Flood deposits and younger alluvial sediments (unconsolidated alluvial valley fill aquifers), 2) Miocene continental flood basalt and intercalated sedimentary units of the Columbia River Basalt Group (CRBG), and 3) pre-basalt basement rocks (predominantly crystalline intrusive granitic rocks and metamorphic rocks).

Generally from youngest to oldest, the main geologic units found within WRIA 53 include the following:

- Holocene alluvial and colluvial deposits less than 10,000 years old.
- Pleistocene Cataclysmic Flood deposits ranging in age from approximately 12,000 years to more than 800,000 years.
- Pleistocene loess (the Palouse Formation) ranging in age from approximately 12,000 years to possibly over 1,000,000 years.
- Columbia River Basalt Group, which in WRIA 53 includes units ranging in age from approximately 14.5 million years to 16.5 million years.

- Pre-basalt basement rocks that probably include intrusive rocks over 40 million years old, and may include metasedimentary rocks greater than 600 million years old.

The CRBG is the most widespread and common of the rock types hosting potable groundwater currently being used in WRIA 53. Basalt flows of the CRBG underlie most of the WRIA except the northern and eastern edges where pre-basalt basement rocks crop out at the earth's surface. The following sections summarize the basic geologic setting of these rocks, and the folding and faulting that influences their distribution. Much of this discussion is based on regional characterization efforts on-going within the Columbia Basin Ground Water Management Area (GWMA) (GWMA, 2004, 2007a, 2007b, 2009a, 2009b, 2009c, 2009d).

4.1 Unconsolidated Alluvial Aquifers

Within WRIA 53 the suprabasalt sediment, or alluvial, aquifer system comprises all saturated sediments that overlie the CRBG and pre-basalt basement. The base of the alluvial aquifer system is defined as the top of these underlying rocks, and it is hosted predominantly by Pleistocene Cataclysmic Flood deposits. The alluvial aquifer system is unconfined, although local semi-confined conditions may be encountered. The alluvial aquifer system water table can lie as shallow as 1 ft (0.3 m) near surface water bodies, including Lake Roosevelt to over 100 feet (30 m) on the high alluvial benches found along the shores of Lake Roosevelt. Where the CRBG and pre-basalt basement is exposed at the Earth's surface and present above the unconfined water table, the alluvial aquifer system is absent.

The presence of bedrock highs acts to localize occurrences of the alluvial aquifer system. Consequently, the alluvial aquifer system generally consists of a number of small, isolated sub-systems that have no direct connection with each other. Existing geologic mapping for the WRIA (Waggoner, 1990) allows one to generally predict where these sub-systems may occur. However, a detailed evaluation of surface geology and well pumping records would be required to delineate the location, extent, and water resources associated with these local alluvial aquifer sub-systems.

Generally, the Pleistocene Cataclysmic Flood deposits that host the most productive portions of the alluvial aquifer system consist of high permeability and high effective porosity sand facies and gravel facies. These strata typically are unconfined, and measured hydraulic conductivity for this unit ranges between 2,000 to 25,000 feet/day, with effective porosity greater than 10 percent (U.S. DOE, 1988). In many cases, water wells in these strata may sustain pumping rates in excess of 2000 gpm, especially where there is a significant degree of hydraulic continuity with surface water or the physical extent of the system great enough to store enough water. However, in areas where high permeability suprabasalt aquifer materials do not have a significant connection with surface water, or the surface water body is small, or the local sediment accumulations are small, it can be relatively easy to dewater the alluvial aquifer system.

4.2 CRBG Aquifers

Numerous studies of CRBG aquifers have been conducted within the Columbia Basin to better understand their hydraulic characteristics and to develop a model of how various factors (e.g., physical characteristic/properties of CRBG flow, tectonic features/properties, erosional features, climate, etc.) interact to create and govern the CRBG groundwater system (e.g., Hogenson, 1964; Newcomb, 1961, 1969; Brown, 1978, 1979; Gephart et al., 1979; Oberlander and Miller, 1981; Livesay, 1986; Drost and Whiteman, 1986; Davies-Smith et al., 1988; USDOE, 1988; Burt, 1989; Johnson et al., 1993; Hansen et al., 1994; Spane and Webber, 1995; Wozniak, 1995; Steinkampf and Hearn, 1996; Packard et al., 1996; Sabol and Downey, 1997). One of the most significant findings of these studies is the similarity of the hydrogeologic characteristics, properties, and behavior of the CRBG aquifers across the region. This similarity allows for the application of the knowledge of the general hydraulic characteristics and behavior of the CRBG aquifers to be applied to CRBG aquifers in other areas.

Groundwater in the CRBG generally occurs in a series of aquifers hosted by the interflow zones between the flow units comprising the upper three CRBG formations (Grande Ronde, Wanapum, and Saddle Mountains) and the interstratified Ellensburg Formation. CRBG aquifers have been characterized as generally semi-confined to confined. The major water-bearing and transmitting zones (aquifers) within the CRBG are variously identified as occurring in sedimentary interbeds of the Ellensburg Formation, between adjacent basalt flows (in the interflow zones), and in basalt flow tops (Gephart et al., 1979; Hansen et al., 1994; Packard et al., 1996; Sabol and Downey, 1997; USDOE, 1988). For the region it is generally accepted that lateral hydraulic gradients and groundwater flow directions in the CRBG aquifers are predominantly down structural dip (Drost and Whiteman, 1986; USDOE, 1988).

The physical characteristics and properties of individual CRBG flows affect their intrinsic hydraulic properties and influence potential distribution of groundwater within the CRBG. Interflow zones, in comparison to dense flow interiors, form the predominant water-transmitting zones (aquifers) within the CRBG (Newcomb, 1969; Oberlander and Miller, 1981; Lite and Grondin, 1988; USDOE, 1988; Davies-Smith et al., 1988; Wozniak, 1995; Bauer and Hansen, 2000; Tolan and Lindsey, 2000). Individual interflow zones are as laterally extensive as the sheet flows between which they occur. Given the extent and thickness (geometry) of individual interflow zones, this creates a series of relatively planar-tabular, stratiform layers that have the potential to host aquifers within the CRBG. Given the typical distribution and physical characteristics of CRBG intraflow structures, groundwater primarily resides within the interflow zones. The physical properties of undisturbed, laterally extensive, dense interiors of CRBG flows result in this portion of the flow having very low permeability (Newcomb, 1969; Oberlander and Miller, 1981; Lite and Grondin, 1988; USDOE, 1988; Davies-Smith et al., 1988; Lindberg, 1989; Wozniak, 1995). While the dense interior portion of a CRBG flow is replete with cooling joints, in their undisturbed state these joints have been found to be typically 77 to +99 percent filled with secondary minerals (clay, silica, zeolite). Void spaces that do occur are typically not interconnected (USDOE, 1988; Lindberg, 1989). The fact that CRBG dense flow interiors typically act as aquitards accounts for the confined behavior exhibited by most CRBG aquifers. In many areas around the Columbia Plateau artesian (flowing) conditions and low pressure zones within the CRBG aquifer system have been encountered.

Field data and inferences based on modeling studies suggest that the hydraulic properties of CRBG aquifers are laterally and vertically complex (e.g., Drost and Whiteman 1986; USDOE, 1988; Whiteman et al., 1994; Hansen et al., 1994). Vertically averaged lateral hydraulic conductivities were estimated in Whiteman et al. (1994) to range from 7×10^{-3} to 1,892 feet/day for the Saddle Mountains, 7×10^{-3} to 5,244 feet/day for the Wanapum, and 5×10^{-3} to 2,522 feet/day for the Grande Ronde aquifers. Hydraulic conductivity of dense basalt flow interiors, where they can even be measured, have been estimated to be 5 orders of magnitude, or less, than flow tops (USDOE, 1988). The available data on hydraulic properties of the various CRBG aquifers, including permeability, porosity, and storativity, indicate that a large variability in local flow characteristics is expected.

Aquifers within the CRBG are typically found at depths of greater than 100-feet below grade. Recharge to the shallow basalt aquifers is most likely a result of direct precipitation and recharge from the unconsolidated valley fill aquifers. Recharge to the deeper CRBG aquifers, deeper than 200 feet, is not defined at this time, but is most likely recharged from distant recharge areas, and/or ancestral Glacial Lake Missoula flood waters, as defined from the age dating completed by the GWMA study showing many CRBG aquifers have water dated at greater than 10,000 years old.

4.3 Granitic Bedrock Aquifers

The granitic bedrock aquifers are primarily located in the northwestern part of the Lower Lake Roosevelt Watershed (west of Lincoln) and in several smaller areas in the east central portion of the watershed. Well logs reviewed determined that water supply wells withdraw water primarily from fractures within granites at depths greater than 100 feet. However, yields are generally low.

5.0 RESULTS OF GROUNDWATER GAUGING

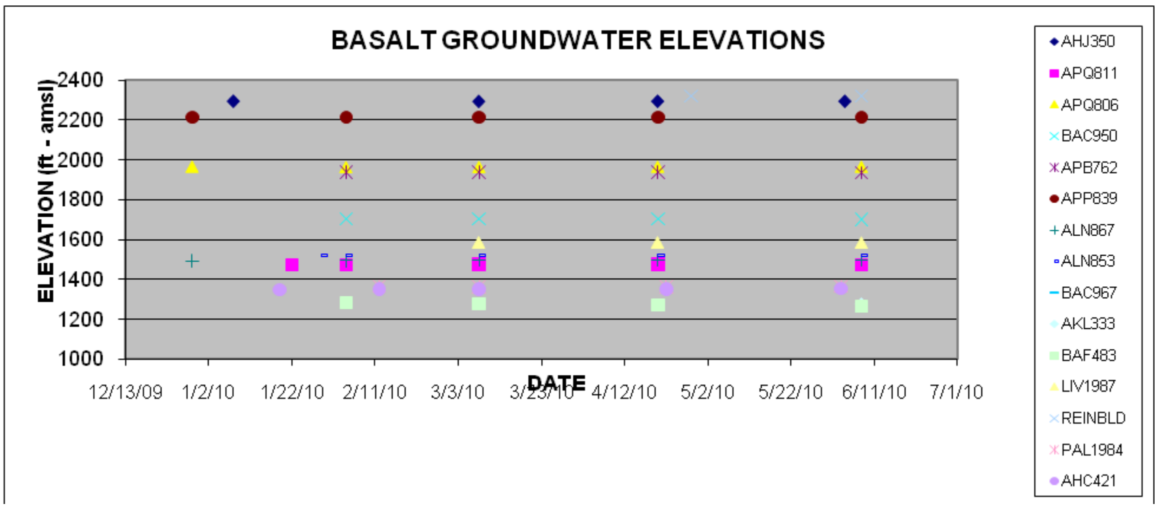
Lincoln County Planning Department mailed out over 300 solicitation letters to landowners throughout the watershed. Approximately 50 responses were received by Lincoln County from landowners who were interested in participating in the Groundwater Gauging Project. In addition, approximately 15 other landowners volunteered to participate whom were contacted through the public outreach program. From these, 58 wells were selected for participation in the project. Twelve of the eight were eventually dropped out of the project due to downhole access problems with gauging the wells.

Water level measurements are collected using a Solinist e-tape and a WL650/200U sonic meter. The Solinist e-tape provides a more accurate reading to the depth of groundwater and is preferred over the sonic meter readings. Prior to collecting any groundwater measurements, the well was measured for latitude and longitude using a handheld field GPS unit. Measurements were entered into the County's GIS system and elevations of the wellheads were determined and recorded in NAVD88 format. Measurements are recorded and maintained at the Lincoln County Planning GIS Department.

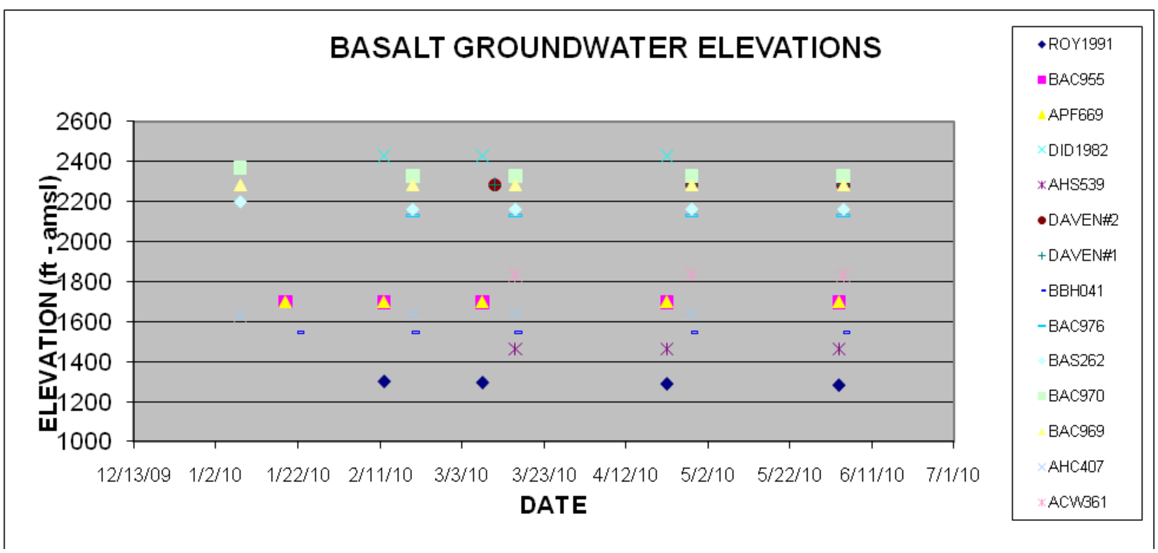
A total of 46 wells are currently be gauged in the WRIA 53 Groundwater Gauging Project. Figure 1 shows the location of the wells being gauged for the project.

5.1 Basalt Wells

Thirty-five (35) wells which withdraw groundwater from the basalt aquifers are currently being gauged for the project. Some wells have been monitored a maximum of five (5) times, while others have only one or two measurements, as they were added later in the project during the spring months. Table 1 presents a summary of the gauging measurements collected in the basalt wells. As shown on the Table, and within Graph 1, Graph 2, and Graph 3, no major fluctuations in groundwater have been observed to date.



Graph 1: Graph showing Basalt Groundwater Elevations in 15 Wells.



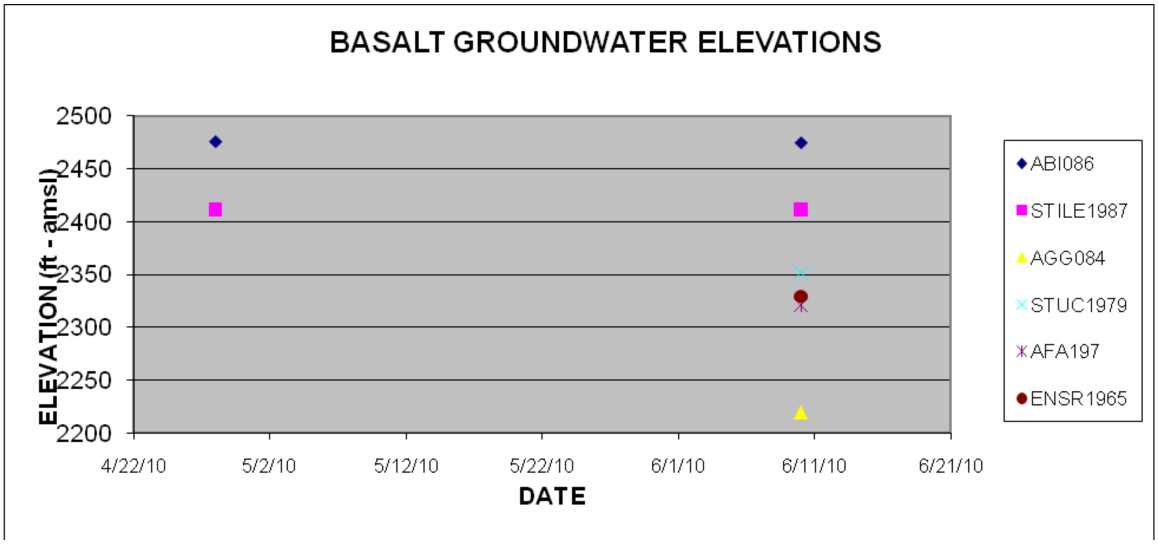
Graph 2: Graph showing Basalt Groundwater Elevations in 14 Wells

TABLE 1: SUMMARY OF WATER LEVEL ELEVATIONS IN BASALT WELLS

Date	AHJ350	APQ811	APQ806	BAC950	APB762	APP839	ALN867	ALN853	BAC967	AKL333	BAF483	LIV1987	REINBLD	PAL1984	AHC421
12/29/2009			1966.74			2214.00	1493.35								
1/8/2010	2293.54														
1/19/2010															1350.46
1/22/2010		1475.15													
1/29/2010								1519.08							
2/4/2010		1474.85	1964.03	1703.94	1939.59	2214.10	1494.98	1519.30	1285.99		1282.50				
2/12/2010														1366.20	1352.88
3/8/2010	2292.64	1475.49	1965.23	1703.64	1938.99	2214.26	1495.80	1520.06	1279.39		1276.60	1585.94		1364.70	1353.03
3/16/2010															
4/20/2010	2293.22	1475.99	1966.39	1703.74	1938.59	2214.28	1496.48	1521.15	1272.39	1274.43	1271.20	1585.74			
4/22/2010														1365.30	1353.03
4/28/2010													2322.90		
6/3/2010														1366.30	1354.22
6/4/2010	2293.10														
6/8/2010		1475.47	1966.23	1702.24	1937.17	2214.13	1496.17	1520.93	1279.89	1279.73	1266.80	1584.94	2321.90		

Date	ROY1991	BAC955	APF669	DID1982	AHS539	DAVEN#2	DAVEN#1	BBH041	BAC976	BAS262	BAC970	BAC969	AHC407	ACW361
1/8/2010										2198.29	2370	2282.94	1632.22	
1/19/2010		1698.13	1700.18											
1/22/2010								1548.11						
2/12/2010	1300.44	1697.61	1700.48	2428.22										
2/19/2010								1548.18	2129.77	2160.69	2327.99	2282.9	1638.42	
3/8/2010	1295.05	1697.53	1700.43	2427.82										
3/11/2010						2285.42	2286.65							
3/16/2010					1462.95			1548.26	2129.75	2161	2328.1	2282.71	1640.31	1833.28
4/20/2010														
4/22/2010	1288.78	1697.68	1700.5	2427.62	1461.64									
4/28/2010						2285.79	2286	1548.33	2129.56	2161.99	2328.15	2283.03	1637.27	1834.38
6/3/2010	1282.43	1697.62	1700.48		1462.61									
6/4/2010						2284.84	2285.98	1548.26	2129.36	2161.09	2327.81	2282.42		1831.78

Date	ABI086	STILE1987	AGG084	STUC1979	AFA197	ENSR1965
4/28/2010	2476.19	2411.73				
6/10/2010	2475.08	2411.84	2219.15	2352.08	2321.1	2329.65



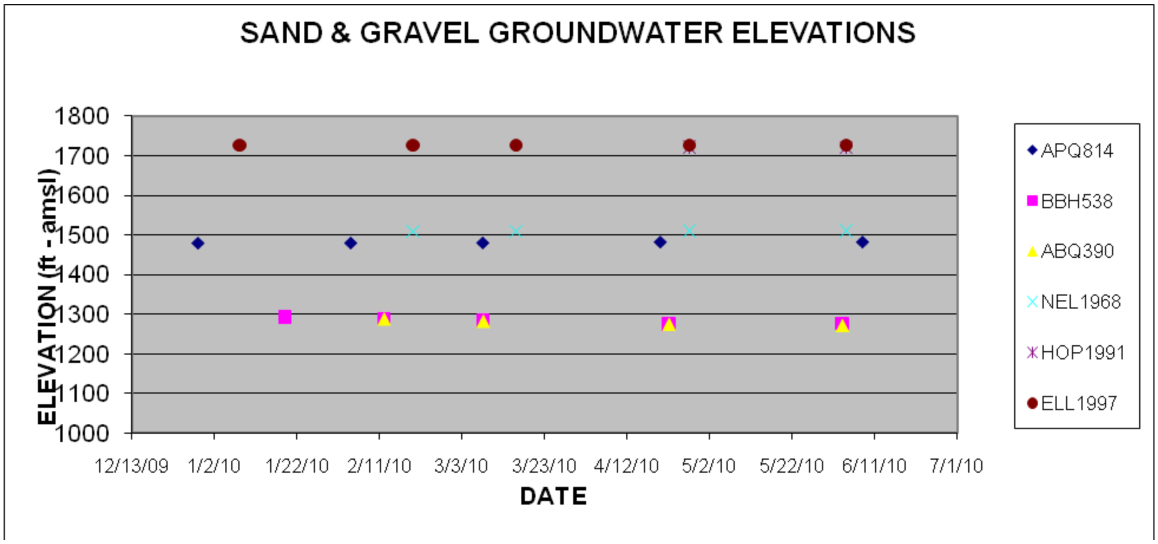
Graph 3: Graph showing Groundwater Elevations in Five Recently Monitored Basalt Wells

5.2 Sand & Gravel Wells

Six (6) wells which withdraw groundwater from the sand & gravel aquifers are currently being gauged for the project. Three Sand & gravel wells have been gauged five times, two have been gauged four times, and one gauged two times. Table 2 presents a summary of the gauging measurements collected in the sand & gravel wells. As shown on the Table, and within Graph 4, no major fluctuations in groundwater have been observed to date in the sand & gravel wells.

TABLE 2: SUMMARY OF WATER LEVEL ELEVATIONS IN SAND & GRAVEL WELLS

Date	APQ814	BBH538	ABQ390	NEL1968	HOP1991	ELL1997
12/29/2009	1479.37					
1/8/2010						1726.38
1/19/2010		1292.42				
2/4/2010	1479.72					
2/12/2010		1288.35	1287.01			
2/19/2010				1509.48		1726.93
3/8/2010	1480.06	1283.30	1281.41			
3/16/2010				1509.83		1726.92
4/20/2010	1482.22					
4/22/2010		1275.36	1273.71			
4/27/2010				1510.87	1722.72	1726.81
6/3/2010		1276.84	1270.61			
6/4/2010				1510.09	1721.12	1726.41
6/8/2010	1482.25					



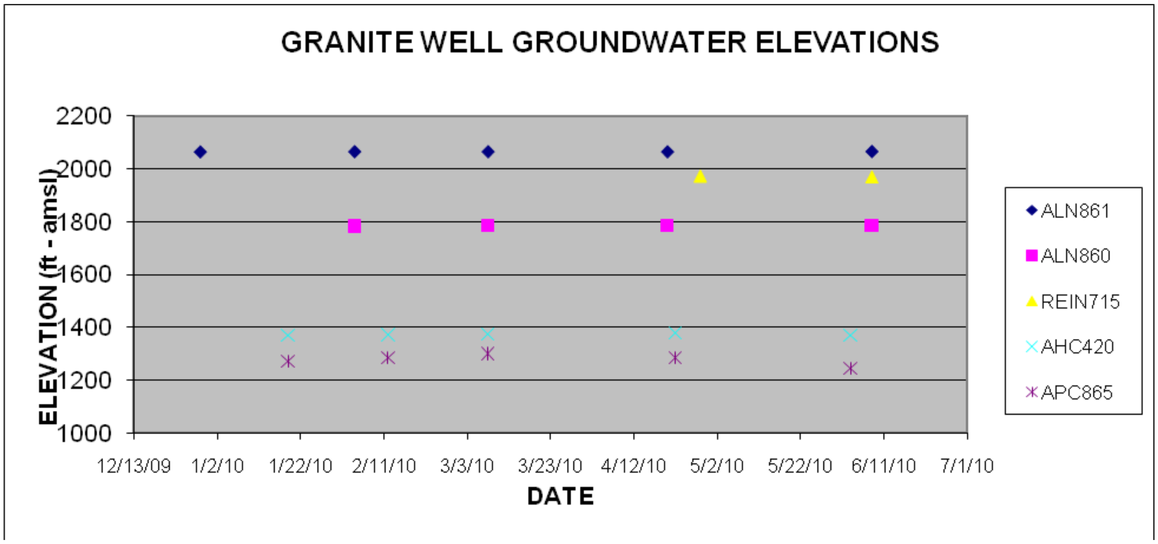
Graph 4: Graph showing Groundwater Elevations in Sand & Gravels Wells

5.3 Granite Wells

Five (5) wells which withdraw groundwater from the basement (granite) aquifers are currently being gauged for the project. Three Granite wells have been gauged five times, one has been gauged four times, and one gauged two times. Table 3 presents a summary of the gauging measurements collected in the granite wells. As shown on the Table, and within Graph 5, no major fluctuations in groundwater have been observed to date.

TABLE 3: SUMMARY OF WATER LEVEL ELEVATIONS IN GRANITE WELLS

Date	ALN861	ALN860	REIN715	AHC420	APC865
12/29/2009	2063.84				
1/19/2010				1369.71	1272.53
2/4/2010	2064.74	1783.14			
2/12/2010				1372.96	1284.83
3/8/2010	2064.88	1785.75		1375.50	1300.61
4/20/2010	2064.39	1786.39			
4/22/2010				1379.25	1285.63
4/28/2010			1972.49		
6/3/2010				1370.41	1245.63
6/8/2010	2065.45	1785.47	1969.19		



Graph 5: Graph showing Groundwater Elevations in Granite Wells

6.0 CONCLUSIONS AND PATH FORWARD

Currently, 35 basalt groundwater wells, six sand & gravel wells, and five granite wells are being gauged under the WRIA 53 Groundwater Gauging Project. The Gauging program has been occurring for a period of six months (12/29/09 through 6/10/10). No major fluctuations in groundwater elevations have been observed to date. However, gauging has only occurred through the winter and spring months. In addition, a wet spring has also occurred. At the time of this memo, the irrigation season was just beginning. In order to fully observe the influences of seasonal fluctuations, a minimum of one year of data collection must occur.

The WRIA 53 Planning Unit will continue to gauge the wells through June 2011. A detailed report on the findings of the gauging project will be prepared by June 30th, 2011.

7.0 REFERENCES

Brown, J.C., 1978, Discussion of geology and ground-water hydrology of the Columbia Plateau with specific analysis of the Horse Heaven Hills, Sagebrush Flat, and Odessa-Lind areas, Washington: Washington State University, Pullman, Washington, College of Engineering Research Report 78/15-23, 51 p.

Brown, J.C., 1979, Investigation of stratigraphy and groundwater hydrology, Columbia River Basalt Group, Washington: Washington State University, College of Engineering Research Division Research Report 79/15-37, 60 p.

Burt, W.C., 1989, The hydrogeology of structurally complex basalts in Black Rock and Dry Creek Valleys, Washington: University of Idaho, Moscow, Idaho, M.S. thesis, 78 p.

Davies-Smith, A., Bolke, E.L., and Collins, C.A., 1988, Geohydrology and digital simulation of the ground-water flow system in the Umatilla Plateau and Horse Heaven

Hills area, Oregon and Washington: U.S. Geological Survey Water-Resources Investigations Report 87-4268, 72 p.

Drost, B.W. and Whitman, K.J., 1986, Surficial geology, structure, and thickness of selected geohydrologic units in the Columbia Plateau, Washington: U.S. Geological Survey Water-Resources Investigations Report 84-4326.

Gephart, R.E., Arnett, R.C., Baca, R.G., Leonhart, L.S., Spane, F.A., Jr., 1979, Hydrologic studies within the Columbia Plateau, Washington - an integration of current knowledge: Richland, Washington, Rockwell Hanford Operations, RHO-BWI-ST-5.

GWMA, 2007a, Geologic framework of selected suprabasalt sediment and Columbia River Basalt Units in the Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, Washington, Ed. 2: Consultants report prepared for Columbia Basin GWMA by GSI Water Solutions, Inc. and Franklin Conservation District, August 2007.

GWMA, 2007b, Geologic framework of the suprabasalt sediment aquifer system, Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, Washington: Consultants report prepared for Columbia Basin GWMA by GSI Water Solutions, Inc. and Franklin Conservation District, August 2007.

GWMA, 2009a, Hydrogeologic Framework of the Columbia River Basalt (CRBG) aquifer system, Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, Washington: Consultants Report (in review) prepared for Columbia Basin GWMA by GSI Water Solutions, Inc. and S.S. Papadopoulos and Associates, Inc., May 2009.

GWMA, 2009b, Geologic Framework of selected the Columbia River Basalt units in the Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, Washington: Consultants Report (in review) prepared for Columbia Basin GWMA by GSI Water Solutions, Inc. and Franklin Conservation District, May 2009.

GWMA, 2009c, Groundwater geochemistry of the Columbia River Basalt Group Aquifer System: Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, June 2009: Consultants report prepared for the Columbia Basin GWMA by GSI Water Solutions, Inc. and S.S. Papadopulos and Associates, Inc.

GWMA, 2009d, Groundwater level declines in the Columbia River Basalt Group and their relationship to mechanisms for groundwater recharge: A conceptual groundwater system model: Columbia Basin Ground Water Management Area of Adams, Franklin, Grant, and Lincoln Counties, June 2009: Consultants report prepared for the Columbia Basin GWMA by GSI Water Solutions, Inc. and S.S. Papadopulos and Associates, Inc.

Hansen, A.J., Jr., Vaccaro, J.J., and Bauer, H.H., 1994, Ground-water flow simulation of the Columbia Plateau regional aquifer system, Washington, Oregon, and Idaho: U.S. Geological Survey, Water-Resources Investigations Report 91-4187, 81 p.

Hogenson, G., 1964, Geology and ground water of the Umatilla River basin, Oregon: U.S. Geological Survey Water-Supply Paper 1620, 162 p.

Johnson, V.G, D.L. Graham and S.P. Reidel (1993) Methane in Columbia River Basalt aquifers: Isotopic and geohydrologic evidence for a deep coal-bed gas source in the Columbia Basin, Washington. American Association of Petroleum Geologists Bulletin 77:1192-1207.

Livesay, D.M., 1986, The hydrogeology of the upper Wanapum Basalt, upper Cold Creek Valley, Washington: Washington State University, Pullman, Washington, M.S. thesis, 159 p.

Morgan, Laurie, January 2005, Critical Aquifer Recharge Areas – Guidance Document, Washington State Department of Ecology Publication #05-10-028, 63 p.

Newcomb, R.C., 1961, Storage of ground water behind subsurface dams in the Columbia River basalt, Washington, Oregon, and Idaho: U.S. Geological Survey Professional Paper 238A, 15 p.

Newcomb, R.C., 1969, Effect of tectonic structure on the occurrence of ground water in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U.S. Geological Survey Professional Paper 383-C, 33 p.

Oberlander, P.L. and Miller, D.W., 1981, Hydrologic studies in the Umatilla structural basin - an integration of current knowledge: Oregon Department of Water Resources, unpublished preliminary report, 41 p.

Packard, F.A., Hansen, A.J., Jr., and Bauer, H.H., 1996, Hydrogeology and simulation of flow and the effects of development alternatives on the basalt aquifers of the Horse Heaven Hills, south-central Washington: U.S. Geological Survey Water-Resources Investigations Report 94-4068, 92 p.

Sabol, M.A., and Downey, S.E., 1997, Support document for consideration of the eastern Columbia Plateau aquifer system as a sole-source aquifer: Seattle, Washington, U.S. Environmental Protection Agency, Document 910/R-97-002, 35 p.

Spane, F.A. and Webber, W.D., 1995, Hydrochemistry and hydrogeologic conditions within the Hanford Site upper basalt confined aquifer system: Battelle Pacific Northwest Laboratory, Richland, Washington, Report PNL-10817, 40 p.

Spane, F.A., Jr., and W.D. Webber (1995) Hydrochemistry and Hydrogeologic Conditions Within the Hanford Site Upper Basalt Confined Aquifer System. PNL-10817, Pacific Northwest Laboratory, Richland, Washington.

St.Godard, Eugene N.J., (2009) Water Resource Inventory Area 53 – Lower Lake Roosevelt Watershed: Phase 2 – Level 1 Hydrogeologic Technical Assessment, prepared by the Water & Natural Resource Group for the WRIA 53 Planning Unit, 111 p, plus appendices.

Steinkampf, W.C. and P.P. Hearn (1996) Ground-water geochemistry of the Columbia Plateau regional aquifer system, Washington, Oregon, and Idaho: U.S. Geological Survey Open-File Report 95- 467.

Steinkampf, W.C., and Hearn, P.P., Jr., 1996, Ground-water geochemistry of the Columbia Plateau aquifer system, Washington, Oregon, and Idaho: U.S. Geological Survey Open-File Report 95-467, 67 p.

Stoffel, K.L., N.L Joseph, S.Z Waggoner, C.W. Gulick, M.A. Korosec, and B.B. Bunning. 1991 Geologic Map of Washington – Northeast Quadrant. Geologic Map GM-39. Washington Department of Natural Resources, Division of Geology and Earth Resources.

USDOE (U.S. Department of Energy), 1988, Site characterization plan, Reference Repository Location, Hanford Site, Washington - consultation draft: Washington, D.C., Office of Civilian Radioactive Waste Management, DOE/RW-0164, v. 1 - 9.

Waggoner, S.Z. 1990. Geologic Map of the Coulee Dam 1:100,000 Quadrangle, Washington. Open File Report 90-15. Washington Division of Geology and Earth Resources. 40 pp., 1 plate.

Whitehead, R.L., 1992,4, Groundwater Atlas of the United States, Segment 7: Idaho, Oregon, Washington. USGS Hydrologic Investigation Atlas730-H, Reston, VA, 31 p.

Whiteman, K.J., J.J. Vaccaro, J.B. Gonthier, and H.H. Bauer. 1994, The Hydrogeologic Framework and Geochemistry of the Columbia Plateau Aquifer System, Washington, Oregon and Idaho, regional Aquifer System Analysis. USGS Professional Paper 1413-B. U.S. Geological Survey, Tacoma, Washington.

Wozniak, K.C., 1995, Chapter 2 - Hydrogeology, *in*, Hydrogeology, groundwater chemistry, and land uses in the lower Umatilla Basin Groundwater Management Area, northern Morrow and Umatilla Counties, Oregon - Final Review Draft: Salem, Oregon, Oregon Department of Environmental Quality Report, p. 2.1-2.80.

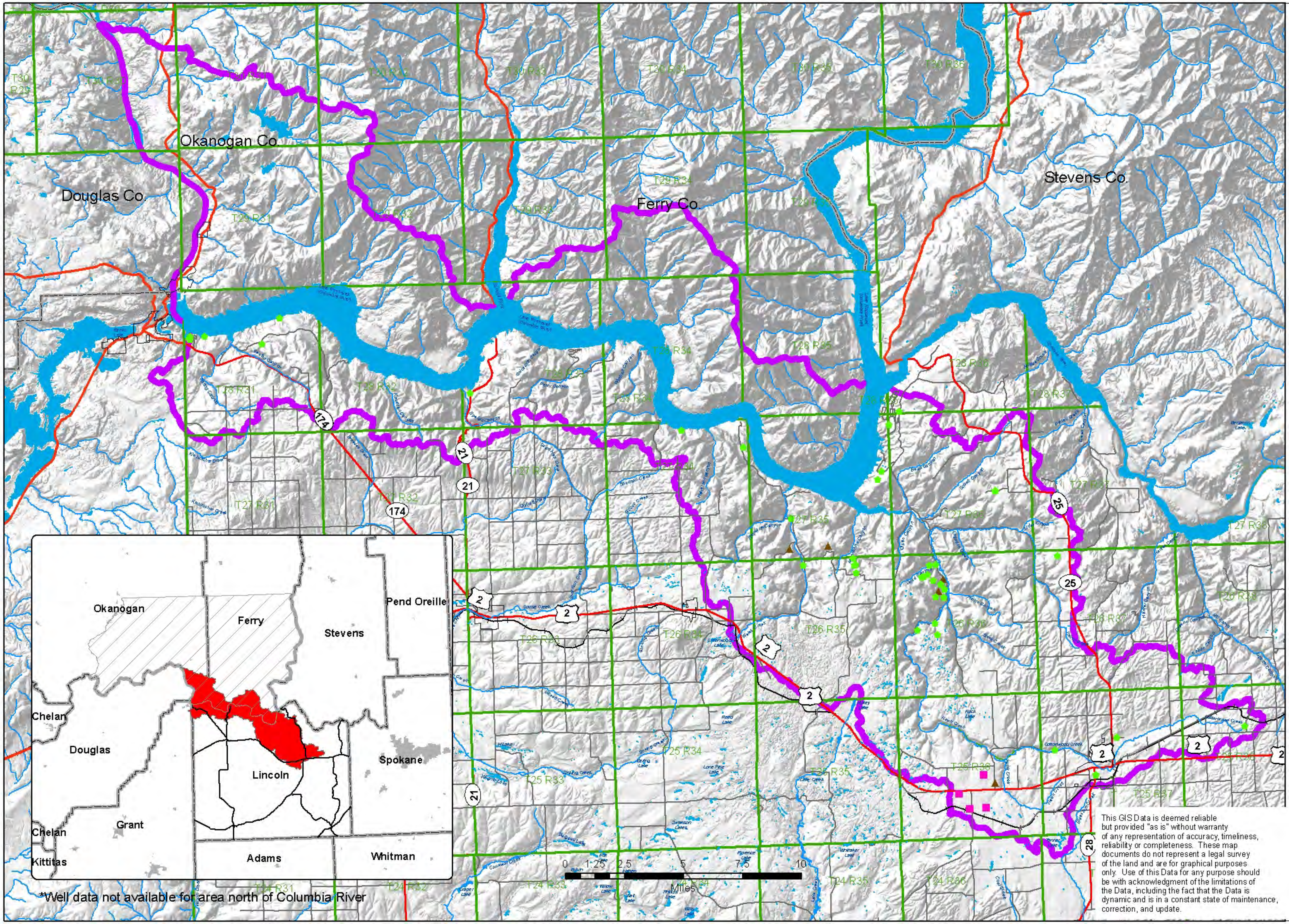


Figure 1

Groundwater Monitoring Wells

Critical Aquifer Recharge Area (CARA)

Dropped Wells
No Water Reached
Water Level Measured
WRIA 53 Bnd
Roads
Highways

N W E S

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