West Plains (WRIA 54) & Lower Hangman Creek Watershed (WRIA 56) Hydrogeologic Characterization & Monitoring Well Drilling Final Report

An Addendum to:

Hangman Creek Watershed (WRIA 56) Hydrogeologic Characterization & Monitoring Well Drilling Final Report

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1 Executive Summary

This report summarizes the results of work conducted in the West Plains of WRIA 54 and the lower Hangman watershed in WRIA 56 to improve the hydrogeologic characterization of the area and install four new monitoring wells. It is an addendum to the *Hangman Creek Watershed (WRIA 56) Hydrogeologic Characterization & Monitoring Well Drilling Final Report* (NLW, 2011).

Four monitoring wells were installed. Two are located in the West Plains and completed in the deep basalt aquifer. Two are located in the Lower Hangman watershed, with one completed in the intermediate unconsolidated deposits aquifer and the other in the shallow unconsolidated deposits aquifer.

The hydrogeology of the West Plains and Lower Hangman watershed was characterized using existing well logs and information from the new monitoring wells.

In general, the vertical gradient is downward throughout the study area except in the vicinity of MW-9, where it is upward and the deep basalt aquifer is under flowing artesian conditions.

Stable isotope and age data for groundwater beneath the West Plains indicates that mixing of younger shallow groundwater with and deep older groundwater is a dominant mechanism in the West Plains. Mixing can occur via deep wells that serve as conduits and coarse unconsolidated deposits directly overlying and recharging the deep groundwater. This is different from flow dynamics in the middle and lower Hangman Creek watershed area, which shows less mixing of shallow and deep groundwater.

Groundwater age dates are thousands of years and indicate potential for low recharge rates and/or long travel paths. This finding warrants caution for future development of groundwater from these aquifers.

2 Introduction

This report summarizes the results of work conducted in the West Plains of WRIA 54 and the Lower Hangman watershed in WRIA 56 to improve the hydrogeologic characterization of the area with data from four new monitoring wells. It serves as an addendum to the *Hangman Creek Watershed (WRIA 56) Hydrogeologic Characterization & Monitoring Well Drilling Final Report* (NLW, 2011). Relevant sections of the Characterization Report are referenced herein rather than repeated.

2.1 Background

The Spokane County Conservation District (SCCD) was motivated to initiate a hydrogeologic study in 2010 to address concerns about anticipated population growth and associated land and groundwater development in the Hangman Creek watershed. That study entailed drilling and testing six monitoring wells and developing a conceptual hydrogeologic model using geologic, hydraulic, and geochemical data collected during field investigations. The conceptual model also incorporated data from the Washington Department of Ecology's (Ecology's) well log database, along with seepage and surface water data from SCCD. The monitoring wells were installed at key locations in the Hangman Creek watershed to provide data for evaluating long-term groundwater trends.

The Characterization Report (NLW, 2011) outlined recommendations for additional work to fill knowledge gaps about:

- The relationship between groundwater in the Marshall Creek sub-basin (WRIA 56) and the West Plains (WRIA 54)
- Groundwater resources in the lower Hangman Creek watershed

There are concerns regarding sustainable groundwater development in the West Plains of WRIA 54, especially where there are localized areas of substantial water level decline and wells going dry.

As in WRIA 56, planners in WRIA 54 are also concerned that future groundwater development may impact groundwater supplies for current users and groundwater discharge to creeks. These planners strive to answer the fundamental question, "What is sustainable groundwater development?"

These recommendations and concerns formed the basis for the scope of work for this investigation.

2.2 Purpose & Scope

The ultimate purpose of this work was to develop information that will allow planners and community members to make informed decisions about future groundwater development. This information will be critical to protecting not only drinking water supplies but also local creek flows.

This study focused on installing monitoring wells and characterizing the hydrogeologic system—more specifically, the hydraulic connections—at key locations within in the lower Hangman watershed and the West Plains. These locations include the Lower Hangman and Marshall Creek sub-basins, where a bedrock ridge affects regional groundwater flow patterns and in the West Plains where concerns about water resources have been reported. This work included:

- Preparing cross sections to characterize the hydrogeology within the West Plains of WRIA 54 and the lower Hangman watershed of WRIA 56 (including Marshall Creek sub-basin)
- Installing monitoring wells in key areas and conducting tests to identify aquifer properties and collect groundwater samples
- Analyzing samples from the monitoring wells and from existing wells (collected by Spokane County) for routine constituents and several naturally occurring isotopes —oxygen-18 (^{18}O), deuterium (D), carbon-13 (^{13}C), carbon-14 (^{14}C), and tritium
- Incorporating the hydrogeologic, water level, and chemistry data into a conceptual model that describes the groundwater flow system within and between the West Plains of WRIA 54 and the lower Hangman watershed of WRIA 56 (including Marshall Creek sub-basin)

2.3 Study Area

The study area for this investigation is shown on **Figure 2-1**. It includes most of the lower Hangman and Marshall sub-basins of WRIA 56, the West Plains of WRIA 54, and those parts of WRIA 34 and 43 that lie within the wedge shape between WRIA 54 and 56.

The West Plains is a relatively flat landscape that includes the deeply incised Deep Creek to the northwest, Hangman Creek and the Spokane River to the east, and topographic highs to the south that form the boundaries with WRIAs 34, 43, and 56. The relationship of this area to the regional Columbia River system is shown in the Characterization Report (NLW, 2011).

2.4 Warranty

This work was requested by the SCCD and completed by Northwest Land & Water, Inc. (NLW). It was performed, and this draft final report was prepared, in accordance with hydrogeologic practices generally accepted at this time, in this area, for the exclusive use of the SCCD, for specific application to the study area. No other warranty, express, or implied, is made.

3 Monitoring Wells

Four monitoring wells were installed in three key areas in spring 2012. Their locations are shown on **Figure 2-1**. At each well, geologic logging, hydraulic testing, and geochemical sampling were conducted. The wells were configured to allow long-term water level monitoring. Drilling, testing, and sampling were completed in accordance with a quality assurance plan (NLW, 2012).

Table 3-1: New wells installed during this study

Well	Location	Depth (ft)
MW-7	Marshall Pit near Marshall	360
MW-8	Hayford Pit near Airway Heights	370.5
MW-9	Lower Hangman Valley	116
MW-10	Lower Hangman Valley	46.5

Geologic logs and construction details are shown for MW-7 through MW-10 on **Figures 3-1 through 3-4,** respectively. The monitoring well identifiers for this study continue sequentially from those installed during 2010–2011 (wells MW-1 through MW-6; NLW, 2011).

The locations for wells MW-7 and MW-8 were selected to investigate conditions in an area of projected population growth and industrial / commercial land development. Groundwater development is likely to occur in the Marshall Creek sub-basin and generally northward in the West Plains. MW-7 is located in the Marshall Creek sub-basin of WRIA 56 and also provides insights into groundwater flow between WRIA 56 and 54.

The locations for MW-9 and MW-10 were selected to provide insights into groundwater flow from the mid to lower Hangman Creek watershed. The borehole for MW-9 was drilled into a deep basalt aquifer in the Lower Hangman Valley but completed in an intermediate zone. Well MW-10 was drilled at the same site and completed in shallow sediments. This configuration was designed not only to characterize hydrogeologic conditions at a range of depths but also to facilitate long-term water level monitoring in an area where local land and well owners are concerned about groundwater sustainability. Furthermore, shallow MW-10 was installed to improve the understanding of groundwater / surface water (Hangman Creek) interactions.

The wells were drilled by H2O Well Services, Inc., of Hayden Lake, Idaho, using an air-rotary Speedstar 30K. This 1150CFM/350psi rig was equipped with downhole tools, including tri-cone and hammer bits. The borehole was advanced via 6- and/or 8-inch “open-hole” drilling. Local intervals were “cased-off” with either with 6- or 8-inch steel casing.

For each well except MW-10, drilling was temporarily suspended at the shallow or intermediate aquifer to allow testing and sampling. Drilling continued into a deeper aquifer in which the monitoring well was installed. The deeper zone was also tested and sampled.

3.1 MW-7

MW-7 is located within the Marshall Creek sub-basin at Spokane County’s Marshall Pit near the town of Marshall. Along the pit’s eastern wall, an in-situ basalt outcrop appears at an estimate depth of 50 feet or less below ground. In contrast, and as described below, the top of basalt in MW-7 was encountered at 222 feet below ground, indicating a steep, subsurface, basalt “canyon” in the pit vicinity.

Two boreholes were drilled at the MW-7 site. The first was abandoned after it could not be advanced below 262.5 feet because the drill bit broke off its shank and could not be retrieved. A second borehole, located about 75 feet away, was advanced to 365 feet. It was completed with six-inch casing, which was driven to 222 feet, and the remainder was drilled “open hole” through basalt. A screen was placed from 345 to 360 feet.

Borehole 1. Deposits of sand and minor layers of gravel or silt/clay were encountered from 0 to 222 feet. The first water-bearing zone, encountered from 233 to 240 feet, occurs in a fractured zone within the upper part of a basalt unit. At 262.5 feet, drilling was suspended, and the interval from 233 to 240 feet was tested and sampled.

Borehole 2. Relatively dense basalt was encountered from 240 to 355 feet, followed by a productive water-bearing zone from 355 to 360 feet in predominantly fractured basalt. Logs for neighboring wells indicate that this water-bearing zone is a sub-regional aquifer that occurs near the basalt-Latah (clay) interface.

3.2 MW-8

MW-8 is located in the West Plains area at Spokane County’s Hayford Pit. The well site lies about 2 miles northeast of downtown Airway Heights, in an area known to have low-to-moderately productive basalt aquifers.

MW-8 was drilled to 380 feet. Eight-inch casing was driven to 18 feet. From 18 to 202 feet, 8-inch open-hole drilling continued. Six-inch casing was lowered to 202 feet (to control loose sand) and driven to 210 feet. The remainder of the borehole (to a depth of 380 feet) was drilled 6-inch open-hole through basalt. A screen was placed from 354 to 368 feet.

A small amount of water (1 gpm) was encountered at 100 feet and increased to 5 gpm at 135 feet. The zone from 100 to 105 was tested and sampled. The first significant water-bearing zone was encountered in a thin, fractured basalt zone (140 to 141 feet) overlying clay. This 1-foot aquifer yielded about 60 gpm during airlifting. Drilling continued to 202 feet within the Latah formation; airlifting from 202 feet yielded about the same rate of 60 gpm, indicating that the water is predominantly from the basalt fracture (140-141 feet). However, a sand zone, 25 feet thick, was encountered and water contribution from it was not discernable but it may yield some water. A second pumping test was conducted and a sample was collected. Drilling resumed and Latah formation was encountered to 210 feet. The 69 feet (141 to 201 feet) of Latah Formation included a sequence of clay, shale, silt, and clean sand. Relatively dense basalt was drilled from 210 to 354 feet. From 354 to 365 feet a sub-regional aquifer of fractured and vesicular basalt yielded approximately 60 gpm during airlifting. The borehole was advanced through dense basalt from 365 to 380 feet.

3.3 MW-9 & MW-10

Located about 1.7 miles south of the intersection of Hatch and Hangman Valley Roads on a private property, MW-9 and MW-10 are 15 feet apart.

MW-9 was drilled to 300 feet. Six-inch casing was driven through alluvial and glaciofluvial sand (some gravel), silt, and clay from 0 to 220 feet. This casing was also advanced from 220 to 223 through "broken" basalt and silt. The remaining borehole was drilled as 6-inch open hole from 223 to 300 feet.

A shallow sand aquifer was encountered from 35 to 55 feet. The 6-inch casing was driven to the bottom of this interval and a pump was installed to sample this shallow aquifer. Water pumped from this zone became increasingly silty and the test was aborted. An "intermediate," relatively thick sand (locally with gravel and silt) aquifer was then encountered from 78 to 203 feet.

A zone of slightly fractured basalt from 265 to 295 produced about 1 gpm of water. A productive zone of fractured basalt from 295 to 300 feet produced about 60 gpm during airlifting. Groundwater continued to flow upward and discharge out of the well casing after the air was shut off, revealing a flowing artesian condition.

The well was shut in, and a valve and pressure gauge was installed. The pressure gauge read 13 psi on May 17, 2012. Ecology, the administrative staff at SCCD, and the property owner were consulted on how to manage this flowing well in perpetuity; all parties agreed that the flowing well should be sealed with cement. Prior to cement sealing, groundwater samples were collected for a full suite of geochemical analyses. Multiple batches of cement were pumped into the borehole and displaced to the lowermost part of the hole to seal the aquifer and stop the flowing artesian condition. Bentonite grout was placed above the cement to a depth of 200 feet.

The cased part of the hole was completed as MW-9; the screen was set from 101.5 to 111.5 feet. This well is screened in the upper part of the "intermediate" aquifer at this site.

The drill rig was moved approximately 15 feet northeast of MW-9 and a shallow borehole was drilled and cased to a total depth of 47.5 feet. This well, MW-10, was screened from 39 to 54 feet, within the relatively clean shallow sand aquifer encountered from 35 to 47.5 feet. This is the approximate depth of the shallow aquifer tapped by other nearby wells.

Note that the screened interval for the shallow aquifer (MW-10) is separated from the underlying "intermediate" aquifer (MW-9) by an aquitard, which occurs from 55 to 78 ft.

4 Hydrogeology

Because the study area for this investigation overlaps with that of WRIA 56, much of the relevant hydrogeology was covered in the Characterization Report (NLW, 2011). This discussion references parts of the Characterization Report and focuses on information that is germane to this investigation.

4.1 Methodology

4.1.1 Data Sources

Digital elevation data was used to construct cross-sections and estimate wellhead elevations. In addition to the logs for the new monitoring wells, data sources included wells in Ecology's database (Ecology, 2003). Spokane County's geologic database (GDB), provided by Mike Hermanson (pers. comm. 2011), includes some wells that are not in Ecology's database. The geologic layer surfaces associated with the Spokane County GDB were incorporated into the project hydrogeologic model. Wells used in the cross-sections are listed in **Addendum Appendix E**. **Appendix E** provides well identification numbers. To view a specific driller's log, type this number in the form on Ecology's website (http://apps.ecy.wa.gov/welllog/).

4.1.2 Well Locations

Accurate well locations are required to calculate land surface elevations from the digital elevation data. Ecology's database typically provides well-location coordinates at the center of the quarter-quarter section indicated on the drillers' log. Unfortunately, this information is often missing or incorrect. Consequently, these locations were refined whenever possible to improve their accuracy, using various methods.

Wells in the geologic database, which had been field-located, were used when available. Mike Hermanson also provided improved locations for some additional wells. For wells that were included in only the Ecology database (and no other sources), the locations were refined using parcel information, if a parcel identification (PID) was specified. If a well could be associated with a parcel, then the location was modified using GIS to identify the center of the parcel. If no PID was available, the taxpayer and well owner names were compared to correlate the wells to parcels. These correlations were mapped and reviewed; associations were made only if the well was located near the parcel. If no parcel information was available, the address on the well log was mapped using Google and/or GIS. Coordinates were obtained using GIS.

4.1.3 Drillers' Logs

The methodology for analyzing drillers' logs is described in the Characterization Report (NLW, 2011). For this investigation, lithologic data for 94 wells and water level data for 83 wells were incorporated into the project database.

4.1.4 Hydrogeologic Cross-Sections

Figure 4-1 shows the well locations and cross-section alignments. **Figure 4-2** provides a key to the lithologic textures shown on cross sections.

Many cross-sections were prepared to understand the general hydrogeology of the study area. Of these "working sections", four final sections were selected to characterize the subsurface geology and identify aquifers and aquitards because they featured relatively deep, detailed well logs and include the monitoring wells and wells sampled by Spokane County **(Figures 4-3 (Addendum 1-1') through 4-6 (Addendum 4-4')**.

Each well shown on the cross sections is labeled with Ecology's identification number and features columns that graphically illustrate geologic, water level, water occurrence, and screening attributes. The "screened interval" column is blank for wells with open boreholes or bottoms. In general, browns represent basalt and include hatching for fractures or vesicles, beige is clay, blue is sand and/or gravel, dark gray is shale, and white with a "crystalline" hatch pattern denotes granite. The column indicating water occurrence can be useful for identifying laterally continuous water-bearing zones; even though many well logs omit this information, water may still be present.

The geologic surfaces from Spokane County were incorporated into the *Viewlog* project database. These layers were consistent with the geology indicated by the graphic logs in some locations but inconsistent in others.

The sections show the approximate top of the Wanapum and Grande Ronde Formations—contacts that are based on lithologic information from the well logs and on geologic layers from the GDB[1]. In addition, the cross sections show contacts that correspond to the top and/or bottom of the Latah Formation, paleochannel deposits, water-bearing zones, and groundwater flow directions. The water-bearing zones are considered to be of limited lateral extent unless they can be correlated with a neighboring well. Groundwater flow directions are shown with blue arrows; an X indicates that the flow direction is into the page, perpendicular to the section alignment.

4.2 Geologic Features

4.2.1 Basalt

Columbia River Basalt (CRB) crops out throughout and underlies most of the Hangman Creek watershed and the study area. The units known to occur in the watershed include the Wanapum (14.5–15.5 Ma) and Grande Ronde (15.5–17 Ma) Formations. The CRBs are discussed in detail in the Characterization Report (NLW, 2011).

Rock samples were collected during drilling for the purpose of identifying individual flow members. Because of budgetary constraints, they were not analyzed for this investigation.

4.2.2 Nonglacial Sedimentary Deposits

Alluvial/colluvial deposits and Latah Deposits are discussed in the Characterization Report (NLW, 2011).

4.2.3 Paleochannel Deposits

These deposits were described as glaciofluvial / lacustrine / flood deposits in the Characterization Report (NLW, 2011).

Paleochannel deposits occur extensively in the West Plains, generally at land surface as a layer that mantles the underlying geologic unit. Locally, they fill the scoop-like scour features of limited lateral extent. At these locations, the bottom of the deposits is bowl-shaped rather than flat. This is commonly observed in the pothole features of eastern Washington that resulted from the Missoula Floods. In many places within the West Plains, these scour features cut into the Wanapum and Grande Ronde.

4.2.4 Basement Rock

The same basement rock that underlies the Hangman Creek watershed occurs beneath the study area. These rocks form a partial bowl-like shape with a higher-elevation "rim" along the west and south sides of the study area. The basement slopes to the northeast and attains greater depths beneath the Spokane River and Hangman Creek, on the north and east sides of the study area. Along the study area's southern boundary, the basement high is part of the subsurface ridge discussed in the Characterization Report (NLW, 2011); this ridge occurs near land surface in the vicinity of Mur2 and divides Deep Creek and Marshall Creek.

4.3 Hydrostratigraphic Features

4.3.1 Occurrence of Aquifers

In general, aquifers in the study area typically occur in basalt flows or within fractured or vesicular zones within the basalt flows. Less commonly, they are formed by the sedimentary sandy layers between basalt units. The thickness of these basalt aquifers ranges from about 1 to 25 feet, and their lateral continuity is typically limited to less than 1 mile. However, although these zones are limited in their lateral extent, on a large scale they are sufficiently interconnected to behave as a single large-scale aquifer.

Alluvial, colluvial, and paleochannel deposits locally contain water from local precipitation runoff ("interflow"). In addition, they may receive water from losing creeks or adjacent basalt aquifers.

[1] *Where information was too limited, these contacts are omitted. Note that these contacts are incongruent with Spokane County's layers in locations where the graphic well logs are inconsistent with their layers.*

In the study area, wells are completed in the paleochannel deposits in the West Plains and in the alluvial / paleochannel deposits along Hangman Creek. Aquifer thickness ranges from 20 to 200 feet.

4.3.2 Multi-Aquifer Wells

Wells in the study area commonly produce water from multiple aquifers because they are seldom constructed with deep seals and they often have open boreholes or open-bottom casing. These "multi-aquifer" wells serve as conduits, facilitating the flow of water down the borehole or along the outside of the casing. They produce from water-bearing zones over depths ranging from 50 to 2,000 feet.

Low-yield domestic wells are generally about 50 to several hundred feet deep. On the other hand, some high-yield municipal wells are up to 2,000 feet deep. Although many municipal wells are properly sealed, those that lack seals can act as conduits for groundwater movement between aquifers at different depths.

4.3.3 Conceptual Hydrogeology by Area

This section describes the hydrogeology of the three geographic areas where the monitoring wells are located and data are most reliable and detailed. As in the Hangman Creek watershed, several characteristics control groundwater flow: the limited areal extent of water-bearing units; the wide range of thickness, fractures, and vesicles in the basalt; and the subsurface basement.

MW-7: Marshall Area

The hydrostratigraphy of this area is shown on **Figures 3-1, 4-3, and 4-6**.

Unsaturated zone. A thick unit of unsaturated paleochannel deposits of differing textures of sand and some gravel extends from land surface to about 220 feet bgs. This sequence overlies basalt.

Shallow aquifer. The uppermost aquifer is a zone of fractured basalt about 7 feet in thickness that occurs from 233 to 240 feet bgs. It produced about 2.5 gpm and is not considered a significant aquifer. It is underlain by an aquitard consisting of a thick sequence of dense basalt.

Deep aquifer. Beneath the aquitard is a deep aquifer that comprises fractured basalt about 5 feet thick from 355 to 360 feet bgs. This aquifer produced 20–30 gpm. It was encountered at about 1,980 feet msl and is considered a significant subregional aquifer based on logs for wells in the vicinity.

MW-8: Hayford Pit Area

The hydrostratigraphy of this area is shown on **Figures 3-2 and 4-5**.

Unsaturated zone. The unsaturated zone comprises about 20 feet of coarse, unconsolidated deposits of gravel that overlie a thick sequence of dense basalt layers to 100 feet.

Uppermost water-bearing zone. This vesicular basalt, about 5 feet thick, produced 1 gpm. It extends from 100 to 105 feet bgs and is not considered a subregional aquifer. This zone overlies about 30 feet of locally vesicular basalt with thin water-bearing zones. Collectively these zones produced about 5 gpm.

Shallow aquifer. The uppermost aquifer is a 1-foot-thick zone of fractured basalt that occurs from about 140 to 141 feet bgs. It produced 60 gpm and directly overlies about 70 feet of Latah deposits, which in turn overlies about 145 feet of dense, non-water-bearing basalt. Despite its limited thickness at MW-8, this aquifer's productivity suggests that it is locally significant; however, it may have a limited lateral extent and would therefore not be considered a significant subregional aquifer.

Deep aquifer. A thin basalt aquifer occurs from 354 to 365 feet bgs under the thick aquitard of Latah deposits and dense basalt. It produced 20 gpm and comprises a 6-foot layer of fractured basalt and a 5-foot layer of vesicular basalt. MW-8 is completed in this deep aquifer. Logs for wells in the vicinity describe a similar stratigraphy; therefore, this aquifer is considered significant at the subregional scale (**Figures 4-1 and 4-3)**.

MW-9 & MW-10: Lower Hangman near Creek

The hydrostratigraphy of this area is shown on **Figures 3-3, 3-4, 4-3, and 4-4**.

Unsaturated zone. The unsaturated zone comprises 35 feet of alluvial deposits of silty gravels, sands, and clay.

Shallow aquifer. The uppermost aquifer comprises 20 feet of unconsolidated sand from 35 to 55 feet bgs, interbedded between clay layers. It produced 3.3 gpm. It is underlain by clay that forms a 22-foot-thick aquitard separating the shallow and intermediate aquifers.

Intermediate aquifer. Beneath the clay aquitard is 126 feet of saturated alluvial or paleochannel sand that occurs from 77 feet to 203 feet bgs. The uppermost zone of this aquifer (77 to 130 feet) was tested and produced 2.1 gpm. Shallow wells in the area produce water from this aquifer and, combined with the shallow aquifer, it is considered important at the local scale within the Hangman Valley. The aquifer is underlain by 17 feet of clay, 20 feet of "broken" basalt with silt/clay, and about 55 feet of slightly water-bearing, locally fractured basalt.

Deep aquifer. Beneath the slightly water-bearing basalt, 5 feet of highly fractured basalt (from 295 to 300 feet bgs) produced 50 gpm under flowing artesian conditions. The pressure head was measured at 35 feet above land surface. This aquifer is likely significant at the regional scale, although no other flowing artesian wells are known to occur in the lower Hangman valley.

4.3.4 Aquifer-Basalt Flow Relationship

Table 4-1 lists the aquifers encountered during the drilling of wells MW-7 through MW-10. Basalt flow identification is based on information in Spokane County's West Plain Geologic Database.

Table 4-1: Local Aquifer Position in Basalt Flows

Well	Aquifer Depth (ft, bgs)	Basalt (B) Sand (S)	Aquifer Position in Unit	Basalt ID*
MW-7	233-240	B	Top	?
MW-7	355-360	B	Top	?
MW-8	100-105	B	Top	W
MW-8	135-141	B	Bottom	W
MW-8	354-365	B	Bottom	GR
MW-9	35-55	S	Top	--
MW-9	77-203	S	Intermediate	--
MW-9	295-300	B	Bottom	--
MW-10	35-57.5	S	Top	--

**W=Wanapum, GR=Grande Ronde*

5 Aquifer Testing & Analysis

Aquifer testing was conducted to evaluate yield and water chemistry at the new wells. Tests were either conducted in open or cased boreholes after encountering the first water-bearing unit ("the shallow zone") or after well completion ("the deep zone"). **Table 5-1** summarizes pertinent test information. Drawdown data for the tests is shown on **Figures 5-1 through 5-8**.

Table 5-1: Pumping Tests

Well	Tested Interval (ft, bgs)	Basalt (B) or Sand (S)	Borehole	Installed Well	Q (gpm)
MW-7	233-240	B	X		2, 6.5, & 7.5
MW-7	355-360	B		X	0.8
MW-8	100-105	B	X		1.0
MW-8	100-202	B	X		29.4
MW-8	354-365	B		X	0.4
MW-9	35-55	S	X		3.3
MW-9	77-130	S		X	2.1

Pumps were installed to facilitate testing. H2O Well Services provided a 1.5HP, 4-inch submersible pump for open-borehole testing. For tests run in the completed 2-inch monitoring wells, a Grundfos Redi-flow2 pump was used. Water levels were measured using a manual sounder. Pumping rates were measured using an inline flow meter and/or a calibrated 5-gallon bucket plus a stopwatch. Monitoring well MW-10 was not tested.

Aquifer parameters were estimated from pumping data and well/aquifer information using the same methodology described in the Characterization Report (NLW, 2011).

The results and parameters used in the pumping test analysis are summarized below.

Table 5-2: Pumping Test Results (Drawdown Data)

Well	Tested Interval (ft, bgs)	Q (gpm)	T (gpd/ft)	Thickness	K (gpd/ft²)	K (ft/d)
MW-7	233-240	7.5	5.2E+1	7	7.4E+0	9.9E-1
MW-7	355-360	0.8	3.5E+2	5	7.0E+1	9.4E+0
MW-8	100-105	1.0	8.4E+0	5	1.7E+0	2.2E-1
MW-8	135-141	29.4	8.1E+2	6	1.4E+2	1.8E+1
MW-8	354-365	0.4	1.3E+3	11	1.2E+2	1.6E+1
MW-9	51.5-56.5	3.3	6.1E+1	5	1.2E+1	1.6E+0
MW-9	77-130	2.1	7.9E+3	53	1.5E+2	2.0E+1

6 Geochemistry

Geochemical data can provide insights into the origins, flow patterns, and residence time of groundwater. These analyses were conducted using the methods described in the Characterization Report (NLW, 2011).

Seventeen groundwater samples were collected: eight samples from existing wells selected by Spokane County, eight from the monitoring wells during testing, and one from an existing well (in lieu of the shallow monitoring well MW-10). The samples were collected to assess:

- The source and age of groundwater recharge
- The degree of mixing between aquifers
- The degree of continuity between groundwater and surface water

6.1 Sampling & Analysis

All samples were analyzed for field parameters, routine chemistry, and the stable isotopes ^{18}O and D. Seven of the eight samples collected by Spokane County and seven of the samples collected during drilling were also analyzed for the stable isotope ^{13}C and the radioactive isotopes tritium and ^{14}C.

To better understand the relationship between groundwater in the shallow and deep aquifers, shallow/deep sample pairs were collected from wells that were carefully selected by Spokane County. These well pairs are completed in two different aquifers, as summarized in **Table 6-1** and shown on **Figure 2-1**.

In addition shallow/deep sample pairs were collected at MW-7; and shallow, intermediate, and deep samples were collected at sites MW-8 and MW-9. Samples collected in association with monitoring well drilling are summarized in **Table 6-2** and shown on **Figure 2-1**. The names in **Table 6-2** denote the location and whether the sample was collected from the borehole (BH) or the completed monitoring well (MW). If an additional number is included, such as BH-9_3, it indicates a second or third sample collected at that site.

Table 6-1: Samples collected by Spokane County

Well	Vicinity	Likely Geologic Unit	Routine	O-18 & D	Tritium, C-14, C-13
167998	Indian Village Estates, just N of study area	Wanapum	x	x	x
470237		Grand Ronde	x	x	x
369725	Eastern part of study area	Grand Ronde	x	x	x
472535		Paleochannel	x	x	
351696	Southern part of study area	Wanapum	x	x	x
617922		Grand Ronde	x	x	x
385958	Western part of study area, near Deep Creek	Wanapum	x	x	x
445291		Grand Ronde	x	x	x

Table 6-2: Samples associated with drilling

Sample Name, Grouped by Site	Depth Interval	Routine	O-18 & D	Tritium, C-14, C-13
BH-7	230 – 240	x	x	x
MW-7	355 – 360	x	x	x
BH-8	100 – 105	x	x	x
BH-8_2	100 – 141	x	x	x
MW-8	354 – 365	x	x	x
BH-9_2	295 – 300	x		
BH-9_3	295 – 300	x	x	x
MW-9	77 – 130	x		
DW-G	48 – 63	x	x	x

Sample BH-9, the first sample from the borehole at the MW-9 site, was collected but not submitted for analysis because the water was very silty. Instead, a nearby shallow domestic well, DW-G, located about 0.1 mile from MW-9, was sampled to represent the shallow groundwater zone at this site. The drillers' log for DW-G included in **Appendix F** indicates that this well yields water from the same shallow sand aquifer as MW-9. BH-9_2 and BH-9_3 were both sampled from the same deep artesian zone. BH-9_2 was sampled when the drill rods were in the borehole but BH-9_3 was collected after the drill rods were removed to alleviate concerns about possible contamination; therefore, BH-9_2 was not submitted for ^{14}C or tritium analysis and is not included in **Table 6-4**. MW-9 was completed in the intermediate groundwater zone; however, the high pH (11) measured during sampling indicates that the groundwater was compromised from the cementing. Consequently, the samples were not submitted for analysis of stable isotopes, ^{14}C, or tritium.

A minimum of three borehole volumes was purged from each well before sampling. Samples for routine constituents were field-filtered (0.45 um) and analyzed by Anatek Labs, Inc. Stable isotope samples were collected without headspace to avoid changes to their signature and submitted to Zymax, Inc. Radiocarbon samples were collected in Nalgene™ bottles, treated with sodium hydroxide, and stored in a cool place. Tritium samples were also collected in Nalgene bottles and stored in a cool place. No glow-in-the-dark watches or other items were worn during the collection of the tritium samples.

6.2 Results

Chemistry data for this project is maintained in a water-quality database. For major ions, an ion balance was calculated as a quality-assurance measure. Routine constituents were plotted on trilinear diagrams as described in the Characterization Report (NLW, 2011). Stable isotopes were plotted with the global and local MWL. Other graphs are shown to illustrate important geochemical relationships. In general, data from the Characterization Report has been incorporated into the graphs prepared for this study and used in the analyses discussed below.

Tables 6-3 and **6-4** summarize the field and laboratory results for samples collected from existing wells and the new monitoring wells, respectively. The ion balances for these analyses are summarized in **Table 6-5**. Because water is electrically neutral, the negative charge of the anions should equal the positive charge of the cations. Samples with ion-balance errors of less than 10 percent indicate acceptable results. As **Table 6-5** indicates, most of the ion balances for these samples exceeded the acceptable error. Anatek Lab repeated the cation analyses, confirmed their accuracy, and concluded that although the bicarbonate values may be too high, the quality-control results were acceptable.

The ion balance error for MW-9 is particularly high. Furthermore, the lab value for total dissolved solids (TDS) is inconsistent with the high conductivity measured in the field, suggesting that the quality of the lab results is unacceptable. The sample from MW-9 had a pH of 11, indicating that it was impacted by the cement used to seal off the lower part of the well (a temporary effect); consequently, it is not considered representative of the local groundwater. Because data from this sample was suspect, it was excluded from the analyses conducted for this report.

The figures discussed in the next sections use the following symbology:

- Well pairs or trios share a similar color.
- Samples collected in 2012 from shallow aquifers are denoted by solid squares; samples collected in 2010 are denoted by a plus (+) sign.

- Samples collected from deep aquifers in 2012 are denoted by solid triangles; samples collected in 2010 are demoted by an X.
- Surface water samples, collected in 2010, are all denoted by blue dots.
- The river mile or the tributary abbreviation is indicated next to each surface-water data point.

Note that samples BH-8_2 and MW-9 are from a water-bearing zone at an intermediate depth and are denoted by a solid diamond. Not all plots show all of the symbols; BH-9_2 only has routine constituent data and 472535 only has routine constituents and stable isotopes of oxygen and deuterium (see **Tables 6-1 and 6-2**).

6.2.1 Routine Constituents

TDS is low in all of the samples, ranging from 130 mg/L in MW-7 to 188 mg/L in BH-7. The major ion chemistry is plotted on a trilinear diagram (**Figure 6-1**); a second trilinear diagram (**Figure 6-2**) incorporates data from the Characterization Report (NLW, 2011). **Figure 6-1** shows a distinct symbol for each well. Conversely, **Figure 6-2** groups the wells for this study as either shallow basalt, deep basalt, or unconsolidated, and samples from the Characterization Report are categorized as either groundwater or surface water.

The cluster in the anion ternary plot indicates that bicarbonate is the dominant anion in all the groundwater samples (**Figures 6-1 and 6-2**). Conversely, the cation ternary shows a wider range in the relative concentrations of major cations. It also indicates that the dominant cation is calcium. The range in values is greatest for calcium and least for magnesium.

The calcium and sodium data suggest that cation exchange plays an important role in water quality. This process causes calcium to decrease and sodium to increase as groundwater reacts with minerals in the aquifer. The longer the groundwater resides in the aquifer, the larger the difference between calcium and sodium. This reaction path explains why the older groundwater may contain less calcium than the shallow groundwater (see section 6.2.3). This reaction path is well documented in CRB groundwater systems (Hearn et al, 1985; Papadopoulos et al, 2009). However, **Figure 6-2** shows no obvious pattern in routine chemistry between shallow and deep aquifers.

6.2.2 Stable Isotopes

^{18}O and D are plotted with the meteoric water line (MWL) and 2010 data in **Figure 6-3**. The 2012 and 2010 data are consistent and indicate a range in the elevation of precipitation recharge. The data plot along a slope that is similar to, but offset from, the global MWL; they also plot closely to the local MWL for southwestern Idaho (Adkins and Bartolino, 2010). The quality assurance data were reviewed, and all standards and duplicates fell within the acceptable criteria. The 2012 data indicate:

- The monitoring well pair and trios clearly illustrate the general pattern that shallow groundwater has a heavier isotopic signature than deeper groundwater.
- The difference in isotopic signature is smaller for samples from existing well pairs than for samples from the monitoring well sample pairs.
- The deep samples from MW-7 and MW-8 are heavier than the deep sample from MW-9, likely because the elevation of the recharge is lower.
- None of the samples collected had as light an isotopic signature as the lightest 2010 sample, which was collected at the MW-3/4 site from an artesian aquifer in the upper Hangman watershed.
- Mixing is likely the primary reason why so many samples from existing wells plot in the same vicinity.

6.2.3 Carbon-14 & Carbon-13

The ^{14}C and ^{13}C results are presented in **Tables 6-3 and 6-4**. The ^{14}C results are reported as “apparent” or “measured” ages, which range from 105 to 13,080 years for the 2012 samples. $\delta\ ^{13}C$ ranges from –14.5 to –18.0 permil.

As discussed in the Characterization Report (NLW, 2011), the $\delta\ ^{13}C$ data indicate that the groundwater is enriched (heavier) relative to typical soil gas, suggesting that carbon mass transfer has occurred since the water infiltrated through the soil zone. The enriched δ ^{13}C values suggest one of two likely processes:

- Degassing of carbon dioxide, as reported for groundwater in the CRB near Skamania (Hinkle, 1996) and in the Palouse basin (Douglas et al., 2007). In this case, the actual age would be nearly equal to the apparent age, and no adjustment would be required.
- Dissolution of carbonate, as reported for a basalt groundwater in southwestern Idaho (Adkins, 2010). In this case, an adjustment would be required. The routine chemistry and the δ ^{13}C are used to identify the carbon mass transfer mechanism.

Degassing would remove dissolved inorganic carbon (DIC) from the groundwater; the lighter isotopes would be more likely to go into the gas phase and groundwater would become enriched (heavier δ ^{13}C) in ^{13}C, but the amount of ^{14}C would remain relatively unchanged. Carbonate dissolution, on the other hand, would contribute DIC to the groundwater; the groundwater would become more enriched in ^{13}C (heavier) and the radioactivity of ^{14}C would be diluted with “dead” carbon.[2]

Based on lack of correlation between δ^{13}C and bicarbonate, carbonate dissolution is an insignificant geochemical process for the 2012 samples (**Figure 6-4**). Rather, volcanic glass dissolution and carbon dioxide degassing are responsible for enriching the groundwater in δ ^{13}C relative to an assumed soil gas of about –22 permil (Appendix C; NLW, 2011). The lower graph on **Figure 6-4** is included as an update to the Characterization Report. The correlation, albeit weak, between increasing groundwater age and increasing (heavier) δ ^{13}C supports the interpretation that this reaction is occurring along the groundwater flow path. The weakness of the correlation likely reflects mixing of shallow and deep aquifer groundwater.

Figure 6-5 shows an inverse relationship between sodium and calcium and a direct relationship between sodium and ^{14}C, indicating that cation exchange progresses with groundwater age. This is consistent with geochemical processes that have been reported for groundwater within the CRB.

[2] *These processes are discussed in detail in Appendix C of the Characterization Report (NLW, 2011).*

These results are consistent with those documented in the Characterization Report (NLW, 2011).

The sample trio from the MW-8 site illustrates a similar pattern on **Figure 6-5** as it did on **Figure 6-3**: The deep sample appears to be mixed with shallow zone groundwater. The hypothetical original, deep groundwater is designated on **Figure 6-5** by a large, light purple circle. BH-8_2 likely represents intermediate-zone groundwater that contains little or no shallow groundwater.

6.2.4 Tritium

Tritium results range from 0.05 to 6.14 TU (**Table 6-3 and 6-4**). All samples except BH-9_3 contain tritium at concentrations that exceed the error, indicating that they contain at least some groundwater that was recharged within the last 60 years. The tritium is considered zero for BH-9_3 because the error is larger than the measured value. Of the seven samples with tritium concentrations greater than 1 TU, four are from shallow wells and three are from deep wells.

Figure 6-6 shows the relationship between tritium, ^{14}C, and ^{18}O, and includes the 2010 data. Low concentrations of tritium (<1 TU) are detected in samples with a ^{14}C age ranging from 4,000 to 10,100 years. In the absence of mixing, samples with ages over 60 years would have no detectable tritium. The tritium data indicates mixing is a significant mechanism in the groundwater system. Similar to the stable isotope data, the range of constituent values (deep and shallow) is wider in samples from the monitoring well pairs than from the existing well pairs.

Again, the sample trio from the MW-8 site illustrates a similar pattern for tritium as for the stable isotopes and ^{14}C: the deep sample appears to be mixed with shallow groundwater. The hypothetical, original deep groundwater is shown on **Figure 6-6** as a large, light purple circle.

7 Interpretation

This section integrates the results of geologic, water level, and geochemical data to describe groundwater flow, interactions with surface water, and residence time. The analysis of groundwater flow dynamics considered the synoptic water level data collected by Spokane County. Mike Hermanson provided contour maps, a water-level shapefile, and hydrographs for continuously monitored wells (pers. comm. 2012). NLW prepared water level contour maps for aquifers in the Grande Ronde and Wanapum. Unit-specific data were selected using GIS and contours were hand-drawn at 100-foot intervals to identify general groundwater flow patterns.

7.1 General Groundwater Flow Patterns & Recharge

7.1.1 Geologic Controls

Spokane County's geologic unit layers were incorporated into Viewlog and used to identify features that may control groundwater flow. Viewlog was used to "step" through the study area in cross-sections and see how these geologic layers change spatially.

Several features control groundwater flow. One is the shape of the basement rock surface. In general, groundwater moves from the basement highs towards the Spokane River and Hangman Creek. Locally, the subsurface basement "ridge" along the southern part of the study area separates groundwater flow in the Deep Creek and Marshall Creek vicinities (**Figure 4-3**). To the west of this ridge, groundwater mostly flows northwesterly towards the Deep Creek River. East of the ridge, it flows east toward Marshall Creek and then northeast toward Hangman Creek.

Another geologic control is the occurrence of the paleochannel deposits, which typically directly overlie the Wanapum but locally scoured into, and directly overlie, the Grande Ronde. Deep paleochannel deposits occur near MW-7 (**Figure 4-6**), MW-8 (**Figure 4-5**), and the three Spokane County well pairs that occur within the study area boundary.

7.1.2 Recharge

The West Plains recharge area is significantly smaller than the recharge area for the Hangman Creek watershed. It is also lower in elevation, a feature that may account for the relatively small range in ^{18}O for samples from the West Plains. However, mixing through contact with the paleochannel deposits or multi-aquifer wells would also affect the isotopic signature in the deep aquifer, and reduce the difference in ^{18}O between shallow and deep groundwater.

That groundwater flow direction in the West Plains is from the basement "rim" towards the Spokane River and Hangman Creek and indicates that recharge occurs from the basement rock into aquifers within the Grand Ronde and Wanapum. Low permeability of the basement rock would result in long travel times; the flow path into the Grand Ronde is deeper and thus longer than into the Wanapum. Greater travel distance results in greater travel time; age of groundwater from basement rock recharge is expected to be older in the Grand Ronde than the Wanapum and older with increasing distance from the basement "rim".

No new analyses have been conducted to improve the recharge rate estimates given in the Characterization Report (NLW, 2011). Those calculations were based on the travel time estimated from groundwater age differences between two points on a flow path. Because of the mixing described above, travel times could not be estimated reliably.

7.1.3 Vertical Flow

The vertical hydraulic gradient within the study area is consistently downward except in the vicinity of MW-9/10, where there are flowing artesian conditions. Spokane County's synoptic water-level data indicates that throughout the West Plains, the vertical gradient is downward and ranges from 0.2 to 1.2 ft/ft. This downward gradient provides the driving force for multi-aquifer wells to introduce groundwater from a shallow aquifer into a deeper aquifer. Data for key locations is summarized in **Table 7-1**.

Table 7-1: Hydraulic gradients at key locations

Well	Area	Unit	WLE (ft msl)	WL Diff (ft)	Aq Elev (ft)	Gradient
167998	N. of study area between Deep and Coulee Cks	W	2,300	549	2,211	1.0 D
470237		GR	1,752		1,676	
472535	East of MW-8 nr Spok. R. /Hangman	Pch	2,015	104	1,747	0.5 D
369725		GR	2,119		1,947	
351696	South of MW-8, at bdy between W56 and W34	W	2,376	126	2,276	1.0 D
617922		GR	2,250		2,149	
358958	West, near Deep Ck	W	2,374	211	2,303	1.2 D
445291		GR	2,163		2,130	
BH-7	South, Marshall	CRB	2,112	20	2,097	0.2 D
MW-7			2,092		1,976	
BH-8	Central, Airway Hghts	W	2,330	248	2,257	1.0 D
MW-8		GR	2,083		2,002	
BH-8_2	Central, Airway Hghts	W	2,300	218	2,219	1.0 D
MW-8		GR	2,083		2,002	
MW-9	SE, L Hangmn Wshed	Sed	1,861	-31	1,751	-0.2 U
Artesian		CRB	1,892		1,560	

W=Wanapum, GR=Grande Ronde, Pch=Paleochannel, CRB=Undifferentiated Basalt, Sed=Sediments; D=Downward, U=Upward

7.1.4 Residence Time

Regardless of whether the deep groundwater is recharged slowly from distant or local locations, or if it was emplaced by glacial Lake Columbia, its residence time in the deep aquifer is very large. In fact, the age of the deep groundwater may be older than indicated by the ^{14}C data because of mixing.

The old age indicates that excessive pumping would remove groundwater faster than it can be replenished.

7.2 Local Flow Conditions

The isotope data indicates that the groundwater flow system in the West Plains and Lower Hangman Creek is more complicated than in Hangman Creek watershed.

The deep groundwater system in the Hangman Creek watershed is characterized by long travel distances from recharge in the distant mountains, with contributions from shallow groundwater as it moves downgradient. The deep groundwater has very old ^{14}C ages, no tritium, and a light isotopic signature.

This conceptual flow model differs from the one suggested by the West Plains monitoring well samples. All of the deep West Plains wells have detectable tritium (445291 has 6.14 TU), the ^{14}C age is younger than expected, and the difference between the shallow and deep samples in each pair is relatively small. Also, in the case of the MW-8 well trio, the intermediate groundwater "appears" older than the deep groundwater.

Table 7-2: Description of isotope data

Well	Vicinity	Description
167998	N. of study area between Deep and Coulee Creeks	Both the shallow and deep ^{14}C age are young, <=300 yrs
470237		
369725	Eastern of MW-8 nr Spokane /Hangman confluence	Age difference is small; deep sample has rel young ^{14}C age
472535		
351696	South of MW-8, at boundary between W56 and W34	Age difference is small; shallow sample has rel. old ^{14}C age
617922		
385958	West, near Deep Ck	Age difference is small; deep sample has rel young ^{14}C age
445291		
BH-8_2	Central, Airway Heights	Intermediate groundwater has older ^{14}C age than deep
MW-8		
BH-7	South, Marshall	Age difference more similar to the pattern observed in Hangman Ck. watershed
MW-7		
DW-G	SE, L Hangman Watershed	Age difference consistent with the pattern observed in Hangman Ck. watershed
MW-9_3		
BH5_85	Along Spangle Creek nr by with WRIA 34	Age of very deep groundwater is relatively young compared to other samples along Hangman
BH5_501		

Groundwater age and ^{18}O for the 2010 and 2012 data are shown on a map of the Hangman watershed and the West Plains (**Figure 7-1**). The pertinent hydrogeologic mechanisms that are operating in the West Plains are discussed in this section and then the isotope data, summarized in **Table 7-2**, is discussed by area. Note that data from MW-5 is included because it is located on the very edge of

WRIA 54 and questions remain about the interpretation of the observed data.

7.2.1 Recharge from the Paleochannel Deposits to the Grand Ronde

The contours shown on **Figure 7-2** indicate a distinctive pattern. In the vicinity of MW-7 and MW-8, the distance between the contours is large, suggesting an increase in transmissivity or a source of recharge. In areas where this distance is largest (the MW-8 vicinity, along Deep Creek, and west and northwest of Fairchild AFB), paleochannel deposits directly overlie the Grande Ronde.

These deposits likely act as a conduit for younger water to be introduced into the deeper groundwater within the Grande Ronde. Younger water from the Wanapum may discharge into the paleochannel deposits and then, with a downward gradient, move directly downward into the Grande Ronde, unimpeded by aquitards that would typically separate the two units. Similarly, precipitation incident on the paleochannel deposits would move downward into the Grand Ronde

This would explain why the deep sample from a well pair has measureable tritium and a younger-than-expected ^{14}C age at all of the sites but MW-9. The dimensions of the paleochannel scour features vary, as do the distances between them and the wells used in this study. As such, the magnitude of cross-communication may vary spatially within the West Plains; as such, the age dates for some well pairs would show more mixing than others. Similarly, the relative amounts of recent precipitation and Wanapum discharge that comprise the paleochannel groundwater may vary, and thus the age and tritium in the underlying aquifers recharged from the paleochannel deposits may vary.

7.2.2 Recharge from Basement Rock

The contours on **Figure 7-2** also suggest that recharge occurs from the granite basement "rim" into the aquifers within the Grand Ronde and Wanapum. The low permeabilty and slow groundwater movement through the basement rock would account for the groundwater in the deeper wells having an older groundwater age than in the shallow wells due to the longer travel distance and time.

7.2.3 Recharge from Deep and Coulee Creeks

Deep Creek and Coulee Creeks discharge into alluvial deposits in the vicinity of where section alignment Addendum 3-3' crosses Deep Creek (near the Indian Village Estates well pair). In this area, the alluvial deposits directly overlie and recharge the Grand Ronde with surface water. Throughout most of the year, water does not flow within Deep Creek channel in this vicinity, but infiltrates into the underlying groundwater system.

7.2.4 Multi-aquifer wells

Multi-aquifer wells would cause cross communication between aquifers and a similar mixing effect, but perhaps on a smaller scale. There is a high density of deep wells in the vicinity of the west well pair near Deep Creek. It is difficult to discern the mixing effect from multi-aquifer wells from that due to paleochannel deposits that recharge the Grand Ronde beneath scour features.

7.2.5 Flow conditions by Area

N. of study area between Deep and Coulee Creeks.

The ^{14}C ages for these groundwater samples, 167996 (Wanapum, shallow) and 470237 (Grand Ronde, deep), are 105.5 and 350 years, respectively; Groundwater flow in the vicinity of these wells differs from the rest of the study area. Their ^{14}C ages are so young that they are considered "modern," despite their depth, suggesting recharge via surface water. Well 167996 is located on an upland between the creeks and completed in Wanapum that is likely part of a small localized flow system; the tritium and young age is consistent with recharge from local incident precipitation. It is common for water level in this well to go below the pump intake during the summer, indicating a localized groundwater system that is susceptible to large changes in water level with increased seasonal pumping. Well 470237, completed in the Grand Ronde where there is no overlying Wanapum (no potential effect of cross communication between aquifers) and, is located at a lower elevation in the vicinity where Deep

Creek discharges into alluvial deposits that directly overlie and recharge the Grand Ronde with surface water. The tritium and young age at this well is consistent with groundwater dominated by nearby recharge from surface water.

East of MW-8 near Spokane/Hangman confluence.

The ^{14}C age of the deep groundwater at this Grand Ronde well, 369725 is 3,310 years. This well is located in the vicinity of deep scour and paleochannel deposits. Age indicates groundwater at this well receives slow basement recharge; significant tritium indicates it also receives recharge from recent water within the paleochannel deposits. This well could also be impacted by cross communication between aquifers.

South of MW-8, at boundary between W56 and W34

The ^{14}C ages for these groundwater samples, 351696 (Wanapum, shallow) and 617922 (Grand Ronde, deep), are 5,080 and 6,100 years, respectively; the age difference is small. The deeper well, 617922, is a monitoring well with a deep well seal; it is likely completed in an intermediate depth basalt aquifer (M. Hermanson, pers. comm., 2012). It may be completed in a similar aquifer as the intermediate depth sample from MW-8, which is thinner, pinches out, and therefore less connected to recharge from nearby paleochannel scour deposits. It is likely that groundwater in both these wells is recharged from basement recharge; as such, the older age of groundwater at the MW-8 site is consistent with its greater travel distance from the basement source of recharge. The shallower well, 351696, has very similar but slightly younger groundwater, suggesting that the Wanapum is also recharged by the basement rock at this vicinity. Both wells have tritium, although concentration in the deeper well is barely greater than the error. The shallower well has more tritium than the deeper well, suggesting more recharge of recent water, which would also account for the younger ^{14}C age. While the deeper well may be slightly affected by cross aquifer communication from neighboring multi-aquifer wells, the deep seal prevents this problem from occurring from this well.

Well 617922 is located in an area where water level decline has affected several municipal wells (pers. comm., M. Hermanson 2012).

West side of study area, near Deep Creek

The ^{14}C ages of these groundwater samples, 445291 (deep) and 385958 (shallow), are 4020 and 1860 years, respectively. The deeper well is located closer to the basement rock and therefore would have a shorter flow path and younger basement recharge than the other deep West Plains wells. However, these wells are also located near many deep multi-aquifer wells and deep scours filled with paleochannel deposits, both conditions could introduce younger water into the Grand Ronde.

MW-7

The ^{14}C ages of these groundwater samples, BH-7 (shallow) and MW-7 (deep), located in the Marshall subbasin, are 2,360 and 10,100 years, respectively. The deep sample at MW-7 is older than groundwater for any of the other samples in the West Plains. The source of this old groundwater may be from basement recharge within the West Plains and/or from distant recharge from within the Hangman watershed.

The significant tritium in the shallow sample and the minor tritium in the deep sample indicate that the shallow aquifer has a significant contribution of recent recharge and the deep aquifer has a smaller contribution from recent recharge. That the deep sample has tritium suggests that the source of the old water is greater than the measured age of 10,100 years.

Basement recharge as the sole source of groundwater at this site is unlikely due to the relatively short travel distance. It is likely that this area is recharged from both the Hangman Creek watershed, where groundwater is older and travel distance is long, and from within the smaller, more local West Plains, where groundwater is younger and travel distance is shorter.

The water level data in the Grande Ronde suggests that groundwater flow paths in this vicinity could be from both these sources. Water level and age data suggest that deep groundwater in the western part of the Marshall subbasin is likely hydraulically connected to deep groundwater beneath the eastern part of the West Plains.

MW-8

The ^{14}C ages of these groundwater samples, BH-8 (shallow), BH-8_2 (intermediate) and MW-8 (deep), are 790, 8220, and 3880 years, respectively. The intermediate aquifer groundwater age is older than the deeper, aquifer groundwater. The intermediate aquifer is very thin and probably not as laterally continuous as the deeper aquifer; consequently, it may not be in direct communication with the paleochannel deposits. Water level data, geologic control, and groundwater age indicate that Wanapum and Grand Ronde aquifers likely receive basement recharge. The presence of tritium in all the samples indicates a mechanism for some recent water to be introduced, however more is introduced to the deep aquifer than the intermediate based on tritium and age data. As such, the intermediate aquifer may contain more basement recharge water and may not be as strongly impacted by younger water from the paleochannel deposits as the deeper aquifer.

MW-9/10

The ^{14}C ages of these groundwater samples, DW-G (shallow) and BH-9_3 (deep), are 1,960 and 13,080 years, respectively. The deep artesian groundwater at this site is the oldest age of all the groundwater analyzed in this phase of the study. It is consistent with the age of deep groundwater in the Hangman watershed and much older than the samples in the West Plains. This age is consistent with the groundwater flow pattern observed in the middle and upper Hangman where deep groundwater is recharged primarily in the distant mountains and includes some more recent recharge. That the ^{14}C age is not older than upgradient samples (even though the travel distance from mountain recharge source is longer) indicates contributions both from the distant mountains and from relatively recent, shallow groundwater recharge. The old ^{14}C age indicates the subsurface ridge does not strongly separate the deep groundwater in the Lower Hangman subbasin from upgradient subbasins. The age of shallow groundwater in this vicinity, 1,960 years at DW-G, indicates groundwater is likely a mixture of 1) very recent recharge from local precipitation, 2) recharge from Hangman Creekwater, and 3) recharge from adjacent upland basalt aquifers.

MW-5

The very deep sample at MW-5 should be at least twice as old as reported if it were recharged from groundwater recharged in the distant mountains within the Hangman watershed. Mixing from paleochannel deposits or multi-aquifer wells is unlikely. MW-5 is located at the boundary between WRIA 56 and WRIA 34. The WRIA boundaries reflect surface drainage and commonly belie the deep groundwater flow paths. It is likely that the deep groundwater at MW-5 is part of a flow system that is recharged from a smaller area with shorter travel distances.

7.3 Groundwater/Surface Water Interactions

Hangman, Marshall, and Deep Creeks and their tributaries are fed by direct precipitation runoff and baseflow (groundwater). The source of baseflow to creeks includes discharge from adjacent alluvial/colluvial deposits and from basalt/Latah aquifers. Discharge from basalt/Latah aquifers may occur directly, where these aquifers intersection creek beds, or indirectly via the alluvial/colluvial deposits.

Locally, losing creeks may recharge the groundwater system. The young ^{14}C age of the north well pair (167996/470237) suggests that the groundwater in that vicinity is recharged by surface water. Creeks tend to lose flow where they are in contact with the high-transmissivity alluvial or paleochannel deposits.

8 Key Findings

F1. Four monitoring wells were installed. Two are located in the West Plains and completed in the deep basalt aquifer. Two are located in the Lower Hangman watershed, with one completed in the intermediate unconsolidated deposits aquifer and the other in the shallow unconsolidated deposits.

F2. In general, the vertical gradient is downward throughout the study area except in the vicinity of MW-9, where it is upward and the deep basalt aquifer is under flowing artesian conditions.

F3. Stable isotope and age data for groundwater beneath the West Plains shows evidence of mixing between shallow and deep groundwater. This is in contrast to data from the middle and lower Hangman Creek watershed area, which shows less mixing of shallow and deep groundwater. Mixing mechanisms in the West Plains may include:

- Multi-aquifer wells that allow groundwater movement from shallow aquifers (for example, the Wanapum) to deep aquifers (for example, the Grande Ronde).
- Paleochannels deposits that transmit shallow water to deep aquifers.

F4. Groundwater age dates are thousands of years indicate potential for low recharge rates and/or long travel paths. This finding warrants caution for future development of groundwater from these aquifers.

F5. Monitoring wells with deep well seals provide more useful groundwater samples than existing wells that have shallow wells seals. Wells without deep well seals allow cross communication between aquifers and may not provide groundwater samples that represent the aquifer.

9 Recommendations

R1. Implement or enhance existing wellhead protection. The mixing of shallow and deep groundwater in the West Plains has important implications about wellhead protection because chemical spills or leaks could potentially contaminate both aquifers. Implementation of wellhead protection measures will be essential to controlling and preventing chemical spills or leaks.

R2. Summarize synoptic water level data. Additional work should be undertaken to summarize the fall 2011 and spring 2012 water level data and prepare contour maps for the Wanapum and Grand Ronde or for shallow, intermediate, and deep aquifers, whichever is most appropriate.

R3. Improve mapping of paleochannel deposits. This will provide an improve understanding of the hydrologic connections between aquifers in the Wanapum, Grande Ronde, and paleochannel. It will further the understanding sustainable water supply as it pertains to engineered aquifer storage, and potential mitigation of future water supply development.

R4. Delineate and make public areas of similar and distinct hydrogeologic characteristics. This type of delineation would alert land and water managers, developers, and conservationists about how and where water may be used sustainably and/or protected for surface water bodies in the future.

R5. Integrate all pertinent hydrogeologic data into a hydrogeologic conceptual model of the West Plains region. All pertinent existing and new work should be integrated into a single set of project files to convey a comprehensive three-dimensional conceptual hydrogeologic model with the goal of groundwater management. Data should include but not be limited to:

- Recent interpretation of whole rock analyses to improve understanding of basalt stratigraphy,
- Recent work done to delineate the near-surface basement rock,
- Mapping of paleochannel deposits,
- Groundwater elevation contours from synoptic water level data (R2),
- Continuous water level data,
- Locations of multi-aquifer wells,
- Locations of commercial / industrial chemical use
- Spatial representation of existing water use data, and

In particular, the data should be displayed graphically, such as in a block diagram to illustrate the dynamics and multiple components of the flow system. A visual conceptual model would help managers focus aquifer-protection strategies in vulnerable areas.

R6. Plan with awareness of old water and limited water resources. The findings about groundwater ages imply that groundwater resources are limited. These findings should be discussed with municipal water purveyors, and private land/water developers in the West Plains and the middle and lower Hangman Creek watershed to raise awareness about the potential for unsustainable groundwater withdrawals. These purveyors and developers should be encouraged to monitor pumping rate and water levels frequently, to review data annually, and to submit this review to a lead agency and/or other stakeholder in the watershed. SCCD and Spokane County Water Resources should continue groundwater monitoring in perpetuity and link this data to the future growth in groundwater use. This will allow managers to project groundwater level trends (aquifer storage changes) and make informed decisions.

R7. Make data accessible to public. A substantial amount of hydrogeologic data has now been developed for the Hangman Creek watershed and West Plains region, especially since 2010. Much of this data contributes to the knowledge base of hydrogeology at local and regional scales. These data should be rendered into concise, easy-to-use formats (such as web-based graphics) to help those involved in water issues—resource managers, permit reviewers, and even land owners who are planning to drill a well.

R8. Conduct whole rock analyses. The rock samples collected during drilling are being stored by Mike Hamilton. These samples should be analyzed to identify the source geologic unit and the results should be incorporated into the conceptual model for this project.

R9. Minimize effect of multi-aquifer wells. New production wells should be constructed with deep seals to avoid cross-aquifer communication.

R10. Monitor shallow and deep groundwater for any new production wells. Because the shallow and deep groundwater systems are connected, water levels in these aquifers should be monitored near deep production wells. This is especially important for production wells that are located in areas where shallow groundwater likely recharges the deep groundwater.

R11. Age date the groundwater sample from the paleochannel deposits. The budget did not allow for more than 7 wells selected by Spokane County to be analyzed for tritium and ^{14}C. The sample from the paleochannel deposits, 472535, should be analyzed for tritium and 14C to gain insight on the relative composition of the paleochannel groundwater. If the paleochannel groundwater is very young and contains more recharge from incident precipitation than groundwater from basalt aquifers discharging into it, then groundwater development from these groundwater resources may be more sustainable and less like “mining” groundwater.

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Table 6-3. Summary of Water Quality Data for Groundwater Samples from 2012 Sampling by Spokane County

Location Description:		Indian Village Estates		Hiway 2 - Deep Creek		Wanapum-PC-GR		Geophysical-NW Bedding	
		Wanapum	Grand Ronde	Wanapum	Grand Ronde	Paleochannel	Grand Ronde	Wanapum	Grand Ronde
	Sample Name:	IVEWA	IVEWA lower	Brooks Rd	Bannock Rd	Polo Ground	W. Greenwood	Hayford Rd	Thorpe Rd
Constituent	**Units** Well ID:	167996	470237	385958	445291	472535	369725	351696	617922
Field									
Conductivity, field	umhos/c	338	450	293	454	498	167	120	
Oxygen, Dissolved	mg/l	12.51	10.29	9.65	0.39	12.72	8.88	0.26	
pH field	std. units	6.83	7.6	7.52	7.64	6.95	7.45	7.32	
Temperature	deg C	6.52	6.3	8.84	10.61	7.84	6.22	7.9	
Physical									
TDS	mg/l	209	249	258	296	263	380	202	117
Isotopes									
Carbon-13	permil	-17.6	-16.4	-14.5	-15.9		-18	-17.5	-16.3
Carbon-14, years	years	105.5+/- 40 y	350+/- 30 y	1860+/- 30 y	4020+/- 30 y		3310+/- 30 y	5080+/- 30 y	6100+/- 30 y
Deuterium	permil	-117.8+/-0.4	-119.9+/-0.4	-126.2	-127.5	-118.7+/-0.4	-118	-122.3	-125.4+/-0.4
Oxygen-18	permil	-15.2+/-0.1	-15.5+/-0.1	-16.3	-16.3	-15.5+/-0.1	-15.2	-15.7	-16.2+/-0.1
Tritium	TU	4.4+/-0.15	3.69+/-0.12	1.99+/-0.1	6.14+/-0.2		5.56+/-0.18	0.26+/-0.09	0.11+/-0.09
Trace Metals									
Dissolved Iron	mg/L	0.01ND	0.01ND	0.01ND	0.132	0.01ND	0.01ND	0.01ND	0.01ND
Dissolved Manganese	mg/L	0.001ND	0.001ND	0.001ND	0.0243	0.001ND	0.001ND	0.00959	0.001ND
Routine Constituents									
Bicarbonate (as CaCO3	mg/L	124	194	90	182	134	194	128	84
Chloride	mg/L	8.21	10.3	2.33	12.7	45.4	23	4.31	1.05
Dissolved Calcium	mg/L	26.4	39.9	26.1	34.3	38.1	60.2	21.2	12.8
Dissolved Magnesium	mg/L	7.19	12.6	9.1	17.5	10.7	14	8.69	4.61
Dissolved Potassium	mg/L	3.31	3.01	0.838	1.87	3.9	3.5	2.69	1.19
Dissolved Silicon	mg/L	18	12.8	17.3	21.1	15.4	17.3	18.6	17.7
Dissolved Sodium	mg/L	13.3	11.6	7.1	17.5	17.6	8.42	10.3	6.34
NH3-N	mg/L as	0.0227	0.02ND	0.02ND	0.0547	0.0329	0.02ND	0.02ND	0.0514
NO3/N	mg/L	6.6	2.92	10.8	0.1ND	8.37	9.8	0.126	0.1ND
Sulfate	mg/L	14.4	21.1	12.8	43.4	20.3	16.5	10.9	4.76

Table 6-4. Summary of Water Quality Data for Groundwater Samples from 2012 Drilling Project WRIA 54/56

Location Description:			Marshall Pit well site		Hayford Pit well site			L. Hangman Ck well site		
			shallow	deep	shallow	intermediate	deep	shallow	intermediate	deep
Constituent	**Units**	Sample Name:	BH-7	MW-7	BH-8	BH-8_2	MW-8	DW-G	MW-9	BH-9_3
Field										
Conductivity, field	umhos/cm		289	247	407	208	220	442	598	279
Oxygen, Dissolved	mg/l		7	3.5	3.5	2	7.7	0.5	0.5	0.5
pH field	std. units		7.29	7.47	7.2	7.4	7.96	7.51	11.13	7.36
Temperature	deg C		12.89	18.4	15.3	11.7	19.5	11.5	15.1	13.9
Physical										
TDS	mg/l		188	130	176	154	182	166	205	184
Isotopes										
Carbon-13	permil		-15.2	-14.5	-16.9	-17.9	-15.5	-15		-14.7
Carbon-14, years	years		2360+/- 30 y	10100+/- 40	790+/- 30 y	8220+/- 40 y	3880+/- 30	1960+/- 30 y		13080+/- 50
Deuterium	permil		-118.3	-126+/-0.4	-118.8+/-0.4	-124.8+/-0.4	-127.2+/-0.4	-119.5+/-0.4		-131.2+/-0.4
Oxygen-18	permil		-15.4	-16.2+/-0.1	-15.4+/-0.1	-16.2+/-0.1	-16.6+/-0.1	-15.2+/-0.1		-16.8+/-0.1
Tritium	TU		3.82+/-0.13	0.61+/-0.09	4.34+/-0.14	0.28+/-0.09	0.52+/-0.09	2.21+/-0.09		0.05+/-0.09
Trace Metals										
Dissolved Iron	mg/L		0.01ND	0.01ND	0.01ND	0.0604	0.01ND	0.0603	0.01ND	0.688
Dissolved Manganese	mg/L		0.0127	0.116	0.00699	0.00162	0.00212	0.517	0.001ND	0.0593
Routine Constituents										
Bicarbonate (as CaCO3	mg/L		118	116	124	103	86	214	5ND	144
Carbonate (as CaCO3)	mg/L								142	
Chloride	mg/L		6.43	1.46	28.7	2.24	8.45	3.24	10.8	2.44
Dissolved Calcium	mg/L		30.5	18	35.4	14.4	14.6	51.7	11.7	19.1
Dissolved Magnesium	mg/L		10	9.32	10.4	7.04	5.69	15.3	1.23	9.97
Dissolved Potassium	mg/L		2.57	2.85	2.06	1.76	4.9	3.17	8.99	2.05
Dissolved Silicon	mg/L		20.2	19.5	15.9	18	18.7	13.2	15.4	23.2
Dissolved Sodium	mg/L		4.03	10.3	7.72	7.77	11.8	9.28	28.3	10.1
NH3-N	mg/L as N		0.02ND	0.02ND	0.0289	0.02ND	0.699	0.0664	1.78	0.0945
NO3/N	mg/L		1.73	0.1ND	4.36	0.221	1.1	0.1ND	0.1ND	0.1ND
Sulfate	mg/L		7.96	7.1	23.1	6.03	9.27	17.5	29.7	4.34

Table 6-5.
Calculated Ion Balance Error for Groundwater Water Samples, 2012
West Plains and Lower Hangman Watershed

Units below reported in equivalents per liter

Sample Name	Potassium	Magnesium	Sodium	Calcium	Chloride	Bicarbonate, as CaCO3	Sulfate	NO3-N	Ion Balance
2012 drilling									
BH-7	0.066	0.833	0.183	1.525	-0.184	-2.360	-0.166	-0.124	**-4.1**
MW-7	0.073	0.777	0.468	0.900	-0.042	-2.320	-0.148	0.000	**-6.2**
BH-8	0.053	0.867	0.351	1.770	-0.820	-2.480	-0.481	-0.311	**-14.8**
BH-8_2	0.045	0.587	0.353	0.720	-0.064	-2.060	-0.126	-0.016	**-14.1**
MW-8	0.126	0.474	0.536	0.730	-0.241	-1.720	-0.193	-0.079	**-9.0**
BH-9_2	0.064	0.983	0.555	1.100	-0.069	-2.840	-0.088	0.000	**-5.2**
BH-9_3	0.053	0.831	0.459	0.955	-0.070	-2.880	-0.090	0.000	**-13.9**
MW-9	0.231	0.103	1.286	0.585	-0.309	0.000	-0.619	0.000	**-26.2**
DW-G	0.081	1.275	0.422	2.585	-0.093	-4.280	-0.365	0.000	**-4.1**
2012 sampling									
167996	0.085	0.599	0.605	1.320	-0.235	-2.480	-0.300	-0.471	**-14.4**
470237	0.077	1.050	0.527	1.995	-0.294	-3.880	-0.440	-0.209	**-13.8**
385958	0.021	0.758	0.323	1.305	-0.067	-1.800	-0.267	-0.771	**-9.4**
445291	0.048	1.458	0.795	1.715	-0.363	-3.640	-0.904	0.000	**-10.0**
472535	0.100	0.892	0.800	1.905	-1.297	-2.680	-0.423	-0.598	**-15.0**
369725	0.090	1.167	0.383	3.010	-0.657	-3.880	-0.344	-0.700	**-9.1**
351696	0.069	0.724	0.468	1.060	-0.123	-2.560	-0.227	-0.009	**-11.4**
617922	0.031	0.384	0.288	0.640	-0.030	-1.680	-0.099	0.000	**-14.8**

Constituent values given in milliequivalents (milligrams per liter / milligrams per milliequivalent).

Positive value indicates cation, negative value indicates anion.

*Ion Balance = [(sum of cations - sum of anions) / (sum of cations + sum of anions)]*100, where anions and cations are in milliequivalents*

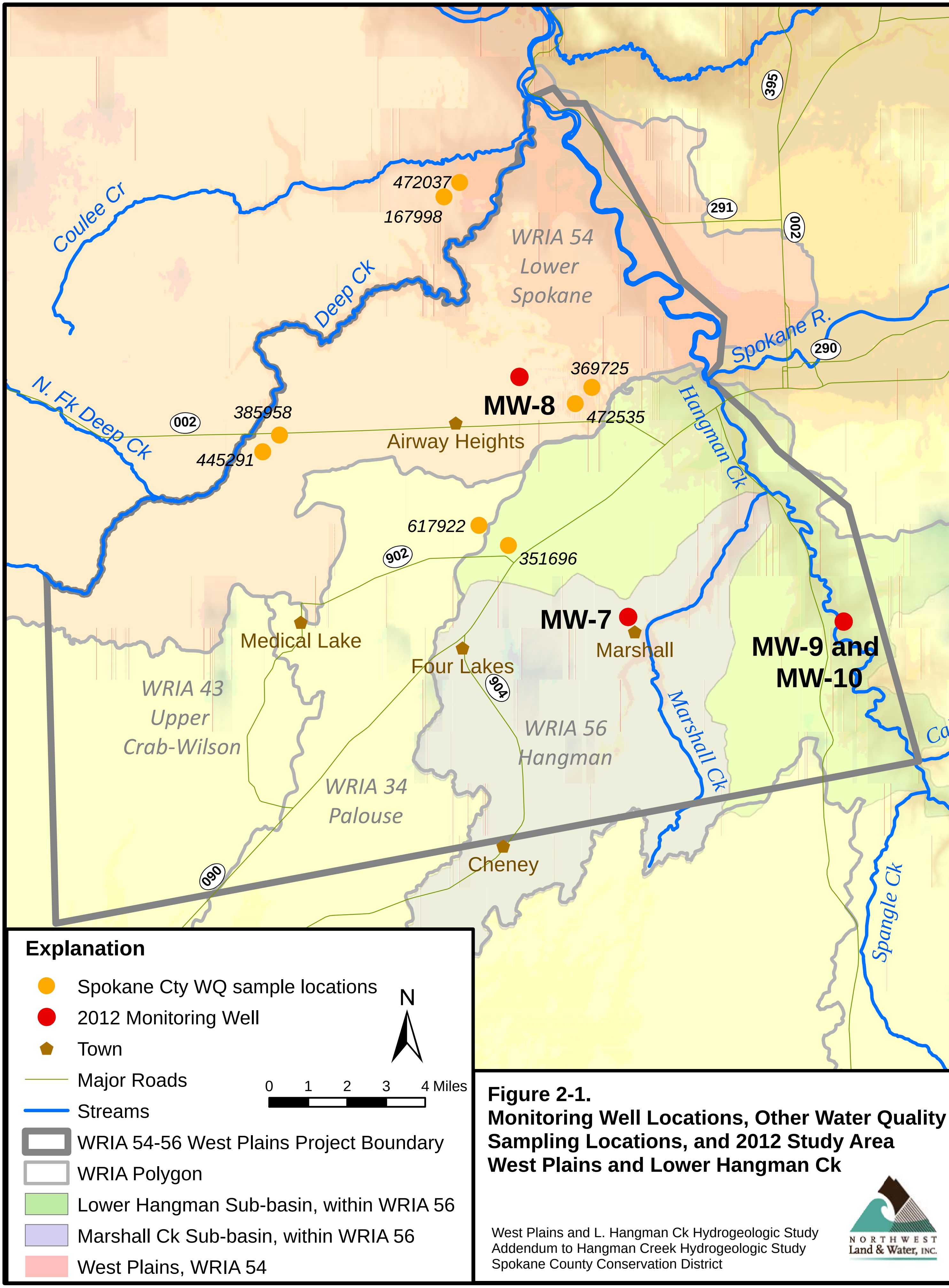


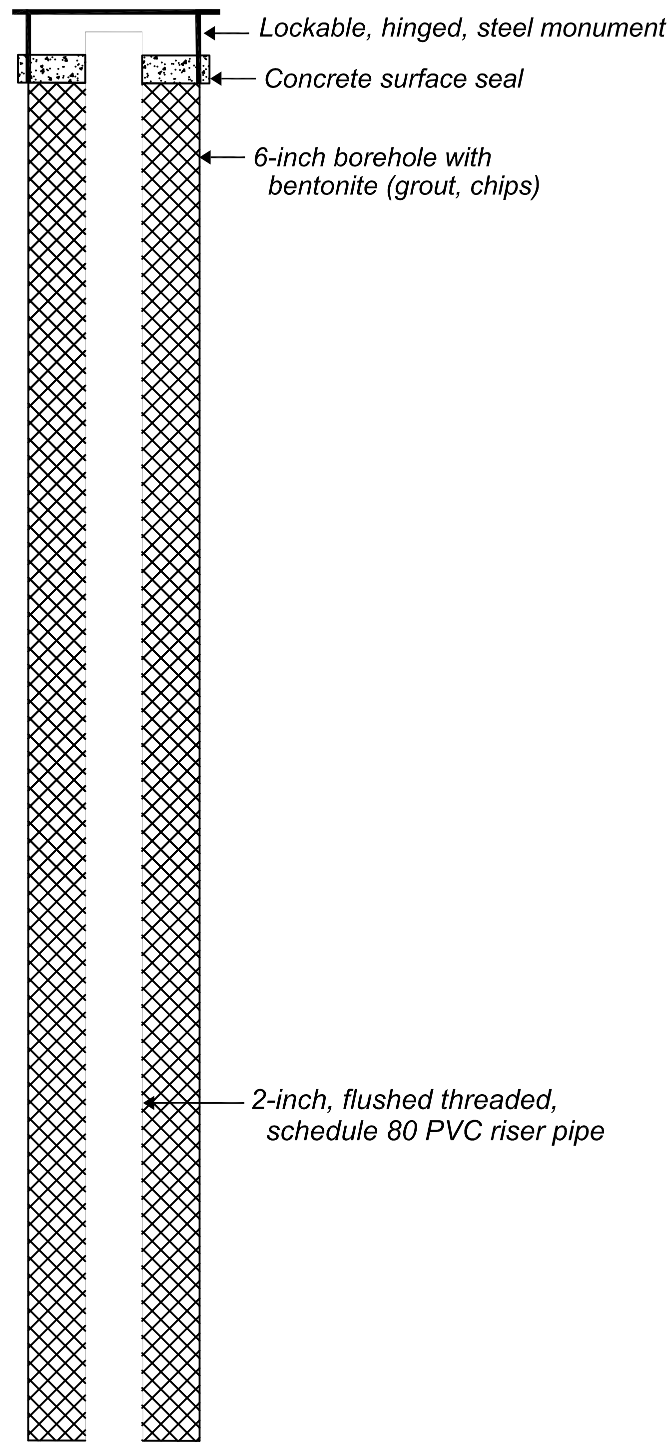
Figure 2-1.
Monitoring Well Locations, Other Water Quality Sampling Locations, and 2012 Study Area West Plains and Lower Hangman Ck

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

Depth Below Ground (feet)	GEOLOGIC LOG	Geo	Hydro	Sample
	Approximate Ground Elevation 2,333 feet msl			
0	Sand (m); sli slty, f&c sndy, brn-gry, ls	Qal	Unsaturated	
	Sand (m); f-m grvly, brn-gry, ls	Glaciofluvial Sediments		
25	Sand (f-m); sli sltly, brn-gry to md dk gry, ls			
	Sand (f-c); f-m grvly, brn-gry to md dk gry			
	Gravel (f-m); m-c sndy, brn-gry to m dk gry			
	Sand (m-c); brn-gry to md dk gry, ls			
50	Sand (f-c); sli f-m gvly, brn-gry to md dk gry, ls			
75	Sand (f-m); sli slty, brn-gry, ls siltier			
	Silt & Sand (f); dk yel-brn, md ls to md stff			
100	Sand (f-m); sli slty; dk yel-brn to brn-gry, ls siltier			
	Sand (m-c); sli f sndy; dk yel-brn to brn-gry			
125	Sand (m); c sndy; lt ol gry to brn-gry, ls			
	Sand (c) & Gravel; m sndy; brn-gry, ls			
150	Sand (m-c)l; sli slty; brn-gry to lt ol gry, ls wet @ 154, circ <1/4 gpm			
175	Sand (m-c) & Gravel (f); brn-gry to lt ol gry, ls; grades to Sand (m-c) thin mod yel-brn silt intrbd			
200	Sand (m-c); brn-gry w/dk yel-brn Silt intrbds			

WELL CONSTRUCTION DETAILS



version 06/26/12

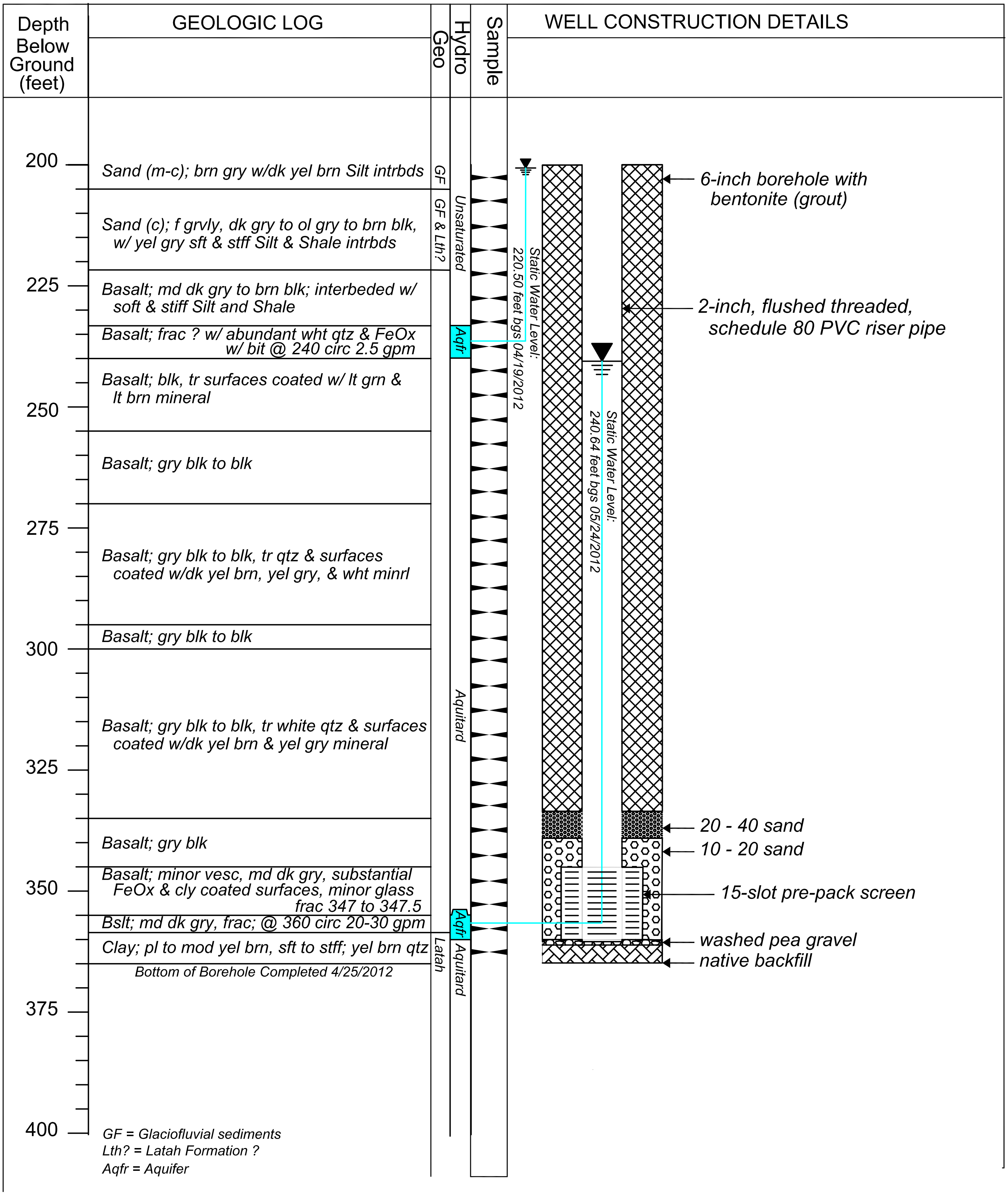
D:\Projects\xxxx\Log&AsBuilts\Asbuilt and GeoLog_ MW7(aka Marshall Plt)_ pg1of2

PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: NE 1/4 SE 1/4 Sec 16, T24N, R42E
WELL NAME: MW-7
WELL TAG ID: BCL 667

Figure 3-1 (pg 1/2)
MW-7 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District



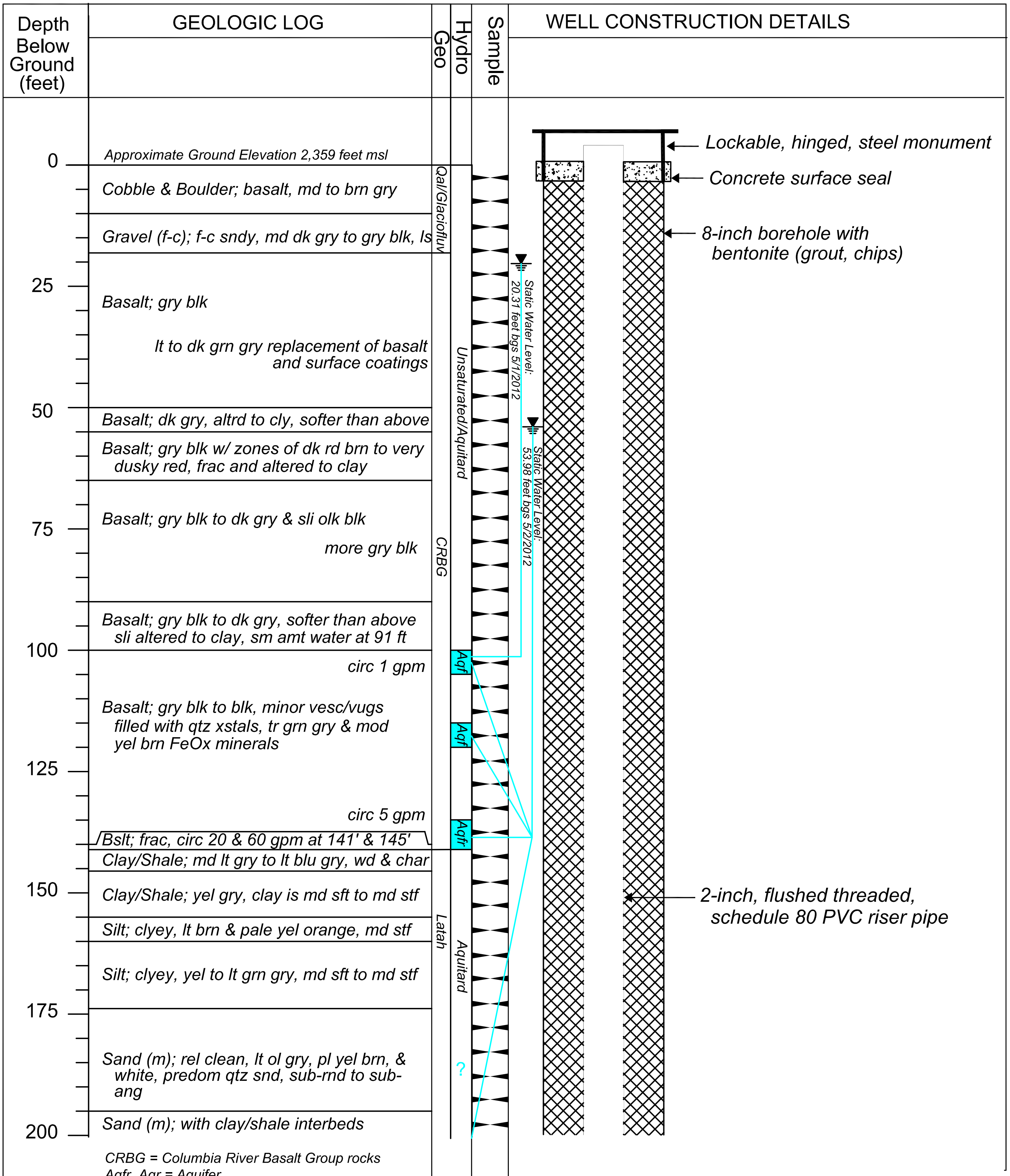
PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: NE 1/4 SE 1/4 Sec 16, T24N, R42E
WELL NAME: MW-7
WELL TAG ID: BCL 667

Figure 3-1 (pg 2/2)

MW-7 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District



CRBG = Columbia River Basalt Group rocks
Aqfr, Aqr = Aquifer
Water level on 5/1/2012 is composite of interval 100 - 202 ft bgs
? water-bearing character uncertain

version 07/19/12

D:\Projects\xxxx\Log&AsBuilts\Asbuilt and GeoLog _ MW8(aka Hayford Pit) _ pg1of2

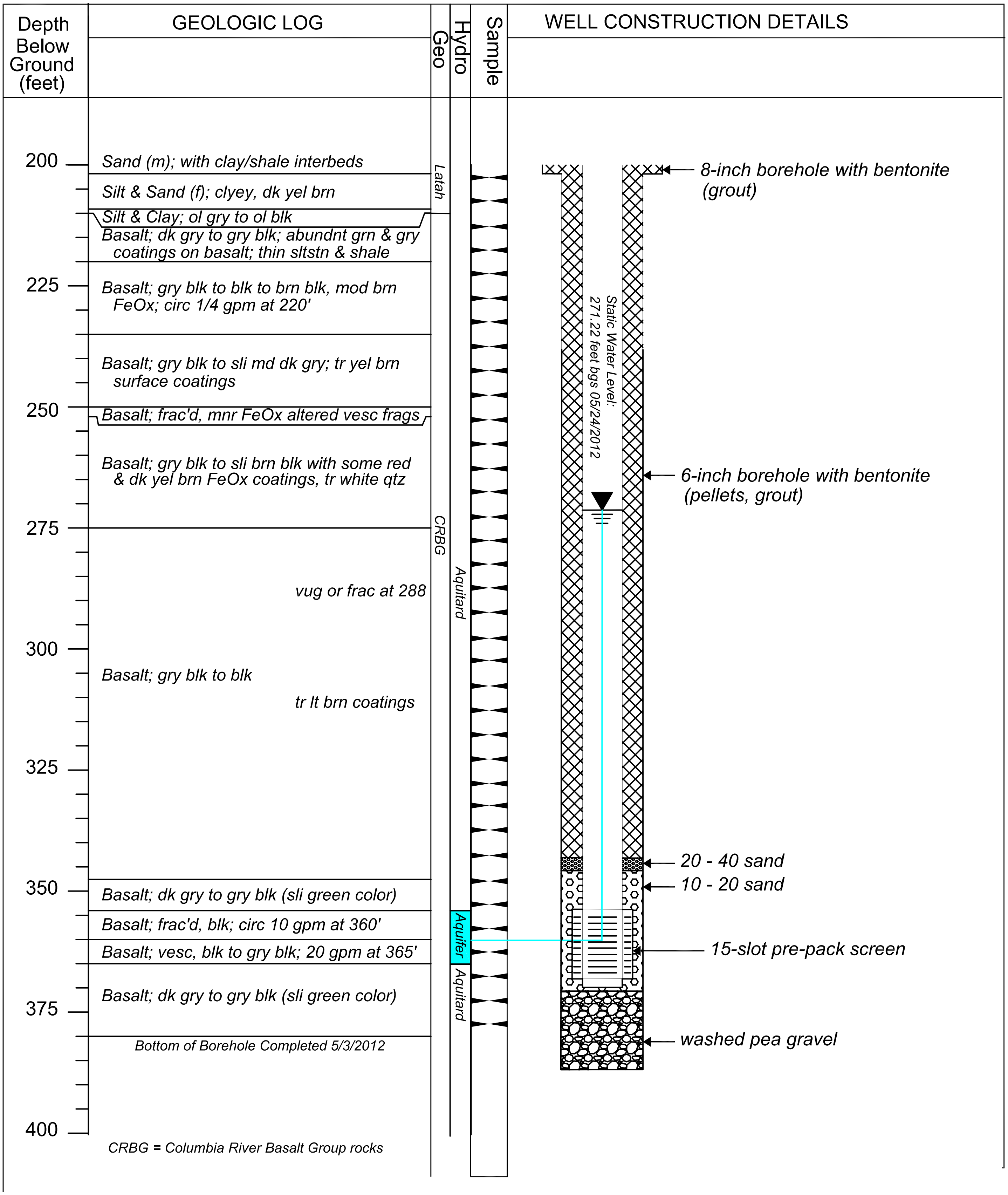
PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: SW 1/4 SW 1/4 Sec 18, T25N, R42E
WELL NAME: MW-8
WELL TAG ID: BCL 668

Figure 3-2 (pg 1/2)

MW-8 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District



version 07/19/12

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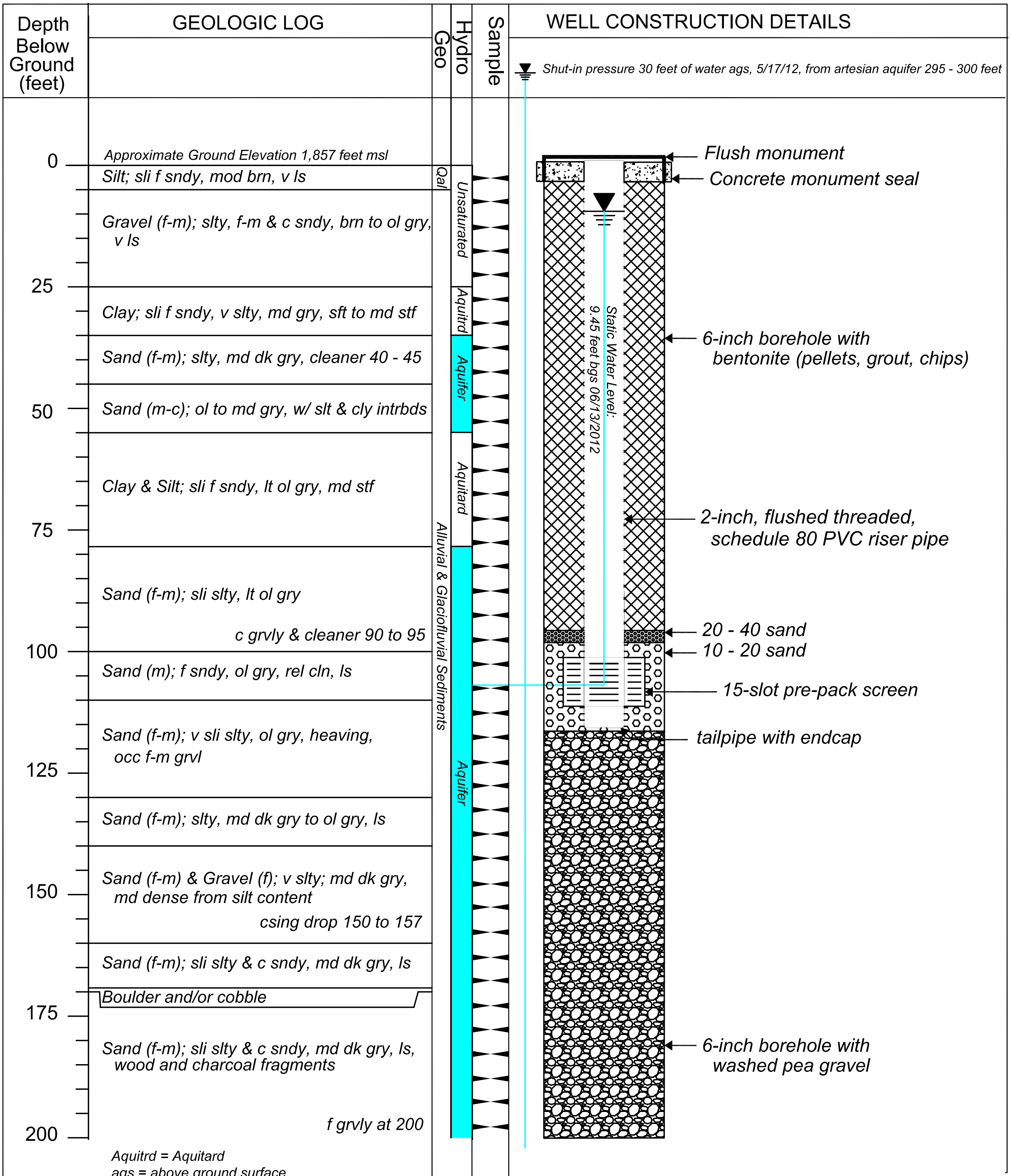
PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: SW 1/4 SW 1/4 Sec 18, T25N, R42E
WELL NAME: MW-8
WELL TAG ID: BCL 668

Figure 3-2 (pg 2/2)

MW-8 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District



PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: SE 1/4 NE 1/4 Sec 17, T49N, R43E
WELL NAME: MW-9
WELL TAG ID: BCL 671

Figure 3-3 (pg 1/2)
MW-9 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

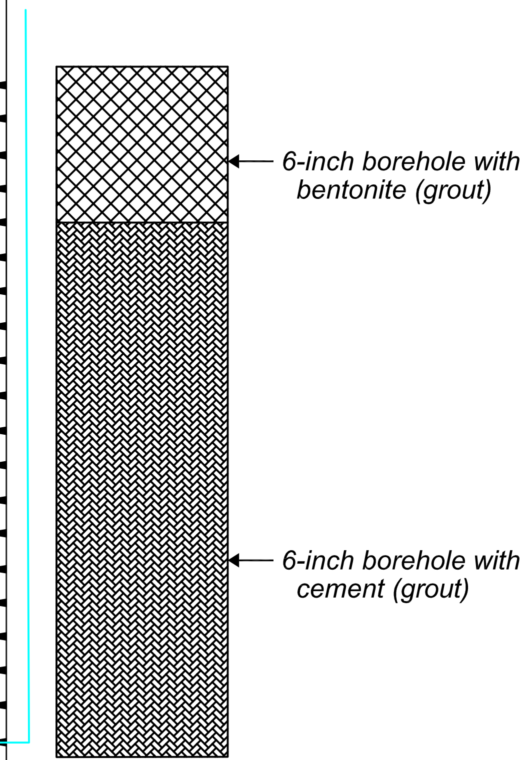
version 07/19/12

D:\Projects\xxxx\Log&AsBuilts\Asbuilt and GeoLog _ MW9(aka xxx) _ pg1of2

Depth Below Ground (feet)	GEOLOGIC LOG	Geo	Hydro	Sample
200	*Sand (f-m); sli slty & c sndy, md dk gry, ls*	*Alluv & GlacioFluv*	*Aqfr*	
	Clay; m sndy, md dk to dk gry, md stf		*Aquitard*	
	Clay; m sndy, ol gry, sft to md stf			
	Basalt (broken?) & Silt; gry to brn blk; FeOx	*CRBG*		
225	*Basalt (broken?) & Silt; ol gry to brn blk*			
	Basalt (broken?) & Clay; ol gry to ol blk			
250	*Basalt; gry blk; tr white qtz & pale yel grn, yel gry replmnt mineral & coatings; tr mod brn FeOx coatings* circ <1 gpm			
275	*Basalt; minor fractures, gry blk, tr mod brn FeOx coatings*			
	Basalt; gry blk, tr pale yel gry replmnt & coatings; tr red brn & mod brn FeOx			
	Basalt; minor frac's, dk gry, lt ol gry surf's			
300	*Basalt; highly frac'd, dk gry, lt ol gry coatings on basalt surfaces, minor mod brn FeOx* circ ~ 50 gpm		*Aqfr*	
	Bottom of Borehole Completed 5/16/2012			
325				
350				
375				
400				

CRBG = Columbia River Basalt Group rocks
Aqfr = Aquifer

WELL CONSTRUCTION DETAILS



version 7/19/12

PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: SE 1/4 NE 1/4 Sec 17, T49N, R42E
WELL NAME: MW-9
WELL TAG ID: BCL 671

Figure 3-3 (pg 2/2)

MW-9 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

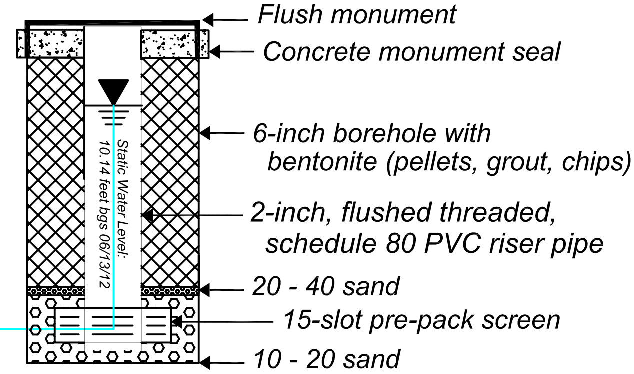
D:\Projects\...\Log&AsBuilts\Asbuilt and GeoLog_ MW9_ pg2of2.dwg

Depth Below Ground (feet)	GEOLOGIC LOG	Geo	Hydro
0	*Approximate Ground Elevation 1,857 feet msl*		
	Silt; sli f sndy, mod brn, v ls	*Qal*	*Unsaturated*
	Sand (f-c) & Gravel (f-m); sli slty, dk yel brn	*Alluvial & Glaciofluvial Sediments*	*Unsaturated*
	Gravel (f-m); v sli slty, dk yel brn, sub-rnd to sub-ang	*Alluvial & Glaciofluvial Sediments*	*Unsaturated*
25	*Sand (f); v slty, md dk gry*	*Alluvial & Glaciofluvial Sediments*	*Unsaturated*
	Clay & Silt; v f sndy, md dk gry, sft to md stf	*Alluvial & Glaciofluvial Sediments*	*Aqt*
	Sand (m-f); ol to md dk gry, rel clean	*Alluvial & Glaciofluvial Sediments*	*Aquifer*
	Sand (f-m); v sli slty, ol to md gry	*Alluvial & Glaciofluvial Sediments*	*Aquifer*
50	*Bottom of Borehole Completed 6/12/2012*		
75			
100			
125			
150			
175			
200			

Aqt = Aquitard

Sample

WELL CONSTRUCTION DETAILS



version 07/19/12

D:\Projects\xxxx\Log&AsBuilts\Asbuilt and GeoLog _ MW10 _ pg1of1

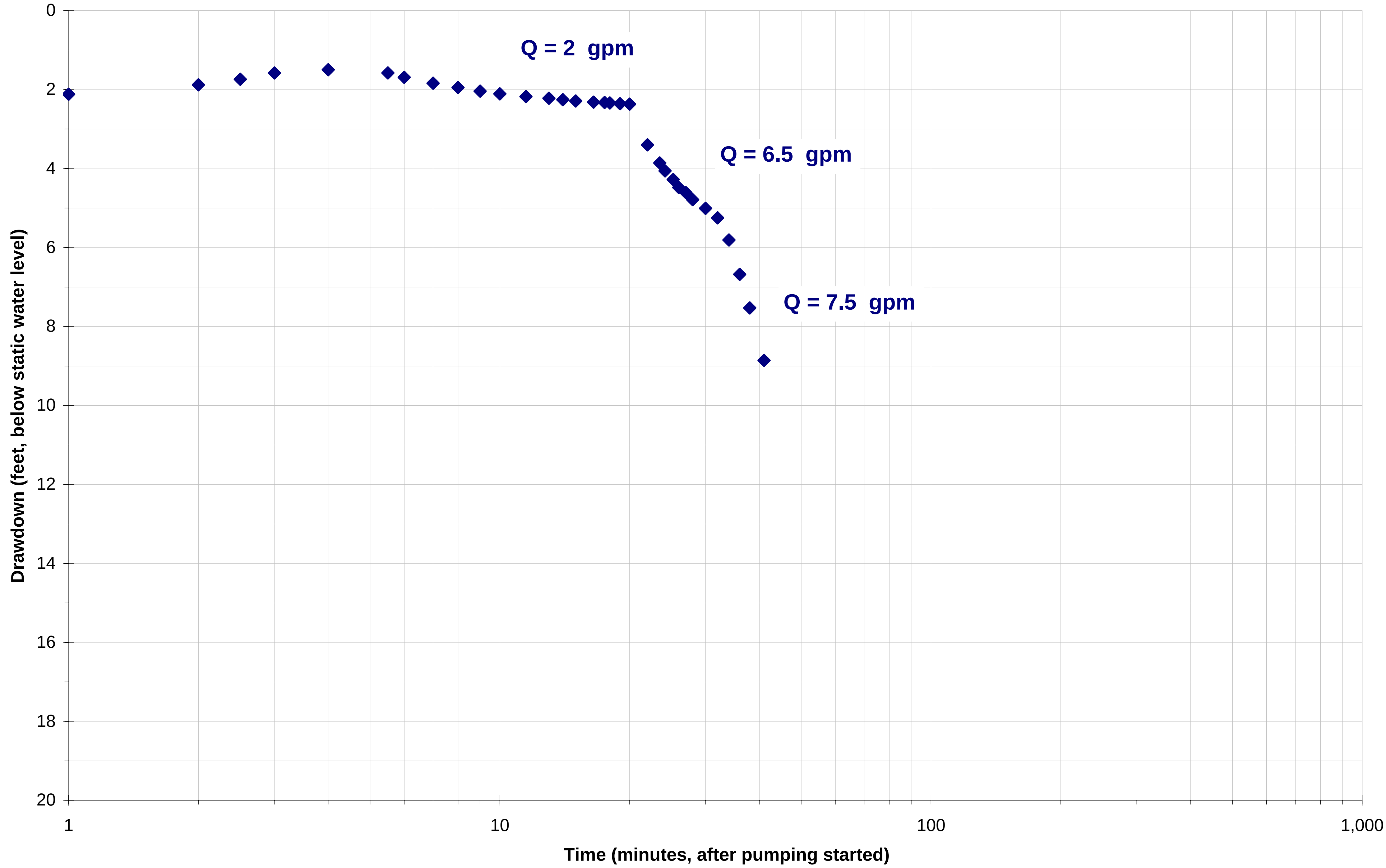
PROJECT NAME: West Plains and L Hangman Ck Study
DRILLING METHOD: Air Rotary
DRILLER: Jim McLeslie, Kevin Young (helper)
FIRM: H2O Well Services, Inc
CONSULTING FIRM: Northwest Land & Water, Inc
REPRESENTATIVE: Jim Mathieu, Hydrogeologist
LOCATION: SE 1/4 NE 1/4 Sec 17, T49N, R43E
WELL NAME: MW-10
WELL TAG ID: BCL 672

Figure 3-4 (pg 1/1)

MW-10 Geologic Log and Well Construction Details

NORTHWEST Land & Water, INC.

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

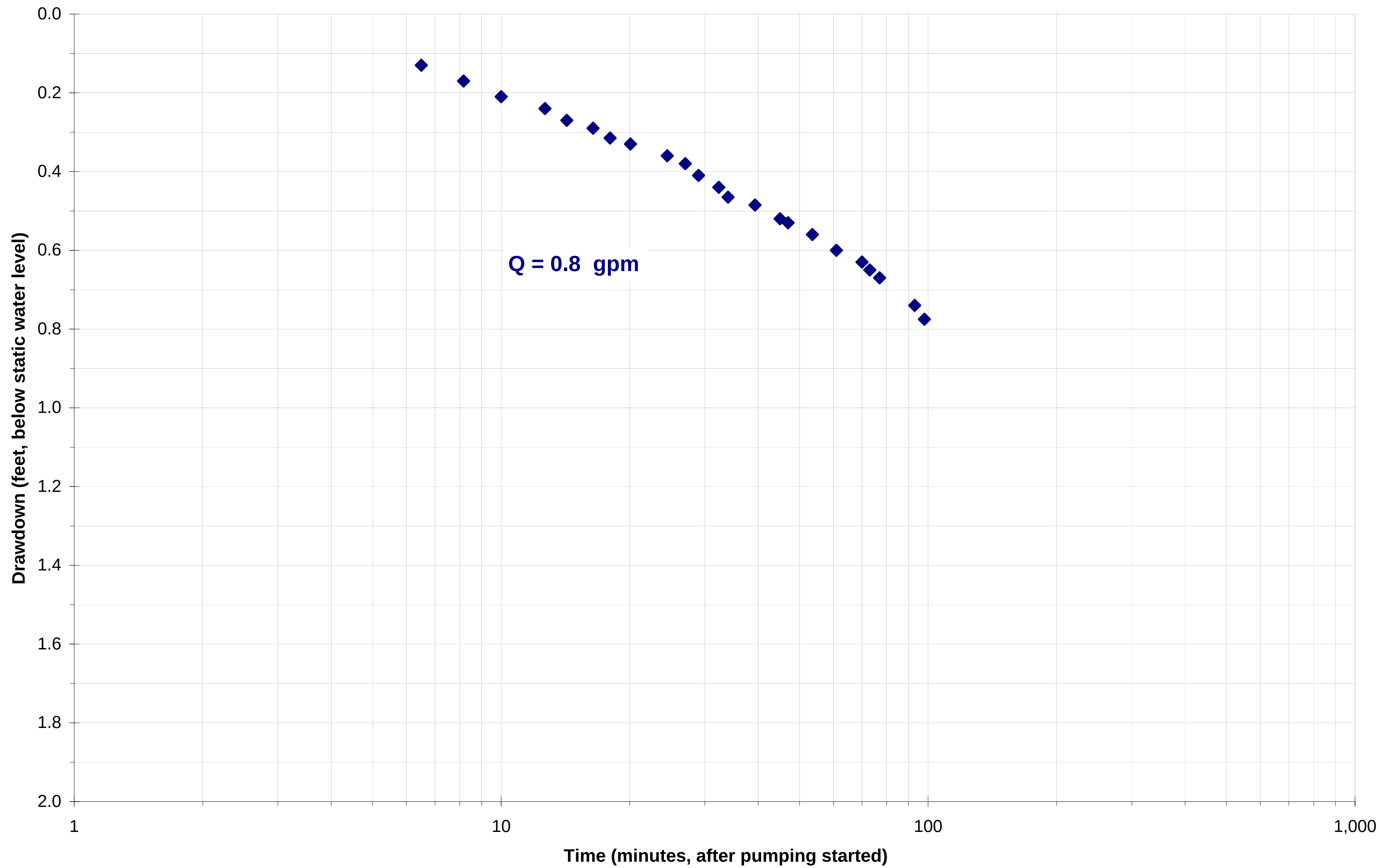


Static Water Level: 228.42 feet below measuring point
Measuring Point: 7.9 feet above ground
Pumping Period: 11:10 to 12:42, April 19, 2012
Pumping Rates (Q): 2, 6.5, and 7.5 gallons per minute

Figure 5-1
BH-7 Drawdown
Test Depth Interval 233 - 240 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.



Static Water Level: 242.79 feet below measuring point

Measuring Point: 2.05 feet above ground

Pumping Period: 09:38 to 11:19, May 25, 2012

Pumping Rates (Q): 0.8 gallons per minute

Figure 5-2

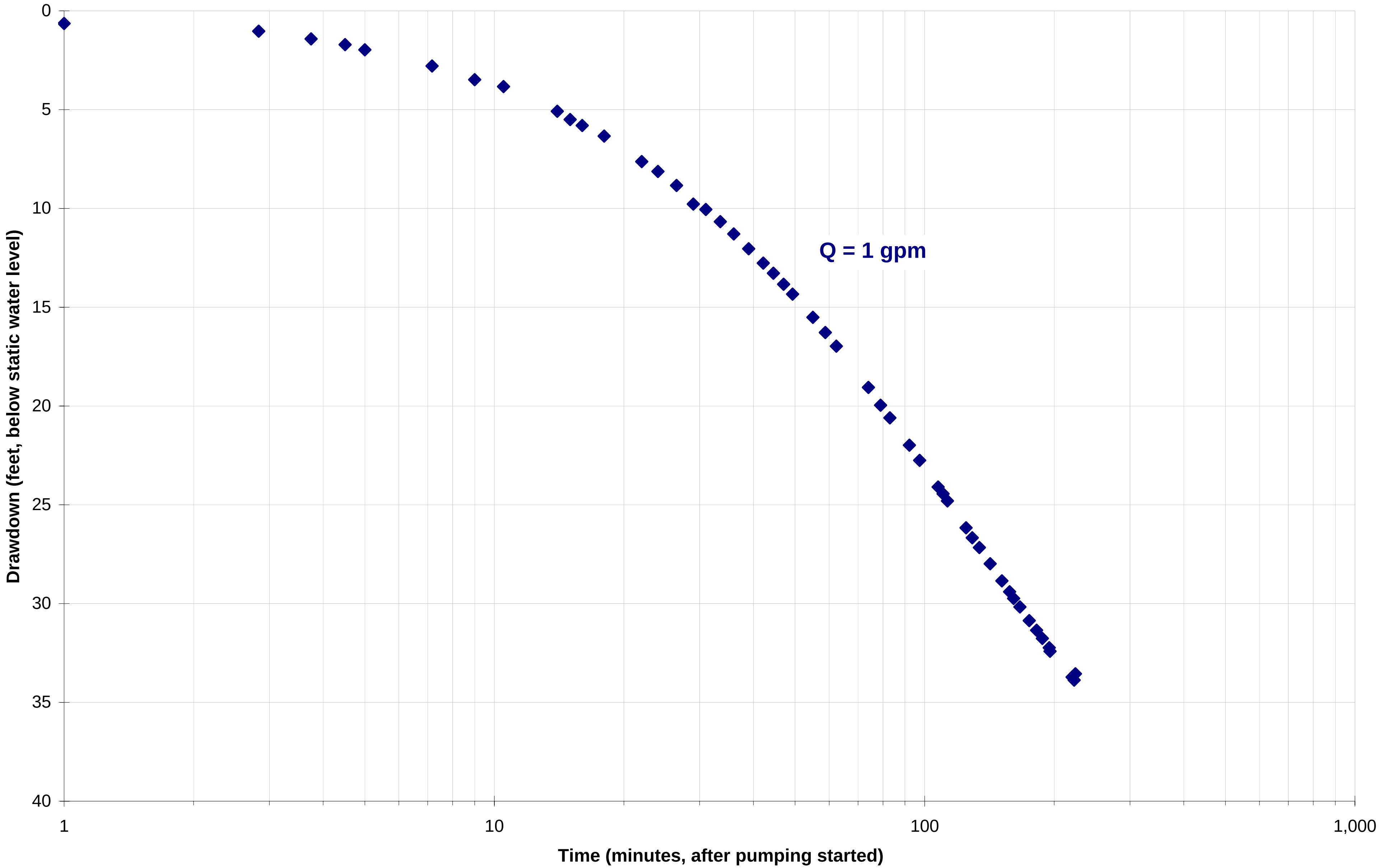
MW-7 Drawdown

Test Depth Interval 355 - 360 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

D:\Projects\...\Borehole MW-7 Pumpng Test.xls v 6/15/2012



Static Water Level: 24.52 feet below measuring point

Measuring Point: 4.2 feet above ground

Pumping Period: 10:47 to 14:30, May 1, 2012

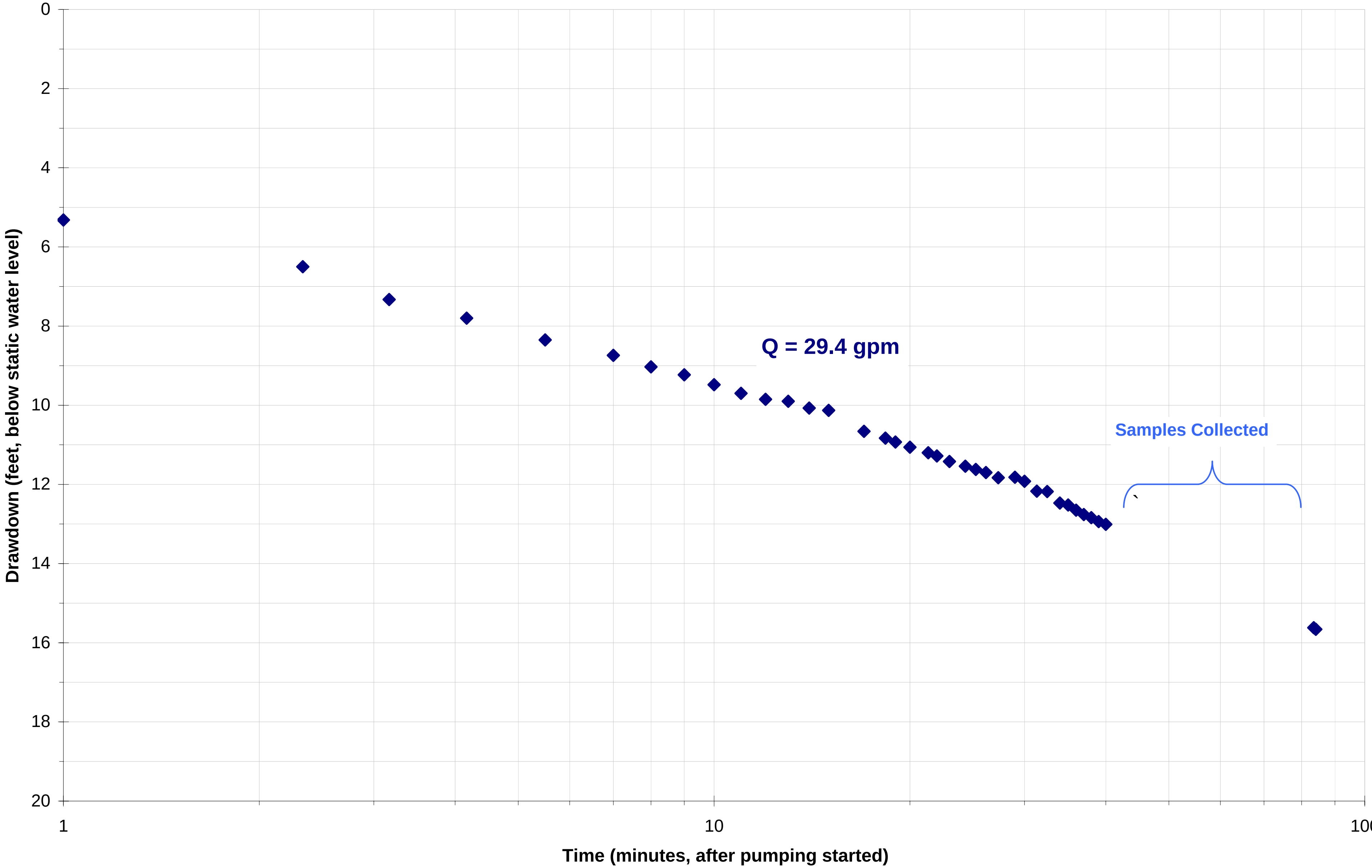
Pumping Rate (Q): 1 gallon per minute

Figure 5-3
BH-8 Drawdown
Test Depth Interval 100 - 105 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

D:\Projects\....\Borehole BH-8 Pumpng Test.xls v 5/10/2012



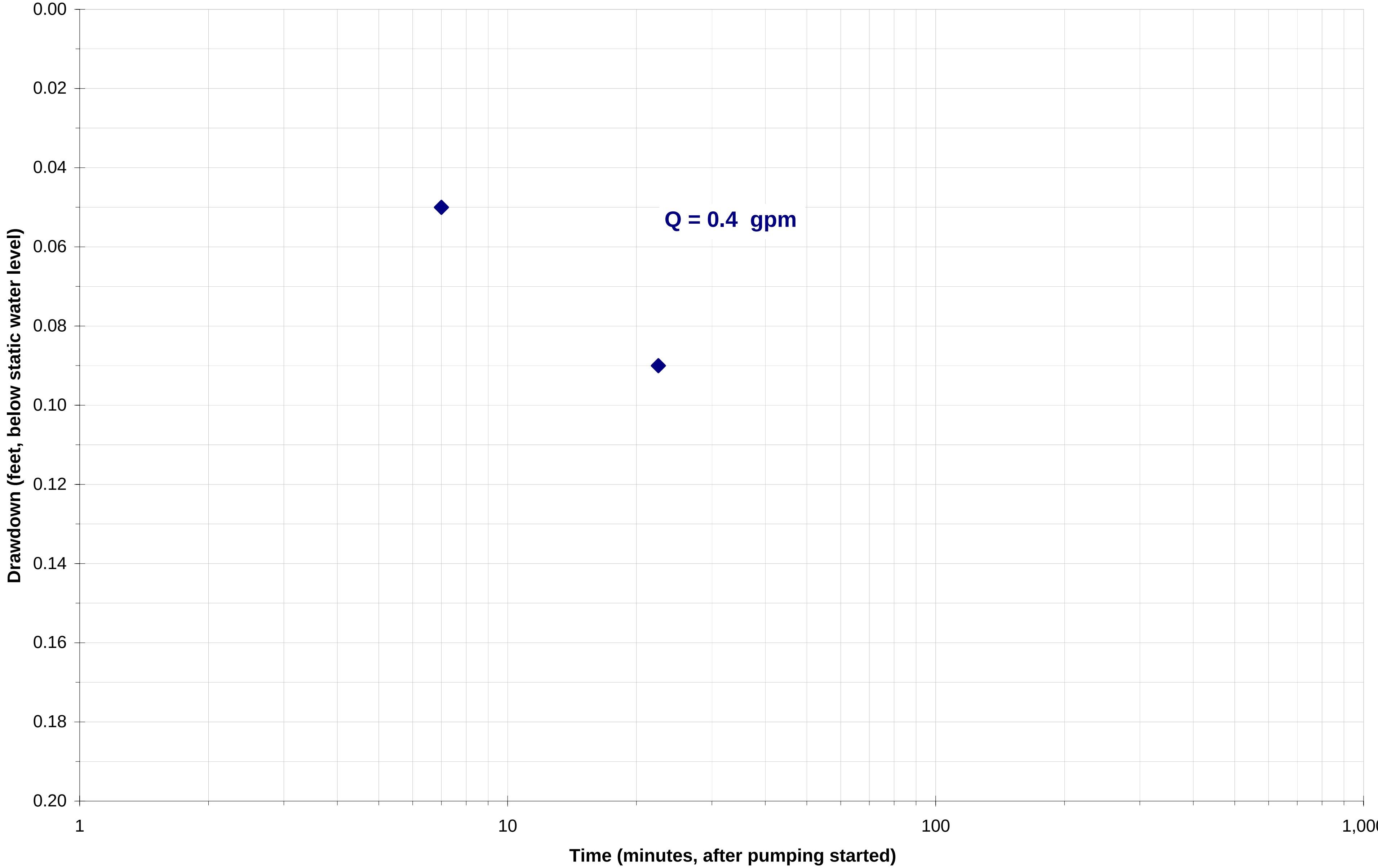
Static Water Level: 56.40 feet below measuring point
Measuring Point: 2.4 feet above ground
Pumping Period: 11:55 to 13:20, May 2, 2012
Pumping Rate (Q): 29.4 gallons per minute

Figure 5-4
BH-8_2 Drawdown
Test Depth Interval 100-141 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

D:\Projects\...\Borehole BH-8_2 Pumpng Test.xls v 5/9/2012



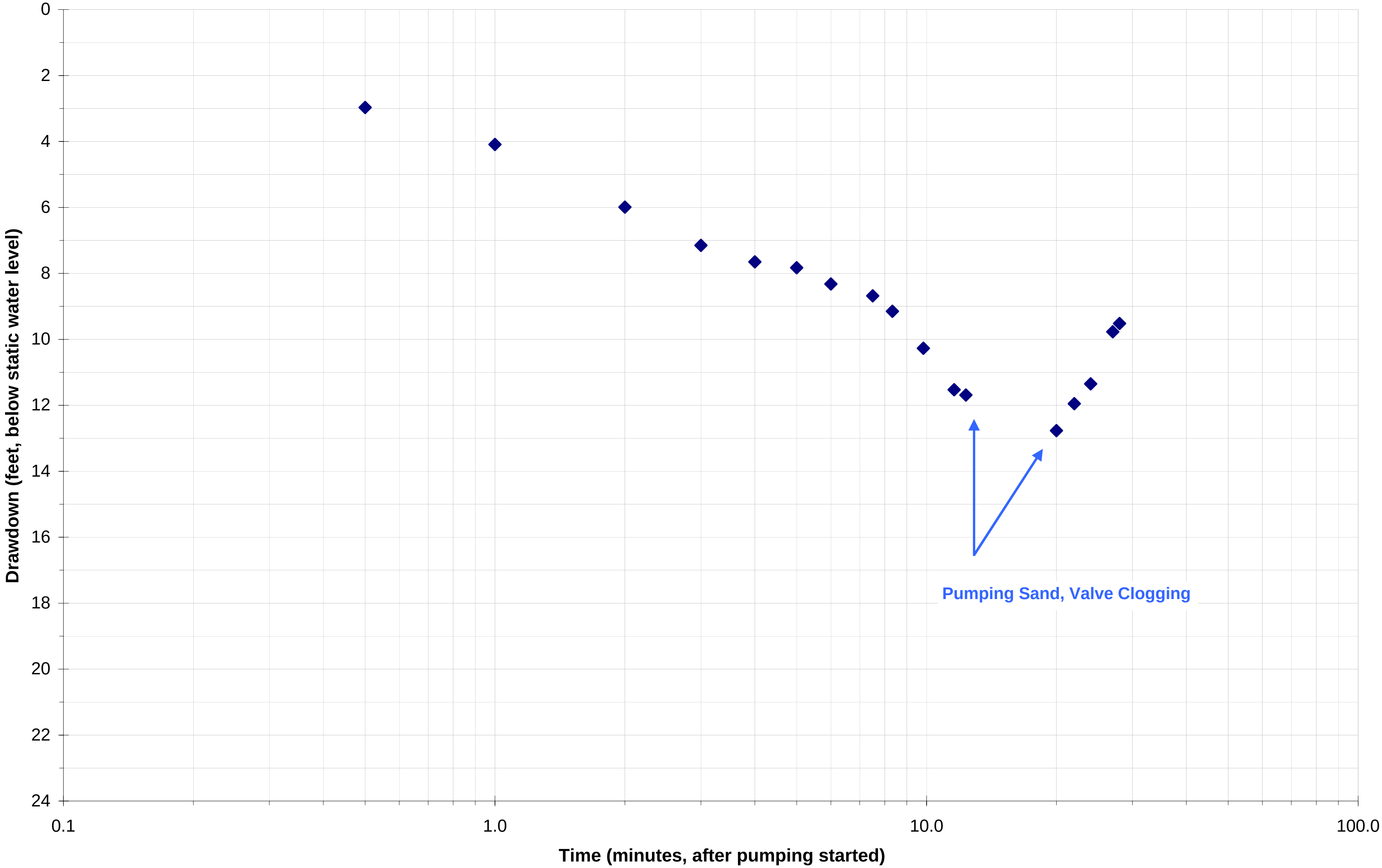
Static Water Level: 273.82 feet below measuring point
Measuring Point: 2.56 feet above ground
Pumping Period (Day 1): 12:52 to 13:40 5/24/12 (no data)
Pumping Period (Day 2): 08:26 to 11:03 5/25/12
Pumping Rates (Q): 0.5 gpm 5/24/12, 0.4 gpm 5/25/12

Figure 5-5
MW-8 Drawdown
Test Depth Interval 354 - 365 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogelogic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

D:\Projects\...\Borehole MW-8 Pumpng Test.xls v 6/15/2012



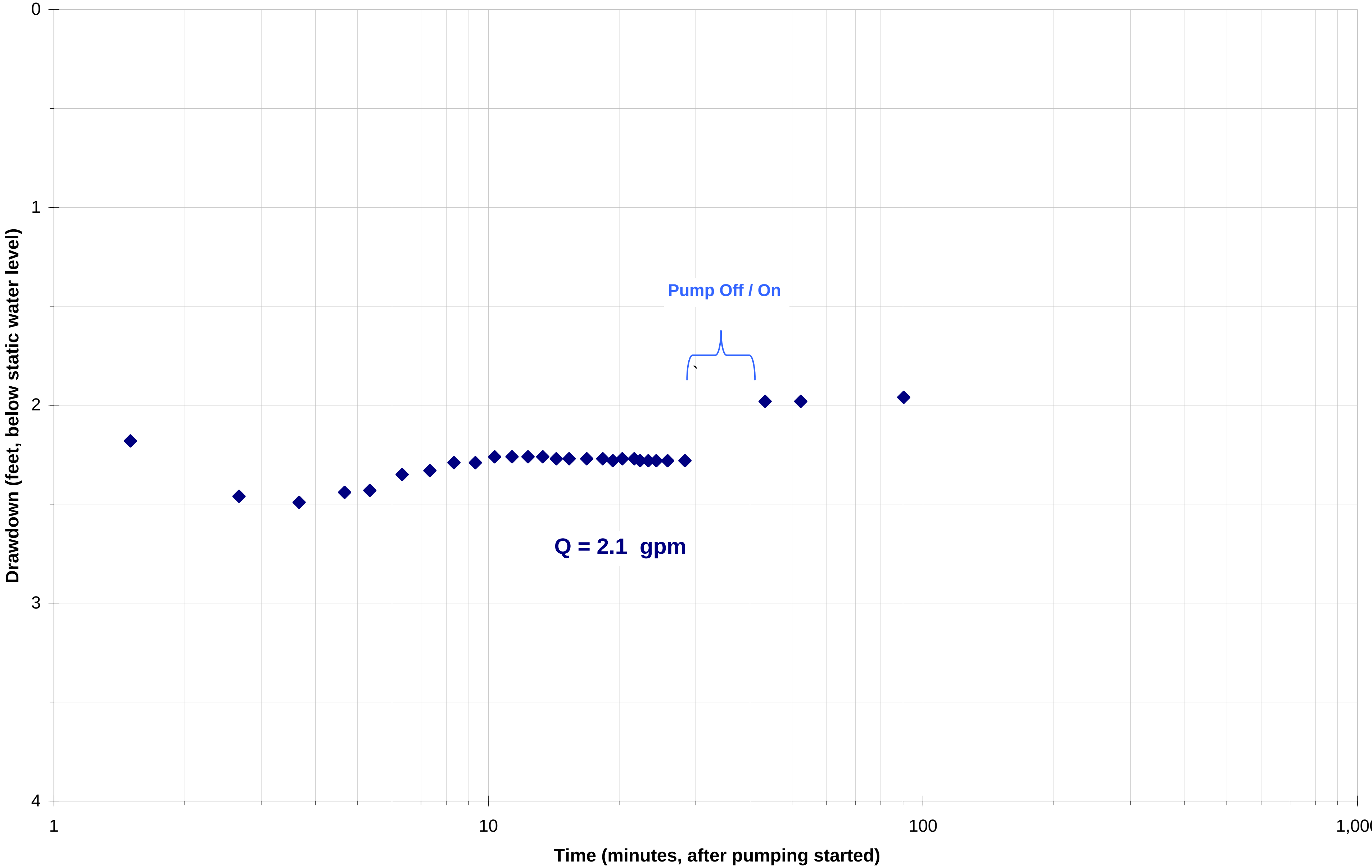
1```

Static Water Level: 14.73 feet below measuring point
Measuring Point: 3.17 feet above ground
Pumping Period : 13:42 to 14:11 May 15, 2012
Pumping Rates (Q): 3.3 gallons per minute

Figure 5-6
BH-9 Drawdown
Test Depth 56.5 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.



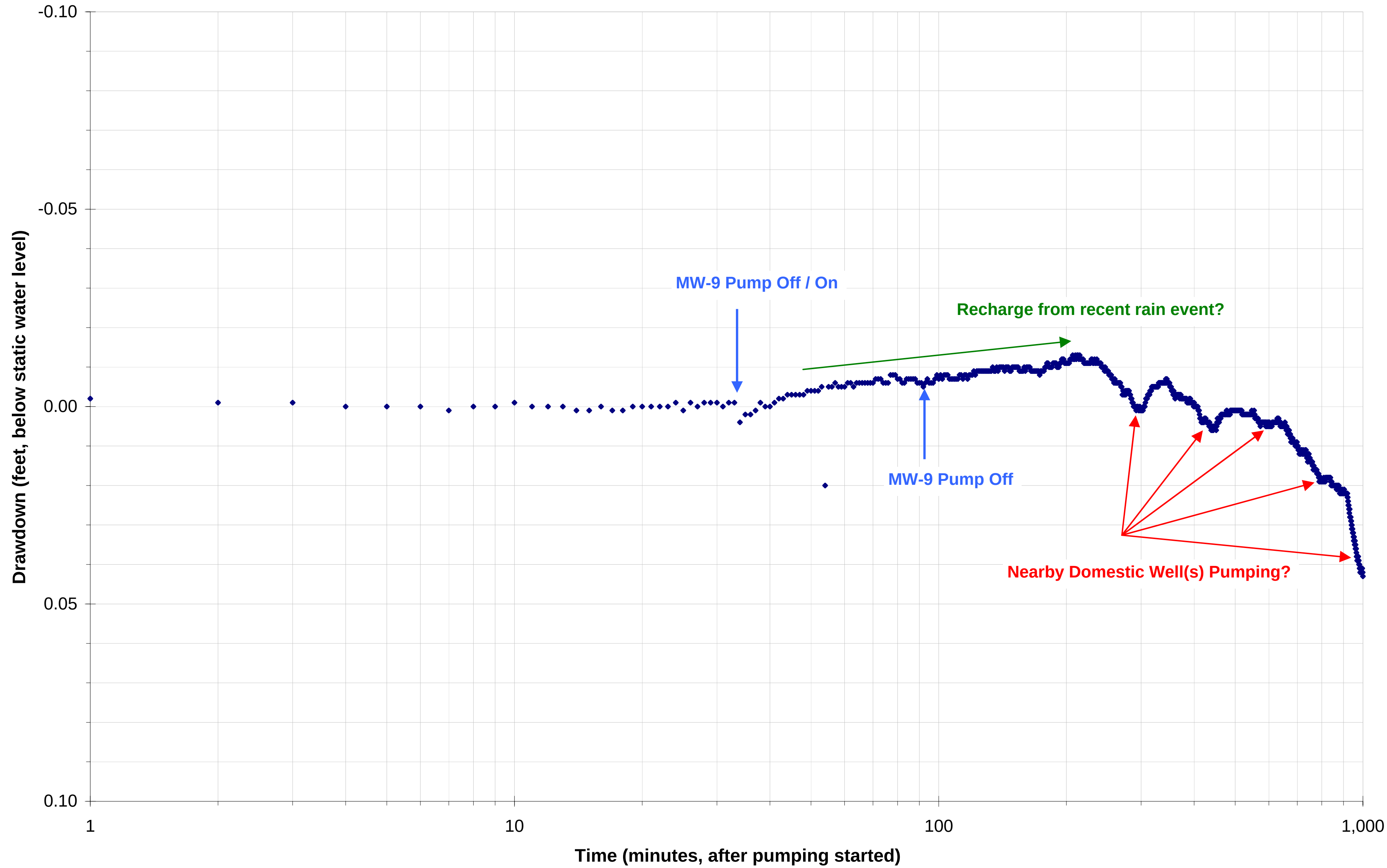
Static Water Level: 11.87 feet below measuring point
Measuring Point: 2.42 feet above ground
Pumping Period : 15:01 to 16:32 June 13, 2012
Pumping Rates (Q): 2.1 gallons per minute

Figure 5-7
MW-9 Drawdown
Test Depth Interval 77 - 130 feet

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

D:\Projects\...\Borehole MW-9 Pumpng Test.xls v 6/15/2012



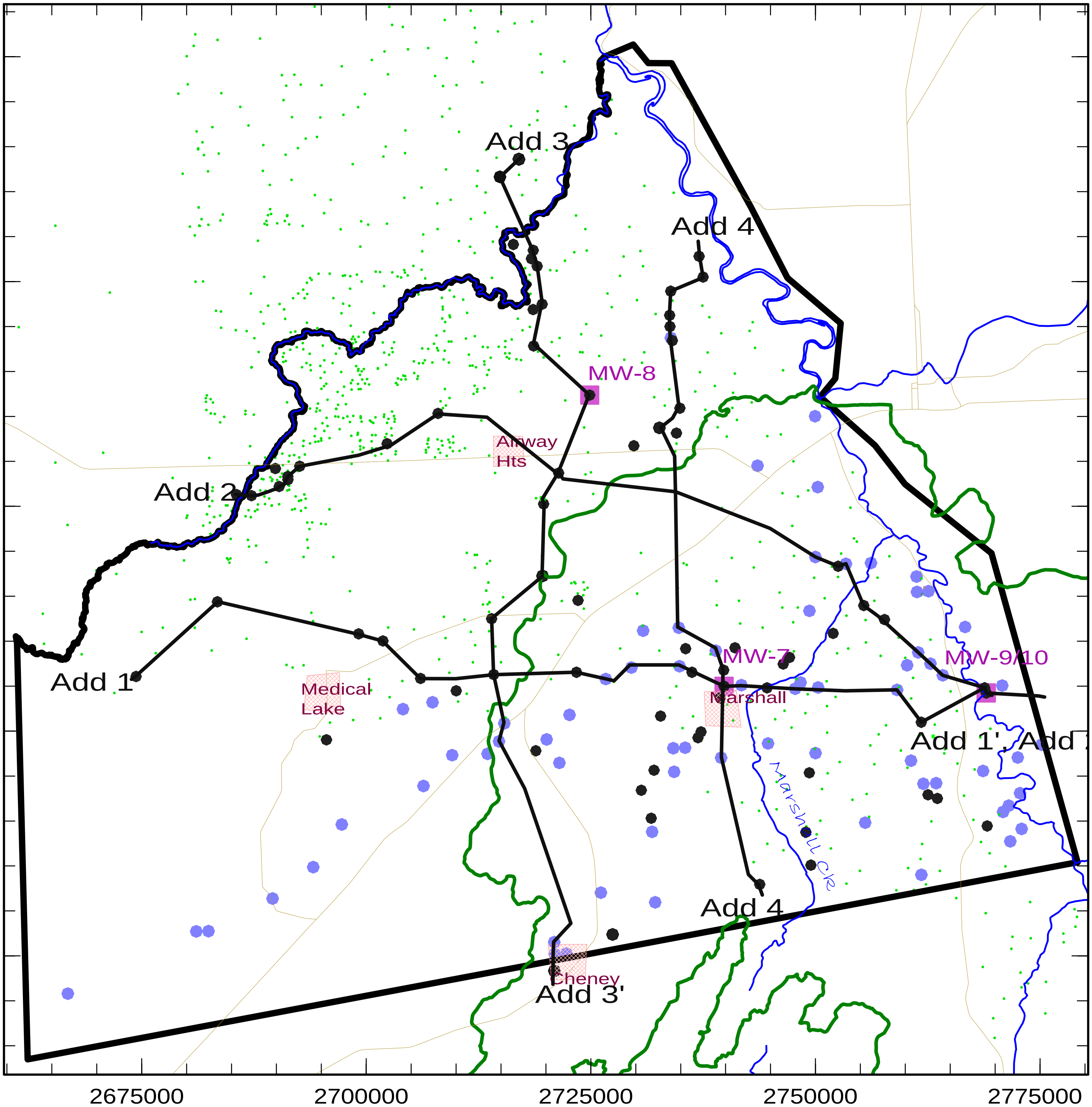
Static Water Level: 11.89 feet below measuring point
Measuring Point: 1.75 feet above ground
Pumping Period : 15:01 to 16:32 at MW-9 June 13, 2012
Pumping Rates (Q): 2.1 gallons per minute at MW-9

Figure 5-8
MW-10 Drawdown during MW-9 Test

West Plains and L Hangman Ck Hydrogeologic Study
Addendum to Hangman Ck Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

D:\Projects\...\Monitoring Well MW-10 during MW-9 Pumpng Test.xls v 6/15/2012



Explanation

- Vicinity Wells with logs and improved locations
- Vicinity Wells with logs and WDOE qq locations
- West Plains Wells in Spokane County GDB
- 2012 monitoring wells
- Indian Village Wells from Mike Hermanson email

Add 1 — Add 1' Addendum Hydrogeologic Section Alignment

Major Roads

Creeks and Rivers

N

0 10000 20000

Figure 4-1.
Wells and Cross-Section Alignments

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

e:\NLWWest Plains\Viewlog\maps\

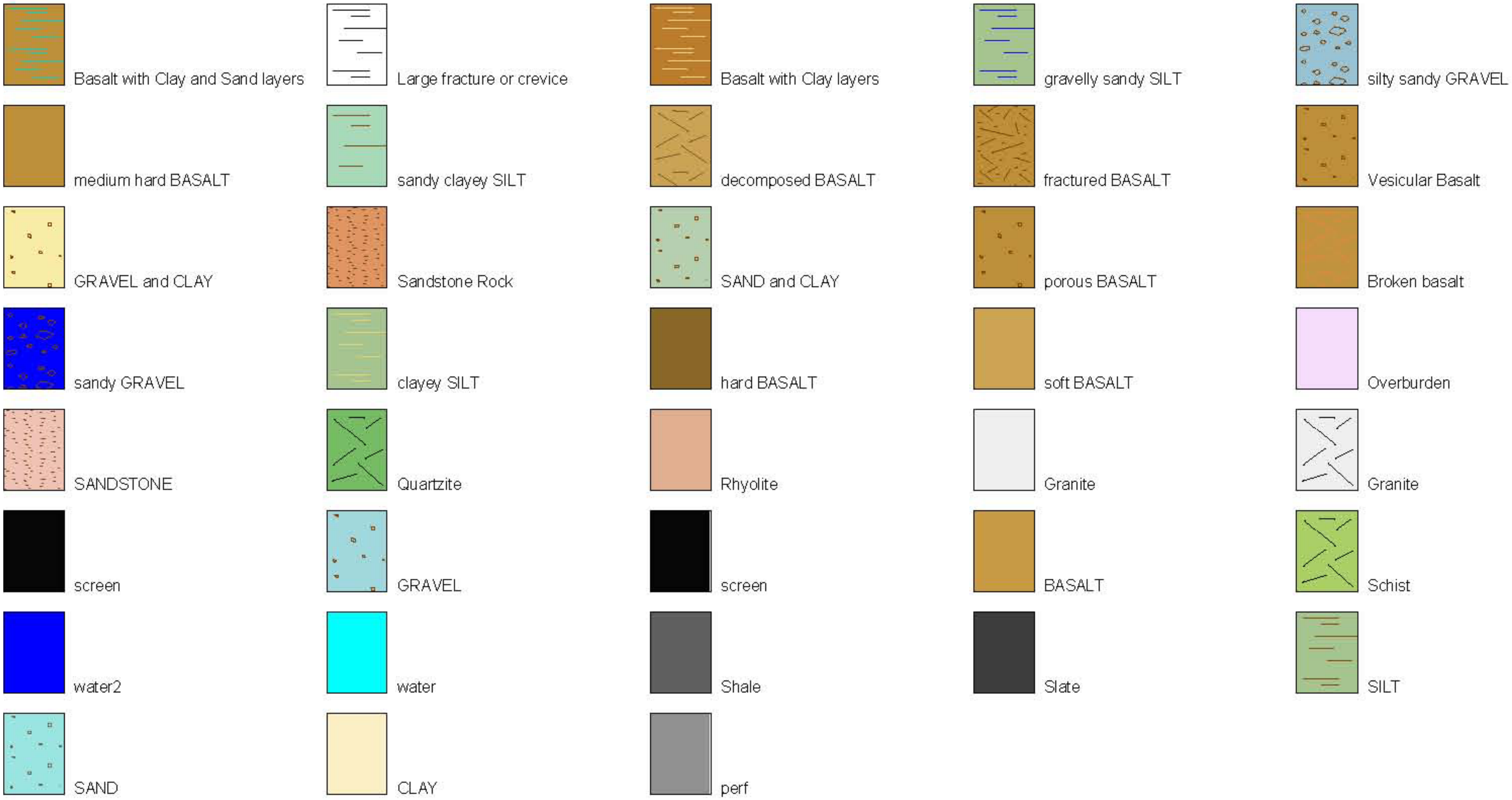
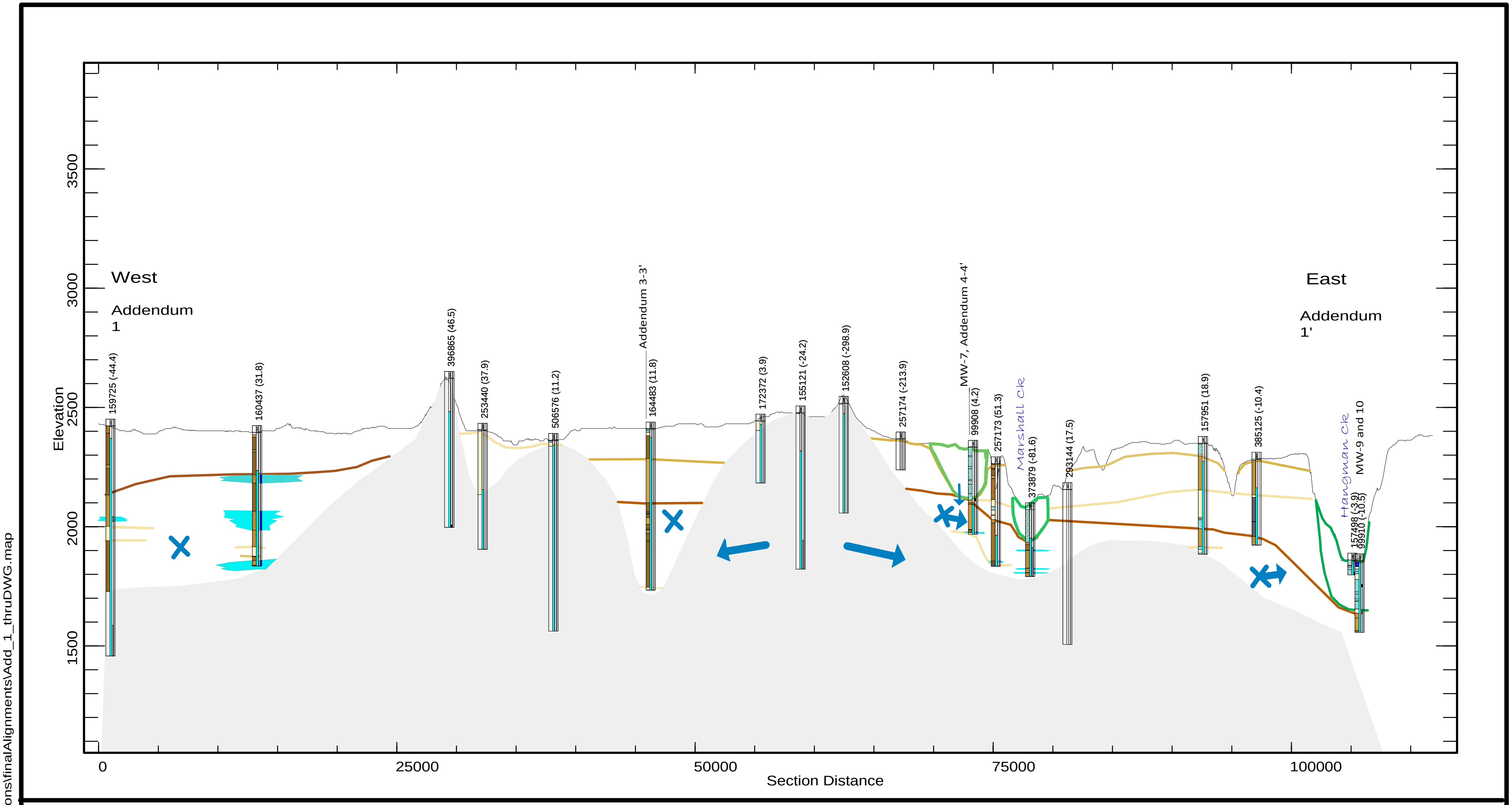


Figure 4-2
Key to Lithology in Hydrogeologic Cross Sections

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology



Explanation

- Bedrock
- Basalt where not indicated otherwise
- Approximate top Wanapum
- Approximate top or bottom Latah
- Approximate Top Grande Ronde
- Groundwater flow direction
- Groundwater flow direction is into the page (northerly)
- Paleochannel deposits
- Aquifer

Well Log Description*

Well Log ID (#) (# = Feet from section trace)

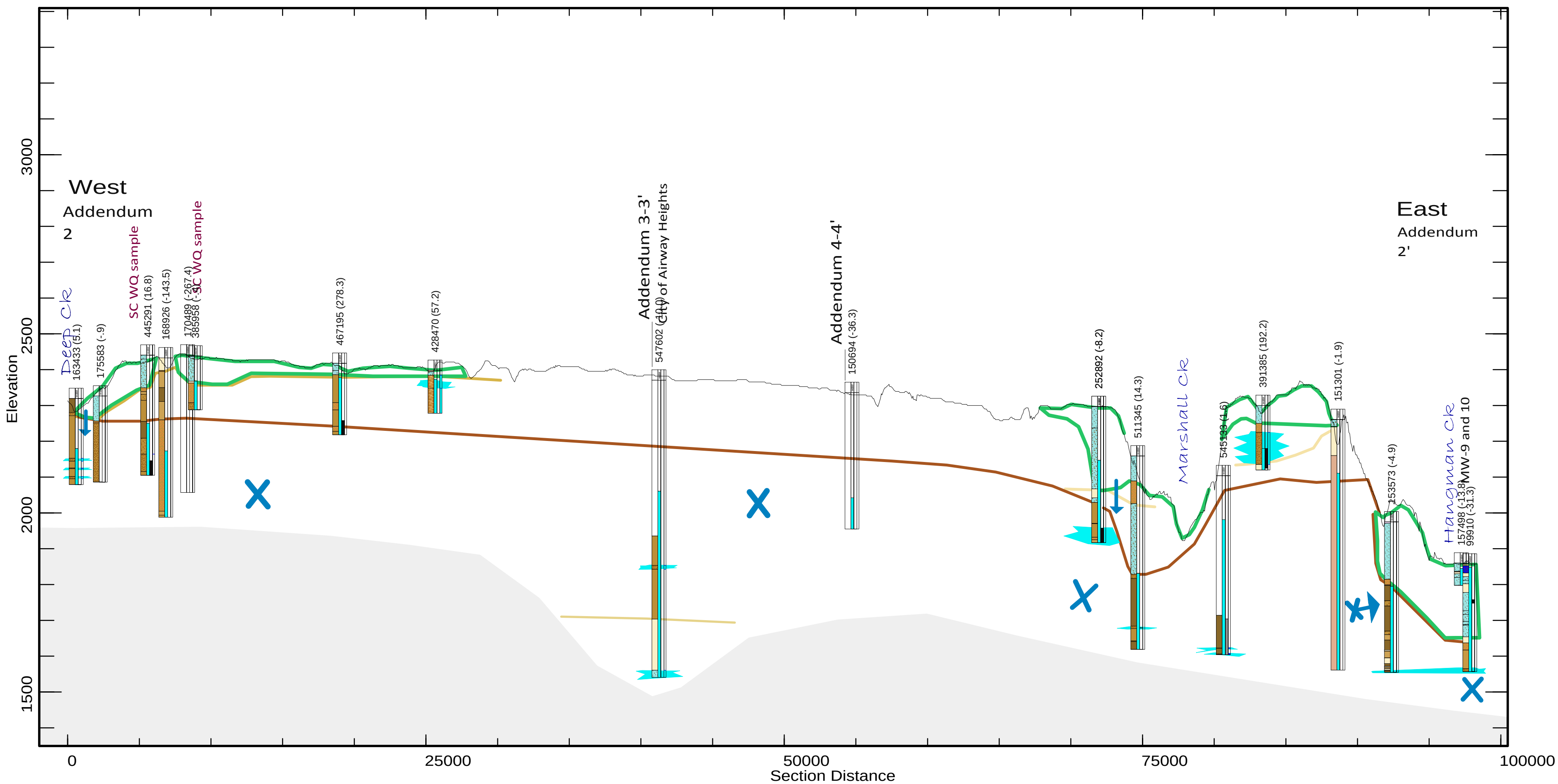
- Fractured Basalt
- SAND
- Hard Basalt
- CLAY
- Granite
- Water Level
- Screen or perforations

* See Figure 4-2 for complete key to lithology

Figure 4-3.
Hydrogeologic Section
Addendum 1-1'

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.



Explanation

Bedrock

Basalt where not indicated otherwise

Approximate top Wanapum

Approximate top or bottom Latah

Approximate Top Grande Ronde

Groundwater flow direction

Groundwater flow direction is into the page (northerly)

Paleochannel deposits

Aquifer

Well Log Description*

Well Log ID (#) (# = Feet from section trace)

Fractured Basalt

SAND

Hard Basalt

CLAY

Granite

Water Level

Screen or perforations

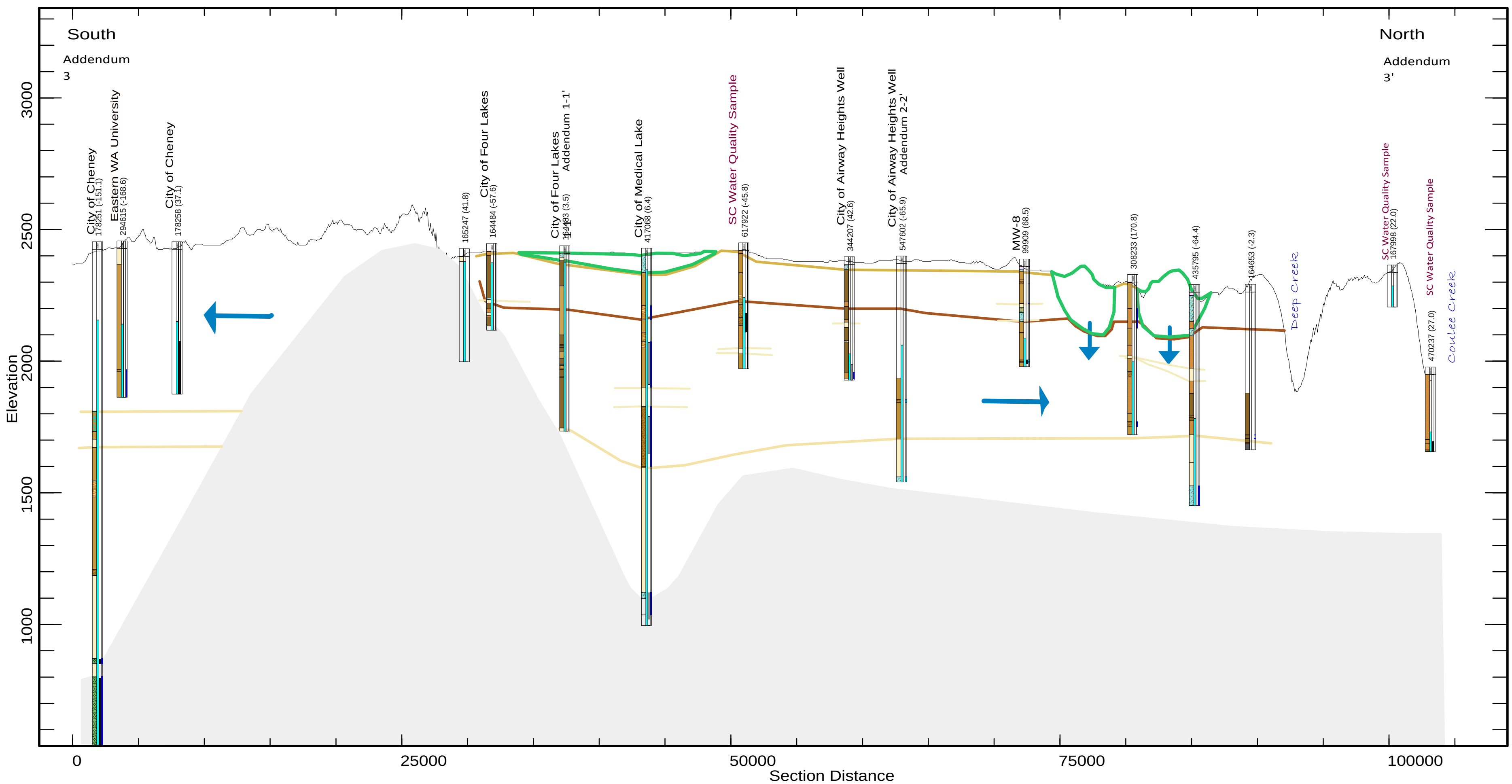
* See Figure 4-2 for complete key to lithology

Figure 4-4. Hydrogeologic Section Addendum 2-2'

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

e:\NLWWest Plains\Viewlog\crosssections\finalAlignments\ADD_2v2_thruDWG.map



Explanation

- Bedrock
- Basalt where not indicated otherwise
- Approximate top Wanapum
- Approximate top or bottom Latah
- Approximate Top Grande Ronde
- Groundwater flow direction
- Groundwater flow direction is into the page (northerly)
- Paleochannel deposits
- Aquifer

Well Log Description*

Well Log ID (#) (# = Feet from section trace)

- Fractured Basalt
- SAND
- Hard Basalt
- CLAY
- Granite
- Water Level
- Screen or perforations

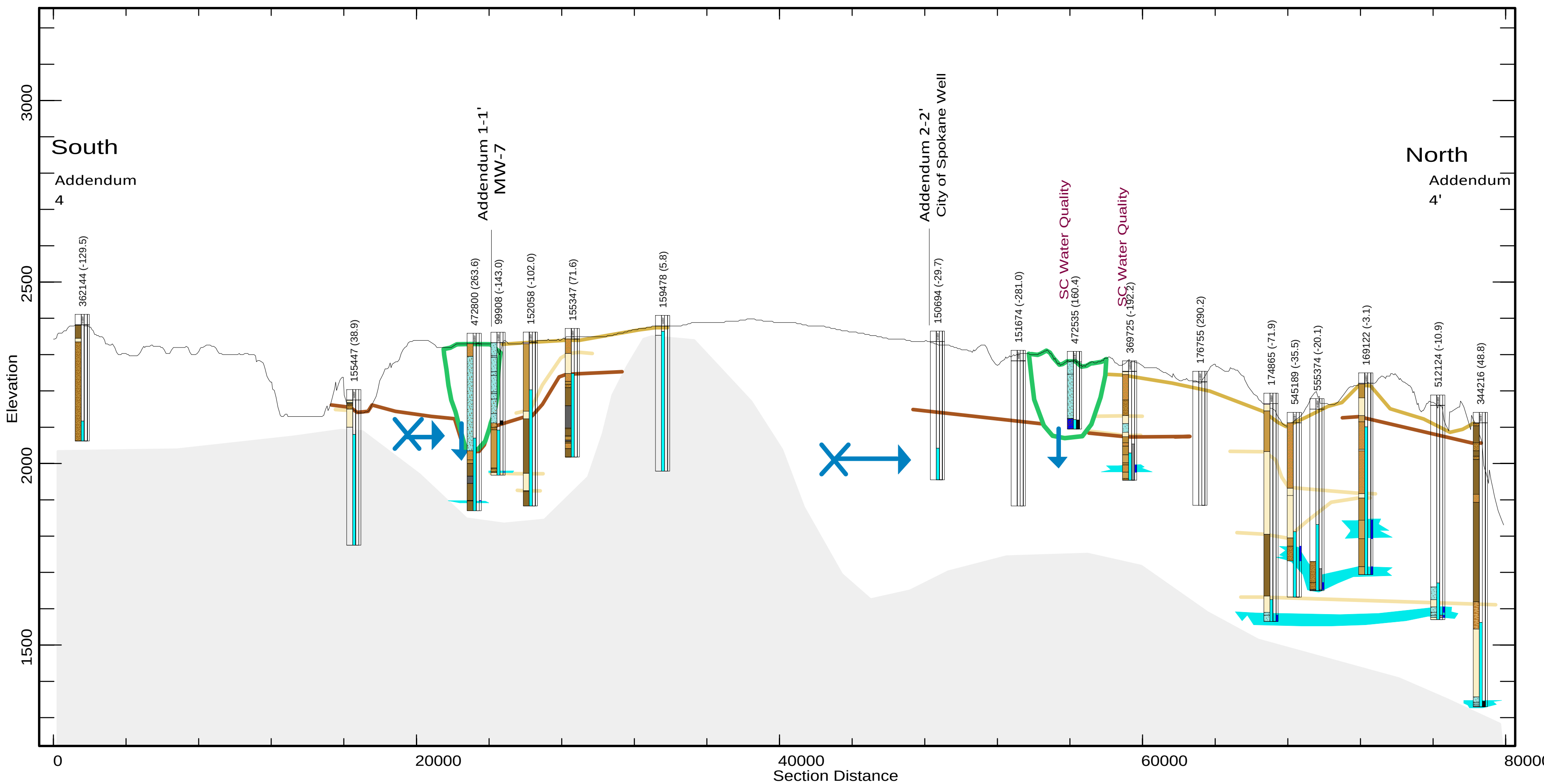
* See Figure 4-2 for complete key to lithology

Figure 4-5. Hydrogeologic Section Addendum 3-3'

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

e:\NLW\West Plains\Viewlog\crosssections\finalAlignments\add_3v2.map



Explanation

- Bedrock
- Basalt where not indicated otherwise
- Approximate top Wanapum
- Approximate top or bottom Latah
- Approximate Top Grande Ronde
- Groundwater flow direction
- Groundwater flow direction is into the page (northerly)
- Paleochannel deposits
- Aquifer

Well Log Description*

Well Log ID (#) (# = Feet from section trace)

- Fractured Basalt
- SAND
- Hard Basalt
- CLAY
- Granite
- Water Level
- Screen or perforations

* See Figure 4-2 for complete key to lithology

Figure 4-6. Hydrogeologic Section Addendum 4-4'

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

e:\NLWWest Plains\Viewlog\crosssections\finalAlignments\add 4.map

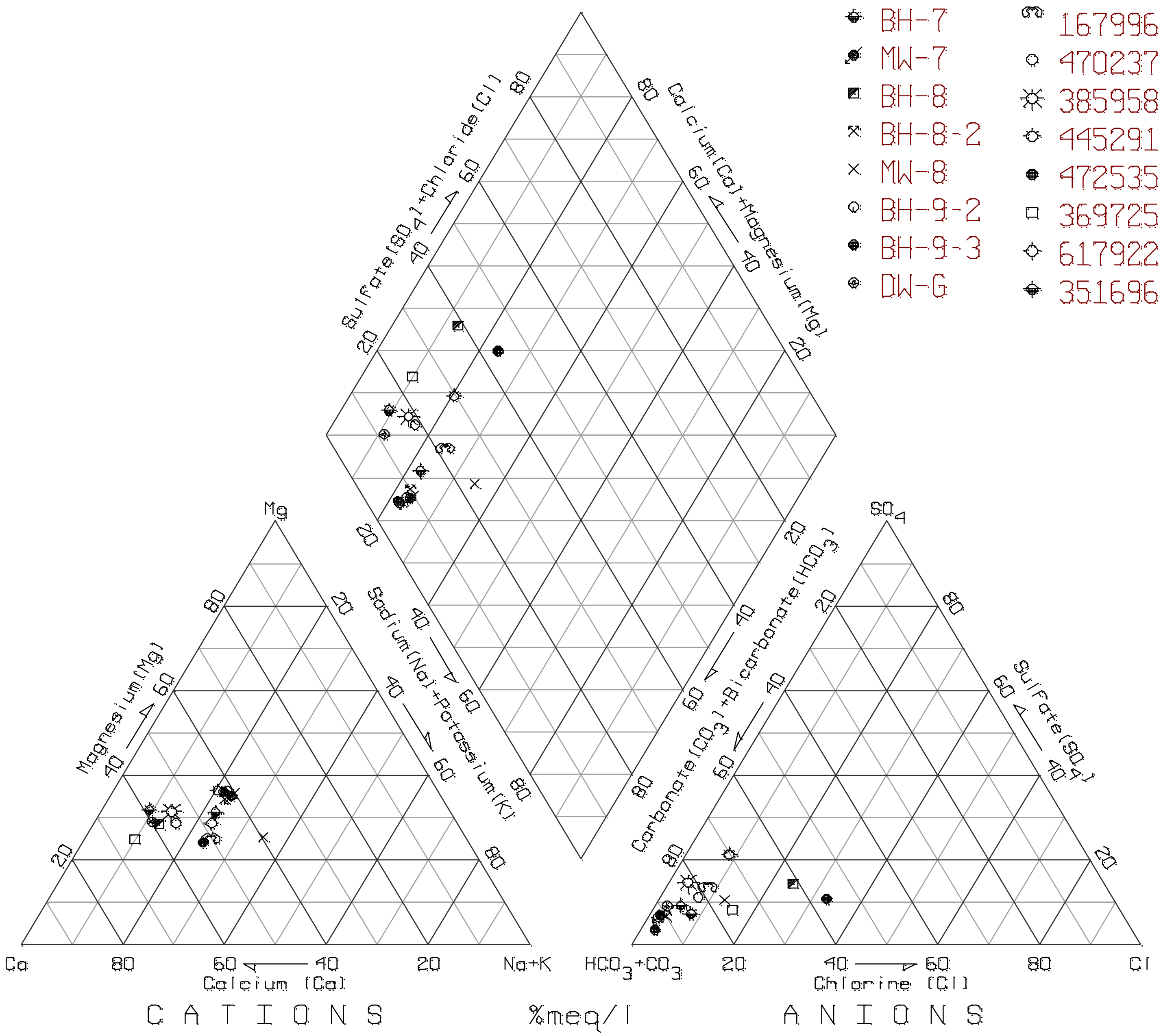


Figure 6-1.
Trilinear Diagram for Samples Collected during 2012 Monitoring Well Drilling and Sampling of Existing Wells

West Plains and Lower Hangman Creek Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology

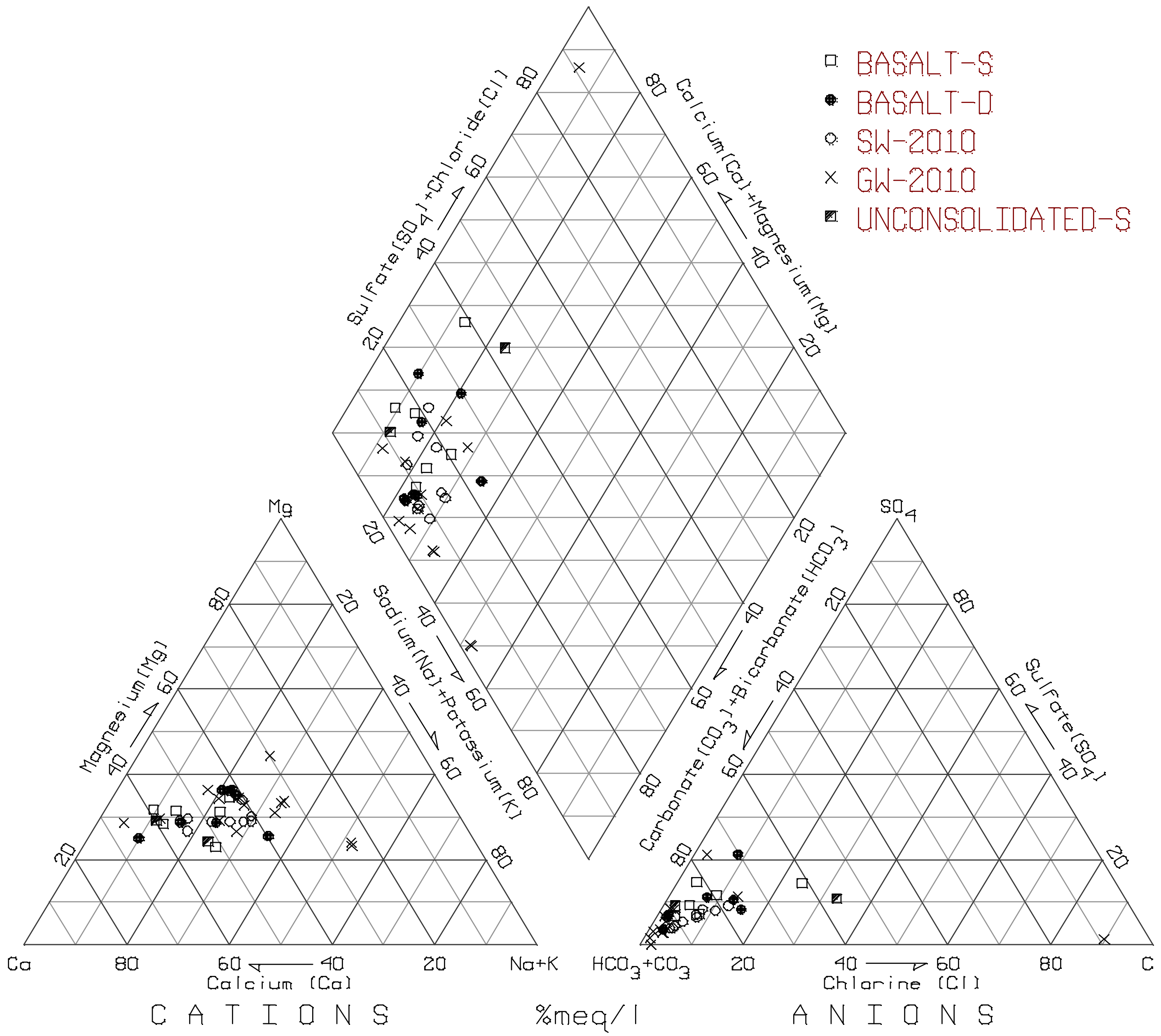
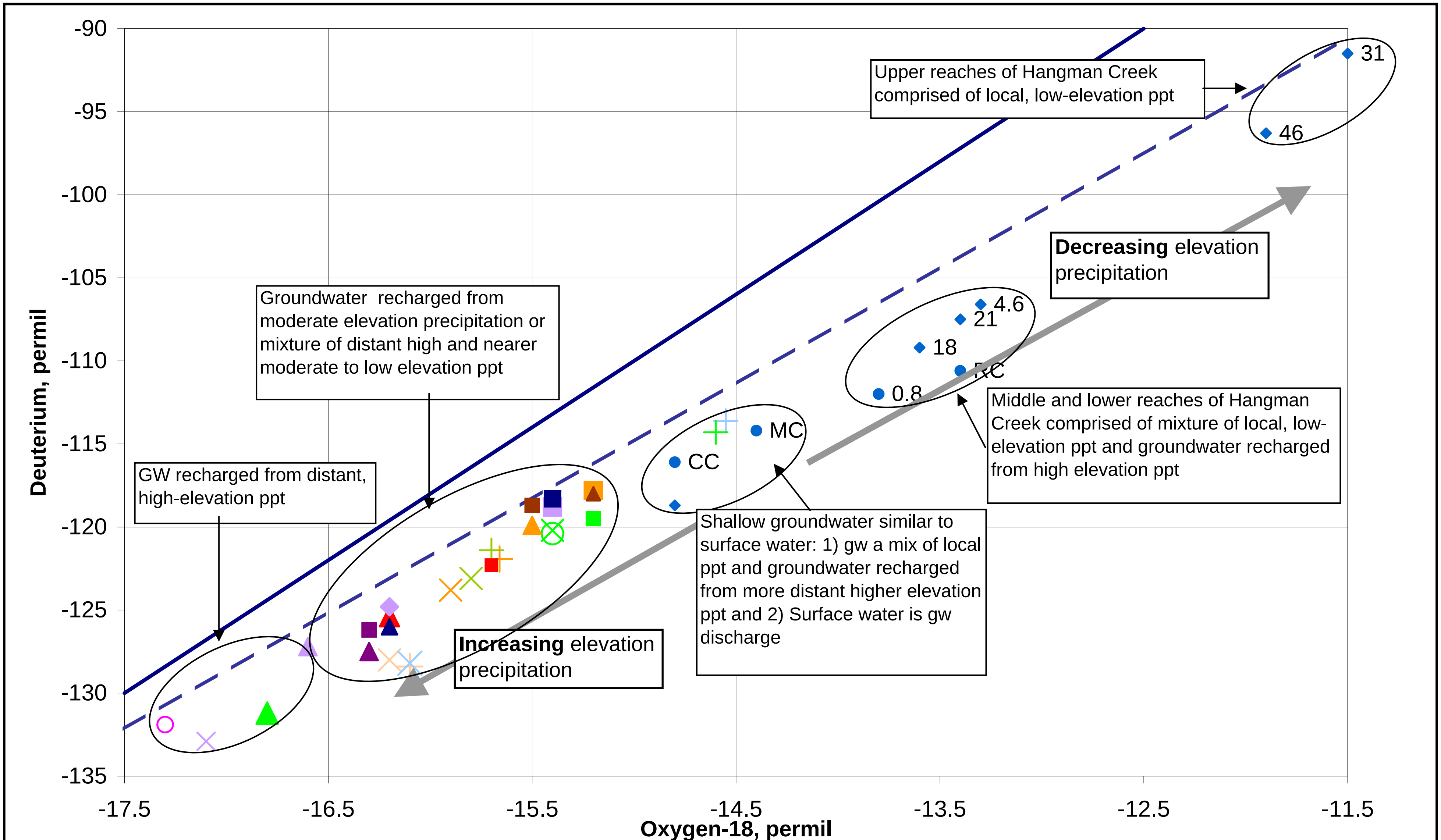


Figure 6-2. Trilinear Diagram for Samples Collected During 2010 and 2012 Monitoring Well Drilling and Sampling of Existing Wells and Surface Water

West Plains and Lower Hangman Creek Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation Distric

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology



BH2_138	BHI_55	MUR2_145
MUR2_188	MW1_137	MW2-276
BH5_85	BH5_501	MW4_76
MW3_195	MW5_355	BH6_78
MW6_224	MWL	Local MWL
0.8	RC	CC
MC	46	21
31	18	4.6
BH-9_3	DW-G	445291
385958	167996	470237
617922	BH-8_2	369725
MW-7	351696	MW-8
BH-8	BH-7	472535

SW: numbers = RM on Hangman Cr, letters = tributary

Figure 6-3
Oxygen-18 and Deuterium with Meteoric Water Line for Select Samples, 2010 and 2012 data

West Plains and L. Hangmank Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology

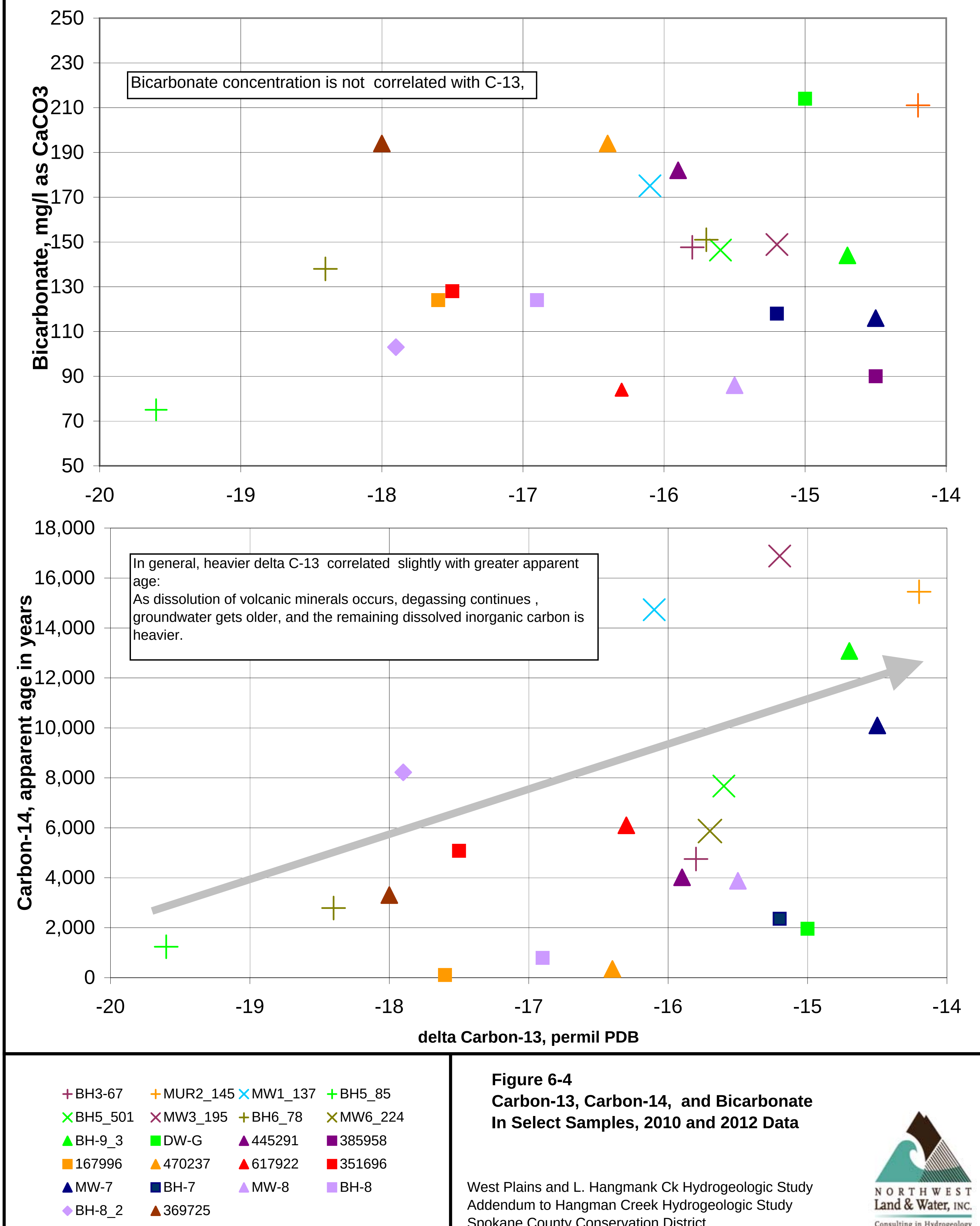
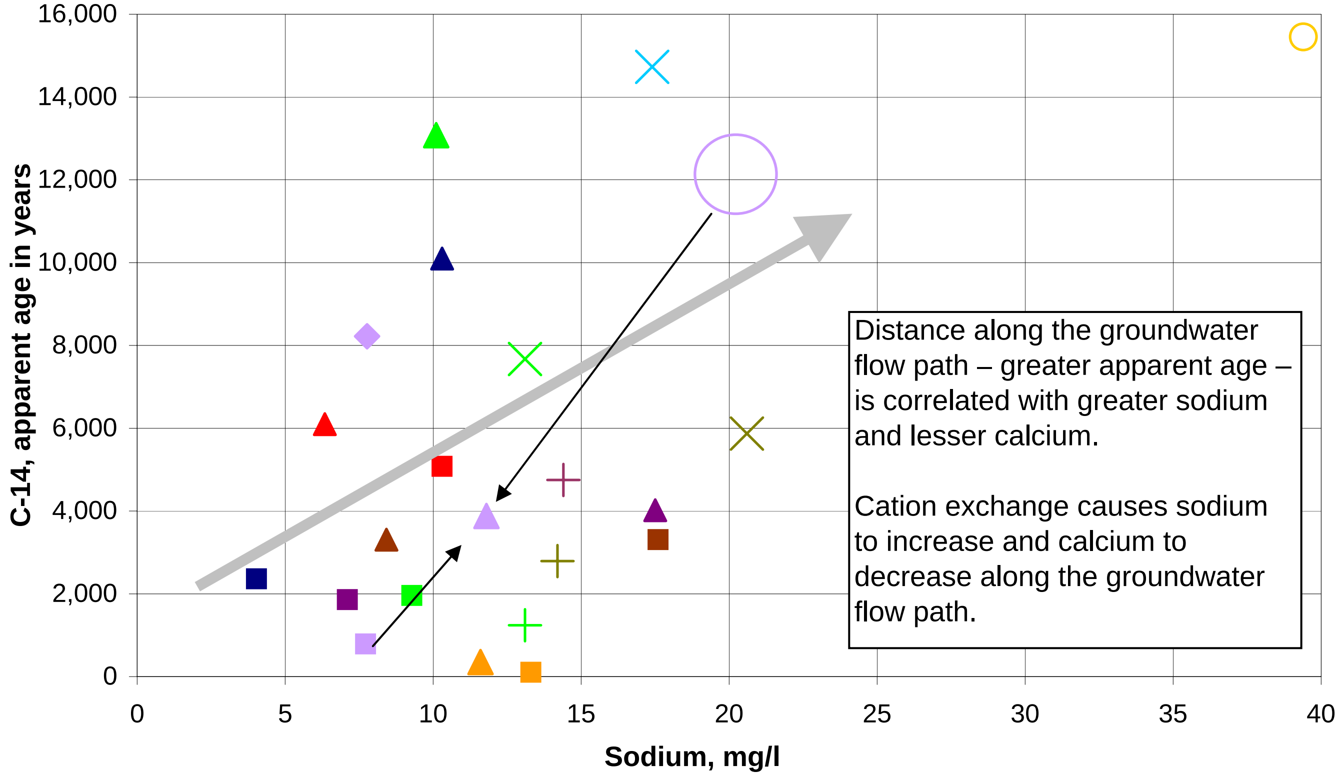


Figure 6-4
Carbon-13, Carbon-14, and Bicarbonate
In Select Samples, 2010 and 2012 Data

West Plains and L. Hangmank Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology



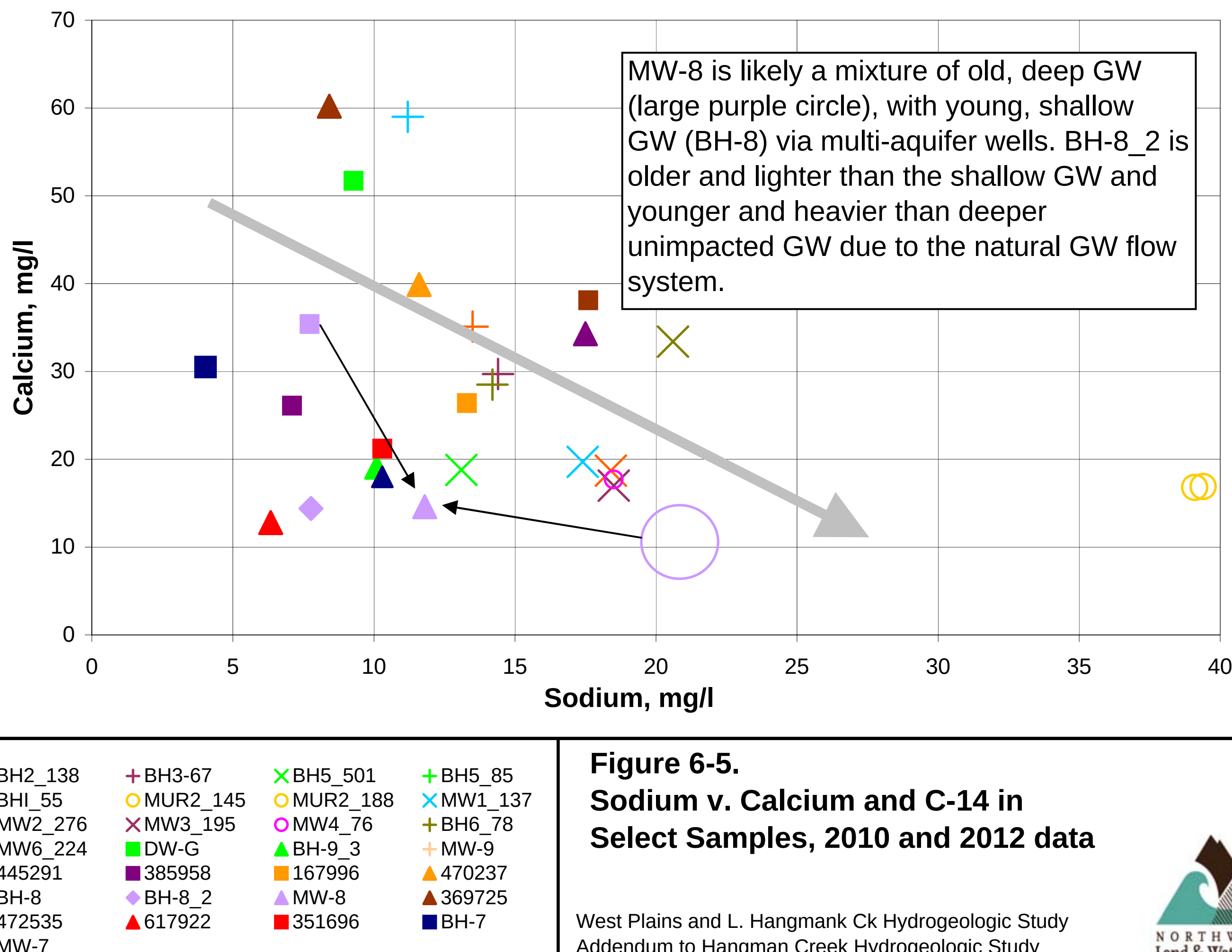


Figure 6-5.
Sodium v. Calcium and C-14 in Select Samples, 2010 and 2012 data

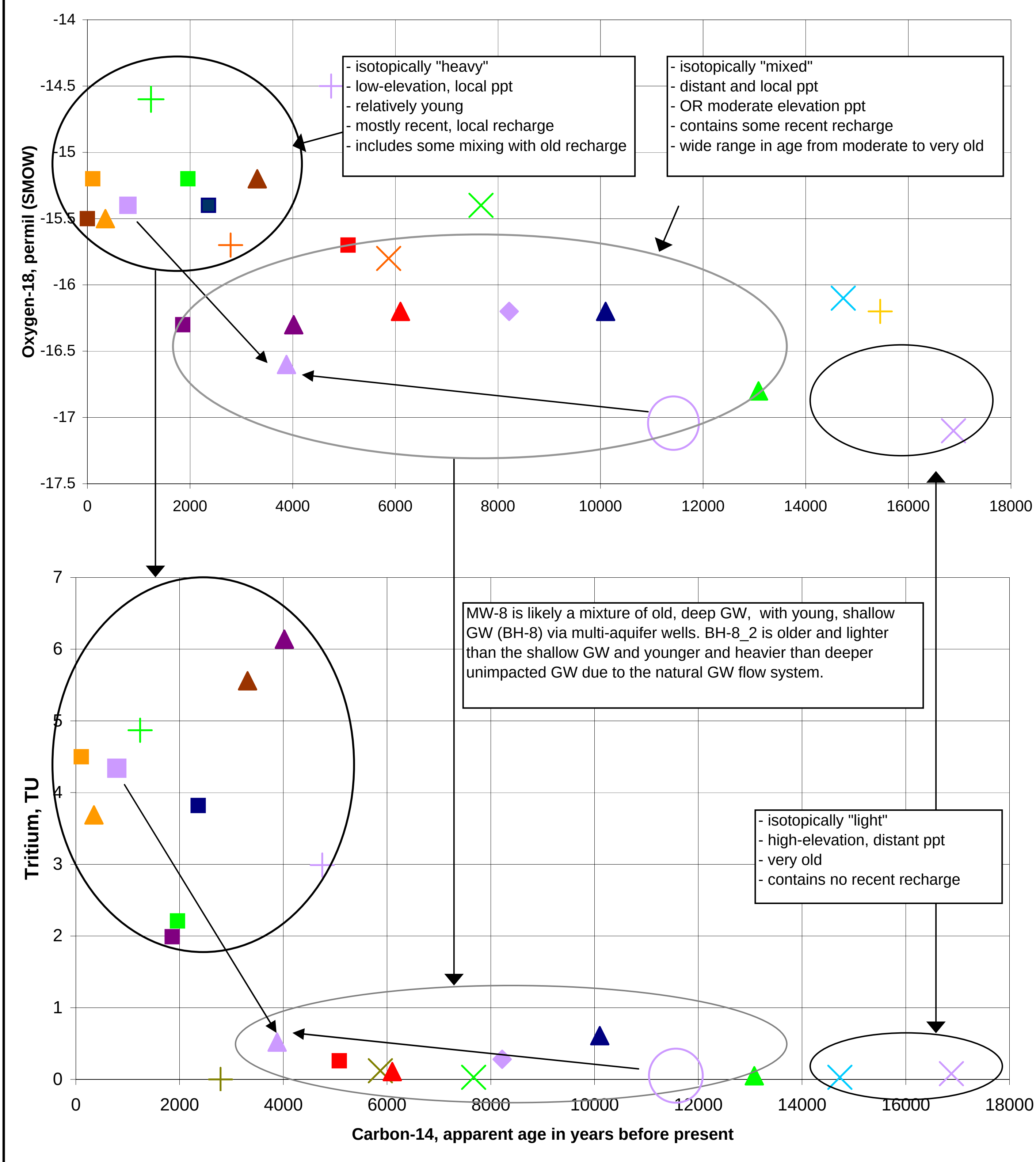


Figure 6-6
Oxygen-18, Carbon-14, and Tritium in Select Samples,2010 and 2012 Data

West Plains and L. Hangmank Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.
Consulting in Hydrogeology

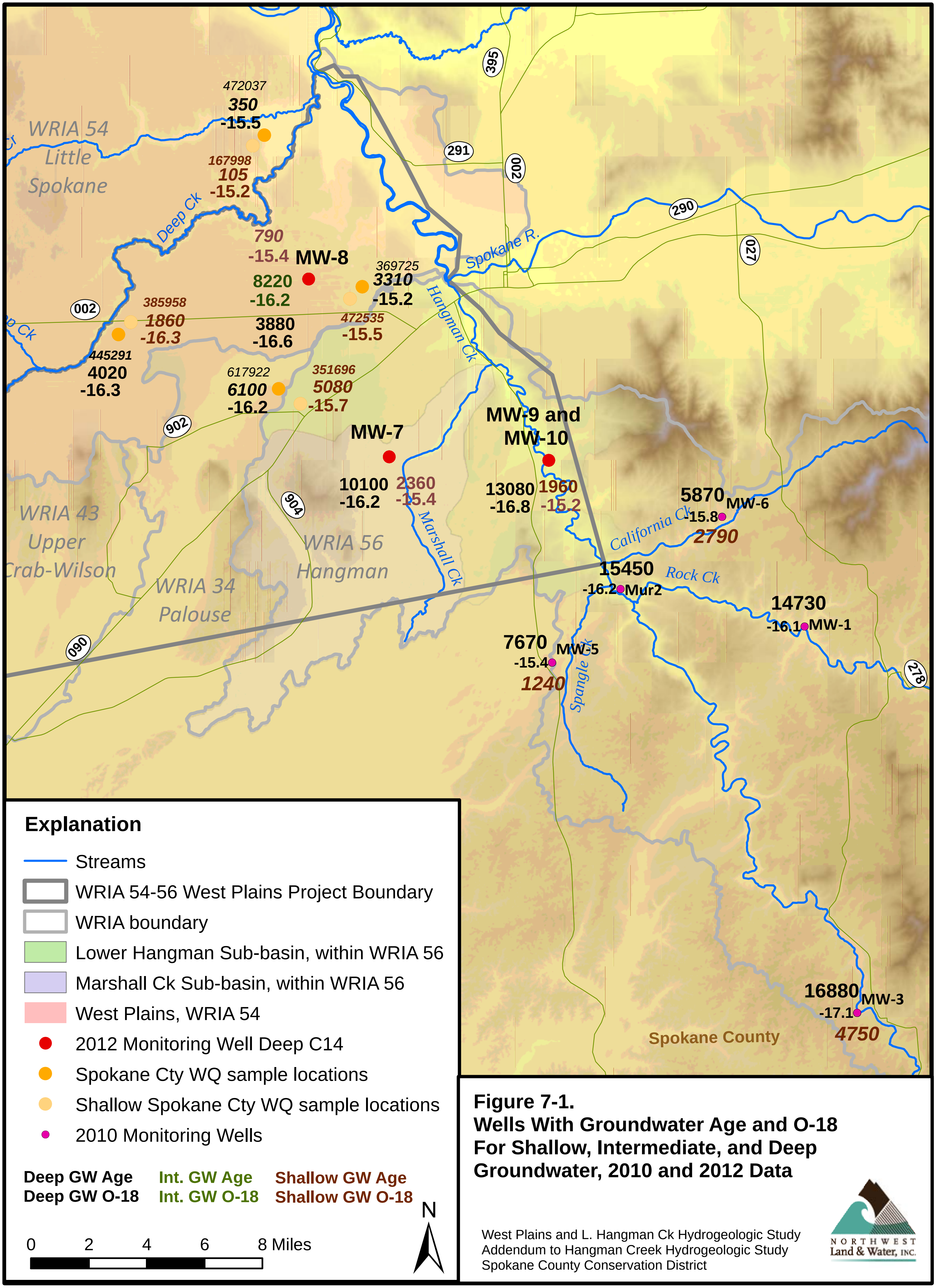


Figure 7-1.
Wells With Groundwater Age and O-18 For Shallow, Intermediate, and Deep Groundwater, 2010 and 2012 Data

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

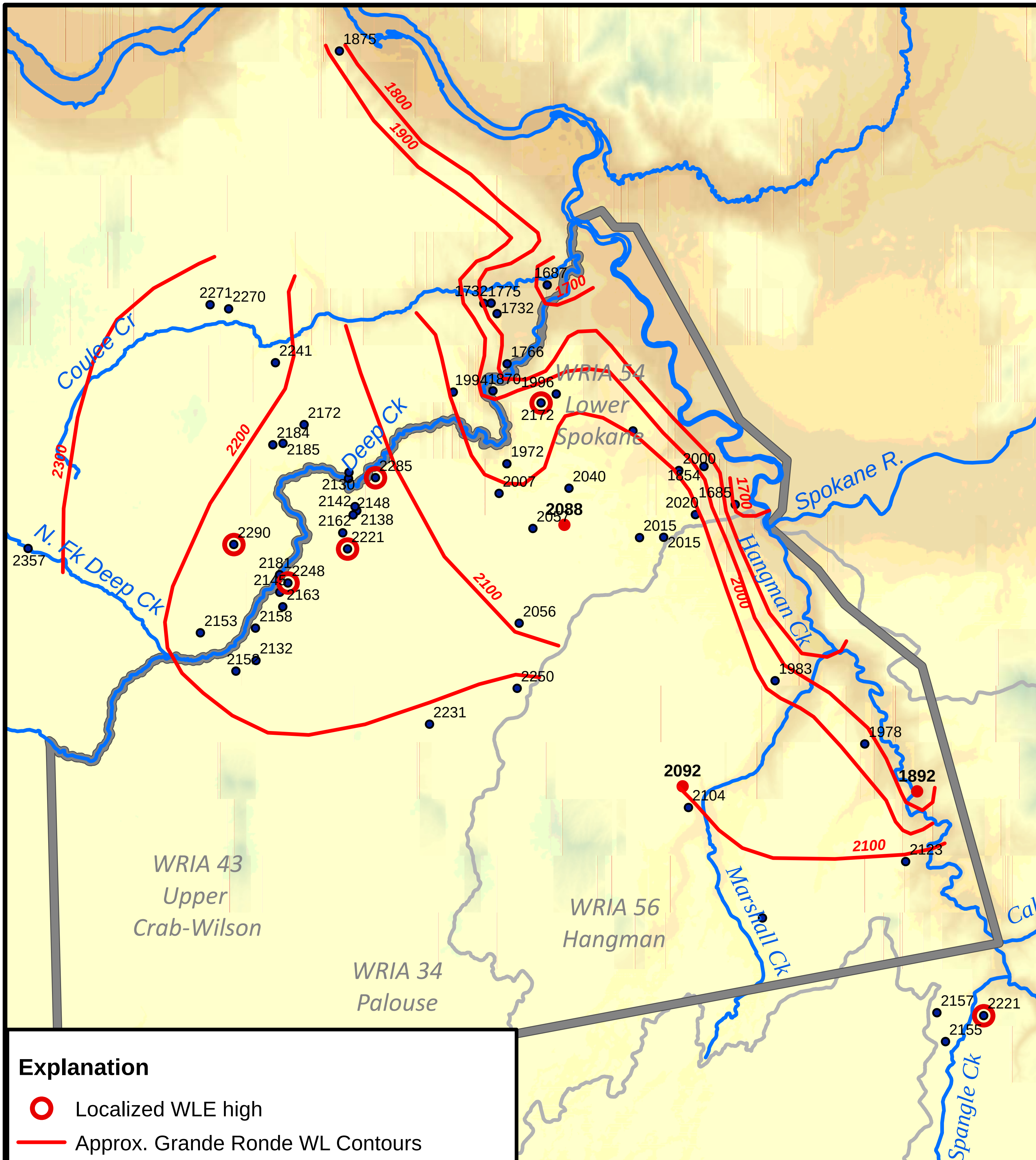


Figure 7-2.
Approximate Groundwater Level Elevation Contours, Grande Ronde Wells With Fall 2011 Water Level Data, and 2012 Monitoring Wells

West Plains and L. Hangman Ck Hydrogeologic Study
Addendum to Hangman Creek Hydrogeologic Study
Spokane County Conservation District

NORTHWEST Land & Water, INC.

Addendum Appendix E.

Wells Included on Hydrogeologic Cross Sections, West Plains and Lower Hangman Creek Hydrogeologic Study

Section	Well Log ID	WDOE Well Tag	Well Depth	X, in feet state plane NAD 27	Y, in feet state plane NAD 27	LSE, in feet msl	Location Source
1	99908	BCL 667	365	2739830	829991	2332.79	Jim Mathieu
1	99910	BCL 671	300	2769006	829243	1857.05	Jim Mathieu
1	152608		460	2729522	832064	2517.00	WDOE qq section
1	155121		655	2726664	830793	2477.00	WDOE qq section
1	157498		62	2768836	829814	1860.00	Jim Mathieu
1	157951		465	2759093	829583	2349.00	WDOE qq section
1	159725	AHC092	964	2674373	831078	2422.00	SC Geologic DB
1	160437		560	2683425	839382	2395.00	SC Geologic DB
1	164483		675	2714180	831293	2409.75	SC Geologic DB
1	172372		260	2723397	831542	2442.97	SC Geologic DB
1	253440	ACY003	500	2701856	835024	2404.57	SC Geologic DB
1	257173	AFL386	430	2741755	830109	2264.00	WDOE qq section
1	257174	AFL407	130	2734303	832149	2368.00	SC Geologic DB
1	293144		650	2747736	829717	2156.00	WDOE qq section
1	373879	AHJ715	280	2744609	829805	2071.00	SC Geologic DB
1	385125	AHJ447	360	2761785	825983	2283.00	SC Geologic DB
1	396865	AKO506	625	2699155	835810	2622.00	Mike H, from PID
1	506576		800	2706045	830854	2362.00	Mike H, from PID
2	99910	BCL 671	300	2769006	829243	1857.05	Jim Mathieu
2	150694		381	2734448	851574	2336.00	WDOE qq section
2	151301		700	2761439	833752	2261.00	WDOE qq section
2	151985		195	2692313	837346	2406.00	SC Geologic DB
2	153573		420	2764168	831202	1975.00	WDOE qq section
2	155350		400	2762801	832499	2162.00	WDOE qq section
2	157498		62	2768836	829814	1860.00	Jim Mathieu
2	163433		240	2685553	851308	2319.37	SC Geologic DB
2	167534		480	2698606	854202	2441.00	WDOE qq section
2	168926		445	2691279	852970	2432.90	SC Geologic DB
2	172795		397	2714569	853436	2421.00	WDOE qq section
2	175583	ABW407	240	2687222	851185	2326.47	SC Geologic DB
2	176586	ACW503	124	2694085	837235	2417.96	SC Geologic DB
2	252892	AEL745	380	2749999	844364	2297.00	WDOE qq section
2	371438	AHE234	439	2707946	853201	2405.00	WDOE qq section
2	382028	AHJ419	557	2753391	843601	2054.00	WDOE qq section
2	511345	AKT973	540	2752526	843337	2159.00	Mike PID
2	545133	AHC446	500	2755377	838965	2104.00	SC Geologic DB
2	547602	AKA185	830	2721415	853700	2370.66	SC Geologic DB

Addendum Appendix E.

Wells Included on Hydrogeologic Cross Sections, West Plains and Lower Hangman Creek Hydrogeologic Study

Section	Well Log ID	WDOE Well Tag	Well Depth	X, in feet state plane NAD 27	Y, in feet state plane NAD 27	LSE, in feet msl	Location Source
2	547602	AKA185	830	2721415	853700	2370.66	SC Geologic DB
3	99909	BCL 668	380	2724874	862370	2359.04	Jim Mathieu
3	164483		675	2714180	831293	2409.75	SC Geologic DB
3	164484		300	2715362	825865	2418.00	WDOE qq section
3	164653		0	2719027	876705	2262.97	SC Geologic DB
3	165247		400	2714776	823852	2398.00	WDOE qq section
3	167998		130	2714884	886648	2336.07	Mike H, email
3	178251		1236	2720941	798332	2425.00	googlearth
3	178258		550	2722812	803596	2425.00	WDOE qq section
3	294615		565	2720979	800200	2428.00	WDOE qq section
3	308233	AGC214	550	2718635	867834	2300.32	SC Geologic DB
3	344207	AGG478	440	2719741	850261	2367.73	SC Geologic DB
3	417068	AHC095	1404	2713955	837505	2400.00	SC Geologic DB
3	435795	AKL320	811	2719584	872487	2262.16	SC Geologic DB
3	470237		292	2716979	888628	1949.00	Mike H, email
3	547602	AKA185	830	2721415	853700	2370.66	SC Geologic DB
3	617922		450	2719615	842258	2421.00	Mike H, email
4	99908	BCL 667	365	2739830	829991	2332.79	Jim Mathieu
4	150694		381	2734448	851574	2336.00	WDOE qq section
4	151674		400	2734389	856104	2283.00	SC Geologic DB
4	152058		450	2739795	831773	2333.00	SC Geologic DB
4	155347		325	2738910	833939	2343.00	WDOE qq section
4	155447		400	2739505	822040	2175.00	WDOE qq section
4	159478		400	2734788	836500	2379.00	WDOE qq section
4	169122		527	2733893	873930	2221.00	SC Geologic DB
4	174865	AAN575	600	2733902	868729	2165.00	WDOE qq section
4	176755	AEB900	340	2734035	864794	2225.00	WDOE qq section
4	344216	AAJ804	782	2737051	877813	2112.00	SC Geologic DB
4	362144	ACH629	320	2743797	807950	2382.00	Mike H, from PID
4	369725	AHJ092	300	2734916	860912	2254.00	SC Geologic DB
4	472535		185	2732623	858727	2280.00	Mike H, email
4	472800	APC646	460	2739398	828687	2330.00	SC Geologic DB
4	512124	AEL723	590	2737491	875506	2160.00	SC Geologic DB
4	545189	AKO963	380	2733812	870002	2112.00	SC Geologic DB
4	555374	ABZ019	500	2733765	871251	2150.00	SC Geologic DB

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

File Original and First Copy with Department of Ecology
Second Copy — Owner's Copy
Third Copy — Driller's Copy

WATER WELL REPORT

STATE OF WASHINGTON

Start Card No. 057621

Water Right Permit No. ______

(1) OWNER: Name Peter Grunte Address 9412 Hangman Valley Rd. Spokane, WA. 99204

(2) LOCATION OF WELL: County Spokane SW ¼ SW ¼ Sec 16 T. 24 N., R. 43 W.M.

(2a) STREET ADDRESS OF WELL (or nearest address) 9412 Hangman VAlley Rd. Spokane, WA.

(3) PROPOSED USE: [X] Domestic [ ] Irrigation [ ] DeWater Industrial [ ] Test Well [ ] Municipal [ ] Other [ ]

(4) TYPE OF WORK: Owner's number of well (if more than one) ______
Abandoned [ ] New well [X] Deepened [ ] Reconditioned [ ]
Method: Dug [ ] Cable [ ] Rotary [X] Bored [ ] Driven [ ] Jetted [ ]

(5) DIMENSIONS: Diameter of well 6 inches.
Drilled 62 feet. Depth of completed well 62 ft.

(6) CONSTRUCTION DETAILS:
Casing installed: 6 " Diam. from +1 ft. to 51 ft.
Welded [X] ______ " Diam. from ______ ft. to ______ ft.
Liner installed [ ] ______ " Diam. from ______ ft. to ______ ft.
Threaded [ ]

Perforations: Yes [ ] No [X]
Type of perforator used ______
SIZE of perforations ______ in. by ______ in.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.
______ perforations from ______ ft. to ______ ft.

Screens: Yes [X] No [ ]
Manufacturer's Name Houston
Type Stainless Steel Model No. ______
Diam. 5 Slot size 10 from 62 ft. to 57 ft.
Diam. 5 Slot size 12 from 57 ft. to 52 ft.

Gravel packed: Yes [ ] No [X] Size of gravel ______
Gravel placed from ______ ft. to ______ ft.

Surface seal: Yes [X] No [ ] To what depth? 18+ ft.
Material used in seal Bentonite
Did any strata contain unusable water? Yes [ ] No [X]
Type of water? ______ Depth of strata ______
Method of sealing strata off ______

(7) PUMP: Manufacturer's Name ______
Type: ______ H.P. ______

(8) WATER LEVELS: Land-surface elevation above mean sea level ______ ft.
Static level 15 ft. below top of well Date 10/10/91
Artesian pressure ______ lbs. per square inch Date ______
Artesian water is controlled by ______ (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level
Was a pump test made? Yes [ ] No [ ] If yes, by whom? ______
Yield: 30 gal./min. with ______ ft. drawdown after ______ hrs.
" Air test approx. 30-G.P.M. "

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)
Time | Water Level | Time | Water Level | Time | Water Level

Date of test ______
Bailer test ______ gal./min. with ______ ft. drawdown after ______ hrs.
Airtest ______ gal./min. with stem set at ______ ft. for ______ hrs.
Artesian flow ______ g.p.m. Date ______
Temperature of water ______ Was a chemical analysis made? Yes [ ] No [ ]

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

MATERIAL	FROM	TO
Sand	0	23
Clay-grey	23	25
Clay-brn. w/sand	25	30
Sand w/clay grey	30	48
Sand	48	63
Clay-brn. w/sand	63	80

Work started 10/10/91, 19 ___ Completed 10/10/, 19 91

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME J & J DRILLING INC. (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)
Address S 5613 Linke RD. Greenacres, WA. 99016

(Signed) [signature] (WELL DRILLER) License No. 1447

Contractor's Registration No. JJDRII-177KU Date 10/16/, 19 91

(USE ADDITIONAL SHEETS IF NECESSARY)

ECY 050-1-20 (10/87) -1329-