EVALUATION OF OXYGEN AND HYDROGEN ISOTOPES IN GROUNDWATER OF THE PALOUSE BASIN AND MOSCOW SUB-BASIN

A Thesis
Presented in Partial Fulfillment of the Requirements for the
Degree of Master of Science
With a
Major in Hydrology
In the
College of Graduate Studies
University of Idaho

by
Lauren R. Carey

October 2011

Major Professor: James L. Osiensky, Ph.D.

AUTHORIZATION TO SUBMIT THESIS

This thesis of Lauren Carey, submitted for the degree of Master of Science with a major in Hydrology and titled "Evaluation of Oxygen and Hydrogen Isotopes in Groundwater of the Palouse Basin and Moscow Sub-basin" has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor ______________________ Date 10-7-11
James L. Osiensky, Ph.D.

Committee Members ______________________ Date 9/27/2011
Gary S. Johnson, Ph.D.

______________________ Date 10-7-2011
Stanley M. Miller, Ph.D.

Department Administrator ______________________ Date 10/14/2011
Mickey E. Gunter, Ph.D.

Discipline's College Dean ______________________ Date 10/14/11
Scott A. Wood, Ph.D.

Final Approval and Acceptance by the College of Graduate Studies

______________________ Date ____________
Jie Chen, Ph.D.

ABSTRACT

Gradually declining water levels in the Palouse Basin aquifer system creates concern over the sustainability of this groundwater supply for current and future residents in eastern Washington and northwestern Idaho. To aid the management of this resource, it is necessary to develop an understanding of aquifer properties. A part of this knowledge comes from understanding how and where recharge enters the aquifer system. The use of environmental isotopes can provide some of this insight. In particular, the presence of tritium, the radioactive isotope of hydrogen, in water indicates that it was recharged within the past 60 years.

Tritium concentrations were therefore measured in wells throughout the Palouse Basin to help determine not only where and at what depths modern recharge occurs, but also to assess how previously measured carbon-14 (^{14}C) ages should be interpreted. The presence of tritium in wells with apparent ^{14}C ages of several thousands of years before present is evidence that mixing is occurring in both the shallow and deep aquifers throughout the Basin. The observed groundwater age is therefore some sort of average of a combination of water with different ages. This illustrates the importance of not relying exclusively on one isotope for determining groundwater age.

In addition to tritium, the stable isotope ratios of oxygen ($\delta^{18}O$) and hydrogen (δD) were measured. $\delta^{18}O$ signatures are distinctly different for the Upper and Lower Aquifers, and are more depleted with depth. A corresponding decrease in tritium concentrations with depth and an increase in apparent ^{14}C age with depth suggest that the majority of the water in the Lower Aquifer was recharged during ice age conditions in the Pleistocene. However, it is seen in the tritium data that significant modern recharge is reaching areas in the upper part of the Lower Aquifer. Some recharge could reach greater depths, but the effect of dilution with older water obscures its presence.

A more focused study of $\delta^{18}O$ concentrations in the Upper Aquifer of the Moscow Sub-basin was also carried out to evaluate the local distribution of $\delta^{18}O$ values with respect to geographic features and possible recharge mechanisms. The data were then modeled geostatistically via simulated annealing and kriging. The resulting images indicated that multiple recharge mechanisms were at work, including recharge from losing streams and areally distributed precipitation (especially where overburden thins).

ACKNOWLEDGEMENTS

The completion of this thesis would not have been possible without the help of many individuals to whom I would like to express my personal thanks. First and foremost, thank you to the Palouse Basin Aquifer Committee for making this project possible through funding.

A special thanks goes to my advisor, Dr. Jim Osiensky, for his guidance and encouragement during my graduate studies, as well as for his help in both the field and office during this project. I would also like to thank my committee members, Dr. Gary Johnson and Dr. Stan Miller, for their insight, advice, and help.

Thank you to all of the local well owners who permitted me to sample your wells. The interest and cooperation you showed for this research was greatly appreciated.

My appreciation is also extended to Steve Robischon for keeping us all organized and on top of things, and to Debbie Jensen for always makings sure things ran smoothly in getting the samples out for analysis. Thank you also to the Stable Isotopes Laboratory in the College of Natural Resources for allowing me to use your facilities, and to Maggie Ward and Ricardo Sánchez-Murillo for your help, advice, and patience.

Finally, very special thanks go to my family and friends for their never-ending support, and for keeping me optimistic and on track.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - Introduction

Statement of Problem

The Palouse Basin (Figure 1) has been the site of extensive dryland grain and legume cultivation since 1910, and the inhabitants rely solely on groundwater for their domestic and municipal water supplies. The first wells drilled into the upper basalt aquifer in the late 1800's in the Moscow, Idaho area were artesian wells flowing at land surface. Left uncapped, aquifer heads in the majority of them fell below land surface by 1900. The same thing happened to shallow Grande Ronde wells in the Pullman area and new wells were drilled deeper. In the 1960's, low water levels and poor water quality in the Upper Aquifer (i.e. Palouse Formation, Sediments of Bovill, Wanapum basalt, and Vantage interbed) led to Moscow drilling deeper to access the Lower Aquifer (i.e. Grande Ronde basalt). Over the past 70 years, the entire area has experienced basin-wide declines of between 0.9 and 1.5 ft (0.27 and 0.46 meters) per year in the Lower Aquifer (Palouse Basin Aquifer Committee, 2010). Even with pumping rates stabilized, water levels continue to decline about 0.9 ft (0.032 meters) per year. This causes concern for the future availability of water for the community, especially if growth continues.

Previous geologic and hydrogeologic models have been unsuccessful at predicting Basin behavior accurately. Research is ongoing, and information is needed pertaining to the recharge rates and mechanisms for water to enter the aquifers. Evaluating the age of the groundwater is one important aspect to the understanding of recharge. Previous age dating studies have revealed that the groundwater in the area may be thousands of years old, with little to no recharge occurring in the Lower Aquifer since the end of the last Ice Age (Crosby and Chatters, 1965). Such an interpretation of the water's apparent age has serious implications for water management. Thus, the understanding of groundwater ages and mixing is important for the accurate evaluation of the aquifer systems and their long-term pumping sustainability.

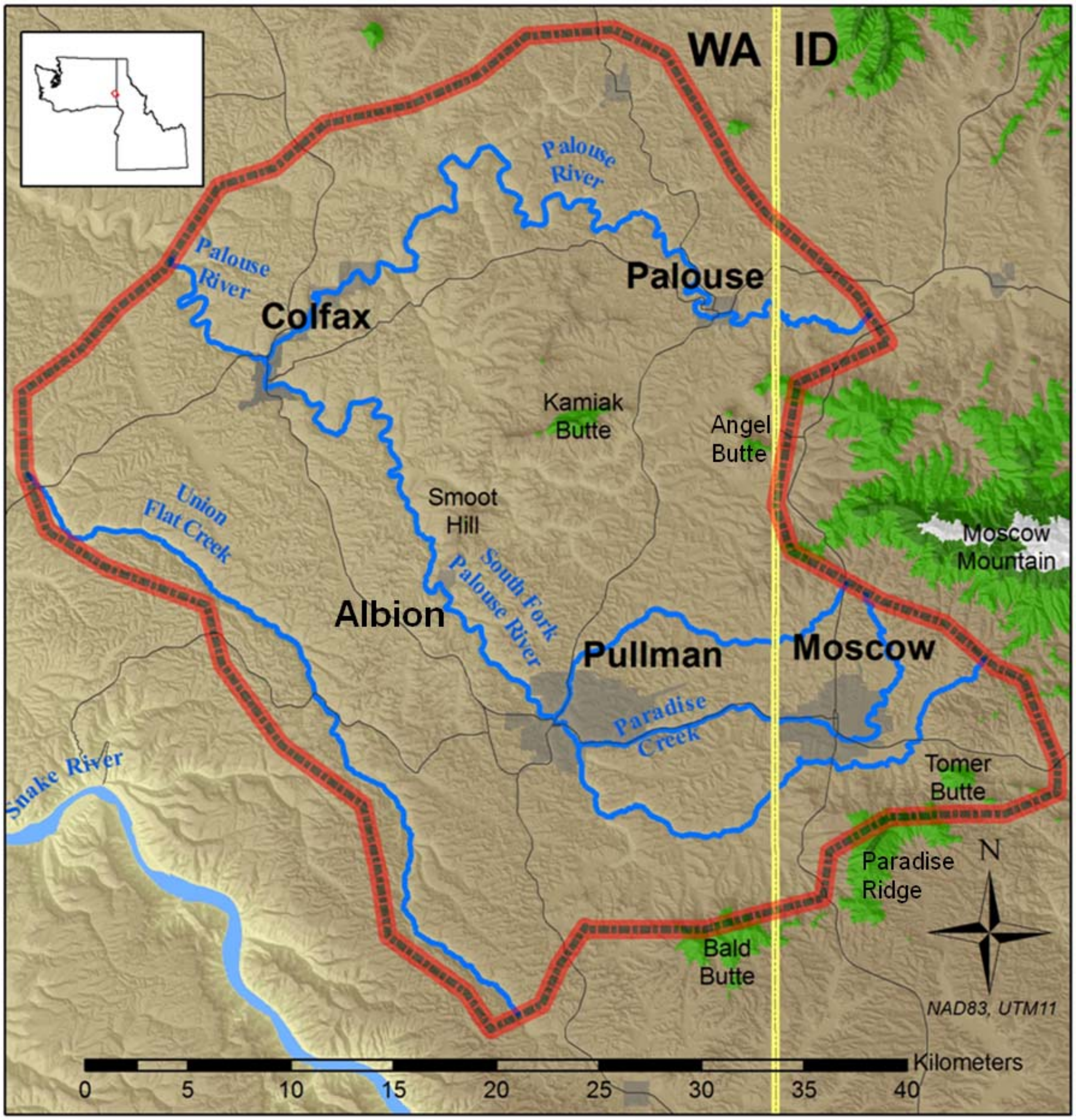


Figure 1. *Location of the Palouse Basin and surrounding geographic features. Dashed red lines indicate the approximate boundaries. (Modified from Bush, 2006).*

Purpose and Objectives

The overall purpose of this project was to aid in the understanding of recharge to the Palouse Basin hydrogeologic system by evaluating isotopic signatures in the groundwater. There were two general objectives:

1. To identify possible areas of recharge throughout the Palouse Basin and to describe potential factors that contribute to that recharge, including possible source areas and seasonality.

2. To assess the validity of the carbon-14 (^{14}C) age dates from previous studies of Palouse Basin groundwater, and evaluate how those dates should be interpreted.

To accomplish these objectives, selected wells within the Palouse Basin were sampled for tritium, and the stable isotope ratios of oxygen ($\delta^{18}O$) and hydrogen (δD). Also, a more focused sampling effort for $\delta^{18}O$ in the Moscow Sub-basin was undertaken. This second data set was then modeled geostatistically by simulated annealing and kriging in order to evaluate for distributional patterns in the data that may be related to recharge mechanisms.

Previous Isotopic Investigations

Geological/hydrogeological investigations of the Palouse Basin began in the late 1800's by Russell (1897). Basin-wide water level declines in the 1960's and 1970's spurred intensified hydrogeologic research. The goal of these studies was primarily to evaluate the sustainability of the groundwater resource systems, and the research included techniques such as tracer tests, pumping tests, geologic mapping, geophysics, and groundwater modeling. Another approach is to interpret the distribution of naturally occurring environmental isotopes in the groundwater. Environmental isotopes can be used to help interpret water migration mechanisms (especially if they are incorporated into the water molecule itself like oxygen and hydrogen isotopes), and are considered conservative in the subsurface under normal temperatures. Applications of oxygen and hydrogen isotopes in hydrogeology are discussed further in Chapter 3. Three predominant studies using isotopic concentrations in groundwater have been completed in the Palouse Basin.

Crosby and Chatters (1965)

Crosby and Chatters conducted the first isotopic study of groundwater in the Palouse Basin in 1964 and 1965. They measured ^{14}C and tritium concentrations, focusing their sampling on the Upper Aquifer in the Pullman-Moscow area. Their results showed that groundwater in the area is distinctly stratified, and that the apparent age of the water increases with depth. They also noted that wells appeared to yield older ages when the pumping rates were high. This was interpreted to be due to larger cones of depression drawing water from deeper parts of the aquifer. The apparent radiocarbon ages of water in the Pullman-Moscow area were found to range from modern to about 24,200 years old in the shallow aquifer (Wanapum aquifer system), and about 6,150 to 32,000 years old in the deeper aquifer (Grande Ronde aquifer system). Crosby and Chatters suggested that water in the deep aquifer system originated largely from the time of Pleistocene glaciations. They believed the deeper aquifer system was filled by the end of the Ice Age. Despite the old ages of the water, they still believed that some recharge was reaching the upper layers of the lower aquifer, but not the deeper layers. Crosby and Chatters could find no evidence of measurable recharge in the Moscow area, but they believed some recharge was occurring in the Pullman area, especially around the edges of the cone of depression from the pumping center, and where the basalt is exposed at the land surface. This hypothesis was based largely on the existence of older aged groundwater in Moscow and younger aged groundwater in Pullman. They estimated the recharge to the Pullman sub-basin to be about 108 million gallons per year. This represented 10% of Pullman pumping rate in 1965. Currently, Pullman pumping is approximately 894 million gallons per year (Palouse Basin Aquifer Committee, 2010).

Larson (1997)

Larson evaluated the $\delta^{18}O$ and δD ratios of groundwater in the Pullman and Moscow areas to test the various conceptual models for Basin recharge. Sampling was conducted on wells that were completed in the loess, Sediments of Bovill, Wanapum, Grande Ronde, and crystalline bedrock (Figure 2). Local precipitation was also sampled on a regular basis. From analyzing the precipitation, Larson found that there was little to no difference between the isotopic signatures of precipitation falling in the basin and that from the higher elevations of the Palouse Range. There was also no observable effect from evaporation or water-rock interactions in the sampled groundwater. If there were appreciable evaporation or interactions, it would lower the slope of the $\delta^{18}O$ versus δD. The $\delta^{18}O$ values of the groundwater, however, were shown to be statistically different between the 42 samples taken from the Upper Aquifer (i.e. loess, Sediments of Bovill, Wanapum, and Vantage interbed) and the 18 samples from the Lower Aquifer (i.e. Grande Ronde and associated interbeds). $\delta^{18}O$ values ranged from -15.4 to -17.5‰ for the Grande Ronde, -14.9 to -15.7‰ for the Wanapum, and -12.5 to -15.7‰ for the loess and alluvium. The significant depletion in groundwater samples from the lower aquifer may be due to:

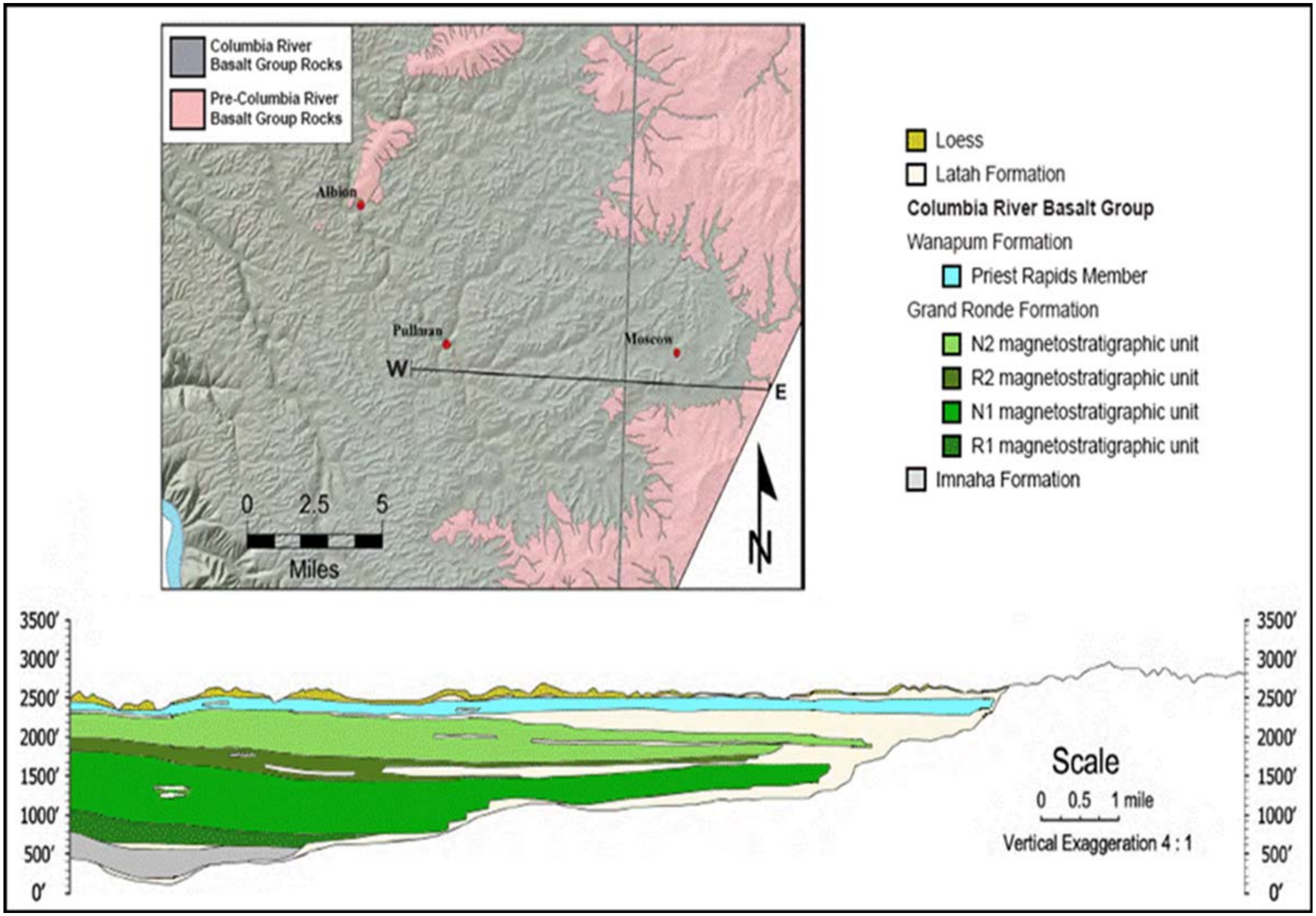


Figure 2. *Generalized geologic cross section of the Palouse Basin. (Modified from Bush and Garwood, 2004 by Bennett, 2009)*

1. Seasonality of recharge,
2. Precipitation originating from a higher altitude, and/or
3. Precipitation was recharged under a different climate regime.

All of the samples were slightly more depleted in heavy isotopes than the Local Meteoric Water Line (LMWL), indicating that recharge probably occurred during the cooler seasons of fall and winter. Larson concluded that, even if the precipitation had shown an elevation effect, both the altitude and seasonality temperature effects cannot account for the entire shift seen in the isotope concentrations. This is especially true considering that isotopic signatures tend to become homogenized during infiltration. Therefore, she concluded that the rest of the shift must be due to world-wide changes in humidity, circulation patterns, and surface air temperature (groundwater from a pre-Holocene glacial period has a different $\delta^{18}O$ signature that is usually 3-12‰ lower than that of modern precipitation (Desaulniers et al., 1981)).

Under this hypothesis, the $\delta^{18}O$ signature of deeper groundwater in the basin does not support the existence of recent recharge. Instead, Larson believes this water was recharged under the cooler climate of the Pleistocene. This is consistent with the ^{14}C ages presented by Crosby and Chatters (1965). However, when Larson and others (1996) used the leakage flux rates from the modeling studies of Lum and others (1990), and Barker (1979) to calculate the mean residence times, their results conflicted with the previous ^{14}C dates. A mean residence time of 63 years was estimated for the Wanapum, and 1,007 years for the Grande Ronde. These values are one to two orders of magnitude lower than those proposed by Crosby and Chatters (1965). This led Larson to conclude that the Wanapum and even parts of the Grande Ronde do receive a significant amount of Holocene recharge via areally distributed precipitation (although the recharge mechanism for the deeper system may be different). Despite the potential for recharge, Larson's results suggested that some of the recharge estimates for the Grande Ronde made prior to her study may be too high.

Douglas (2004)

Douglas completed an extension of the Crosby and Chatters (1965) ^{14}C dating study. ^{14}C analyses were run for groundwater samples collected from around the entire Palouse Basin, not just the Pullman-Moscow area. The sampling focused on the Lower

Aquifer because Crosby and Chatters (1965) had focused their ^{14}C sampling on wells completed in the Upper Aquifer. Douglas found the oldest water in the Basin to be located near Palouse and Moscow, and the youngest water near Pullman and Colfax. Douglas also observed a stratification of groundwater ages, similar to that seen in the other studies, with a general increase in age with depth. Ages range between 12,993 and 26,406 years before present for the lower Grande Ronde, and from 4,420 to 11,832 years before present for the upper Grande Ronde. Water in the Wanapum and loess represents water of modern origins to 14,605 years before present (it should be noted that the ^{14}C age dates represent a "model age" rather than a true age because the initial concentrations need to be assumed). Douglas thought that the variable age dates in the Wanapum may be due to mixing. She therefore recommended tritium sampling to verify ^{14}C dates as well as to determine if groundwater mixing is occurring between older and younger water. Her results, nevertheless, show that Holocene recharge is reaching elevations of at least 2198 ft (670 meters) above mean sea level (AMSL), which includes all of the Wanapum and upper portions of the Grande Ronde. The ages do not reflect identifiable horizontal flow paths, so are therefore taken to represent the vertical travel times. This shows that recharge is slow, as would be expected given the low vertical hydraulic conductivity of the basalts. Douglas believed that younger water may be found near a hypothesized groundwater divide between Pullman and Moscow. She also concluded that the stratification of groundwater ages is consistent with areally distributed recharge.

CHAPTER 2 - Site Characterization

Introduction

Understanding aquifer characteristics, especially the climatic and hydrogeologic aspects, is important for any groundwater study. In the Palouse Basin, the interpretation of the hydrogeology has been a difficult process given the geologic complexity of the aquifers. Water-bearing zones consist primarily of basalt interflow zones and interbedded sedimentary units. In contrast to porous media, different geological, mechanical, and geochemical processes govern the basic movement of groundwater in fractured rocks. Flow is often localized and extremely preferential. The hydraulic properties of basalt are primarily controlled by the fracturing that exists in the rock. Different fracture geometries, orientations, and densities have large influences on groundwater flow, and usually result in localized, preferential pathways. In addition, large amounts of clay in the interbedded sediments may restrict water infiltration between basalt flows. All of these factors combine to create complicated aquifer conditions that may be locally perched, unconfined, or confined, depending on the spatially variable characteristics of the basalt. Paleotopography and paleostreams, as well as relatively impermeable crystalline bedrock also exert controls on groundwater flow.

Geography and Climate

The Palouse Basin is a groundwater basin located on the eastern margin of the Columbia Plateau and measures approximately 500 mi^2 (1295 km^2) (Bush, 2005), depending on where boundaries are drawn (Figure 1). Typically, it is considered to be bounded to the east by the crystalline rocks of the Palouse Range, the south by crystalline rocks of Paradise Ridge, unnamed buttes and Bald Butte, and to the southwest by the Snake River canyon; the western and northern boundaries are still largely undefined. The land surface is drained by the South and North Forks of the Palouse River, and associated tributaries. The climate is moderate and semi-arid (Black et al., 1998). Summertime temperatures throughout the Palouse Basin can reach above 100°F while wintertime lows are below zero (Western, 2010). Average precipitation increases to the east due to an increase in land surface elevation (20.17 inches in Colfax and 23.6 inches in Moscow), and is usually low intensity. About 75% of the precipitation received by the area falls in the period between October and April; less than 20% of the total precipitation is in the form of snow (Foxworthy and Washburn, 1963). Pollen studies and mammal zoology indicate that the Basin once had a cooler, wetter climate under late Pleistocene Ice Age conditions (Larson, 1997). These conditions ended around 13,000 years ago and average temperatures have since increased by 3°C (5.4°F) (Larson, 1997).

Regional Geology

The Columbia River Basalt Group (CRBG) covers approximately 55,000 mi^2 (142,450 km^2) in Oregon, Washington, and Idaho in what is known as the Columbia Plateau. It consists of basalt from the Yakima and Picture Gorge Basalt subgroups. The CRBG erupted intermittently over an 11 million-year period during the Miocene to early Pliocene (17 to 6 million years ago). The majority of the material was erupted during the first 1.5 million years. The total volume of the CRBG has been estimated to be between 35,500 mi^3 (148,000 km^3) and 53,400 mi^3 (222,600 km^3) (Bush and Seward, 1992). Basalt flows originated from fissures and feeder dikes located in southeast Washington, northeast Oregon, and west-central Idaho. Approximately 120 to 150 individual flows exist, most of which can be identified by the chemistry of the basalt. These flows vary in thickness from one ft (0.3 m) to as much as 400 ft (122 m), averaging three to 100 ft thick (0.91 to 30.5 m) (Bush and Seward, 1992; Foxworthy and Washburn, 1963). The CRBG is thickest towards the middle of the shallow Pasco Basin, the paleobasin in central Washington that was filled during the eruptions. In the vicinity of Moscow and Pullman, the maximum thickness of the basalt is estimated to be about 1,300 and 2,000 ft (396 and 610 m) thick, respectively (Smoot and Ralston, 1987); this increases to over 3,000 ft (914 m) to the northwest of Pullman.

The basalt itself is very dense, and gray to black in color. Fractures are common throughout the basalt in three main forms (Figure 3): columnar hexagonal joints, vertical blocky joints, and horizontal platy fractures (Swanson and Wright, 1978). In addition, regional fractures exist that can span hundreds to thousands of feet in length (Bennecke, 1996). However, the lateral continuity of fractured zones in the basalt is poorly known and could be limited. These fractures present possible conduits for water flow and may represent areas where vertical recharge can occur. Massive flows usually develop simple fractures while thin flows tend to develop complex fractures (Lin, 1967). All of the fractures, however, are subject to differential erosion and weathering. Often, these fractures form clastic dikes as they are filled with sediment. In this case, the fine clays commonly found as filling material may impede the percolation of water into the basalt interior.

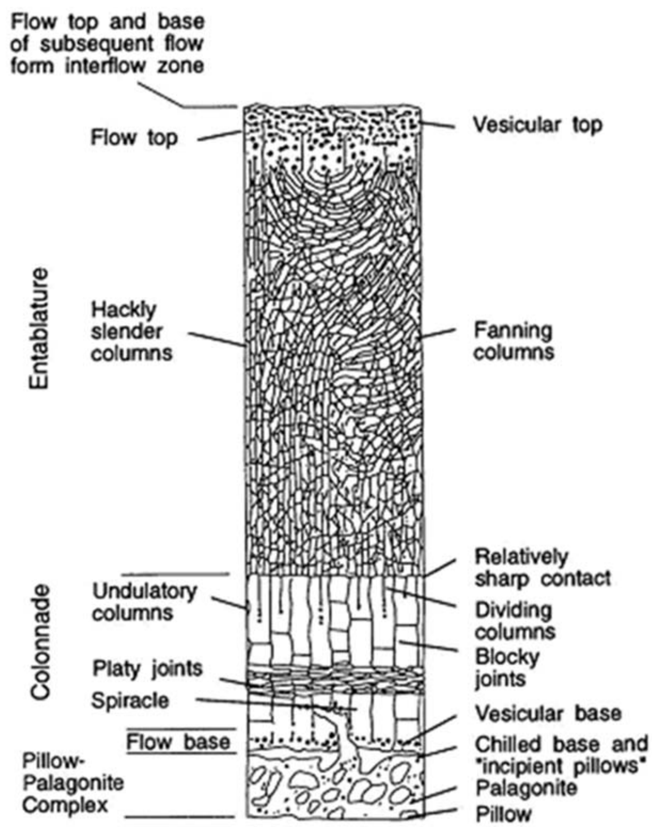


Figure 3. *Conceptual model of basalt intraflow structures. (From Swanson and Wright, 1978).*

Each basalt flow exhibits physical characteristics common to CRBG flows. Colonnade texture denotes large columns that are usually found at the base of the flow and typically range from one to 16 ft (0.3 to 5 m) in diameter, depending on the individual flow. Entablature structure refers to smaller columns commonly found towards the upper part of flows (Figure 3). Curved columns in this section are common and are usually less than 3.5 ft (1.1 m) in diameter (Figure 4). These columns generally have a less uniform orientation and are highly segmented by irregular cross joints. Pillow texture is sometimes seen in flows, but is more common towards the edges of the plateau where the basalt flows may have encountered water accumulated behind basalt dams caused by earlier flows. All of the flows are locally vesicular. The lower parts of the flows tend to have blocky or columnar jointing with some scattered vesicles while the upper part of the flows is usually highly vesicular, jointed, and weathered. Therefore, the top and bottom sections of the flows represent the principal aquifer zones and groundwater flow sections due to the high permeability created by the fractured state. Conversely, basalt interiors tend to be very dense and restrict horizontal and vertical flow (Figure 5), often creating perched conditions above the regional water table.

Figure 4. *Example basalt entablature with curved columns.*

Figure 5. *Example of dense basalt interior.*

The Yakima basalt was divided into the upper, middle, and lower formations by Wright and others (1973). These were renamed later by Swanson and others (1979), as the Saddle Mountains, Wanapum, and Grande Ronde Formations, respectively. The Imnaha Formation underlies the Grande Ronde. All four of these formations are found in the Palouse region. These formations may include several members, as shown in Table 1. The term “member” is used to denote a flow or group of flows that have shared unique characteristics that allow them to be identified and separated from others. The distribution of formation members and individual basalt flows throughout the Columbia Plateau is discontinuous, depending on the origin and extent of the flows as well as the pre-flow topography of the area. Those found within the Palouse Basin, and especially within the vicinity of Pullman and Moscow, are discussed below in greater detail with respect to the local hydrogeology.

	Geologic Unit		Thickness (feet)	Age (mya)
	Palouse Formation		0-300	2—Present
	Sediments of Bovill (Latah Formation)		0-200	-
Columbia River Basalt Group	Saddle Mountains Basalt	Monumental Member	0-100?	6
		Ice Harbor Member		8.5
		Buford Member		
		Elephant Mountain Member		10.5
		Pomona Member		12
		Esquatzel Member		
		Weissenfels Ridge Member		
		Asotin Member		13
		Wilbur Creek Member		
		Umatilla Member		
	Wanapum Basalt (with Latah Formation interbeds)	Priest Rapids Member	0-250	14.5
		Roza Member		
		Frenchman Springs Member		15.3—15.5
		Eckler Mountain Member		
	Vantage (Equivalent) Member (Latah Formation)		0-400	-
	Grande Ronde Basalt (with Latah Formation interbeds)		0-3,500	15.6—16.5
	Imnaha Basalt			16.5—17
	Sediments of Moscow (Latah Formation)		?	-
	Idaho Batholith and Belt Series Supergroup		-	Cretaceous—Pre-Cambrian

Table 1. *Generalized stratigraphy of the Columbia River Basalt Group and other associated geologic units in the Palouse Basin. (Modified from Hopster, 2003 and Garwood, 2001).*

Local Hydrogeology

Although the Columbia Plateau is dominated by the CRBG, the specific geology in locations throughout the Plateau differs from place to place. This section describes the hydrogeologic units commonly found in the Palouse Basin and, in particular, within the vicinity of Moscow and Pullman. This includes the crystalline bedrocks, basalts, and sediments. Figure 2 shows a geologic cross section through the area.

Crystalline Rocks

The oldest geologic units in the area are the basement rocks which consist of Pre-Cambrian metasediments of the Belt Series Supergroup intruded by Cretaceous granitoid plutonic rocks of the Idaho Batholith (Pierce, 1998). The metasediments are chiefly quartzites, and are composed of recrystallized quartz, muscovite, biotite, and zircon. Schists and gneisses also occur as part of this unit. The intrusive rocks are medium to coarse grained, and include primarily hornblende granodiorite, as well as quartz tonalite and hornblende monzodiorite (Provant, 1995). Pegmatite dikes are present locally in the basement rocks and are thought to be part of the Chief Joseph Dike Swarm of Oregon, Washington, and Idaho (Hooper, 1997). They are more common in tonalite, but few crop out at the surface, which makes it difficult to map their distribution.

Basement rocks crop out at the edges of the Pullman-Moscow area as the Palouse Range. They include Moscow Mountain, Bald Butte, Paradise Ridge, Tomer Butte, Kamiak Butte, Smoot Hill and unnamed hills, which form a horseshoe-shaped ring around the Moscow area (Figure 1). The basement rocks beneath Moscow have been shown to exhibit a surface with deep valleys separated by narrow ridges (Crosby and Chatters, 1965). This pre-basalt topography presented a major control on the emplacement of the Grande Ronde Formation in terms of shape and lateral extent. New drainage systems formed after bedrock channels were filled with basalt, and then again on top of each subsequent basalt flow. These drainages were in turn partially filled with sediments which may now provide preferential flow paths for groundwater that mimic the ancestral drainage pattern(s).

Wells completed in basement rocks of the Pullman-Moscow sub-basin provide domestic water in some areas along the perimeter of the basin. The majority of these wells are located in the eastern part of the basin close to where the bedrock is exposed. Granite and metamorphic wells can be productive in fracture zones, and productivity typically decreases with depth as permeability and porosity also decrease. Local yields in the crystalline rock can be up to 20 gallons per minute (gpm), but are commonly less than about five gpm. Many wells go dry in drought years. Crystalline rock well yields are too small compared to that of most basalt or sediment wells to be considered productive for municipal purposes. Instead, crystalline basement rocks are often assumed to have negligible permeability and therefore typically are considered to be no-flow boundaries for modeling purposes.

Basalts

Groundwater flow in the basalts of the Palouse Basin is primarily restricted to interflow zones (i.e. the top and bottom of the individual flows), and horizontal and vertical cooling fractures; sediment interbeds within interflow zones may form conduits or barriers depending on the grain size of the sediments. Typically the greatest groundwater flow occurs horizontally along contact zones between two or more basalt flows. Basalt interiors tend to have very low vertical hydraulic conductivity so they typically form confining layers. For CRBG basalts, lateral hydraulic conductivity is up to 6.1 x 10^{-2} feet per second (ft/s) or 1.9 centimeters per second (cm/s), while vertical hydraulic conductivity only reaches 1.0 x 10^{-5} ft/s or 3.0 x 10^{-4} cm/s (Vaccaro, 1999). The majority of the vertical hydraulic conductivity may be attributable to relatively few high-permeability fractures. Clastic dikes, vertical joints, and vertical fractures are important features for facilitating the downward percolation of water into the basalt, while fracture fillings such as silt, clay, and secondary silica deposits restrict vertical infiltration. Discontinuous fractures can lead to the compartmentalization of the system.

Imnaha Formation

The Imnaha Formation is the oldest unit of the CRBG. Basalt flows of this formation vary widely in thickness, and Imnaha basalt has been identified in only one location in the Palouse Basin: at the bottom of Washington State University well #7 (WSU 7), the deepest well in the Pullman area (Wyatt-Jaykim Engineers and Ralston, 1987).

Grande Ronde Formation

The Grande Ronde comprises about 90% of the total CRBG by volume (Reidel et al., 1989), and consists of fine to very fine grained Miocene aphyric basalt flows that are interbedded with layers of Latah Formation sediments (Wright et al., 1973; Swanson et al., 1979). Accumulations of Grande Ronde basalt flows cover several hundred square miles (tens of hundreds of square kilometers), and can exceed 3,300 ft (1006 m) in total thickness (Bush and Seward, 1992). Up to 17 different flows are believed to exist in the western part of the Palouse Basin; however, geochemical, stratigraphic, and paleomagnetic analyses are required to distinguish them from each other (Reidel et al., 1989; Provant, 1995; Teasdale, 2002). The individual flows range in thickness from less than three ft to over 165 ft (0.9 to 50 m) and generally thin to the East (Lin, 1967; Lum et al., 1990). All of the Grande Ronde flows can be divided into four groups based on normal or reversed magnetic polarity: R_1, N_1, R_2, and N_2 (Swanson et al., 1979) (Figure 2).

The number of Grande Ronde flows that exist within the Basin increases to the west. Not all of the flows advanced the entire distance to the basement rock outcrops east of Moscow; some flows created dams that influenced the deposition of sediments in these locations. The resulting sediments are part of the Latah Formation. At least three sections of the Grande Ronde are separated by sediment interbeds of sand, silt, and clay as a consequence of this damming (Kopp, 1994). In addition, the Grande Ronde is not in direct contact with the basement rocks in the Moscow area, but is separated from it by Latah Formation sediments that range from clay to gravel, and are known as the Sediments of Moscow (Bush, 2005; Bennett, 2009).

The Grande Ronde basalts constitute the primary groundwater resource system for the Palouse Basin and now produce 95% of the municipal water supply. Wells completed in the Grande Ronde are usually at least 500 ft (152 m) deep, and can yield up to 3,000 gpm (Kopp, 1994). Water levels are typically 250 to 300 ft (76.2 to 91.4 m) below ground surface (bgs). Water levels within the Grande Ronde change very little with depth. Water level data collected during the drilling of WSU well 7 at the Washington State University in Pullman, WA indicated only a few feet of water level differences over a change of depth of 2000 ft (610 m) (Wyatt-Jaykim Engineers and Ralston, 1987). This indicates that the multiple producing zones in the Grande Ronde are hydraulically connected and that the dominant flow within them is horizontal (Heinemann, 1994). There is less seasonal fluctuation observed in Grande Ronde water levels compared to those in the Wanapum, but the Grande Ronde water level trends are very similar throughout the basin, again indicating there may be a basin-wide hydraulic connection (Moran, 2011).

The contact between the Grande Ronde and the Wanapum does not represent the actual transition between aquifers. The Grande Ronde aquifer system is a collection of at least three individual, but connected aquifers, separated by aquitards (McVay, 2007; Owsley, 2002). The deep aquifers in the Moscow area are laterally constrained and hydrogeologically isolated from the overlying Wanapum aquifers by low hydraulic conductivity layers at the base of the Vantage (McVay, 2007). No hydraulic connections have ever been detected between the Grande Ronde and the Wanapum during aquifer tests (Douglas, 2004).

Natural groundwater discharge from the Grande Ronde aquifer system in the Palouse Basin has never been positively identified. While the total spring discharge from numerous small springs in the Snake River Canyon is several cubic feet per second, the springs have oxygen-18 signatures that correspond to Wanapum water, not Grande Ronde (Hopster, 2003). It has also been noted that there is a conspicuous lack of large springs from the walls of both the Snake and Palouse River canyons (Walters and Glancy, 1969).

Wanapum Formation

The Wanapum is a Miocene age (14.5 mya), medium to coarse grained basalt, with small phenocyrsts of plagioclase and olivine in a matrix of intergranular pyroxene, ilmenite blades, and devitrified glass (Provant, 1995; Wright et al., 1973). It forms the majority of outcrops seen in the Pullman-Moscow area. The Wanapum and Grande Ronde can be differentiated chemically by their magnesium and titanium concentrations; the Grande Ronde has low magnesium concentrations and high amounts of titanium while the Wanapum is the reverse (Smoot and Ralston, 1987). The Wanapum is also thinner than the Grande Ronde, ranging from about 20 ft (6 m) thick east of Moscow to 250 ft (76 m) thick in several wells.

Only the Priest Rapids and Roza Members of the Wanapum Formation are found in the Palouse Basin. The Roza Member does not exist in the Pullman-Moscow area, but can be found near Colfax along the North Fork of the Palouse River and along Union Flat Creek (Heinemann, 1994). The Wanapum Formation itself is not laterally continuous to the west because it has been incised by stream channels. In the Pullman-Moscow area, the Wanapum consists solely of the Lolo flow of the Priest Rapids Member. Because the Lolo exists as a single flow, interflow zones exist only sporadically between separate lobes. However, weathering is initiated where widely spaced vertical joints and minor gas vesicles exist (Lin, 1967). These vertical joints are more common than horizontal fractures.

The Wanapum aquifer system (Vantage equivalent sediments, Wanapum basalt and overlying Latah Formation sediments) was the principal source of water for the Moscow area until the 1960's when Wanapum pumping was reduced due to declining water levels and water quality issues. Since then, the water levels have recovered about 50-60 ft (15.2-18.3 m), and the Wanapum is used as a supplemental source for municipal water in Moscow and as the primary source for area domestic wells. The Wanapum is productive in the Moscow area, but is not dependable in other parts of the Palouse Basin. Municipal Wanapum wells yield 500-1,500 gpm, while domestic wells completed in the Wanapum typically produce less than 100 gpm. Wanapum wells are typically 100-500 ft (30.5-152.4 m) deep, and water levels in the Wanapum are less than 150 ft (45.7 m) bgs, but depend on topography. In general, the productivity of the Wanapum decreases toward Pullman. It is thought that this is due to the corresponding lack of Latah Formation sediments to the west (Badon, 2007; Bennett, 2009).

The Wanapum has been shown to be very compartmentalized and poorly connected hydraulically in an east-west direction (Badon, 2007), which is likely to cause an uneven distribution of recharge. Nimmer (1998) showed that groundwater in the upper 80 ft (24.4 m) of the Wanapum follows distinct, preferential flow paths along horizontal cooling fractures for distances of at least ten feet. It is therefore considered to be heterogeneous and anisotropic. The Wanapum is often represented as multiple (at least 2) hydraulically connected aquifers separated by a leaky aquitard (Li, 1991; Kopp, 1994; Hernandez, 2007; Bennett, 2009). Often, as in this study, the Vantage is considered to be part of the Wanapum aquifer system. These two aquifers are believed to be separated by a basalt aquitard formed by the lower half of the Lolo flow. The Wanapum may also be unconfined in areas, and is hydraulically connected vertically from the Sediments of Bovill through the Vantage (Kopp, 1994; Bennett, 2009; Hernandez, 2007) in the vicinity of the Groundwater Field Lab (Table 1). These hydraulic relationships may be true elsewhere in the basin.

The Wanapum is hydraulically more dynamic than the Grande Ronde aquifer. The vertical flow gradients change seasonally and groundwater potential decreases with depth (Foxworthy and Washburn, 1963; Hernandez, 2007; Bennett, 2009). In addition, it is known to receive recharge, as deduced from the relatively quick recovery of water levels and seasonal fluctuations. It is believed to receive recharge directly from the loess in some areas (Baines, 1992) as well as from Paradise Creek, the South Fork of the Palouse River, and associated tributaries. Badon (2007) suggests that the Sediments of Bovill may be important in transferring recharge from these streams to the Wanapum basalt, and that recharge to the Wanapum may be related to the saturated thickness of the Sediments of Bovill. These sediments also provide a hydraulic connection for groundwater/surface water interaction between the Wanapum aquifer system and the local streams and creeks. Streams are losing streams (providing recharge to the Wanapum) when flows are high, and are gaining in late summer (receiving discharge from the Wanapum and associated sediments). Such discharge from the Wanapum has been found along Union Flat Creek west of Pullman and the Snake River Canyon near Almota, Washington (Hopster, 2003). Heinemann (1994) found Wanapum discharge areas in the central portion of Union Flat Creek and the upper reach of the North Fork of the Palouse River, as well as in the lower reaches of Four Mile Creek and Paradise Creek. No discharge was found in the South Fork of the Palouse River. Heinemann also suggested that the Vantage Member is a main source of Wanapum discharge to streams that have incised canyons through these sediments in the western part of the Palouse Basin.

Saddle Mountains Formation

The Saddle Mountains is a sequence of minor basalt flows limited in areal extent that are considered to be intravalley flows. Hooper and others (1985) described the basalts as being medium to coarse grained with micro phenocrysts of plagioclase and olivine in an intergranular matrix with minor glass. These flows often fill paleochannels that were eroded into the Lolo basalt (Provant, 1995). Saddle Mountains basalt has been identified several miles west of Pullman (along Union Flat Creek) (Swanson et al, 1979), and under McClure Hall at the University of Idaho (Provant, 1995; Owsley, 2003). In addition, ten feet of the Saddle Mountains Weissenfels Ridge Member of the Lewiston Orchards flow was identified within the Sediments of Bovill in the IDWR 1 well in northwest Moscow (Figure 6) (Bush, 2006).

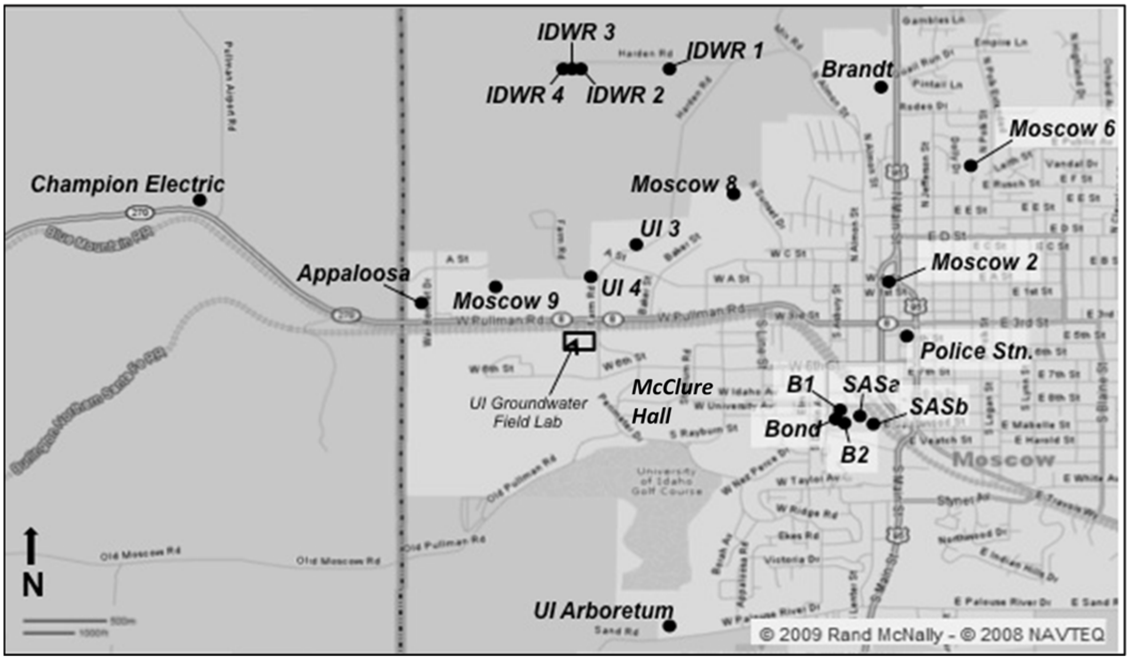


Figure 6. *Sampled well locations in west-central Moscow, ID.*

Sediments

Sediment interbeds may form aquifers or aquitards, depending on the grain size distribution. The sediments in the Palouse Basin display heterogeneity and anisotropy that often arises from the transitory stream deposition of clays, silts, sands and gravels. The primary flow paths for groundwater are thought to be through the coarser layers, which represent buried stream channel deposits. Brown (1998) offers two conceptual models for sedimentary aquifers in the area. One is a sand and silt aquifer with discontinuous layers or lenses of coarser sands and gravels. The second is an aquifer that consists of sands and silts with interbedded, continuous layers of coarse sands and gravels. These coarser layers within the sediments ultimately control the lateral groundwater movement. Tracer tests conducted in the sediments in the Parker Farm area in Moscow show a presence of both lateral and vertical preferential pathways (Petrich, 1995; and Brown, 1998). Therefore, the sediments can have prolific water bearing zones, depending on the locations of these buried stream channels. The hydrogeologic sedimentary units in the Palouse Basin are the Latah Formation (which includes the Vantage (Equivalent) Member, Sediments of Moscow, Sediments of Bovill), and the Palouse Formation.

Latah Formation

The Latah Formation is comprised of marginal deposits of clay and detrital grains ranging from sand to fine gravel. Grain sources include basalt, basement rock, reworked loess, and minor amounts of organic matter. The Latah Formation was named by Pardee and Bryan (1926) after similar outcrops near Latah Creek, just south of Spokane.

Sediment structures indicate that these deposits were formed in fluvial and lacustrine environments, both as laterally extensive layers as well as isolated lenses of varying thickness. Lacustrine environments arose from the damming of stream drainages by advancing basalt flows (Lin, 1967). There were at least three such damming events which created lakes, swamps, and the creation of new drainages (Reidel et al., 1989). Latah Formation sediments from these lacustrine depositional environments can contain large amounts of clay; east of Moscow, some drill logs have reported up to hundreds of feet of clay (Lum et al., 1990). Grain sizes in fluvial deposits are dependent upon the sizes of the source drainage systems. Large grained deposits coincide with larger stream systems that were able to deposit the coarser material. These coarser channel deposits (shoestring sands) represent possible conduits for groundwater flow, but are probably irregularly shaped and exist sporadically in 3-D space.

Sediment interbeds can range from one to 300 ft (0.3 - 91.4 m) in thickness (Foxworthy and Washburn, 1963). They are thickest under Moscow and in the eastern part of the basin, and then gradually pinch out just west of Pullman. In the Moscow sub-basin, sediments can represent up to 70% of the stratigraphic section (Crosby and Chatters, 1965).

Sediments of Moscow

The Sediments of Moscow are the informal name for the Latah sediments found between the crystalline basement rocks and the CRBG basalt. The sediments were first described by Laney et al. (1923) as coarse sand and gravel stream deposits composed of weathered bedrock material, which constituted what they termed the “parent aquifer” beneath Moscow. The influence of this aquifer on vertical gradients within the Grande Ronde and Imnaha basalts, as well as on groundwater discharge out of the basin is still unknown (McVay, 2007).

Vantage Member

The material of the Latah Formation found between the Grande Ronde and Wanapum Formations is considered to be the Vantage Member equivalent of the Miocene Ellensberg Formation that is found in central Washington (Reidel and Hooper, 1989). In the Pullman-Moscow area, this is referred to informally as the "Vantage Member". It is composed of considerable sand and some fine gravel interbedded with siltstone, claystone, and shale with quartz, feldspar, biotite, minor muscovite, and trace amounts of olivine or sphene (Kopp, 1994). There are also variable amounts of clay, including swelling clays from lake bed deposits. Thickness of the Vantage varies from zero just west of Pullman to over 300 ft (91.4 m) in Moscow (Kopp, 1994; Owsley, 2003). In addition, the sediments coarsen to the east and grade laterally into the collective Latah Formation (in this location often referred to as the Sediments of Moscow) on the eastern edge of the Basin.

The Vantage can be a significant aquifer, especially in the Moscow area where these sediments are coarsest and thickest. There are, however, interbedded clay rich layers in the Vantage which act as aquitards. There seems to be little downward movement of water in the Vantage as implied by similar water levels in wells completed at different depths in the Vantage, but in the same spatial location (Bennett, 2009).

Sediments of Bovill

The Sediments of Bovill is the informal name for the sediments of fluvial origin overlying the Wanapum basalt. They represent the uppermost part of the Latah Formation and are Miocene in age. Figure 7 shows that the extent of these deposits is limited to the Moscow sub-basin. The Sediments of Bovill were named for similar deposits near Bovill, Idaho (Provant, 1995). They consist of well sorted to poorly sorted, subrounded sands, gravels, and silts with kaolinite-rich layers. They are derived from locally weathered granites and metasediments as well as reworked sediments in the area (Foxworthy and Washburn, 1963; Petrich, 1995). This unit is usually lumped into the Palouse Formation in well logs, but can be identified by their yellow and white clay content or large sand grains (Hopster, 2003).

Most of the Sediments of Bovill are fluvial in nature (transitory channel deposits), but some also accumulated in lacustrine, bog, and deltaic environments. They are often thinly interbedded, with some cross-bedding and fining upwards sequences two to five feet thick (Provant, 1995). Considering this environment, it has been suggested by Fairley et al. (2006) that the coarser sediment horizons should have greater continuity in the direction of the drainages and therefore poor lateral correlation. This condition creates many opportunities for preferential flow. The finer grained sediments are usually found in lenses with little lateral continuity beyond 30 to 165 ft (9.1 - 50.3 m) (Fairley et al., 2006).

Provant (1995) and Bush (2005) hypothesized that the Sediments of Bovill influence the quantity and locations of groundwater recharge in the eastern part of the Pullman-Moscow area where they redistribute recharge laterally over the Moscow area. Flow is controlled by spatially variable hydraulic heads and the hydraulic conductivity of the sediments. Based on aquifer test data in the Moscow area, Bennett (2009) found the Sediments of Bovill act as a leaky aquitard. Stream and creek seepage is believed to be the main recharge mechanism for the Sediments of Bovill, occurring in winter to spring (February to May) (Hernandez, 2007).

Bennett (2009) observed drawdown in the Sediments of Bovill during pumping of the Wanapum aquifer. He believes that recharge to the Wanapum could be induced when water levels rise in the Sediments of Bovill, and the downward, vertical hydraulic gradient is steepened. However, the amount of fines that cover the Wanapum basalt, and fill fractures increases to the east of Moscow (Fairley et al., 2006). This silt and clay layer can be up to 20-25 ft (6.1 - 7.6 m) thick in places. The presence of this clay layer may locally affect the ability of the Sediments of Bovill to provide recharge to the Wanapum under non-pumping conditions.

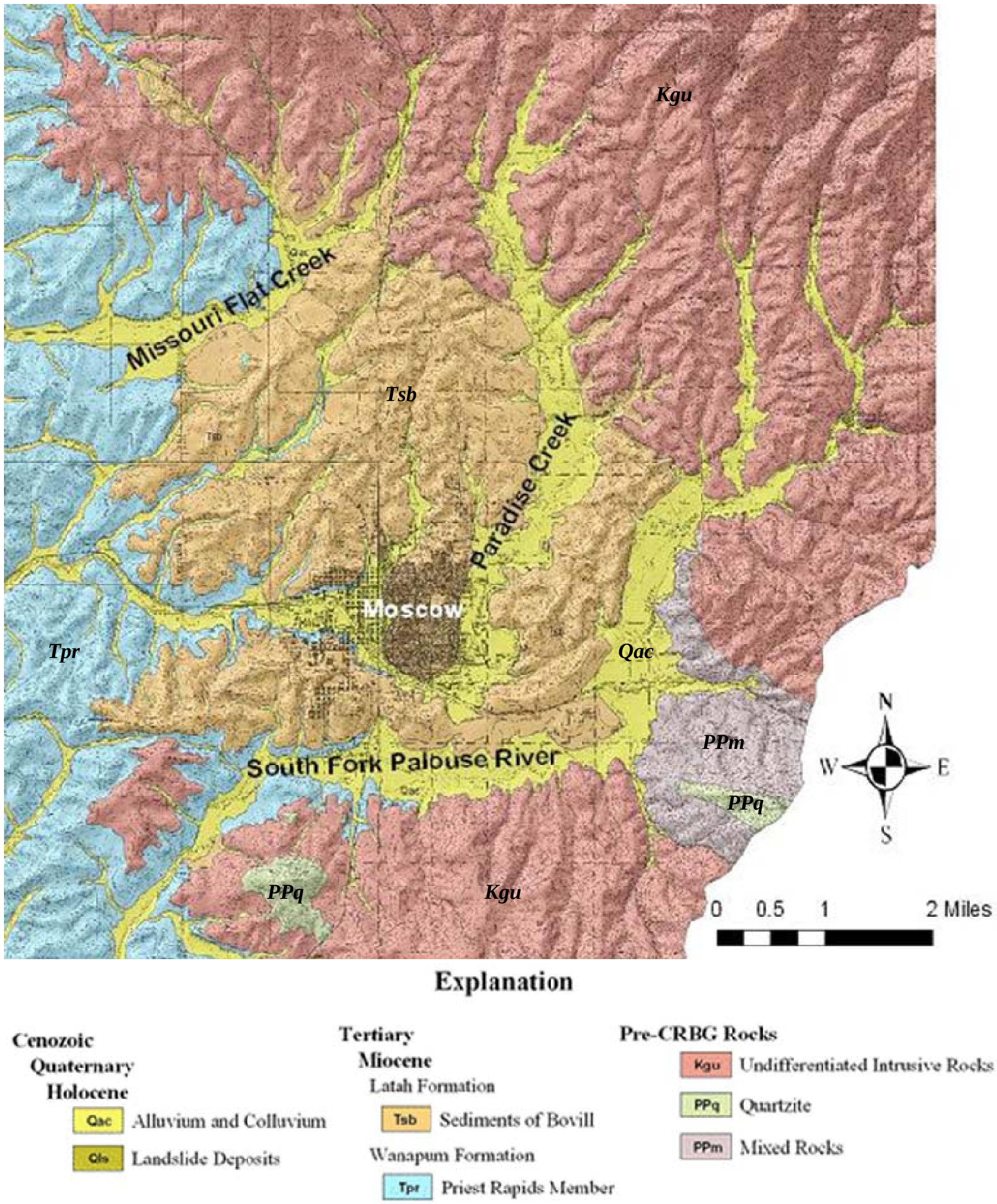


Figure 7. *Surface geologic map of the Moscow area showing the extent of the Sediments of Bovill (tan unit, Tsb). (Modified from Bush et al., 2007).*

Palouse Formation

The Palouse Formation is a collection of Pleistocene age paleosols with eolian, volcanic, glacio-fluvial, and glacial-lacustrine sediments (Lin, 1967) that covers approximately 75% of the Palouse Basin (Williams and Allman, 1969). The formation was formed by multiple episodes of soil development (paleosols) interrupted by periods of rapid loess deposition that occurred over the last two to four million years. There are estimated to be upwards of 21 different loess deposition events, most of which are separated by a paleosol (Krapf, 1978; Reuter, 1995). Superposition of paleosols is more common in the eastern part of the basin due to the higher amount of precipitation experienced there. The source of the loess material is located about 95 miles (153 km) west of the Palouse Basin in southwest Washington and the Walla Walla area, Yakima Valley, and Pasco and Quincy Basins (Russell, 1897; Smoot and Ralston, 1987).

The loess is a compact and somewhat indurated silt clay loam of quartz and feldspar composition, with low sand percentages (Foxworthy and Washburn, 1963). It has a massive blocky structure with some layering and areas of bioturbation, and is reworked locally (Johnson, 1991). No apparent bedding exists in most areas, but there are sequences of extremely dense paleosol fragipans (brittle subsurface soil horizons that restrict root and water movement) interstratified with less dense eluvial horizons (O'Geen, 2002; Foxworthy and Washburn, 1963). Provant (1995) described these eluvial horizons as pale, bleached zones overlying paleosol argillic horizons that are the result of chemical weathering and leaching.

The windblown materials of the Palouse Formation formed southwest-northeast trending dunes according to the prevailing wind direction, giving rise to the rolling topography of the Palouse (Lin, 1967). These hills are steepest on the north side and the continuing headward erosion maintains this profile. Topography may also be influenced by underlying hills and valleys in the basalt as well as the erosional characteristics of the loess itself (Foxworthy and Washburn, 1963; Walters and Glancy, 1969). Loess deposits range in thickness from zero to 200 ft (61 m); the thickest portions are represented by hill tops, while the loess covering valley areas is much thinner (Crosby and Chatters, 1965; Teasdale, 2002). The thickness and grain sizes of the loess also decrease from southwest to northeast in the primary direction of wind (Hopster, 2003). The loess has high porosity (0.35 to 0.50), but low permeability due to its fine sand and clay content (Foxworthy and Washburn, 1963; Lin, 1967). Lin (1967) estimated that the loess is over 25% clay by weight, which can significantly limit the rate of percolation.

Because the loess of the Palouse Formation covers roughly 75% of the Palouse Basin, it is an important factor for recharge. In general, the water table in the loess conforms similarly to the topography (Lum et al., 1990). However, where the loess is thicker, water is often trapped in perched aquifers or discharged laterally to surface depressions (Hopster, 2003; Hernandez, 2007). Small springs are common due to these perched conditions. Evapotranspiration also represents a substantial part of discharge from the loess (Foxworthy and Washburn, 1963). Wells completed in the loess typically only produce about one gpm.

The spatial distribution of overburden thickness, slope angle, amount of bioturbation, soil development, and fragipans all affect loess infiltration rates. Typically, it is assumed that recharge is greater in low lying areas of the loess; however, Johnson (1991) found that organic matter, clays and caliche (carbonate-rich) material erode from the slopes and are washed down onto the lower slopes and valleys, reducing the vertical hydraulic conductivity in these locations. His recharge estimations for the crest slope are therefore four times greater than those for the backslope or footslope. It has also been previously thought that recharge to the loess was greater in the eastern part of the basin due to the higher amount of precipitation experienced there; however, O'Geen (2002) believes that the regolith is more developed in this part of the basin due to the basin-wide climatic gradient, and therefore vertical percolation is more restricted. In addition, fragipans found in the loess impede infiltration of precipitation or runoff. To help explain ^{14}C age dates in the Wanapum and Grande Ronde aquifer systems, Douglas (2004) suggested that the percolation of water through the loess is less to the east; this is consistent with the larger number of fragipans in this direction.

Alluvial Deposits

Alluvial materials in the Palouse Basin consist of Holocene stream and slope wash deposits that cover about 30% the land surface, and grade laterally into the loess (Bush, 2005). Composition varies from stream to stream; however, major constituents are reworked loess, silt and clay, and sands and gravels of basalt and basement rocks (Pardo, 1993; Bush, 2005).

Tectonics

Deformation is minimal in the Palouse Basin. In places, the rocks are folded into northwest-trending narrow anticlinal ridges separated by wide synclinal troughs (Bush, 2005). These folds were suggested as contributing to the sectioning of the Palouse Basin into several hydrogeologic sub-basins by forming partitions. This gentle folding of the basalt also controls the orientations of the major streams in the area. The South Fork of the Palouse River, Union Flat Creek, and the Snake River all flow roughly parallel to each other as a result of the folding (Foxworthy and Washburn, 1963). In the Pullman area, a few structural features exist that dip slightly to the northwest and increase in dip with increasing distance to the northwest (Lum et al., 1990; Bush, 2005). In the Moscow area, a slight southeast dip has been observed in some of the rocks. Subsidence due to the compaction of clay and sediment interbeds from basalt loading may account for some of the dip, especially in the eastern part of the basin below Moscow (Smoot and Ralston, 1987).

Conceptual Hydrogeologic Model

Bush (2005) proposed that the Palouse Basin can be subdivided into six geologically distinct sub-basins based on stratigraphy, deformation and hydrogeology (Figure 8), which may or may not be hydraulically connected to one another. The heterogeneity of each sub-basin can cause short-term differences in hydraulic behavior (McVay, 2007). The Pullman-Moscow “Basin” is actually two of these sub-basins, and incorporates an area of about 256 mi^2 (663 km^2) surrounding the two cities (83 mi^2 in Latah County, Idaho, and 173 mi^2 in Whitman County, Washington) (Heinemann, 1994). Major streams in Palouse Basin are: Missouri Flat Creek, Four Mile Creek, Paradise Creek, and the South Fork of the Palouse River (Figure 1). Groundwater is of the calcium bicarbonate type and is distinctly stratified with deeper waters yielding older apparent age dates, as seen by Crosby and Chatters (1965), Larson (1997), and Douglas (2004).

A general “bathtub” hydrogeologic conceptualization for the Palouse Basin has existed throughout the years. Under this concept, when recharge into the Basin is greater than discharge (natural discharge plus pumping) out of the Basin, water levels will rise. When discharge is greater than recharge, water levels will fall. The eastern boundary of the Basin is formed by the relatively low hydraulic conductivity crystalline rocks of the Palouse Range, which form westward-open crescent shaped boundaries around Moscow (Figure 1). The southwestern-most boundary is formed by the Snake River Canyon. Other boundaries, particularly towards the west, are still undefined. Many studies, including those by Bush (2005), Crosby and Chatters (1965), Foxworthy and Washburn (1963), Lin (1967), Barker (1979), Teasdale (2002), and Owsley (2003), have proposed the existence of a hydraulic barrier between Moscow and Pullman based on different seasonal water level fluctuations, lack of measured hydraulic connection during aquifer tests, and water chemistry differences between the two cities. This area may also represent an area of

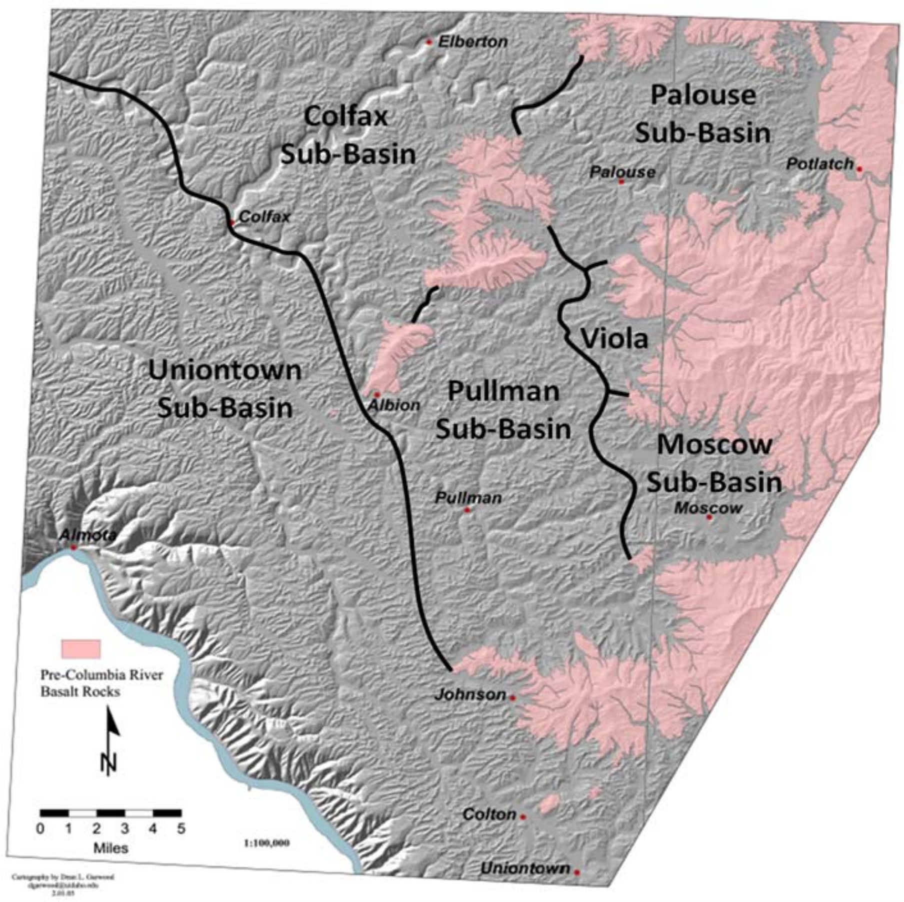


Figure 8. *Sub-basins of the Palouse Basin, as delineated by Bush (2005). These sub-basins do not imply the presence or lack of hydraulic connection between each other, but are used merely to denote smaller, specific areas within the Palouse Basin. (Modified from Bush and Garwood, 2005).*

recharge (Crosby and Chatters, 1965; Douglas, 2004). McVay (2007), however, came to the conclusion that Moscow and Pullman share a connected Grande Ronde aquifer and that the “hydraulic boundary” develops between the two cities due to the intersection of cones of depression from the pumping centers. The greater transmissivity found in the Pullman area may accentuate this feature. A geophysical study in this area by Klein et al. (1987) did not reveal any evidence of a physical, geologic barrier (e.g., dike, fault, etc.).

Several previous studies have suggested that the Snake River represents a major area for natural groundwater discharge from the Palouse Basin. Lum and others (1990) estimated that 27% of the total basin groundwater outflow is to the Snake River canyon, but the lack of springs in the area does not appear to support this conceptual hydrogeologic model. More recently it has been suggested that groundwater appears to flow to the west and northwest out of the basin, laterally to streams (where they are incised into the basalt) (Heinemann, 1994), and towards pumping centers. Groundwater flow is highly variable, both spatially and temporally, and it is possible that flow is following ancient channels as proposed by Lin (1967). According to Hopster (2003), local, intermediate, and regional flow systems should exist even within the Pullman-Moscow sub-basin area. The hummocky terrain seen throughout the Palouse Basin suggests that these various scales of flow, described further by Freeze and Witherspoon (1967), would also exist basin-wide (Figure 9).

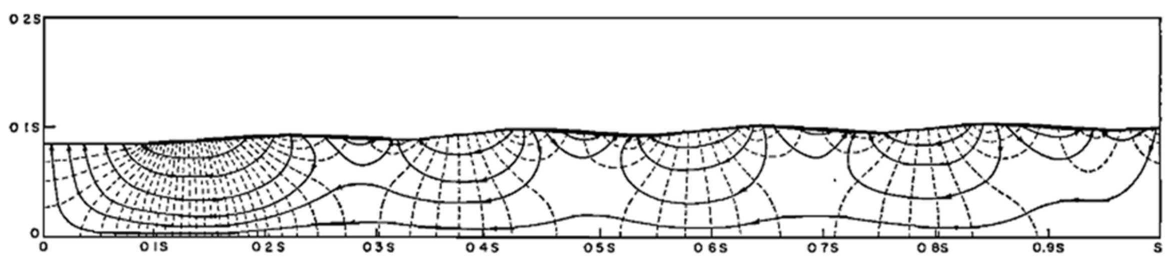


Figure 9. *Effects of surface terrain and water table configuration on groundwater flow through a homogeneous and isotropic system. (Freeze and Witherspoon, 1967).*

Discharge from the aquifers in the form of pumping is of special concern for the sustainable management of the water system. Due to the dry-land agricultural nature of the area, no large scale crop irrigation occurs; however, considerable summer-time groundwater pumping occurs each year for domestic, city and university lawn irrigation.

This summer-time pumping far exceeds normal everyday pumping for municipal and domestic water supply needs. While water is recharged seasonally to the Wanapum aquifer, pumping in the Grande Ronde aquifer exceeds recharge and results in the steady decline of water levels basin wide (Palouse Basin Aquifer Committee, 2010).

Rates of recharge to the system are difficult to estimate. However, recharge rates are assumed to be very low due to the low vertical hydraulic conductivity of the basalts and clay-rich sediments. Factors that affect recharge include the amount of precipitation, intensity of precipitation, topography, condition of the ground surface, evaporation, thickness of the loess, amount of clay in the loess and Latah Formation sediments, fractures in the basalt, weathering of the basalt, etc. Recharge is thought to be maximized when conditions permit high amounts of precipitation and low amounts of evaporation (i.e. during winter and early spring). It is believed that agricultural activity in the area has reduced the permeability of the soils, which may contribute to declining aquifer levels (Lum et al., 1990).

Several hypotheses have been proposed to explain recharge in the Palouse Basin in the vicinity of Moscow and Pullman. The first hypothesis proposed by Laney et al., (1923) suggested that recharge water enters the basin along the crystalline basement and sediment contacts as infiltration of runoff from the local mountains. Infiltrating water then percolates into the coarser grained Sediments of Moscow between the basalts and basement rocks and is redistributed to fracture zones and other sedimentary interbeds. Several other investigators have suggested this same conceptual model to explain recharge including Foxworthy and Washburn (1963), Lin (1967), and Bush (2005), among others. The paleochannels incised into the crystalline basement rocks described by Lin (1967) may represent some of the main pathways for recharge to enter the system from Moscow Mountain and other members of the Palouse Range. Shallow, spot, test-hole drilling by Fairley et al. (2006), however, did not penetrate any buried stream channel deposits. Based on a grain-size analysis of the test-hole drill cuttings and cores, Fairley et al. (2006) confirmed the results of previous clay exploration drilling in the area, and concluded that the sediments on the east side of the Moscow sub-basin consist primarily of low hydraulic conductivity sediments at most of test hole locations. These low hydraulic conductivity sediments, where present, should influence infiltration and reduce the potential for groundwater recharge from areal precipitation and surface runoff along the mountain margin.

It has also been proposed that recharge enters the uppermost aquifer system through losing streams. Water percolating from streams or sediments has three available pathways, as described by Hernandez (2007):

1. Water can enter near surface horizontal fractures by way of vertical fractures that sub-crop to the streambed sediments.
2. Vertical fractures connect shallow horizontal fractures to deeper horizontal fractures.
3. Smaller conchoidal fractures in the upper part of the basalt are connected to larger horizontal fractures by vertical fractures.

This hypothesis is supported by Provant (1995), Pierce (1998), and Badon (2007).

Another commonly accepted hypothesis suggests that recharge water originating from areal precipitation percolates through the overlying loess and constitutes the primary recharge mechanism for the area (Crosby and Chatters, 1965; Walters and Glancy, 1969; Barker, 1979; Smoot and Ralston, 1987; Lum et al., 1990; Bauer and Vaccaro, 1990; Johnson, 1991; Heinemann, 1994; Provant, 1995; Larson et al., 2000; Douglas, 2004; Fairley et al., 2006).

While the dominant recharge mechanism is debatable, it is generally accepted that some combination of the aforementioned conceptual models is required to account for the total recharge that reaches the aquifer systems. Seasonal recharge to the Sediments of Bovill and Wanapum aquifer system from Paradise Creek has been observed by investigators in the vicinity of the University of Idaho Groundwater Field Lab (Li, 1991; Pardo, 1993; Kopp, 1994; Hernandez, 2007). There have also been observations of upper aquifer wells that show a fairly rapid response to increased precipitation, especially in the eastern portion of the basin (Provant, 1995). In addition to several sources of recharge, there may be different recharge mechanisms for the different aquifers.

For the purposes of this study, the different geologic units of the Palouse Basin have been broken up into two main hydrogeologic groups, which will be referred to in this report as the Upper and Lower Aquifers. The Upper Aquifer consists of the Loess, Sediments of Bovill, Wanapum Formation, and Vantage Member of the Latah Formation. The Lower

Aquifer is made up of the Grande Ronde basalt and associated interbedded Latah sediments. In the Moscow area, the Sediments of Moscow are included in the Upper Aquifer if there is no overlying basalt unit, and are included in the Lower Aquifer if they are located beneath Grande Ronde basalt.

CHAPTER 3 – Methods

Introduction

For this study, groundwater samples from within the Palouse Basin were analyzed for tritium, oxygen-18 ($^{18}O/^{16}O$ or $\delta^{18}O$), and deuterium ($^{2}H/^{1}H$ or δD). Knowing the tritium content of the groundwater is necessary to improve understanding of the carbon-14 (^{14}C) age dates from previous studies. A positive tritium detection (reflecting at least some component of modern recharge) along with an older ^{14}C age date will indicate that mixing is occurring. If this is the case, the ^{14}C ages would not be representative of the true age of the water, but would instead be the product of mixing of older and younger water. The stable oxygen and hydrogen isotopic ratios of the groundwater were also evaluated. The evolution of $\delta^{18}O$ and δD values via fractionation factors such as evaporation, precipitation, and other geographic influences can provide information on source areas and seasonal timing of recharge entering the shallow subsurface. In order to determine if there was a geographic trend or pattern in the $\delta^{18}O$ and δD values, a separate, more in-depth sampling was conducted on shallow wells within the distribution of the Sediments of Bovill. This geologic member is of interest because of its suggested influence on groundwater flow and infiltration in the Moscow area of the Palouse Basin. The $\delta^{18}O$ and δD data were modeled geostatistically by the methods of simulated annealing and kriging to evaluate the areal distribution of the values.

Data Collection

Groundwater samples were collected from 97 wells within the Palouse Basin over a two-year period. Locations of these wells are shown in Figure 6 and Figure 10 through Figure 15. All of these samples were analyzed for $\delta^{18}O$ and δD, but the collection of tritium samples was more limited due in large part to the cost factor associated with the laboratory analyses. A few wells that lacked radiocarbon ages were also sampled for ^{14}C, and these results are reported in Appendix B. All samples were collected after purging the well casing and plumbing, and before the water passed through water treatment devices and, if possible, before entry into pressure tank systems.

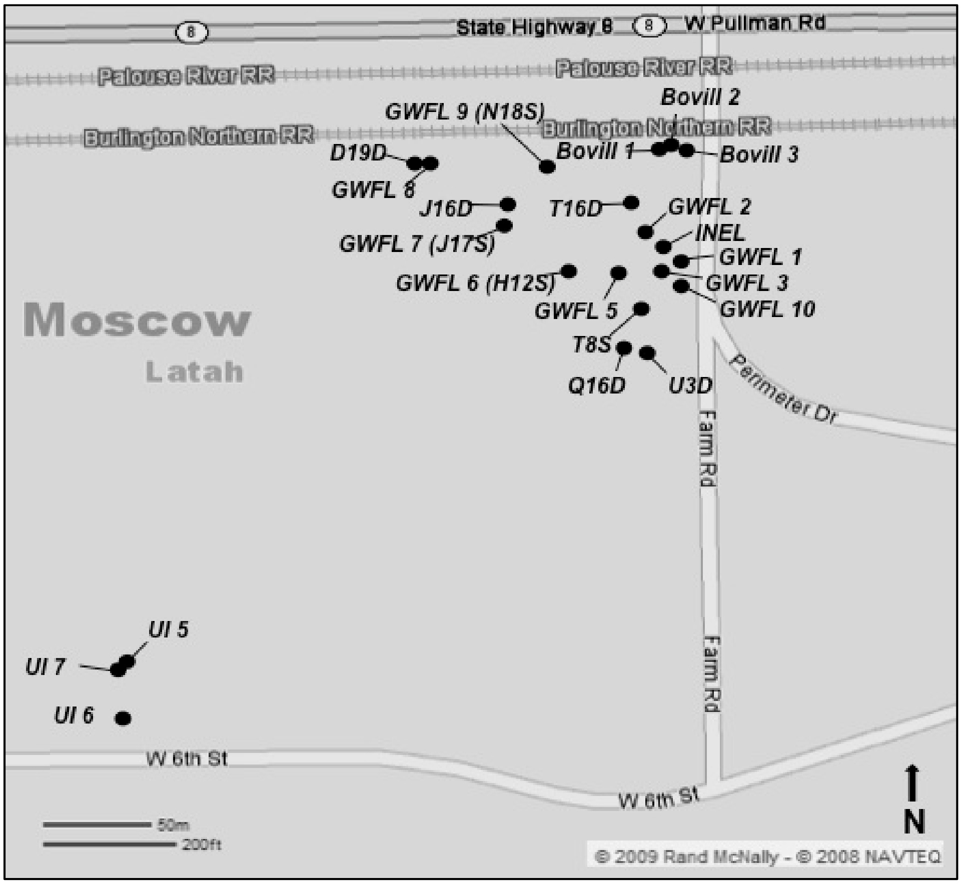


Figure 10. *Sampled well locations in the vicinity of the University of Idaho Groundwater Field Lab, Moscow, ID.*

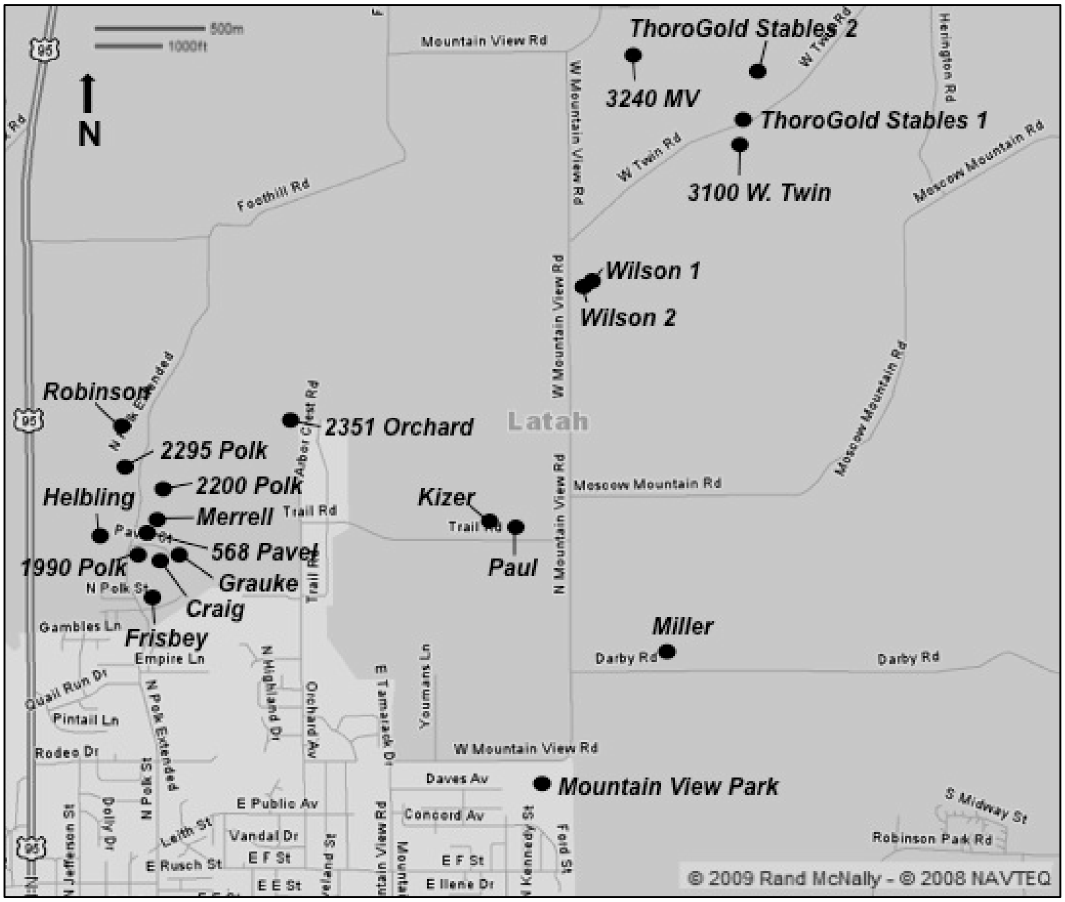


Figure 11. *Sampled well locations in northeastern Moscow, ID.*

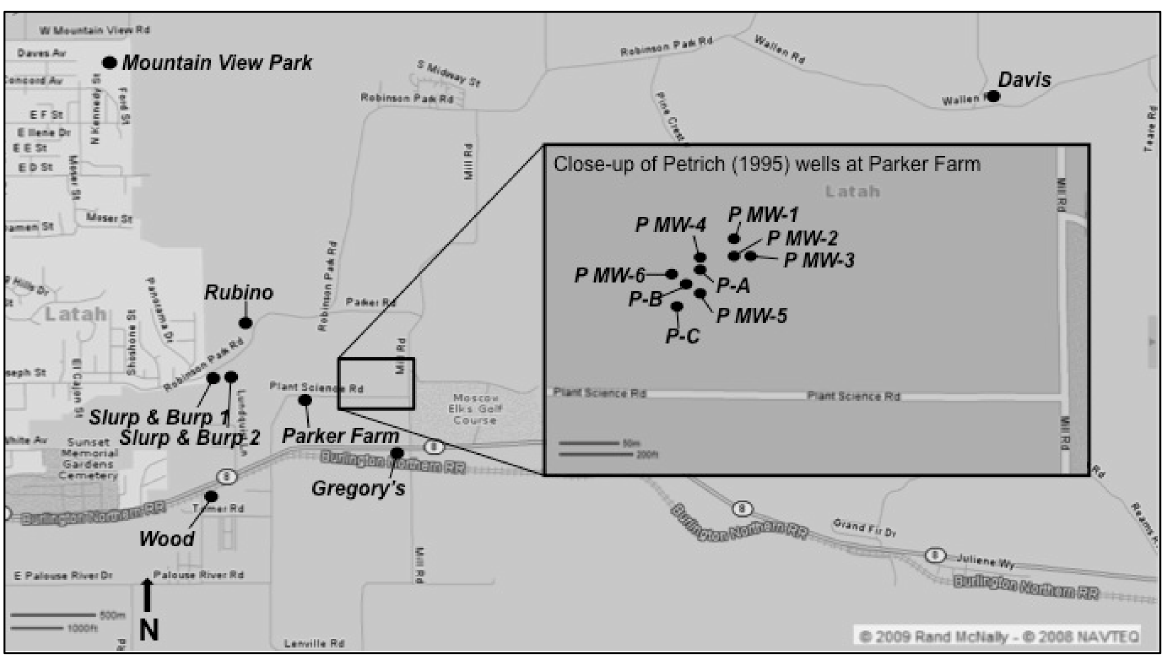


Figure 12. *Sampled well locations in east-central Moscow, ID.*

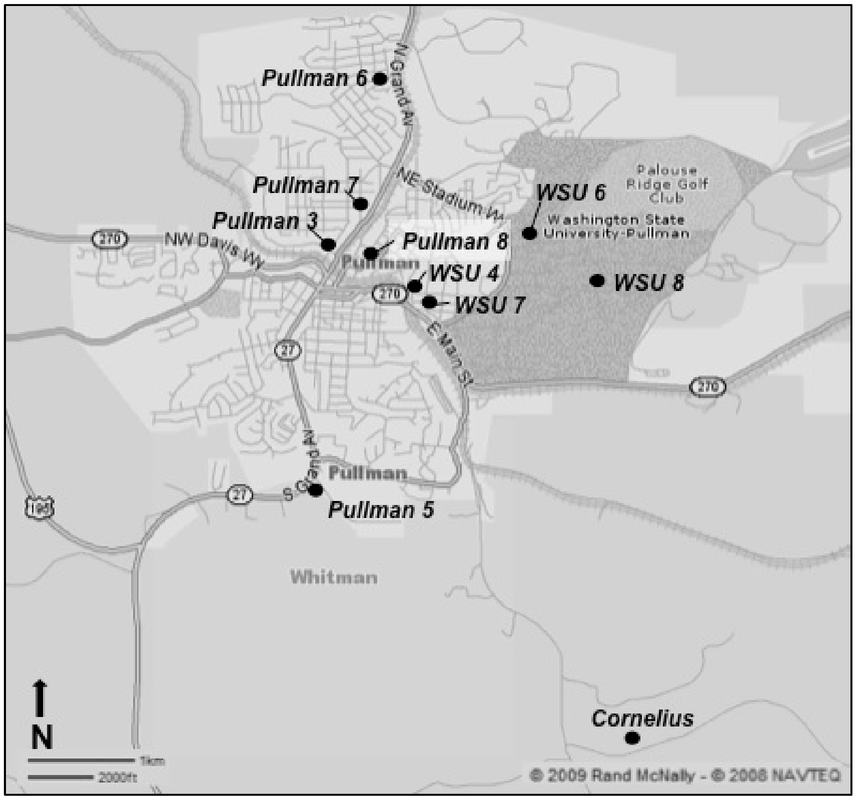


Figure 13. *Sampled well locations in Pullman, WA.*

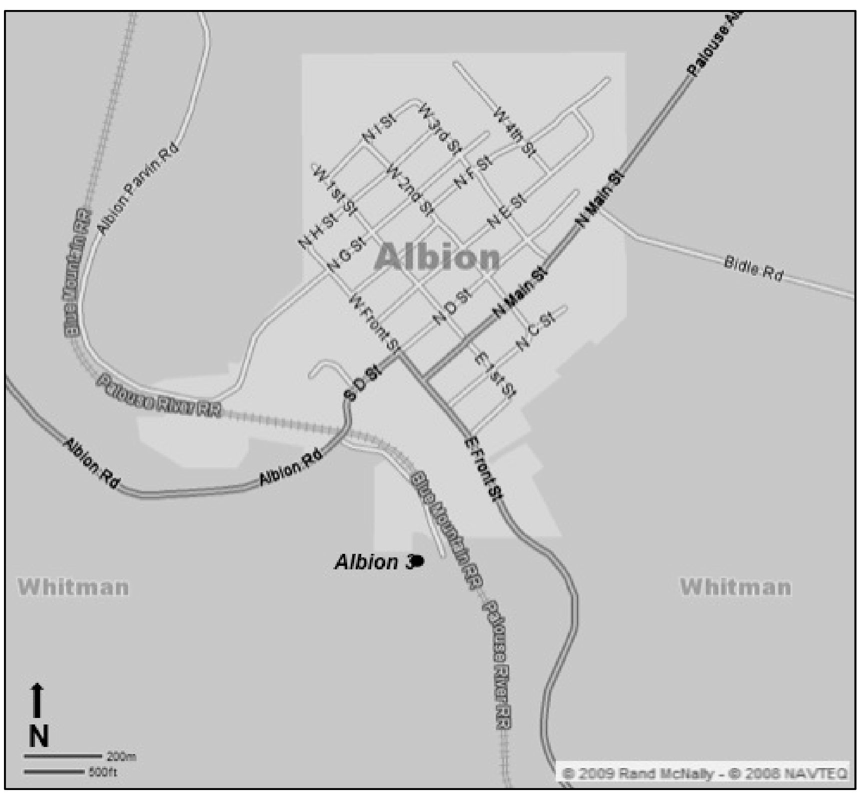


Figure 14. *Sampled well location in Albion, WA.*

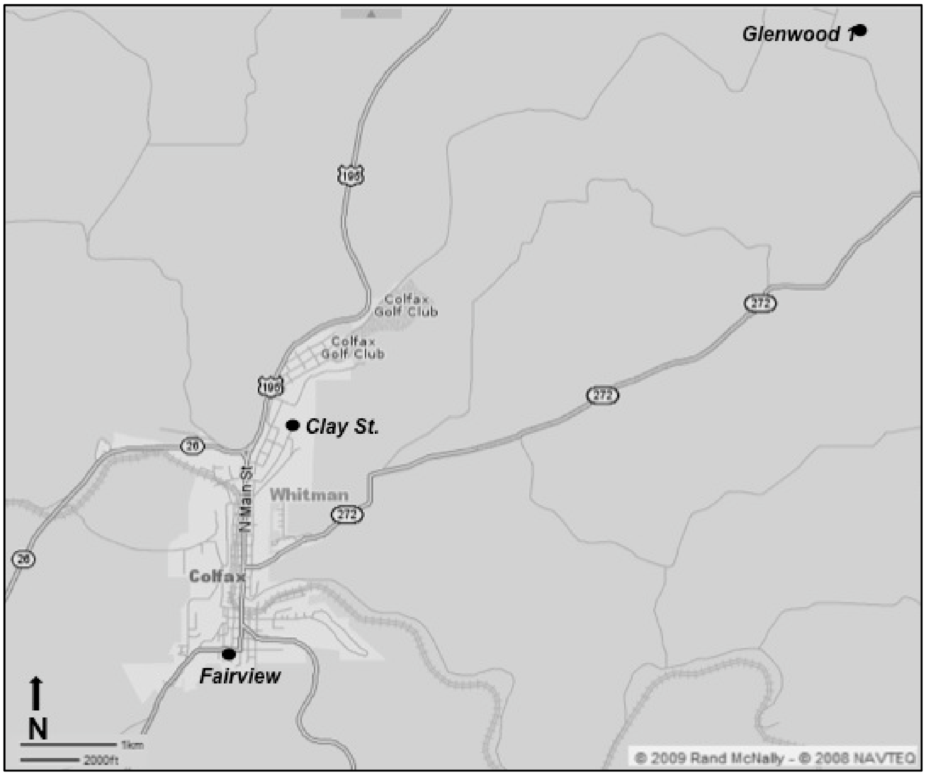


Figure 15. *Sampled well locations in Colfax, WA.*

Tritium was sampled primarily at high yield university and municipal supply wells in order to compare the results to previous ^{14}C age dates collected from the same wells during previous studies. These samples were collected in triple-rinsed 1-liter polyethylene plastic bottles and shipped to the Rosenstiel School of Marine and Atmospheric Science Tritium Laboratory at the University of Miami, Florida. Here, samples were analyzed for tritium content via low-level gas proportional counting with electrolytic enrichment. Results are reported in tritium units (TU) and the precision with this method of analysis is 0.10 TU or 3.5%, whichever is greater.

$\delta^{18}O$ and δD samples for the geostatistical modeling component of this study focused on the upper aquifer within the Moscow Sub-basin. More specifically, wells included in the simulated annealing model were restricted to those completed in the Upper Aquifer and within the area mapped (Figure 7) as containing the Sediments of Bovill. Limiting the sampling to one aquifer level removes some of the depth issues related to the spatial modeling of the results. In order to incorporate specific depths, enough samples (at least 30) must be taken from each stratigraphic unit to make geostatistical analysis feasible.

This becomes even more difficult considering that many wells have multiple screened intervals. In addition, $\delta^{18}O$ and δD signatures attenuate and become smoothed with depth, so samples were taken from shallow depths in hope of preserving the natural variations of recharging water. The sampling area was restricted to the mapped extent of the Sediments of Bovill to evaluate the significance of the sediments in the areal distribution of groundwater recharge to the Wanapum aquifer system. In an ideal study, especially for the geostatistical modeling of data, sampling locations would be designed to provide an adequate distribution of lags (distances between two points), as well as to avoid spatial gaps in sampling locations. For this study, however, sampling was limited to locations that already had wells in place. The vast majority of the target wells to be sampled for the modeling part of this study were domestic wells. Locating the owner, gaining access to the well and permission to sample proved difficult. Much of the success came from going door-to-door and/or leaving fliers about the project. Samples were collected in 30-milliliter glass bottles with no head space and capped tightly. This process ensured that no air bubble remained that would allow gas exchange within the sample.

The samples were analyzed with a Picarro® L1102-i isotopic water liquid analyzer by wavelength-scanned cavity ringdown spectroscopy (WS-CRDS), and were run by the Idaho Stable Isotopes Laboratory in the College of Natural Resources at the University of Idaho, Moscow. During this process, the samples are inserted into 2 mL glass vials and loaded into the machine's autosampler. Each sample is analyzed six times in order to eliminate memory effects, and then the value of the sixth sample is reported. Normalization of the data is accomplished by analyzing two internal standards. In addition, sets of three known standards are incorporated into the data set roughly every ten samples and analyzed along with the other samples. These are used to both calibrate the results and to check the calibration. Both $^{18}O/^{16}O$ and D/H ratios were measured and are reported as $\delta^{18}O$ and δD with units of ‰ (per mil) relative to Vienna Standard Mean Ocean Water (VSMOW). The accuracy of the results are <0.1‰ and <0.5‰, respectively. Local precipitation data were provided for comparison by Sánchez-Murillo, et al. (2011).

Well information from available well logs was used to determine the depth interval of the screened casing (Appendix C). The productive zone elevation was taken as the average of the screened interval(s) (Table C1). In wells for which no information could be found, or where multiple well logs were possible, the elevation of the productive zone was estimated by examining the completion records for similar wells in the area.

Tritium Analysis

Elements are defined by the number of protons and neutrons that exist in the nucleus. Isotopes are variations of a given element that are chemically alike, but differ by the number of neutrons they have. Usually, one abundant and one minor isotope exist, although some elements may have multiple isotopes. Common, naturally occurring environmental isotopes include: carbon, hydrogen, oxygen, nitrogen, and sulfur. Analyzing their abundance in hydrogeological systems can yield important information and insight into processes that govern the movement of water. The relative concentrations of oxygen and hydrogen isotopes are common tracers used in groundwater and surface water studies.

Tritium is the radioactive isotope of hydrogen. Hydrogen exists in several forms: ordinary or common hydrogen (^{1}H or protium), hydrogen-2 (^{2}H or deuterium), and hydrogen-3 (^{3}H or tritium). Ordinary hydrogen comprises over 99.98% of all naturally occurring hydrogen. Deuterium comprises about 0.02%, and tritium comprises about a billionth of a billionth of natural hydrogen. Each form of hydrogen has a single proton in its nucleus, but the numbers of neutrons vary. Tritium has two neutrons in its nucleus which makes it unstable and therefore a radioactive isotope of hydrogen. This instability causes tritium to decay spontaneously to helium-3 (^{3}He) through beta decay. During this decay process, a beta particle (or high-energy electron) is released. The decay rate, or half life, of tritium is reported differently depending on the source. The current recommended half life is 12.32 years, but some sources use the older half life of 12.43 years (Kazemi et al., 2006; Tritium Laboratory, 2010).

Tritium concentrations are usually expressed in Tritium Units (TU) where one TU is the equivalent of one tritium atom (or one THO molecule) per 10^{18} atoms of hydrogen (or 10^{18} H_2O molecules). Tritium concentrations are also commonly reported in terms of Tritium Ratios (TR), where 1TR = 1TU. One TU is also equivalent to 0.1181 Becquerel per kilogram (Bq/kg) where 1 Becquerel is equal to one decay per second (Tritium Laboratory, 2010).

Tritium is produced by several mechanisms. Naturally, it occurs through cosmic ray bombardment of nitrogen and deuterium in the upper atmosphere:

$$^{14}N + {}^{1}n \rightarrow {}^{12}C + {}^{3}H \quad \text{and} \quad {}^{2}H + {}^{2}H \rightarrow {}^{3}H + {}^{1}H$$

The production rate of tritium in the upper atmosphere is known as the background concentration. Naturally occurring tritium in the atmosphere produces rainfall with concentrations of roughly 30 atoms per square centimeter of Earth's surface per minute or a concentration of 3-10 TU in the northern hemisphere and 1-5 TU in the southern hemisphere (Kazemi et al., 2006; Happle, 2010). Production is also greatest at higher geomagnetic latitudes; that is, natural tritium concentrations tend to be greatest near the poles and lower close to the equator. Another natural source of tritium is through the neutron radiation of lithium in rocks (especially granitic rocks): $^{6}Li + n \rightarrow {}^{3}H + \alpha$. The average rock-produced tritium is on the order of less than 0.2 TU (Kazemi et al., 2006).

One of the most important and significant sources of tritium is from thermonuclear tests. These tests began in the northern hemisphere in 1952 and peaked around 1963 and 1964 in the northern and southern hemispheres, respectively (Figure 16). They were conducted primarily by the United States, United Kingdom, and USSR, so tritium concentrations, therefore, are higher in the northern hemisphere than in the southern. The additions of tritium in the atmosphere from these thermonuclear weapons tests (especially stratospheric tests) are substantial and produced a traceable marker for use in age dating, though it obscured the natural background tritium concentrations. At the northern hemisphere peak in 1963, the tritium concentrations arising from thermonuclear weapons were three orders of magnitude greater than the natural tritium concentrations. Since the treaty banning nuclear tests in the atmosphere in 1963, the bomb tritium has all but decayed and tritium concentrations in precipitation are approaching pre-bomb levels. Tritium is also the byproduct of nuclear reactor operations. The form and amount of tritium produced by such operations depends on the reactor design, but concentrations can be substantial.

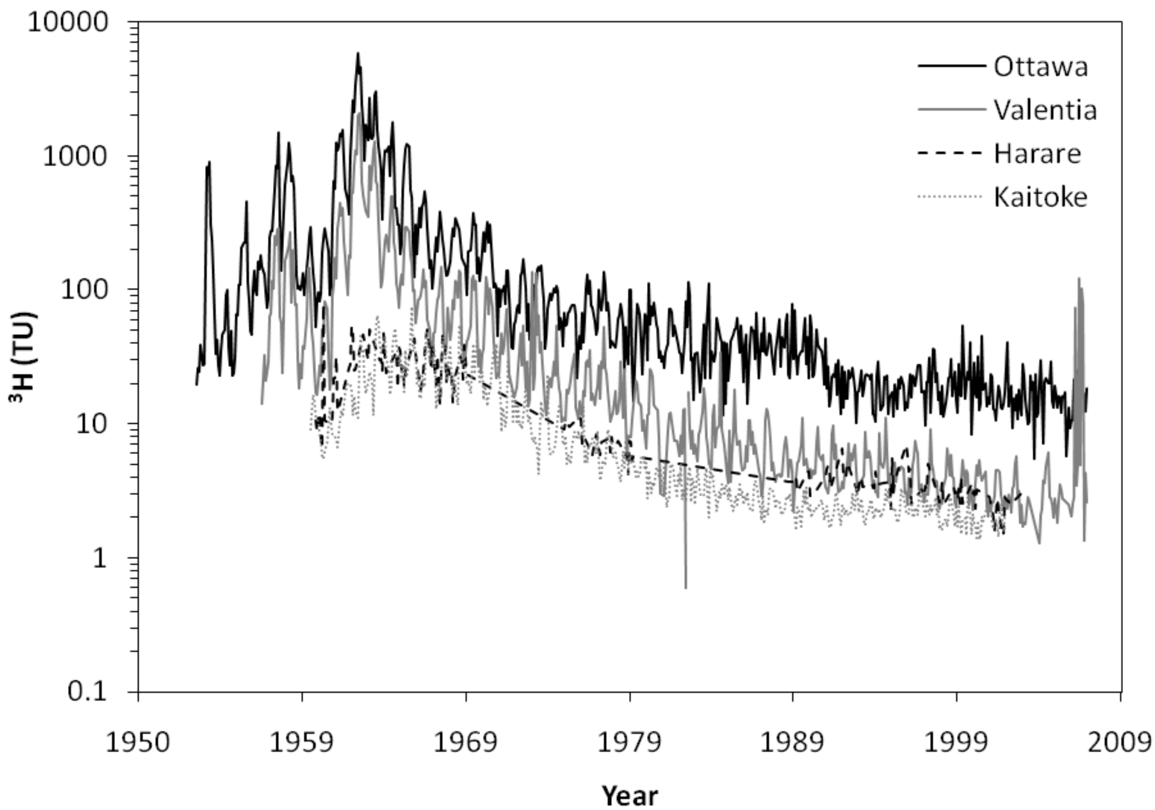


Figure 16. *Tritium concentrations in precipitation since 1950 at four IAEA stations: Ottawa, Canada (northern hemisphere, continental); Valentia, Ireland (northern hemisphere, marine); Harare, Zimbabwe (southern hemisphere, continental); and Kaitoke, New Zealand (southern hemisphere, marine). Data from IAEA (2011).*

Because the number of protons and not neutrons determines the chemical bonding of an atom, tritium behaves like normal hydrogen and can therefore readily be incorporated into hydrologic and biologic cycles by simply replacing a hydrogen atom. Water that has tritium replacing at least one hydrogen atom is known as tritiated water. The amount of tritium infiltrating with precipitation is controlled primarily by the quantity of tritium present in the atmosphere when the precipitation formed. The technique of using tritium as a tool for age dating water was first developed by Begemann and Libby (1957). Most methods for analyzing tritium content yield only qualitative results; the precise age cannot be determined. The presence of tritium itself, however, indicates the presence of "young" water (i.e. less than about 50-60 years old) due to recharge or possibly borehole leakage. However, the absence of thermonuclear tritium does not in itself necessarily indicate an absence of modern recharge, just older than about 60 years.

Oxygen-18/Deuterium Analysis

Oxygen has three isotopes: ^{16}O, ^{17}O, and ^{18}O. The superscripts refer to the atomic mass of the isotope. Most oxygen is present in the form of oxygen-16 (^{16}O). The ratio of oxygen-18 to oxygen-16 is 1:500 (Drever, 1997). The amount of ^{18}O in a sample depends on the amount of fractionation (isotope partitioning) the isotopes have undergone as a result of natural processes. A mass spectrometer is used to measure the isotopic ratio in a sample.

Stable isotope abundance is usually reported as delta (δ). These values have units of per mil (‰), or parts per thousand, and are calculated relative to a standard:

$$\delta_A = \frac{R_A - R_{Stand.}}{R_{Stand.}} \times 10^3$$

where: δ_A is the isotopic ratio of the sample, and R_{Stand} is the absolute isotopic ratio in the standard. Currently, Vienna Standard Mean Ocean Water (VSMOW) is the established standard for $^{18}O/^{16}O$ ratios ($\delta^{18}O$). This replaced the old standard, Standard Mean Ocean Water (SMOW) (Kehew, 2001). Delta values indicate whether a particular sample is enriched or depleted in ^{18}O relative to the standard. For example, a $\delta^{18}O$ of +10 is equal to an $^{18}O/^{16}O$ ratio that is 1% (or 10 per mil) greater than the VSMOW. Mean ocean water samples are used as a standard because, as Welham (1987) describes, oxygen isotopic variations in seawater are very small (+/- 1.5 ‰). It should be noted that there have been a few instances of extreme variations in the ^{18}O content of ocean water, but these are attributed to glacial periods.

Hydrogen isotopic concentrations are often used in conjunction with oxygen isotopic concentrations, since both isotopes are found in water. The main hydrogen isotope of interest is ^2H, also known as deuterium (D). It has been found that a relationship exists between $\delta^{18}O$ and δD values, such that $\delta D = 8\ \delta^{18}O + 10$ VSMOW (Kehew, 2001). This is known as the Global Meteoric Water Line (GMWL) (Figure 17).

Fractionation is the change of isotopic ratio due to chemical or physical processes. The amount of fractionation that takes place depends on the reaction rate, environmental factors, and the temperature. The isotope fractionation factor (α) between substances A and B is:

$$\alpha_{A-B} = \frac{R_A}{R_B} = \frac{1 + {}^{\delta_A}/_{1000}}{1 + {}^{\delta_B}/_{1000}} = \frac{1000 + \delta_A}{1000 + \delta_B}$$

where: R_A in this case is the ratio of ^{18}O to ^{16}O in phase A, and R_B is the ratio of ^{18}O to ^{16}O in phase B. The value for α is usually equal to about one (Kyser, 1987). Physiochemical reactions between various species lead to the partitioning of isotopes of the same element between reactants and products (Hoefs, 1987). An example of such a physiochemical reaction is the process of evaporation. Fractionation can reach an equilibrium condition similar to chemical equilibrium or can be in disequilibrium, where partitioning continues to occur (Kyser, 1987). For most studies, the system is assumed to be in equilibrium. In reality, it takes a very long time for a system to achieve equilibrium in low temperature environments.

Temperature affects fractionation the most (Mazor, 1991). Therefore, it is important to know fractionation patterns as a function of temperature variations. Temperature has such an effect on fractionation because the bond strength between the light and heavy oxygen isotopes decreases as the temperature rises. The net effect of temperature is expressed in the following empirical function from Mazor (1991):

$$\delta^{18}O = 0.7T_a - 13‰$$

where: T_a is the local mean annual air temperature.

Temperature is also the leading factor that controls the isotopic concentrations in precipitation. This dependence on temperature is what leads to seasonal variations in ^{18}O concentrations, and the temperature effect (Dutton et al., 2005). According to this "temperature effect", lower temperatures lead to lower precipitation isotopic ratios (δ_P). Seasonality signals manifest themselves with higher negative (i.e., more negative) ^{18}O values in winter.

Short term isotopic separations are controlled by phase separation processes (like the transition of water into ice, liquid, and vapor). Kinetic factors, like evaporation, usually govern the enrichment of ^{18}O. Higher temperatures, and arid areas, lead to more evaporation. During evaporation, the heavier isotopes (i.e. ^{18}O and D) are preferentially partitioned to the aqueous phase (Kehew, 2001). This means that they will remain in the liquid phase while the lighter isotopes (i.e. ^{16}O) will evaporate out into the vapor form.

Therefore, there is a general lowering of δ_P from summer to winter and from the equator to the poles. The "latitude effect" describes this progressive depletion of heavy isotopes in precipitation at high latitudes (Hoefs, 1987; Mazor, 1991). Evaporation causes water to plot off the GMWL on a separate evaporation line that has a lower slope than that of the GMWL (Figure 17). Each evaporation line is determined primarily by the prevailing temperature and the air humidity. Its intercept with the GMWL can change depending on evaporation conditions (Gat et al., 1991).

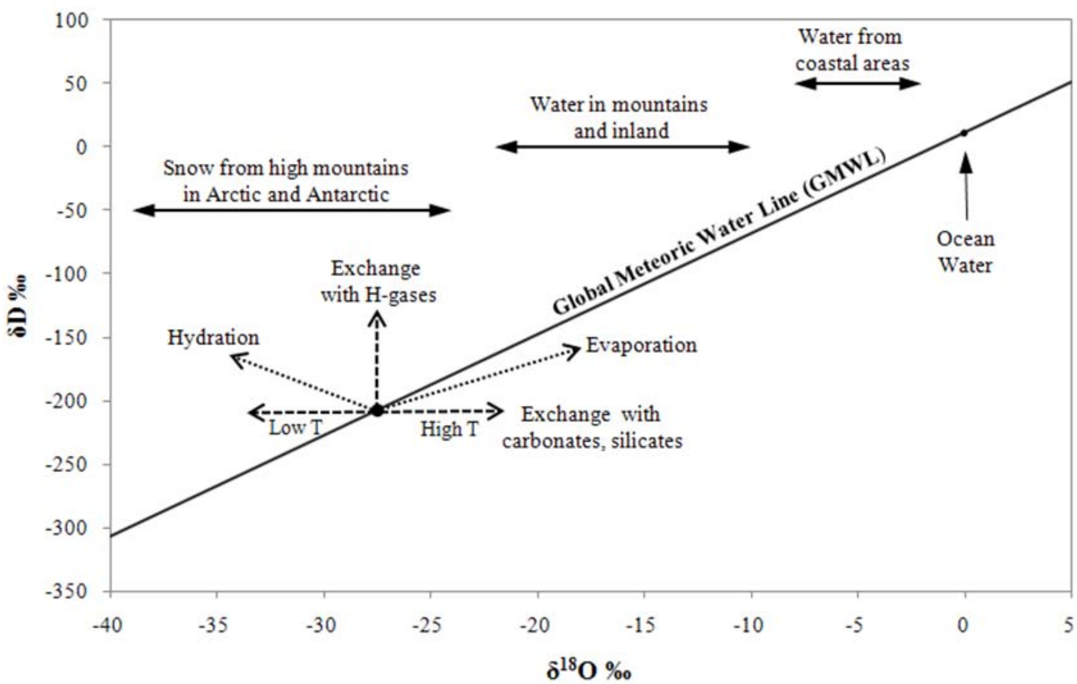


Figure 17. *Variation in isotopic composition due to climatic/physiographic region and processes that cause departure from the GMWL. (Modified from Welham, 1987; Kehew, 2001)***.**

Upon condensing, the reverse relationship is found: the heavier isotope ^{18}O will condense first and be removed in the form of precipitation, while the remaining vapor will then be enriched in ^{16}O, or isotopically "lighter". This process is sometimes known as "rainout effect" or the "continental effect" and is illustrated in Figure 18. Successive rainout events cause a general lowering of ^{18}O concentrations with increasing distance from the ocean. This isotopic evolution of vapor remaining in an air mass is described mathematically using the Rayleigh Distillation Model, which is expressed by:

$$R = R_0 f^{(\alpha-1)}$$

where: R is the isotopic ratio of the water vapor at any point along the path of the air mass, R_0 is original isotopic ratio from the source, α is the fractionation factor at the temperature of the air mass, and f is the residual fraction of water vapor in the cloud (Kehew, 2001). These two phase separation processes (evaporation and condensation) are two of the most important sources of isotopic separation (Hoefs, 1987).

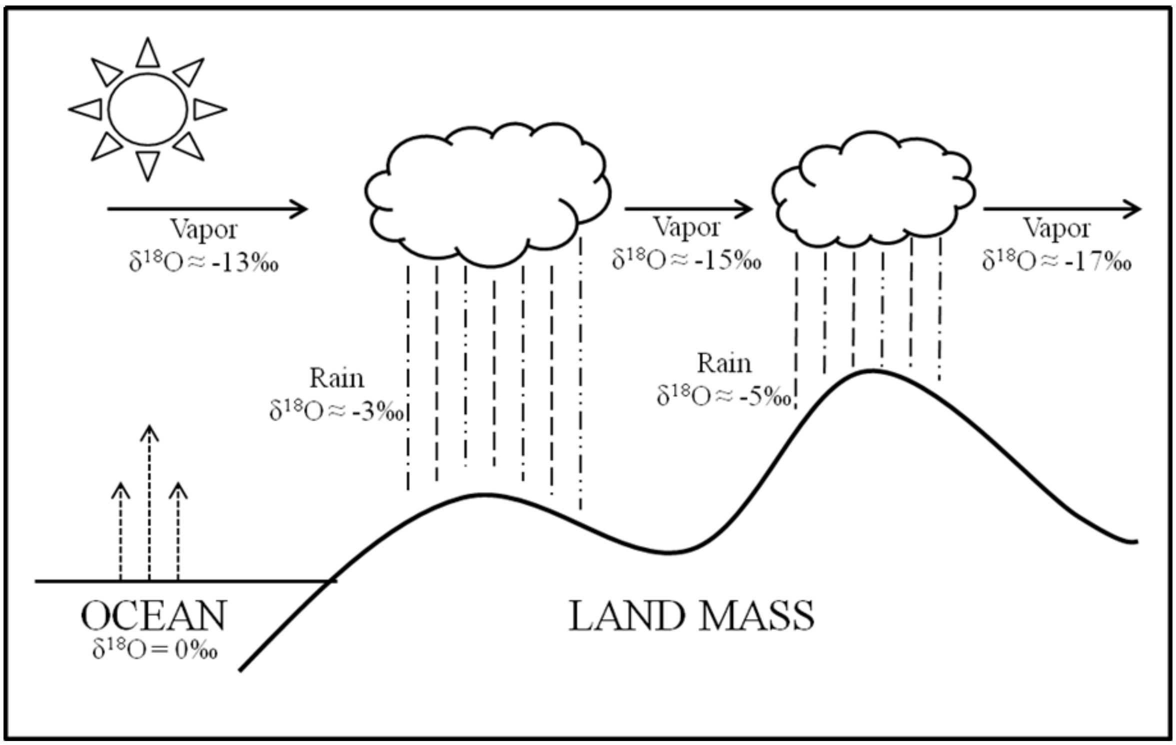


Figure 18. *Conceptual evolution of isotopic ratios due to condensation and preferential rainout of isotopically heavy water during vapor movement inland. (Modified from Hoefs, 1987)***.**

Some areas are also often associated with higher amounts of precipitation (e.g. mountainous terrain, equatorial areas, etc). The "amount effect" takes into account the combination of temperature, rain intensity, and evaporation. It has been found that higher intensity precipitation events lead to more negative δ_P values (Welham, 1987). A coupling of temperature and rainout effects due to elevation is known as the "altitude effect". ^{18}O concentrations decrease by 0.15 to 0.5 ‰ per 100 meters of rise in elevation, depending on the location (Welham, 1987). This makes precipitation at higher elevations progressively lighter. Also, higher altitudes correspond to lower temperatures, which lead to a further decrease in ^{18}O concentrations. It is true that evaporation from high latitudes leads to more fractionation, but there is typically less evaporation as a consequence of the cooler temperatures.

Regional effects on fractionation include latitude and continentality (where water is removed with changes in elevation). Local scale effects that control fractionation processes between ^{18}O and ^{16}O include altitude, seasonal climatic effects, and secondary evaporation (evaporation that occurs during precipitation) (Kehew, 2001). Snow dominated catchments, especially, are subject to a wider range of input conditions. Therefore, a greater variability of isotopic signatures is seen (Kurás et al., 2008). Picking out the signature of each effect is often difficult because they are masked by all of the other effect signals. However, the elevation effect is not as easily masked as the continental effect (i.e., masked by the seasonal effect) (Drever, 1997).

Water isotopes behave conservatively in the subsurface in almost all low-temperature environments (i.e., less than 50 to 100°C), where rock-water contact times are short relative to the kinetics of mineral-water isotope exchange reactions (Hoefs, 1987; Kyser, 1987; Welham, 1987; Mazor, 1991; Drever, 1997). Non-equilibrium can be caused by kinetic isotope effects, which are associated with biological activity, rapid precipitation, and loss of volatiles. This is described in depth by Kyser (1987). In most cases and studies using $^{18}O/^{16}O$, the exchange rates between water and thermodynamically stable minerals is considered to be negligible, unless geothermal fluids are involved.

The Meteoric Water Line is a convenient reference line for understanding and tracing groundwater origins and movement. For smaller scale studies, a Local Meteoric Water Line (LMWL) should be established from annual precipitation values. Deviations from the MWL are primarily due to evaporation and secondary evaporation (which is especially seen in warm and arid regions). Evaporation of groundwater in soil is more concentrated in shallower areas, and deeper waters are not usually affected (Krishnamurthy and Bhattacharya, 1991). Such evaporation effects lead to a lower slope than that of the GMWL.

The isotopic concentration of groundwater is dependent on the occurrence of evaporation, movement of vapor, condensation, precipitation, and movement through the vadose zone. In the subsurface, fractionation can be caused by ultra-filtration (which usually has a very small effect on the isotopic ratios) and gas exchange (which can possibly lead to substantial effects) (Welham, 1987). Seasonal variations in δ_P can be strongly attenuated in the groundwater depending on the geological characteristics of the material and the depth at which it is found. Lawrence and White (1991) show that the seasonal signatures of a region often change from season to season and are not constant. For instance, above average temperatures can lead to different seasonal isotopic rainfall trends. Some seasons show good correlations from one year to the next, while others show very little. Much of the time though, groundwater tends to represent averaged modern precipitation isotope concentrations because any "new" water loses its signature during percolation (Kehew, 2001; Mazor, 1991). Dispersion and diffusion in deeper groundwaters have a tendency to smooth isotopic variations. During recharge, some or much of the soil moisture water remains isolated and unchanged for many months. A homogenation process then takes place as new percolating rainfall mixes with a larger volume of relatively immobile water in the soil matrix (further described in Wenner et al., 1991). This homogenation is greatest when soil moisture is at a maximum (i.e., in early spring). Also, clay-rich soils buffer isotopic composition the most because they tend to retain the most moisture (O'Driscoll et al., 2005). As a result of these dispersive and homogenation processes, by the time that recharge arrives at the vadose zone, its isotopic value is usually close to the weighted mean annual values of the isotopic concentrations in precipitation (Wenner et al., 1991; Mazor, 1991). The point at which a loss of variation with depth occurs is known as the "critical depth" and can vary both seasonally and spatially (O'Driscoll et al., 2005).

Highly negative ^{18}O values are created by colder temperatures, higher altitudes, and farther distances away from the ocean. If groundwater is more depleted in ^{18}O than the average precipitation value, then it is a good indication that principal recharge takes place during winter months. ^{18}O concentrations can also be used to estimate the elevation of recharge or source areas, and the source water (precipitation, surface water, etc.) (Kehew, 2001). If highly negative ^{18}O values are observed, this can indicate that recharge occurred under pre-Holocene climatic conditions. Caution must be exercised though, because not all paleowaters (between about 10,000 and 35,000 years old) are isotopically different than present meteoric waters (Welham, 1987).

Geostatistical Modeling

Geostatistics arose in the mining industry and has been used heavily in the past for that purpose; however, it is being used more and more by other scientists and natural resource modelers. Geostatistics focuses on the characterization of spatial dependence in attributes, or physical properties, in an area. The primary goal is to use that dependence to estimate the values at unsampled locations. To do this, inferences are made based on samples from a given population and the degree of similarity or dissimilarity as a function of distance and direction. The result of geostatistical analysis is commonly in the form of a map showing the distribution of values, both sampled and unsampled.

Spatial estimates can be obtained using simple averaging of regional or local values, multiple regression or trend surface modeling, spatial interpolation techniques, or simulations. While interpolators, like kriging, yield one answer for the best estimate, simulations can produce multiple realizations. Each realization is equally probable, so having several or several hundred to compare allows the user to consider different outcomes. In addition, simulated realizations reproduce the desired statistics (e.g. mean, variance, skewness, etc.), have the desired Probability Distribution Function (PDF), data histogram or Cumulative Relative Frequency (CRF); also, they should have the same spatial dependence (from the variogram), and should honor known data. Each simulation should also produce a measure of uncertainty that may be used in risk analysis. The output from simulation techniques are more representative of reality than ordinary kriging because the uncertainty, or “noise”, seen in normal sampling can be reproduced in the final product. This feature of simulations is useful in situations such as in this study, where the inherent smoothing of a spatial interpolator (such as kriging) might mask important distribution patterns. Regardless of whether an interpolator or simulation technique is used, a model of spatial continuity is needed. This can be in the form of a variogram, covariance, or other representation of spatial dependence.

Several categories of simulations exist:

1. Gaussian based simulations which rely on a normal-score transform to produce an assumed Gaussian distribution. These include the frequency domain method, Sequential Gaussian Simulation (SGS), and the Lower-Upper (LU) decomposition of the covariance matrix;

2. Indicator-based simulations for continuous-type variables or categorical-type variables;
3. Simulated Annealing (SA) which relies on thousands of trial-and-error variable swappings in order to achieve the desired statistical output.

Simulated Annealing

SA got its name from the similarity of the process of annealing metals. The annealing process refers to a heat process that raises the temperature of a metal to a point where the particles can randomly arrange themselves in the liquid phase. The mixture is then cooled very slowly so that the particles can re-arrange themselves at the lowest energy state available. For this to occur, the initial temperature must be sufficiently high and the temperature during cooling must not be reduced so rapidly as to freeze the particles in place at a higher level of energy (van Laarhoven and Aarts, 1987; Albright, 2007). In the case of SA, the temperature is analogous to the energy level of the system. In the past, more studies have employed SGS than SA. While SGS is good for visualizing large scale patterns, SA is better suited for greater detail, especially when dealing with smaller areas (King, 2000). In addition, SA is not limited to 2-point statistics, does not require any distributional assumptions, does not employ an explicit Random Function (RF) model, and does not require data transformations (King, 2000). For these reasons, SA was chosen to model the $\delta^{18}O$ data for this study.

SA employs combinatorial optimization which selects a solution that satisfies a set of constraints and that either maximizes or minimizes a given objective function (Albright, 2007). In this study, a model variogram was fit to the data values and used as the objective function component in the SA process. Variogram models show the spatial dependence of the variable(s), or attribute(s), being considered. Calculation of the variogram is related to the moment of inertia of a cloud of points about a 45° line in any lag-scatterplot at a specified separation distance (h-scatterplot) (Miller, 2009). This moment of inertia is known as the semivariogram, or variogram, and is expressed as:

$$\gamma(h) = \frac{1}{2n_h}\sum_{i=1}^{n_h}(x_i - x_{i+h})^2$$

where: h represents the lag distance, $\gamma(h)$ is the estimated variogram value at lag h, n_h is the number of data values for a given lag h, x_i is the data value at location x_i, and x_{i+h} is the data value at location x_{i+h}. The calculated variogram value for a certain lag distance is then plotted by one of several methods:

1. Mean-lag (or Lag-mean) method—the variogram value is plotted at the mean lag for each bin;
2. Lag-centered method—the variogram value plots in the middle of each bin;
3. Weighted lag method—a user-specified weighting function is applied to each lag bin such that individual lags get different weights depending on their distance from the center of the lag bin;
4. Overlapping lag window—variogram values plot at the mean of the lag bin, but bins can overlap. This creates a smoother line, but may not be possible to use for every program.

Once the variogram values are plotted, the variogram can be modeled by fitting certain mathematical functions through the data (e.g. exponential, Gaussian, linear, logarithmic, spherical, etc.). The three key parameters that describe the variogram model are the nugget, sill, and range (Figure 19). The nugget is a gauge of measuring uncertainty and can also reflect the natural variability of an attribute (Miller, 2009). For example, a nugget of 0.61 corresponds to 61% variability in the data that is unexplained and is due to either spatial variability, sampling error, or both. Typically, it is desired that the nugget be less than 0.5 (King, 2000). The sill is equal to the sample variance (σ^2). The range, or range of influence, is the distance at which the variogram model approaches the sill. Past the point when the model reaches the sill, the variogram values tend to oscillate about the variance and show low spatial dependence.

In order to obtain a reasonable variogram, there should be at least thirty data points per lag bin and the longest lag used for computation of the variogram should be no greater than 60% of the maximum lag found for the study area (Miller, 2009). Directional variograms can be computed for which data pairs are viewed in directional bins (or tolerance windows) as specified by the user. From this, spatial dependence range ellipses can be constructed that illustrate the directions of the maximum and minimum ranges of influence (Miller, 2009). Variograms for this study were computed in Surfer® (Golden Software, Inc, 1999).

Isotropic (or omni-directional) variograms were used to ensure an adequate number of pairs per lag bin and also to reduce the amplification of bias inherent in the sampling distribution. Once the variograms are modeled, the model specifications can be input into the SA parameter file (Appendix A).

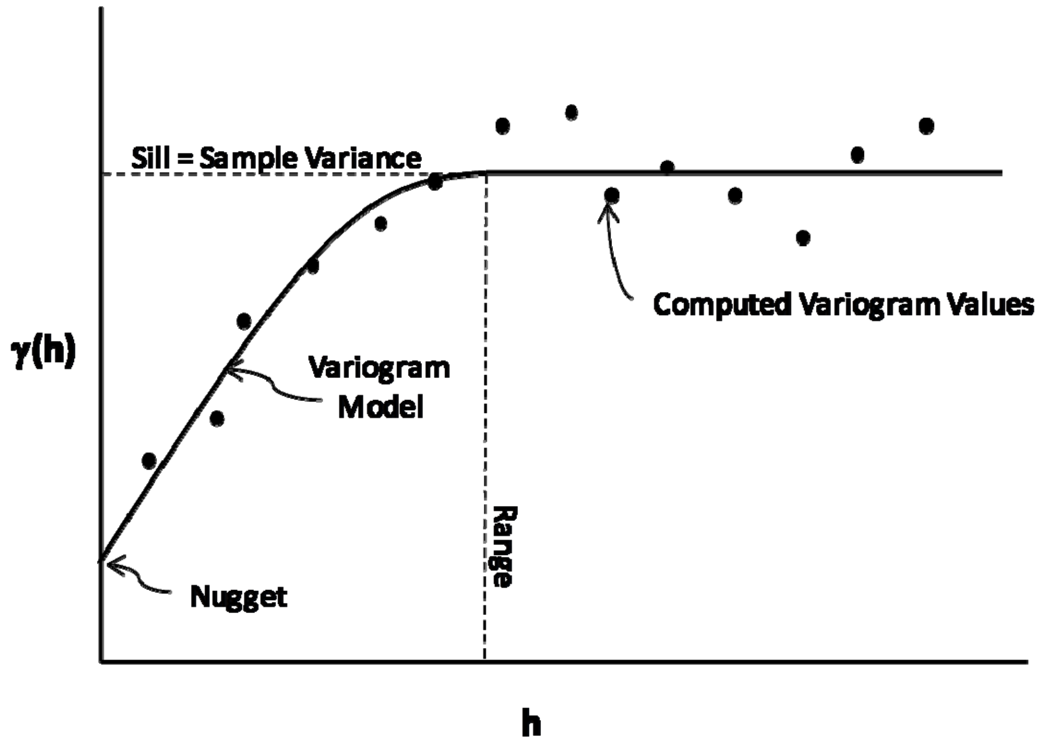


Figure 19. *Example of a variogram plot that exhibits spatial dependence.*

The main process of SA is to continually perturb a randomly generated image until it matches the specified characteristics from the objective function. The perturbations are accepted or rejected depending primarily on whether or not they lower the objective function. However, not all perturbations failing to lower the function are rejected. Doing so might cause the system to get locked into a premature, local minimum.

The SA cooling schedule for the process is specified by the user. The parameters that need to be defined are the initial temperature, t_0, the reduction factor, λ, the maximum number of perturbations to be attempted at any one temperature, K_{max}, the acceptance target, K_{accept}, the stopping number, S, and the low objective function indicating convergence, ΔO. The reduction factor is responsible for lowering the temperature, and is assigned a value of $0 < \lambda < 1$. As stated previously, care must be taken that the temperature is not reduced too rapidly. The higher this temperature control parameter, the greater the probability that an unfavorable change will be accepted and the system will become locked in a local minimum, or suboptimal solution (Deutsch and Journel, 1998). Whenever K_{max} or K_{accept} are reached, the temperature is multiplied by λ and the process continues at the next temperature level. K_{max} is usually on the order of 100 times the number of nodes (or grid points) while K_{accept} is commonly on the order of 10 times the number of nodes (Deutsch and Journel, 1998). The stopping number, S, indicates that if K_{max} is reached S times, the algorithm must end. The simulation is complete when all values are locked in place and further perturbations are unable to further reduce the objective function, or when a specified minimum objective function value, ΔO, is attained.

The SA algorithm functions sequentially as follows (Deutsch and Journel, 1998; King, 2000):

1. Create an initial image $\{z_0^l(\mathbf{u}_j'),\ j = 1, \ldots N\}$, where the superscript *l* refers to the realization, and the numerical subscript refers to the iteration number. Condition the image by moving the known data to the nearest node on the user-specified rectangular grid, $\mathbf{u}_j'$. These values are locked into place and will not be changed during the perturbations. Then randomly assign a value to the remaining nodes by drawing from the population distribution.
2. Calculate an initial objective function value, O_0^l, for the initial realization. The general objective function, O, represents the weighted sum of the squared differences between the original data statistics and the statistics of the output realizations:

$$O = \sum_{c=1}^{C} w_c O_c$$

where: w_c is the weight (w_c, c = 1,…,C), which is inversely proportional to the average absolute value of the objective function components, O_c. The objective function should converge to zero (van Laarhoven and Aarts, 1987).

Using a variogram as a conditioner (as is done in this investigation), the objective function may be written as (Deutsch and Journel, 1998):

$$O = \sum_{h=1}^{L} \frac{[\gamma^*(h) - \gamma(h)]^2}{\gamma(h)^2}$$

where: L is the number of lags used, $\gamma^*(h)$ is the simulated variogram value, and $\gamma(h)$ is the target, or original variogram model. The division by the square of the original variogram gives more weight to the duplication of variogram values at shorter lags, which are nearer to the origin (King, 2000).

3. Perturb the data set by swapping the values of non-conditioned locations, $z^l_{old}(\mathbf{u}'_j)$ and $z^l_{old}(\mathbf{u}'_k)$.
4. Calculate the new objective function, O^l_i. Set $O^l_{new} = O^l_i$. $\Delta O = O^l_{old} - O^l_{new}$.
5. Accept or reject the perturbation based on the Boltzman decision rule:

$$P\{accept\} = \begin{cases} 1 & \Delta O \geq 0, \\ e^{\frac{\Delta O}{t_i}} & \text{otherwise} \end{cases}$$

where: t_i is the temperature at the i-th perturbation (representative of the annealing schedule). This shows that the perturbation is always accepted if it lowers the objective function, and accepted with a certain probability if the objective function is increased. This probability decreases as the iterations progress due to the lowering of the overall temperature.

6. If the perturbation is accepted, then $O^l_{old} = O^l_i$.
7. If stopping criteria are not met, continue the perturbation procedure (steps 3-6) until a low objective function is reached. Otherwise, start a new realization with step 1.
8. Once all *l* realizations are completed, the algorithm ends.

The *sasim* program from GSLIB was utilized to perform the SA process. GSLIB is a collection of geostatistical software developed by graduate students at Stanford and was compiled by Deutsch and Journel (1992). The manner of incorporating the $\delta^{18}O$ and δD data into the *sasim* program via parameter files and its subsequent simulation are discussed in greater detail in Appendix A. The output data from the annealing process are displayed in maps created through Surfer® in Chapter 4.

CHAPTER 4 – Results and Discussion

Introduction

Table 2 provides a summary of the isotope values of sampled well water throughout the Palouse Basin, including tritium concentrations, $\delta^{18}O$ and δD values, and available ^{14}C uncorrected ages. The majority of the ^{14}C ages are from Douglas (2004), but a few samples were age dated during this study. Those results are provided in Appendix B. Additional well information and a partial collection of well logs are also available in Appendix C.

Both $\delta^{18}O$ and δD have units of ‰ (per mil) relative to Vienna Standard Mean Ocean Water (VSMOW). The accuracy of the results are <0.1‰ and <0.5‰, respectively. The tritium results are reported as tritium units (TU). The negative tritium values are a product of the laboratory counting procedure. The net tritium count rate is the difference between the count rate of the sample and that of a tritium-free sample (Tritium Laboratory, 2010). Therefore, with any given set of "unknown" samples with no tritium content, the distribution of the net results become symmetric around zero TU. The negative values are reported as-is for statistical purposes, but in essence have a concentration of zero TU. The accuracy of the tritium results, obtained by low-level gas proportional counting with enrichment, is 0.1 TU or 3.5%, whichever is greater. Therefore, samples with measured concentrations greater than this detection limit are classified as being positive for tritium; those with levels below the detection limit are classified as being negative for tritium (i.e. devoid of tritium). This distinction is important because a sample with any measureable tritium in it must have at least some component of modern recharge.

Well Name	Tritium (TU)	$\delta^{18}O$ (‰)	δD (‰)	^{14}C Uncorrected Age (ybp)	Aquifer	Geologic Unit
Albion 3	0.06	-16.85702	-129.752	18120	Lower	Grande Ronde
Appaloosa	3.23	-14.52782	-111.738	-	Upper	Wanapum
Bond**	2.36	-15.34079	-116.993	2730*	Upper	Wanapum
Brandt	0.01	-15.39138	-118.063	-	Upper	Wanapum
Champion Electric (CE)	0.16	-15.94113	-123.069	11800*	Lower	Grande Ronde
Clay Street	0.12	-16.33220	-125.742	14000*	Lower	Grande Ronde
Cornelius	0.04	-16.03032	-121.806	-	Lower	Grande Ronde
Fairview	0.09	-16.38337	-126.560	15100*	Lower	Grande Ronde
Garfield†	-0.02	-	-	9230*	Lower	Grande Ronde
Glenwood 1	0.11	-16.52791	-127.158	15500*	Lower	Grande Ronde
Gregory's	0.16	-15.87500	-119.997	-	Upper	Wanapum
IDWR 1	-0.11	-14.84925	-114.245	2550	Upper	Sed. of Bovill
IDWR 2	0.82	-15.42584	-117.632	9120	Upper	Wanapum
IDWR 3	0	-15.59511	-119.507	10040	Upper	Vantage
IDWR 4	0.01	-17.04543	-130.630	25700	Lower	Grande Ronde
Miller	-0.01	-15.46854	-116.684	-	Upper	Wanapum
Moscow 2	0.28	-15.91925	-120.222	8700*	Upper	Wanapum
Moscow 6	0.04	-17.18406	-130.651	22600*	Lower	Grande Ronde
Moscow 8	-0.07	-16.96150	-130.174	21100*	Lower	Grande Ronde
Moscow 9	0.01	-16.91863	-130.120	19100*	Lower	Grande Ronde
Mountain View Park (MVP)	0.16	-15.72067	-121.676	-	Upper	Sed. of Bovill/Wanapum
Palouse 1	0.04	-17.16743	-131.692	21900*	Lower	Grande Ronde
Palouse 3	-0.01	-17.45831	-132.495	26400*	Lower	Grande Ronde
Parker Farm	0.07	-15.71762	-119.526	-	Upper	Wanapum
Police Station	0.87	-15.28091	-118.928	7740	Upper	Wanapum
Pullman 3	0.34	-16.47613	-126.595	13000*	Lower	Grande Ronde
Pullman 5	0.67	-16.62798	-127.891	16300*	Lower	Grande Ronde
Pullman 6	0	-16.84095	-129.095	17100*	Lower	Grande Ronde
Pullman 7	-0.02	-16.74133	-127.973	16500*	Lower	Grande Ronde
Pullman 8	0.1	-16.61227	-127.363	-	Lower	Grande Ronde
UI 5	1.45	-14.91773	-114.119	3300*	Upper	Wanapum
UI 7	0.43	-15.50925	-118.377	-	Upper	Vantage
UI Arboretum	3.36	-14.60045	-111.865	-	Upper	Sed. of Bovill
UI3	0.01	-16.94157	-130.340	20500*	Lower	Grande Ronde

Table 2. *Sample isotopic characteristics and stratigraphic information.*

* *From Douglas, 2004.*

** *From City of Moscow, 2011.*

† *Tritium sampled at end of project, well not used in analysis.*

Well Name	Tritium (TU)	$\delta^{18}O$ (‰)	δD (‰)	^{14}C Uncorrected Age	Aquifer	Geologic Unit
UI4	0.02	-17.04283	-132.137	19700*	Lower	Grande Ronde
WSU 4	0.02	-16.84052	-129.005	-	Lower	Grande Ronde
WSU 6	0.08	-17.04387	-132.759	21100*	Lower	Grande Ronde
WSU 7	-0.01	-16.67871	-128.205	18000*	Lower	Grande Ronde
WSU 8	-0.03	-16.96247	-130.731	18400*	Lower	Grande Ronde
1990 Pavel	-	-14.83183	-112.382	-	Upper	Wanapum
2200 Polk	-	-15.28912	-115.377	-	Upper	Wanapum
2295 Polk	-	-14.64245	-112.138	-	Upper	Sed. of Bovill/Wanapum
2350 Trail	-	-15.62956	-119.774	-	Upper	Wanapum
2351 Orchard	-	-14.68936	-111.444	-	Upper	Sed. of Bovill
2485 Polk	-	-14.87032	-113.092	-	Upper	Wanapum
3240 MV	-	-15.19581	-115.255	-	Upper	Wanapum
568 Pavel	-	-15.32573	-115.900	-	Upper	Wanapum
B1	-	-14.75864	-113.823	-	Upper	Sed. of Bovill
B2	-	-14.69435	-113.478	-	Upper	Sed. of Bovill
Bovill 1	-	-14.32351	-109.609	-	Upper	Sed. of Bovill
Bovill 2	-	-13.07682	-107.163	-	Upper	Sed. of Bovill
Bovill 3	-	-14.48908	-111.718	-	Upper	Sed. of Bovill
Craig	-	-15.39213	-115.579	-	Upper	Wanapum
D19D	-	-15.23432	-116.413	-	Upper	Wanapum
Davis	-	-15.18996	-114.954	-	Granite	Granite
Frisbey	-	-15.41827	-116.306	-	Upper	Wanapum
Grauke	-	-15.33673	-115.940	-	Upper	Wanapum
GWFL 1	-	-14.83359	-114.006	-	Upper	Wanapum
GWFL 10	-	-14.37497	-110.473	-	Upper	Wanapum
GWFL 2	-	-14.71898	-112.784	-	Upper	Wanapum
GWFL 3	-	-14.68174	-112.075	-	Upper	Wanapum
GWFL 4	-	-14.15032	-110.171	-	Upper	Sed. of Bovill
GWFL 5	-	-14.26358	-108.414	-	Upper	Wanapum
GWFL 6	-	-13.79023	-110.171	-	Upper	Sed. of Bovill
GWFL 7	-	-13.66597	-108.000	-	Upper	Sed. of Bovill
GWFL 8	-	-14.54749	-110.632	-	Upper	Wanapum
GWFL 9	-	-14.22545	-111.506	-	Upper	Sed. of Bovill
Helbling	-	-15.36319	-116.177	-	Upper	Wanapum
INEL-D	-	-15.35333	-117.006	-	Upper	Wanapum
INEL-S	-	-14.65888	-112.305	-	Upper	Wanapum

Table 2 cont. *Sample isotopic characteristics and stratigraphic information.*
** From Douglas, 2004.*

Well Name	Tritium (TU)	$\delta^{18}O$ (‰)	δD (‰)	^{14}C Uncorrected Age	Aquifer	Geologic Unit
Inn	-	-14.87273	-112.642	-	Upper	Sed. of Bovill/Wanapum
J16D	-	-14.73354	-113.887	-	Upper	Wanapum
John Rubino	-	-14.91468	-114.056	-	Upper	Wanapum
Kizer	-	-15.79557	-119.541	-	Upper	Wanapum
Merrell	-	-15.15339	-115.555	-	Upper	Wanapum
P MW-1	-	-14.03518	-109.260	-	Upper	Sed. of Bovill
P MW-2	-	-14.22210	-109.925	-	Upper	Sed. of Bovill
P MW-3	-	-14.04671	-108.626	-	Upper	Sed. of Bovill
P MW-4	-	-14.46318	-110.833	-	Upper	Sed. of Bovill
P MW-5	-	-14.41814	-110.741	-	Upper	Sed. of Bovill
P MW-6	-	-14.40460	-110.879	-	Upper	Sed. of Bovill
P-A	-	-14.41594	-111.280	-	Upper	Sed. of Bovill
P-B	-	-14.49043	-111.095	-	Upper	Sed. of Bovill
P-C	-	-14.41442	-110.948	-	Upper	Sed. of Bovill
Q16D	-	-14.76147	-113.615	-	Upper	Wanapum
Q16D dupe	-	-14.63608	-113.190	-	Upper	Wanapum
S & B 1	-	-14.21316	-108.568	-	Upper	Wanapum
S & B 2	-	-14.62604	-111.505	-	Upper	Wanapum
SASa	-	-14.59691	-114.077	-	Upper	Sed. of Bovill
SASb	-	-14.96123	-115.987	-	Upper	Wanapum
T16D	-	-15.19084	-116.922	-	Upper	Wanapum
TS 1	-	-15.46372	-117.314	-	Upper	Wanapum
TS 2	-	-14.19958	-110.604	-	Upper	Sed Of Bovill
U3D	-	-14.81836	-113.791	-	Upper	Wanapum
UI 6	-	-15.48741	-118.011	-	Upper	Vantage
Wilson 1	-	-15.32387	-116.054	-	Upper	Wanapum
Wilson 2	-	-15.58763	-119.167	-	Upper	Wanapum
Wood	-	-15.59955	-118.236	-	Upper	Wanapum

Table 2 cont. *Sample isotopic characteristics and stratigraphic information.*

Tritium

Figure 20 shows the east-west positions of the tritium samples and their producing elevations. The land surface profile shown in the figure is only approximate, but is shown here strictly for reference purposes. Also displayed is the approximate boundary between the Upper and Lower Aquifers. Use of the Upper Aquifer as a water source diminishes to the west along with its thickness, so the boundary line is not continued much past the extent of Pullman, WA. Out of the 38 wells sampled for tritium, only 16 had concentrations above the detection limit. The figure illustrates that a clear demarcation does not exist between samples that have measureable amounts of tritium (positive for tritium) and those that do not (negative for tritium). This suggests that recharge is not uniform and that infiltrating water is following preferential pathways (possibly down certain boreholes). In addition, extensive clay content in sediments can cause the groundwater movement to be sluggish and create a local compartmentalization of the flow system and/or a lack of hydraulic connection between areas that is reflected in the spatial differences of isotope data, including $\delta^{18}O$, δD, ^{14}C and tritium (Chowdhury et al., 2008; Šilar, 1969).

Depth below ground surface, even more so than elevation, seems to have an impact on where tritium is found. This is also illustrated in Figures Figure 21 and Figure 22. The majority of the wells that do contain tritium are located either in the Upper Aquifer, or in the upper part of the Lower Aquifer. However, there are exceptions. Several wells in the Moscow area (most notably IDWR 1, Brandt, and Miller) are positioned in the Upper Aquifer and do not have measurable tritium while nearby wells at similar depths do. This relationship has also been observed in other studies, such as that by Bassett et al. (2008). They found their raw tritium data inconclusive due to the inconsistent scatter of tritium concentrations with well depth; some deep wells had measureable amounts of tritium while some of the shallow ones did not. Measurable tritium levels in the deep wells were attributed to well design such that the sample water consisted of water from both the lower and upper aquifers. The values obtained from those wells therefore were not representative of the actual water composition from the deep aquifer. Shallow wells with no tritium were thought to be groundwater discharge areas where deeper water devoid of tritium was being forced to the surface, possibly by a geologic barrier. The depths of the sampled wells in the Palouse Basin are more apparent in Figure 21.

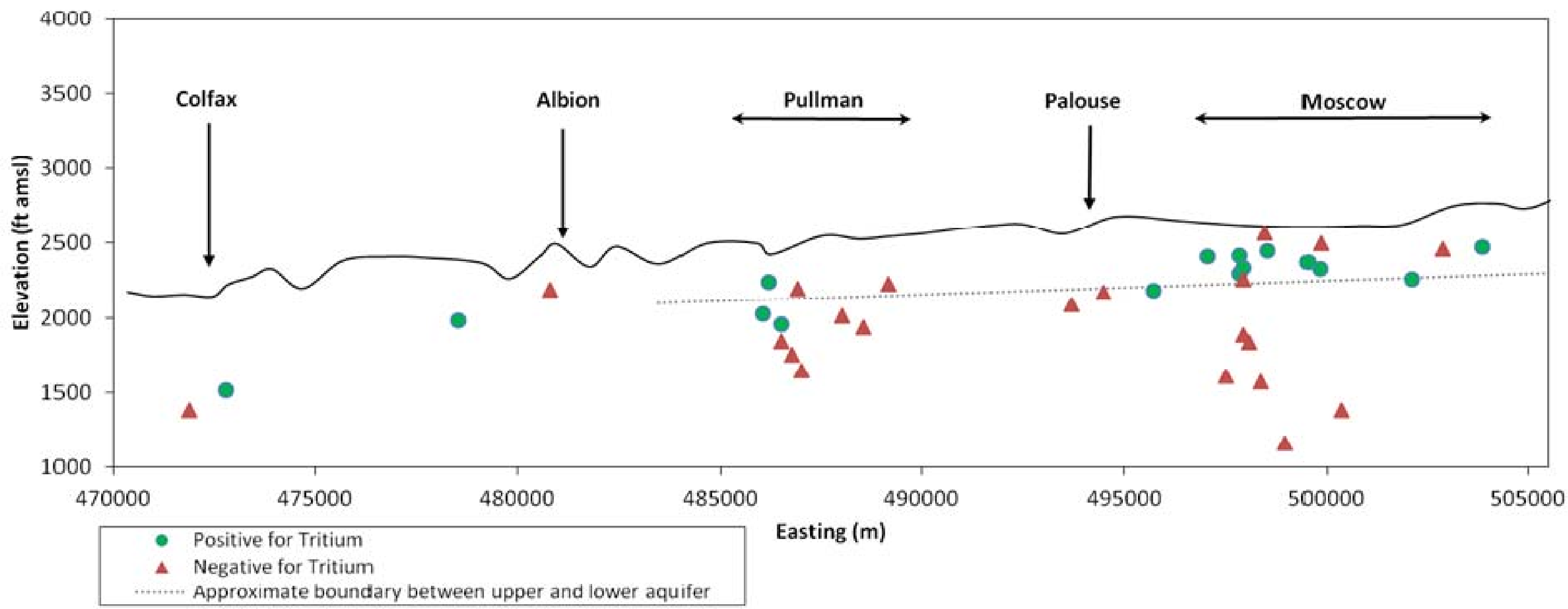


Figure 20. *Relative position of tritium samples based on elevation and Easting. Samples labeled as positive for tritium have measured concentrations above the detection limit (i.e. ≥0.1 TU); samples labeled as negative for tritium have measured concentrations below the detection limit. Land surface elevation is not accurate, but is shown here as a reference. In addition, the approximate boundary between the upper and lower aquifer is displayed.*

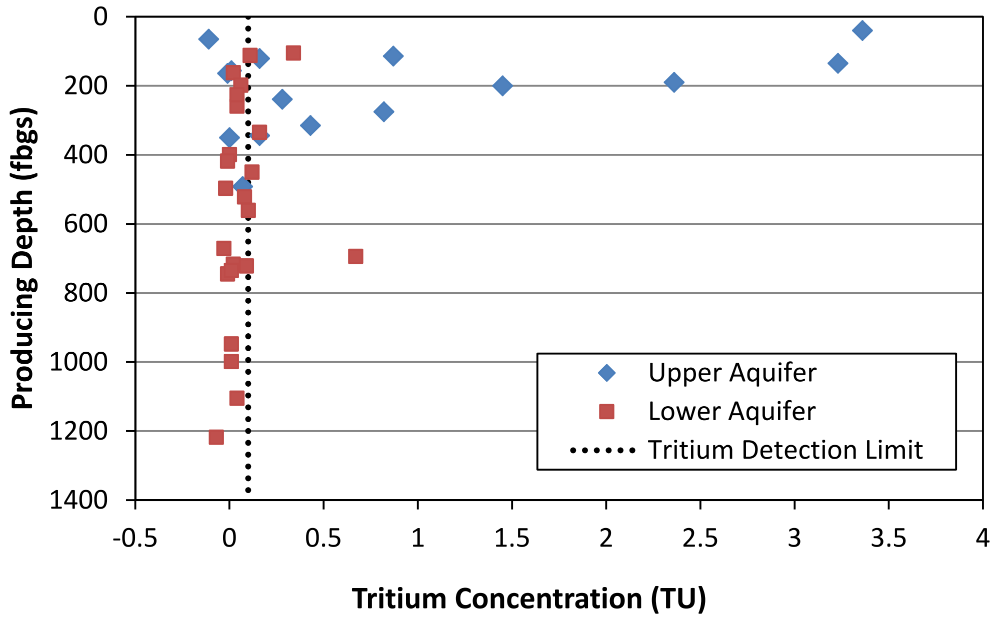


Figure 21. *Sample tritium concentrations as a function of producing depth (feet below ground surface).*

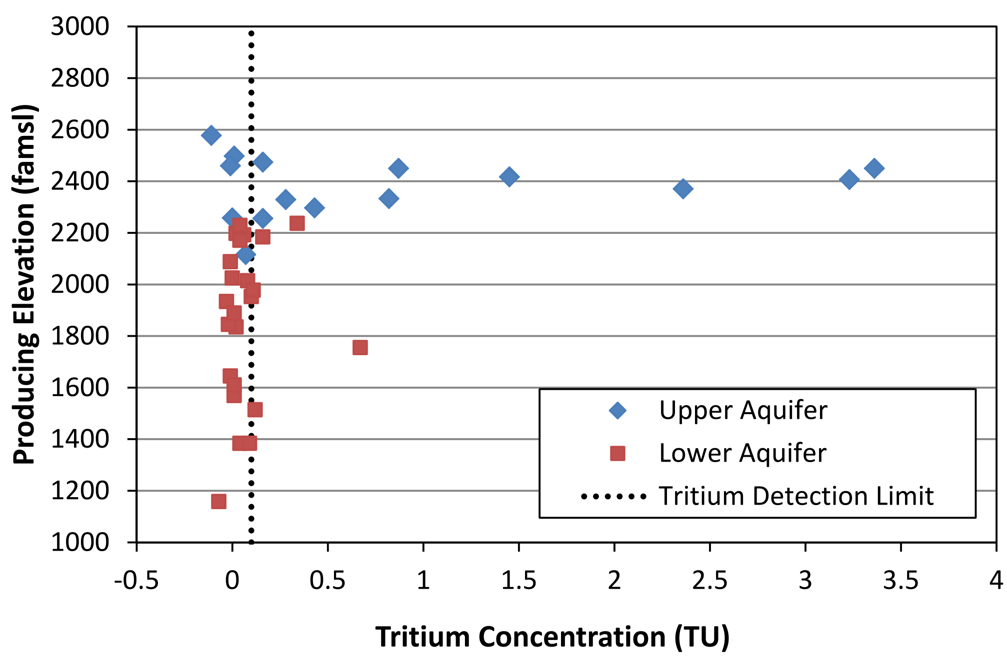


Figure 22. *Sample tritium concentration as a function of producing elevation (feet above mean sea level).*

Conspicuous deep wells that have measureable amounts of tritium in their samples include Pullman 5, Pullman 8, and Clay Street. All three of these well are over 400 ft deep. Well logs for the construction of these wells in question (Appendix C) show that the topmost part of the open intervals in the wells start at 672, 327, and 300 fbgs, respectively. Therefore, even though the plotted producing depths may be deeper than the start of the screened intervals in the wells (producing depths and elevations are taken as the average of the open interval), tritiated water is nonetheless attaining depths of at least 300 fbgs. In the vicinity of Pullman 5, tritium is detected at depths of at least 672 fbgs. Assuming that adequate borehole seals exist in these wells, the well construction details suggest that all of the water in the samples is derived from the Lower Aquifer and not from Upper Aquifer contributions.

Pullman 5, Pullman 8, and Clay Street are the deepest wells in the Basin that tested positive for tritium, and all of them are located in the western part of the basin. It is possible that recharge is making it down to greater depths in the western part of the basin due to the reduced influence of sediments such as the Vantage and Sediments of Bovill as suggested by Crosby and Chatters (1965). The clay content in these units poses a potential barrier to infiltration and groundwater flow. The well location in relation to creeks and floodplains appears as if it is also an important factor. Timing for this recharge to reach these depths is within about 60 years. After this, the tritium in any water sample would have decayed past the detection limit. In addition, recharge must be reaching these depths in sufficient volumes to overcome the effects of dilution from mixing.

The resolution of the various forms of groundwater dating is reduced by dispersion and diffusion effects. In addition, mixtures of different waters can further induce changes in $\delta^{18}O$, δD, ^{14}C, and tritium values (Fernandes and Carreira, 2008; O'Driscoll et al., 2005). Therefore, it is important to consider the effect that mixing would have on isotopic signatures, especially on the apparent ^{14}C age dates and tritium concentrations. Mixing in groundwater of the Palouse Basin is evident from the presence of tritium in samples with age dates much older than 60 years (Table 2, Figure 23). The blend of waters from different ages yields ^{14}C ages and tritium values that are not consistent with either the most recent component of groundwater or the oldest. It is likely that the oldest water in the mixture is even older than the age dates suggest, but has been diluted by newer water.

Similarly, older water devoid of tritium can dilute the modern component and result in a lower overall tritium concentration for that sample. In some cases, the dilution could be to a degree to produce a negative tritium reading (or false nondetect) even though there is still a modern component of recharge in the sample.

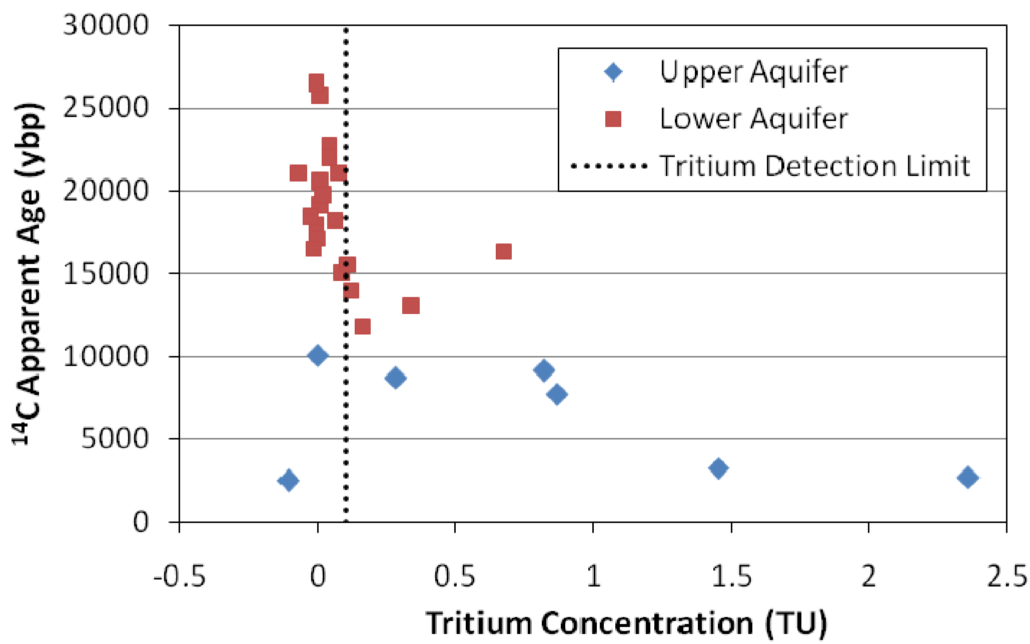


Figure 23. *Sample tritium concentration vs.* ^{14}*C apparent age (years before present).*

A slight correlation exists between ^{14}C apparent age dates and tritium concentration (Figure 23). All of the samples with measurable tritium have age dates younger than 16,300 ybp. Additionally, the higher tritium concentrations tend to have younger ^{14}C ages than those with less measurable tritium. Exceptions to this could be areas of discharge (groundwater flow from older, deeper water, to shallower depths) or mixtures of water containing proportionally greater percentages of older water.

Tritium concentrations in the atmosphere have not remained constant, so the input signature for water entering the aquifer system(s) varies year to year. Figure 24 shows the initial atmospheric signature for various years and the decay of that signature to the present day. Tritium in groundwater behaves conservatively, so once in the sub-surface, the initial tritium signature from the atmosphere will decay exponentially. Historic atmospheric data in the vicinity of the Palouse Basin are not available. Because tritium concentrations in the atmosphere vary with both distance from the equator, and distance from the ocean, data from Ottawa, Canada have been chosen for comparison. This is due to Ottawa's similarity in latitude and continentality, as well as for the completeness of the data record. The data comes from the International Atomic Energy Agency and World Meteorological Organization and includes monthly measurements of tritium in the atmosphere from 1953 to 2007 (IAEA/WMO, 2011). Monthly values were averaged to provide a mean value for each year. Values were also extrapolated from the end of the IAEA/WMO record to an estimated present day atmospheric concentration of 10 TU (Happle, 2010). To avoid confusion, only selected years were plotted in Figure 24 to show the range of possible input signatures over the past 56 years. The complete data record can be viewed in Figure 16.

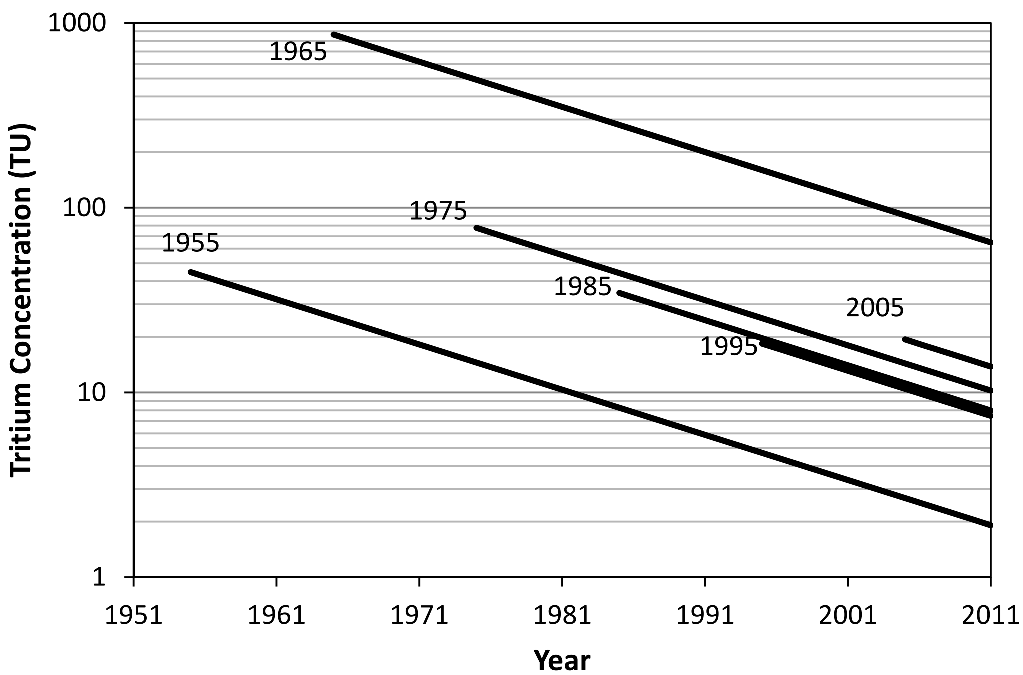


Figure 24. *Atmospheric tritium signatures from Ottawa, Canada, and exponential decay once water has entered the sub-surface.*

Simple dilution equations can demonstrate the effects of mixing on a tritium signature in groundwater. Table 3 shows possible dilution factors for each sampled well that contains measurable amounts of tritium based off of the decayed input tritium signal for select years. Because year-to-year recharge volumes are unknown, the dilution factor for each selected year accounts only for recharge from that year (i.e. the dilution factor does not take the effects of dilution of previous year's recharge into account). The dilution factors were calculated by dividing the decayed input signature for each year by the measured tritium concentration in each sample. The decayed input signature represents what the current value is for water recharged in a given year after it has experienced exponential decay in the sub-surface. The resulting dilution factor provides an example of how much water for a given year might be incorporated in a sample devoid of tritium (i.e. older mixed water) and still be able to yield the observed sampled value. For example, if all of the modern water component in the Appaloosa well sample was recharged exclusively in 1975, that water would have a tritium signature of 10.24 TU today. This recharge can be diluted 19.82 times (one part 1975 water to 19.82 parts older water free from tritium), and the resulting mixture will still give a sample tritium concentration of 3.23 TU as measured in 2011.

	Year	1955	1960	1965	1975	1985	1995	2005	2010
	TU in 2011	1.91	8.31	64.87	10.24	7.99	7.47	13.81	11.26
Well	TU								
Appaloosa	3.23	3.70	16.08	125.52	19.82	15.46	14.45	26.73	21.78
Bond	2.36	5.06	22.01	171.79	27.12	21.15	19.78	36.59	29.81
Champ. Elec.	0.16	74.70	324.60	2533.90	400.09	312.03	291.70	539.65	439.70
Claystreet	0.12	99.60	432.80	3378.53	533.45	416.05	388.93	719.53	586.27
Glenwood 1	0.11	108.65	472.15	3685.67	581.95	453.87	424.29	784.94	639.57
Gregory's	0.16	74.70	324.60	2533.90	400.09	312.03	291.70	539.65	439.70
IDWR 2	0.82	14.58	63.34	494.42	78.07	60.88	56.92	105.30	85.80
Moscow 2	0.28	11.95	51.94	405.42	64.01	49.93	46.67	86.34	70.35
Mt. View Park	0.16	74.70	324.60	2533.90	400.09	312.03	291.70	539.65	439.70
Police Station	0.87	13.74	59.70	466.00	73.58	57.39	53.65	99.25	80.87
Pullman 3	0.34	35.15	152.75	1192.42	188.28	146.84	137.27	253.95	206.92
Pullman 5	0.67	17.84	77.52	605.11	95.54	74.52	69.66	128.87	105.00
Pullman 8	0.1	119.52	519.36	4054.24	640.14	499.25	466.72	863.44	703.53
UI 5	1.45	8.24	35.82	279.60	44.15	34.43	32.19	59.55	48.52
UI 7	0.43	27.79	120.78	942.85	148.87	116.11	108.54	200.80	163.61
UI Arboretum	3.36	3.56	15.46	120.66	19.05	14.86	13.89	25.70	20.94

Table 3. *Example dilution factors in sampled wells based on original input signatures for specific years.*

Another way of looking at the possible mixing scenarios is by transforming the dilution factors into percentages that represent the theoretical amount of tritiated water in a sample for a given year:

$$\text{Modern Percentage of Sample} = \frac{1}{(\text{Dilution Factor} + 1)} \times 100$$

A few example percentages are provided in Table 4. Looking at this equation in terms of the Appaloosa well example above, one unit of water recharged in 1975 was able to be diluted 19.82 times and still give the measured value seen in that sample. This means that the sample itself potentially contains 20.82 units of water (19.82 parts old water, and one part "new" water). By dividing the modern component of water (1 unit, composed solely of 1975 recharge) by the total volume of water (20.82 units, or the dilution factor plus one), a modern percentage of the sample is obtained. In this case, if the modern component of recharge represents only water that entered the system in 1975, the sample component containing tritium comprises roughly 24% of the Appaloosa sample. The other 76% therefore contains older water that has no tritium and has diluted the "real" tritium signature from the recharged water. Although these values are unrealistic considering that recharge is likely to occur in previous years as well, and not just the year specified in the table, they are able to illustrate how mixing of waters can affect the tritium results in a sample. The higher the input tritium signature of recharging water, the more it can be diluted and still produce the observed sample concentration. As an example, if all modern recharge in a sample occurred in 1964 or 1965 around the atmospheric tritium peak, it could represent only a small fraction of the sample.

In some cases, it might be feasible that these low percentages could be accounted for by well borehole leakage from the surface or shallower depths. However, if the recharge came from a different year with a lower initial tritium value, its contribution in a sample could be very substantial. This is especially true in high-yield production wells such as municipal wells that pump large volumes of water. Water is drawn from further distances, so it is less likely that borehole leakage would account for all of the tritiated water in the well. For example, Pullman 5 is a municipal well that typically pumps at 1683 gpm. If all of the modern component of water was recharged in 1965 around the tritium peak, it would still represent about 17.2 gpm of the total water being pumped. This is a considerable amount of water considering that the well typically pumps for several hours per day. If the water were recharged before the tritium peak at, this contribution would rise to over 415 gpm. Averaged contribution percentages were not included because recharge varies from year to year and it is impossible to know the exact weighting of all of the input tritium signatures combined. Instead, a range of potential percentages should be considered for each sample.

	Year	1955	1960	1965	1968	1975	1985	1995	2005	2010
	TU in 2011	1.91	8.31	64.87	18.77	10.24	7.99	7.47	13.81	11.26
Well	**TU**									
Appaloosa	3.23	62.81	27.99	4.74	1.47	23.98	28.79	30.19	18.95	22.30
Bond	2.36	55.24	22.12	3.51	0.24	18.73	22.81	24.01	14.59	17.33
Champ. Elec.	0.16	7.72	1.89	0.25	1.78	1.54	1.96	2.10	1.14	1.40
Claystreet	0.12	5.90	1.42	0.18	0.58	1.16	1.48	1.58	0.86	1.05
Glenwood 1	0.11	5.44	1.31	0.17	15.18	1.06	1.36	1.45	0.79	0.97
Gregory's	0.16	7.72	1.89	0.25	14.78	1.54	1.96	2.10	1.14	1.40
IDWR 2	0.82	30.01	8.98	1.25	0.84	7.41	9.31	9.89	5.60	6.79
Moscow 2	0.28	12.77	3.26	0.43	7.17	2.66	3.39	3.61	1.99	2.43
Mt. View Park	0.16	7.72	1.89	0.25	2.24	1.54	1.96	2.10	1.14	1.40
Police Station	0.87	31.27	9.48	1.32	0.84	7.83	9.82	10.43	5.92	7.17
Pullman 3	0.34	15.10	3.93	0.52	4.18	3.21	4.08	4.35	2.40	2.93
Pullman 5	0.67	25.95	7.46	1.02	3.44	6.14	7.74	8.23	4.63	5.62
Pullman 8	0.1	4.97	1.19	0.15	0.53	0.97	1.24	1.32	0.72	0.88
UI 5	1.45	43.13	14.86	2.19	0.64	12.40	15.36	16.26	9.50	11.41
UI 7	0.43	18.36	4.92	0.66	4.43	4.03	5.11	5.44	3.02	3.68
UI Arboretum	3.36	63.73	28.79	4.92	11.17	24.70	29.61	31.03	19.56	22.99

Table 4. *Modern component of recharge for well samples given as a percentage of the total sample for a given year.*

The same principles illustrated above can be useful in looking at the remaining samples that contain no measurable amounts of tritium. Table 5 contains minimum dilution factors and maximum percentages of modern water in a given sample for selected years. These values are applicable to all of the wells that tested negative for tritium and represent how much modern recharge potentially could be in a sample without the overall tritium concentration surpassing the detection limit of 0.1 TU. From these values, it is clear that even if a sample comes back as negative for tritium, a small component of young water could still be present, but obscured by dilution.

It should be noted that because there is a relatively uniform downward gradient from the Upper Aquifer to the Lower Aquifer, any leaky borehole will allow shallow water to move persistently down the borehole, causing it to act as an injection well. This is especially true for non-pumping wells like the Bond well (190 ft deep). Shallow water could have potentially been leaking down the borehole, and, after many years, created a "plume" of tritiated water. Even after purging, the well sample could still primarily consist of water from this plume. Conversely, pumping wells should be less affected by leakage than non-pumping wells because the water is continually evacuated. Exceptions to this would include wells that have properly designed seals to prevent downward flow in boreholes (such as the IDWR wells).

It is evident from the tritium results, as well as from ^{14}C apparent ages, that a straightforward interpretation of isotopic age results is impractical and will in all probability lead to false conclusions. In assuming that the results represent a kinematic age alone (the piston flow age of a water based on its travel time through and aquifer), mixing and dilution are unable to be accounted for (Varni and Carrera, 1998; Goode, 1996). In addition, an area that exhibits local and regional groundwater flow paths is also likely to have groundwater that consists of a mixture of water with various transit times arising from the corresponding flow-line lengths (Etcheverry and Perrochet, 2000). Varni and Carrera (1998) therefore describe age measurements as the result of some sort of averaging of the age distributions in any one water sample. Determining the contributions of each age distribution is a challenge. To complicate matters, the contributions of older water trapped in pore spaces and/or aquitards can significantly affect apparent groundwater age, even in small quantities (Bethke and Johnson, 2002). Consequently, the overall local groundwater age in an aquifer consists of both the kinematic age as well as the addition of older/newer water from neighboring aquitards/aquifers.

Year	1955	1960	1965	1975	1985	1995	2005	2010
TU in 2011	1.91	8.31	64.87	10.24	7.99	7.47	13.81	11.26
Dilution Factor	19.12	83.11	648.74	102.43	79.89	74.68	138.16	112.58
Maximum Percentage of Sample	4.969	1.189	0.154	0.967	1.236	1.321	0.719	0.880

Table 5. *Minimum dilution factors and maximum sample percentages of modern recharge for a given year in wells without measurable amounts of tritium. The values represent possible mixtures of water that result in a sample concentration of less than 0.1 TU.*

Many of the samples in the Palouse Basin have ^{14}C age dates of thousands of years before the present. Evidence of mixing from the presence of tritium in some of these samples suggests that the oldest component of water may be even older than the calculated age date. Such large residence times are often the product of depth and/or compartment-alization (Adkins and Bartolino, 2010). Crosby and Chatters (1965), Larson (1997), and Douglas (2004) all came to the conclusion that groundwater age in the Palouse Basin generally increases with depth. However, while the older water contribution may increase with increasing depth, it is not necessarily devoid of the presence of modern recharge.

Oxygen-18

Because a known relationship exists between $\delta^{18}O$ and δD, both of the values do not necessarily need to be considered apart from defining a local meteoric water line. Traditionally, it is the $\delta^{18}O$ that is the focus between the two. Therefore, in this study, the $\delta^{18}O$ values were utilized instead of δD for the various graphs and simulations, as keeping with that tradition. Figure 25 shows the groundwater samples plotted against the local meteoric water line (LMWL) constructed by Sánchez-Murillo et al. (2011) and the global meteoric water line(GMWL) (Kehew, 2001). The data fit the LMWL well and do not exhibit any evaporation trend, except in the three samples with the highest $\delta^{18}O$: Bovill 2, GWFL 6, and GWFL 7. These wells are shallow and in close proximity to Paradise Creek, so the signatures seen here are most likely reflective of the creek's contribution to the groundwater in the area. Surface water, such as that from Paradise Creek, is characteristically enriched in $\delta^{18}O$ due to the evaporation it experiences at land surface. Data from the Upper Aquifer and Lower Aquifer separate out into two distinct groups. Those from the Upper Aquifer have $\delta^{18}O$ values ranging from -13.08‰ to -15.92‰. $\delta^{18}O$ values in the Lower Aquifer range from -15.94‰ to -17.46‰. When overlapped $\delta^{18}O$ and δD signatures are observed between samples in different aquifers, it is often attributable to the similarity of the source water for both of the aquifers (Bassett et al., 2008). The clear-cut separation of the $\delta^{18}O$ and δD signatures in this data set implies that the water in the different aquifers could very well have come from different sources and/or entered the system in different ways or times.

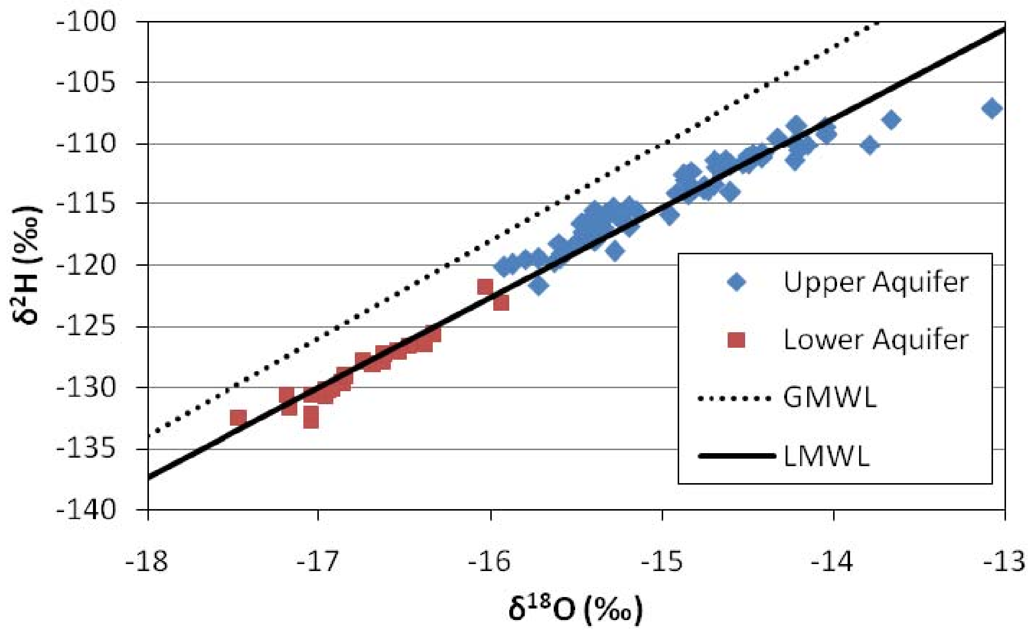


Figure 25. *Stable isotope ratios of groundwater samples in relation to the Global Meteoric Water Line (GMWL) and the Local Meteoric Water Line (LMWL). GMWL: $\delta^2H=8\delta^{18}O+10$ (Kehew, 2001). LMWL: $\delta^2H=7.365\delta^{18}O-4.878$ (Sánchez-Murillo et al., 2011).*

$\delta^{18}O$ values in profile decrease overall with increasing depth (Figure 26 and Figure 27). The strongest correlation between $\delta^{18}O$ and depth is seen in the Upper Aquifer. As sample depths and elevations decrease, the data points start to scatter. This scatter is most likely a product of homogenization, but could also be due to imprecise plotting of the producing depths and elevations. Samples from the Upper Aquifer also show nearly twice the amount of variation in $\delta^{18}O$ values (2.84‰) despite having a narrower range of depth, as compared to samples in the Lower Aquifer (1.52‰). This is an additional result from the effects of dispersion and diffusion on the isotopic signature of infiltrating water. Groundwater in the Upper Aquifer is able to retain some of the seasonality in the recharging water while deeper water signatures become smoothed.

Figure 28 shows the relationship between measured tritium in a sample and the $\delta^{18}O$ signature. As $\delta^{18}O$ values increase, the probability of finding tritium in that sample also increases. No tritium is observed in any sample that has a $\delta^{18}O$ value less than -16.63 and the majority of samples with measureable amounts of tritium have $\delta^{18}O$ signatures greater than -15.94‰.

Samples that have relatively high $\delta^{18}O$ values and do not contain any measurable amounts of tritium include IDWR 1, Miller, and Brandt. If water were being forced to lower depths by a geological barrier in these locations, it would be likely that the samples would also have depleted $\delta^{18}O$ signatures. Since the $\delta^{18}O$ values do not seem depleted relative to the producing depth and/or elevation of the well, it is more likely that the observed concentrations of both $\delta^{18}O$ and tritium are being affected by the local geology. These wells could be located within discontinuous layers of clay or in areas that have high clay content. The low hydraulic conductivity of the clay would impede groundwater flow and infiltration, which may contribute to an older apparent age in a sample. In addition, the high porosity but low permeability of clay allows water molecules to become entrapped in the pore spaces, and to affect isotopic signatures.

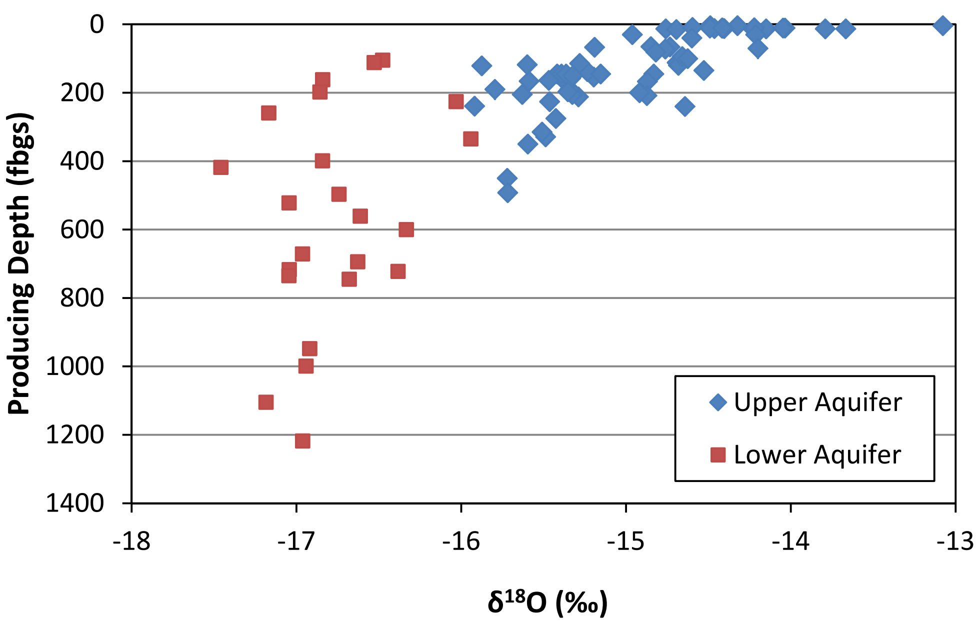


Figure 26. *$\delta^{18}O$ values as a function of producing depth (feet below ground surface).*

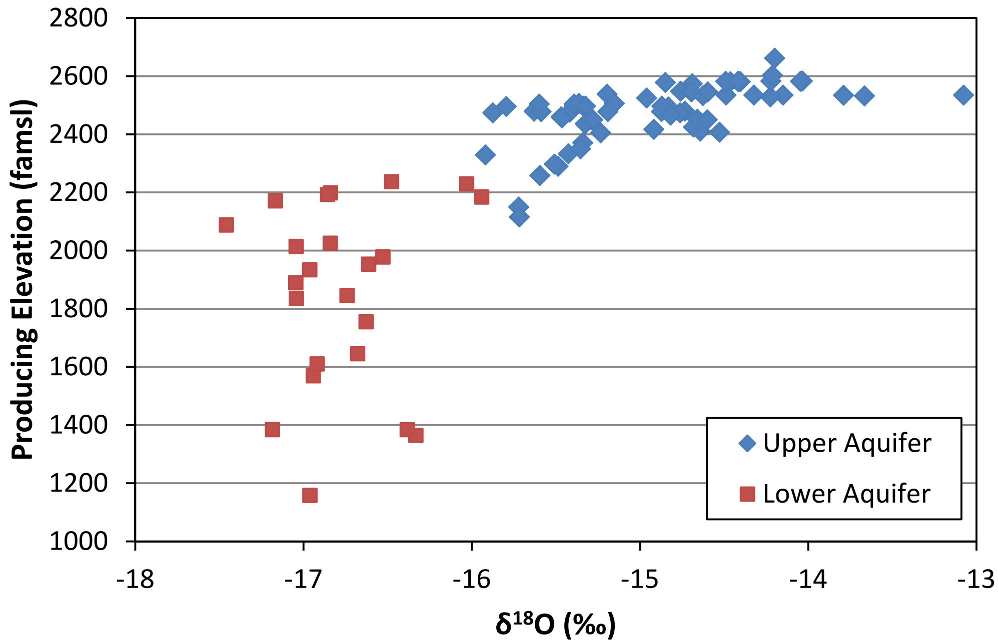


Figure 27. *$\delta^{18}O$ values as a function of producing elevation (feet above mean sea level).*

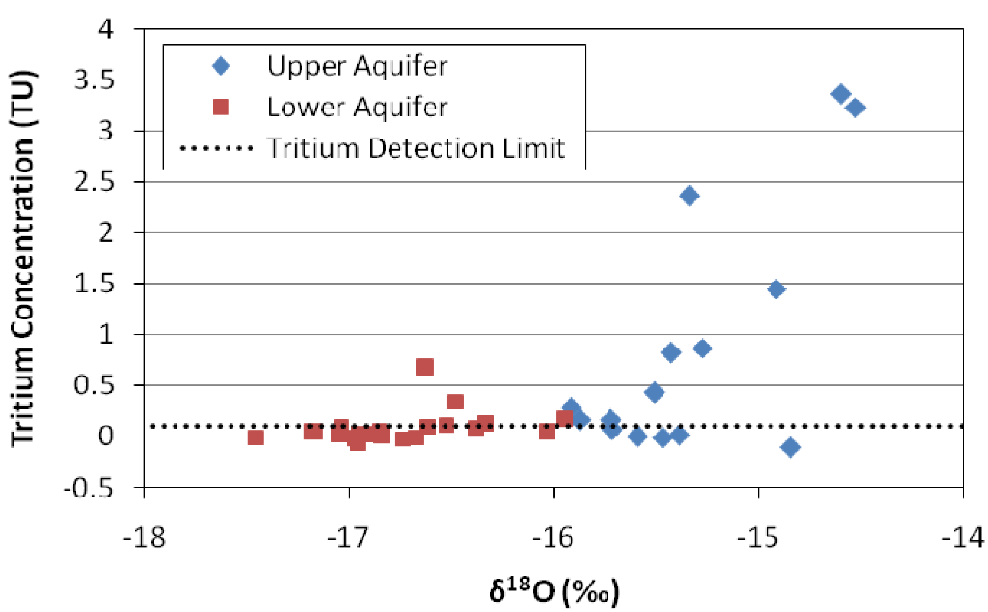


Figure 28. *$\delta^{18}O$ as a function of tritium concentration.*

A potentially useful relationship that revealed itself in the data is that between $\delta^{18}O$ and ^{14}C apparent age (Figure 29). All of the ^{14}C ages used in this graph, except for the seven wells sampled during this study (Appendix B), came from Douglas (2004); all of the $\delta^{18}O$ values represent samples collected during this study. The strong correlation exhibited by the two values in this data set presents a way to use $\delta^{18}O$ values to estimate the apparent age of well water for a very small fraction of the cost of actually analyzing the ^{14}C content. Upon expanding the data set to include additional $\delta^{18}O$ values from previous studies as well (Larson, 1997; Douglas, 2004), the fit of the trend line decreases by almost half (Figure 30). The main spread in Figure 30 largely consists of $\delta^{18}O$ data points from Douglas (2004). Such large differences in sampling results between studies may be an artifact of different laboratory measurement procedures. It is unclear how or if Douglas' data were calibrated, and if they were, what standards were used for the data correction. In consequence of the uncertain compatibility between data sets, it is still possible that a positive relationship between $\delta^{18}O$ and ^{14}C apparent age exists. If so, this would be a valuable resource to employ in future research.

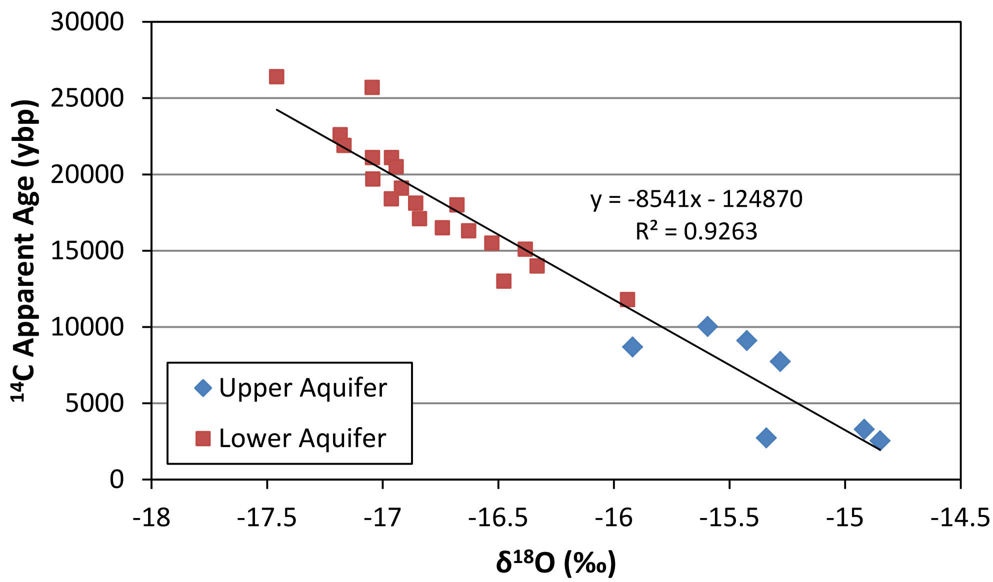


Figure 29. *$\delta^{18}O$ as a function of ^{14}C apparent age.*

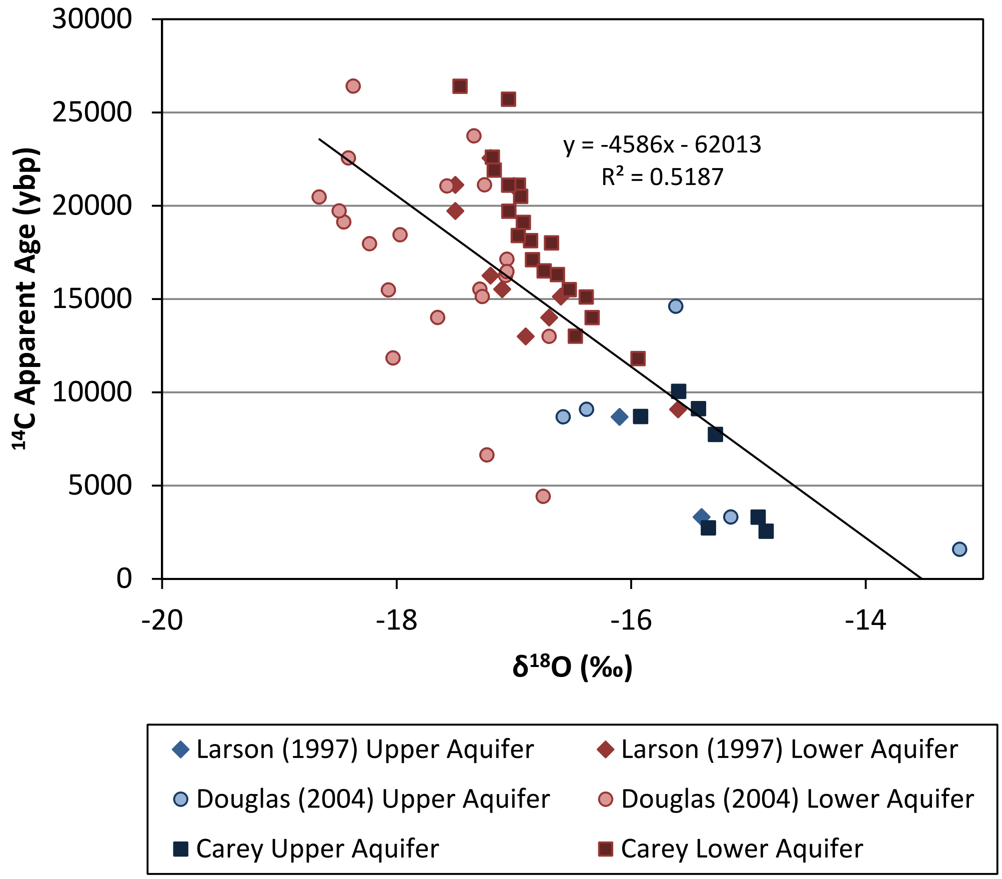


Figure 30. *Expanded data set of $\delta^{18}O$ as a function of ^{14}C apparent ages.*

The significant depletion of $\delta^{18}O$ concentrations in the Lower Aquifer indicates that the majority of this water experienced much different environmental factors and overall evolution and than that in the Upper Aquifer. As proposed by Crosby and Chatters (1965), Larson (1997), and Douglas (2004), the lower signatures seen at greater depths in the Palouse Basin is a result of recharge originating from the colder and wetter conditions present during the last Ice Age. While this water is Pleistocene in age, it did not necessarily take that long to reach its current position. Modern infiltration rates in the Basin are not able to characterize past infiltration rates since groundwater flow changes noticeably as a function of paleoclimate (Schwartz et al., 2010). During glacial advances, cold and wet conditions encourage infiltration due to the relative abundance of water from precipitation and areas of standing water. This causes water table levels to rise, and Schwartz et al. (2010) estimate recharge to be at least an order of magnitude greater during glacial maximums. Depending on the aquifer's time constant, the system may still be in a state of transition from the difference in infiltration rates experienced over the period of thousands of years. Domenico and Schwartz (1998) define an aquifer's time constant (τ_c) as:

$$\tau_c = \frac{S \cdot L_T^2}{T}$$

where S is the storativity (in a confined aquifer) or specific yield (in an unconfined aquifer), L_T is the aquifer length, and T is the transmissivity. It represents how long it takes an aquifer to reach a new equilibrium after a hydraulic perturbation. Large basin time constants (typical of large-scale flow systems) mean that the hydraulic heads at one location may be reflecting past conditions, while those at a different location may be reflecting present day conditions (Schwartz et al., 2010). It is difficult to explain the patterns in flow of a system without a model that can take these historical transients of recharge into account (i.e. decreasing rates of recharge over the past 20,000 years or so). The steady-state view is reasonable for short periods of time (i.e. decades), but not for the length of time observed in the ^{14}C age dates (Schwartz et al., 2010). The isotopic data (including $\delta^{18}O$, tritium, and ^{14}C concentrations) therefore represents an important tool that can be used as constraints for flow and transport model parameters (Goode, 1996). Proper calibration of groundwater models and interpretation of groundwater ages are both interdependent since both crucially depend on the correct identification of the nature of an aquifer (Fernandes and Carreira, 2008).

Geostatistical Modeling of Oxygen-18

Geostatistical mapping of the data was done with the intent of illustrating spatial patterns and possible relationships to physical features in the area. In particular, simulated annealing was employed to help preserve and highlight the local variations in $\delta^{18}O$ signatures. Mapped samples were limited to the area covered by the Sediments of Bovill (i.e. the Moscow area) not only to ensure concentrated sampling capable of showing sufficient detail, but also because of the suggested importance of the Sediments of Bovill to recharge. In addition, samples are restricted to the upper aquifer to eliminate the complications of dealing with a third dimension. The simulated and mapped area is shown in Figure 31. Figure 32 shows the omnidirectional variogram of the $\delta^{18}O$ data. The formula for the model can be represented by the equation: 0.1 + 0.229 sph(625), where 0.1

is the nugget, 0.229 is the scale (or distance from the nugget to the sill), "sph" stands for a spherical model, and 625 is the range of influence, in meters. When directional windows were tested for the variograms, the number of data points in each lag bin became insufficient. In addition, there was not a clear maximum or minimum range of influence. Therefore, the omnidirectional variogram model is incorporated in the simulations.

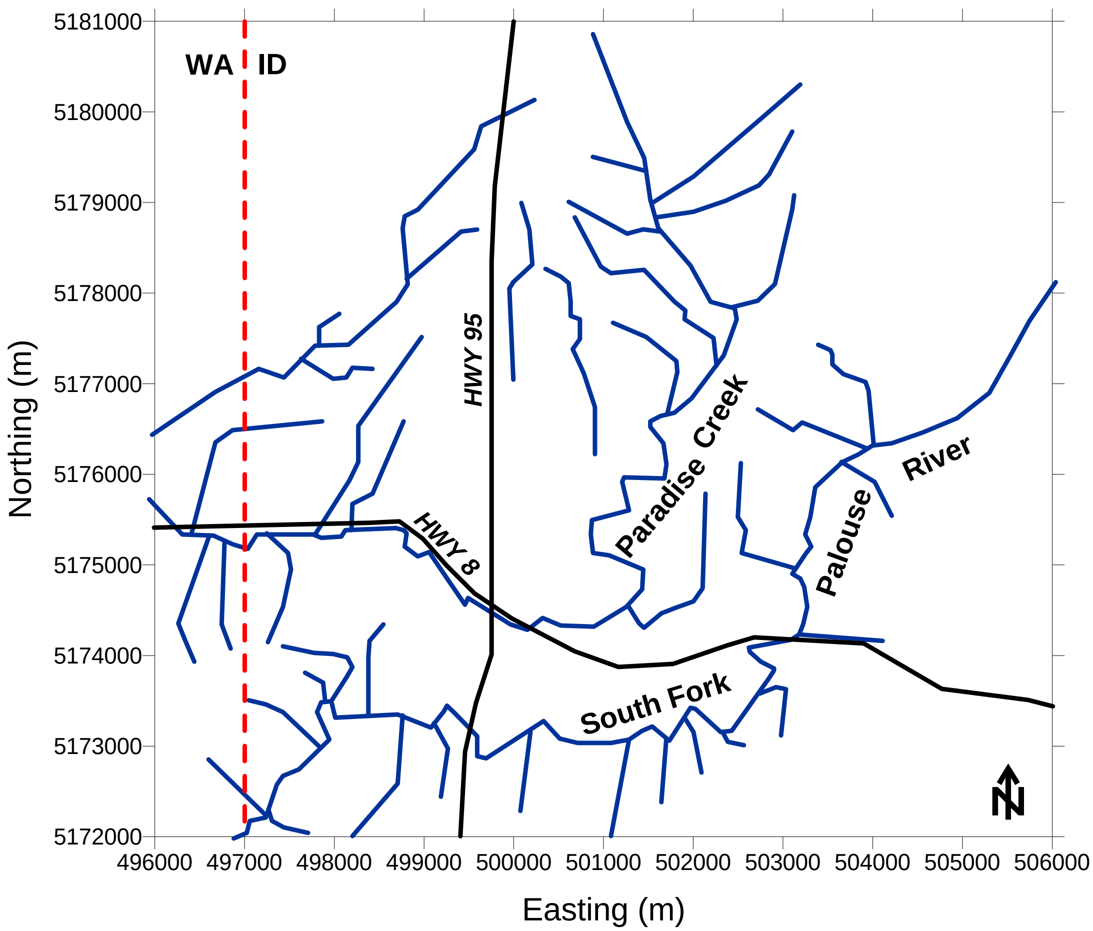


Figure 31. *Location map for simulated and kriged images.*

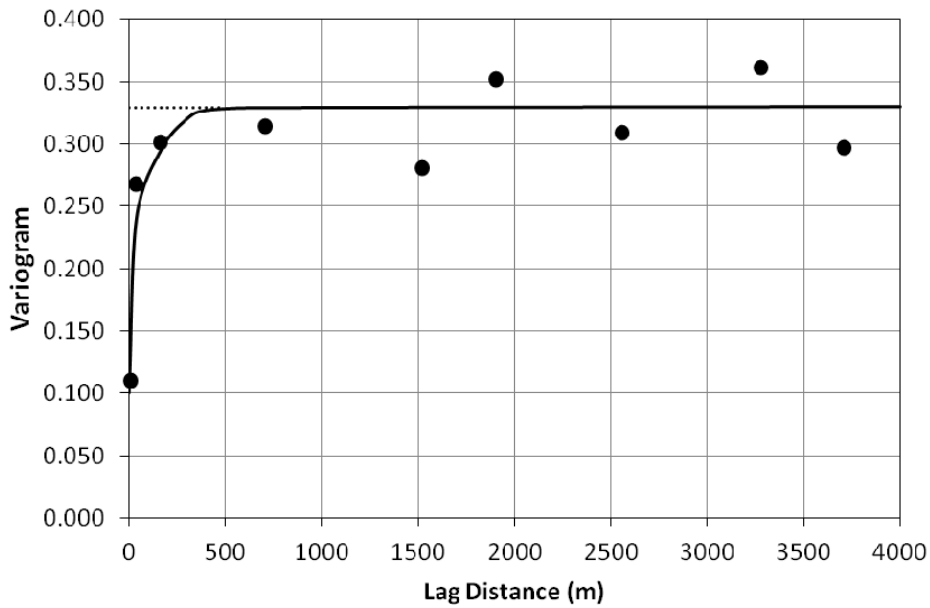


Figure 32. *Isotropic variogram model for $\delta^{18}O$ values in the Upper Aquifer and in the vicinity of Moscow, ID: 0.1+ 0.229 sph(625).*

Over 100 simulations were run using the GSLIB program *sasim*. An outline of the simulation procedure is provided in Appendix A. After trying various gridding techniques, kriging was chosen because of its ability to display the apparent pattern in the data by smoothing between simulated nodes. All of the simulated annealing output images showed a mottled distribution of $\delta^{18}O$ values. In places, similar values joined together to create a banded appearance. Major creeks and drainages were therefore overlaid on the images to ascertain whether the banded patterns corresponded to creek locations. Since all simulations are equally probable, one representative simulation with creek locations is presented in Figure 33. A probability map was also constructed from the results of 100 simulations (Figure 34), which represents the probability that a $\delta^{18}O$ value will exceed a given threshold value. A threshold of -15‰ was chosen after trial-and-error evaluations with the typical range of $\delta^{18}O$ signatures seen in the simulations. It signifies a good cut-off value between the higher and lower $\delta^{18}O$ signatures seen in the Upper Aquifer. The probabilities tended to be around 50%, indicating that there may be a certain randomness to the distribution of $\delta^{18}O$ values in the simulations. However, the probability map does show areas that more consistently include $\delta^{18}O$ concentrations that are higher or lower than -15‰. Overall, the simulations give one interpretation of the general pattern of $\delta^{18}O$ signatures in the Upper Aquifer. While the location of relatively higher or lower values may have quite a bit of variability to it, all of the simulations show that these locations are very mottled and preferential.

No east-west geographic trends in the $\delta^{18}O$ data were observed in any of the simulated images. This implies that if water is recharging from the mountain front in the eastern part of the basin, it is either 1) not showing up in $\delta^{18}O$ values, 2) not influential on groundwater in the Upper Aquifer, 3) following preferential pathways off the mountain front which appear as bands of similar $\delta^{18}O$ signatures in the simulated images, or 4) is not a major recharge mechanism.

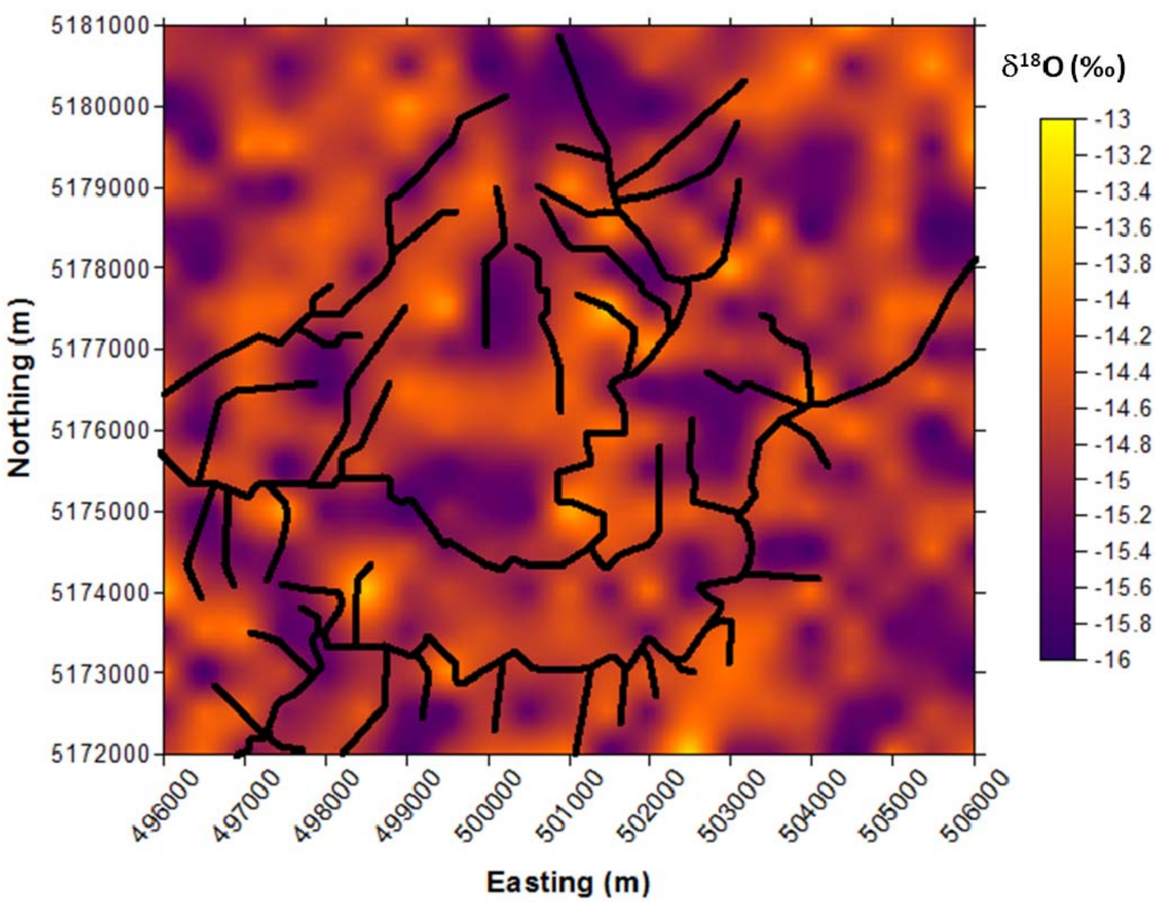


Figure 33. *Example simulated annealing image of $\delta^{18}O$ values. Black lines represent local creeks and drainages.*

It was seen previously that δ^{18}O values may have a close relationship to the apparent age of a water sample (Figure 29). Therefore, areas simulated with lower δ^{18}O concentrations (i.e., less negative) possibly represent areas of younger groundwater, or areas where a greater percentage of modern recharge is entering the Upper Aquifer. Seen with the creek overlay, many of the simulated images tend to exhibit areas of lower δ^{18}O concentrations along creek locations (i.e., brighter shades). This suggests that water is entering the system in-part through losing stream contributions. Low δ^{18}O values are not continuous under the entire creek or drainage path, but the creeks in the area are not suspected to leak uniformly (Heinemann, 1994; Hopster, 2003). In addition, the areas of low δ^{18}O concentrations are not all restricted to creek locations. Only the major drainages and streams are mapped, so these low values may be situated under minor drainages and/or depressions that contain seasonal standing water. Another possibility is that the δ^{18}O distribution mapped reflects recharged water that has been redistributed within the

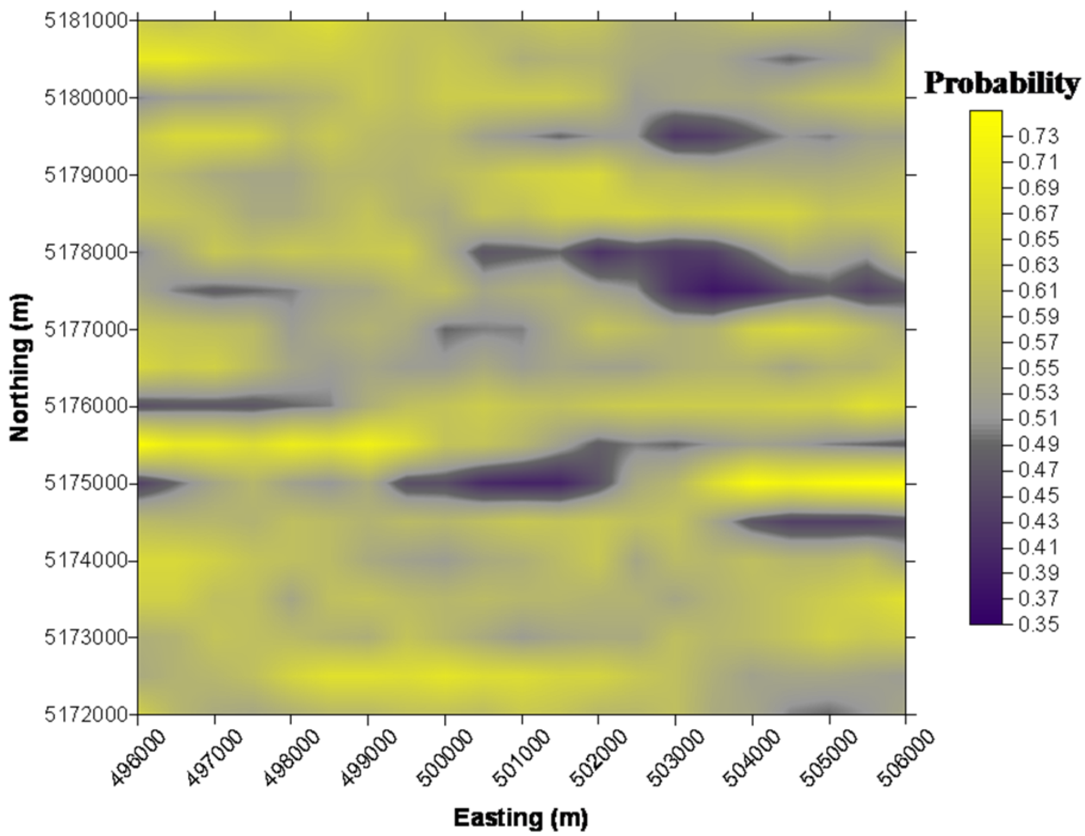


Figure 34. *Probability map showing the likelihood that a δ^{18}O value for a given area will exceed -15‰.*

Sediments of Bovill through buried stream channels. There may also be multiple recharge mechanisms at work, such as direct infiltration from precipitation and snow melt. A major control on infiltrating water is the abundance, thickness, and topography of sediments between the surface and the basalt flow tops. These sediments include the Palouse Formation that creates the dune-like hills in the Palouse Basin.

While simulated annealing is good for preserving the "noise" seen in normal sampling and the slight differences in $\delta^{18}O$ signatures, kriging represents a better method for looking at how the thickness of sediments above the basalt units (i.e. overburden) affects $\delta^{18}O$ signatures. This is due to kriging's ability to provide a smoothed picture of both the overburden thickness (which in itself has a smooth undulating topography) and an additional way to look at the $\delta^{18}O$ data.

Overburden thicknesses were taken from well logs in the Moscow area. "Overburden" was taken to be the thickness of all of the soil above the Wanapum basalt or basement rock. This was done for consistency since the Sediments of Bovill and the loess are often lumped together as one unit on well logs or are indistinguishable. Assigning a well location was achieved through use of the U.S. Public Land Survey System (U.S.P.L.S.S.) coordinates provided on the individual well logs as well as with the assistance of the Idaho Department of Water Resources (IDWR) well locator tool (Idaho Department of Water Resources, 2011). However, well logs can often be unreliable so the location of the well and thickness of the overburden in that site may not be precise. Despite this, the information gleaned from these well logs is able to provide the best available estimate of sub-surface geology.

The well log data were then used to create a kriged map of overburden thickness in the Moscow area (Figure 35). The variogram model for the overburden thickness is: 700 + 2425 sph(1950). The $\delta^{18}O$ data were similarly kriged to compare with the overburden thickness (Figure 36). The same variogram model from the SA process was used to krige the data. The smoothing effect of kriging is particularly apparent in the kriged image of $\delta^{18}O$ data, where the range of values seen in sampling has been reduced. The spotty appearance of the map may partly be due to the variations in $\delta^{18}O$ between sampled locations as a function of depth. Therefore, better resolution may be possible with a data set that is more restricted in terms of sample depth.

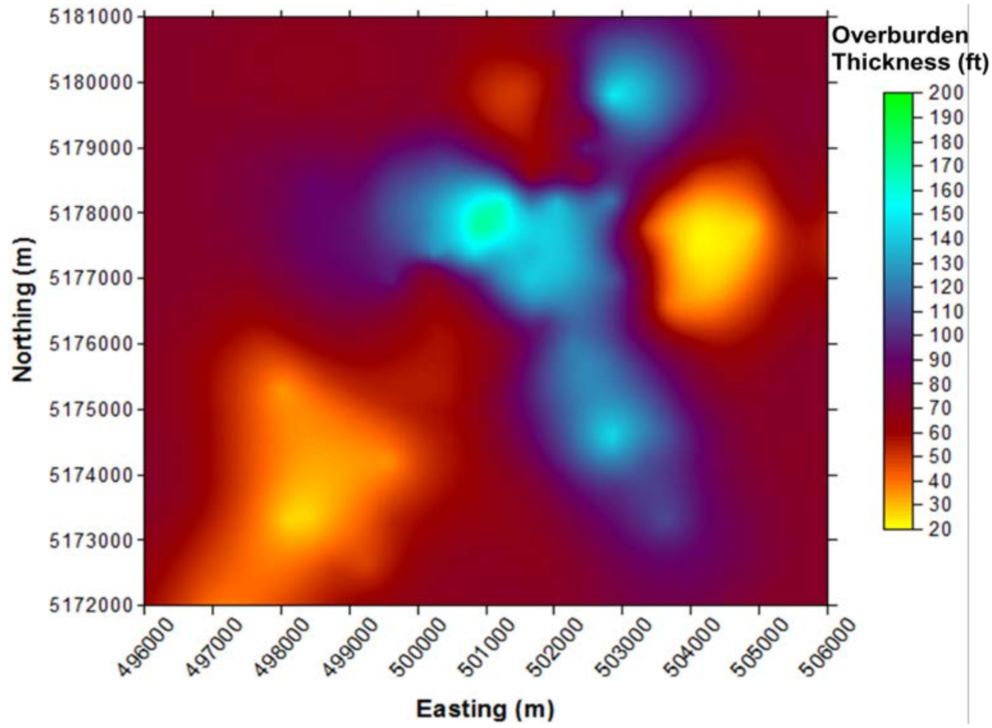


Figure 35. *Kriged image of overburden thickness.*

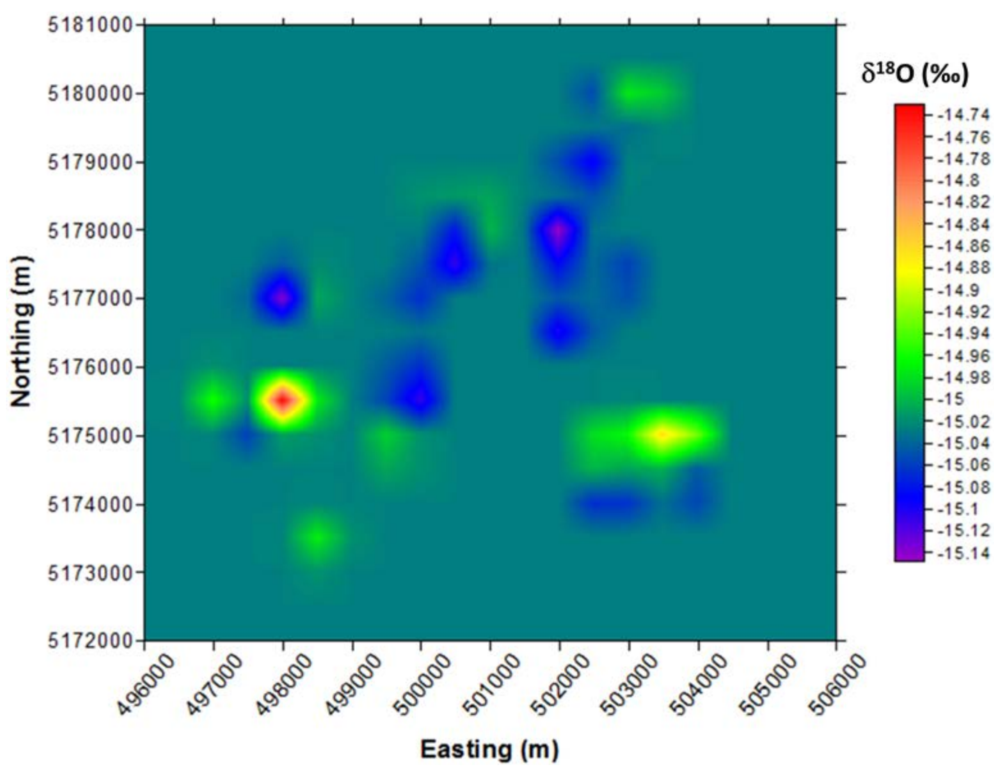


Figure 36. *Kriged image of $\delta^{18}O$ values.*

While much of it is smoothed, the presence of the relatively high and low spots in the kriged image of $\delta^{18}O$ may still be useful. The areas of lower $\delta^{18}O$ values tend to be located in areas covered in thicker overburden (50 feet or more), while higher values are typically in areas with less overburden coverage. Based on this relationship, it appears that there is more opportunity for recharge to infiltrate into the Upper Aquifer system in areas with thinner sediment coverage. As with Figure 33, the presence of higher $\delta^{18}O$ values at locations with less overburden may be younger or have a greater percentage of a modern recharge component in the groundwater than in areas with thicker overburden. Some of the irregularities (e.g. higher $\delta^{18}O$ values in areas of thick overburden) may be due to the lateral migration of shallow groundwater through layers of higher permeability.

Using geostatistics as a tool to evaluate data at unsampled locations provides an opportunity to make use of the relationships inherent in the data and get an idea as to what the overall distribution of the parameter as a whole might be. It is apparent from the images above that multiple results and possibilities are likely. The simulated annealing images display a distribution of $\delta^{18}O$ data that are highly variable and preferential. Bands of similar valued data suggest that there may well be a relationship between $\delta^{18}O$ values and surface water contributions from losing streams. On the other hand, a simple kriged image of the sampled data gives a much smoother distribution of $\delta^{18}O$ values with more depleted signatures occupying the central portion of the Moscow area. Upon comparing this image to a kriged map of overburden thickness, a potential relationship between the two data sets became noticeable in which lower $\delta^{18}O$ values tend to be located under areas with greater overburden thicknesses. Although different, it is not readily apparent which type of image more closely represents the true distribution of values. A more detailed sampling would be needed (perhaps with greater depth or geologic unit restrictions) to narrow down the best geostatistcal method, and provide a more accurate representation of subsurface oxygen isotope concentrations. As it stands, however, the data suggest that both water from losing creeks and infiltration from areally distributed precipitation are major recharge mechanisms for at least the Upper Aquifer. Since there is no obvious geographical pattern in relation to the location of mountain fronts, it is still unclear as to whether runoff is entering the system along the sediment/basement contact. In addition, the influence of this recharge may be greater in the Lower Aquifer, but does not manifest itself at shallower depths.

CHAPTER 5 – Conclusions and Recommendations

Conclusions

The additional data collected during this study provide important information about the hydrogeology of the Palouse Basin aquifer systems as a whole. In particular, the data illustrate the complex nature of recharge and groundwater mixing that occurs throughout the basin. Specific conclusions regarding each component of the project are as follows:

Tritium

- The presence of tritium in groundwater means that some component of the groundwater is less than 60 years of age regardless of how the tritiated water got there.
- The presence of tritium in large-bore, high-yield municipal wells indicates that substantial volumes of tritiated water are entering the pump intakes of these wells at the present time.
- The presence of tritium in wells with considerably older ^{14}C age dates is evidence that mixing of old in situ groundwater with groundwater that is less than 60 years old occurs.
- No definite relationship exists with either depth or elevation of water producing zones to predict which wells have measurable amounts of tritium and which do not. Therefore, either recharge is following preferential pathways created by local differences in geology and/or the locations of paleochannels, or young water leaks down the poorly sealed wellbores in these wells.
- Depth has a large influence on whether or not a well has measurable amounts of tritium; generally, tritium concentrations in well samples decrease with increasing depth of the wells.
- Well proximity to surface water or streams may also account for some of the occurrence of tritium in groundwater, especially in deeper wells.
- Tritiated water appears to exist at greater depths in the western part of the basin. This may be directly related to the thinning of sediments to the west, reducing the

effects of porous media flow compared to the east side of the basin. Groundwater flow in the west side of the basin is primarily fracture controlled.

- Tritium levels below the detection limit in shallow wells may be due to the presence of low hydraulic conductivity clay lenses or layers that retard the vertical migration of tritiated water.
- The effects of dilution and mixing can significantly change the tritium concentration in a sample, or obscure it altogether. For wells with old ^{14}C age dates that also contain detectable tritium, mixing and dilution affect both the ^{14}C age date and the tritium concentration. The resultant, apparent age date will underestimate the actual age of the groundwater, and the measured tritium concentration also will be underestimated. It is possible therefore that a sample can have a component of modern recharge and still test negative for tritium.

Oxygen-18

- Water from the Upper and Lower Aquifers separate into two distinct groups based on the $\delta^{18}O$ and δD signatures. Consistent with the findings of Larson (1997), water in the Upper Aquifer has a $\delta^{18}O$ range of -13.08‰ to -15.92‰ while water from the Lower Aquifer has a $\delta^{18}O$ range of -15.94‰ to -17.46‰.
- The more depleted signatures seen in the Lower Aquifer are attributed to the cold and wet environmental conditions of the Pleistocene Ice Age, as first suggested by Larson (1997).
- $\delta^{18}O$ values generally decrease with increasing depth. Scatter in the data with depth is primarily due to the homogenization of isotopic signatures during infiltration. Groundwater at depth is likely composed of recharge from different flow paths, all of which experience varying degrees of homogenization depending on the lengths of the paths and contributions from older water in pore spaces.
- Tritium is more likely to be found in samples with higher $\delta^{18}O$ values.
- There appears to be a very strong linear correlation between $\delta^{18}O$ and apparent ^{14}C age: ^{14}C apparent age increases with depletion of $\delta^{18}O$ signatures. The correlation becomes weaker with the compilation of data sets from multiple studies.

Consequently, the compatibility of data sets is questionable based on the potential differences in laboratory measurement procedures and data correction.

Geostatistical Modeling of Oxygen-18

- Geostatistics proved to be a useful tool for evaluating the distribution of $\delta^{18}O$ signatures in regards to recharge.
- Simulated annealing images of $\delta^{18}O$ values in Moscow show a great deal of variation from one image to the next. However, all of them present a dappled pattern for $\delta^{18}O$ concentrations in the Upper Aquifer. Many of the simulations have bands of higher $\delta^{18}O$ concentrations that are located under streams and drainages, suggesting that losing streams are contributing recharge in these areas.
- No east-west correlation in $\delta^{18}O$ data was observed. Therefore, if recharge is coming into the aquifer system from the mountain front along the contact with basement rock, it is either: 1) not showing up in $\delta^{18}O$ values, 2) not influential on groundwater in the Upper Aquifer, 3) following preferential pathways off the mountain front which appear as bands of similar $\delta^{18}O$ signatures in the simulated images, or 4) is not a major recharge mechanism.
- Kriged image maps of overburden thickness and $\delta^{18}O$ values show that depleted $\delta^{18}O$ concentrations tend to be located in areas with thicker overburden. This implies that relatively older water may be exerting an influence on the overall $\delta^{18}O$ signature in these locations. In addition, it shows that infiltration from areally distributed precipitation is another likely source of recharge.

General Conclusions

- The presence of a single isotope (whether tritium, ^{18}O, D, or ^{14}C) in groundwater by itself is not definitive of conditions of origin. Consequently, the use of multiple tracers is necessary for correct interpretation of isotopic results.
- Recharge to the aquifer systems is likely through a combination of mechanisms, including leakage from creeks and infiltration from areally distributed precipitation, especially where overburden is thinner.

- Groundwater in any given location potentially consists of a mixture of water of different ages arising from the different travel times associated with local, intermediate, and regional flow paths.
- Recharge appears to follow preferential pathways brought about by natural features in the local geology or paleotopography.
- The older water contribution increases with increasing depth, but old groundwater is not necessarily devoid of the presence of modern recharge water.
- In general, apparent groundwater age increases with increasing depth. However, these apparent ages do not necessarily reflect the travel time of a water to reach a given depth. The total groundwater in an area is likely composed of a mixture of water from multiple flow paths and hence, various ages.

Recommendations

Environmental isotope analyses of groundwater in an area can greatly aid budget analysis and sustainability of an aquifer by confirming or refuting previous conceptions of a groundwater system. In this sense, age dating and mixing analysis with isotopic tracers can complement the standard hydrogeological data used in groundwater models and provide additional information for calibration. It is therefore advisable to incorporate available environmental isotope results into various conceptual models to aid in the development of more accurate numerical models.

In order to properly do this, a sufficient vertical and horizontal sampling density is necessary. When possible, sampling should be continued for the purposes of adding to the data library started by this and other studies. It will also need to be determined if different collections of data (especially $\delta^{18}O$) are compatible on the whole. In addition, further evaluation of the apparent relationship between $\delta^{18}O$ and ^{14}C apparent ages should be considered, as it could allow an estimation of groundwater age without the costly process of shipping samples off for ^{14}C analysis.

Understanding of the distribution of $\delta^{18}O$ in the subsurface can also be facilitated by additional sampling. Seasonal sampling of groundwater can be used to evaluate the mean residence times of stream baseflow or vertical travel times through the soil by making use of sinusoidal relationships. The implied relationship seen in geostatistical modeling between $\delta^{18}O$ values and creek locations could be assessed further by extensive soil water sampling of $\delta^{18}O$ at various depths and distances from creeks. This would ensure the depths of the samples are constrained and provide a better depiction of $\delta^{18}O$ distribution as well as the extent of groundwater contribution from surface water.

REFERENCES

Adkins, C.B., and Bartolino, J.R., 2010. Distribution of Isotopic and Environmental Tracers in Groundwater, Northern Ada County, Southwestern Idaho. USGS Scientific Investigations Report 2010-5144.

Albright, B., 2007. An Introduction to Simulated Annealing. The College Mathematics Journal, Jan. 2007, vol. 38, no. 1.

Badon, N., 2007. Implementation of a Groundwater Monitoring Program and Aquifer Testing in the Wanapum Aquifer System, Latah County, Idaho. M.S. Thesis, University of Idaho, Moscow, Idaho.

Baines, C.A., 1992. Determination of Sustained Yield for the Shallow Basalt Aquifer in the Moscow Area, Idaho. M.S. Thesis, University of Idaho, Moscow, Idaho.

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

Bassett, R.L., Steinwand, A., Jorat, S., Petersen, C., and Jackson, R., 2008. Forensic Isotope Analysis to Refine a Hydrologic conceptual Model. Ground Water Vol. 46, No. 3, p. 372-383.

Bauer, H., and Vaccaro, J.J., 1990. Estimates of Ground-Water Recharge to the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho, for Predevelopment and Current Land Use Conditions. USGS Water Resource Investigation 88-4108.

Begemann, F., and Libby, W. F., 1957. Continental Water Balance, Groundwater Inventory and Storage Times, Surface Ocean Mixing Rates and World-Wide Water Circulation Patterns from Cosmic-Ray and Bomb Tritium. Geochimica and Cosmochimica Acta 12, p. 277–296.

Bennecke, W.M., 1996. Basalt Features Observed in Outcrops, Cores, Borehole Video Imagery and Geophysical Logs, and Basalt Hydrogeologic Study at the Idaho National Engineering Laboratory, Eastern Idaho. M.S. Thesis, Boise State University, Boise, Idaho.

Bennett, B., 2009. Recharge Implications of Strategic Pumping of the Wanapum Aquifer System in the Moscow Sub-basin. M.S. Thesis, University of Idaho, Moscow, Idaho.

Bethke, C.M., and Johnson, T.M., 2002. Paradox of Groundwater Age. Geology Vol. 30 No. 2, p.107-110.

Black, A.E., Strand, E., Morgan, P., Scott, J.M., Wright, R.G., and Watson, C., 1998. Biodiversity and Land-use History of the Palouse Bioregion: Pre-European to Present.

In: Sisk, T.D., ed., 1998. Perspectives on the Land-use History of North America: a Context for Understanding Our Changing Environment. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999), 104 p.

Brown, P.A., 1998. Spore, Microsphere, and Encapsulated Sphere Transport in a Heterogeneous Aquifer. M.S. Thesis, University of Idaho, Moscow, Idaho.

Bush, J.H., 2005. The Columbia River Basalt Group of the Palouse Basin with Hydrological Interpretations, Western Latah County, Idaho and Eastern Whitman County, Washington. Idaho Geological Survey, Moscow, Idaho.

Bush, J.H., 2006. Geologic Report on Moscow Monitoring Wells.

Bush, J.H., and Garwood, D.L, 2004. Geologic Cross-Section Moscow-Pullman, Idaho-Washington.

Bush, J.H., and Garwood, D.L, 2005. Physiographic Map of the Palouse Basin, Washington and Idaho.

Bush, J.H., Garwood, D.L., and Hinds, J.J., 2007. Compiled Bedrock Geologic Map of the Palouse Basin: Preliminary Draft, one sheet.

Bush, J.H., and Seward, W.P., 1992. Geologic Field Guide to the Columbia River Basalt, Northern Idaho and Southeastern Washington. Idaho Geological Survey, Information Circular 49.

Chowdhury, A.H., Uliana, M., and Wade, S., 2008. Ground Water Recharge and Flow Characterization Using Multiple Isotopes. Ground Water Vol. 46, No. 3, p. 426-436.

City of Moscow, 2011. Bond Well $\delta^{18}O$, δD, and Tritium Results.

Crosby III, J.W., and Chatters, R.M., 1965. Water Dating Techniques as Applied to the Pullman-Moscow Ground-Water Basin, Washington State University, College of Engineering, Bulletin.

Deutsch, C.V., and Journel, A.J., 1998. GSLIB Geostatistical Software Library and User's Guide, 2nd edn. Oxford University Press, New York.

Desaulniers, D.E., Cherry, J.A., and Fritz, P., 1981. Origin, Age, and Movement of Pore Water in Agrillaceous Quaternary Deposits at Four Sites in Southwestern Ontario. Journal of Hydrology Vol. 50, p. 231-257.

Douglas, A.A., 2004. Radiocarbon Dating as a Tool for Hydrogeological Investigations in the Palouse Basin. M.S. Thesis, University of Idaho, Moscow, Idaho.

Drever, James I., 1997. Isotopes. *The Geochemistry of Natural Waters: Surface and Groundwater Environments*. 3rd ed. New Jersey: Prentice Hall, p. 311-325.

Dutton, A., Wilkinson, B.H., Welker, J.M., Bowen, G.J., and Lohmann, K.C., 2005. Spatial Distribution and Seasonal Variation in $^{18}O/^{16}O$ of Modern Precipitation and River Water Across the Conterminous USA. Hydrological Processes: 19, p. 4121-4146.

Etcheverry, D., and Perrochet, P., 2000. Direct Simulation of Groundwater Transit-time Distributions Using the Reservoir Theory. Hydrogeology Journal, No. 8, p. 200-208.

Fairley, J.P., Solomon, M.D., Hinds, J.J., Grader, G.W., Bush, J.H., and Rand, A.L., 2006. Latah County Hydrologic Characterization Project (Final Report). Idaho Department of Water Resources.

Fernandes, G., and Carreira, P.M., 2008. Isotopic Evidence of Aquifer Recharge During the Last Ice Age in Portugal. Journal of Hydrology 361, p. 291-308.

Foxworthy, B.L., and Washburn, R.L., 1963. Ground Water in the Pullman area, Whitman County, Washington. U.S. Geological Survey, Water Supply Paper 1655.

Freeze, R.A., and Witherspoon, P.A., 1967. Theoretical Analysis of Regional Groundwater Flow: 2. Effect of Water-Table Configuration and Subsurface Permeability Variation. Water Resources Research, Vol. 3, No. 2, p. 623-634.

Garwood, D.L., 2001. Bedrock Geology of the Lewiston Orchards North of Lapwai 7 ½ - Minute Quadrangles, Nez Perce County, Idaho. M.S. Thesis, University of Idaho, Moscow, Idaho.

Gat, J.R., and Bowser, C., 1991. The Heavy Isotope Enrichment of Water in Coupled Evaporative Systems. In: Taylor, H.P. Jr., O'Neil, J.R., and Kaplan, Isaac, R., eds. *Stable Isotope Geochemistry: A Tribute to Samuel Epstein*. Special Publication No. 3: The Geochemical Society, p. 159-168.

Golden Software, Inc., 1999. Surfer® Version 7.0. Contouring, gridding, and surface mapping software.

Goode, D.J., 1996. Direct Simulation of Groundwater Age. Water Resources Research, Vol. 32, No. 2, p. 289-296.

Happle, J., 2010. Personal Communication. Research Associate Professor and Director, Rosentiel School of Marine and Atmospheric Science Tritium Laboratory, University of Miami, Florida.

Heinemann, R., 1994. The Relation Between Streams and Ground-Water Flow Systems within the Pullman-Moscow Area of Washington and Idaho. M.S. Thesis, University of Idaho, Moscow, Idaho.

Hernandez, H.P., 2007. Observations of Recharge to the Wanapum Aquifer System in the Moscow Area, Latah County, Idaho. M.S. Thesis, University of Idaho, Moscow, Idaho.

Hoefs, J., 1987. *Stable Isotope Geochemistry*. 3rd ed. New York: Springer-Verlag, 241 p.

Hood, D., 2011. Letter report, Re: Radiocarbon Dating Results for Samples IDWR 4, IDWR 2, IDWR 3, IDWR 1, Albion 3, Bond. President, Beta Analytics, Inc., Miami, Florida.

Hooper, P.R., 1982. The Columbia River Basalts. Science, v. 215, p. 1463-1468.

Hopster, D., 2003. A Recession Analysis of Springs and Streams in the Moscow-Pullman Basin. M.S. Thesis, University of Idaho, Moscow, Idaho.

IAEA/WMO, 2011. International Atomic Energy Agency/World Meteorological Organization Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: http://www.iaea.org/water.

Idaho Department of Water Resources, 2011. Well Driller's Locater Tool. Accessible at: http://maps.idwr.idaho.gov/locator/.

Johnson, G.E., 1991. Estimating Groundwater Recharge Beneath Different Slope Positions in the Palouse Formation Using a Numerical Unsaturated Flow Model. M.S. Thesis, Washington State University, Pullman, Washington.

Kazemi, G.A., Lehr, J.H., and Perrochet, Pierre, 2006. *Groundwater Age*: Hoboken, NJ, John Wiley & Sons, Inc, 325 p.

Kehew, Alan E., 2001. Applications of Isotopes in Hydrogeology. *Applied Chemical Hydrogeology*. New Jersey: Prentice Hall, p. 256-288.

King, S.L., 2000. Sequential Gaussian Simulation vs. Simulated Annealing for Locating Pockets of High-Value Commercial Trees in Pennsylvania. Annals of Operations Research 95, p. 177-203.

Klein, D.P., Sneddon, R.A., and Smoot, J.L., 1987. A Magnetotelluric Study of the Thickness of Volcanic and Sedimentary Rock in the Pullman-Moscow Basin of Eastern Washington. U.S. Geological Survey Open-File Report, Denver, Colorado.

Kopp, W.P., 1994. Hydrogeology of the Upper Aquifer of the Pullman-Moscow Basin at the University of Idaho aquaculture site. M.S. Thesis, University of Idaho, Moscow, Idaho.

Krapf, R.W., 1978. Characterization of Loess Deposits and Paleosols of the Palouse Formation in Idaho and Washington. Ph.D. Dissertation, University of Idaho, Moscow, Idaho.

Krishnamurthy, R.V., and Bhattacharya, S.K., 1991. Stable Oxygen and Hydrogen Isotope Ratios in Shallow Ground Waters from India and a Study of the Role of Evapotranspiration in the Indian Monsoon. In: Taylor, H.P. Jr., O'Neil, J.R., and

Kaplan, Isaac, R., eds. *Stable Isotope Geochemistry: A Tribute to Samuel Epstein*. Special Publication No. 3: The Geochemical Society, p. 187-193.

Kurás, P.K., Weiler, M., and Alila, Y., 2008. The Spatiotemporal Variability of Runoff Generation and Groundwater Dynamics in a Snow-Dominated Catchment. Journal of Hydrology 352, p. 50-66.

Kyser, T.K., 1987. Equilibrium Fractionation Factors for Stable Isotopes. In: Kyser, T.K., ed. *Short Course in Stable Isotope Geochemistry of Low Temperature Fluids*, Vol 13. Saskatoon: Mineralogical Association of Canada, p. 1-84.

Laney, F.B., Kirkham, V.R.D., and Piper, A.M., 1923. Groundwater Supply at Moscow, Idaho. Idaho Bureau of Mines and Geology, Pamphlet #8.

Larson, K.R., Keller, C.K., Allen-King, R.M., Hathhorn, W.E., and Larson, P.B., 1996. Groundwater Recharge and Residence Times in the Pullman-Moscow Basin: A Stable Isotope Study. State of Washington Water Research Center, Report A-196-WASH, 24 p.

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

Lawrence, James R., and White, James W.C., 1991. The Elusive Climate Signal in the Isotopic Composition of Precipitation. In: Taylor, Hugh P. Jr., O'Neil, James R., and Kaplan, Isaac R., eds. *Stable Isotope Geochemistry: A Tribute to Samuel Epstein*. Special Publication No. 3: The Geochemical Society, p. 169-185.

Li, T., 1991. Hydrogeologic Characterization of a Multiple Aquifer Fractured Basalt System. Ph.D. Dissertation, University of Idaho, Moscow, Idaho.

Lin, C.-L., 1967. Factors Affecting Ground-Water Recharge in the Moscow Basin, Latah County, Idaho. M.S. Thesis, Washington State University, Pullman, Washington.

Lum II, W.E., Smoot, J.L., and Ralston, D.R., 1990. Geohydrology and Numerical Model Analysis of Ground-Water Flow in the Pullman-Moscow Area, Washington and Idaho, U.S. Geological Survey Water-Resources Investigations Report 89-4103, p. 1-73.

Mazor, Emanuel., 1991. *Chemical and Isotopic Groundwater Hydrology: The Applied Approach*. 2nd ed. New York: Marcel Dekker, Inc., 413 p.

McVay, M., 2007. Grande Ronde Aquifer Characterization in the Palouse Basin. M.S. Thesis, University of Idaho, Moscow, Idaho.

Miller, S.M., 2001. CONVT2D. Fortran program for data conversion.

Miller, S.M., 2009. Geological Engineering 428 (Geostatistics) course notes. Professor of Geological Engineering, University of Idaho, Moscow, Idaho.

Moran, K., 2011. Interpretation of Long-Term Grande Ronde Aquifer Testing in the Palouse Basin of Idaho and Washington. M.S. Thesis, University of Idaho, Moscow, Idaho.

Nimmer, R.E., 1998. Groundwater Tracer Studies in Columbia River Basalt. M.S. Thesis, University of Idaho, Moscow, Idaho.

O'Driscoll, M.A., DeWalle, D.R., McGuire, K.J., Gburek, W.J., 2005. Seasonal 18O Variations and Groundwater Recharge for Three Landscape Types in Central Pennsylvania, U.S.A. Journal of Hydrology 303, p. 108-124.

O'Geen, A.T., 2002. Assessment of Hydrologic Processes Across Multiple Scales in Soils/Paleosol Sequences Using Environmental Tracers. M.S. Thesis, University of Idaho, Moscow, Idaho.

Owsley, D., 2003. Characterization of Grande Ronde Aquifers in the Palouse Basin Using Large Scale Aquifer Tests. M.S. Thesis, University of Idaho, Moscow, Idaho.

Palouse Basin Aquifer Committee, 2010. 2009 Palouse Ground Water Basin Water Use Report.

Pardee, J.T., and Bryan, K., 1926. Geology of the Latah Formation in Relation to the Lavas of the Columbia Plateau near Spokane. 140-A, USGS.

Pardo, B.B., 1993. Relation Between Groundwater and Surface Water at the University of Idaho Groundwater Research Site. M.S. Thesis, University of Idaho, Moscow, Idaho.

Petrich, C.R., 1995. Microsphere and Encapsulated Cell Transport in a Heterogeneous Subsurface Environment. Ph.D. Dissertation, University of Idaho, Moscow, Idaho.

Pierce, J.L., 1998. Geology and Hydrogeology of the Moscow East and Robinson Lake Quadrangles, Latah County, Idaho. M.S. Thesis, University of Idaho, Moscow, Idaho.

Provant, A.P., 1995. Geology and Hydrogeology of the Viola and Moscow West Quadrangles, Latah County, Idaho and Whitman County, Washington. M.S. Thesis, University of Idaho, Moscow, Idaho.

Reidel, S.P., Tolan, T.L., Hooper, P.R., Beeson, M.H., Fecht, K.R., Bentley, R.D., and Anderson, J.L., 1989. The Grande Ronde Basalt, Columbia River Basalt Group; Stratigraphic Descriptions and Correlations in Washington, Oregon, and Idaho. In: Reidel, S.P., and Hooper, P.R., eds. Volcanism and Tectonism in the Columbia River Flood-Basalt Province, Geological Society of America Special Paper 239, p. 21-54.

Reuter, R., 1995. Transport and Flow Characteristics of Perched Water in Loess-Derived Soilscapes. M.S. Thesis, University of Idaho, Moscow, Idaho.

Russell, I.D., 1897. A Geological Reconnaissance in Southeastern Washington. U.S. Geological Survey, Water-Supply Paper 4.

Sánchez-Murillo, R., Brooks, E.S., and Boll, J., 2011. Unpublished data.

Schwartz, F.W., Sudicky, E.A., McLaren, R.G., Park, Y.-J., Huber, M., and Apted, M., 2010. Ambiguous Hydraulic Heads and ^{14}C Activities in Transient Regional Flow. Ground Water Vol.48, No. 3, p. 366-379.

Smoot, J.L., and Ralston, D.R., 1987. Hydrogeology and a Mathematical Model of Ground-water Flow in the Pullman-Moscow Region, Washington and Idaho. Idaho Water Resources Research Institute, Moscow, Idaho, 118 p.

Šilar, J., 1969. Ground Water Structures and Ages in the Eastern Columbia Basin, W.A. Washington State University College of Engineering Research Division, Bulletin 315.

Swanson, D.A., and Wright, T.L., 1978. Bedrock Geology of the Southern Columbia Plateau and Adjacent Areas. Chapt. 3 in: Baker, V.R., and Nummedal, D., eds. *The Channeled Scabland*. Washington D.C.: Planetary Geology Program, National Aeronautical and Space Administration.

Swanson, D.A., Wright, T.L., Hopper, P.R., and Bentley, R.D., 1979. Revisions in Stratigraphic Nomenclature of the Columbia River Basalt Group. U.S. Geological Survey Bulletin 1457-G, 59 p.

Teasdale, E.W., 2002. Hydrogeologic Sub-Basins in the Palouse Area of Idaho and Washington. M.S. Thesis, University of Idaho, Moscow, Idaho.

Tritium Laboratory, 2010. General Comments on Tritium Results. University of Miami Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science, Miami, Florida.

Vaccaro, J.J., 1999. Summary of the Columbia Plateau Regional Aquifer-System Analysis, Washington, Oregon, Idaho. U.S. Geological Survey, Professional Paper 1413-A.

van Laarhoven, P.J.M., and Aarts, E.H., 1987. Simulated Annealing: Theory and Applications. D. Reidel Publishing Company, Dordrecht, Holland, 186 p.

Varni, M., and Carrera, J., 1998. Simulation of Groundwater Age Distributions. Water Resources Research, Vol. 34, No. 12, p. 3271-3281.

Walters, K.L., and Glancy, P.A., 1969. Reconnaissance of Geology and of Ground-Water Occurrences and Development in Whitman County, Washington, Washington Department of Water Resources Water Supply Bulletin 26, 169 p.

Welham, John A. 1987. Stable Isotope Hydrology. In: Kyser, T.K., ed. *Short Course in Stable Isotope Geochemistry of Low Temperature Fluids*, Vol 13. Saskatoon: Mineralogical Association of Canada, p. 129-161.

Wenner, David B., Ketcham, Peter D., and Dowd, John F., 1991. Stable Isotopic Composition of Waters in a Small Piedmont Watershed. In: Taylor, Hugh P. Jr., O'Neil, James R., and Kaplan, Isaac R., eds. *Stable Isotope Geochemistry: A Tribute to Samuel Epstein*. Special Publication No. 3: The Geochemical Society, p. 195-203.

Western Regional Climate Center, 2010. Climatological Data Summaries. http://www.wrcc.dri.edu/climsum.html.

Williams, R.E., and Allman, D.W., 1969. Factors Affecting Infiltration and Recharge in a Loess Covered Basin. Journal of Hydrology, Vol. 8, p. 265-281.

Wright, T.L., Grolier, M.J., and Swanson, D.A., 1973. Chemical Variation Related to the Stratigraphy of the Columbia River Basalt, Geological Society of America Bulletin, Vol. 84, No. 2, p. 371-385.

Wyatt-Jaykim Engineers, and Ralston, D.R., 1987. Construction Report for the WSU 7 Production/Test Well. Project no. 0939.

APPENDIX A:

GSLIB MODELING

This appendix contains a general overview of the simulated annealing procedure utilized in this study to allow future work to emulate the process if needed. The final simulated annealing images were achieved through a series of steps employing a combination of programs. Foremost of these is the GSLIB software and its *sasim* program (included on the CD in the back). The process begins with the creation of a data file in Windows Notepad or an equivalent program (see example data file in Figure A1 below). The heading should contain a title line, a line indicating the number of lines remaining before the actual data, and explanations of each data column occupying those subsequent lines. Note: The programs utilized in this study are not capable of dealing with the large numbers seen in the UTM coordinate system. Therefore, the lengths in all of the input files have been changed to kilometers and must be switched back into meters as the final step before mapping.

Before the creation of a parameter file, a variogram model must be established for the data. This can be done with whichever software the user prefers (Surfer was utilized for this project). The description of the model can then be included in the parameter file. An example *sasim* parameter file is shown in Figure A2. Each entry in the parameter file is explained in greater detail by Deutsch and Journel (1998). The resulting output file created by *sasim* (Figure A3) must be modified before entering it into the conversion program. This program (CONVT2D) was designed by Miller (2001) and is also included on the CD in the back. It rearranges the values for the multiple simulations into an easily readable format that can then be modeled. The output file heading is modified as shown in Figure A4 and an example of a final output file is shown in Figure A5. The data are now ready to be displayed through mapping software such as Surfer.

```
O-18 Data 4-2011
4
Easting     km
Northing    km
Elev        km
O-18        ‰
499.8315  175.711  1  -17.797
503.8565  174.359  1  -17.752
498.5615  173.429  1  -16.467
502.7465  174.066  1  -17.475
499.8625  176.954  1  -17.264
502.8705  177.281  1  -17.342
503.0665  179.573  1  -16.742
503.0795  179.662  1  -17.337
503.1855  179.888  1  -16.063
502.5195  179.957  1  -17.067
502.0355  177.835  1  -17.505
497.0685  175.541  1  -16.394
502.3865  178.871  1  -17.196
502.3395  178.864  1  -17.462
500.3135  178.292  1  -16.739
500.2945  178.095  1  -16.509
500.4535  178.015  1  -17.161
500.3945  177.750  1  -16.700
500.4005  177.836  1  -17.198
501.0225  178.188  1  -16.557
501.9665  177.816  1  -17.672
500.4115  177.527  1  -17.292
500.1795  177.807  1  -17.236
500.6145  177.719  1  -17.209
500.4755  177.737  1  -17.265
497.8765  175.143  1  -16.788
497.8765  175.109  1  -17.362
497.8745  175.141  1  -17.384
500.4495  177.897  1  -17.026
503.4025  174.671  1  -17.594
502.1125  176.611  1  -17.598
498.1005  175.334  1  -16.703
498.0835  175.346  1  -16.588
498.0905  175.331  1  -16.550
498.0805  175.313  1  -16.014
498.0695  175.330  1  -16.128
498.0445  175.332  1  -15.651
………
```

Figure A1. *Example data file (424O18.dat)*

```
                    Parameters for SASIM
                    ********************

START OF PARAMETERS:
1  1  0  0  0                        \components: hist,varg,ivar,corr,cpdf
1  1  1  1  1                        \weight:     hist,varg,ivar,corr,cpdf
0                                    \0=no transform, 1=log transform
8                                    \number of realizations
21     496.000    0.500              \grid definition: nx,xmn,xsiz
19    5172.000    0.500              \                 ny,ymn,ysiz
 1       10.0       1.0              \                 nz,zmn,zsiz
69069                                \random number seed
0                                    \debugging level
debug1.txt                           \file for debugging output
O18424a.out                          \file for simulation output
1                                    \schedule (0=automatic,1=set below)
1.0   0.1   20000   2500   3   0.001 \  schedule: t0,redfac,ka,k,num,Omin
200   1                              \  maximum perturbations, reporting
50                                   \  maximum number without a change
1                                    \conditioning data:(0=no, 1=yes)
424O18.dat                           \  file with data
1    2    0    4                     \  columns: x,y,z,attribute
-1.0e21    1.0e21                    \  trimming limits
1                                    \file with histogram:(0=no, 1=yes)
424O18.dat                           \  file with histogram
4   3                                \  column for value and weight
20                                   \  number of quantiles for obj. func.
0                                    \number of indicator variograms
2.78                                 \  indicator thresholds
../data/seisdat.dat                  \file with gridded secondary data
1                                    \  column number
1                                    \  vertical average (0=no, 1=yes)
0.60                                 \correlation coefficient
../data/cal.dat                      \file with paired data
2   1   0                            \  columns for primary, secondary, wt
-0.5   100.0                         \  minimum and maximum
0                                    \  number of primary thresholds
0                                    \  number of secondary thresholds
14                                   \Variograms: number of lags
0                                    \  standardize sill (0=no,1=yes)
1   0.26                             \  nst, nugget effect
1   0.076   0.0   0.0   0.0          \  it,cc,ang1,ang2,ang3
      0.3000   0.3000   1.0          \  a_hmax, a_hmin, a_vert
```

Figure A2. *Example simulated annealing parameter file (for* sasim*)*

```
SASIM Realizations
 1  21  19  1 496.00000   5172.0000   10.000000   .500000   .500000   1.00000   8
value
-16.343930
-17.473620
-15.417490
-16.080810
-16.702490
-16.267090
-16.053720
-16.330110
-16.628870
-16.538210
-17.362020
-16.063230
-16.605550
-16.629660
-16.088840
-17.767940
-16.058210
-16.740510
-17.403530
-16.557840
-17.064130
-16.904510
-16.740860
-16.963850
-16.636650
-16.570870
-17.264600
-16.383680
-17.250600
-17.786370
-16.552480
-16.730240
-16.551490
-17.351360
-17.281460
……..
```

Figure A3. *Example* sasim *output file (O18424a.out)*

```
SASIM Realizations O-18 data (4-2011)
1
simulated value
8
21      496     .5
19      5172    .5
-17.096330
-16.478940
-17.450680
-16.554800
-15.900580
-15.728990
-17.697200
-17.621850
-14.994060
-15.967410
-16.556080
-17.196600
-17.221850
-16.629660
-16.066440
-16.502940
-17.234380
-16.740510
-16.316350
-15.369610
-16.469700
-16.596300
-16.215170
-16.585620
-17.503910
-16.570870
-16.947350
-16.627530
-17.364380
-17.466330
-16.271000
-14.938960
-16.065870
-16.040180
-16.628780
……
```

Figure A4. *Example modified output file. The heading from the output file has been altered for the CONVT2D program*

496.0	5172.0	-17.4	-17.6	-16.5	-17.1	-17.2	-16.1	-16.5	-16.5
496.5	5172.0	-16.1	-16.4	-16.3	-16.3	-17.4	-16.1	-17.2	-17.4
497.0	5172.0	-16.1	-16.7	-17.5	-17.2	-16.2	-17.2	-16.7	-17.5
497.5	5172.0	-16.2	-17.6	-16.6	-17.3	-17.2	-17.1	-16.1	-16.4
498.0	5172.0	-17.2	-16.2	-17.6	-16.3	-17.8	-16.6	-17.4	-16.7
498.5	5172.0	-17.8	-17.5	-16.1	-16.4	-17.2	-16.1	-16.3	-17.6
499.0	5172.0	-17.3	-17.5	-17.2	-16.7	-17.2	-16.8	-16.6	-15.5
499.5	5172.0	-16.3	-17.3	-17.5	-17.3	-17.5	-17.0	-17.0	-17.5
500.0	5172.0	-17.4	-16.7	-16.7	-15.9	-17.2	-15.1	-16.7	-16.5
500.5	5172.0	-17.2	-17.5	-17.6	-16.0	-16.7	-17.1	-16.3	-17.4
501.0	5172.0	-17.3	-17.6	-16.4	-17.3	-16.7	-16.8	-17.4	-17.1
501.5	5172.0	-16.5	-17.2	-17.8	-17.3	-15.3	-16.1	-16.8	-17.3
502.0	5172.0	-16.6	-17.4	-17.3	-16.1	-17.3	-16.5	-17.3	-17.7
502.5	5172.0	-16.7	-16.3	-17.8	-16.6	-16.1	-17.3	-17.2	-17.7
503.0	5172.0	-17.3	-17.5	-17.0	-16.9	-17.2	-16.8	-16.3	-17.5
503.5	5172.0	-16.6	-17.4	-15.5	-16.6	-16.4	-16.6	-16.6	-17.0
504.0	5172.0	-17.2	-16.5	-16.6	-17.0	-15.0	-16.0	-17.7	-16.4
504.5	5172.0	-17.5	-16.7	-16.5	-17.3	-16.1	-16.9	-17.7	-17.5
505.0	5172.0	-17.0	-17.4	-17.3	-17.8	-16.4	-16.5	-16.4	-17.5
505.5	5172.0	-16.5	-16.7	-16.1	-17.1	-16.7	-17.5	-15.9	-17.3
506.0	5172.0	-17.2	-15.9	-17.1	-16.8	-16.4	-15.9	-16.6	-16.6
496.0	5172.5	-17.0	-17.4	-17.8	-17.1	-16.7	-17.4	-17.2	-17.5
496.5	5172.5	-17.4	-16.4	-17.1	-16.6	-17.7	-16.5	-15.3	-16.0
497.0	5172.5	-17.6	-17.8	-16.5	-16.3	-17.8	-16.3	-16.4	-16.3
497.5	5172.5	-17.3	-16.5	-16.3	-16.1	-16.6	-17.2	-15.5	-17.5
498.0	5172.5	-16.3	-16.4	-16.1	-16.8	-17.2	-17.4	-15.9	-17.4
498.5	5172.5	-16.4	-17.8	-17.5	-16.7	-16.6	-17.4	-16.3	-16.1
499.0	5172.5	-17.2	-17.3	-16.8	-16.2	-16.6	-17.2	-15.2	-15.6
499.5	5172.5	-15.9	-17.2	-17.0	-17.3	-17.3	-15.7	-16.7	-17.5
500.0	5172.5	-17.3	-16.6	-15.6	-15.6	-17.6	-16.6	-17.2	-16.7
500.5	5172.5	-17.4	-16.5	-17.6	-16.5	-17.6	-17.2	-17.3	-16.7
501.0	5172.5	-15.4	-16.3	-17.6	-16.1	-16.2	-16.4	-15.9	-16.6
501.5	5172.5	-16.4	-17.3	-16.7	-17.2	-16.8	-17.2	-17.3	-16.1
502.0	5172.5	-16.4	-17.1	-16.4	-17.1	-16.1	-17.5	-17.2	-16.5
502.5	5172.5	-16.1	-16.1	-17.2	-16.6	-16.6	-17.8	-16.7	-16.6
503.0	5172.5	-17.1	-16.5	-16.5	-17.8	-16.1	-16.1	-16.4	-16.5
503.5	5172.5	-17.6	-17.5	-16.3	-16.8	-16.0	-16.1	-16.6	-16.5
504.0	5172.5	-17.3	-16.6	-17.4	-17.5	-17.4	-17.7	-17.7	-17.8
504.5	5172.5	-17.3	-17.1	-16.8	-17.2	-16.5	-17.6	-16.7	-17.4
505.0	5172.5	-17.3	-16.6	-17.2	-16.7	-17.1	-15.8	-17.2	-16.1
505.5	5172.5	-16.4	-16.7	-16.3	-17.6	-17.4	-17.5	-16.3	-17.1
506.0	5172.5	-16.8	-15.5	-16.3	-16.4	-16.6	-17.6	-16.6	-17.6
496.0	5173.0	-15.0	-17.2	-17.3	-16.8	-16.3	-17.2	-17.4	-16.6
496.5	5173.0	-17.5	-17.5	-17.4	-17.5	-16.2	-17.4	-16.1	-16.1
497.0	5173.0	-16.6	-16.2	-16.2	-16.6	-17.0	-16.6	-16.5	-17.1
497.5	5173.0	-16.4	-17.3	-16.6	-16.8	-17.1	-17.4	-16.8	-17.8
498.0	5173.0	-16.7	-15.7	-16.6	-16.1	-17.5	-16.5	-17.3	-16.4

……

Figure A5. *Example output file from CONVRT2D*

APPENDIX B:

^{14}C RESULTS

Although the sampling for carbon-14 (^{14}C) was not within the scope of this thesis, previous ^{14}C age dates were used for comparison with the tritium results. The use of multiple isotopes as tracers in groundwater is important because the interpretation of any one on its own may exclude information that can be elucidated by considering the concentrations of other parameters. In the interest of continuing to collect information concerning Palouse Basin groundwater age, several wells that had not been previously analyzed for ^{14}C were sampled during this study. The results are reported here so that they will be available for future research. These ^{14}C results are apparent radiocarbon ages and have not been corrected for any physical, chemical, or biological reactions that may have occurred in the system. They therefore do not necessarily represent the residence time of the water within the aquifer. However, previous studies of ^{14}C in the Palouse Basin (Crosby and Chatters, 1965; Douglas, 2004) have shown that adjustments of these apparent ages to account for any reactions does not significantly affect the apparent age of the water and lies within the range of uncertainty. This is largely due to the fact that the Palouse Basin is predominantly a silicate environment. As shown in this study, these apparent ages are also the product of possible mixing occurring within the system, so should be interpreted in conjunction with the corresponding tritium results and any other information available.

Groundwater samples were taken from Albion well 3, the Bond well, the IDWR wells 1, 2, 3, and 4, and the Police Station well. The samples were collected in triple-rinsed 1-liter polyethylene plastic bottles after the wells were purged, and shipped to Beta Analytic Inc. in Miami, Florida for analysis. Here, the Dissolved Inorganic Carbon (DIC) in the water is precipitated out for radiocarbon analysis via Accelerator Mass Spectrometry (AMS) (Hood, 2011). Results are reported both as fraction of modern water (Fmdn) and as apparent radiocarbon years before present (Table B1).

Sample	Date Sampled	Apparent ^{14}C Age (fraction modern)	$^{13}C/^{12}C$ Ratio
IDWR 4	09/07/10	25700 +/- 120 BP (Fmdn 0.0408 +/- 0.0006)	-15.2 ‰
IDWR 3	09/23/10	10040 +/- 50 BP (Fmdn 0.2865 +/- 0.0017)	-14.2 ‰
IDWR 2	09/23/10	9120 +/-50 BP (Fmdn 0.3213 +/- 0.0020)	-15.3 ‰
IDWR 1	09/23/10	2550 +/- 30 BP (Fmdn 0.7280 +/- 0.0027)	-14.3 ‰
Albion 3	10/22/10	18120 +/- 70 BP (Fmdn 0.1048 +/- 0.0009)	-14.5 ‰
Bond	12/28/10	2730 +/- 30 BP (Fmdn 0.7119 +/- 0.0026)	-16.2 ‰
Police Station	04/29/11	7740 +/- 50 BP (Fmdn 0.3815 +/- 0.0023)	-14.8 ‰

Table B1. *^{14}C results.*

APPENDIX C:

WELL INFORMATION AND WELL LOGS

The lack of well identification numbers on many of the wells and inaccuracies in using the U.S.P.L.S.S. to locate each well made tracking down the correct well log difficult. The well logs that could be identified with confidence for the wells sampled in this study are provided in this appendix. Producing depths and elevations for those wells whose logs could not be found were estimated by looking at surrounding well logs in the area. If construction details varied significantly or no local well log could be located, no specific producing depth or elevation was assigned to the well. It was sufficient for most of the purposes of this investigation just to identify the well simply as being completed in the Upper Aquifer or Lower Aquifer. Those wells whose depth and elevation are uncertain were not used in the graphs depicting these characteristics. Table C1 contains the known well information.

Well Name	UTM Coordinates			Degree Decimals		Producing Depth (fbgs)	Producing Elevation (famsl)	Aquifer
	Zone	Easting	Northing	Latitude	Longitude			
1990 Pavel	11	500394	5177750	46.75330	-116.9948	145	2494	Upper
2200 Polk	11	500453	5178015	46.75569	-116.9941	212	2450	Upper
2295 Polk	11	500294	5178095	46.75641	-116.9962	240	2411	Upper
2350 Trail	11	502035	5177835	46.75406	-116.9734	205	2479	Upper
2351 Orchard	11	501022	5178188	46.75724	-116.9866	112	2574	Upper
2485 Polk	11	500313	5178292	46.75818	-116.9959	167	2497	Upper
3100 W. Twin	11	503066	5179573	46.76970	-116.9598	208	2478	Upper
3240 MV	11	502519	5179957	46.77316	-116.9670	154	2538	Upper
568 Pavel	11	500400	5177836	46.75408	-116.9948	205	2436	Upper
Albion 3	11	480816	5181334	46.78527	-117.2513	198	2192	Lower
Appaloosa	11	497068	5175541	46.73342	-117.0384	135	2407	Upper
B1	11	499568	5174849	46.72719	-117.0057	13	2548	Upper
B2	11	499575	5174821	46.72694	-117.0056	15	2546	Upper
Bond	11	499551	5174827	46.72700	-117.0059	190	2371	Upper
Bovill 1	11	498095	5175372	46.73190	-117.0249	4	2535	Upper
Bovill 2	11	498098	5175373	46.73191	-117.0249	4	2535	Upper
Bovill 3	11	498103	5175371	46.73189	-117.0248	4	2535	Upper
Brandt	11	499862	5176954	46.74614	-117.0018	156	2498	Upper
CE (Champion Electric)	11	495742	5176207	46.73941	-117.0557	335	2184	Lower
Clay Street	11	472794	5193476	46.89426	-117.3571	450	1514	Lower
Cornelius	11	489176	5170922	46.69177	-117.1416	226	2229	Lower
Craig	11	500475	5177737	46.75318	-116.9938	145	2504	Upper
D19D	11	497992	5175377	46.73194	-117.0263	138	2405	Upper
Davis	11	507364	5176428	46.74136	-116.9036	118	2640	Granite
Fairview	11	471887	5191022	46.87214	-117.3689	722	1384	Lower
Frisbey	11	500411	5177527	46.75129	-116.9946	145	2476	Upper
Glenwood 1	11	478522	5197370	46.92951	-117.2821	112	1978	Lower
Grauke	11	500614	5177719	46.75302	-116.9920	158	2497	Upper
Gregory's	11	503856	5174359	46.72277	-116.9495	121	2474	Upper
GWFL 1	11	498100	5175334	46.73156	-117.0249	†	†	Upper
GWFL 10	11	498099	5175322	46.73145	-117.0249	†	†	Upper
GWFL 2	11	498083	5175346	46.73166	-117.0251	†	†	Upper
GWFL 3 (S12D)	11	498090	5175331	46.73153	-117.0250	120	2425	Upper

Table C1. *Well information.*
† Actual depth/elevation unknown.

Well Name	UTM Coordinates			Degree Decimals		Producing Depth (fbgs)	Producing Elevation (famsl)	Aquifer
	Zone	Easting	Northing	Latitude	Longitude			
GWFL 4 (T8S)	11	498080	5175313	46.73137	-117.0251	13	2535	Upper
GWFL 5	11	498069	5175330	46.73152	-117.0253	†	†	Upper
GWFL 6 (H12S)	11	498044	5175332	46.73154	-117.0256	13	2534	Upper
GWFL 7 (J12S)	11	498025	5175353	46.73173	-117.0258	13	2532	Upper
GWFL 8	11	497997	5175377	46.73194	-117.0262	†	†	Upper
GWFL 9 (N18S)	11	498039	5175375	46.73193	-117.0257	15	2529	Upper
Helbling	11	500179	5177807	46.75381	-116.9977	145	2506	Upper
IDWR 1	11	498498	5177093	46.74739	-117.0197	65	2578	Upper
IDWR 2	11	497969	5177073	46.74720	-117.0266	275	2333	Upper
IDWR 3	11	497963	5177074	46.74721	-117.0267	350	2258	Upper
IDWR 4	11	497956	5177075	46.74722	-117.0268	735	1889	Lower
INEL-D	11	498091	5175342	46.73163	-117.0250	197	2350	Upper
INEL-S	11	498091	5175342	46.73163	-117.0250	94	2452	Upper
J16D	11	498025	5175361	46.73180	-117.0258	66	2480	Upper
John Rubino	11	502996	5175114	46.72957	-116.9608	†	†	Upper
Kizer	11	501966	5177816	46.75389	-116.9743	190	2496	Upper
Merrell	11	500449	5177897	46.75462	-116.9941	145	2506	Upper
Miller	11	502870	5177281	46.74907	-116.9624	164	2460	Upper
Moscow 2	11	499831	5175711	46.73495	-117.0022	239	2329	Upper
Moscow 6	11	500366	5176529	46.74231	-116.9952	1105	1384	Lower
Moscow 8	11	498990	5176315	46.74039	-117.0132	1218	1158	Lower
Moscow 9	11	497529	5175673	46.73460	-117.0323	948	1610	Lower
MVP (Mtn. View Park)	11	502112	5176611	46.74305	-116.9723	344	2256	Upper
P MW-1	11	503686	5174810	46.72683	-116.9518	11	2583	Upper
P MW-2	11	503686	5174797	46.72672	-116.9518	10	2583	Upper
P MW-3	11	503696	5174797	46.72672	-116.9516	11	2582	Upper
P MW-4	11	503664	5174796	46.72671	-116.9520	12	2581	Upper
P MW-5	11	503665	5174778	46.72655	-116.9520	11	2582	Upper
P MW-6	11	503653	5174787	46.72663	-116.9522	12	2581	Upper
P-A	11	503659	5174782	46.72658	-116.9521	11	2582	Upper
Palouse 1	11	494493	5195152	46.90988	-117.0723	259	2171	Lower
Palouse 3	11	493694	5194707	46.90587	-117.0828	418	2088	Lower
Parker Farm	11	503402	5174671	46.72558	-116.9555	492	2116	Upper

Table C1 cont. *Well information.*
† Actual depth/elevation unknown.

Well Name	UTM Coordinates			Degree Decimals		Producing Depth (fbgs)	Producing Elevation (famsl)	Aquifer
	Zone	Easting	Northing	Latitude	Longitude			
P-B	11	503655	5174770	46.72647	-116.9522	11	2582	Upper
P-C	11	503664	5174789	46.72664	-116.9520	11	2582	Upper
Police Station	11	499971	5175352	46.73171	-117.0004	114	2450	Upper
Pullman 3	11	486207	5175407	46.73207	-117.1805	105	2237	Lower
Pullman 5	11	486056	5173337	46.71345	-117.1824	694	1755	Lower
Pullman 6	11	486787	5177123	46.74753	-117.1730	399	2025	Lower
Pullman 7	11	486516	5175822	46.73582	-117.1765	497	1845	Lower
Pullman 8	11	486522	5174359	46.72265	-117.1764	561	1953	Lower
Q16D	11	498075	5175292	46.73117	-117.0252	72	2474	Upper
S & B 1 (Slurp and Burp)	11	502742	5174787	46.72663	-116.9641	30	2603	Upper
S & B 2 (Slurp and Burp)	11	502853	5174788	46.72664	-116.9627	100	2533	Upper
SASa	11	499665	5174824	46.72697	-117.0044	9	2546	Upper
SASb	11	499711	5174793	46.72669	-117.0038	30	2525	Upper
T16D	11	498070	5175362	46.73181	-117.0253	67	2478	Upper
TS 1	11	503079	5179662	46.77050	-116.9597	226	2456	Upper
TS 2	11	503185	5179888	46.77253	-116.9583	70	2662	Upper
U3D	11	498083	5175290	46.73116	-117.0251	81	2466	Upper
UI 5	11	497876	5175143	46.72984	-117.0278	200	2417	Upper
UI 6	11	497876	5175109	46.72953	-117.0278	329	2290	Upper
UI 7	11	497874	5175141	46.72982	-117.0278	315	2297	Upper
UI Arboretum	11	498561	5173429	46.71441	-117.0188	40	2450	Upper
UI3	11	498399	5175935	46.73696	-117.0210	999	1569	Lower
UI4	11	498100	5175726	46.73508	-117.0249	717	1835	Lower
Wilson 1	11	502386	5178871	46.76339	-116.9688	150	2497	Upper
Wilson 2	11	502339	5178864	46.76332	-116.9694	166	2478	Upper
Wood	11	502746	5174066	46.72014	-116.9641	118	2504	Upper
WSU 4	11	486935	5175191	46.73014	-117.1805	162	2198	Lower
WSU 6	11	488020	5175640	46.73421	-117.1568	522	2014	Lower
WSU 7	11	487027	5175073	46.72908	-117.1698	745	1645	Lower
WSU 8	11	488559	5175391	46.73197	-117.1497	671	1934	Lower

Table C1 cont. *Well information.*
† Actual depth/elevation unknown.

Form 238-7
6/07

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

RECEIVED
APR 30 2010
IDWR/North

1. WELL TAG NO. D D0056785
Drilling Permit No. 858893
Water right or injection well #
2. OWNER: Philip McMurray
Name
Address 2200 North Polk
City Moscow State ID Zip 83843

3. WELL LOCATION:
Twp. 39 North ☒ or South ☐ Rge. 5 East ☐ or West ☒
Sec. 5 1/4 N/E 1/4 N/W 1/4
Gov't Lot County Latah
Lat. 46° 45 326 (Deg. and Decimal minutes)
Long. 116° 59: 657 (Deg. and Decimal minutes)
Address of Well Site 2200 North Polk City Moscow
Lot. Blk. Sub. Name

4. USE:
☒ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation ☐ Thermal ☐ Injection ☐ Other

5. TYPE OF WORK:
☒ New well ☐ Replacement well ☐ Modify existing well ☐ Abandonment ☐ Other

6. DRILL METHOD:
☒ Air Rotary ☐ Mud Rotary ☐ Cable ☐ Other

7. SEALING PROCEDURES:

Seal material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method/procedure
Bitonite	0	140	37 Sacks	Pour

8. CASING/LINER:

Diameter (nominal)	From (ft)	To (ft)	Gauge/Schedule	Material	Casing	Liner	Threaded	Welded
6"	+2	140	.250	Steel	☒	☐	☐	☒
4"	20	243	160PSI	Plastic PVC	☐	☒	☐	☐

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s)

9. PERFORATIONS/SCREENS:
Perforations ☒ Y ☐ N Method Drill
Manufactured screen ☐ Y ☒ N Type -
Method of installation With Drill

From (ft)	To (ft)	Slot size	Number/ft.	Diameter (nominal)	Material	Gauge or Schedule
-180	243	3/4	60	4"	PVC	160 PSi

Length of Headpipe N/A Length of Tailpipe N/A
Packer ☐ Y ☒ N Type

10. FILTER PACK:

Filter Material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method
none				

11. FLOWING ARTESIAN:
Flowing Artesian? ☐ Y ☒ N Artesian Pressure (PSIG)
Describe control device Well Cap

12. STATIC WATER LEVEL and WELL TESTS:
Depth first water encountered (ft) 219 Static water level (ft) 166
Water temp. (°F) 53° Bottom hole temp. (°F)
Describe access port Well Cap

Well test:

Drawdown (feet)	Discharge or yield (gpm)	Test duration (minutes)
	50	60

Test method: Pump ☐ Bailer ☐ Air ☒ Flowing artesian ☐

Water quality test or comments: Clean

13. LITHOLOGIC LOG and/or repairs or abandonment:

Bore Dia. (in)	From (ft)	To (ft)	Remarks, lithology or description of repairs or abandonment, water temp.	Water Y	Water N
10	0	3	Brown Top Soil		
	3	18	Tan Clay		
	18	22	Cementing Sand		
	22	35	tan Clay		
	35	40	yellow Clay		
8	40	60	Broken Basalt		
	60	65	med Basalt		
	65	80	med Soft Basalt		
	80	100	Cementing Sand		
	100	128	Cementing Sand		
	128	140	med Basalt		
	140	143	med Basalt		
6	143	200	Med Basalt		
	200	219	med Basalt		
	219	220	Soft Basalt-5gpm	✓	
	220	228	med Soft Basalt		
	228	230	Soft Basalt-45gpm	✓	
	230	243	Med Basalt		

SCANNED
MAY 06 2010
ENTERED DBV

Completed Depth (Measurable): 243Ft
Date Started: 3-25-10 Date Completed: 3-31-10

14. DRILLER'S CERTIFICATION:
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Company Name Action Drilling Co. No. 618
*Principal Driller Alvin [signature] Date 4-27-10
*Driller Date
*Operator II Date
Operator I [signature] Date 4-27-10

* Signature of Principal Driller and rig operator are required.

39N 05W 05

2200 Polk

Form 238-7
6/93

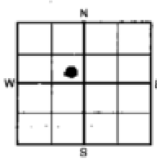
Use Typewriter or Ball Point Pen

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

1. DRILLING PERMIT NO. 87-94-N-14-000
Other IDWR No.

2. OWNER:
Name Darrell E Paul
Address 2223 Cumanian Loop Rd
City Moscow State Id Zip 83843

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.



T. 39N North ☑ or South ☐
R. 5W East ☐ or West ☑
Sec. 4, ___ 1/4 SE 1/4 NW 1/4
Gov't Lot ___ County Latah

Address of Well Site 1 mile east of Moscow
(Give at least Direction + Distance to Road or Landmark)

Lot No. ___ Block No. ___ Subd. Name ___

4. PROPOSED USE:
☑ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other ___

5. TYPE OF WORK
☑ New Well ☐ Modify or Repair ☐ Replacement ☐ Abandonment

6. DRILL METHOD
☐ Mud Rotary ☑ Air Rotary ☐ Cable ☐ Other ___

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
Bentonite	0	40	10 sacks	dry

Was drive shoe seal tested? Y☐ N☑ How? ___

8. CASING/LINER:

Diameter	From	To	Guage	Casing	Liner	Steel	Plastic	Welded	Threaded
6"	+2	179	250	✓		☑	☐	☑	☐
4"	170	235			✓	☐	☑	☐	☐
						☐	☐	☐	☐
						☐	☐	☐	☐

Final location of shoes ___
Top Packer or Headpipe ___ Bottom Tailpipe ___

9. PERFORATIONS/SCREENS
☐ Perforations Method ___
☐ Screens Type ___ Material ___

From	To	Slot Size	Number	Diameter	Tele/Pipe Size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐

SE NW 4 39N 5W

10. WELL TESTS:
☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Depth	Time
30			

Temperature of water ___ Was a water analysis done? Yes ☐ No ☐
By whom? ___
Water Quality (odor, etc.) ___
Bottom Hole Temperature ___

11. STATIC WATER LEVEL:
___ ft. below surface Depth artesian flow found ___
Artesian pressure ___ lb. Describe access port ___
Describe Controlling Devices: ___

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	GPM	SWL
8	0	3	dirt		
	3	72	clay sticky		
	72	86	sand soft		
	86	142	clay		
	142	149	wood and sand		
	149	176	sandy clay		
6	176	235	basalt hard		✓

Date: Started May 13, 94 Completed May 16, 94

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Uhlenkott Drilling Firm No. 125
Firm Official Ray Uhlenkott Date May 23, 94
and
Supervisor or Operator Wm Uhlenkott Date May 23, 94
(Sign once if Firm Official & Operator)

FORWARD WHITE COPY TO WATER RESOURCES

2350 Trail

RECEIVED

Form 238-7 SEP 26 2000
11/97

IDWR/North

IDAHO DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

RECEIVED OCT 11 2000 IDWR/North

Office Use Only
Inspected by ______
Twp ____ Rge ____ Sec ____
____ 1/4 ____ 1/4 ____ 1/4
Lat: : : Long: : :

1. WELL TAG NO. D 0013741

DRILLING PERMIT NO. ______

Other IDWR No. 766725

2. OWNER:
Name Dave Rizzau
Address 8705 NE Rising Star Lane
City Newburg State OR Zip 97132

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

POSTED

Twp. 40 North ☑ or South ☐
Rge. 5 East ☐ or West ☑
Sec. 33, ____ 1/4 NW 1/4 NE 1/4
Gov't Lot ____ County Latah
Lat: : : Long: : :
Address of Well Site ______
(Give at least name of road + Distance to Road or Landmark) City ______
Lt. ____ Blk. ____ Sub. Name ______

4. USE:
☑ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other ______

5. TYPE OF WORK check all that apply (Replacement etc.)
☑ New Well ☐ Modify ☐ Abandonment ☐ Other ______

6. DRILL METHOD
☑ Air Rotary ☐ Cable ☐ Mud Rotary ☐ Other ______

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
Bentonite	0	50	6 bags	Top Pour

Was drive shoe used? ☐Y ☑N Shoe Depth(s) ______
Was drive shoe seal tested? ☐ Y ☐ N How? ______

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
6"	+2	94	.250	steel	☑	☐	☑	☐
4 1/2	-75	175	160	PVC	☐	☑	☐	☐
					☐	☐	☐	☐

Length of Headpipe ______ Length of Tailpipe ______

9. PERFORATIONS/SCREENS
Perforations Method Saw
Screens Screen Type ______

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
134	174	1/8	20		PVC	☐	☑
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
68 ft. below ground Artesian pressure ____ lb.
Depth flow encountered ____ ft. Describe access port or control devices: Top of well

11. WELL TESTS:
☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
12 gpm			

Water Temp. 54° Bottom hole temp. ______
Water Quality test or comments: Good
Depth first Water Encounter 168 ft

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
8	0	2	dirt		✓
	2	90	clay		
6"	90	173	basalt	✓	

RECEIVED
Department of Water Resources

Completed Depth ~~170 ft~~ 173 ft (Measurable)
Date: Started 9/20/00 Completed 9/21/00

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Company Name Uhlenkott Firm No. ~~120~~ 125
Firm Official Ray Uhlenkott Date 9/23/00
and
Driller or Operator [signature] Uhlenkott Date 9/23/00
(Sign once if Firm Official & Operator)

40N 5W 33 FORWARD WHITE COPY TO WATER RESOURCES

Form 238-7
1/94

POSTED

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

Use Typewriter or Ball Point Pen

1. DRILLING PERMIT NO. 87-94-N-48-000
Other IDWR No.

2. OWNER:
Name Don Schiebe
Address 224 E. E St.
City Moscow State Id Zip 83843

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

Twp. 39N North ☐ or South ☐
Rge. 5W East ☐ or West ☐
Sec. 5, SE 1/4 SE 1/4 ___ 1/4
Gov't Lot ___ County Latah

Address of Well Site Lane off M. Polk
City
(Give at least name of road + Distance to Road or Landmark)

Lt. ___ Blk. ___ Sub. Name ___

4. PROPOSED USE:
☒ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other

5. TYPE OF WORK
☒ New Well ☐ Modify or Repair ☐ Replacement ☐ Abandonment

6. DRILL METHOD
☐ Mud Rotary ☒ Air Rotary ☐ Cable ☐ Other

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
bentonite	0	50	50 lbs.	slurry

Was drive shoe used? Y ☑ N ☐
Was drive shoe seal tested? Y ☐ N ☑ How?

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
8"	+	114	.250	Steel	☑	☐	☑	☐
					☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe ___ Length of Tailpipe ___

9. PERFORATIONS/SCREENS
☐ Perforations Method
☐ Screens Screen Type

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
120 ft. below ground Artesian pressure ___ lb.
Depth flow encountered 145 ft. Describe access port or control devices:
SESE 5 39N 5W

11. WELL TESTS:
☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
approx. 40			

Water Temp. ___ Bottom hole temp. ___
Water Quality test or comments:

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
10	0	50	overburden		✓
8	50	113	overburden		✓
8	113	145	basalT, firm		✓
8	145	146	FracT. basalT	✓	

RECEIVED
SEP 23 1994
NORTHERN REGION
IDWR

007916

Completed Depth 146 (Measurable)
Date: Started 8/29/94 Completed 9/2/94

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Witt Well Drilling Firm No.
Firm Official Earl L Witt Date 9/2/94
and
Supervisor or Operator Roger Witt Date 9/16/94
(Sign once if Firm Official & Operator)

FORWARD WHITE COPY TO WATER RESOURCES

568 Pavel

ALBION TOWN WELL NO. 3 - WELL LOG

DRILLED AUGUST, 1978, BY

UHLENKOTT WELL DRILLING, FENN, IDAHO

Location: NW ¼, SE ¼ Sec. 15, T. 15 N., R. 44 E., W.M., Whitman County, State of Washington.

Depth(ft.)		Material
0-2		Fill Dirt
2-29		Medium Soft Basalt
29-35		Soft Decomposed Rock w/Brown Seams
35-68		Soft Broken Basalt, Brown Seams
68-93		Hard Black Basalt
93-97		Medium Hard Brown Basalt
97-110		Hard Black Basalt
110-114		Medium Soft Black Basalt w/Brown Seams
114-117		Medium Hard Black Basalt w/Green Seams
117-119		Medium Hard Black Basalt w/Brown Seams
119-125		Hard Grey Basalt
125-128		Medium Soft Grey Basalt
128-136	CONFINING LAYER	Very Soft Whitish Brown Clay
136-140		Medium Hard Basalt
140-147		Soft Decomposed Rock
147-154		Medium Hard Black Basalt
154-161		Soft Colored Rock
161-165		Medium Soft Black Basalt
165-172		Soft Basalt w/Tannish Seams (some water)
172-183		Soft Rotten Rock w/some clay
183-212		Soft Green Clay
212-216		Medium Hard Basalt w/Green Seams(water)
216-247		Hard Basalt w/Green Seams
247-252		Medium Soft Black Basalt w/Green Seams
252-265		Medium Soft Black Basalt w/Green Seams
265-287		Soft Green Rock w/some clay
287-320		Unknown
320-380		Soft to Medium Hard Granite

Rotary Drilled

L00800-03 Albion Water Dist.

Albion 3

RECEIVED
JAN 11 1984
Department of Water Resources

Form 238-7
1/78

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name: Appaloosa Horse Club
Address: Moscow
Owner's Permit No. 87-83-N-11

2. NATURE OF WORK

☑ New well ☐ Deepened ☐ Replacement
☐ Abandoned (describe method of abandoning) ____

3. PROPOSED USE

☑ Domestic ☐ Irrigation ☐ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ____ (specify type)

4. METHOD DRILLED

☑ Rotary ☑ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other ____

5. WELL CONSTRUCTION

Casing schedule: ☑ Steel ☐ Concrete ☐ Other ____

Thickness	Diameter	From	To
.250 inches	8 inches	+ 1 feet	55 feet
inches	inches	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet

Was casing drive shoe used? ☑ Yes ☐ No
Was a packer or seal used? ☐ Yes ☑ No
Perforated? ☐ Yes ☑ No
How perforated? ☐ Factory ☐ Knife ☐ Torch
Size of perforation ____ inches by ____ inches

Number	From	To
perforations	feet	feet
perforations	feet	feet
perforations	feet	feet

Well screen installed? ☐ Yes ☑ No
Manufacturer's name ____
Type ____ Model No. ____
Diameter ____ Slot size ____ Set from ____ feet to ____ feet
Diameter ____ Slot size ____ Set from ____ feet to ____ feet
Gravel packed? ☐ Yes ☑ No ☐ Size of gravel ____
Placed from ____ feet to ____ feet
Surface seal depth 55 Material used in seal: ☐ Cement grout ☑ Puddling clay ☐ Well cuttings
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☑ Overbore to seal depth
Method of joining casing: ☐ Threaded ☑ Welded ☐ Solvent Weld
☐ Cemented between strata
Describe access port ____

6. LOCATION OF WELL

Sketch map location must agree with written location.

N / W / E / S

Subdivision Name ____
Lot No. ____ Block No. ____
County LATAH
NW ¼ SW ¼ Sec. 8, T. 39 N, R. 6 W.

7. WATER LEVEL

Static water level 20 feet below land surface.
Flowing? ☐ Yes ☑ No G.P.M. flow 100+
Artesian closed-in pressure ____ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ____ °F. Quality ____

8. WELL TEST DATA

☐ Pump ☐ Bailer ☑ Air ☐ Other ____

Discharge G.P.M.	Pumping Level	Hours Pumped

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
10	0	29	[illegible]		✓
10	29	42	[illegible] broken		✓
10	42	55	[illegible]		✓
8	55	214	basalt hard	✓	

CC5459

RECEIVED
JAN 5 1984
Department of Water Resources
Northern District Office

MICROFILMED

10. Work started 1/15/83 finished 1/18/83

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Earl Witt Well Drilling No. 58
Address 1017 [illegible] Lewiston Date 11/14/83
Signed by (Firm Official) Earl L. Witt
and
(Operator) Roger L. Witt

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Appaloosa Horse Club

Soil Boring Log
University of Idaho

Hole No.	Bond 3
Page	1/1
Logged by	K. Brackney

Project	Bond/Sweet Ave	Elevation	
Location		Northing	
Date began	3/5/93	Easting	
Date completed	3/5/93	Total depth	16.8 ft.
Sampling method	CME Soil Core	Hole diameter	8 1/4 in
Equipment	SIMCO/HSA	Screen interval	10-15 ft.
Scale 1"=4'			

Depth (ft)	Sample interval/Recovery	Sample ID	Soil Description Color, texture, moisture, etc.	Unified Classification	Graphic Log		Well Construction/ Abandonment	
0		0	0-3.2' Black soil, roots	OL		0		0
		(4')	3.2'-4' lt. brn soil, roots	OL		3.2		Bentonite
4		4	4-5.8' gy-brn clay	ML		4		
		(5')	5.8-7.2' silty clay brn-grn mottled, mica	ML		5.8		
8			7.2-8.8' gry-grn mica silty clay	ML		7.2		7.9
		9'	9-9.4 Med-fn sand, minor silt	SW		8.8		8.5
		(1.6)	9.4'-10.6' lt gy clay w/ thin sand interbed	MH		9.4		10
12	?		10.6-14.8' med-crs sand w/ qtz gravel up to 2" diam. (poor recovery; lost 10.6-14')	SW		10.6		20 slot Well screen
		14'	15.1-15.5' Clean med qtz-Kspar sand + wood frags	CH / SW		14.8 / 15.1 / 15.5		15'
16		(2.5)	15.5-16.8 Sticky, lt gy clay	CH		16.8		8-12 Sand Pack
		16.8			TD		T.D	

Note: Encountered water 8-9' Static W.L. at 3.63' Below PVC Collar. 1.75' PVC stickup 6" diam steel casing, 4' long w/2' stickup.

Soil Boring Log
University of Idaho

Hole No.	Bond 2
Page	1/1
Logged by	K. Brackney

Project	Bond / Sweet Ave	**Elevation**	
Location		**Northing**	
Date began	3/4/93	**Easting**	
Date completed	3/4/93	**Total depth**	17.9'
Sampling method	CME Continuous Core	**Hole diameter**	8 1/4"
Equipment	SIMCO HSA	**Screen interval**	12-17'
Scale 1" = 4'			

Depth (ft)	Sample interval	Sample ID	Soil Description Color, texture, moisture, etc.	Unified Classification	Graphic Log		Well Construction/ Abandonment	
0		0	0-2' med brn organic rich topsoil + tree roots	OL	Fill	0		0
		(0)	2-3.5' top soil surrounding red brick rubble			2		
4						3.5		Bentonite
		5'	5-8.5' mottled med brn clay loam soil; highly struct., roots to 7'	OL		5		
8		(4.8)						
			8.5-9.2' Transition zone			8.5		
		10'	9.2-11.1 gy-grn silt with orang. mottles: micatious, <10% fn sand. @ 10' DTW=7.1'			9.2 11		10.5 11
12		(3.8)	12-±13.5' gy mica silt Occ. wood chip	MH		11.1		12 8-12 Sand Pack
		15	13.5'-16.2' Med-crs loose sand (gy qtz + K-spar)	SW		13.5		20 slot screen
16		(2.2')	16.2-16.7' med-fn gy sand and silt.	SM		16.2 16.7		17'
		17.9	16.7-17.9 Oxidized wood & peat	PT		17.9		17.9

Form 238-7
6/89

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name Steve Brandt

Address Moscow

Owner's Permit No. 87-90-N-2

2. NATURE OF WORK

☑ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase
☐ Abandoned (describe abandonment procedures such as materials, plug depths, etc. in lithologic log)

3. PROPOSED USE

☑ Domestic ☐ Irrigation ☐ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ________ (specify type)

4. METHOD DRILLED

☑ Rotary ☑ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other

5. WELL CONSTRUCTION

Casing schedule: ☑ Steel ☐ Concrete ☐ Other

Thickness	Diameter	From	To
.250 inches	8 inches	+ 1 feet	119 feet
inches	inches	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet

Was casing drive shoe used? ☑ Yes ☐ No
Was a packer or seal used? ☐ Yes ☑ No
Perforated? ☐ Yes ☑ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation ______ inches by ______ inches

Number		From	To
	perforations	feet	feet
	perforations	feet	feet
	perforations	feet	feet

Well screen installed? ☐ Yes ☑ No
Manufacturer's name
Type ________ Model No.
Diameter ____ Slot size ____ Set from ______ feet to ______ feet
Diameter ____ Slot size ____ Set from ______ feet to ______ feet
Gravel packed? ☐ Yes ☑ No ☐ Size of gravel
Placed from ______ feet to ______ feet
Surface seal depth 119 Material used in seal: ☐ Cement grout ☑ Bentonite ☐ Puddling clay ☐
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☑ Overbore to seal depth
Method of joining casing: ☐ Threaded ☑ Welded ☐ Solvent Weld
☐ Cemented between strata
Describe access port

6. LOCATION OF WELL

Sketch map location must agree with written location.

N / W / E / S

Subdivision Name

Lot No. ______ Block No. ______

County Latah

SE ¼ SE ¼ Sec. 6, T. 39 N ☑ / S ☐, R. 5 E ☐ / W ☑

7. WATER LEVEL

Static water level 128 feet below land surface.
Flowing? ☐ Yes ☑ No G.P.M. flow
Artesian closed-in pressure ______ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ____ °F. Quality
Describe artesian or temperature zones below.

8. WELL TEST DATA

☐ Pump ☐ Bailer ☑ Air ☐ Other

Discharge G.P.M.	Pumping Level	Hours Pumped
approx. 5		

9. LITHOLOGIC LOG

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
8	0	45	overburden, clay		✓
8	45	46	Quartz + sand	✓	
8	46	115	clay		✓
8	115	153	basalt, firm	✓	

RECEIVED
MAY 29 1990
NORTHERN REGION
IDWR

10.

Work started 4/11/90 finished 4/13/90

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Witt Well Drilling Firm No. 58

Address 2019 Powers Ln. Date 4/29/90

Signed by (Firm Official) Earl L. Witt

and

(Operator) Roger Witt

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Brandt

RECEIVED
Form 238-7 2/94 ... 2 0 1995 ... REGION IDWR
POSTED

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

Use Typewriter or Ball Point Pen

091413

1. DRILLING PERMIT NO. 87-90-N-2-100
Other IDWR No.

2. OWNER:
Name Steve Brandt
Address
City Moscow State ID Zip 83843

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

N / W / E / S

Twp. 39 North ☑ or South ☐
Rge. 5 East ☐ or West ☑
Sec. 6, ___ 1/4 SE 1/4 SE 1/4 (10 acres, 40 acres, 160 acres)
Gov't Lot ___ County LATAH

Address of Well Site ___
___ City ___
(Give at least name of road + Distance to Road or Landmark)

Lt. ___ Blk. ___ Sub. Name ___

4. PROPOSED USE:
☑ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other ___

5. TYPE OF WORK DEEPEN
☐ New Well ☑ Modify or Repair ☐ Replacement ☐ Abandonment

6. DRILL METHOD
☐ Mud Rotary ☑ Air Rotary ☐ Cable ☐ Other ___

7. SEALING PROCEDURES ✓

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD

Was drive shoe used? ☐ Y ☐ N Shoe Depth(s) ___
Was drive shoe seal tested? Y☐ N☐ How? ___

8. CASING/LINER: ✓

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe ___ Length of Tailpipe ___

9. PERFORATIONS/SCREENS ✓
☐ Perforations Method ___
☐ Screens Screen Type ___

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
135 ft. below ground Artesian pressure ___ lb.
Depth flow encountered ___ ft. Describe access port or control devices: ___

SESE 6 39N 5W

11. WELL TESTS:
☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
approx. 15		275	30 min.

Water Temp. ___ Bottom hole temp. ___
Water Quality test or comments: ___

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
8	154	279	basalT, firm	✓	

RECEIVED AUG 22 1996 Department of Water Resources
MICROFILMED OCT 09 1996

Completed Depth 279' (Measurable)
Date: Started 8/6/94 Completed 8/11/94

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Witt Well Drilling Firm No. 58
Firm Official Earl L Witt Date 12/15/95
and
Supervisor or Operator Roger Witt Date 12/15/95
(Sign once if Firm Official & Operator)

FORWARD WHITE COPY TO WATER RESOURCES

Brandt cont.

JUN-1-95 TUE 16:26 BRA REAL ESTATE 5098841745 P.02

B
4 of 4

UHLENKOTT WELL DRILLING AND SUPPLIES

PUMP SALES AND SERVICE

FENN, IDAHO 83531 Phone 962-3923

Well Log

Depth and Strata

0 feet
Top soil (s)
[illegible] feet
Brown clay(s)
[illegible] feet
Bluish clay(s)
13 feet
[illegible] Gravel - sandy (m.s.)
29 feet
[illegible] gravel w/sand w/broken basalt
44 feet
Black basalt(v.H)
175 feet
Bluish brown clay (s)
150 feet
Bluish brown clay (m.s.)
[illegible] feet
Clay, more yellowish (s)
192 feet
Clay w/basalt chips (s)
[illegible] feet
Black basalt (m.h.)
206 feet
Black basalt w/ blue shale (m.s.)
233 feet
Black basalt (m.h.)
262 feet
Black basalt (m.s.)
71 feet
Black basalt w/blue shale (m.s.)
302 feet
Blue shale (m.s.)
352 feet
Greenish sand (v.s.)
[illegible]4 feet
[illegible]

WELL NO. [illegible]

OWNER OF WELL Kennewick Industrial

LOCATION OF WELL Moscow - Pullman Highway

NEAREST POST OFFICE

STATE Washington COUNTY Whitman

DRILLING BEGUN Oct. 15, 1983 WELL FINISHED Oct. 17, 1983

Well Record

CASING SIZE 8 5/8" x .250 / 6" / 8 inch CASING DEPTH 4" PVC from 16' to [illegible] / 8 5/8" to 47' [illegible]

HOLE SIZE HOLE DEPTH 304 Feet

CAPACITY OF WELL 100 Plus Gallons per minute Static: 234' [illegible]

PUMP SETTINGS Check pump records

CASING PERFORATIONS 60' of 6" PVC from 304' to 364'

Invoice

DATE Oct. 27, 1983

Item	Unit Price	Amount
10 inch drilling -- 47 feet	$ 25.00	$ 1,175.00
8 inch drilling -- 337 feet	13.50	4,549.50
8 inch casing -- 49 feet	9.25	453.25
8 inch drive shoe -- 1	105.00	105.00
Bentonite -- 3 sacks	10.00	30.00
Labor for setting 6" liner 360'	1.25	450.00

TOTAL AMOUNT DUE 6,762.75 [illegible]
5.50 [illegible]

MEMO: Hit water at 300 feet 7 gallon per minute, and again at 360 feet 100 gallon per minute.

Paid 11-10-83 — 6652.— Paid in Full 6652.75

CE (Champion Electric)

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG

No. Appli. 1122
Cert. 660-A

Date November 3, 1949

Record by Paul A. Durand

Source Driller's Record

Location: State of WASHINGTON

County Whitman

Area

Map

Tr. 8, City of Colfax ¼ ¼ sec. 11 T. 16 N., R. 43 E.

DIAGRAM OF SECTION

Drilling Co. A. A. Durand & Son

Address P. O. Box 437; Walla Walla

Method of Drilling Date Nov. 6-7 1949

Owner City of Colfax

Address Colfax, Wash.

Land surface, datum ft. above / below

Correlation	Material	Thickness (feet)	Depth (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses. If material water-bearing, so state and record static level if reported. Give depths in feet below land-surface datum unless otherwise indicated. Correlate with stratigraphic column, if feasible. Following log of materials, list all casings, perforations, screens, etc.)		
	Clay	5	5
	Coarse gravel	3	8
	Cemented gravel	17	25
	Broken basalt	4	29
	Basalt	28	57
	Clay	6	63
	Fractured basalt	26	89
	Hard basalt	2	91
	Honeycomb basalt	5	96
	Hard basalt	4	100
	Softer basalt	2	102
	Hard basalt	7	109
	Fractured basalt with clay seams	2	111
	Hard basalt	3	114
	Broken basalt with clay	14	128
	Honeycomb basalt	9	137

Turn up (over) Sheet of sheets

Clay Street

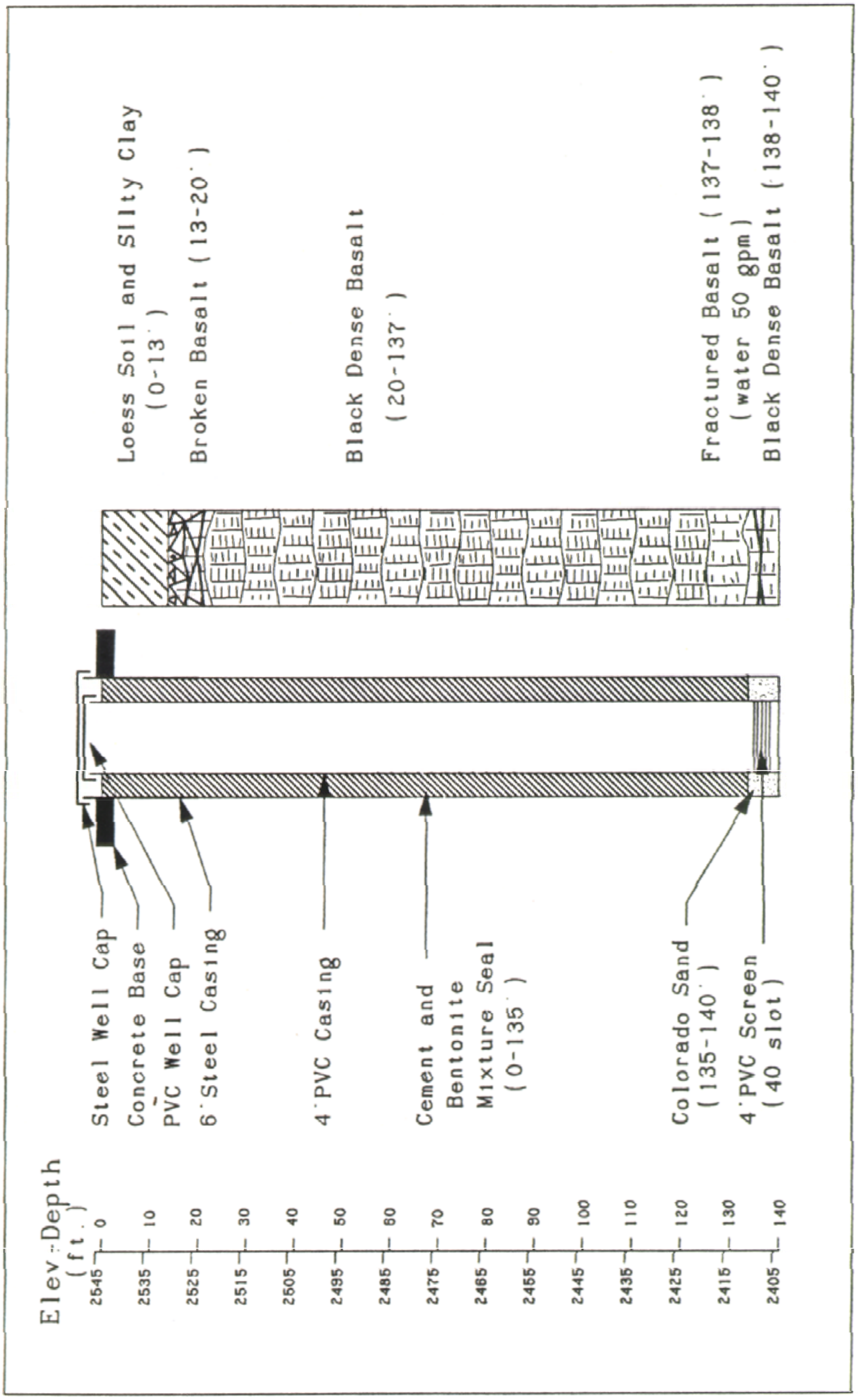
CLAY ST. WELL

WELL LOG.-(Continued) No.____/____-____

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Depth forward	——	
	Yellow clay	9	146
	Fractured basalt	6	152
	Hard basalt	5	157
	Honeycomb basalt	1	158
	Hard basalt	9	167
	Fractured basalt	8	175
	Medium soft basalt	15	190
	Dense basalt with crevices	7	197
	Dense black basalt	35	232
	Black basalt sand (some water)	6	238
	Black basalt	3	241
	Red cinder basalt (some water)	7	248
	Broken red basalt	8	256
	Black cinder basalt	9	265
	Fractured black basalt	8	273
	Conglomerates, caving badly	37	310
	Black basalt, hard	19	329
	Porous black basalt	7	336
	Very hard gray	33	369
	Fractured basalt with blue clay seams	15	384
	Very hard gray basalt	10	394
	Fractured basalt with blue clay seams	72	466
	Very hard gray basalt	29	495
	Sandy basalt (water bearing)	3	498
	Very hard gray basalt	17	515
	Fractured black basalt, caving	30	545
	Very hard basalt	55	600
	Pump Test:		
	Dim: 595' x 20x16 Drilled		
	SWL: 180'		
	DD: 0		
	Yield: 711 g.p.m.		
	Casing: 16 O.D. dia. Ex. Hvy. Std. Well Casing from 0 to 174' & 12½ I.D. dia. Ex. Hvy. Std. Well Casing from 0 to 30		
	Perforations:		
	None Meter 6412C		

S F 7440-46 REMINGTON IRC-10 20 749-24

Clay Street cont.


Elev. Depth
(ft.)
2545 0
2535 10
2525 20
2515 30
2505 40
2495 50
2485 60
2475 70
2465 80
2455 90
2445 100
2435 110
2425 120
2415 130
2405 140
Steel Well Cap
Concrete Base
PVC Well Cap
6" Steel Casing
4" PVC Casing
Cement and
Bentonite
Mixture Seal
(0-135')
Colorado Sand
(135-140')
4" PVC Screen
(40 slot)
Loess Soil and Silty Clay
(0-13')
Broken Basalt (13-20')
Black Dense Basalt
(20-137')
Fractured Basalt (137-138')
(water 50 gpm)
Black Dense Basalt (138-140')

D19D

RECEIVED
DEC 2 0 1995
NORTHERN REGION
IDWR

Form 238-7
7/94

POSTED

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

Use Typewriter or Ball Point Pen

1. DRILLING PERMIT NO. 97-95-N-61-0010
Other IDWR No.

2. OWNER:
Name John Grauke
Address 317 N. Harp
City Moscow State Id Zip 83843

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

Twp. 39 North ☒ or South ☐
Rge. 5 East ☐ or West ☒
Sec. 5 , N 1/4 SE 1/4 1/4
Gov't Lot County Latah

Address of Well Site 2 blocks E. of Polk on Pavel Rd City Moscow
(Give at least name of road + Distance to Road or Landmark)

Lt. Blk. Sub. Name

4. PROPOSED USE:
☒ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other

5. TYPE OF WORK
☒ New Well ☐ Modify or Repair ☐ Replacement ☐ Abandonment

6. DRILL METHOD
☐ Mud Rotary ☒ Air Rotary ☐ Cable ☐ Other

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
bentonite	0	125	400lbs.	dry

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s)
Was drive shoe seal tested? Y ☐ N ☒ How?

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
8	+1	125	.264	Steel	☐	☐	☒	☐
					☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe Length of Tailpipe

9. PERFORATIONS/SCREENS
☐ Perforations Method
☐ Screens Screen Type

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
140 ft. below ground Artesian pressure lb.
Depth flow encountered ft. Describe access port or control devices:

11. WELL TESTS:
☐ Pump ☐ Bailer ☒ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
approx. 30			30 min.

Water Temp. Bottom hole temp.
Water Quality test or comments:

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
10	0	122	overburden		✓
10	122	125	basalt, firm		✓
8	125	149	basalt, firm		✓
8	149	166	soft basalt	✓	

LICSO-FILED 007921
OCT 15 1997

Completed Depth 166 (Measurable)
Date: Started 11/1/95 Completed 11/4/95

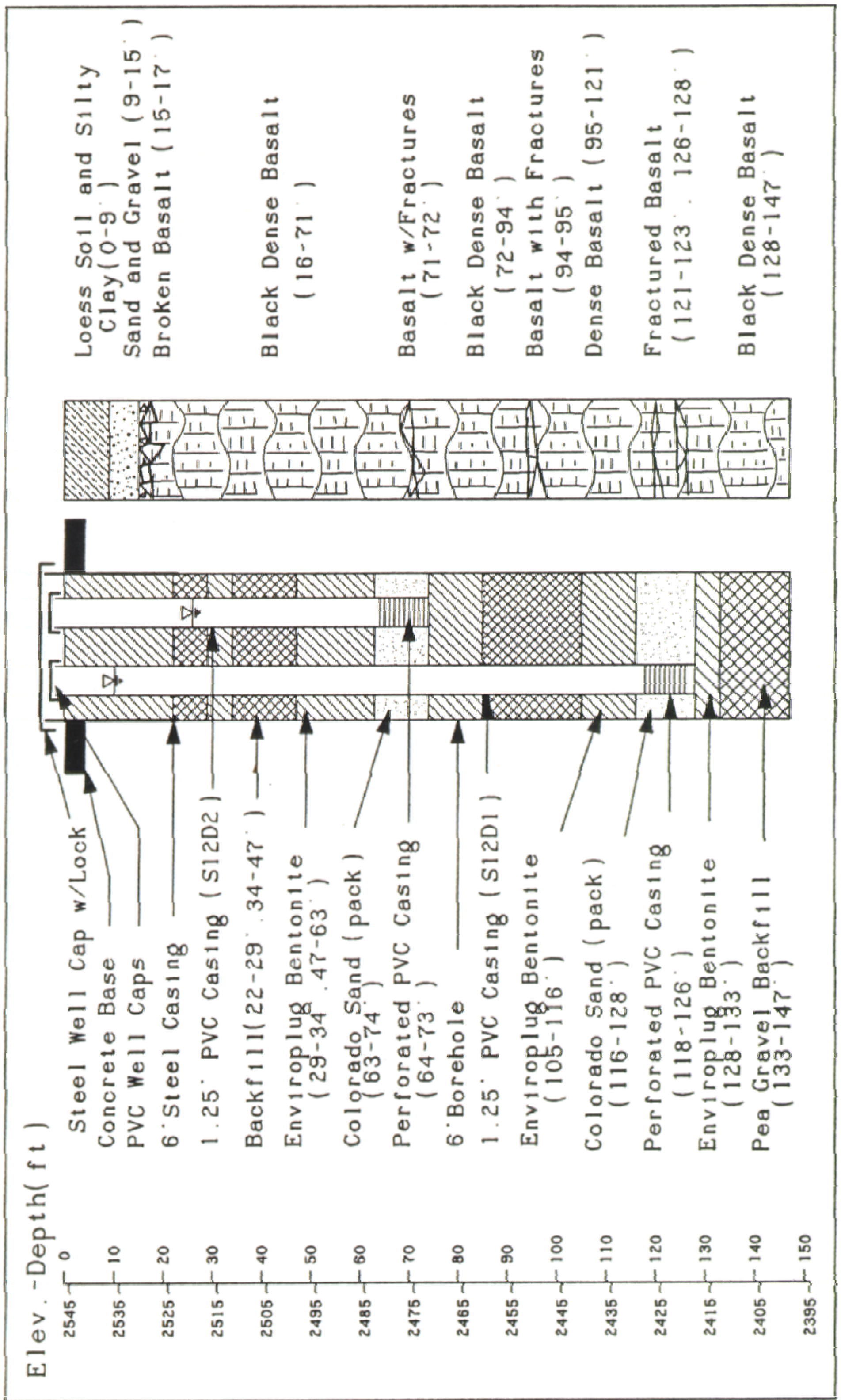
13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Witt Well Drilling Firm No. 58
Firm Official Earl L. Witt Date 11/24/95
and
Supervisor or Operator Roger Witt Date 11/24/95
(Sign once if Firm Official & Operator)

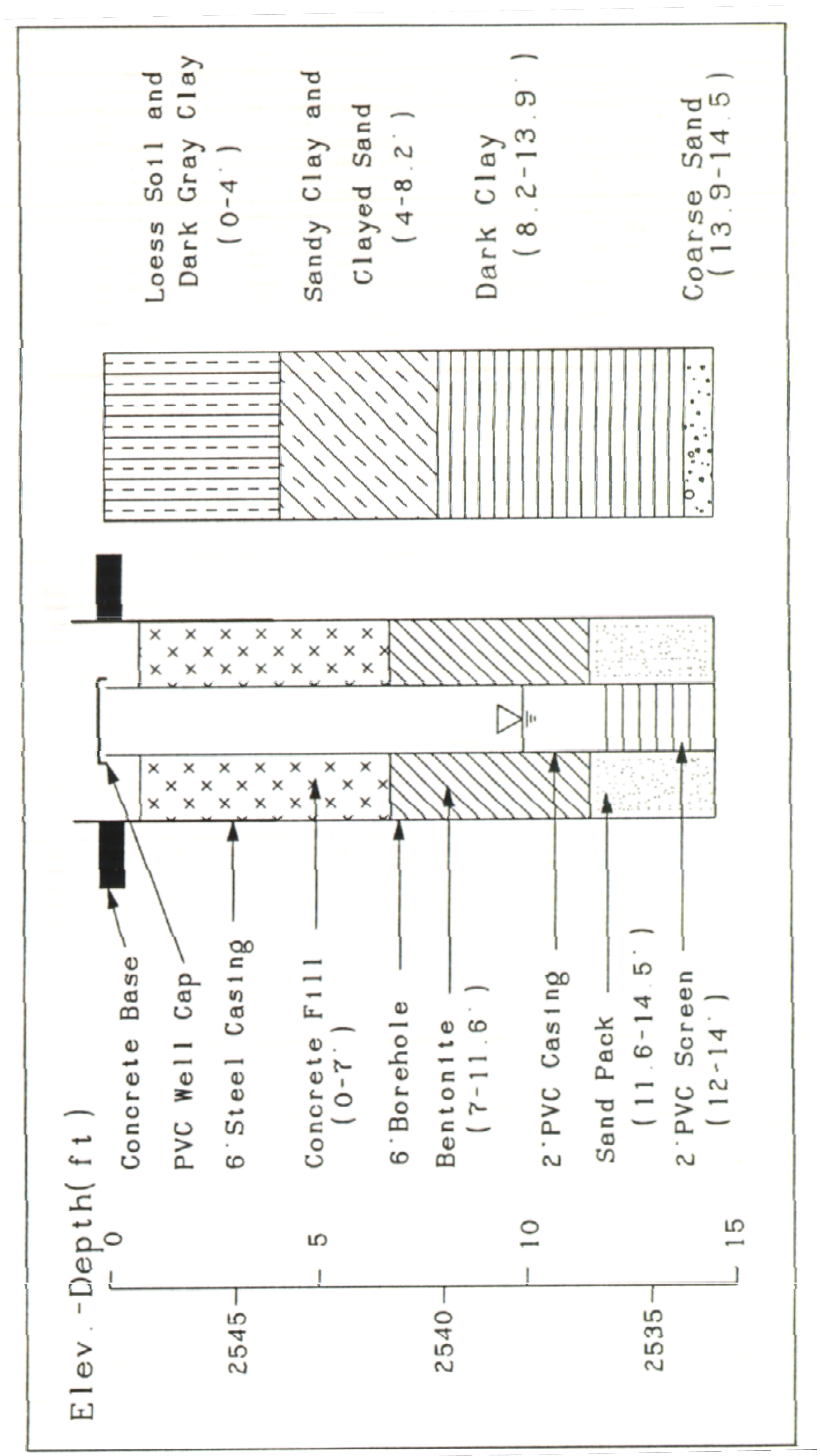
SE 5 39N 5W

FORWARD WHITE COPY TO WATER RESOURCES

Grauke

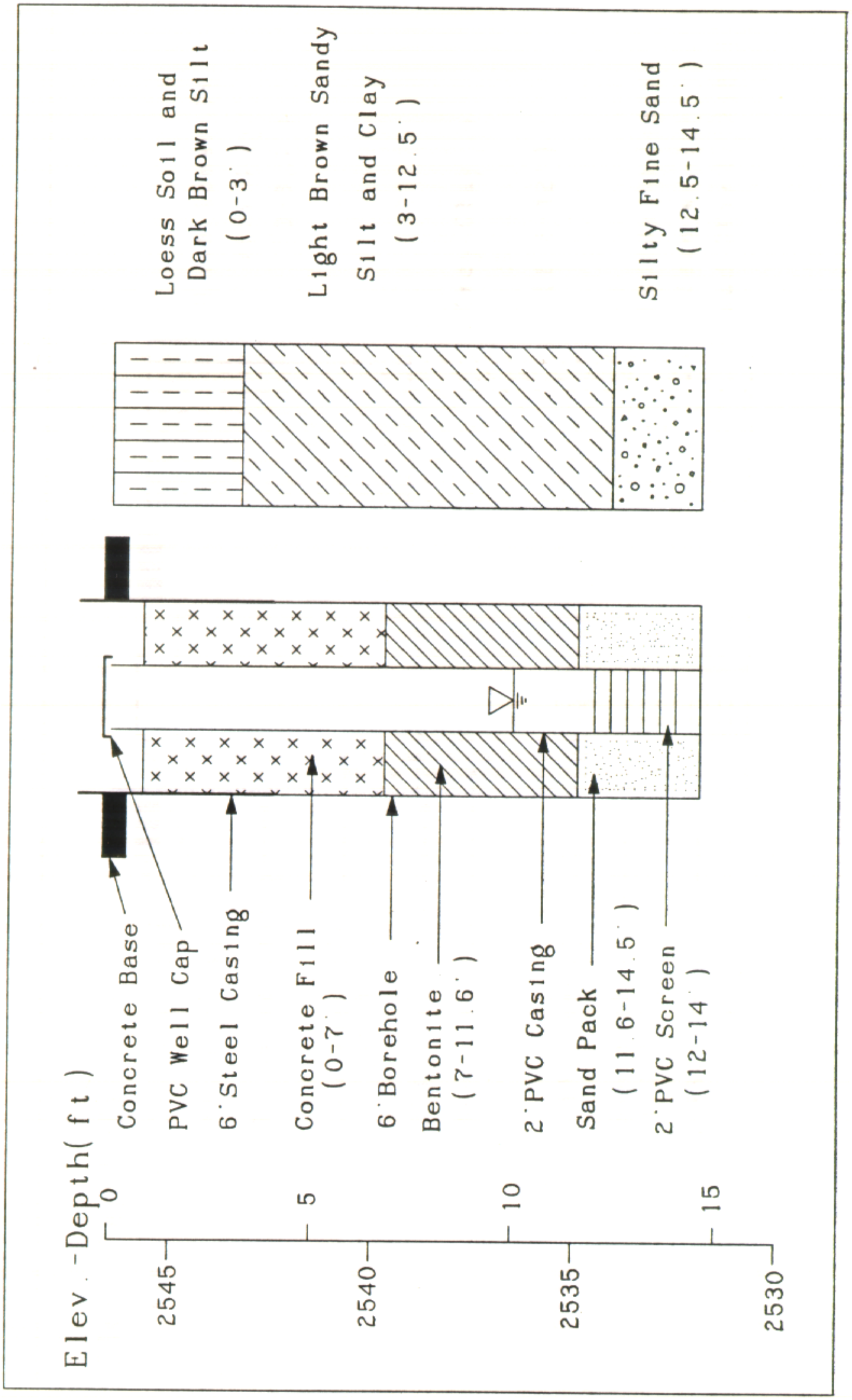

Elev.-Depth(ft)
2545 2535 2525 2515 2505 2495 2485 2475 2465 2455 2445 2435 2425 2415 2405 2395
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Steel Well Cap w/Lock
Concrete Base
PVC Well Caps
6' Steel Casing
1.25' PVC Casing (S12D2)
Backfill(22-29', 34-47')
Enviroplug Bentonite (29-34', 47-63')
Colorado Sand (pack) (63-74')
Perforated PVC Casing (64-73')
6' Borehole
1.25' PVC Casing (S12D1)
Enviroplug Bentonite (105-116')
Colorado Sand (pack) (116-128')
Perforated PVC Casing (118-126')
Enviroplug Bentonite (128-133')
Pea Gravel Backfill (133-147')
Loess Soil and Silty Clay(0-9')
Sand and Gravel (9-15')
Broken Basalt (15-17')
Black Dense Basalt (16-71')
Basalt w/Fractures (71-72')
Black Dense Basalt (72-94')
Basalt with Fractures (94-95')
Dense Basalt (95-121')
Fractured Basalt (121-123', 126-128')
Black Dense Basalt (128-147')

GWFL 3 (S12D)

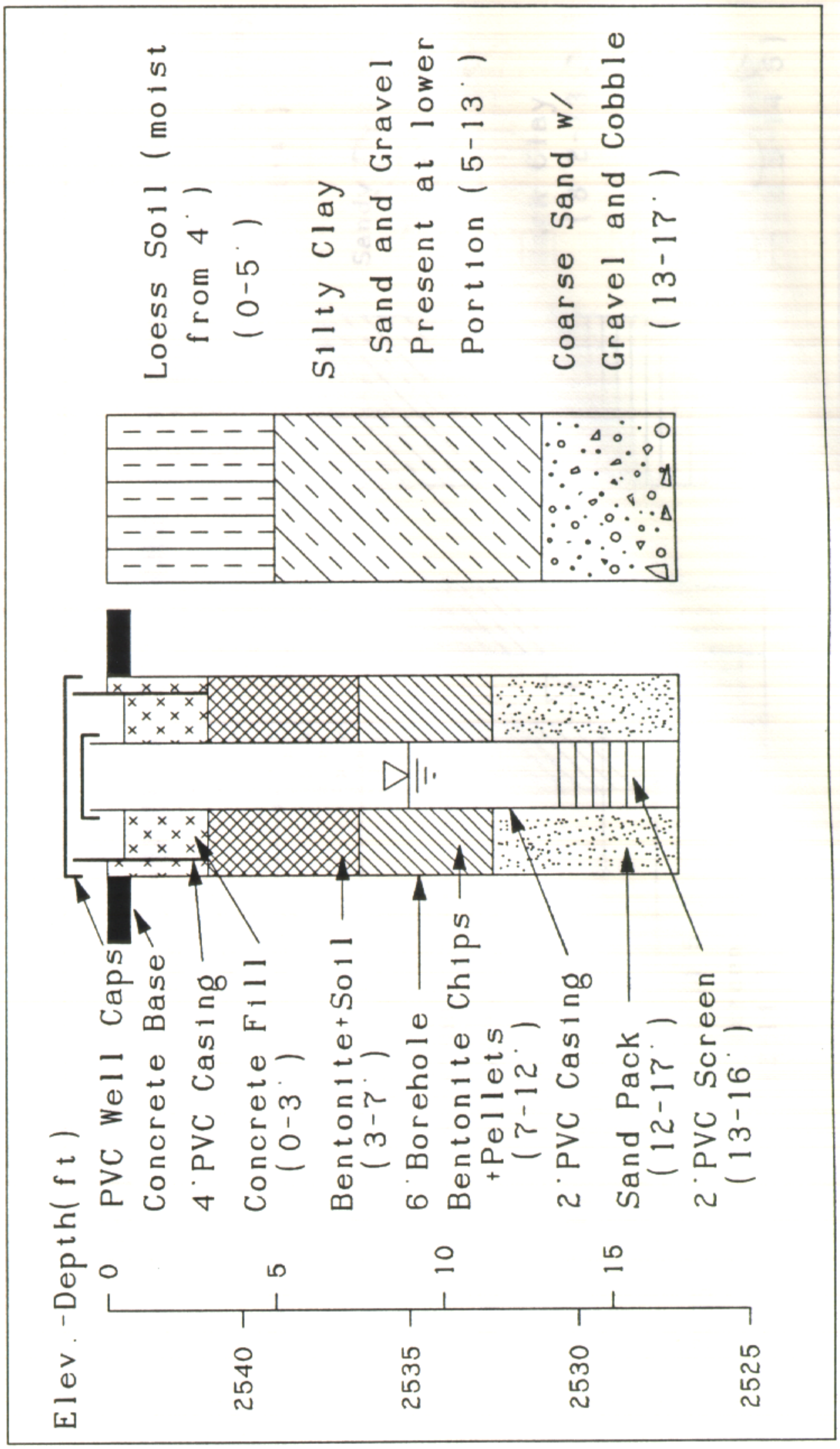


Elev. -Depth(ft)
0
5
10
15
2545
2540
2535
Concrete Base
PVC Well Cap
6" Steel Casing
Concrete Fill
(0-7')
6" Borehole
Bentonite
(7-11.6')
2" PVC Casing
Sand Pack
(11.6-14.5')
2" PVC Screen
(12-14')
Loess Soil and
Dark Gray Clay
(0-4')
Sandy Clay and
Clayed Sand
(4-8.2')
Dark Clay
(8.2-13.9')
Coarse Sand
(13.9-14.5)

GWFL 4 (T8S)


Elev.-Depth(ft)
2545
2540
2535
2530
0
5
10
15
Concrete Base
PVC Well Cap
6' Steel Casing
Concrete Fill (0-7')
6' Borehole
Bentonite (7-11.6')
2' PVC Casing
Sand Pack (11.6-14.5')
2' PVC Screen (12-14')
Loess Soil and Dark Brown Silt (0-3')
Light Brown Sandy Silt and Clay (3-12.5')
Silty Fine Sand (12.5-14.5')

GWFL 6 (H12S)



Elev.-Depth(ft)
0
5
10
15
2540
2535
2530
2525
PVC Well Caps
Concrete Base
4' PVC Casing
Concrete Fill
(0-3')
Bentonite+Soil
(3-7')
6' Borehole
Bentonite Chips
+Pellets
(7-12')
2' PVC Casing
Sand Pack
(12-17')
2' PVC Screen
(13-16')
Loess Soil (moist
from 4')
(0-5')
Silty Clay
Sand and Gravel
Present at lower
Portion (5-13')
Coarse Sand w/
Gravel and Cobble
(13-17')

GWFL 9 (N18S)

Unit	Depth (feet)	Description
Top soil	0–8	Top soil, dark dusky brown (5 yr 2/2).
Latah Formation (Sediments of Bovill Member)	8–19	Clay, dark yellowish orange (10 yr 6/6), slightly silty.
	19–25	Granule gravel, 2mm to 6mm, average 4mm, occasional pebble 10-20mm, very angular to subangular, 99% quartz, minor muscovite and feldspar, most grains transparent, very light gray (N8) to yellowish gray (5 yr 8/1), water bearing. Samples are stained and contain yellow clay. Percent clay undetermined, but believed to be relatively high.
Saddle Mountains Basalt (Weissenfels Ridge Member, Lewiston Orchards Flow)	25–35	Basalt, fine-grained, occasional plagioclase phenocryst 3-4mm, medium dark gray (N4), Fe and Mn stains on uppermost and lowermost chips.
Latah Formation (Sediments of Bovill Member)	35–40	Clay, pale blue (5B 6/2) with white (N9) centers, when wet color changes to blue and generally recorded as blue clay by most drillers, very slick.
	40–47	Clay, varied colored, yellowish gray (5 yr 7/2) to pale yellowish orange (10 yr 8/6), minor black streaks (N1), approximately 10% silt and very fine sand.
	47–58	Clay, pale yellowish orange (10 yr 7/2), very slick.
	58–70	Granule gravel, 3-5mm, coarser in places 6-7mm, occasional 10-15mm pebble, 99% quartz, minor muscovite and feldspar, subangular to subrounded. Samples stained yellow and contained yellow clay. Not possible to estimate percent of clay.
	70–72	Clay, pale yellowish orange (10 yr 7/2).

IDWR 1

This well was constructed at the West Drilling Site to a total depth of 282 feet using an air rotary rig. Eight-inch diameter temporary steel casing was driven to a depth of 63 feet and then removed as the permanent casing was installed. The well has 4-inch diameter PVC casing to a depth of 280 feet with 0.010-inch, factory slotted casing in the depth interval of 270 to 280 feet. A sand pack was installed around the casing in the depth interval of 265 to 280 feet with a bentonite seal from land surface to a depth of 265 feet. Eight-inch diameter surface casing was installed to a depth of about 10 feet and equipped with a locking cap. The reported yield by the driller was 50 gpm. The reported depth to water was 170 feet below ground surface. The geologic log prepared by the well driller is provided below.

0 to 3 feet gravel fill

3 to 18 feet brown clayish soil

18 to 43 feet yellow clayish soil

43 to 58 feet soft brown basalt with rounds

58 to 110 feet hard basalt

110 to 116 feet basalt with water, 5 gpm

116 to 245 feet hard basalt

245 to 248 feet basalt with rounds

248 to 277 feet hard basalt

277 to 282 feet sand and clay, water

IDWR 2

This well was constructed at the West Drilling Site to a total depth of 355 feet using an air rotary rig. Twelve-inch diameter temporary steel casing was installed and driven to a depth of 60 feet. A 12-inch diameter open hole was drilled through the basalt and then 8-inch diameter temporary steel casing was advanced to a depth of 345 feet. Both sections of temporary casing were removed as the permanent casing was installed. The well has 4-inch diameter PVC casing to a depth of 350 feet with 0.010-inch, factory slotted casing in the depth interval of 345 to 355 feet. A sand pack was installed around the casing in the depth interval of 340 to 355 feet. The product "Hole Plug" was installed from land surface to a depth of 340 feet. Eight-inch diameter surface casing was installed to a depth of about 10 feet and equipped with a locking cap. The reported yield by the driller was 50+ gpm. The reported depth to water was 140 feet below ground surface. The geologic log prepared by the well driller is provided below.

0 to 2 feet fill rock

2 to 10 feet brown top soil

10 to 19 feet loamy-tan clay

19 to 23 feet yellowish-tan clay with sand

23 to 43 feet broken basalt

43 to 50 feet whitish tan clay

50 to 58 feet honey basalt

58 to 61 feet light grey soft basalt

61 to 110 feet hard basalt

110 to 116 feet basalt with water, 5 gpm

116 to 245 feet hard basalt

245 to 249 feet broken basalt with rounds

249 to 280 feet hard basalt

280 to 301 feet sand, lots of water

301 to 304 feet hard grey clay

304 to 345 feet sand with clay seams and wood

345 to 348 feet hard clay with basalt

348 to 355 feet sand with water

IDWR 3

Unit	Depth (feet)	Description
Top soil	0–2	Top soil, dark dusky brown (5 yr 2/2).
Latah Formation (Sediments of Bovill Member)	2–30	Clay, dark yellowish brown (10 yr 4/2), slightly silty.
	30–50	Clay, white (N9) to yellowish gray (5 yr 7/2).
Wanapum Basalt Priest Rapids Member (Lolo chemical type)	50–60	Basalt, vesicular, fine-grained, medium-gray (N5), iridescent coatings common.
	60–70	Basalt, vesicular.
	70–110	Basalt, dense, fine to medium-grained, occasional plagioclase phenocryst, medium-gray (N5), fractured at 110 ft.
	110–245	Basalt, dense, same as above.
	245–247	Basalt gravels, 2-3cm, angular to sub-rounded, same as host rock, interpreted as non-depositional.
	247–276	Basalt, dense, fine to medium-grained, occasional plagioclase phenocrysts.
Latah Formation (Vantage Member)	276–278	Sand, coarse to very coarse (1/2mm to 2mm), 90% quartz, 10% basalt?, minor muscovite and feldspar?, subangular to subrounded, sample mixed with chips from above.
	278–285	Clay, white (N9) to very light gray (N8).
	285–290	Sand, very coarse (1.5-2mm), 90% quartz, 10% basalt?, minor muscovite, subrounded, fairly well sorted, rare wood fragments.
	290–335	Sand, silt and clay, occasional granule of quartz and some subrounded basalt (3-5%). Abundant wood fragments and sample sticky 299-305 feet.
	335–360	Sand, silt, and clay, greenish gray clay in overflow ditch, but not in samples. Sand is coarse to very coarse-grained.
	360–370	Clay, brownish gray (5 yr 4/1), sandy?, abundant wood fragments.
	370–410	Sand, coarse .5 to 1mm to very coarse (1.5mm), subangular to subrounded, fairly well sorted with silt and clay, minor wood fragments with some abundant intervals, color of mud is greenish gray, abundant silt in overflow ditch after drilling, occasional very fine-grained well rounded siltite granule.
	410–423	Sand, slightly coarser than above.
	423–485	Clay and silt, mud a moderate brown (5YR 4/4) in color.
	485–499	Clay and silt, mud a grayish yellow green (5GY 7/2) in color.
Grande Ronde Basalt (N2 Member)	499–510	Basalt, vesicular with small openings, iridescent coatings.
	510–580	Basalt, dark gray (N3), very fine-grained, dense.
	580–585	Basalt, dark gray (N3), vesicular and iron stained, minor vesicle fillings.
Latah Formation	585–620	Clay, grayish green (10GY 5/2), silty in places.
	620–665	Sand, coarse to very coarse (1/2mm to 2mm), subangular, 95% quartz with siltite, basalt?, and minor muscovite fragments.
	665–720	Clay, brownish gray (5YR 4/1), silty in places.
Grande Ronde Basalt (R2 Member)	720–735	Basalt, dark gray (N3), very fine-grained.

IDWR 4

DRILL CUTTINGS LOG

INEL PACKER TEST WELL

MOSCOW, IDAHO

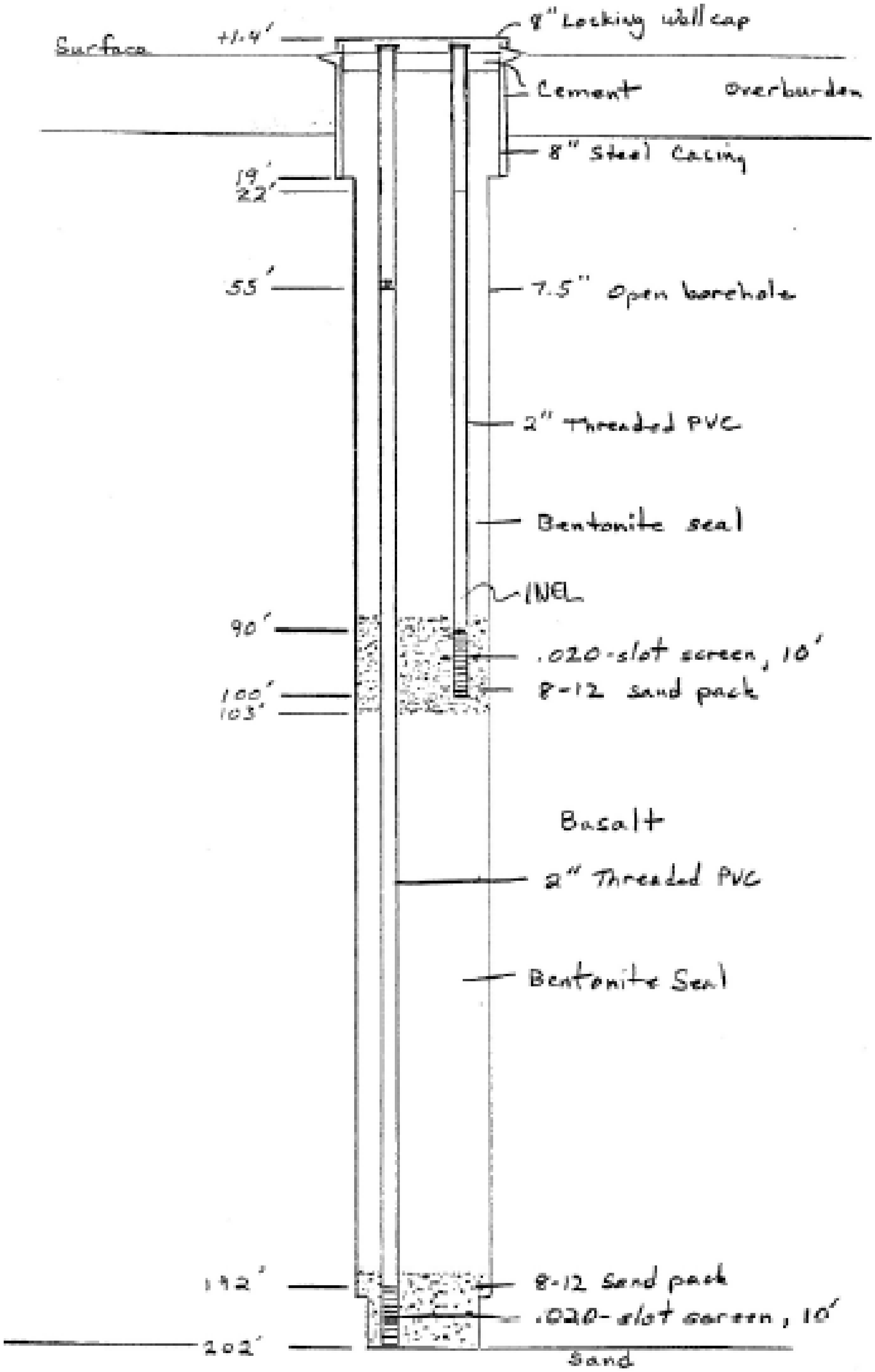
DEPTH (FT)	DESCRIPTION (logged 4/1/92 by JDK)
0 - 7	No cuttings, soil and silt
7 - 14	No cuttings, orange-brown and gray clay
14 - 16	Coarse, poorly-sorted granitic and basalt sand with some granitic pebbles
16 - 20	Coarse sand and broken vesicular basalt fragments up to 2 inches; sand may be contamination from above
20 - 55	Dark gray to black basalt, some localized cavity filling, pale amber to pale greenish alteration (?) (or possibly palagonite); green clay filling along fractures @ 52'
55 - 65	Medium gray basalt with considerable alteration; scattered light tan weathered basalt and possibly baked sediments; approximately 5 gpm water
65 - 70	Dark gray basalt with black glassy patches; pale greenish cavity filling
70 - 75	Dark gray basalt with light tan coatings along fractures (possibly siderite or opalized material)
75 - 80	Dark gray basalt with orange and rust oxidation coatings along fractures and cavities
80 - 90	Black, dense basalt with sparse cavity filling; some pale greenish to amber phenocryst (probably pyroxenes)
90 - 100	Black, glassy basalt with angular olive-brown cavity filling
100 - 105	Medium gray to dark gray basalt; one large plag lath noted about 0.2" long; considerable alteration
105 - 125	Dark gray to black, dense basalt, less alteration

INEL

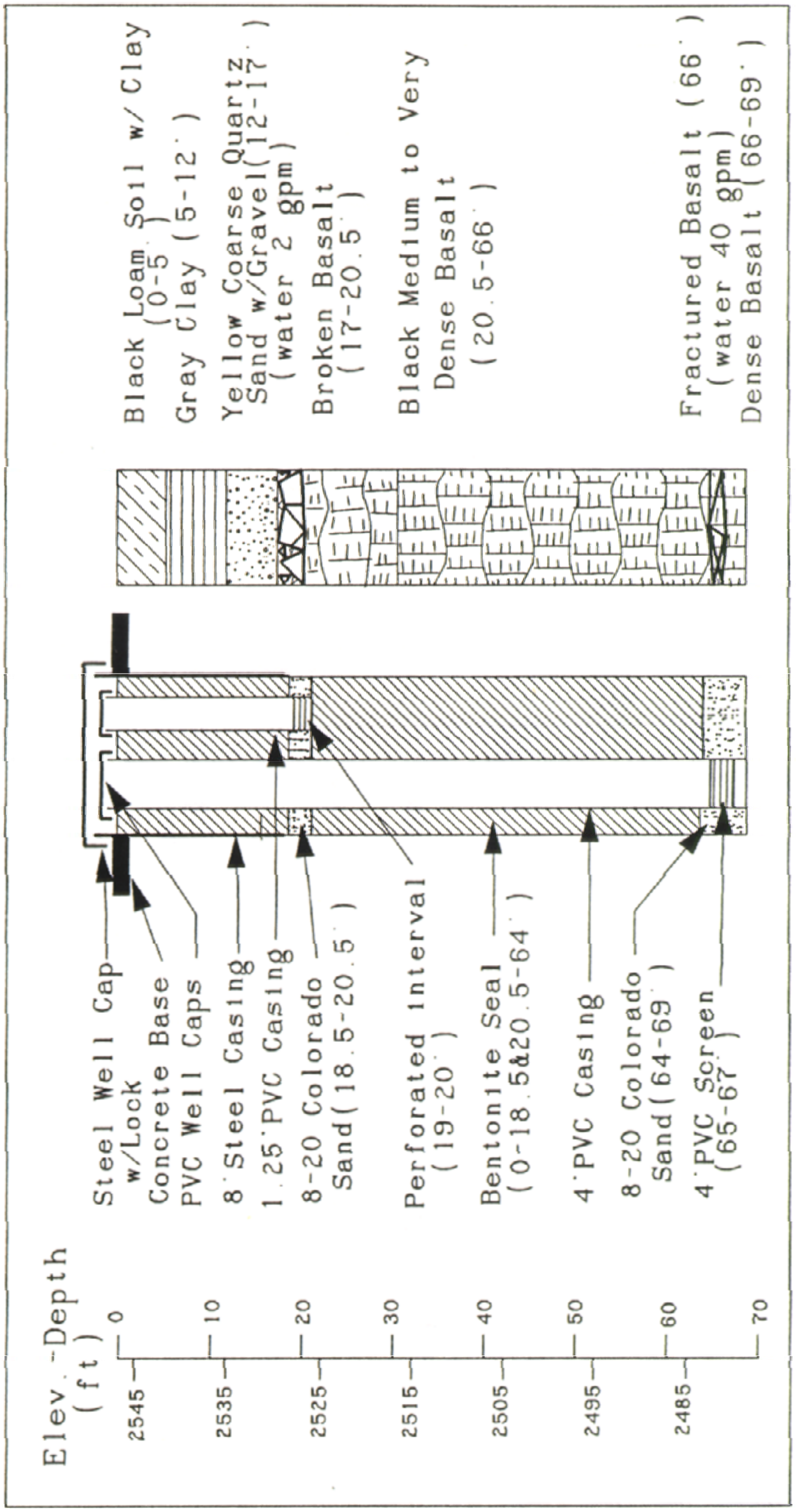
125 - 145	Medium gray to dark gray basalt, minor opal or siderite along fractures, moderate alteration around cavities with some oxidation
145 - 155	Medium gray basalt, more alteration, oxidation along some fractures; irregular thin black glassy crystals(?) throughout
155 - 170	Dark gray basalt, more dense, less alteration
170 - 180	Medium gray basalt, slightly more alteration
180 - 200	Medium gray basalt, altered; abundant irregular black specks; thin greenish-gray coating on some surfaces
200 - 202	Dark gray, dense basalt, scattered vesicles with filling
202 - 205 T.D.	Gray, well-sorted arkose consisting of subangular to subrounded clear quartz, white feldspar, black basalt and minor moscovite

The entire basalt sequence is diktytaxitic with variable amounts of alteration(?) or coatings around the diktytaxitic openings giving the cuttings a mottled appearance under the hand lens. The term "alteration" does not imply hydrothermal or deuteric alteration, but is used as descriptively for the soft pale greenish and amber material around the diktytaxitic cavities. Dense portions of the basalt have a felted texture. Judging from the stratigraphic position of the basalt, it is likely a flow of the Priest Rapids Member of the Wanapum Basalt sequence. Although possible sediment fragments were seen at 55 - 65', no flow top material or other indication of a flow top or flow-to-flow contact was apparent. Identification of the sediment fragments is therefore questionable.

INEL cont.


8" Locking well cap
Surface
+1.4'
Cement
Overburden
8" Steel Casing
19'
22'
55'
7.5" Open borehole
2" Threaded PVC
Bentonite seal
INEL
90'
.020-slot screen, 10'
100'
103'
8-12 sand pack
Basalt
2" Threaded PVC
Bentonite Seal
192'
8-12 Sand pack
.020-slot screen, 10'
202'
Sand

INEL cont.


Elev.-Depth
(ft)
2545
2535
2525
2515
2505
2495
2485
0
10
20
30
40
50
60
70
Steel Well Cap w/Lock
Concrete Base
PVC Well Caps
8' Steel Casing
1.25' PVC Casing
8-20 Colorado Sand (18.5-20.5')
Perforated Interval (19-20')
Bentonite Seal (0-18.5&20.5-64')
4' PVC Casing
8-20 Colorado Sand (64-69')
4' PVC Screen (65-67')
Black Loam Soil w/Clay (0-5')
Gray Clay (5-12')
Yellow Coarse Quartz Sand w/Gravel (12-17') (water 2 gpm)
Broken Basalt (17-20.5')
Black Medium to Very Dense Basalt (20.5-66')
Fractured Basalt (66') (water 40 gpm)
Dense Basalt (66-69')

J16D

Form 238-7
6/02

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

Office Use Only
Well ID No.
Inspected by
Twp ____ Rge ____ Sec ____
____ 1/4 ____ 1/4 ____ 1/4
Lat: : : Long: : :

1. WELL TAG NO. D 0039838
DRILLING PERMIT NO. 832875
Water Right or Injection Well No.

2. OWNER:
Name Rex Cosgrove
Address 2210 Trail Road
City Moscow State Id. Zip 83843

3. LOCATION OF WELL by legal description:
You must provide address or Lot, Blk, Sub. or Directions to well.
Twp. 39 North ☑ or South ☐
Rge. 5 East ☐ or West ☑
Sec. 4, SE 1/4 NW 1/4 ____ 1/4
Gov't Lot ____ County Latah
Lat: : : Long: : :
Address of Well Site Same
City
Lt. ____ Blk. ____ Sub. Name

4. USE:
☑ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other

5. TYPE OF WORK check all that apply (Replacement etc.)
☑ New Well ☐ Modify ☐ Abandonment ☐ Other

6. DRILL METHOD:
☑ Air Rotary ☐ Cable ☐ Mud Rotary ☐ Other

7. SEALING PROCEDURES

Seal Material	From	To	Weight / Volume	Seal Placement Method
BentoniTe	0	63	350lbs	Dry

Was drive shoe used? ☑ Y ☐ N Shoe Depth(s) 198
Was drive shoe seal tested? ☐ Y ☑ N How?

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
8	+1	198	250	Steel	☑	☐	☑	☐
					☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe ____ Length of Tailpipe ____
Packer ☐ Y ☑ N Type

9. PERFORATIONS/SCREENS PACKER TYPE
Perforation Method
Screen Type & Method of Installation

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. FILTER PACK

Filter Material	From	To	Weight / Volume	Placement Method

11. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
190 ft. below ground Artesian pressure ____ lb.
Depth flow encountered ____ ft. Describe access port or control devices:

39N 5W 4

12. WELL TESTS:
☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
approx 25		220'	1 Hr.

Water Temp. ____ Bottom hole temp. ____
Water Quality test or comments:
Depth first Water Encounter 199

13. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
10	0	63	overburden Sand & Clay		✓
8	63	196	clay		✓
8	196	201	basalT, firm	✓	
8	201	202	Shale		✓
8	202	206	basalT, firm		✓
8	206	207	Fract. basalT		✓
8	207	228	basalT, firm	✓	

RECEIVED
JUN 01 2005
IDWR/North

Completed Depth 228 (Measurable)
Date: Started 4/26/05 Completed 4/29/05

14. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Company Name WiTTWell Drilling Firm No. 58
Principal Driller [signature] Date 5/4/05
and
Driller or Operator II ____ Date ____

Operator I ____ Date ____
Principal Driller and Rig Operator *Required.*
Operator I must have signature of Driller/Operator II.

FORWARD WHITE COPY TO WATER RESOURCES

Kizer

5/18/98 db

77440

Form 238-7
3/95

IDAHO DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

Use Typewriter or Ballpoint Pen

POSTED

Office Use Only
Inspected by ______
Twp____ Rge____ Sec____
____1/4 ____1/4 ____1/4
Lat: : : Long: : :

1. DRILLING PERMIT NO. D000 3727 ~~87-98-N-10~~
Other IDWR No.

2. OWNER:
Name Stanley M. Miller
Address 2117 Robinson Park Road
City Moscow State Id Zip 83843

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

Twp. 39 North ☑ or South ☐
Rge. 5 East ☐ or West ☑
Sec. 4, ____ 1/4 NE 1/4 SE 1/4
Gov't Lot ____ County Latah
Lat: : : Long: : :
Address of Well Site 2077 Darby Rd Moscow City Id
(Give at least name of road + Distance to Road or Landmark)
Lt.______ Blk.______ Sub. Name______

4. USE:
☑ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other

5. TYPE OF WORK check all that apply (Replacement etc.)
☑ New Well ☐ Modify ☐ Abandonment ☐ Other

6. DRILL METHOD
☑ Air Rotary ☐ Cable ☐ Mud Rotary ☐ Other

7. SEALING PROCEDURES

SEAL/FILTER PACK Material	From	To	AMOUNT Sacks or Pounds	METHOD
Bentonite	0	48	12 bags	Dry

Was drive shoe used? ☐ Y ☑ N Shoe Depth(s)
Was drive shoe seal tested? ☐ Y ☑ N How?

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
8"	+2	124	250	steel	☑	☐	☑	☐
6"	-120	180	160	PVC	☐	☑	☐	☐
					☐	☐	☐	☐

Length of Headpipe______ Length of Tailpipe______

9. PERFORATIONS/SCREENS
☐ Perforations Method
☐ Screens Screen Type

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
115 ft. below ground Artesian pressure ____ lb.
Depth flow encountered ______ ft. Describe access port or control devices: top of well

11. WELL TESTS:
☐ Pump ☐ Bailer ☑ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
200 plus			

Water Temp. ______ Bottom hole temp. ______
Water Quality test or comments:
Depth first Water Encountered 148

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
10	0	2	dirt		✓
	2	14	Clay		✓
	14	23	sand		✓
	23	57	clay		✓
	57	120	sand & clay		✓
	120	148	basalt		✓
	148	180	same basalt some blue mineral in seams	✓	
			200 gpm		

RECEIVED

APR 24 1998

NORTHERN REGION
IDWR

Completed Depth 180 ft (Measurable)
Date: Started 4/9/98 Completed 4/12/98

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Uhlenkott Drilling Firm No. 125
Firm Official Ray Uhlenkott Date 4/23/98
and
Supervisor or Operator Jim Uhlenkott Date 4/23/98
(Sign once if Firm Official & Operator)

T39N R5W 4 NESE

FORWARD WHITE COPY TO WATER RESOURCES

Miller

CITY OF MOSCOW

WELL NO. 2

A ST. AND JACKSON ST.

240'

ELEVATION	MATERIAL
2558	
	Soil
2532	
	Basalt
2456	
	Gravel
2431	
	Basalt, vesicular at top
2409	
	Basalt, very dense at base
2344	
	Blue-Gray Clay or Shale
2328	
	Blue-Gray Clay or Shale
2314	
	Gray Granite Sand
2295	
	Blue Gray Sandy Shale
2289	
	Gray Sand, 3/8" Pebbles at 280ft.
2263	
	Cemented Sand
2256	
	Blue-Green Micaceous Shale
2254	
	Black-Brown Soil
2243	
	Brown Clay-Soil at top, many small Pebbles at base
2213	
	Blue-Gray Micaceous Shale
2173	
	Brown Sandy Shale
2124	
	Sand Cemented by Pyrite and Silica
2106	
	Light Brown Shale
2068	
	Blue-Gray Non-Micaceous Shale and Sand
2043	
	Chocolate-Brown Shale
2015	
	Quartzite
2008	

Moscow 2

87-64-N-3

City of Moscow

Well No. 2 - Domestic

B. 31815 97-2023

NE NW. 18 T. 39 N. R. 5 W.

Drilled 1925 - A. A. Durand, Walla Walla, Washington

Total depth - 560 feet

Filled and concrete plug at 240 feet

20" casing seal in basalt at 40 feet

Remainder open

Original static	-	20 feet
Present static	-	100 feet
Drawdown	-	20 feet
Capacity	-	1200 GPM
Water Temp	-	54° F

Moscow 2 cont.

87-3028
87-~~64~~ 56-N-1-1

RECEIVED
APR 29 1964
Department of Reclamation

City of Moscow, Idaho
Well No. 6 - Domestic
SE NW 8 39N 5W

Drilled originally in 1955 - Driller - A.A. Durand and Son
Walla Walla, Washington

Depth	-	280 feet
Static	-	110 Feet
Capacity	-	1200 GPM
Drawdown	-	20 feet
Temp	-	54° F

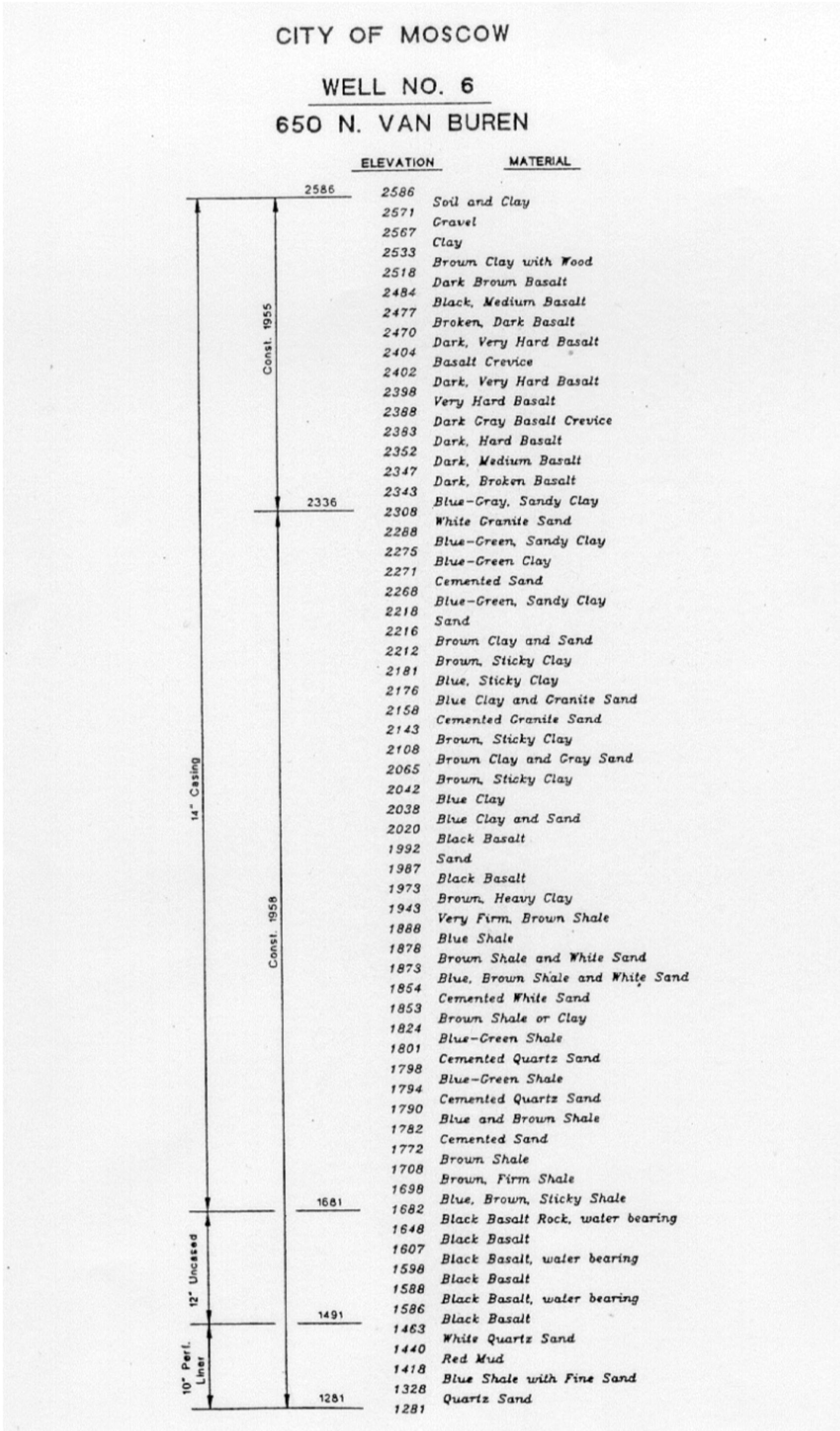
Well went dry in December, 1957

Started present well February, 1958
Complete May, 1960 Driller - Oliver Zinkgraf

Depth	-	1305 feet
Static	-	275 feet
Drawdown	-	25 feet
Capacity	-	1150 GPM
Water Temp	-	72° F

14 inch casing from surface, sealed in basalt at 905 feet
10 inch perforated liner - 1095 - 1305

Moscow 6



CITY OF MOSCOW

WELL NO. 6

650 N. VAN BUREN

ELEVATION	MATERIAL
2586	Soil and Clay
2571	Gravel
2567	Clay
2533	Brown Clay with Wood
2518	Dark Brown Basalt
2484	Black, Medium Basalt
2477	Broken, Dark Basalt
2470	Dark, Very Hard Basalt
2404	Basalt Crevice
2402	Dark, Very Hard Basalt
2398	Very Hard Basalt
2388	Dark Gray Basalt Crevice
2383	Dark, Hard Basalt
2352	Dark, Medium Basalt
2347	Dark, Broken Basalt
2343	Blue-Gray, Sandy Clay
2308	White Granite Sand
2288	Blue-Green, Sandy Clay
2275	Blue-Green Clay
2271	Cemented Sand
2268	Blue-Green, Sandy Clay
2218	Sand
2216	Brown Clay and Sand
2212	Brown, Sticky Clay
2181	Blue, Sticky Clay
2176	Blue Clay and Granite Sand
2158	Cemented Granite Sand
2143	Brown, Sticky Clay
2108	Brown Clay and Gray Sand
2065	Brown, Sticky Clay
2042	Blue Clay
2038	Blue Clay and Sand
2020	Black Basalt
1992	Sand
1987	Black Basalt
1973	Brown, Heavy Clay
1943	Very Firm, Brown Shale
1888	Blue Shale
1878	Brown Shale and White Sand
1873	Blue, Brown Shale and White Sand
1854	Cemented White Sand
1853	Brown Shale or Clay
1824	Blue-Green Shale
1801	Cemented Quartz Sand
1798	Blue-Green Shale
1794	Cemented Quartz Sand
1790	Blue and Brown Shale
1782	Cemented Sand
1772	Brown Shale
1708	Brown, Firm Shale
1698	Blue, Brown, Sticky Shale
1682	Black Basalt Rock, water bearing
1648	Black Basalt
1607	Black Basalt, water bearing
1598	Black Basalt
1588	Black Basalt, water bearing
1586	Black Basalt
1463	White Quartz Sand
1440	Red Mud
1418	Blue Shale with Fine Sand
1328	Quartz Sand
1281	

Moscow 6 cont.

06/11/97 12:47 ☎1 208 883 7113 MOSCOW WATER DPT ☒002/003

87-64-N-10 746989
39N 05W 07
NE SE NW

CITY OF MOSCOW

WELL NO. 8

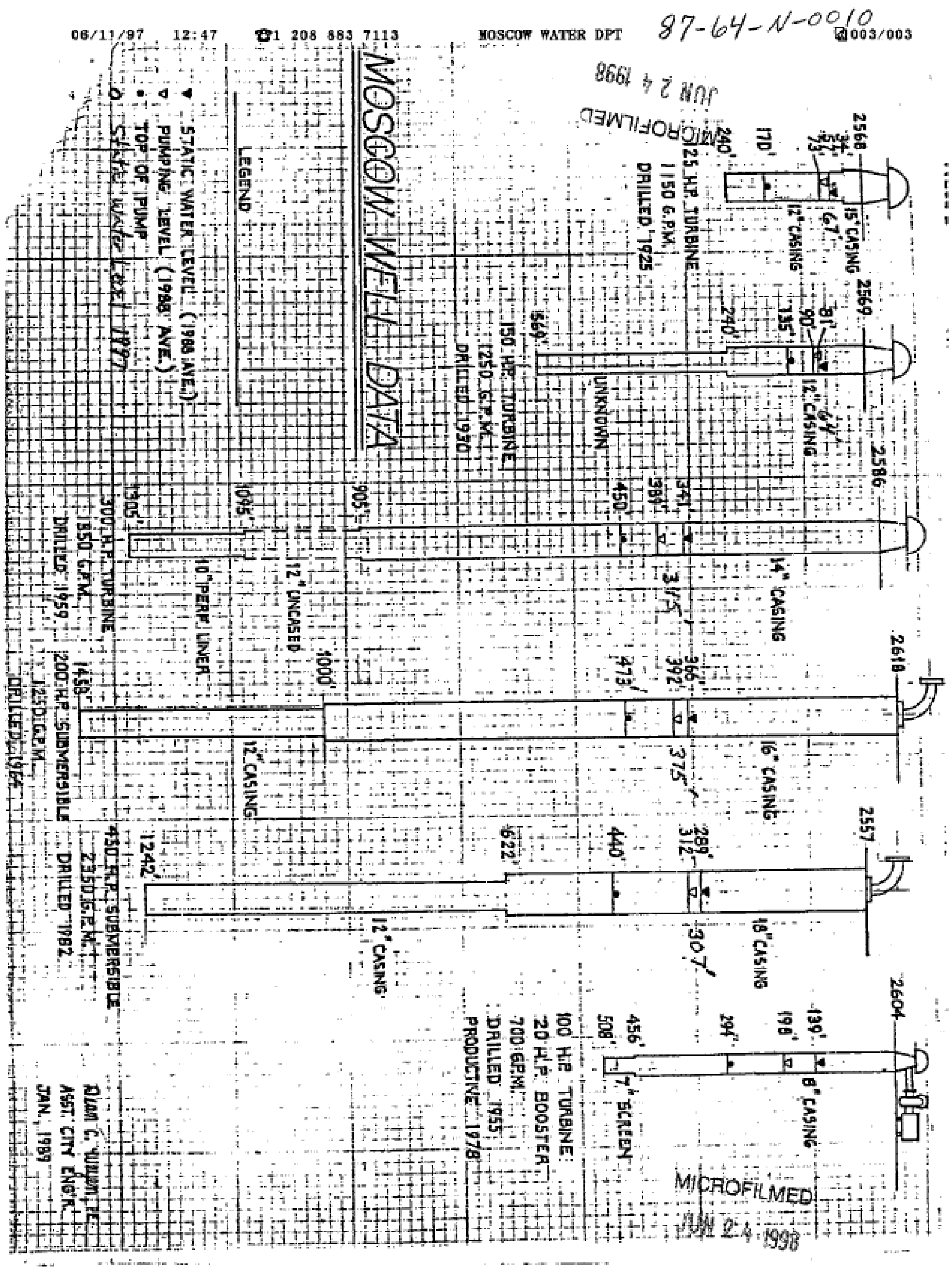
SUNRISE DRIVE

16" Casing: 2618 – 1616
12" Casing: 1616 – 1160

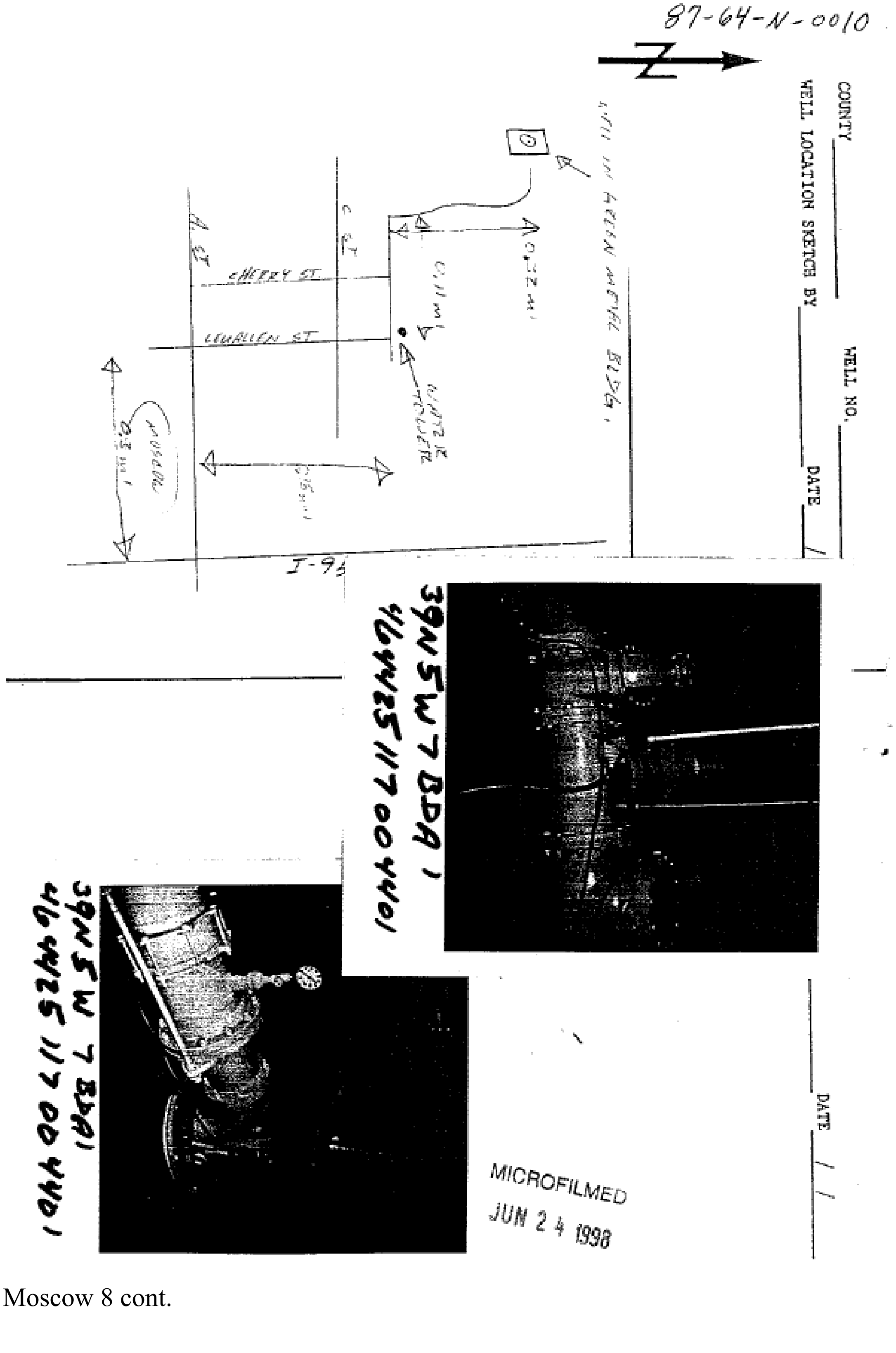
ELEVATION	MATERIAL
2618	Brown Clay
2595	Clay and Gravel
2570	Gravel
2563	Clay and Gravel
2532	White Clay
2509	Broken Basalt
2507	Brown Clay
2457	Yellow Clay
2450	Basalt
2437	Black Clay
2433	Basalt
2253	Sand
2221	Sandstone
2204	Sticky Clay
2200	Sandy Clay
2183	Sticky, Gray Clay
2136	Shale
2133	Sticky, Brown Clay
2065	Black Basalt
1967	Gray Basalt
1925	Sticky, Brown Clay
1887	Broken Basalt
1838	Clay
1798	Cement Sand
1766	Sticky Clay
1699	Gray Clay
1667	Basalt
1655	Broken Basalt with Clay
1652	Black, Dense Basalt
1483	Gray, Hard Basalt
1359	Sticky Clay
1314	Sandy Clay
1304	Sticky Clay
1249	Sandy, Gray Clay
1226	Granitic Rock
1160	

39N 5W 07 NESENW

Moscow 8



Moscow 8 cont.



Moscow 8 cont.

87-64-N-0010

IDAHO DEPARTMENT OF WATER RESOURCES
STATEWIDE GROUND-WATER QUALITY MONITORING PRO
Pre-Sampling Inspection Sheet

Darla This probably doesn't need filming (just keep papers together) Thanks

USGS Site ID 464425117004401
Station Name (T.R,SEC, 1/4,1/4,1/4, #) 39N 5W 7BDA1 NE of NE of NW
IDWR SSN (to be assigned later)

Owner's Name City of Moscow Phone 883-7000
Address P.O. Box 9203 Moscow 83843

Does the owner grant permission to sample the well? y
Is it okay to sample the well if no one is home? y Comments Call 1st
well #8 Gary Smith or Mike Dimmick 882-3122

Is the information on the driller's log in agreement with the well and location? yes

Does the well appear to have a good seal? yes

Can the water-level be measured? no How? (access port, removal of well cap, etc.)

Is there a septic tank or drain field nearby? no How far?

Is there a nearby potential contamination source? (feedlot, industry, etc.)

What is the most likely sampling point? hosebib on mainline
How far is it from the well? 5'
What does the water flow through between the well and sampling point? type of piping - (galvanized steel PVC) pressure tank (size in gallons) —, water treatment equipment, etc.)

Considering the goals of this program, does the well appear to be a viable site? ~~5/3/96~~ yes

Field Inspector's Name AmT Date 5/3/96

Sketch the probable sampling point and distribution system. Sketch the site location if the sketch on the site schedule is incomplete or incorrect.
Notes: Do in July if possible - they will be doing some work on well sometime this summer

phone OK.

Moscow 8 cont.

File - Well 9

Form 238-7
/78

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name: City of Moscow

Address: 122 E. 4th St., Moscow, ID 83843

Owner's Permit No. 87 - 7069

2. NATURE OF WORK

[X] New well [ ] Deepened [ ] Replacement
[ ] Abandoned (describe method of abandoning)

3. PROPOSED USE

[ ] Domestic [ ] Irrigation [ ] Test [X] Municipal
[ ] Industrial [ ] Stock [ ] Waste Disposal or Injection
[ ] Other ________ (specify type)

4. METHOD DRILLED

[X] Rotary [ ] Air [ ] Hydraulic [ ] Reverse rotary
[ ] Cable [ ] Dug [ ] Other

5. WELL CONSTRUCTION

Casing schedule: [X] Steel [ ] Concrete [ ] Other

Thickness		Diameter		From		To	
375	inches	24	inches +	1½	feet	50	feet
375	inches	180D	inches +	1½	feet	649½	feet
250	inches	16	inches	795	feet	945	feet
See Attached Exhibit "A"		12	inches		feet		feet

Was a drive shoe used? [X] Yes [ ] No
Was a ~~xxxx~~ or seal used? [X] Yes [ ] No
Perforated? [ ] Yes [ ] No
How perforated? [ ] Factory [ ] Knife [ ] Torch
Size of perforation ____ inches by ____ inches

See Attached Exhibit "A"

Number		From		To	
	perforations		feet		feet
	perforations		feet		feet
	perforations		feet		feet

Well screen installed? [X] Yes [ ] No
Manufacturer's name
Type ________ Model No.
Diameter ___ Slot size ___ Set from ___ feet to ___ feet
Diameter ___ Slot size ___ Set from ___ feet to ___ feet
Gravel packed? [ ] Yes [ ] No [ ] Size of gravel
Placed from ___ feet to ___ feet
Surface seal depth 50 Material used in seal: [X] Cement grout [ ] Puddling clay [ ] Well cuttings
Sealing procedure used: [ ] Slurry pit [ ] Temp. surface casing [ ] Overbore to seal depth
Method of joining casing: [ ] Threaded [X] Welded [ ] Solvent Weld [ ] Cemented between strata
Describe access port: 2" pipe at 30% angle welded to 18" casing

6. LOCATION OF WELL

Sketch map location must agree with written location.

N / W / E / S

Subdivision Name: N/A

Lot No. ______ Block No. ______

County: Latah

NW ¼ ___ ¼ Sec. 12, T. 39 N/S, R. 6 E/W.

7. WATER LEVEL See attached Exhibit "B"

Static water level 280 feet below land surface.
Flowing? [ ] Yes [ ] No G.P.M. flow ______
Artesian closed-in pressure ______ p.s.i.
Controlled by: [ ] Valve [ ] Cap [ ] Plug
Temperature ____ °F. Quality ______

8. WELL TEST DATA

[X] Pump [ ] Bailer [ ] Air [ ] Other

Discharge G.P.M.	Pumping Level	Hours Pumped
2800	552	36

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
	0	10	hard yellow clay		
	10	20	soft brown rock		
	20	28	black basalt		
	28	36	black basalt some porous	x	
	36	60	medium black basalt, some fracture		
	60	80	med hard black basalt dense formation		
	80	115	hard black basalt some small fractures		
	115	145	very hard basalt black		
	145	165	hard black basalt		
	165	175	hard black basalt w/fractures		
	175	180	hard gray basalt		
	180	184	hard gray basalt fractured		
	184	212	hard hard gray basalt w/ occasional crevice		
	212	215	cemented sand, some wood, some green clay		
	215	220	sand porous black basalt mixed		
	220	230	gray green loose sand	x	
	230	245	gray green loose sand	x	
	245	270	hard blue gray clay, sand mixed		
	270	294	hard sticky brown clay dark		
	294	312	soft white & gray coarse sand		
	312	348	cemented brown & white sand, finer		
	348	380	cemented brown sand, clay silt fine		
	380	390	brown clay w/some hard slate		
	390	400	hard brown clay		
	400	410	light gray w/white clay mixed		
	410	413	white hard clay, basalt chips		
	413	459	soft black basalt w/hard layers		
	459	492	sticky brown clay		
	492	500	soft brown clay		
	500	504	fractured or broken gray basalt very hard, drills tough smooths out at 548		
	504	565	hard gray basalt		
	565	572	hard grayish black basalt, heavily fractured (Continued)		

10. Work started Aug 18, 1981 finished June 26, 1982

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name: Leach Well Drilling, Inc. Firm No. 99

Address: 821 W. Broadway, Moses Lake, WA 98837 Date

Signed by (Firm Official) *Nathaniel L. Leach*

and

(Operator) *Sam*

IF ADDITIONAL SHEETS ARE NECESSARY...

Moscow 9

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

USE TYPEWRITER OR BALLPOINT PEN

Page 2

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name City of Moscow

Address

Owner's Permit No.

2. NATURE OF WORK

☑ New well ☐ Deepened ☐ Replacement
☐ Abandoned (describe method of abandoning)

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☐ Test ☑ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other (specify type)

4. METHOD DRILLED

☑ Rotary ☐ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other

5. WELL CONSTRUCTION

Casing schedule: ☐ Steel ☐ Concrete ☐ Other

Thickness	Diameter	From	To
inches	inches +	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet

Was casing drive shoe used? ☐ Yes ☐ No
Was a packer or seal used? ☐ Yes ☐ No
Perforated? ☐ Yes ☐ No
How perforated? ☐ Factory ☐ Knife ☐ Torch
Size of perforation inches by inches

Number	From	To
perforations	feet	feet
perforations	feet	feet
perforations	feet	feet

Well screen installed? ☐ Yes ☐ No
Manufacturer's name
Type Model No.
Diameter Slot size Set from feet to feet
Diameter Slot size Set from feet to feet
Gravel packed? ☐ Yes ☐ No ☐ Size of gravel
Placed from feet to feet
Surface seal depth Material used in seal: ☐ Cement grout ☐ Puddling clay ☐ Well cuttings
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☐ Overbore to seal depth
Method of joining casing: ☐ Threaded ☐ Welded ☐ Solvent Weld ☐ Cemented between strata
Describe access port

6. LOCATION OF WELL

Sketch map location must agree with written location.

N / W / E / S

Subdivision Name

Lot No. Block No.

County

¼ ¼ Sec. , T. N/S, R. E/W.

7. WATER LEVEL

Static water level feet below land surface.
Flowing? ☐ Yes ☐ No G.P.M. flow
Artesian closed-in pressure p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature °F. Quality

8. WELL TEST DATA

☐ Pump ☐ Bailer ☐ Air ☐ Other

Discharge G.P.M.	Pumping Level	Hours Pumped

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
	572	584	hard gray basalt		
	584	595	large vertical crevices like column rock		
	595	599	clay & broken rock mixed		
	599	629	clay, soft brown		
	629	643	med hard brown clay		
	643	645	broken brown basalt & clay		
	645	658	frac. soft to med brown basalt		
	658	667	med soft black basalt w/thin layers of green slate, some porous	x	
	667	677	med black basalt fractured	x	
	677	678	med black basalt, some crevices		
	678	688	heav frac soft black basalt	x	
	688	697	med hard black basalt some frac		
	697	714	hard black basalt		
	714	721	soft black basalt porous		x
	721	727	med hard black basalt		
	727	737	broken porous black & brown basalt, green slate top of aquifer	X	
	737	754	hard black basalt, sm frac		
	754	762	frac black basalt		
	762	767	soft black basalt some green cemented sand mix, tree		
	767	773	black basalt & green cemented sand		
	773	777	soft black basalt		
	777	798	~~soft black basalt~~ med hard black basalt		
	798	809	med hard black basalt frac porous cemented sand mixed	x	
	809	813	dark sand some cemented		
	813	817	cemented sand, hard almost clay		
	817	842	hard dark brown clay slate appearance		
	842	845	brown & gray clay mix, basalt		
	845	850	gray clay, wood chips, tree		
	850	857	gray clay, green clay sand cemented		
	857	867	cemented gray sand, gray clay		

Continued

10.

Work started finished

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Leach Well Drilling Firm No. 99

Address Date

Signed by (Firm Official)

and

(Operator)

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE ...

Moscow 9 cont.

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

Page 3

1. WELL OWNER

Name City of Moscow

Address

Owner's Permit No.

2. NATURE OF WORK

☐ New well ☐ Deepened ☐ Replacement
☐ Abandoned (describe method of abandoning)

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☐ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other (specify type)

4. METHOD DRILLED

☐ Rotary ☐ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other

5. WELL CONSTRUCTION

Casing schedule: ☐ Steel ☐ Concrete ☐ Other

Thickness	Diameter	From	To
inches	inches +	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet
inches	inches	feet	feet

Was casing drive shoe used? ☐ Yes ☐ No
Was a packer or seal used? ☐ Yes ☐ No
Perforated? ☐ Yes ☐ No
How perforated? ☐ Factory ☐ Knife ☐ Torch
Size of perforation inches by inches

Number		From	To
	perforations	feet	feet
	perforations	feet	feet
	perforations	feet	feet

Well screen installed? ☐ Yes ☐ No
Manufacturer's name
Type Model No.
Diameter Slot size Set from feet to feet
Diameter Slot size Set from feet to feet
Gravel packed? ☐ Yes ☐ No ☐ Size of gravel
Placed from feet to feet
Surface seal depth Material used in seal: ☐ Cement grout ☐ Puddling clay ☐ Well cuttings
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☐ Overbore to seal depth
Method of joining casing: ☐ Threaded ☐ Welded ☐ Solvent Weld
☐ Cemented between strata
Describe access port

6. LOCATION OF WELL

Sketch map location must agree with written location.

N / W / E / S

Subdivision Name

Lot No. Block No.

County

¼ ¼ Sec. , T. N/S, R. E/W.

7. WATER LEVEL

Static water level feet below land surface.
Flowing? ☐ Yes ☐ No G.P.M. flow
Artesian closed-in pressure p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature °F. Quality

8. WELL TEST DATA

☐ Pump ☐ Bailer ☐ Air ☐ Other

Discharge G.P.M.	Pumping Level	Hours Pumped

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
	867	877	cemented gray sand		
	877	897	dark brown hard clay		
	897	907	dark brown clay hard like slate		
	907	917	light brown clay hard		
	917	928	dark brown clay hard		
	928	939	black hard clay soft basalt mix		
	939	986	hard black basalt		
	986	992	heav frac hard black basalt		
	992	1035	frac rough drilling, black basalt		
	1035	1130	hard black basalt		
	1130	1150	little softer black basalt small fractures		
	1150	1170	hard black basalt		
	1170	1202	med hard black basalt some frac		
	1202	1228	hard black basalt		
	1228	1242	med hard black basalt		
	1242	1250	soft black basalt some hard grayblue clay mix, almost slate appear.	x	
	1250	1253	soft light brown clay		

10.

Work started finished

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Leach Well Drilling Firm No. 99

Address Date

Signed by (Firm Official)

and

(Operator)

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Moscow 9 cont.

To

Well Log City Of Moscow
IRRIG. WELL @ N.E. MOSCOW PARK

RECEIVED OCT 18 1983

Uhlenkott Well Drilling
Fenn, Idaho 83531
Phone (208) 962-3209
Pumps - Sales - Service

REGARDING: **DATE:** Oct. 16, 1983

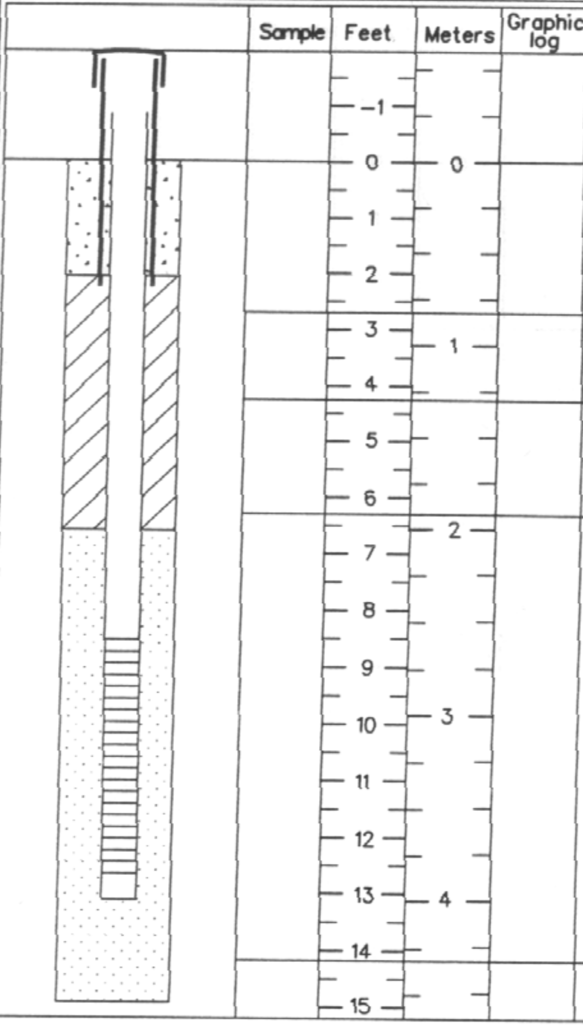
0 - 7 Overburden (Dirt)
7 - 19 Brown Clay
19 - 26 Sand
26 - 45 Clay and Sand Mix
45 - 75 Decomposed Granite and some clay
75 - 135 Med. soft grey type Basalt
135 - 145 Grey Sand with some water
145 - 243 Med hard grey Basalt
243 - 248 Brown seams in grey Basalt
248 - 287 Grey Basalt (hard)
287 - 294 Seams in Grey Basalt were brown to Tan with some Water
294 - 311 Grey Hard Basalt
311 - 329 Softer Med. Grey Basalt (Granite type rock) More water 20 - 25 GPM
329 - 344 Brown Sand Water Bearing (600 - 1000 GPM)

By William Uhlenkott
William Uhlenkott

MVP (Mountain View Park)

Plant Science Farm   Well: MW–1

Date Drilled	4–7–92	Surface Elevation	790.68 m
Total Depth	4.57 m	Inner Casing Elevation	791.05 m
Drilling Method	HSA	Drilled by	Kaufman/Petrich
Casing	5–cm dia; 150–cm screen	Logged by	Petrich



Sample/Log Codes

AF: Auger Flight
AT: Auger Tip
AC: Auger Cuttings
PC: Pipe Core
SS: Split Spoon Core
S: Sound

Lithologic Log	Log Code
Dark gray silty clay, occasional fine sand.	AC
Clayey silt, some some sandy zones	AC S
Gray silty clay, increasing sand with depth	AC AF
Gray clayey silt with fine–grained sand, grading to a poorly sorted, gravelly, coarse granitic sand; gravels to 3–cm diameter	AC AF S
Dense, very stiff, light bluish–gray clay	AT

Note: well width dimensions are not drawn to scale

C. Petrich

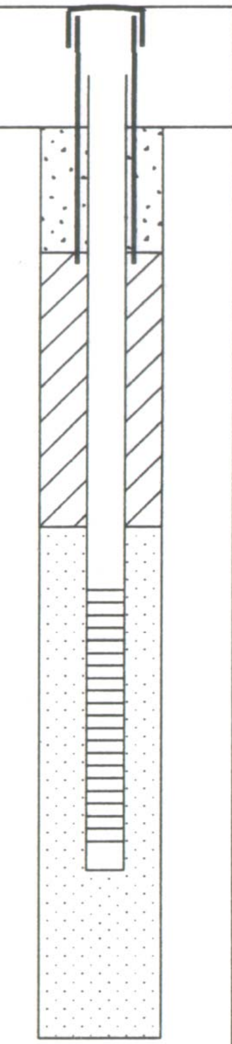
P MW-1

Plant Science Farm Well: MW-2

Date Drilled	4-7-92	Surface Elevation	790.41 m
Total Depth	4.57 m	Inner Casing Elevation	790.82 m
Drilling Method	HSA	Drilled by	Kaufman/Petrich
Casing	5-cm dia; 150-cm screen	Logged by	Petrich

Sample | Feet | Meters | Graphic log

Sample/Log Codes
AF: Auger Flight
AT: Auger Tip
AC: Auger Cuttings
PC: Pipe Core
SS: Split Spoon Core
S: Sound



Lithologic Log	Log Code
Dark gray silty clay, occasional fine sand.	AC
Coarse granitic sand	AC S
Brownish silty clay, grading to blue-gray color	AC AF
Gray clayey silt with fine-grained sand, grading to a poorly sorted, gravelly, coarse granitic sand; gravels to 3-cm diameter	AC AF S
Dense, very stiff, light bluish-gray clay	AT

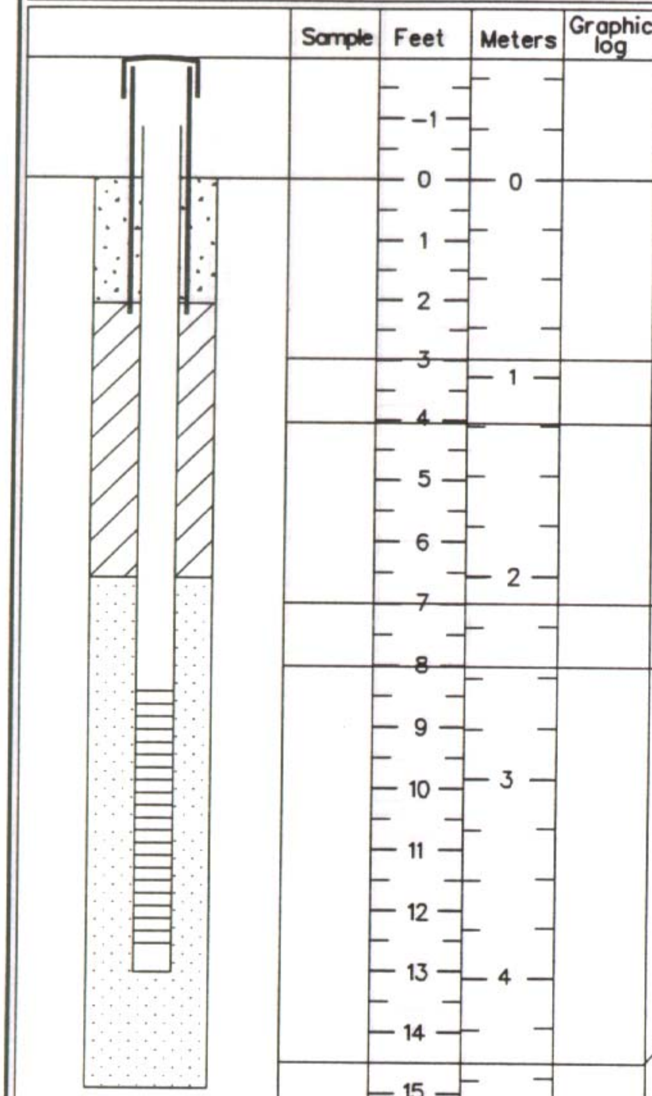
Note: well width dimensions are not drawn to scale

C. Petrich

P MW-2

Plant Science Farm **Well:** MW–3

Date Drilled	4–7–92	Surface Elevation	790.43 m
Total Depth	4.57 m	Inner Casing Elevation	790.82 m
Drilling Method	HSA	Drilled by	Kaufman/Petrich
Casing	5–cm dia; 150–cm screen	Logged by	Petrich



Sample/Log Codes
AF: Auger Flight
AT: Auger Tip
AC: Auger Cuttings
PC: Pipe Core
SS: Split Spoon Core
S: Sound

Lithologic Log	Log Code
Dark gray silty clay, occasional fine sand.	AC
Coarse granitic sand	AC S
Brownish silty clay, grading to blue–gray color	AC AF
Increasing coarse sand, some silt, clay	AS
Angular to subrounded, coarse, poorly sorted granitic sands; some granitic some subrounded gravels to 7 cm diameter	AC AF S
Dense, very stiff, light bluish–gray clay	AT

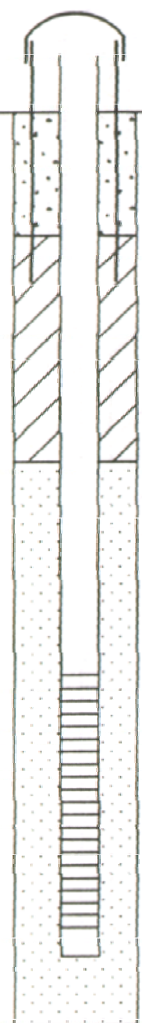
Note: well width dimensions are not drawn to scale

C. Petrich

P MW-3

Plant Science Farm   Well: MW-4

Date Drilled	4-28-92	Surface Elevation	790.41 m
Total Depth	4.57 m	Inner Casing Elevation	790.85 m
Drilling Method	HSA	Drilled by	JK
Casing	5-cm dia; 150-cm screen	Logged by	JK



Sample/Log Codes
AF: Auger Flight
AT: Auger Tip
AC: Auger Cuttings
PC: Pipe Core
SS: Split Spoon Core
S: Sound

Feet	Meters	Lithologic Log	Log Code
0–1	0	Dark brown silt	
1–2.5		Dark brown sandy silt	SS AC
2.5–4	1	Medium brown silt	SS AC
4–6		Greenish-gray micaceous coarse sand, minor clay, some pebbles to 0.5"; strongly oxidized from 1.13–1.22 m	SS AC
6–9.5	2	Greenish-gray, poorly sorted silty, sandy gravels; sand very coarse; cobbles to 7.5-cm, well-rounded	AC S SS
9.5–10.2	3	tan-brown micaceous sandy silt	SS
10.2–10.8		Medium & coarse, moderately well-sorted orange-brown sand	S AC
10.8–11.8		Fine to medium brown sand, minor silt	
11.8–13.7	4	Very coarse sand, cobbles to 7.5 cm	AC S
13.7–15		Very stiff, very light tan clay	S AF AT

Well width dimensions are not drawn to scale

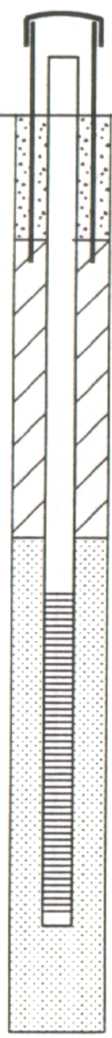
C. Petrich

P MW-4

Plant Science Farm Well: MW-5

Date Drilled	4-28-92	Surface Elevation	790.29 m
Total Depth	4.63 m	Inner Casing Elevation	790.80 m
Drilling Method	HSA	Drilled by	JK
Casing	5-cm dia; 150-cm screen	Logged by	JK

Well Construction | Sample | Feet | Meters | Graphic log



Sample/Log Codes

AF: Auger Flight
AT: Auger Tip
AC: Auger Cuttings
PC: Pipe Core
SS: Split Spoon Core
S: Sound

Lithologic Log	Drill Code	Log Code
Dark brown silt, abundant roots		
Medium to dark brown silt, occasional oxidized specks		
Brown sandy and/or clayey oxidized silt		
Bluish-gray micaceous fine sand and silt, clay		
Very coarse sand, silt, pebbles		
Gray silt, clay, wood fragments		
Saturated very coarse sand, gravel, cobbles to 8 cm; sub-angular to subround, poorly sorted		
Light gray to bluish gray silty clay; occasional oxidized spots		
Light gray, very stiff clay		

Well width dimensions are not drawn to scale

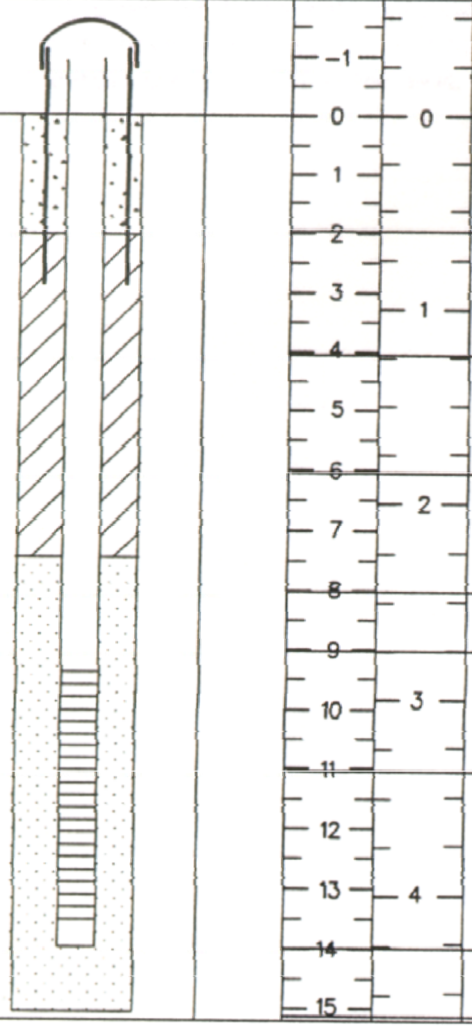
C. Patrich

P MW-5

Plant Science Farm   Well: MW-6

Date Drilled	4-29-92	Surface Elevation	790.39 m
Total Depth	4.63 m	Inner Casing Elevation	790.77 m
Drilling Method	HSA	Drilled by	CP
Casing	5-cm dia; 150-cm screen	Logged by	CP

Sample/Log Codes
AF: Auger Flight
AT: Auger Tip
AC: Auger Cuttings
PC: Pipe Core
SS: Split Spoon Core
S: Sound



Sample | Feet | Meters | Graphic log

Lithologic Log	Log Code
Dark brown silt	AC S
Medium to dark brown clayey silt with scattered coarse sand grains	AC
Dark brown silty clay with occasional pebbles	AC
Bluish gray silt with clay	AC
Bluish gray fine sand, coarser with depth, mica, some clay	AC
Gravels in silty clay matrix, dark brown	AC S
Coarse sand, gravel, silt, and clay	S
Stiff bluish gray silty clay	AT

Well width dimensions are not drawn to scale

C. Petrich

P MW-6

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
AND DEVELOPMENT

WELL LOG Well #3 No. A.6118

Date 8-2, 1962

Record by well driller

Source driller's record

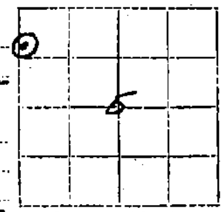


Diagram of Section

Location: State of WASHINGTON

County Whitman

Area

Map

¼ ¼ sec. 5 T. 14 N., R. 45 E.

Drilling Co. Dickerson Machinery Co.

Address Spokane, Wash.

Method of Drilling Date June 5, 1962.

Owner City of Pullman, Wash.

Address

Land surface, datum ft. above / below

(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses. If material water-bearing, so state and record static level if reported. Give depths in feet below land-surface datum unless otherwise indicated. Correlate with stratigraphic column, if feasible. Following log of materials, list all casings, perforations, screens, etc.)

Correlation	Material	Thickness (feet)	Depth (feet)
	Fill	7	7
	Gray silt	9	16
	Yellow decomposed rock	6	22
	Hard gray rock	2	24
	Yellow rock not very hard	25	49
	" " harder	14	63
	Grey rock not very hard	16	79
	" " but harder	13	92
	" " not so hard	6	98
	Soft green rock	8	106
	Fairly hard black rock	6	112
	Hard grey rock	10	122
	Soft black rock	29	151
	Soft red rock	8	159
	Gray rock crevices, water	3	162
	Soft red rock	5	167
	(over)		

Turn up Sheet ..... of ..... sheets

Pullman 3

GWP-8098

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

WELL LOG

Record by: Driller
Source: Driller's Record

Location: State of WASHINGTON
County: Whitman
Area:
Map:
SE ¼ NE ¼ sec. 7 T. 14 N., R. 45 E.
Diagram of Section
Drilling Co. Charles Jungmann Drilling Co.
Address: 115 Rees - P.O. Box 624, Walla Walla, WA
Method of Drilling: Cable Date 11/19/68-5/20 19 69
Owner: City of Pullman
Address: P. O. Box 438, Pullman, WA. 99163
Land surface, datum 2445 ft. above ~~below~~ Sea Level
SWL: 148 Date 5/21, 19 69 Dims. 12" X 712'

CORRE-LATION	MATERIAL Municipal	From (feet)	To (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses. If material water-bearing, so state and record static level if reported. Give depths in feet below land-surface datum unless otherwise indicated. Correlate with stratigraphic column, if feasible. Following log of materials, list all casings, perforations, screens, etc.)		
	Top Soil - Soft - Black	0	5
	Rock - Hard - Black	5	9
	Basalt - Med. Hard - Black	9	24
	Basalt - Hard - Black	24	54
	Basalt - Hard - Gray	54	67
	Basalt - Hard - Dark	67	72
	Basalt - Med. - Dark	72	77
	Clay - Med. Soft - Green & Blue	77	83
	Clay - Med. - Blue Brown	83	92
	Clay - Med. - Gray	92	108
	Basalt - Med. - Black	108	139
	Basalt & Clay - Soft - Black	139	172
	Rock - Med. Soft - Black	172	230
	Continued		

Turn up Sheet ...... of ...... sheets

Pullman 5

GWP 8098

WELL LOG.—Continued No........./.........-.........

Corre-lation	Material	From (feet)	To (feet)
	Depth forward	———	
	Basalt - Hard - Black	230	277
	Basalt - Med. Hard - Black	277	418
	Basalt - Med. Soft - Black	418	465
	Basalt - Med. - Black	465	508
	Basalt - Med. Soft - Black	508	528
	Basalt - Hard - Black	528	530
	Basalt - Med. Hard - Black	530	538
	Basalt - Med. - Black	538	559
	Basalt - Med. Hard - Black	559	568
	Clay, - Soft - Gray	568	570
	Basalt - Med. Hard - Black	570	583
	Basalt - Med. - Black	583	591
	Basalt - Med. Soft - Black	591	599
	Clay, Sticky - Soft - Green	599	610
	Basalt - Med. Hard - Black	610	612
	Basalt - Med. - Black	612	625
	Rock & Clay - Soft - Black	625	645
	Basalt - Med. Hard - Black	645	675
	Basalt - Med. Soft - Black	675	682
	Basalt - Med. - Black	682	698
	Basalt - Med. Hard - Black	698	712
	Casing: 18" from 0 to 200'		
	16" from 200' to 532'		
	12" from 532' to 672'		
	Pump: Peerless Pump, HU S.F.	1.15,	250 HP
Pump Test	Well Test: 1799 gpm, 175' DD,	5 Hr.	
	2285 gpm, 190' DD,	½ HR.	(5-21-69)
	Temp H_2O - 58°F		
	Recovery Data		
	0 min - 175' 0 min - 190'		
	2 min - 148' 20 Sec - 148		

F. F. No. 1449—OS—12-65.

Surface Seal 0-200' Cement.

Pullman 5 cont.

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION
DIVISION OF WATER RESOURCES

WELL LOG GWC 6607-A

Record by Driller

Source Drillers record

Location: State of WASHINGTON

County Whitman

Area

Map

NE ¼ NW ¼ sec. 32 T 15 N., R 45 E W.

Diagram of Section

32

Drilling Co. Charles Jungmann Drilling Co.

Address 115 Rees Ave. W.W., Wash.

Method of Drilling new well & / cable Date October 3, 1968

Owner City of Pullman

Address City Hall

Land surface, datum ft. above below

SWL: 132' Date June 12, 1968 Dims.: 18-12 X 51

CORRELATION	MATERIAL	From (feet)	To (feet)
	(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses. If material water-bearing, so state and record static level if reported. Give depths in feet below land-surface datum unless otherwise indicated. Correlate with stratigraphic column, if feasible. Following log of materials, list all casings, perforations, screens, etc.)		
	Municipal		
	Basalt Black	0	59
	Clay, green	59	91
	Basalt, broken	91	134
	Basalt, grey	134	162
	Basalt, black	162	318
	Basalt, Brown	318	326
	Basalt, Black	326	518
	casing 30" from 0-8'		
	18" from +2-235'		
	Surface sealed with casing -		
	cement 235'		

Turn up Sheet ..... of ..... sheets

CITY of PULLMAN WELL #6

Pullman 6

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

Ecology
y - Owner's Copy
Driller's Copy

102176

WATER WELL REPORT

STATE OF WASHINGTON

Notice of Intent W129452
UNIQUE WELL I.D. # AFB 046
Water Right Permit No

OWNER: Name CITY OF PULLMAN Address SE 325 PARADISE ST, PULLMAN WA 991

(1) LOCATION OF WELL: County WHITMAN SW 1/4 SW 1/4 Sec 32 T 15N N R 45E WM

(2a) STREET ADDRESS OF WELL: (or nearest address) NW CORNER OF INTERSECTION OF RITCHIE & GRAND AV PULLMAN WA

TAX PARCEL NO. NONE

(3) PROPOSED USE: ☐ Domestic ☐ Irrigation ☐ DeWater ☐ Industrial ☐ Test Well ☒ Municipal ☐ Other

(4) TYPE OF WORK: Owner's number of well (if more than one) 7
☒ New Well ☐ Deepened ☐ Reconditioned ☐ Decommission
Method: ☐ Dug ☐ Cable ☐ Rotary ☐ Bored ☐ Driven ☐ Jetted

(5) DIMENSIONS: Diameter of well 14" 16" 18" inches
Drilled 720' feet Depth of completed well 718' ft

(6) CONSTRUCTION DETAILS
Casing Installed:
☒ Welded 20" Diam from +1 ft to 202 ft
☒ Liner installed 18" Diam from +4 ft to 279 ft
☐ Threaded 14" Diam from 368 ft to 718 ft

Perforations: ☒ Yes ☐ No
Type of perforator used FACTORY
SIZE of perforations 2.5 in by 1/8 in
44100 perforations from 368 ft to 718 ft

Screens: ☒ Yes ☐ No ☐ K-Pac Location
Manufacturer's Name
Type V WIRE Model No
Diam 16 Slot Size 150 from 274 ft to 351.75 ft
Diam Slot Size from ft to ft

Gravel/Filter packed: ☐ Yes ☒ No ☐ Size of gravel/sand
Material placed from ft. to ft

Surface seal: ☒ Yes ☐ No To what depth? 202 ft
Material used in seal PORTLAND CEMENT
Did any strata contain unusable water? ☐ Yes ☐ No
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 97 ft below top of well Date 3-16-01
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 3,100 gal/min with 7.5 ft drawdown after 48 hrs
Yield gal/min with ft drawdown after hrs
Yield gal/min with ft drawdown after hrs
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
NA					

Date of test
Bailer test gal/min with ft drawdown after hrs
Airtest gal/min with ft drawdown after hrs
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? ☐ Yes ☐ No

(10) WELL LOG or DECOMMISSIONING PROCEDURE DESCRIPTION
Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. Indicate all water encountered.

MATERIAL	FROM	TO
SEE ATTACHED SHEET		

RECEIVED
JUL 0 6 2001
DEPT OF ECOLOGY

RECEIVED

Work Started 5-17 2000 Completed 3-16 2001

WELL CONSTRUCTION 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.

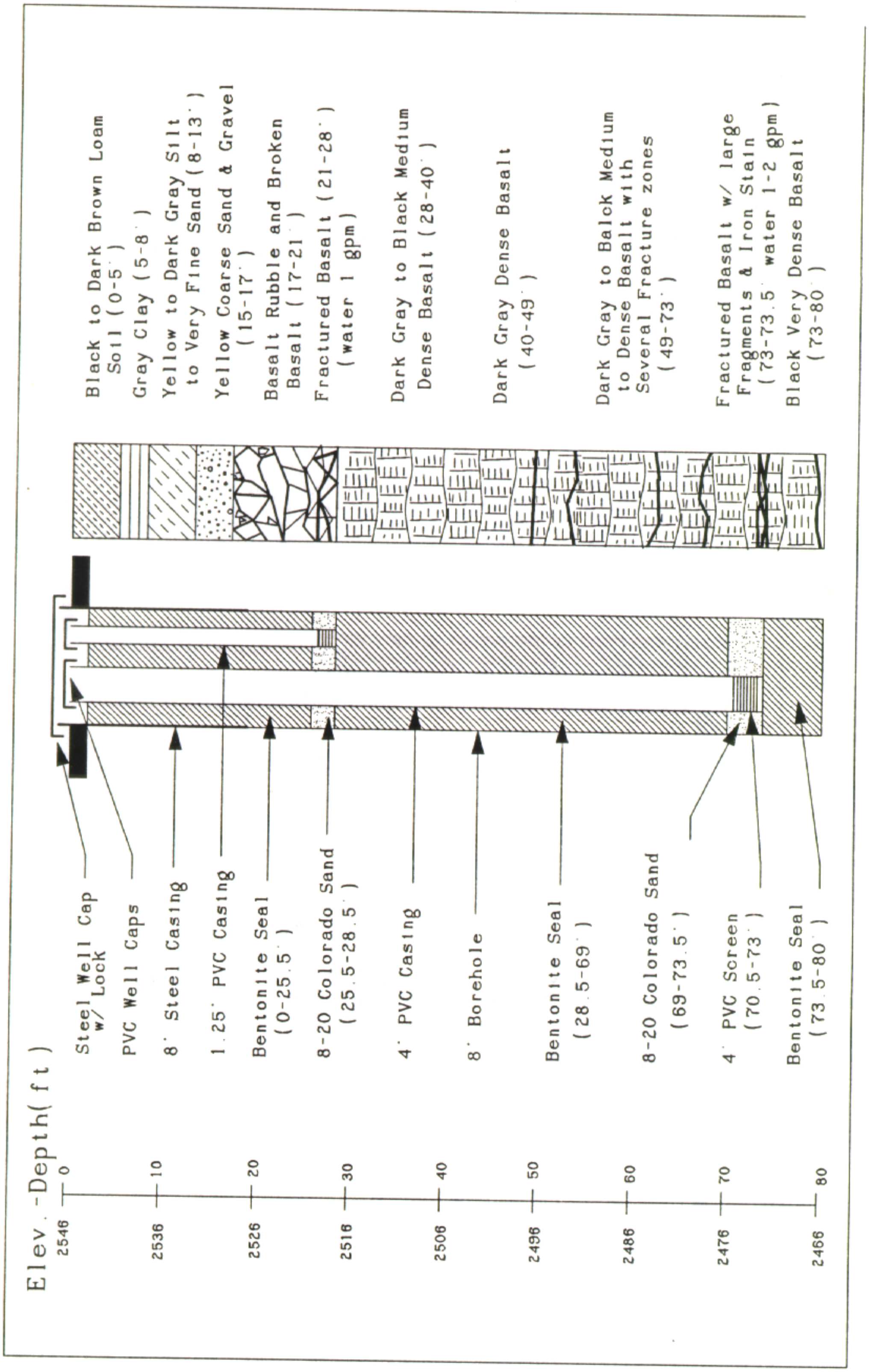
Type or Print Name Terry McCoy License No 2222
(Licensed Driller/Engineer)
Trainee Name License No
Drilling Company GEO-TECH EXPLORATIONS
(Signed) Terry McCoy License No 2222
(Licensed Driller/Engineer)
Address 19700 SW TETON, TUALATIN, OR 97062
Contractor's Registration No 110CZ Date 4-10 2001

(USE ADDITIONAL SHEETS IF NECESSARY)

Ecology is an Equal Opportunity and Affirmative Action employer. For special accommodation needs, contact the Water Resources Program at (360) 407-6600. The TDD number is (360) 407-6006.

ECY 050-1-20 (11/98)

Pullman 7


Elev. -Depth(ft)
2546 0
2536 10
2526 20
2516 30
2506 40
2496 50
2486 60
2476 70
2466 80
Steel Well Cap w/ Lock
PVC Well Caps
8' Steel Casing
1.25' PVC Casing
Bentonite Seal (0-25.5')
8-20 Colorado Sand (25.5-28.5')
4' PVC Casing
8' Borehole
Bentonite Seal (28.5-69')
8-20 Colorado Sand (69-73.5')
4' PVC Screen (70.5-73')
Bentonite Seal (73.5-80')
Black to Dark Brown Loam Soil (0-5')
Gray Clay (5-8')
Yellow to Dark Gray Silt to Very Fine Sand (8-13')
Yellow Coarse Sand & Gravel (15-17')
Basalt Rubble and Broken Basalt (17-21')
Fractured Basalt (21-28') (water 1 gpm)
Dark Gray to Black Medium Dense Basalt (28-40')
Dark Gray Dense Basalt (40-49')
Dark Gray to Balck Medium to Dense Basalt with Several Fracture zones (49-73')
Fractured Basalt w/ large Fragments & Iron Stain (73-73.5' water 1-2 gpm)
Black Very Dense Basalt (73-80')

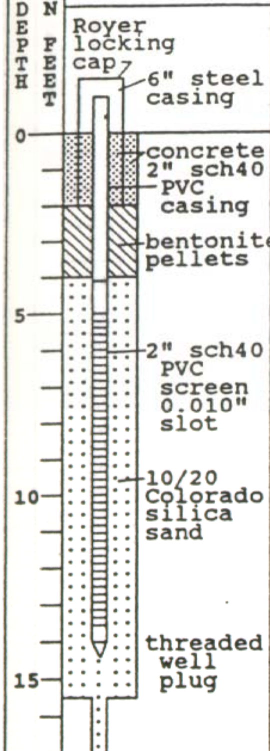
Q16D

RETEC REMEDIATION TECHNOLOGIES INC

MONITORING WELL LOG

WELL NUMBER: MW-2	SHEET 1 OF 1
PROJECT NAME/NUMBER: PUREGRO - MOSCOW/30-529	DRILLING CO: PONDEROSA Drilling
LOCATION: NE corner of site, west of sump	DRILLER: R. Mills
SCHEDULE: INITIATED: 10-25-90; COMPLETED: 10-25-90	WATER LEVEL: DEPTH: 5.9'; DATE: 10-26-90
RIG TYPE: Mobile B-80	METHOD: HSA
BORING DEPTH: 15.5'	BORING DIAMETER: 8.25"
LOGGED BY: D. Baker	

WELL CONSTRUCTION



DEPTH IN FEET	USCS	SOIL DESCRIPTION	TYPE	DEPTH	BLOWS	% RECOV	P.I.D. ppm
0	SP	GRAVELLY SAND: Dark yellow brown (10 YR4/2); f-c; some f gravel, little silt; mst.					
	ML	SANDY SILT: Grayish brown (5YR3/2); some m-vc sand, tr f gravel, tr clay; mst. 4.5': wet	S	X	5 10 15	100	
5	SP	GRAVELLY SAND: Grayish brown (5YR 3/2); m-vc; little f gravel, tr silt; wet.	S	X	14 20 21	100	
	SM	SILTY SAND: Dark yellow brown (10YR 4/2); vf-vc; little silt, tr f gravel; well graded; wet.					
10	SP	SAND: Light brown (5YR5/6); m-vc; tr silt; wet.	S		3 8 10	100	
	SP	GRAVELLY SAND: Pale yellow brown (10 YR6/2); c-vc; some fine gravel, tr silt; wet.					
	ML	SANDY SILT: Olive gray (5Y4/1); some vf-m sand; tr silt; sl micaceous; wet. 11.5': layer of stems.					
15	ML	CLAYEY SILT: Moderate brown (5YR 3/4); little clay; semiconsolidated, horizontal partings; mst. 16': 1" gray sandy silt layer. 17': bark layer.	S		7 22 27	100	
20							
25							

REMARKS:

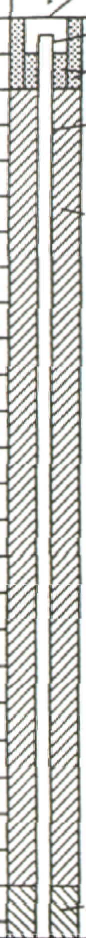
X Denotes laboratory sample

SASa

RETEC REMEDIATION TECHNOLOGIES INC

MONITORING WELL LOG

WELL NUMBER: MW-3D	SHEET 1 OF 2
PROJECT NAME/NUMBER: PUREGRO - MOSCOW/30-529	DRILLING CO: PONDEROSA Drilling
LOCATION: North of ammonia tank	DRILLER: R. Mills
SCHEDULE / INITIATED: 10-23-90 / COMPLETED: 10-24-90	WATER LEVEL / DEPTH: 22.3' / DATE: 10-26-90
	RIG TYPE: Mobile B-80
	METHOD: HSA
BORING DEPTH: 30.5'	BORING DIAMETER: 8.25"
	LOGGED BY: D. Baker



WELL CONSTRUCTION: flush mount; locking well cap; concrete; 2" sch40 PVC casing; concrete bentonite grout; bentonite slurry

DEPTH IN FEET	USCS	SOIL DESCRIPTION	TYPE	DEPTH	BLOWS	% RECOV	PID ppm
0	GM	SILTY GRAVEL: Grayish brown (5YR 3/2); little silt, little vf-vc sand; rounded (pea gravel); mst.	S	X	4 11 17	100	
	ML	GRAVELLY SILT: Dusky brown (5YR2/2), moderate brown (5YR4/4); some f gravel; tr vf-m sand; vertical contacts; mst.					
	ML	CLAYEY SILT: Moderate brown (5YR4/4) white, mottled; little clay; white in lenses and filling fractures; tr cynders; mst.					
5		5':dusky brown (5YR2/2); little clay no white lenses, no cynders.	S	X	7 19 22	85	
10	SM	SILTY SAND: Light olive gray (5Y6/1) vf-vc; and silts; well sorted layers coarsening downwards (m-vc); micaceous; wet.	S		8 23 24	100	
15		m-c; little silt.	S		11 23 24	100	
	GW	SANDY GRAVEL: Light olive gray (5Y 6/1); f; some c-vc sand; subangular to subrounded; wet.					
20	CL	CLAY: Moderate yellowish brown (10YR 5/4), medium dark gray (N4), mottled; tr silt; low plasticit; wet.	S		12 17 40	100	
25		24-25': hard drilling.					

REMARKS:

X Denotes laboratory samples.

SASb

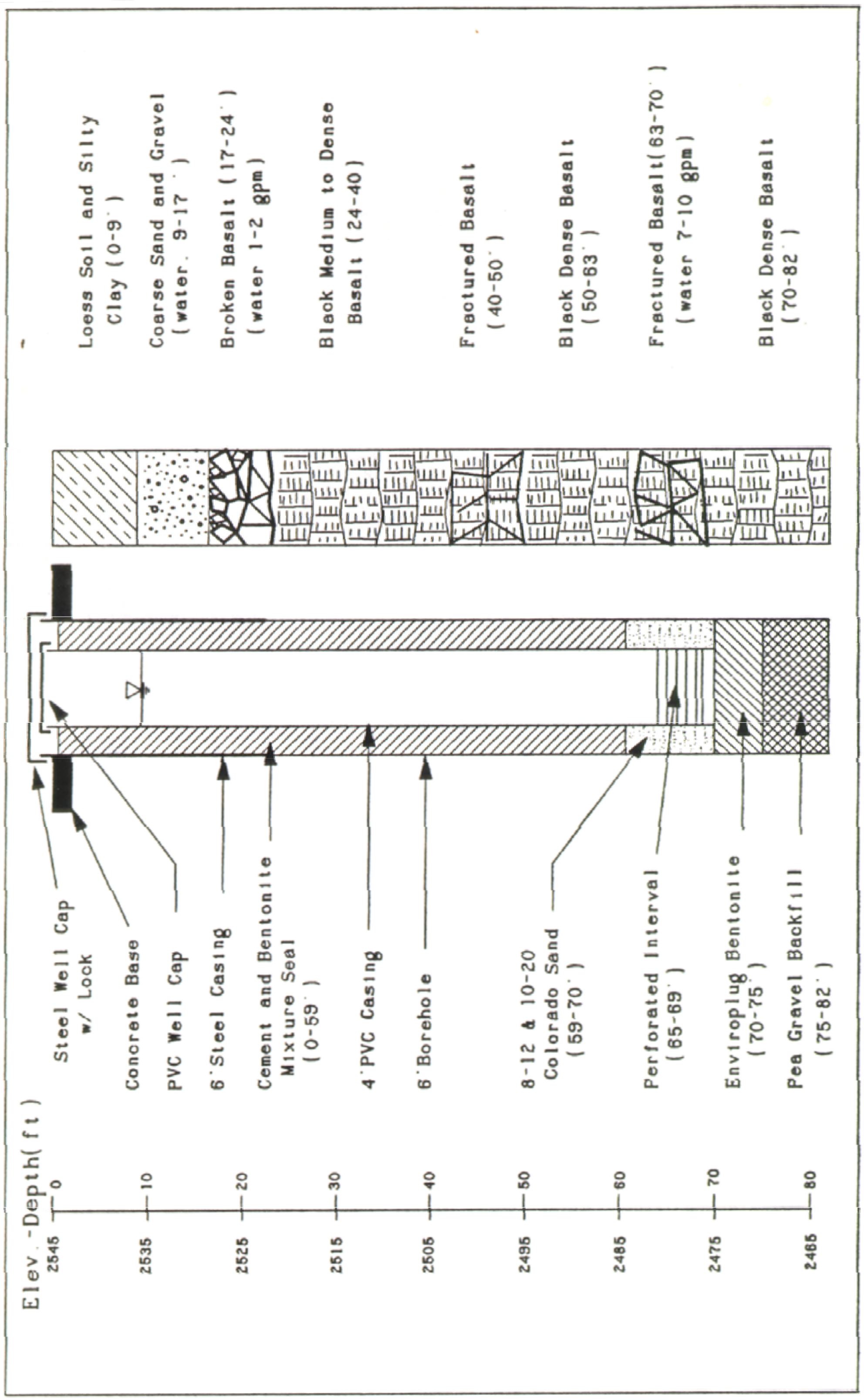
RETEC REMEDIATION TECHNOLOGIES INC | MONITORING WELL LOG | WELL NUMBER: MW-3D

SHEET 2 OF 2

DEPTH IN FEET	WELL CONSTRUCTION	USCS	SOIL DESCRIPTION	TYPE	DEPTH	BLOWS	%RECOV	PID ppm
25	bentonite slurry; bentonite pellets; 10/20 silica sand		SILTSTONE: Dusky yellowish brown (10 YR2/2); parts along irregular horizontal surfaces; micaceous. 26.5': softer.	S		70 3"	10	
30	2" PVC screen 0.010" slot; slip-on cap		black; large vuggy pores.	S		50 2"	10	
35								
40								
45								
50								
55								

REMARKS:

SASb cont.


Elev.-Depth(ft)
2545 0
2535 10
2525 20
2515 30
2505 40
2495 50
2485 60
2475 70
2465 80
Steel Well Cap w/ Lock
Concrete Base
PVC Well Cap
6"Steel Casing
Cement and Bentonite Mixture Seal (0-59')
4"PVC Casing
6"Borehole
8-12 & 10-20 Colorado Sand (59-70')
Perforated Interval (65-69')
Enviroplug Bentonite (70-75')
Pea Gravel Backfill (75-82')
Loess Soil and Silty Clay (0-9')
Coarse Sand and Gravel (water. 9-17')
Broken Basalt (17-24') (water 1-2 gpm)
Black Medium to Dense Basalt (24-40)
Fractured Basalt (40-50')
Black Dense Basalt (50-63')
Fractured Basalt(63-70') (water 7-10 gpm)
Black Dense Basalt (70-82')

T16D

RECEIVED
Form 238-7
11/97 JGE JAN 08 2001
IDWR/North

IDAHO DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

Office Use Only
Inspected by ____
Twp ____ Rge ____ Sec ____
____ 1/4 ____ 1/4 ____ 1/4
Lat: : : Long: : :

1. WELL TAG NO. D D0013641
DRILLING PERMIT NO. ____
Other IDWR No. 766134

2. OWNER:
Name MICK HESS
Address 1312 E ST
City MOSCOW State ID Zip 83843

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

POSTED

Twp. 40 North [X] or South [ ]
Rge. 5 East [ ] or West [X]
Sec. 33 ____ 1/4 NE 1/4 NE 1/4
10 acres 40 acres 160 acres
Gov't Lot ____ County LATAH
Lat: Long:
Address of Well Site WEST TWIN RD
(Give at least name of road + Distance to Road or Landmark)
City MOSCOW
Lt. ____ Blk. ____ Sub. Name ____

4. USE:
[X] Domestic [ ] Municipal [ ] Monitor [ ] Irrigation
[ ] Thermal [ ] Injection [ ] Other

5. TYPE OF WORK: check all that apply (Replacement etc.)
[X] New Well [ ] Modify [ ] Abandonment [ ] Other

6. DRILL METHOD:
[X] Air Rotary [ ] Cable [ ] Mud Rotary [ ] Other

7. SEALING PROCEDURES:

Seal/Filter Pack Material	From	To	AMOUNT Sacks or Pounds	METHOD
BENTONITE	0	172	45	DRY

Was drive shoe used? [X] Y [ ] N Shoe Depth(s) 172 & 213
Was drive shoe seal tested? [X] Y [ ] N How? 300 PSI

8. CASING/LINER:

Diameter	From	To	Guage	Material	Casing	Liner	Welded	Threaded
8	+1	172	1/4	STEEL	[X]	[ ]	[X]	[ ]
6	1	213	1/4	STEEL	[X]	[ ]	[X]	[ ]
					[ ]	[ ]	[ ]	[ ]

Length of Headpipe ____ Length of Tailpipe ____

9. PERFORATIONS/SCREENS:
[ ] Perforations Method ____
[ ] Screens Screen Type ____

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						[ ]	[ ]
						[ ]	[ ]
						[ ]	[ ]

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
197 ft. below ground Artesian pressure ____ lb.
Depth flow encountered ____ ft. Describe access port or control devices: WELL CAP

11. WELL TESTS:
[ ] Pump [ ] Bailer [X] Air [ ] Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
2		280	1 HR

Water Temp. 53 Bottom hole temp. ____
Water Quality test or comments: ____
Depth first Water Encounter 107

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
14	0	1	SOIL		
14	1	172	SAND & CLAY		
8	172	199	SAND & CLAY	X	
8	199	213	BASALT MEDIUM BLACK		
6	213	279	BASALT MEDIUM BLACK		
6	279	305	SAND	X	

Completed Depth 305 (Measurable)
Date: Started 8/15/2000 Completed 8/21/2000

13. DRILLER'S CERTIFICATION:
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Company Name MCPHERSON & WRIGHT DRILLING Firm No. 0376
Firm Official Ted Wright Date 12/17/00
and
Driller or Operator Gary D. Wright Date 12/17/00
(Sign once if Firm Official & Operator)

40N 5W 33

FORWARD WHITE COPY TO WATER RESOURCES

TS 1 (Thorogold Stables)

Form 238-7
1/78

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

USE TYPEWRITER OR BALLPOINT PEN

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

ENT'D

1. WELL OWNER

Name John Ratti

Address Moscow

Owner's Permit No. 87-80-N-Z

2. NATURE OF WORK

☑ New well ☐ Deepened ☐ Replacement
☐ Abandoned (describe method of abandoning) ______

3. PROPOSED USE

☑ Domestic ☐ Irrigation ☐ Test ☐ Municipal
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ______ (specify type)

4. METHOD DRILLED

☑ Rotary ☑ Air ☐ Hydraulic ☐ Reverse rotary
☐ Cable ☐ Dug ☐ Other ______

5. WELL CONSTRUCTION

Casing schedule: ☑ Steel ☐ Concrete ☐ Other ______

Thickness		Diameter		From		To	
.250	inches	10"	inches	+ 1	feet	56	feet
.250	inches	8"	inches	2	feet	79	feet
	inches		inches		feet		feet
	inches		inches		feet		feet

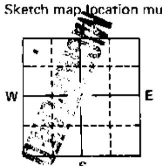
Was casing drive shoe used? 8" ☑ Yes 10" ☑ No
Was a packer or seal used? ☐ Yes ☑ No
Perforated? ☐ Yes ☑ No
How perforated? ☐ Factory ☐ Knife ☐ Torch
Size of perforation ______ inches by ______ inches

Number		From		To	
	perforations		feet		feet
	perforations		feet		feet
	perforations		feet		feet

Well screen installed? ☐ Yes ☑ No
Manufacturer's name ______
Type ______ Model No. ______
Diameter ____ Slot size ____ Set from ______ feet to ______ feet
Diameter ____ Slot size ____ Set from ______ feet to ______ feet
Gravel packed? ☐ Yes ☑ No ☐ Size of gravel ______
Placed from ______ feet to ______ feet
Surface seal depth ______ Material used in seal: ☐ Cement grout ☑ Puddling clay ☐ Well cuttings
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☑ Overbore to seal depth
Method of joining casing: ☐ Threaded ☑ Welded ☐ Solvent Weld
☐ Cemented between strata
Describe access port ______

6. LOCATION OF WELL

Sketch map location must agree with written location.



Subdivision Name ______

Lot No. ______ Block No. ______

County LaTah

NW ¼ NW ¼ Sec. 3, T. 39 N/S, R. 5 E/W.

7. WATER LEVEL

Static water level 40 feet below land surface.
Flowing? ☐ Yes ☑ No G.P.M. flow ______
Artesian closed-in pressure ______ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ______ °F. Quality ______

8. WELL TEST DATA

☐ Pump ☐ Bailer ☑ Air ☐ Other ______

Discharge G.P.M.	Pumping Level	Hours Pumped
15		

9. LITHOLOGIC LOG

Hole Diam.	Depth From	Depth To	Material	Water Yes	Water No
12	0	40	overburden, clay		✓
10	40	[illegible]	overburden, clay		✓
10	48	56	Quartz, clay		✓
8"	56	62	Quartz clay		✓
8"	62	78	Quartz	✓	

10.

Work started 9/21/80 finished 9/26/80

11. DRILLERS CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Earl Witt Well Drilling Firm No. 58

Address 619 Powers Lewiston Date 2/9/81

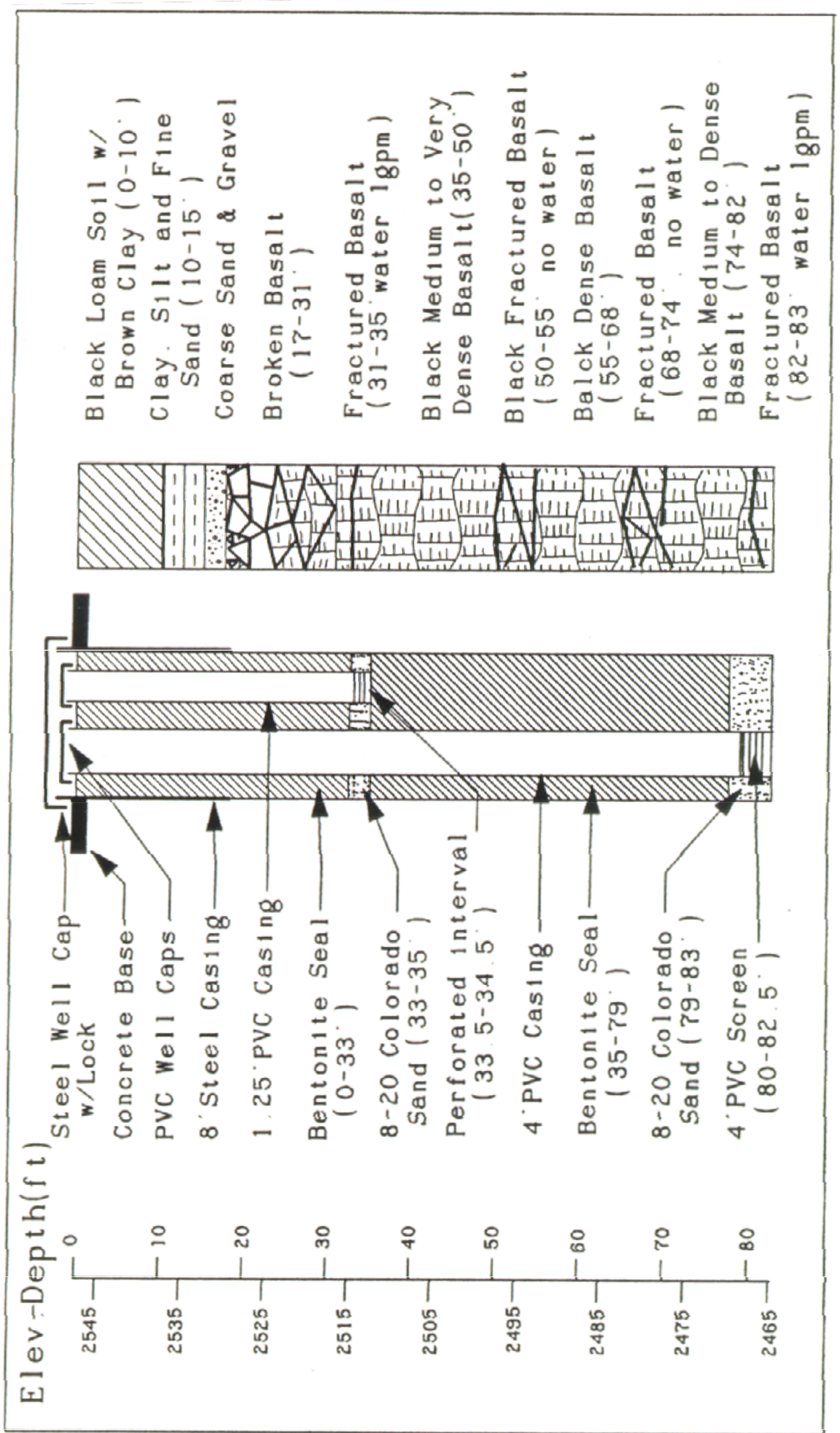
Signed by (Firm Official) Earl L. Witt

and

(Operator) Roger Witt

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

TS 2 (Thorogold Stables)



Elev.-Depth(ft)
2545
2535
2525
2515
2505
2495
2485
2475
2465
0
10
20
30
40
50
60
70
80
Steel Well Cap w/Lock
Concrete Base
PVC Well Caps
8' Steel Casing
1.25' PVC Casing
Bentonite Seal (0-33')
8-20 Colorado Sand (33-35')
Perforated Interval (33.5-34.5')
4' PVC Casing
Bentonite Seal (35-79')
8-20 Colorado Sand (79-83')
4' PVC Screen (80-82.5')
Black Loam Soil w/ Brown Clay (0-10')
Clay, Silt and Fine Sand (10-15')
Coarse Sand & Gravel
Broken Basalt (17-31')
Fractured Basalt (31-35' water 1gpm)
Black Medium to Very Dense Basalt(35-50')
Black Fractured Basalt (50-55' no water)
Balck Dense Basalt (55-68')
Fractured Basalt (68-74' no water)
Black Medium to Dense Basalt (74-82')
Fractured Basalt (82-83' water 1gpm)

U3D

RECEIVED
JUN 18 1999
IDWR/North

Form 238-7
5/96

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT
Use Typewriter or Ballpoint Pen

076413

Office Use Only
Inspected by ______
Twp ____ Rge ____ Sec ____
____1/4 ____1/4 ____1/4
Lat: : : Long: : :

1. DRILLING PERMIT NO. 87-99-N-0008-501
Other IDWR No. 87-07141
WELL ~~TAG #~~ D0010030

2. OWNER:
Name UNIVERSITY OF IDAHO
Address MOSCOW
City MOSCOW State ID Zip 83844
WELL # 4

3. LOCATION OF WELL by legal description:
Sketch map location must agree with written location.

POSTED

Twp. 39 North ☒ or South ☐
Rge. 6 East ☐ or West ☒
Sec. 12, ____ 1/4 SE 1/4 SE 1/4
(10 acres) (40 acres) (160 acres)
Gov't Lot ____ County LATAH
Lat: : : Long: : :
Address of Well Site 500 FT NORTH OF INTERSECTION S.H#8 + PERIMETER City MOSCOW
(Give at least name of road + Distance to Road or Landmark)
Lt. ______ Blk. ______ Sub. Name ______

4. USE:
☐ Domestic ☒ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other ______

5. TYPE OF WORK check all that apply (Replacement etc.)
☐ New Well ☒ Modify ☐ Abandonment ☐ Other ______

6. DRILL METHOD
☐ Air Rotary ☒ Cable ☐ Mud Rotary ☐ Other ______

7. SEALING PROCEDURES

SEAL/FILTER PACK			AMOUNT	METHOD
Material	From	To	Sacks or Pounds	

Was drive shoe used? ☒Y ☐N Shoe Depth(s) 575 FT
Was drive shoe seal tested? ☐Y ☐N How? ______

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
14"	502	506	.375	STEEL	☐	☒	☒	☐
8	506	575	.322	STEEL	☐	☒	☒	☐
					☐	☐	☐	☐

Length of Headpipe ______ Length of Tailpipe ______

9. PERFORATIONS/SCREENS N/A
☐ Perforations Method ______
☐ Screens Screen Type ______

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
300 ft. below ground Artesian pressure ____ lb.
Depth flow encountered ____ ft. Describe access port or control devices: ______

11. WELL TESTS:
☐ Pump ☐ Bailer ☐ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time

Water Temp. ______ Bottom hole temp. ______
Water Quality test or comments: ______ Depth first Water Encountered ______

12. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
			LINER + SEALS TOP +		
			BOTTOM WAS INSTALLED TO		
			REPAIR SPLIT IN 10" CASING		
			FROM APPROX. 550 TO 565 FT.		
			AND SEAL TOP OF 10" EXISTING		
			LINER AT 507 FT		
			INCLOSED IS DETAILED		
			SKETCH OF REPAIR		

Completed Depth 734 (Measurable)
Date: Started APRIL 27-99 Completed MAY 21-99

13. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name HOLMAN DRILLING CORP Firm No. 108
Firm Official [signature] Date JUNE 16-99
and
Supervisor or Operator [signature] Date JUNE 16-99
(Sign once if Firm Official & Operator)

39N 6W 12

FORWARD WHITE COPY TO WATER RESOURCES

UI 4

Form 238-7
11/91

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

USE TYPEWRITER OR BALLPOINT PEN

1. WELL OWNER

Name University of Ida
Address Moscow Idaho
Drilling Permit No. ~~12-39N-6W~~
Water Right Permit No. 87-90-N-28

2. NATURE OF WORK

☑ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase ☐ Modification
☐ Abandoned (describe abandonment or modification procedures such as liners, screen, materials, plug depths, etc. in lithologic log, section 9.)

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☐ Monitor
☑ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ________ (specify type)

4. METHOD DRILLED

☑ Rotary ☑ Air ☐ Auger ☐ Reverse rotary
☐ Cable ☐ Mud ☐ Other ________ (backhoe, hydraulic, etc.)

5. WELL CONSTRUCTION

Casing schedule: ☐ Steel ☐ Concrete ☐ Other ________

Thickness	Diameter	From	To
.380 inches	12 inches	+ 2 feet	245 feet
____ inches	____ inches	____ feet	____ feet
____ inches	____ inches	____ feet	____ feet

Was casing drive shoe used? ☑ Yes ☐ No
Was a packer or seal used? ☑ Yes ☐ No
Perforated? ☐ Yes ☑ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation? ____ inches by ____ inches

Number		From	To
____	perforations	____ feet	____ feet
____	perforations	____ feet	____ feet
____	perforations	____ feet	____ feet

Well screen installed? ☑ Yes ☐ No
Manufacturer Johnson Type Stainless
Top Packer or Headpipe ________
Bottom of Tailpipe ________

Diameter 12 Slot size 30 Set from 160 feet to 180 feet
Diameter 12 Slot size 35 Set from 220 feet to 230 feet
Gravel packed? ☐ Yes ☑ No ☐ Size of gravel ________
Placed from ________ feet to ________ feet

Surface seal depth 70 Material used in seal: ☑ Cement grout
☐ Bentonite ☐ Puddling clay ☐ ________
Sealing procedure used: ☐ Slurry pit
☐ Temp. surface casing ☑ Overbore to seal depth
Method of joining casing: ☐ Threaded ☑ Welded
☐ Solvent Weld ☐ Cemented between strata
Describe access port ________

6. LOCATION OF WELL

Sketch map location **must** agree with written location.

Subdivision Name ________
Lot No. ____ Block No. ____

County Latah Sec 12 39N 6W

SW ¼ NE ¼ Sec. ~~13~~ 12, T. 39 N ☑ S ☐ R. ~~3~~ E ☐ W ☑

7. WATER LEVEL

Static water level 83 feet below land surface.
Flowing? ☐ Yes ☑ No G.P.M. flow 250
Artesian closed-in pressure ________ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ____ °F. Quality ________
Describe artesian or temperature zones below.

8. WELL TEST DATA

☐ Pump ☐ Bailer ☑ Air ☐ Other ________

Discharge G.P.M.	Pumping Level	Hours Pumped

9. LITHOLOGIC LOG 080039

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
18	0	80	clay		
	68	73	med soft basalt		
	73	94	med basalt gray		
	94	96	soft layer basalt gray		
	96	125	hard basalt		
	125	128	softer layer basalt		
	128	136	med basalt gray		
	136	138	softer basalt		
	138	156	little harder basalt		
	156	172	seams in softer basalt (150 gpm)	✓	
	172	180	some [illegible] red		
	180	205	med hard basalt		
	205	220	very hard basalt		
	220	230	softer basalt		
	230	245	Shale some gray or black maybe basalt (250 to 300 gpm)	✓	

RECEIVED
MAR 31 1992
NORTHERN REGION
IDWR

10.

Work started Jan 1991 finished Mar 1991

11. DRILLER'S CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Ullerbott Drill Firm No. 125
Address Fern Idaho Date Mar 92
Signed by Drilling Supervisor Roy Ullerbott
and
(Operator) William Ullerbott
(If different than the Drilling Supervisor)

AUG 11 1992

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Form 238-7 4/82 (ENT'D)

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

MAR 2 4 1993

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name UNIVERSITY OF IDAHO

Address MOSCOW IDAHO 83843

Drilling Permit No. 87-92-N-44

Water Right Permit No. 87-07141

2. NATURE OF WORK

☒ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase ☐ Modification
☐ Abandoned (describe abandonment or modification procedures such as liners, screen, materials, plug depths, etc. in lithologic log, section 9.)

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☐ Monitor
☒ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ______ (specify type)

4. METHOD DRILLED

☒ Rotary ☒ Air ☐ Auger ☐ Reverse rotary
☐ Cable ☐ Mud ☐ Other ______ (backhoe, hydraulic, etc.)

5. WELL CONSTRUCTION

Casing schedule: ☒ Steel ☐ Concrete ☐ Other ______

Pulled

Thickness	Diameter	From	To
.250 inches	8 inches	+ 2 feet	62 feet
.250 inches	6 inches	2 feet	-314.5 feet
inches	inches	feet	feet

Was casing drive shoe used? ☐ Yes ☒ No
Was a packer or seal used? ☒ Yes ☐ No 2-5" K Paker
Perforated? ☐ Yes ☒ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation? ______ inches by ______ inches

Number	From	To
perforations	feet	feet
perforations	feet	feet
perforations	feet	feet

Well screen installed? ☒ Yes ☐ No
Manufacturer ______ Type Stainless Steel
Top Packer or Headpipe 309' to 315.9
Bottom of Tailpipe 342 to 348

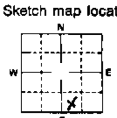
Diameter 5 Slot size 20 Set from 315.9 feet to 342 feet
Diameter ____ Slot size ____ Set from ____ feet to ____ feet
Gravel packed? ☐ Yes ☒ No ☐ Size of gravel ______
Placed from ______ feet to ______ feet

Surface seal depth 80 Material used in seal: ☐ Cement grout ☒ Bentonite ☒ Puddling clay ☐ ______
Sealing procedure used: ☒ Slurry pit ☒ Temp. surface casing ☒ Overbore to seal depth
Method of joining casing: ☐ Threaded ☒ Welded ☐ Solvent Weld ☐ Cemented between strata

Describe access port ______

6. LOCATION OF WELL

Sketch map location must agree with written location.



Subdivision Name ______
West 6th Street
Lot No. ______ Block No. ______
County Latah

Address of Well Site Agriculture Resaerch Facility (give at least name of road)

T. 39 N ☒ or S ☐
SW ¼ SE ¼ Sec. 13, R. 6 E ☐ or W ☒

7. WATER LEVEL

Static water level 148' feet below land surface.
Flowing? ☐ Yes ☒ No G.P.M. flow ______
Artesian closed-in pressure ______ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ______ °F. Quality ______
Describe artesian or temperature zones below.

8. WELL TEST DATA

☐ Pump ☐ Bailer ☒ Air ☐ Other ______

Discharge G.P.M.	Pumping Level	Hours Pumped
200+		

9. LITHOLOGIC LOG 104724

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
10	0	62	Silty Clay, Brn		X
8	62	73	Basalt Dark Brn Weathered		X
8	73	77	Basalt light brn w/clay		X
8	77	85	Basalt Drk/Brn Med. Hard		X
8	85	94	Basalt lght Brn Fractured		X
8	94	120	Basalt Blk Hard		X
8	120	145	Baslat Lght Brn fractured W/Water apx 30 to 40 gpm	X	
8	145	235	Baslat Blk Hard		X
8	235	250	Basalt Blk Fractured		X
8	250	270	Silty Sand Brn	X	
8	270	279	Silty Sand w Weed	X	
8	279	288	Sand Course W/Water	X	
8	288	305	Sand Finer w/Water	X	
8	305	342	Sand w/some Gravel W/Water	X	
8	342	351	Silty Sand hard Packed		X

RECEIVED
FEB 2 2 1993
NORTHERN REGION IDWR

MICROFILMED
AUG 0 9 1993

10.

Work started 1/18/93 finished 2/5/93

11. DRILLER'S CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name H2O WELL SERVICE Firm No. 448

Address HAYDEN LAKE, ID Date 2-11-93

Signed by Drilling Supervisor [signature]

and

(Operator) [signature]
(If different than the Drilling Supervisor)

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

RECEIVED JUN 17 1993 Department of Water Resources

RECEIVED JUN 01 1993 Department of Water Resources

Form 238-7 4/92

ENT'D

KC

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

WELL DRILLER'S REPORT

USE TYPEWRITER OR BALLPOINT PEN

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name UNIVERSITY OF IDAHO WELL #7

Address MOSCOW IDAHO 83844-1231 Facilities Management

Drilling Permit No. 87-93-N-2-000

Water Right Permit No. 87-7141

2. NATURE OF WORK

☒ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase ☐ Modification
☐ Abandoned (describe abandonment or modification procedures such as liners, screen, materials, plug depths, etc. in lithologic log, section 9.)

3. PROPOSED USE

☐ Domestic ☐ Irrigation ☐ Monitor
☒ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ______ (specify type)

4. METHOD DRILLED

☒ Rotary ☒ Air ☐ Auger ☐ Reverse rotary
☐ Cable ☐ Mud ☐ Other ______ (backhoe, hydraulic, etc.)

5. WELL CONSTRUCTION

Casing schedule: ☒ Steel ☐ Concrete ☐ Other ______

Thickness	Diameter	From	To
.250 inches	16 inches +	1 feet	15 feet
.250 inches	14 inches	1.5 feet	70 feet
.250 inches	10 inches	2.0 feet	284 feet

Was casing drive shoe used? ☒ Yes ☐ No
Was a packer or seal used? ☐ Yes ☒ No
Perforated? ☐ Yes ☒ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☐ Gun
Size of perforation? ______ inches by ______ inches

Number		From	To
	perforations	feet	feet
	perforations	feet	feet
	perforations	feet	feet

Well screen installed? ☒ Yes ☐ No
Manufacturer Cook Type Stainless Telescoping
Top Packer or Headpipe 283 to 285
Bottom of Tailpipe 349

Diameter 6 Slot size 20 Set from 290 feet to 300 feet
Diameter 6 Slot size 30 Set from 317 feet to 338 feet
Gravel packed? ☐ Yes ☒ No ☐ Size of gravel ______
Placed from ______ feet to ______ feet

Surface seal depth 70 Material used in seal: ☐ Cement grout ☒ Bentonite ☐ Puddling clay ☐ ______
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☐ Overbore to seal depth
Method of joining casing: ☐ Threaded ☒ Welded ☐ Solvent Weld ☐ Cemented between strata
Hole Plug 3/8 55 BAGS
Describe access port ______

6. LOCATION OF WELL

Sketch map location **must** agree with written location.

Subdivision Name ______

Lot No. ______ Block No. ______

County LATAH

N W 12 E S X

Address of Well Site AGRICULTURE RESEARCH FACILITY (give at least name of road)

SW 1/4 SE 1/4 Sec. 12, T. 39 N ☒ or S ☐, R. 6 E ☐ or W ☒

7. WATER LEVEL

Static water level 183 feet below land surface.
Flowing? ☐ Yes ☒ No G.P.M. flow ______
Artesian closed-in pressure ______ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature ______ °F. Quality ______
Describe artesian or temperature zones below.

8. WELL TEST DATA

☐ Pump ☐ Bailer ☒ Air ☐ Other ______

Discharge G.P.M.	Pumping Level	Hours Pumped
200+		

9. LITHOLOGIC LOG 104725

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
16	0	15	CLAY MED BROWN		X
14	15	70	CLAY MED BROWN		X
12	70	81	BASALT BROKEN W/CLAY & SAND	X	
12	81	140	BASALT DARK GRAY MEDIUM		X
12	140	148	BASALT FRACTURED W/YELLOWSEAMS	X	
12	148	235	BASALT DARK GRAY HARD		X
12	235	260	SILT STONE BROKEN W/SAND		X
10	260	307	SAND W/WOOD W/W COURSE	X	
10	307	315	SILT STONE GRAY MED HARD		X
10	315	340	SAND MED COURSE W/WATER	X	
10	340	349	SAND STONE HARD		X
			NOTE:		
			10"		
			2-K PACKER SET AT 283'TO 285'		
			36' OF 5" CASING W/SCREENS		
			14" CASING REMOVED		
			16" SURFACE PIPE REMOVED		

RECEIVED MAY 24 1993 NORTHERN REGION IDWR

MICROFILMED AUG 09 1993

10.

Work started 04/15/93 finished 05/04/93

11. DRILLER'S CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name H2O WELL SERVICE Firm No. #448

Address 582 W HAYDEN AVE Date 05/04/93

Signed by Drilling Supervisor [signature]

and

(Operator) [signature] (If different than the Drilling Supervisor)

TPK

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Form 238-7
6/02

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

Office Use Only
Well ID No.
Inspected by
Twp ____ Rge ____ Sec ____
____ 1/4 ____ 1/4 ____ 1/4
Lat: : : Long: : :

1. WELL TAG NO. D 00 40 389
DRILLING PERMIT NO. ~~834672~~ correct permit #
Water Right or Injection Well No. ~~L A 279897~~ 835876

2. OWNER:
Name James R Wallace
Address 2780 N Mountain View Rd
City Moscow State Id Zip 83843

3. LOCATION OF WELL by legal description:
You must provide address or Lot, Blk, Sub. or Directions to well.
Twp. 40 North ☒ or South ☐
Rge. 5 East ☐ or West ☒
Sec. 33, ___ 1/4 NW 1/4 SE 1/4
10 acres 40 acres 160 acres
Gov't Lot ___ County Latah
Lat: : : Long: : :
Address of Well Site 2788 N Mountain View Rd
(Give at least name of road + Distance to Road or Landmark) City Moscow
Lt. ___ Blk. ___ Sub. Name ___

4. USE:
☐ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation
☐ Thermal ☐ Injection ☐ Other ___

5. TYPE OF WORK check all that apply (Replacement etc.)
☐ New Well ☒ Modify ☐ Abandonment ☐ Other Bypass

6. DRILL METHOD:
☒ Air Rotary ☐ Cable ☐ Mud Rotary ☐ Other ___

7. SEALING PROCEDURES

Seal Material	From	To	Weight / Volume	Seal Placement Method
old well				

Was drive shoe used? ☐ Y ☐ N Shoe Depth(s) ___
Was drive shoe seal tested? ☐ Y ☐ N How? ___

8. CASING/LINER:

Diameter	From	To	Gauge	Material	Casing	Liner	Welded	Threaded
old well					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐

Length of Headpipe ___ Length of Tailpipe ___
Packer ☐ Y ☐ N Type ___

9. PERFORATIONS/SCREENS PACKER TYPE
Perforation Method ___
Screen Type & Method of Installation ___

From	To	Slot Size	Number	Diameter	Material	Casing	Liner
						☐	☐
						☐	☐
						☐	☐

10. FILTER PACK

Filter Material	From	To	Weight / Volume	Placement Method

11. STATIC WATER LEVEL OR ARTESIAN PRESSURE:
143 ft. below ground Artesian pressure ___ lb.
Depth flow encountered ___ ft. Describe access port or control devices: ___
top of well

40 N 5W 33

12. WELL TESTS:
☐ Pump ☐ Bailer ☐ Air ☐ Flowing Artesian

Yield gal./min.	Drawdown	Pumping Level	Time
unknown			

Water Temp. ___ Bottom hole temp. ___
Water Quality test or comments: ___
___ Depth first Water Encounter ___

13. LITHOLOGIC LOG: (Describe repairs or abandonment)

Bore Dia.	From	To	Remarks: Lithology, Water Quality & Temperature	Water Y	Water N
6	153	278	Never blew water or material from well		

RECEIVED
AUG 29 2005
IDWR/North

Completed Depth 275 ft (Measurable)
Date: Started 7/14/05 Completed 7/15/05

14. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.
Company Name Uhlenkott Drill Firm No. 125
Principal Driller Don Uhlenkott Date 8/21/05
and
Driller or Operator II ___ Date ___
Operator I ___ Date ___
Principal Driller and Rig Operator *Required.*
Operator I must have signature of Driller/Operator II.

FORWARD WHITE COPY TO WATER RESOURCES

Form 238-7
6/07

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

1. WELL TAG NO. D D00 55559
Drilling Permit No. 853387
Water right or injection well #

2. OWNER
Name SEAN WILSON
Address 2780 N MOUNTAIN VIEW ROAD
City MOSCOW State ID Zip 83843

3. WELL LOCATION:
Twp. 40 North ☒ or South ☐ Rge. 05 East ☐ or West ☒
Sec. 33 SW 1/4 SE 1/4 NW 1/4
10 acres 40 acres 160 acres
Gov't Lot -- County LATAH
Lat. ° ' (Deg. and Decimal minutes)
Long. ° ' (Deg. and Decimal minutes)
Address of Well Site 2780 N MOUNTAIN VIEW ROAD City MOSCOW
Lot -- Blk. -- Sub. Name --

4. USE:
☒ Domestic ☐ Municipal ☐ Monitor ☐ Irrigation ☐ Thermal ☐ Injection
☐ Other

5. TYPE OF WORK check all that apply (Replacement etc.)
☒ New Well ☐ Replacement well ☐ Modify existing well
☐ Abandonment ☐ Other

6. DRILL METHOD:
☒ Air Rotary ☐ Mud Rotary ☐ Cable ☐ Other

7. SEALING PROCEDURES

Seal material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method/procedure
BENTONITE	0	65	900#	TOP POUR

8. CASING/LINER:

Diameter (nominal)	From (ft)	To (ft)	Gauge/ Schedule	Material	Casing	Liner	Threaded	Welded
8"	+2	138	.250	STEEL	☒	☐	☐	☒
					☐	☐	☐	☐
4.5	20	180	160	PVC	☐	☒	☐	☐

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s) 138

9. PERFORATIONS/SCREENS:
Perforations ☒ Y ☐ N Method SAW
Manufactured screen ☐ Y ☒ N Type
Method of installation

From (ft)	To (ft)	Slot size	Number/ft	Diameter (nominal)	Material	Gauge or Schedule
140	185	1/8 X4	42	4.5	PVC	160

Length of Headpipe N/A Length of Tailpipe
Packer ☐ Y ☒ N Type

10. FILTER PACK:

Filter Material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method
N/A				

11. FLOWING ARTESIAN:
Flowing Artesian? ☐ Y ☒ N Artesian Pressure (PSIG)
Describe control device

40N 05W 33

12. STATIC WATER LEVEL and WELL TESTS:
Depth first water encountered (ft) 165 Static water level (ft) 150
Water temp. (°F) 55 Bottom hole temp. (°F)
Describe access port TOP OF CASING - CAP

Well test:

Drawdown (feet)	Discharge or yield (gpm)	Test duration (minutes)
	12.5	1.5

Test method: ☐ Pump ☐ Bailer ☒ Air ☐ Flowing artesian

Water Quality test or comments: GOOD

13. LITHOLOGIC LOG and/or repairs or abandonment:

Bore Dia. (in)	From (ft)	To (ft)	Remarks, lithology or description of repairs or abandonment, water temp.	Water Y	Water N
10	0	140	SAND & CLAY		X
6	140	185	BLACK BASALT	X	

RECEIVED
SEP 25 2008
IDWR/North

Completed Depth (Measurable) 185
Date: Started 09/12/08 Completed 09/16/08

14. DRILLER'S CERTIFICATION
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.
Company Name TWO U DRILLING, LLC Co. No. 125
*Principal Driller TU Date 09/16/08
*Driller BU Date 09/16/08
*Operator II Date
Operator I Date
* Signature of Principal Driller and rig operator are required.

9-29-08

Wilson 2

Form 238-7 4/92 POSTED

STATE OF IDAHO
DEPARTMENT OF WATER RESOURCES

USE TYPEWRITER OR BALLPOINT PEN

WELL DRILLER'S REPORT

State law requires that this report be filed with the Director, Department of Water Resources within 30 days after the completion or abandonment of the well.

1. WELL OWNER

Name CONNIE WOOD
Address MOSCOW
Drilling Permit No. 87-94-N-0006
Water Right Permit No.

2. NATURE OF WORK

☒ New well ☐ Deepened ☐ Replacement
☐ Well diameter increase ☐ Modification
☐ Abandoned (describe abandonment or modification procedures such as liners, screen, materials, plug depths, etc. in lithologic log, section 9.)

3. PROPOSED USE

☒ Domestic ☐ Irrigation ☐ Monitor
☐ Industrial ☐ Stock ☐ Waste Disposal or Injection
☐ Other ______ (specify type)

4. METHOD DRILLED

☒ Rotary ☒ Air ☐ Auger ☐ Reverse rotary
☐ Cable ☐ Mud ☐ Other ______ (backhoe, hydraulic, etc.)

5. WELL CONSTRUCTION

Casing schedule: ☒ Steel ☐ Concrete ☒ Other PVC

Thickness		Diameter		From		To	
250	inches	7"	inches	+ 2	feet	63	feet
250	inches		inches	-40	feet	176	feet
	inches		inches		feet		feet

Was casing drive shoe used? ☒ Yes ☐ No
Was a packer or seal used? ☐ Yes ☒ No
Perforated? ☒ Yes ☐ No
How perforated? ☐ Factory ☐ Knife ☐ Torch ☒ Gun SAW
Size of perforation? 1/4 inches by 2 inches

Number		From		To	
102	perforations	100	feet	176	feet
	perforations		feet		feet
	perforations		feet		feet

Well screen installed? ☐ Yes ☒ No
Manufacturer ______ Type ______
Top Packer or Headpipe ______
Bottom of Tailpipe ______

Diameter ___ Slot size ___ Set from ___ feet to ___ feet
Diameter ___ Slot size ___ Set from ___ feet to ___ feet
Gravel packed? ☐ Yes ☒ No ☐ Size of gravel ______
Placed from ______ feet to ______ feet

Surface seal depth 20 Material used in seal: ☐ Cement grout ☒ Bentonite ☐ Puddling clay ☐ ______
Sealing procedure used: ☐ Slurry pit ☐ Temp. surface casing ☒ Overbore to seal depth
Method of joining casing: ☐ Threaded ☒ Welded ☐ ~~Solvent Weld~~ M.S ☐ Cemented between strata
Describe access port WELL SEAL

6. LOCATION OF WELL

Sketch map location **must** agree with written location.

Subdivision Name HIGHWAY 8 EAST
Lot No. ______ Block No. ______
County LATAH
Address of Well Site ______ (give at least name of road)
SW NE SE 1/4 ___ 1/4 Sec. 16, T. 39 N ☒ or S ☐, R. 5 E ☐ or W ☒

7. WATER LEVEL

Static water level 100 feet below land surface.
Flowing? ☐ Yes ☒ No G.P.M. flow ______
Artesian closed-in pressure ______ p.s.i.
Controlled by: ☐ Valve ☐ Cap ☐ Plug
Temperature 54 °F. Quality GOOD
Describe artesian or temperature zones below.

8. WELL TEST DATA

☐ Pump ☐ Bailer ☒ Air ☐ Other ______

Discharge G.P.M.	Pumping Level	Hours Pumped
6+	176	1

9. LITHOLOGIC LOG

Bore Diam.	Depth From	Depth To	Material	Water Yes	Water No
10-8	0	47	CLAY		—
8	48	63	SAND	—	
7	63	126	CLAY		—
7	126	176	SHALE	—	

RECEIVED
JUL 13 1994
NORTHERN REGION IDWR

10. Work started 6/5/94 finished 6/8/94

11. DRILLER'S CERTIFICATION

I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Firm Name Burns Well Drilling, Inc. Firm No. 103
Address Rt. 2 Box 615 Grangeville, Idaho 83530 Date 7/9/94
Signed by Drilling Supervisor [signature]
and
(Operator) G. R. Burns
(If different than the Drilling Supervisor)

USE ADDITIONAL SHEETS IF NECESSARY — FORWARD THE WHITE COPY TO THE DEPARTMENT

Wood

Appl# 6405

STATE OF WASHINGTO

DEPARTMENT OF CONSERVATION
AND DEVELOPMENT Appli# #6064

Well #4

WELL LOG No........./.........-.........

Date April 9, 1963

Record by Driller

Source Driller's Record

Location: State of WASHINGTON

County Whitman

Area

Map

......¼ ......¼ sec. 5 T. 14 N., R. 45 E.

	⊙		
	5		

Diagram of Section

Drilling Co. Holman Drilling Corporation

Address 3410 E. 9th, Spokane 31, Washington

Method of Drilling................ Date Nov. 29, 1962

Owner Washington State University

Address Pullman, Washington

Land surface, datum..........ft. above/below

(Transcribe driller's terminology literally but paraphrase as necessary, in parentheses. If material water-bearing, so state and record static level if reported. Give depths in feet below land-surface datum unless otherwise indicated. Correlate with stratigraphic column, if feasible. Following log of materials, list all casings, perforations, screens, etc.)

CORRELATION	MATERIAL	THICKNESS (feet)	DEPTH (feet)
	Top soil	15	15
	Brown clay	8	23
	Basalt, hard	45	68
	Brown sandy clay	17	85
	Green & blue, conglomerate	13	98
	Basalt, soft water bearing	10	108
	Basalt, medium hard	28	136
	Basalt, hard	63	199
	Basalt, soft	11	210
	Basalt, soft & fractured water bearing	10	220
	Basalt, medium hard fractured	15	235
	Basalt, hard very broken, water bearing	28	263
	Basalt, crevice, hard water bearing	7	270

Turn up Sheet.......of.......sheets

WSU 4

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

Application No. G3-22065
Permit No. G3-22065P

(1) OWNER: Name Washington State University Address Pullman, Washington 99163

(2) LOCATION OF WELL: County Whitman — NW ¼ NW ¼ Sec. 4 T. 14 N., R. 45E W.M.

Bearing and distance from section or subdivision corner

(3) PROPOSED USE: Domestic ☐ Industrial ☐ Municipal ☒ Irrigation ☐ Test Well ☐ Other ☐

(4) TYPE OF WORK: Owner's number of well (if more than one) 6
New well ☒ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☒ Driven ☐
Reconditioned ☐ Rotary ☐ Jetted ☐

(5) DIMENSIONS: Diameter of well [illegible] inches.
Drilled 702 ft. Depth of completed well 702 ft.

(6) CONSTRUCTION DETAILS:

Casing installed: 24" Diam. from +2 ft. to 25'6" ft.
Threaded ☐ 20" Diam. from [illegible] ft. to 155'5" ft.
Welded ☒ 16" Diam. from +2 ft. to 392'1" ft.

Perforations: Yes ☐ No ☒
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 ☐ No ☒
Manufacturer's Name
Type Model No.
Diam. Slot size from ft. to ft.
Diam. Slot size from ft. to ft.

Gravel packed: Yes ☐ No ☒ Size of gravel:
Gravel placed from ft. to ft.

Surface seal: Yes ☒ No ☐ To what depth? 155'5" ft.
Material used in seal [illegible]
Did any strata contain unusable water? Yes ☐ No ☒
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 215 ft. below top of well Date [illegible]
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? [illegible]

Yield: gal./min.	with ft. drawdown	after hrs.
1515	95	8

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
[illegible]		11 mins.			

Date of test [illegible]
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m. Date
Temperature of water 52° Was a chemical analysis made? Yes ☒ No ☐

(10) WELL LOG:

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 formation.

MATERIAL	FROM	TO
TOP SOIL	0	3
BROWN CLAY	3	21
BROKEN BASALT-CLAY	21	32
BLACK BASALT	32	73
BROKEN BASALT WITH CLAY	73	105
BLACK BASALT	105	141
BROWN BROKEN BASALT-CLAY	141	156
BLACK BASALT	156	166
BLUE CLAY	166	188
BROKEN BASALT	188	190
GREEN CLAY	190	195
BROKEN BASALT-CLAY	195	215
BLACK BASALT	215	340
GREY BASALT	340	360
BLACK BASALT	360	400
GREY BASALT	400	413
BLACK BASALT	413	479
GREY BASALT	479	485
BLACK BASALT	485	688
BROKEN BASALT	688	690
[illegible] SAND	690	702

1500 gpm
1400 gpm
com ind

well test data in file

Work started [illegible], 19[illegible] Completed [illegible], 1975

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME [illegible] (Person, firm, or corporation) (Type or print)
Address [illegible]
[Signed] [illegible] (Well Driller)
License No. [illegible] Date [illegible], 1975

OK

(USE ADDITIONAL SHEETS IF NECESSARY)

S. F. No. 7356—OS—(Rev. 4-71).

WSU 6

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

Application No. G3-28278
Permit No. G3-28278P

(1) OWNER: Name WASHINGTON STATE UNIVERSITY Address PULLMAN WA

(2) LOCATION OF WELL: County WHITMAN — SW ¼ NE ¼ Sec. 5 T. 14 N., R. 45 E W.M.

Bearing and distance from section or subdivision corner

(3) PROPOSED USE: Domestic ☐ Industrial ☐ Municipal ☒ Irrigation ☐ Test Well ☒ Other ☐

(4) TYPE OF WORK: Owner's number of well (if more than one) #7
New well ☒ Method: Dug ☐ Bored ☐
Deepened ☐ Cable ☐ Driven ☐
Reconditioned ☐ Rotary ☒ Jetted ☐

(5) DIMENSIONS: Diameter of well 16" X 12" X 10" inches.
Drilled 2224 ft. Depth of completed well 1814 ft.

(6) CONSTRUCTION DETAILS:

Casing installed:
20" Diam. from +1' to 170'
16" Diam. from +2 ft. to 365 ft.
12" Diam. from 366 ft. to 543 ft.
12" Diam. from 583 ft. to 673 ft.
12 — 713 — 725
12 — 775 — 908
12 — 948 — 1006

Threaded ☐
Welded ☒

Perforations: Yes ☐ No ☒
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 ☒ No ☐
Manufacturer's Name JOHNSON
Type STEEL HI-CAP Model No. PIPE SIZE
Diam. 12 Slot size 80 from 543 ft. to 580 ft.
Diam. 12 Slot size 80 from 573 ft. to 713 ft.
12 — 80 — 725 — 775
12 — 80 — 908 — 948

Gravel packed: Yes ☐ No ☒ Size of gravel:
Gravel placed from ft. to ft.

Surface seal: Yes ☒ No ☐ To what depth? 170 ft.
Material used in seal NEAT CEMENT
Did any strata contain unusable water? Yes ☐ No ☒
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.... 2415.6 ft.
Static level 154 ft. below top of well Date 9-20-89
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? CONTRACTOR

Yield (gal./min.)	with ft. drawdown	after hrs.
1700	4.9	3.5
3000	11.6	5.5
2400	9.0	7.0

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
0	163				
17 HR	154				

Date of test 10-7-87
Bailer test gal./min. with ft. drawdown after hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? Yes ☒ No ☐

(10) WELL LOG:

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 formation.*

MATERIAL	FROM	TO
TOP SOIL + CLAY	0	5
GRAY BASALT HARD	5	125
CLAY YELLOW	125	140
★ BASALT GRAY MED	140	360
★ BASALT GRAY-BRN MED	360	480
BASALT GRAY HARD	480	550
★ BASALT GRAY MED	550	670
★ BASALT GRAY SOFT	670	800
BASALT GRAY MED	800	920
★ BASALT GRAY MED	920	980
SAND STONE SALT + PEPPER	980	1004
BASALT BLACK MED	1004	1070
SAND STONE GRAY	1070	1115
★ BASALT BLK SOFT	1115	1430
BASALT GRAY MED	1430	1575
★ SAND GRAY SOFT	1575	1595
★ BASALT GRAY MED	1595	1740
★ BASALT BLK SOFT	1740	1840
★ SAND GRAY SOFT	1840	1882
BASALT BLK + GRAY CLAY	1882	1930
★ BASALT GRAY HARD-MED	1930	1980
BASALT GRAY HARD	1980	2210
CLAY BRN + GRAY	2210	2224

★ INDICATES WATER BEARING ZONE

HOLE BACKFILLED WITH DRILL CUTTINGS TO 1824 FT

NEAT CEMENT PLUG PLACED FROM 1824 TO 1814 FT

16" CASING CEMENTED AT 365 FT WITH 60 SKS OF CEMENT, USING a INJECTION LINE + CEMENT FLOAT SHOE

Work started July 20, 1987. Completed SEPT 24, 1987

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

NAME HOLMAN DRILLING CORP
(Person, firm, or corporation) (Type or print)

Address E3410 9TH AVE SPOKANE WA 99202

[Signed] Arnold E Holman
(Well Driller)

License No. 0189 Date OCT 20, 1987

RECEIVED
MAR 21 1989
DEPARTMENT OF ECOLOGY
SPOKANE REGIONAL OFFICE

(USE ADDITIONAL SHEETS IF NECESSARY)

ECY 050-1-20

WSU 7

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

Please print, sign and return to the Department of Ecology

RECEIVED SEP 22 2003 DEPARTMENT OF ECOLOGY EASTERN REGIONAL OFFICE

Water Well Report 138651

Original – Ecology, 1st copy – owner, 2nd copy – driller

ECOLOGY

Construction/Decommission SEP 17 2003

☑ Construction

☐ Decommission *ORIGINAL INSTALLATION Notice of Intent Number* WE00919

Current Notice of Intent No. WE00919

Unique Ecology Well ID Tag No. AHG660

Water Right Permit No. G3-22065C

Property Owner Name Washington State University

Well Street Address Wilson Road and Hog Lane

City Pullman County Whitman

Location NW1/4-1/4 NW1/4 Sec 4 Twn 14 R 45 EWM ☑ or WWM ☐ (circle one)

Lat/Long (s, t, r still REQUIRED) Lat Deg ______ Lat Min/Sec ______ Long Deg ______ Long Min/Sec ______

Tax Parcel No. ______

PROPOSED USE: ☐ Domestic ☐ Industrial ☑ Municipal ☐ DeWater ☐ Irrigation ☐ Test Well ☐ Other ______

TYPE OF WORK: Owner's number of well (if more than one) campus well #8

☑ New well ☐ Reconditioned ☐ Deepened *Method:* ☐ Dug ☐ Bored ☐ Driven ☐ Cable ☑ Rotary ☐ Jetted

DIMENSIONS: Diameter of well 16 inches, drilled 812 ft. Depth of completed well 812 ft.

CONSTRUCTION DETAILS

Casing Installed: ☑ Welded 20" Diam. from 0 ft. to 66 ft.; ☐ Liner installed 16" Diam. from 0 ft. to 812 ft.; ☐ Threaded ______" Diam. from ______ ft. to ______ ft.

Perforations: ☐ Yes ☑ No

Type of perforator used ______

SIZE of perfs ______ in. by ______ in. and no. of perfs ______ from ______ ft. to ______ ft.

Screens: ☑ Yes ☐ No ☐ K-Pac Location ______

Manufacturer's Name See attached sheet for screen information

Type ______ Model No. ______

Diam. ______ Slot size ______ from ______ ft. to ______ ft.

Diam. ______ Slot size ______ from ______ ft. to ______ ft.

Gravel/Filter packed: ☑ Yes ☐ No ☐ Size of gravel/sand pea gravel

Materials placed from 285 ft. to 750 ft.

Surface Seal: ☑ Yes ☐ No To what depth? 280 ft.

Material used in seal neat cement

Did any strata contain unusable water? ☐ Yes ☒ No

Type of water? ______ Depth of strata ______

Method of sealing strata off ______

PUMP: Manufacturer's Name ______

Type: ______ H.P. ______

WATER LEVELS: Land-surface elevation above mean sea level ______ ft.

Static level 333 ft. below top of well Date 3-31-03

Artesian pressure ______ lbs. per square inch Date ______

Artesian water is controlled by ______ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level

Was a pump test made? ☒ Yes ☐ No If yes, by whom? Layne Of WA

Yield: 2500 gal./min. with 100 ft. drawdown after 12 hrs.

Yield: ______ gal./min. with ______ ft. drawdown after ______ hrs.

Yield: ______ gal./min. with ______ ft. drawdown after ______ hrs.

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
2000	436	2005	337	2010	337
2015	337	2020	337	2025	337

Date of test 9/15/03

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 53° Was a chemical analysis made? ☑ Yes ☐ No

CONSTRUCTION OR DECOMMISSION PROCEDURE

Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information indicate all water encountered. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Tan clay	0	38
Clay with gravel	38	42
Brown clay	42	66
Black basalt	66	115
Grey basalt	115	223
Black basalt w/ green claystone	223	235
Green clay w/ green claystone	235	246
Broken black w/ green claystone	246	280
Black w/ grey basalt	280	345
Black w/ brown scoria	345	373
Black Basalt	373	455
Black w/ black scoria	455	465
Black Basalt	465	500
Black w/ brown scoria	500	514
Black basalt	514	528
Grey basalt	528	543
Black w/ brown scoria & green claystone	543	557
Grey basalt (hard)	557	578
Black w/ black scoria	578	595
Black basalt	595	642
Black basalt w/ green claystone minerals	642	686
Broken black basalt	686	691
Black basalt	691	719
Black w/ green claystone	719	754
Gravels and cobbles	754	758
Black basalt - fractured	758	759
Sand & gravels	759	762
Cemented gravels	762	801
Cemented gravels - tight	801	810
Cemented gravels	810	812

Start Date 2-26-03 Completed Date 7-03-03

WELL CONSTRUCTION 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.

Driller/Engineer/Trainee Name (Print) Robert Stoddt

Driller/Engineer/Trainee Signature [signature]

Driller or trainee License No. 1789

IF TRAINEE, Driller's Licensed No. ______ Driller's Signature ______

Drilling Company Geo-Tech Explorations, Inc.

Address 19700 S.W. Teton Ave.

City, State, Zip Tualatin, OR 97062

Contractor's Registration No. 100CZ Date 9/15/03

Ecology is an Equal Opportunity Employer. ECY 050-1-20 (Rev 2/03)

WSU 8