Ground Water Quality Technical Report No. 24

Isotopic Age Dating of Municipal Water Wells in the Lewiston Basin, Idaho

Idaho Department of Environmental Quality
Lewiston Regional Office
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Isotopic Age Dating of Municipal Water Wells in the Lewiston Basin, Idaho

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Acknowledgements

This research investigation was a cooperative study, supported by the Lewiston Clarkston Aquifer Committee in conjunction with Asotin County, Washington Public Utilities District (PUD), City of Lewiston, Idaho Department of Environmental Quality, Idaho Rural Water Association, Lewiston Orchards Irrigation District, and the Nez Perce Tribe. This study would not have been possible without the support and commitment of the each of these entities.

We wish to thank Barbara Williams, PhD., P.E., of the Department of Biological and Agricultural Engineering at the University of Idaho, who peer reviewed this report and provided a valuable sounding board for the authors. Her knowledge of the Lewiston Basin, and her involvement in producing Source Water Assessments for the Department of Environmental Quality were a valuable asset in this peer review. We also wish to thank an anonymous reviewer whose intimate knowledge of the Columbia River Basalts and the hydrogeology of the area provided another very useful sounding board for the authors and provided a separate point of view of great value.

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Executive Summary

The purpose of this study was to determine the age of water in selected drinking water wells in the *Lewiston Basin Aquifer*. *Hydrological isotopes* were used to estimate the time ground water has resided in the lower basalt aquifer system within the Lewiston ground water basin, and the results were correlated to specific geologic and hydrogeologic conditions in the basin that control recharge.

Background information on the Lewiston Basin Aquifer

The Lewiston Basin Aquifer is a *sole source* aquifer (Federal Register, 53 FR 49920, December 12, 1988) located in southeastern Washington and western north central Idaho. Public water systems that withdraw water from the aquifer supply the Lewiston, Idaho and Clarkston, Washington areas, the community of Lapwai and Nez Perce tribal wells in the Lapwai area. In addition, the Potlatch Pulp and Paper Mill, located on the northeastern edge of Lewiston, withdraws water from the Lewiston Basin Aquifer for industrial use.

Study methods

The study used carbon-14 dating, tritium detection, carbon-13 analysis, and *fractionization* (isotope partitioning) of oxygen-18 (^{18}O) and deuterium (^{2}H).

Results and conclusions

Study results and conclusions were as follows:

- Tritium above the detection limit was found in 5 of 10 wells, indicating that some percentage of water in these wells is modern recharge. The presence of tritium, the proximity of these wells to the Clearwater and Snake rivers, and the relative water levels in the rivers indicate that these wells are drawing modern water from the rivers. C-14 data in the same wells indicates that four of these five wells contain a mixture of older ground water and modern recharge. These wells may need to be further evaluated from a source water protection point of view.
- Radiocarbon age dating provided ^{14}C ages ranging from 2,830 to 34,670 years. Given the geologic conditions and tritium detections in individual wells, these age dates appear to be consistent. To further refine ^{14}C age dates, geochemical modeling can be completed to analyze the mass transfers of carbon within the hydrogeologic system. To complete this modeling, samples of common ions need to be collected from the sampled wells.
- Continued monitoring of environmental isotopes is recommended and encouraged to increase the number of samples and data points in the basin.
- A potential hydraulic barrier boundary separating northern and southern aquifer systems in the Grande Ronde Basalts of the Lewiston basin warrants further investigation. The northern aquifer system appears to be hydraulically linked to the Clearwater and Snake Rivers. The southern aquifer appears to be hydraulically linked

to the topographically higher basalt outcrops near the regional Limekiln fault near Waha. The sources of water vary dramatically in the quantity of water that is available to recharge these separate aquifer systems. Obviously, the northern aquifer system has a much larger source of water (two major rivers) for recharge than the southern aquifer system (snow melt and small streams).

- Water level data from additional wells completed in the Grand Rhonde aquifer will provide more evidence for the existence of the hydraulic barrier boundary. This information is relatively inexpensive to obtain.

Introduction

This project was conducted as a cooperative study supported by the Lewiston Clarkston Aquifer Committee in conjunction with Asotin County, Washington Public Utilities District (PUD), City of Lewiston, Idaho Department of Environmental Quality, Idaho Rural Water Association, Lewiston Orchards Irrigation District, and Nez Perce Tribe. The main goal of the committee in developing this project was to enhance ground water knowledge and protect drinking water sources in the Lewiston Ground Water Basin. The committee decided that the use of isotopic analyses would provide beneficial insight as to water "ages" in local municipal drinking water wells and an estimate of the ground water travel time from the recharge areas to selected wells. The isotopic data also could indicate if any of the wells sampled are influenced by Snake River and/or the Clearwater River. Inferences could then be made to other wells with similar well completions and in the general vicinity of the sampled wells.

Purpose of this study

The purpose of this study was to determine the age of water in selected drinking water wells located in the *Lewiston Basin Aquifer* (Figure 1). *Hydrological isotopes* were used to estimate the time ground water has resided in the lower basalt aquifer system within the Lewiston ground water basin, and the results were correlated to specific geologic and hydrogeologic conditions in the basin that control recharge. The isotopic data were evaluated with respect to the potential influence of the Snake and Clearwater Rivers on public potable water supply wells.

Overview of sampling performed during this study

Ground water samples were collected from ten existing municipal wells completed in the basalt aquifer system (Figure 2). The samples were analyzed for isotopes of carbon (^{14}C and ^{13}C), oxygen (^{18}O), deuterium (^{2}H) and tritium (^{3}H).

Isotopic analysis allows an interpretation of the ground water characteristics that are independent of preconceived notions based on the geology. The results of these analyses were then used to assess and/or identify possible recharge mechanisms to the aquifers and the locations of these recharge zones, along with estimates of residence time in the aquifer.

Background information on the Lewiston Basin Aquifer

The Lewiston Basin Aquifer is a *sole source* aquifer (Federal Register, 53 FR 49920, December 12, 1988) located in southeastern Washington and western north central Idaho. Public water systems that withdraw water from the aquifer supply the Lewiston, Idaho and Clarkston, Washington areas, the community of Lapwai and Nez Perce tribal wells in the Lapwai area. In addition, the Potlatch Pulp and Paper Mill, located on the northeastern edge of Lewiston, withdraws water from the Lewiston Basin Aquifer for industrial use.

The Lewiston Basin Aquifer is hosted by the *Grande Ronde Basalt* of the *Columbia River Basalt Group* (CRBG). Water levels in the aquifer have remained stable despite ground water extraction of up to 1.75 billion gallons per year as of 1991 (Stevens, 1994, p. 42).

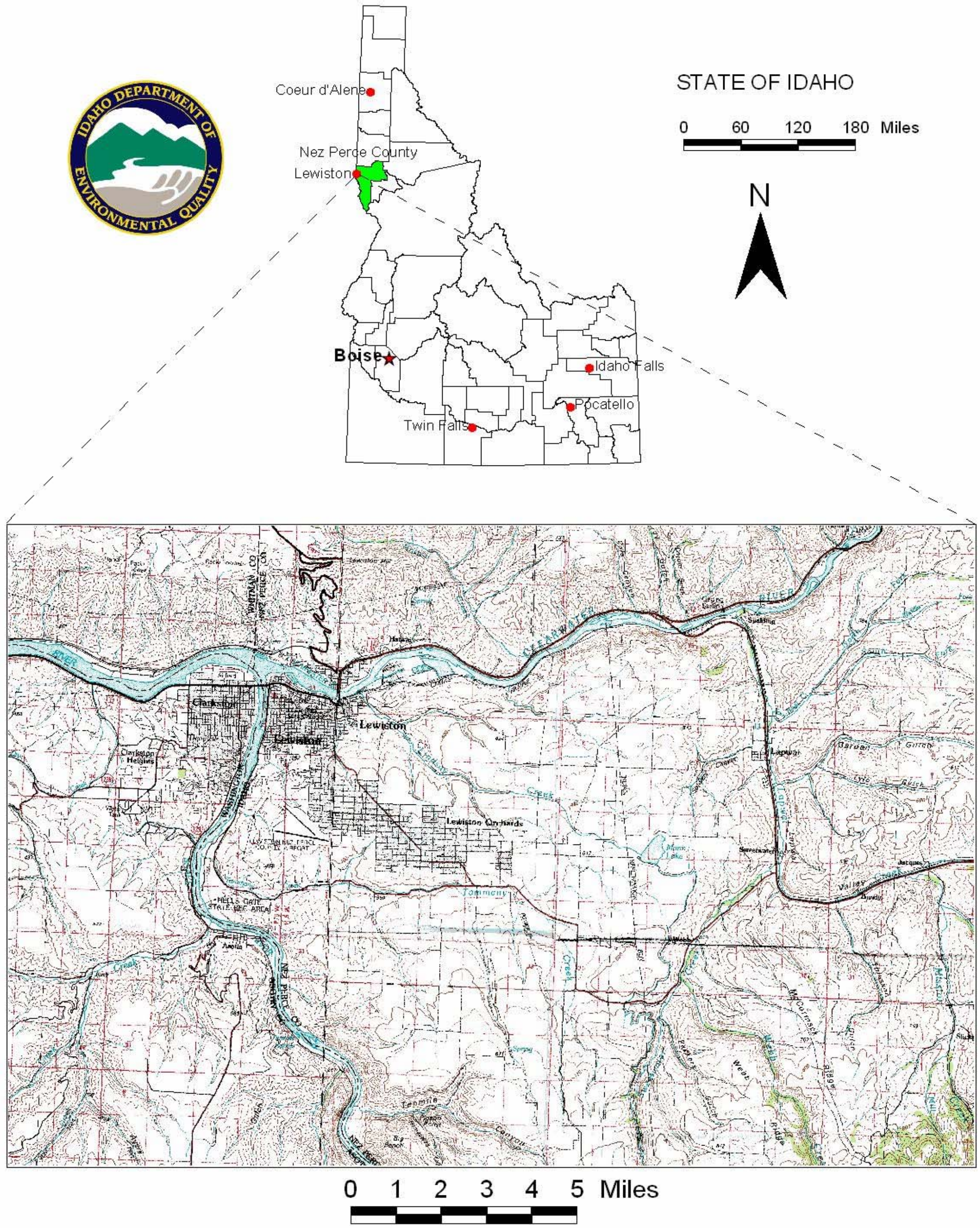

Figure 1. Location of the Lewiston Basin Aquifer.

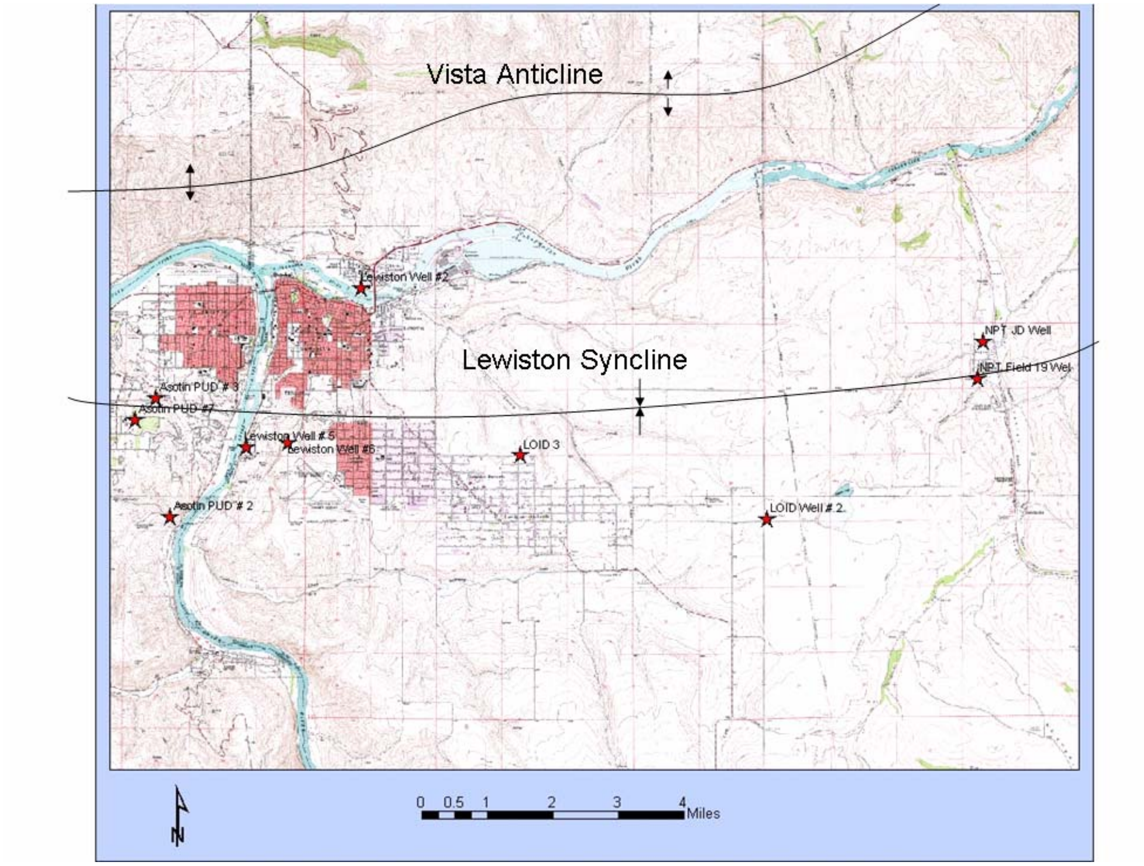

Figure 2. Location of study area and sampled wells. The *Lewiston Syncline* is a concave upward fold that plunges west at about 2 degrees and is the dominant structural feature of the basin. The *Vista Anticline* is a concave downward fold, with dips up to 60 degrees on the north margin of the basin. Historically, this fold is believed to have significant influence on ground water recharge.

Hydrogeologic Setting and Characteristics

The Lewiston Basin comprises four-hundred square miles, situated in the southeastern section of Washington and western north central Idaho (Stevens, 1994), drained by the Snake and Clearwater Rivers and their tributaries.

Geologically, the basin is dominated by flood basalt—the CRBG—deposited over older granite and metamorphic rock bases. These basalt flows consist of multiple layers of basalt with *lacustrine* and *fluvial* sediments of the *Latah Formation* blended between the flows.

From the base upward, the CRBG is divided into the *Grande Ronde Basalt*, the *Wanapum Basalt*, and the *Saddle Mountains Basalt*. The Snake and Clearwater River Canyons dissect all three formations.

Columbia River Basalt Group Influence on Ground Water Flow

Figure 3 and Figure 4 illustrate geologic features of the basalt system found in the Lewiston Basin. The CRBG is the primary rock unit, controlling ground water flow in the basin. During formation, a sequence of eruption and cooling periods created a flow-on-flow layering effect of the basalts. Ground water occurrence is predominantly confined to the basalt flow tops, flowing laterally within the sequence of basalt flows.

Physical characteristics of the Columbia River Basalt flows include interior flow structures with low porosity and low hydraulic conductivity, while interflow zones have high porosity and high hydraulic conductivity (DOE, 1981). The interior structures generally form confining layers between successive confined interflow zones, thus restricting vertical movement between the multiple systems.

Figure 3. The *entablatures* and *flow tops* of the Columbia River Basalts. These features host the predominant ground water flow paths. Interiors of basalt flows should be classified as *aquitards*, with relatively thin flow tops acting as aquifers.

Figure 4. Enlarged view of flow top. The large *vesicles* in the basalt flow top are magnified to exhibit detail. Often, the flow top is still moving after the top begins to crust over, causing *autobrecciation* of the flow top, which increases its permeability.

Methods and Materials

This study used *isotopic analysis* to estimate the age of ground water samples collected from ten municipal water wells (Figure 2). This section describes the methods of analysis and the sampling/analysis protocols used during the course of the study.

Using isotopes to determine the age of water

Isotopes are atoms of the same chemical element having the same number of protons but differing numbers of neutrons. Isotopes are alike chemically, but differ in mass.

Naturally occurring environmental isotopes of elements found in abundance in the environment include carbon, hydrogen, oxygen, nitrogen, and sulfur. These *environmental isotopes* are essential elements of hydrogeological and biological systems, and analyzing their abundance can yield important information:

- In stable isotopes, the large relative mass differences among isotopes of lighter elements create measurable changes in the natural abundance of an isotope (Clark and Fritz, 1997). The most abundant light element stable isotopes include deuterium, helium (^{4}He) lithium (^{7}Li), beryllium (^{9}Be), boron (^{8}B), carbon (^{13}C), nitrogen (^{15}N), oxygen (^{18}O) and sulfur (^{34}S).
- In radioactive isotopes, or *radioisotopes*, which decay at a constant rate proportional to the number of atoms of the isotope present, age is indicated by changes in radioactive *activity*. The radioisotopes commonly employed in hydrogeology include tritium (^{3}H) and carbon-14 (^{14}C).

For this study, water samples were analyzed for the presence of tritium (^{3}H), carbon-14 (^{14}C), (^{13}C) carbon-13, (^{18}O) oxygen-18, and deuterium (^{2}H).

Analysis of oxygen-18 and deuterium in water

Analysis of oxygen-18 (^{18}O) and deuterium (^{2}H) involves measuring the *fractionization* (isotope partitioning) of these stable isotopes that has occurred as a result of natural meteorological (meteoric) processes:

> The meteoric relationship of ^{18}O and ^{2}H arises from fractionization during condensation from the vapour mass. However, it is a Rayleigh distillation during rainout that is responsible for the partitioning of ^{18}O and ^{2}H between warm and cold regions. (Clark and Fritz, 1997).

Fractionization is measured by comparing a known standard ratio concurrent with a sample ratio (Figure 5). Isotope ratios are expressed in delta units (δ) as *per mille* (parts per thousand or $^{o}/_{oo}$) differences relative to the standard.

Parts Per Mil Nomenclature

$$\text{Delta } (\delta) \text{ Isotope} = \frac{\text{Ratio}_{sample} - \text{Ratio}_{standard}}{\text{Ratio}_{standard}} \times 1000$$

For example: A $\delta^{18}O$ = -10 /mil means there is 10 parts per thousand less ^{18}O in the sample than in the standard, standard "mean" oceanic water (SMOW)

Figure 5. Nomenclature for isotopic ratios. (Siegel, 2000)

Craig (1961) observed a predictable relationship between ^{18}O and ^{2}H, noting that fresh waters correlate on a global scale. He developed a *global meteoric water line* (GMWL) that defines the relationship between ^{18}O and ^{2}H in worldwide fresh surface waters through Equation 1.

$$\delta\, ^{2}H = 8\, \delta^{18}O + 10\ ^{o}/_{oo}\ SMOW$$

Equation 1. Relationship between ^{18}O and ^{2}H in worldwide fresh surface waters.

Where,

$\delta\, ^{2}H$ = isotopic ratio of deuterium,
$\delta^{18}O$ = isotopic ratio of oxygen-18, and
10 $^{o}/_{oo}$ SMOW = Standard Mean Ocean Water

This observation is only applicable globally because it represents an average of many local and/or regional meteoric water lines, thus differences exist due to varying climatic and geographic parameters.

Analysis of Tritium in water

Tritium (^{3}H) is a short-lived radioisotope of hydrogen with a half-life of 12.43 years (Clark and Fritz, 1997). Produced by both natural and manmade sources, tritium enters the hydrological cycle via precipitation.

Tritium concentrations are expressed as absolute concentrations using tritium units (TU). A tritium unit corresponds to the equivalent of 1 tritium atom in 10^{18} atoms of hydrogen.

The presence of tritium in ground water at concentrations above the natural concentration is evidence for modern recharge to a specific hydrologic system, providing an estimate of the age of the water. Table 1 provides general guidelines for qualitative interpretations of tritium in ground water for continental regions. (It has been estimated that prior to thermonuclear bomb testing in 1952, the natural tritium concentration in precipitation was in the range of about 5-20 tritium units [Payne, 1972].)

Table 1. Tritium interpretation guidelines for continental regions. Mixing and the convergence of ground water flow paths from different recharge origins results in blending of water with "mixed ages." Therefore, as in most age dating analyses, the process provides more of an estimate rather than an "age" of the ground water mean residence time(Clark and Fritz, 1997).

Tritium Conc.	Qualitative "Age"
<0.8 TU	Submodern—recharged prior to 1952
0.8 to ~4TU	Mixture between submodern and recent recharge
5 to 15 TU	Modern (<5 to 10 yrs)
15 to 30 TU	Some "bomb" ^{3}H present
>30 TU	Considerable component of recharge from 1960s or 1970s
>50 TU	Dominantly the 1960s recharge

Analysis of radiocarbon in water

Radiocarbon (^{14}C) in atmospheric CO_2 was discovered by Willard Libby in 1947, who recognized its potential for age dating (Clark and Fritz, 1997). As with tritium, ^{14}C atoms are produced continuously in the earth's atmosphere as neutrons generated by cosmic radiation interact with ^{14}N. The ^{14}C atoms oxidize to form $^{14}CO_2$ molecules, which become mixed with inactive atmospheric CO_2.

In the atmosphere, natural production is balanced by decay to maintain a steady-state atmospheric $^{14}CO_2$ activity of approximately 13.56 disintegrations per minute (dpm) per gram of C, or around one ^{14}C atom per 10^{12} stable C atoms (Clark and Fritz, 1997). Atmospheric $^{14}CO_2$ mixes with all living biomass through photosynthesis and with meteoric waters and oceans through CO_2 exchange reactions.

Once water becomes recharged and enters the zone of saturation, it becomes isolated from the atmosphere, and the dissolved $^{14}CO_2$ will radioactively decay at a rate of one-half of the radiocarbon atoms every 5,730 years.

Carbon-13 is a stable isotope that is generally sampled and assessed to trace open and closed system evolution of dissolved inorganic carbon (DIC) in ground water. Carbon mass transfers between reservoirs can change the isotopic composition of the DIC. The magnitude of this effect can be traced by the stable carbon isotopic ratio $^{13}C/^{12}C$. By convention, ^{13}C values are calculated relative to the Peedee belemnite international standard, which has a $\delta^{13}C = 0\ ^{o}/_{oo}$ (per mil) (Craig, 1957). ^{13}C was sampled for, but corrections based on each sampled ^{13}C concentration were not applied during this study. Due to the fact that the ground water system is basalt, it was assumed, for purposes of this study, that radiocarbon concentrations in the Lewiston basin are only affected by radioactive decay.

Sample collection protocol, sample rounds, and analysis methods used

Samples were collected from wells that were determined (from well logs) to be drawing water only from the Grande Ronde Basalts. Two samples were also collected from the Snake River for oxygen-18, deuterium, and tritium analysis.

Collection protocol

Samples were collected at sample ports in the well houses, after flushing of the casing and well plumbing, as close to the well head as possible and before passage through water treatment systems. The wells had either been pumping at the time of sample collection or were allowed to pump for at least five minutes prior to sample collection.

Sampling rounds

A first round of sampling occurred in December 2002, with the collection of samples from wells NPT Field 19 #1, NPT Lapwai JD, Lewiston #5, Lewiston #6, LOID #2, Asotin #3, and a sample from the Snake River. A second round of sampling occurred in July 2003, with the collection of samples from wells LOID #3, Lewiston #2, Asotin #2, and Asotin #7.

Analysis methods used

Samples analyzed for deuterium, tritium, and oxygen-18 were sent to the Environmental Isotope Lab, University of Waterloo, Waterloo, Ontario, Canada for analysis. Water samples were analyzed for tritium using a liquid scintillation counter and the isotopic ratios of $^{18}O/^{16}O$ and $^{2}H/^{1}H$ were determined through the use of mass spectrometry.

Carbon 14 and carbon-13 analysis was done at Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand. Age, delta-14C, and absolute percent modern carbon values are as defined by Stuiver and Polach (1977). All water samples collected during this project were analyzed for ^{14}C and ^{13}C through scintillation counting and accelerator mass spectrometry (AMS). The analytical precision for $\delta^{18}O$ values is usually better than ± 0.2 ‰, and the analytical error for deuterium is usually ±1.0 ‰ (Clark and Fritz, 1997). The laboratory detection limit for tritium is 0.8 tritium units.

Results and Discussion

Table 2 presents the sample location, environmental isotope results, and well log information for each of the sampled sites plus results for the Snake River, Clearwater River, and Salmon River from the USGS NASQAN database (Coplen and Kendall, 2000).

Table 2. Isotopic characteristics, ages, and stratigraphic data for sampled wells.

Sample ID	^{18}O per mil	^{2}H per mil	^{3}H T.U.	^{13}C DIC per mil	^{14}C Age	Total well depth (ft bls)	L.S. Elev (ft)	Perforated Interval (ft bls)
NPT Field 19 #1	-13.99	-111.89	**0.8**	-14.23	3,061	255	1,100	208
NPT Lapwai JD	-13.97	-111.29	**0.8**	-13.83	2,830	220	1,100	164-206
City of Lewiston # 2	-15.10	-119.28	5.4	-14.35	3,043	275	740	None. Cased to ?
City of Lewiston # 5	-15.88	-125.33	6.3	-15.06	5,074	600	800	205, 485, 600
City of Lewiston # 6	-16.84	-133.58	**0.8**	-16.08	24,460	1793	1,240	1,428-1,755
LOID # 2	-14.96	-119.58	**0.8**	-14.47	12,164	1959	1,730	None. Cased to 1,376
LOID # 3	-16.42	-127.87	**0.8**	-19.58	34,670	2617	1,415	None. Cased to 2617
Asotin PUD # 2	-16.27	-126.93	11.84	-14.58	9,592	1800	793	None. Cased to 119
Asotin PUD # 3	-15.79	-123.60	7.4	-14.92	5,433	1103	999	None. Cased to 559
Asotin PUD # 7	-16.08	-126.72	8.32	-15.6	10,806	1540	1,180	None. Cased to 1,180
Snake River – Asotin*	-16.57	-126.66	6.38					
Snake River at Weiser, NASQAN	-16.39 avg n=10 -15.58 to -16.75	-126.0 avg n=10 -123.7 to -128.8						
Clearwater River at Spalding, NASQAN,	-15.46 avg n=17 -14.65 to -16.1	-114.8 avg n=17 -110.6 to -118.2						
Salmon River at Whitebird, NASQAN	-17.49 avg n=17 -16.95 to -18.05	-132.6 avg n=17 -129.8 to -136.7						

Tritium values in **bold** are below the laboratory detection limit of 0.8 tritium units (T.U.).
* Average of two values from two samples collected for this investigation.

Carbon-14 analysis findings

Figure 6 compares Carbon-14 ages for individual wells relative to the elevation of their producing zone. It is apparent that a relationship exists between increasing age with decreasing elevation (or increasing depth). Carbon-14 ages in the ground water samples from the Lewiston Basin aquifer system ranged from 2,830 to 34,670 years.

The primary assumption in interpreting the ^{14}C data is that the system is closed to the addition of new carbon. The last time carbon was added to the system was during infiltration through the vadose zone. This assumption appears reasonable because the host rocks are basalt and the aquifers are confined.

Carbon-13 analysis findings

As mentioned before, carbon mass transfers between reservoirs can change the isotopic composition of dissolved inorganic carbon (DIC). $\delta^{13}C$ values are generally used in radioactive age dating methods as a “check” on the system. If groundwater $\delta^{13}C$ values deviate from approximately -15.1 ‰ per mil, gains or losses in carbon by reactions subsequent to recharge may have occurred (Clark and Fritz, 1997). If this is the case, adjustment models based on water chemistry and $\delta^{13}C$ values can be applied to model mass balance reactions occurring in the study area. For this study corrections were not applied, however $\delta^{13}C$ values for all of the wells, except LOID #3, exist around the value of -15.1 ‰ per mil (Table 2). LOID #3 has a $\delta^{13}C$ value of -19.58 per mil, indicating that this age date may be affected by a mass transfer of carbon from the system due to a process other than radioactive decay.

Tritium analysis findings

Tritium was detected above the detection limit of 0.8 TU in 5 out of the 10 sampled wells (Figure 7). These wells are interpreted to be mixed with recent surface water and do not satisfy the assumption of a closed ground water system. The five wells with tritium below the detection limit are discussed in relationship to their stable isotopic ratios of ^{18}O and ^{2}H.

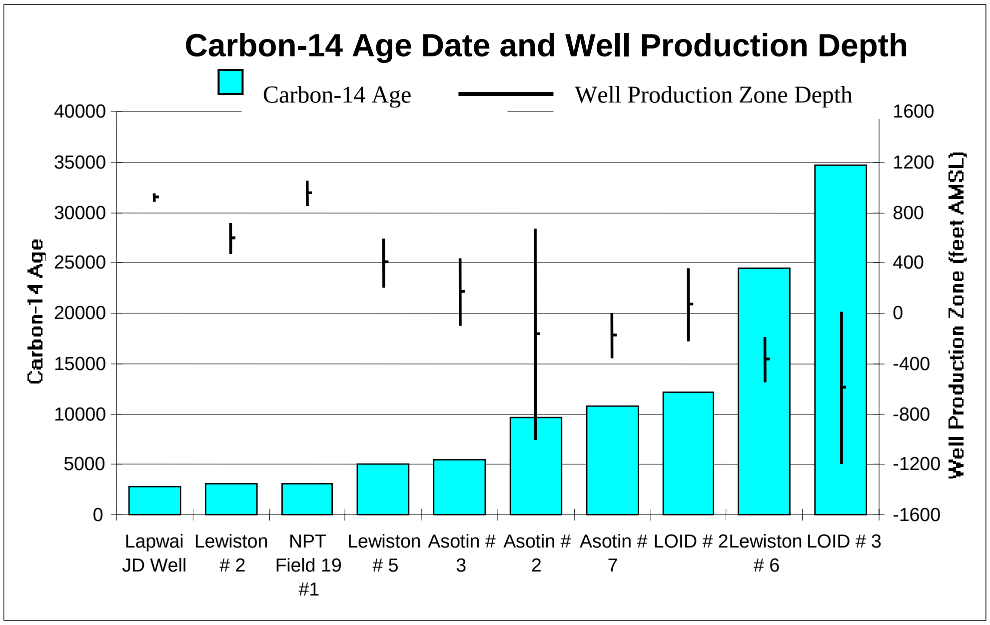

Figure 6. Carbon-14 age date vs. well production zone. The main observation noted is that ground water age increases with decreasing production zone elevation (or increasing depth).

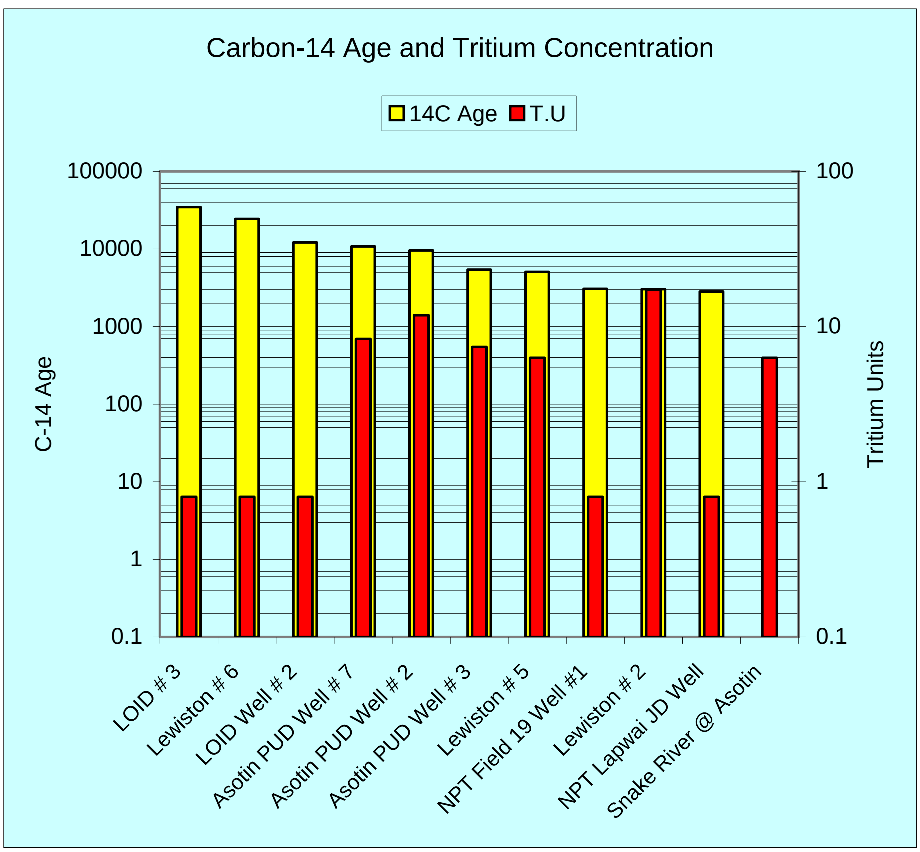

Figure 7. Carbon-14 age vs. tritium concentration in sampled wells. Five of the 10 sampled wells have concentrations of tritium above the laboratory detection limit of 0.8 TU.

Oxygen-18 and deuterium (^{2}H) analysis findings

The relationship between ^{18}O and ^{2}H for five wells with nondetectable tritium is displayed in Figure 8, along with error bars for the two parameters. The cooler the temperature is at the time of recharge, the more negative the ground water ^{18}O and ^{2}H values of the recharge water, as indicated by the Global Meteoric Water Line (GMWL) calculated from Equation 1. As temperatures rise, the ^{18}O and ^{2}H values of ground water recharge becomes more positive.

Average ^{18}O and ^{2}H values for the Clearwater and Snake River from the USGS NASQAN database (Coplen and Kendall, 2000) have been added as well, showing the mean isotopic ratio for each of the two rivers:

- The Clearwater River watershed lies within a modified Pacific Maritime Climate and has a greater proportion of heavy isotopes when compared to the Snake River Watershed.
- Although the Snake has its headwaters in the high elevations of the Rocky Mountains, much of the river's course runs through low elevation and lower latitude areas than the Clearwater River.

Ground water with the youngest C-14 age (Lapwai wells) plots near the modern Clearwater River isotopic signature. However, the absence of detectable tritium in this water indicates there has been no contribution from the river to ground water in this area within the past 50 years. Ground water with the oldest C-14 age (Lewiston Well # 6 and LOID # 3) plots near the modern Snake River signature, but the oxygen and deuterium results indicate a cooler recharge water temperature than the modern Snake River water. The Pleistocene Ice age ended approximately 12,000 years ago, and we know that the climate then was much cooler than today. The old water samples are probably not directly comparable to today's Snake River isotopic ratios. The absence of detectable tritium in this ground water indicates there has been no recharge from the river to ground water for at least the past 50 years.

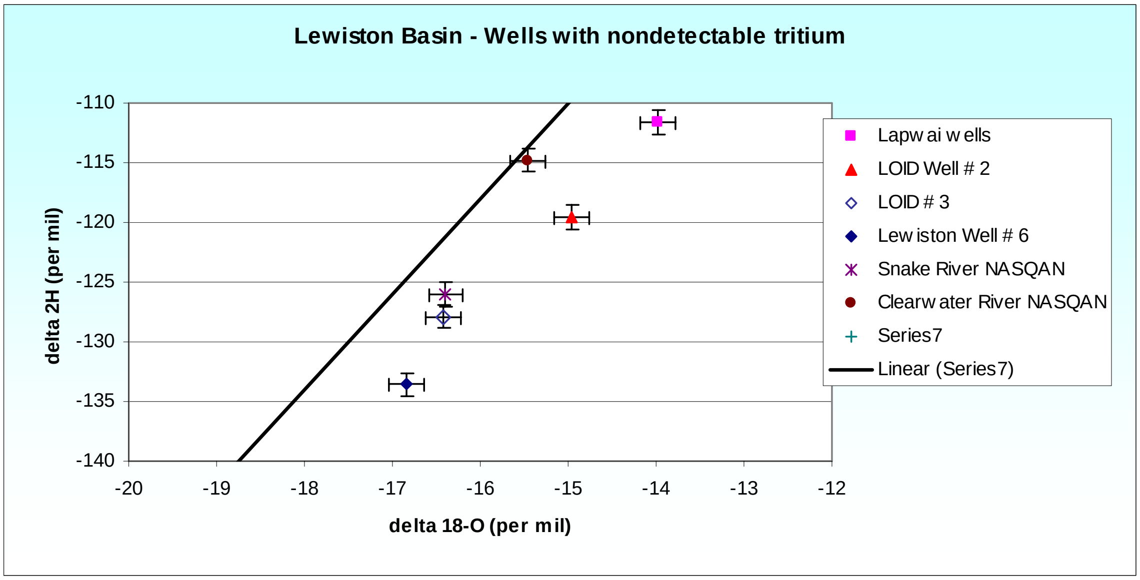

Figure 8. Comparison of stable isotopes in the Lewiston Basin for ground water and surface water. The five wells that satisfy the criteria of closed system are plotted in the figure (i.e. wells samples that were non-detects in tritium). Snake and Clearwater River points are averages from NASQAN data (Table 2).

Results of the ^{18}O and ^{2}H signatures of the water samples from each well provide a basis for hypothesizing the origin of the water or source of recharge. Figure 9 displays each of the sampled wells and interprets which wells are receiving recent recharge based on tritium detections. Well LOID #3 has a ^{14}C age of 34,670 years and has a cold water recharge source based on oxygen-deuterium results. Lewiston #6 appears to be of comparable age with no identifiable tritium present and a cold water recharge source based on oxygen-deuterium results, suggesting a similar source of the ground water. Lewiston #5 is much nearer the Snake River and the isotopic signature suggests a younger source of water and/or mixing with higher tritium content water, such as the Snake River.

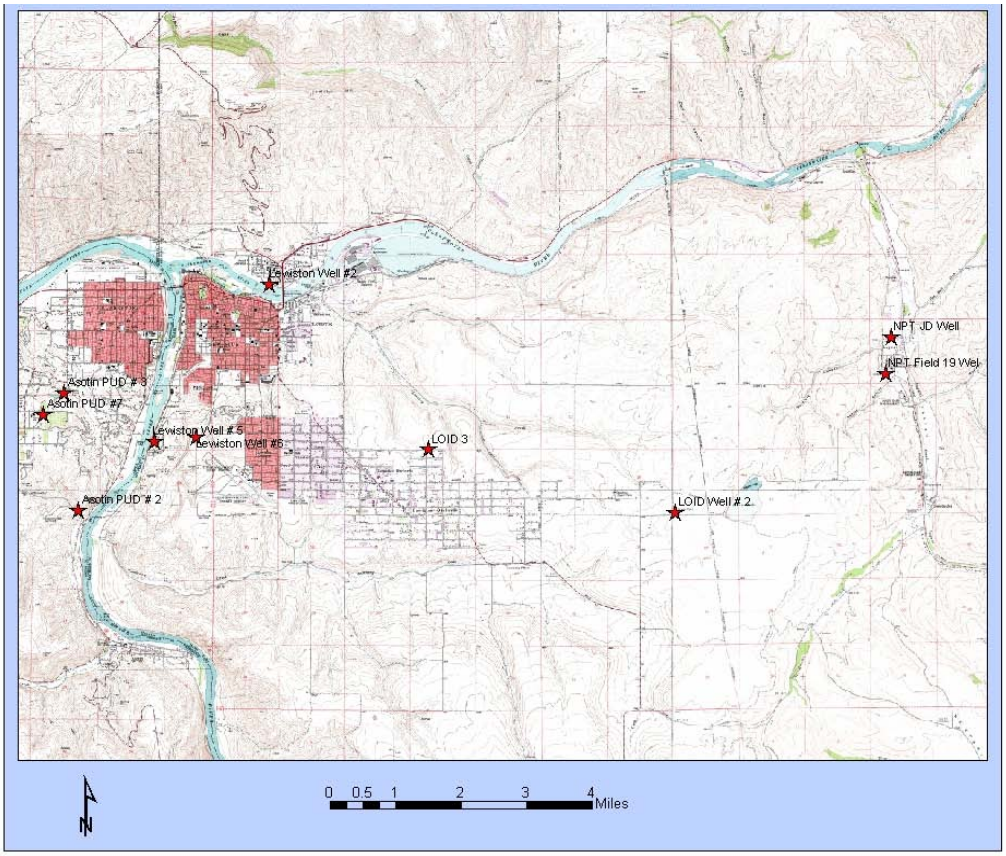

Figure 9. Wells sampled in the Lewiston Basin for ^{2}H and ^{18}O signatures.

Table 3 provides a summary of Figure 9, indicating the hypothesized temperature of recharge based on ^{18}O and ^{2}H analyses and whether or not the well is receiving modern recharge based on tritium analysis. Kendall and McDonnell (p. 231) discuss the use of ^{18}O and ^{2}H to evaluate climatic conditions under which ground water was recharged.

Table 3. Identification of wells containing tritium along with interpretations of the relative temperature of recharge water in wells not containing tritium.

Well Name	^{3}H above D.L.	^{18}O & ^{2}H Signature
NPT Field 19 #1	No	Warm Water Recharge
NPT Lapwai JD	No	Warm Water Recharge
City of Lewiston # 2	Yes	--
City of Lewiston # 5	Yes	--
City of Lewiston # 6	No	Cold Water Recharge
LOID # 2	No	Warm Water Recharge
LOID # 3	No	Cold Water Recharge
Asotin PUD # 3	Yes	--
Asotin PUD # 2	Yes	--
Asotin PUD # 7	Yes	--

Analysis of the isotopic signatures from the ground water samples indicates a potential identification of a cold Snake River signature as the most depleted isotopic signature. Indication of this is Lewiston #6, which has a ^{14}C age date of 24,600 years and is most likely of Pleistocene Age. The rationale for this interpretation is that the isotopic signature is more depleted than the modern Snake River, but it is located near the Snake River. The wells containing tritium are of mixed ratios of older water with modern recharge water.

The isotope data provide useful information for source water protection activities:

- Adjacent to the confluence of the Snake and Clearwater Rivers, tritium detections in Lewiston 2 and 5, and Asotin PUD wells 3, 7 and 2 indicate vertical ground water movement is occurring, either by downward leakage or by induced down dip recharge from the river(s) due to pumping. Based on information from the Lindsay Creek aquifer, downward movement of water through horizontal layered basalt is probably limited, so down dip flow is the most reasonable mechanism for ground water movement to the above wells. Although there appears to be active ground water movement, this does not necessarily mean there is a direct ground water-surface water connection.
- The ^{14}C ages presented in Table 2 show there is still a very long travel time from surface water to ground water even for wells with the most recent ages.
- ^{14}C and $^{18}O/^{2}H$ data from wells in the central part of the basin indicate that the ground water system is either stagnant or very slow moving. Travel time estimates for the

central part of the basin illustrate this point. Typical hydraulic conductivity values for the Grand Ronde Aquifer, hydraulic gradient estimates, and effective porosity values can be used to estimate ground water flow rates. Based on conductivity and porosity values presented in the *Source Water Assessment and Addendum* (Williams et al., 2001) and a hydraulic gradient of about 2 ft/mile, the average ground water velocity may be 0.1 ft/day. These velocities suggest a distance along a flow path to a recharge area of greater than about 138 miles for ground water that is 20,000 years old. Actual distances to potential recharge areas from the center of the Lewiston basin are on the order of 10 miles so the above flow path estimates are clearly in error. The above disparity suggests that either the values used in calculating the ground water velocity are in error, or the continuity of the ground water flow paths is in error. Cohen and Ralston (1980) reported a complex transmissivity distribution and/or possible barrier boundaries based on analysis of a long term aquifer test of APUD wells in 1979. This work demonstrates that a continuous ground water flow path from a recharge area to a particular well probably does not exist for much of the basin.

This discussion is based solely on evaluation of the isotopic data. Evaluation of other data provides a means to verify or refute part or all of the above conclusions. Ground water elevations in selected wells provide an excellent tool to evaluate flow system dynamics, especially in Columbia River Basalts where surficial expressions of structures or hydrologic barriers are often lacking.

Ground water elevations

Evidence of limited vertical hydraulic conductivity within the study area is provided by the presence of the Lindsay Creek aquifer (Figure 10). This perched aquifer, located in the north central part of the study area, is hosted by the *Priest Rapids Member* of the *Wanapum Basalt*. There is approximately 500 feet head difference between it and the underlying Grande Ronde aquifer of approximately 500 feet. A more important recharge avenue to the aquifer is believed to be leakage from the river in areas where overlying beds are thin or in areas where beds dip toward the center of the basin.

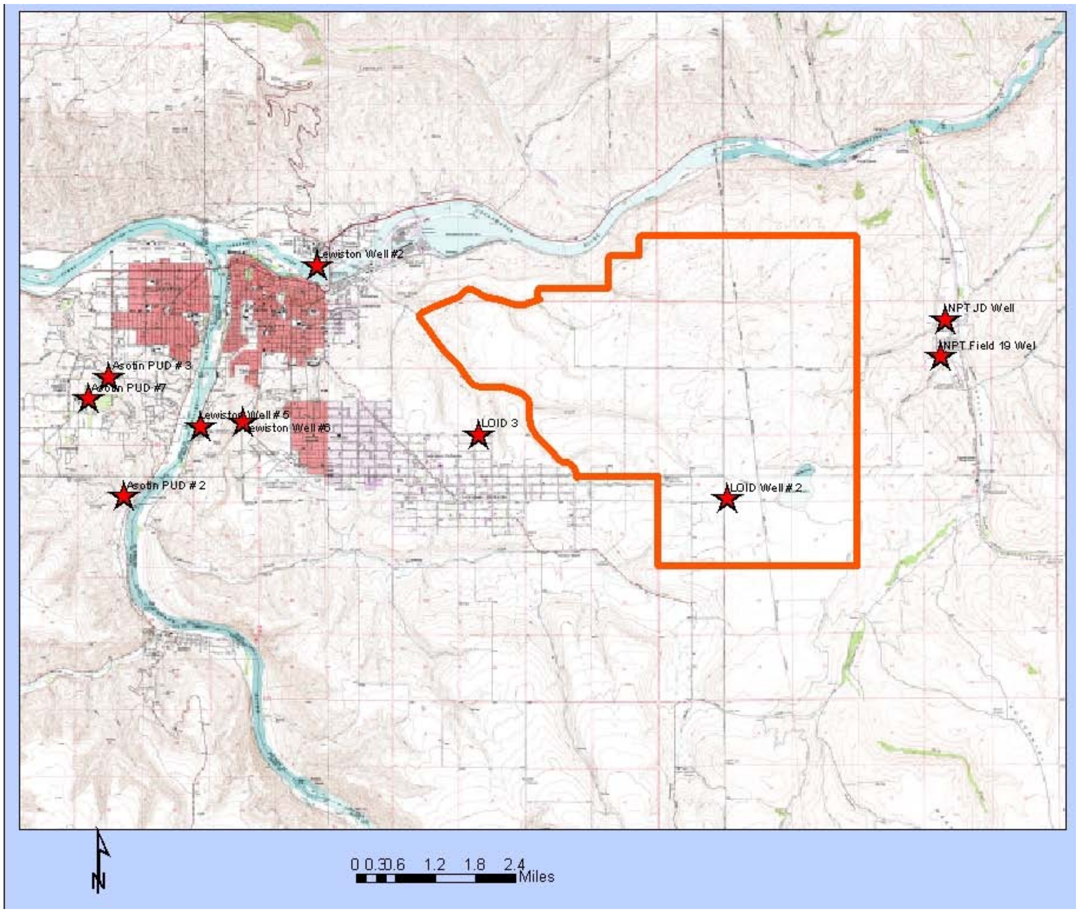

Figure 10. Location of the Lindsay Creek Ground Water Management Area (shown in orange) in relation to the sampled wells in the study area. The Lindsay Creek Aquifer was designated a Ground Water Management Area in 1992 by the Idaho Department of Water Resources.

Figure 11 provides a contour map of water levels within the study area; Table 4 shows well data. A cone of depression is located under the town of Clarkston, near the confluence of the Snake and Clearwater Rivers. The river confluence area is dominated by slack water from Lower Granite Reservoir, located about 30 miles downstream. When the reservoir was filled in 1975, water levels in the Asotin PUD and Lewiston wells rose about 20 feet, indicating a strong hydraulic connection between the river and ground water (Stevens, 1994). Since the reservoir filled, present day water levels have remained stable indicating a hydraulic connection between the river and the aquifer.

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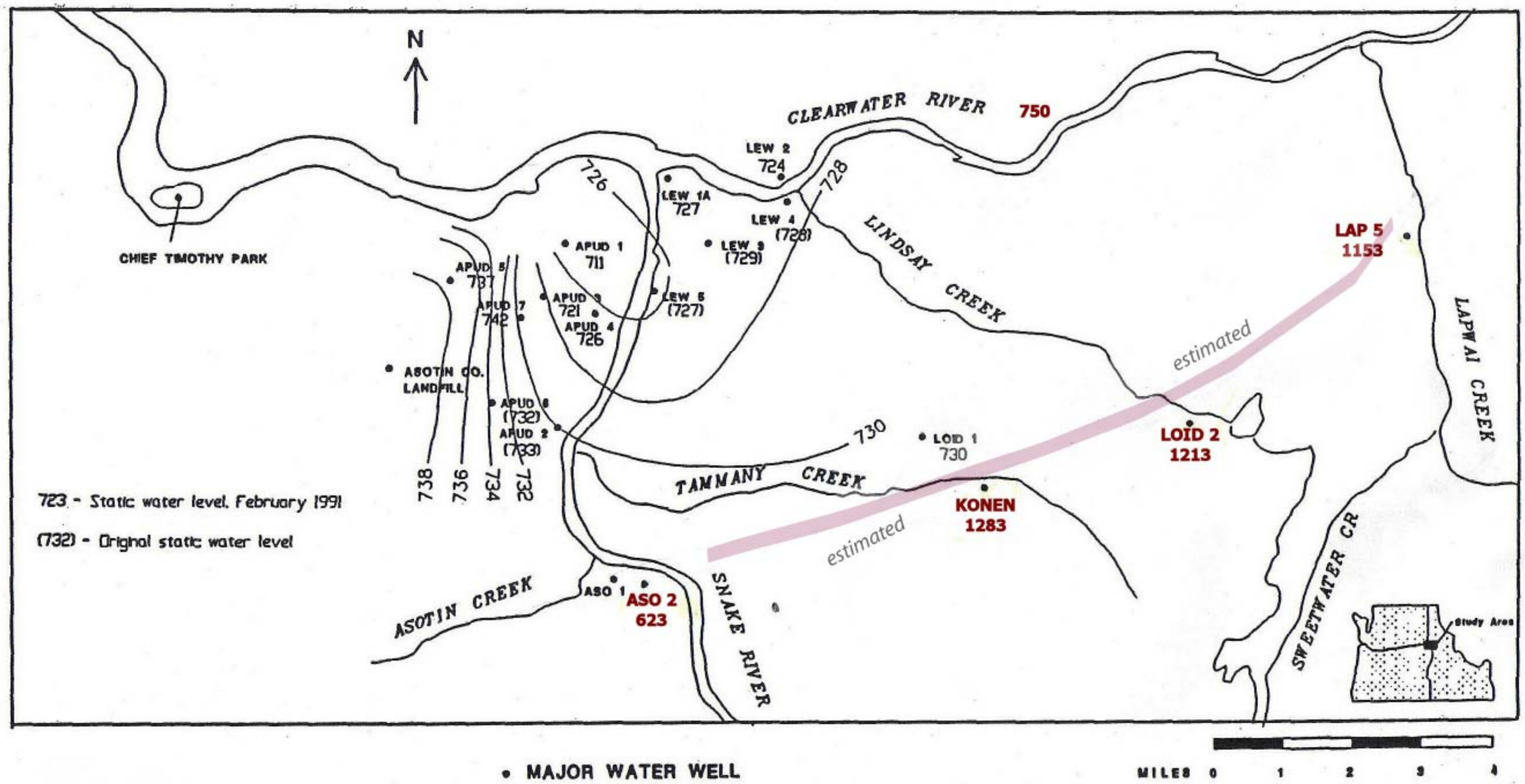

Figure 11. Water level contour map of measured water levels in the study area in 1994 (from Stevens 1994). The line shows the estimated location of the barrier.

Table 4. Well data for the study area in 1994 (Stevens, 1994).

Well	Surface Elevation (msl)	Elevation of Well Bottom (msl)	Elevation of Static Water Level (msl)	Elevation of Open Interval (msl)	Elevation of Mid-Open Interval (msl)	Specific Capacity/Length Open Interval (gpm/ft/ft)
LOID 1	1567	33	740	559-33	103	0.007
LOID 2	1740	-218	1213	364-218	73	0.006
KONEN	1383	784	1283	1127-784	955	
ASO 2	656	134	623	255-134	326	
LAP 5	1181	741	1153	841-741	791	

Evidence of the presence of a hydraulic discontinuity or barrier boundary in the central part of the basin is suggested by the differences in ground water elevations observed in wells LOID #2, LOID #3, Konen well, and Lewiston #5. The ground water elevation in LOID #2 was 1,213 ft msl (Stevens, 1994) while the elevations were 735 ft msl in 1997 in LOID #3 (*Source Water Assessment* Addendum, 2001) and 727 ft msl in Lewiston #5 (Stevens, 1994). The Konen well had a ground water elevation similar to LOID #2 at 1,283 ft msl. The hydraulic gradient is about 4 ft/mile between LOID #3 and Lewiston #5, while the gradient is about 120 ft/mile between LOID #2 and LOID #3 at similar separation distances although neither may be estimated on direct flow paths in the aquifer. For comparison, and on a more direct flow path south of Lewiston on the fringes of the cone of depression, the hydraulic gradient appears to be about 2 ft/mile.

The disparity in ground water elevations between the LOID #2 and #3 wells might be attributed to leakage via the annular space between the well casing and the formation in LOID #2. Potential leakage from the younger (higher elevation) Wanapum Basalts to the older (deeper) Grande Ronde Basalts is not believed to be significant, if present at all, to cause the large disparity. A 1993 aquifer test on LOID #2 at 660 gpm resulted in a drawdown of about 230 ft after 26 hours of pumping (Wyatt, et al., 1994). A separate step-drawdown aquifer test of LOID #3 was conducted in 1997 (Eliason, 1997). The pumping rates ranged from 459 gpm to 1,542 gpm for a total duration of 24 hours. The drawdown ranged from 81 ft at the lowest pumping rate to 335 ft at the highest pumping rate. The inverse or ground water mounding via long-term leakage at flow rates greater than those above would be required for development and maintenance of the high ground water elevation seen in LOID #2. It is unlikely that leakage in the range of 1,000 gallons per minute, the approximate flow rate required to create a 500-foot head difference, is occurring between the Wanapum and Grand Ronde aquifers.

The disparity in hydraulic gradients and ground water elevations suggests the presence of a hydraulic barrier boundary that transects the basin from Asotin on the southwest to just north of Lapwai on the northeast, passing between LOID #2 and LOID #3. Also, the ground water elevation in LOID #2 places the location of the recharge source much higher in elevation than the corresponding elevations of the recharge areas outlined along the Clearwater River or the Snake River. Stevens (1994) reports an initial ground water elevation in LOID #2 of about 1,550 ft msl in 1986 before water levels declined due to pumping to near 1,200 ft msl in 1988 through the end of the record in 1992. The maximum measured ground water elevation indicates a recharge source area for LOID #2 south south-east of the well in outcrop areas of the Grande Ronde Basalts. The ground water elevations in wells LOID #2, Konen, and Lapwai #5 are near 1,200 ft msl, with Lapwai #5 having the lowest elevation. This suggests that ground water may flow north from the Craig Mountain area.

The apparent age of the ground water in LOID #2 (12,200 years) suggests a recharge location that is closer to the well than is evident from the ages indicated for ground water in the other wells noted. A ground water flow path length from the recharge area to LOID #2, calculated using the values noted previously, appears to be in excess of about 85 miles. This value appears to be an order of magnitude too large when compared to the distance to the Grande Ronde Basalt outcrop near the Limekiln Fault, located about 10 miles south to south-south-east of the well (Figure 10). The elevation at this outcrop area is needed to match the elevation (about 1,550 ft) of the pre-pumping ground water level in LOID #2. Reducing the calculated distance to the proposed recharge area is easily achieved by modifying the values for the variables. For instance, the transmissivity and hydraulic conductivity may decrease with increasing distance from the central part of the Lewiston Basin (Wyatt, et al., 1994). A half order of magnitude decrease in hydraulic conductivity and a half order of magnitude increase in effective porosity nearly match the distance to this potential recharge area.

Ground water chemistry

Stevens (1994) provided an early interpretation of the hydrochemistry of the ground waters in the Lewiston Basin; only a small part of his analysis is presented here. Stevens prepared Stiff diagrams of the ground waters from several wells and concluded the diagrams fit three general groupings. Group 1 includes the following wells: LOID #1, APUD #2, APUD #3, and City of Asotin #2. Group 1 represents water with a long residence time. Group 2 includes: LOID #2, Konen well and Lapwai #5. Group 2 represents water with "relatively short to intermediate residence times." Group 3 represents water from the Lewiston #5 well and does not fit any of his conceptual models.

Stevens also evaluated other variables and hydrochemistry relationships including pH. He noted that pH "demonstrates a direct relation with the elevation of the mid-open interval…" Also, the Konen well, which was originally drilled to an elevation of -1,557 ft msl and has since caved to a depth of 784 ft msl, is probably producing water from a considerably deeper depth based on the pH.

Stevens also considered ground water temperatures in his evaluation. The Konen well, LOID #1, and LOID #2 all had temperatures of 24^{o} C or greater while Lapwai #5 had the coolest ground water at about 14^{o} C. Stevens concluded that:

> "there are elevated temperatures near the confluence of the Snake and Clearwater Rivers, along Lindsay Creek, near the City of Asotin, and one well south of the Lewiston Orchards area. The higher temperatures in the Lindsay Creek wells may reflect a structural feature in this area. However, no structural features have been observed in this vicinity. The anomalous water temperatures of the well directly south of the Lewiston Orchards may be due to an extension of the linear feature that is causing the higher temperatures at Lindsay Creek."

Figure 12 illustrates a south-north cross section through LOID #2. The Vista Anticline is the dominant geologic feature in this cross-section. A characteristic of an anticlinal fold is that the older units are exposed in the eroded center of the fold. This is in contrast to the Lewiston Syncline (concave upward) where the youngest rocks are exposed in the center of the fold. It is important to note that the younger basalt flows exposed on the right or north side of the section are eroded away. The Priest Rapids Basalt hosts the Lindsay Creek Aquifer. A significant aquitard is located at the base of this unit, which prevents vertical ground water infiltration. The Vista Anticline is interpreted to funnel ground water directly into the Grande Ronde Basalt via the Snake River.

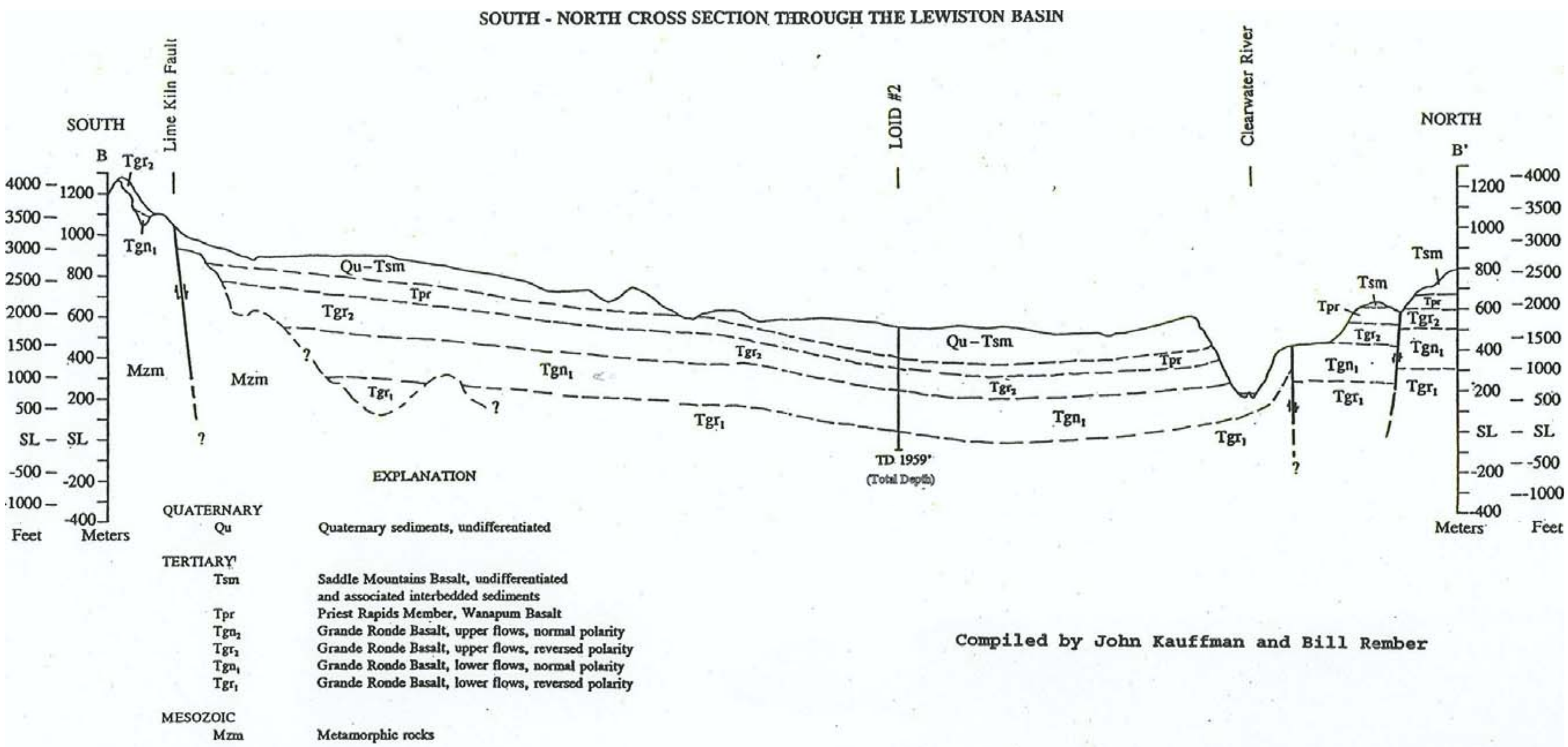

Figure 12. South-north cross section in the Lewiston Basin (Stevens, 1994). This cross section is shown as a line on Figure 13.

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Alternate conceptual model

Stevens (1994) presents a comprehensive analysis of past evaluations of the Lewiston Basin hydrogeologic system and furthers the interpretation of the system with updated information. He concluded that most of the wells completed in the Saddle Mountains and Wanapum Basalts are shallow domestic and irrigation wells with yields averaging in the range of 10 to 20 gpm. All of the major producing wells (yields greater than 1,000 gpm) are completed in the Grande Ronde Basalts and have ground water levels near river level elevations except for LOID #2 and the Konen well. The LOID #2 well is completed in the R1 unit of the Grande Ronde Basalts. Stevens noted the ground water elevations in these two wells are about 480 feet higher than the other wells completed in the Grande Ronde Basalts.

Stevens (1994) offers two alternative conceptual models for this hydrogeologic system in the Grande Ronde Basalts. The first conceptual model is based on the concept of two separate aquifers based on horizontal stratification that is correlated to paleomagnetic sub-units of the formation. The upper Grande Ronde aquifer correlates with the N1 and R2 units with ground water elevations of 720 to 740 feet. The lower Grande Ronde aquifer correlates with the R1 unit and has a characteristic ground water elevation of about 1,200 feet. The recharge area for the lower aquifer is then attributed to the higher elevations near the Lime-Kiln Fault located south of LOID #2. APUD #2 well is located west of the Snake River and was drilled to a depth that should have encountered the R1 unit but “dramatic flowing well conditions” that would be associated with these very high ground water elevations were not noted in the original records for the well. Stevens concludes, based on this and other information, that the horizontal stratification model is not valid.

Stevens presents a second conceptual model of a single aquifer in the Grande Ronde Basalts that is separated into “semi-isolated compartments by roughly north-south-trending geologic discontinuities. One discontinuity would separate the LOID #2 and Konen wells from LOID #1 and the other wells to the west. A second discontinuity would isolate the LOID # 2 area from the Lapwai Valley and Grande Ronde basalt outcrops to the east. The structural features that form the Clearwater Escarpment would bound the aquifer on the north.” Stevens concludes, based on his analysis, that this conceptual model fits the available hydrogeologic information.

The information presented in this report supports consideration of an alternate conceptual model for the aquifers of the Lewiston Basin contained within the Grande Ronde Basalts. The key to defining this alternate conceptual model is the disparity between ground water elevations in wells located in the Grande Ronde Basalts. Ground water elevations within the northern part of the basin are near the elevations of the Clearwater and Snake Rivers that serve as sources of recharge for the northern part of the aquifer. The separation of the basin into northern and southern parts is implied through the presence of much higher ground water levels in the southern part of the basin and steep hydraulic gradients across the potential hydraulic barrier that separates the two parts of the basin. Initial ground water elevations in LOID #2 were reported to be about 1,550 ft msl. Once this well was pumped, ground water elevations declined and appeared to stabilize at an elevation near 1,200 ft msl, suggesting a more remote and/or limited source of recharge unlike the wells completed in the northern basin aquifer. The recharge area for LOID #2 must occur at an elevation higher than 1,550 feet msl, which must be to the south toward the Limekiln fault and the community of Waha.

The separation of the aquifer(s) into separate systems also is supported by the apparent age of the ground waters in the northern and southern areas. The ground water in the northern part of the basin is on the order of 20,000 to 30,000 years old, whereas ground water in the southern aquifer near the potential hydraulic barrier is about 12,000 years old. It should be noted that the apparent ground water age in the Lapwai wells is for wells that appear to be completed in the lower Grande Ronde Basalts since the elevation of the open intervals in the wells (NPT Field 19 #1 and NPT Lapwai JD) are from 936 to 892 feet msl. Lapwai well #5 is reportedly open from 741 to 841 feet msl and also appears to be completed in the lower Grande Ronde Basalts. The ground water in the NPT Field 19 #1 and NPT Lapwai JD wells has an age of about 3,000 years old; ground water from Lapwai well #5 was not age dated or sampled and analyzed for tritium content. Tritium was below detection limits in the Lapwai wells NPT Field 19#1 and NPT Lapwai JD. The disparity between the ages of this ground water and the ground water from LOID #2 suggests the north-south trending hydraulic barriers proposed by Stevens may separate the ground waters represented by these two groups of wells.

A third line of evidence pointing to a barrier is the differing hydraulic characteristics of the two areas. The low hydraulic gradients associated with the aquifer system in the northern part of the basin are controlled by the river stages in the Clearwater and Snake Rivers, which are only slightly different in the recharge areas, especially following completion of the Lower Granite Dam. Hydraulic gradients in the southern aquifer system are controlled by the difference in altitudes between recharge areas along the outcrops to the south and the potential discharge areas such as Lapwai Creek and or the Snake River. Assuming the hydraulic conductivities and effective porosities are nearly the same in the northern and southern aquifer systems, one would expect to see faster flow through the upper aquifer, which is reflected in the apparent ages of the ground water. In the northern part of the basin, long-term water level declines were reversed, seasonal water level fluctuations were damped, and water levels rose approximately 20 feet—all in response to reservoir filling following construction of Lower Granite Dam (Wyatt, et al, 1994). In the southern part of the basin, water levels at LOID #2 have declined approximately 320 feet in response to pumping, and water levels did not respond to Lower Granite dam filling.

Previous investigators working with aquifers in the Columbia River Basalt Group have identified the presence of hydraulic barriers from aquifer tests and often presumed the barriers are caused by north-south trending dikes that served as the source of some of the basalt flows. The hydraulic barrier boundary proposed in this study is primarily linked to the disparity in ground water elevations and the coincident location of an interpreted lineament visible on topographic and orthographic maps of the area. This curvilinear lineament extends from east of Asotin Creek in Washington State to near Tom Beall

Creek, which is a tributary to Lapwai Creek just north of Lapwai, Idaho (Figure 13). The influence of this feature on pre-development ground water flow systems is supported by the historical records of 1836. In 1836, the Spauldings established their mission near a big spring at the foot of Thunder Hill, about 2 miles above the mouth of Lapwai Creek (Nez Perce County Sheriffs Office, no date). The hydraulic barrier proposed in this report crosses Lapwai Creek near this area and could cause ground water discharge at a topographic low from the southern aquifer system.

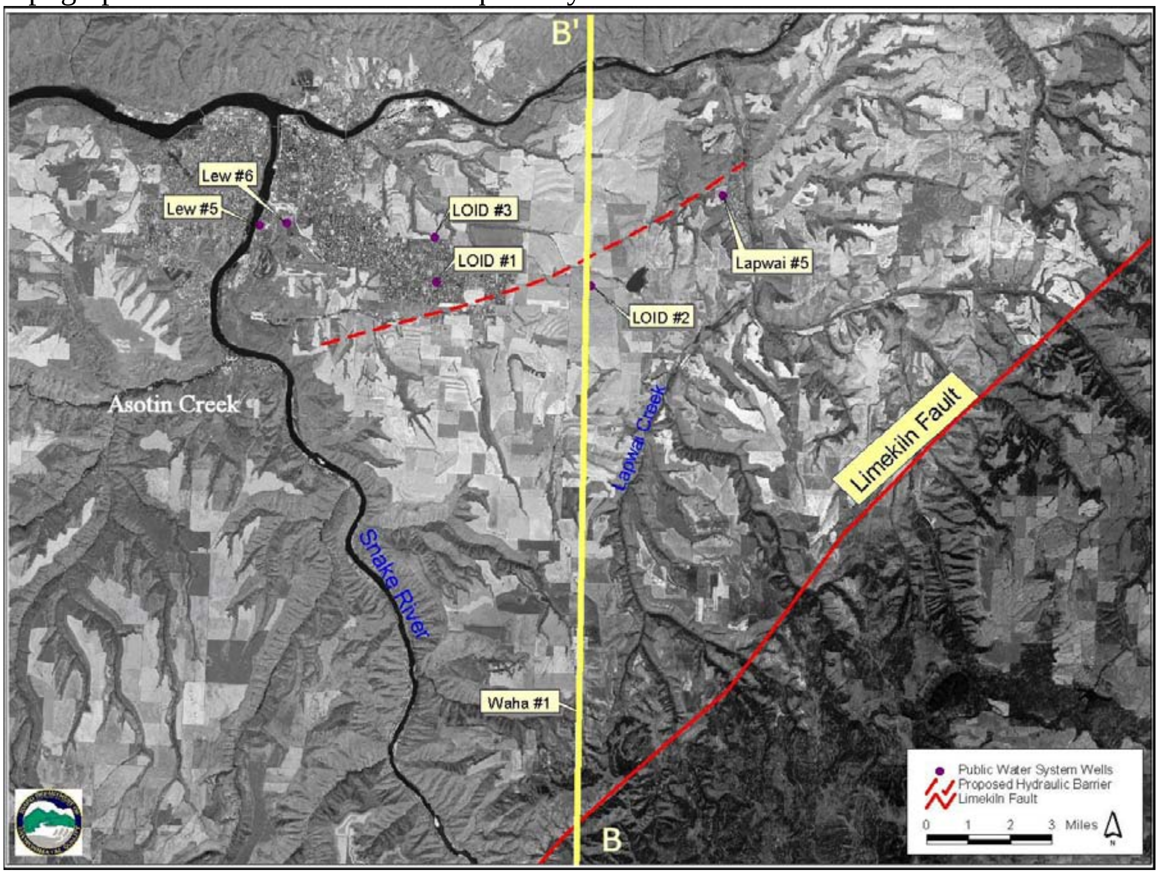

Figure 13. Air photo of Lewiston Basin, showing location of Limekiln Fault, hydraulic barrier, and public water system wells. The yellow line is the location of cross-section B-B' on Figure 12.

The nature of the hydraulic barrier described above is not well understood. Rember and Kauffman (1993) show the axis of the Lewiston Syncline located in the same general area as the hydraulic barrier identified in this study. (See Figure 2 for the location of the Lewiston syncline); Hooper et al. (1985) also note the existence of a syncline in the same general area. The difference in hydraulic head noted across the barrier does not seem to be accounted for by a structural feature such as a syncline, where individual basalt flows should not be offset by downwarping alone. As noted above, most dike systems associated with Columbia River basalt flows are oriented north-south rather than east-west; in any case, it is not clear that a dike system would produce the head differences noted in the wells. There are no obvious surface features that indicate the presence of a fault with enough offset to produce the head loss in the basin wells, but given the compressional history of the basin, i.e formation of anticlines and synclines, faulting seems a likely candidate. Additional investigation is needed to define the feature.

Newcomb (1961) documented the effect that geologic structures can have on ground water flow and ground water elevations in Columbia River Basalts. Examples are cited such as the Upper Cold Creek Syncline east of Yakima, Washington; this site is notable for the head differential across the barrier (580 feet pre-development). This barrier is attributed to a fault (or sharp fold). The faults described by Newcomb are mainly normal faults with fracture planes between 60° and 70° below the horizontal. Normal faults are generally attributed to tensional strains. Newcomb (1961, p. 4) noted:

> "The water-transmission characteristics of the fault zones differ considerably from those of the unbroken basalt. The fault fracturing provides a zone of low permeability (fig. 3), along which small amounts of water can move vertically in some places. The lowest sags in the fault traces, where they cross stream valleys, are generally marked by small seepage springs. The permeable interflow zones that provide the lateral, or generally horizontal, routes of ground-water movement are obliterated in the fault zones and the lateral movement of the water is virtually stopped."

The conceptual model presented in this report is based on very limited data and correlation to similar conditions documented at other locations associated with the Columbia River Basalts. The second conceptual model presented by Stevens (1994) may be the correct model or it may work partially or wholly in combination with the conceptual model presented in this report to control the movement of ground water within the Lewiston Basin.

Conclusions and Recommendations

Environmental isotopic analyses of ground water in the Lewiston Basin has provided an initial look at identifying potential recharge mechanisms along with the locations of these recharge zones. Combined together, each individual isotopic analyses supports the following conclusions regarding residence time and recharge zones:

- Tritium was detected above the detection limit of 0.8 TU in 5 out of the 10 sampled wells. As a result, it is evident that some percentage of water produced from some wells is modern recharge; these wells may need to be evaluated further from a source water protection point of view.
- Radiocarbon age dating provided ^{14}C ages ranging from 2,830 to 34,670 years. Given the geologic conditions and tritium detections in individual wells, these age dates appear to be consistent. A relationship was observed between increasing ^{14}C age with decreasing well production zone depth.
- Analysis of ^{18}O signatures within the sampled wells provided an initial examination at determining the origin or recharge waters for the 5 sampled wells that were not contaminated with tritium.
- As this investigation was the first to use environmental isotopes for analyses of recharge conditions and locations in the Lewiston Basin Aquifer System, several recommendations have been formulated to provide direction for future studies.
- Continued monitoring of environmental isotopes is recommended and encouraged to increase the number of samples and data points in the basin.

- To further refine ^{14}C age dates, geochemical modeling can be completed to analyze the mass transfers of carbon within the hydrogeologic system. To complete this modeling, samples of common ions need to be collected from the sampled wells. These chemical parameters can then be geochemically modeled in programs, such as *NETPATH* (Plummer, 1994).
- The potential presence of separate northern and southern aquifer systems in the Grande Ronde Basalts of the Lewiston basin warrants further investigation. The northern aquifer system appears to be hydraulically linked to the Clearwater and Snake Rivers. The southern aquifer appears to be hydraulically linked to the topographically higher basalt outcrops south of LOID #2, near the regional Limekiln fault near Waha. The sources of water vary dramatically in the quantity of water that is available to recharge these separate aquifer systems. Obviously, the northern aquifer system has a much larger source of water (two major rivers) for recharge than the southern aquifer system (snow melt and small streams).
- The head data and the tritium data suggest that several wells in what is now generally referred to as the Lewiston Basin Aquifer are not (or do not have the potential to be) recharged by the major rivers (e.g. LOID #2, Konen well, NPT wells). These wells may be in isolated zones of the Grande Ronde. Ground water levels to the south and east of the possible hydraulic barrier proposed in this report should be monitored over the long-term for possible water level decline, particularly as large volume uses (e.g. municipal and irrigation) increase in these areas.
- Water level data from additional wells completed in the Grand Rhonde aquifer will provide more evidence for the existence of the hydraulic barrier boundary. This information is relatively inexpensive to obtain.
- The ground water elevation in LOID #2, located in the southern part of the Lewiston basin, suggests a different source of recharge for this part of the aquifer compared to LOID #3, located in the northern part of the basin. These results warrant further investigation. A barrier boundary is postulated to exist between wells LOID #2 and LOID #3, extending southwest to northeast across the basin separating the basin into lower (northern) and upper (southern) aquifer systems.
- In general, the Grande Ronde Basalts are characterized to have high horizontal permeability and low vertical permeability. Generally, ground water recharge occurs along the basin margins, where basalts contact major rivers or topographically higher outcrops.
- Prevalent hydrogeologic conditions are the dominant factors controlling ground water flow in the Lewiston Basin. The two primary geologic features influencing ground water flow are the Lewiston Syncline and Vista Anticline. The Vista Anticline is interpreted to allow ground water recharge directly into the Grande Ronde Basalts, while the Lewiston Syncline is interpreted to restrict flow into the basalts. In other words, the shortest ground water flow paths occur along the down dip limb of the anticline, while the longer flow paths are down the limb of the syncline.

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