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Hydrogeologic Assessment of the Tucannon River, Pataha Creek, and Asotin Creek Drainages, WRIA 35, Columbia, Garfield, and Asotin Counties, Washington

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Prepared for

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EXECUTIVE SUMMARY

Hydrogeologic Assessment of the Tucannon River, Pataha Creek, Asotin Creek Drainages, WRIA 35, Columbia, Garfield, and Asotin Counties, Washington

Report date: 18 May 2005

A hydrogeologic assessment of the portion of WRIA 35 generally lying within the Asotin Creek, Tucannon River, and Pataha Creek drainages was conducted using previously prepared and existing reports, maps, and well information. The objective of the assessment was to summarize basic groundwater conditions in the project area to the extent possible given the existing information. Except for a general reconnaissance of the area, no fieldwork was done for this assessment. The assessment identified the main geologic units underlying the project area and evaluated the relationship between these units and groundwater occurrence and movement, summarized the possible effects of geologic structure (folds and faults) on groundwater distribution, and presented a basic conceptual model of probable groundwater occurrence and movement beneath the project area.

The predominant geologic unit underlying the project area, and the unit that hosts the most widespread aquifers, is the Columbia River Basalt Group (CRBG). The CRBG is overlain by a series of relatively localized clastic deposits (clay, silt, loess, sand, and gravel) and underlain by widespread (but very deep) metamorphic rocks. The sediments overlying the CRBG host generally localized aquifers, referred to as the suprabasalt sediment aquifer system, while the underlying metamorphic rocks contain little or no usable groundwater. General geologic and hydrogeologic conditions in the project area are summarized below.

Sediments overlying the CRBG

The sediments which overlie the CRBG consist of a variety of wind-deposited to water-deposited strata. These strata typically are localized in stream valleys or covering deeply eroded upland areas.

Alluvial deposits: Generally coarse, well-bedded, stream-rounded, basaltic, alluvial clastic strata (predominantly sand and gravel) are found as thin (generally less than 50 feet thick) deposits partially filling many valley and canyon bottoms. More angular to blocky, commonly muddy gravel and debris also is found at the mouths of small canyons feeding into the larger valleys and in landslide and talus deposits at the base of steep slopes and canyon walls. These coarse basaltic alluvial deposits range from Pleistocene to Holocene in age (possibly older than 700,000 years to present).

Loess: Loess is a wind deposited silt and very fine sand. It mantles most of the upland areas within the project area lying between the edge of the Snake River canyon and the Blue Mountains. The loess, also referred to as the Palouse Formation, is deeply incised by stream erosion and rarely more than 100 feet thick. It is potentially early Pleistocene to late Pleistocene in age (>750,000 to 10,000 years).

Cataclysmic flood deposits: Localized accumulations of well bedded mixed lithology (basalt, quartzite, granite, gneiss, metavolcanics) pebble to boulder gravel and sand are found in the Snake River Canyon and at and near the mouths on many tributary valleys. Cataclysmic flood deposits in the Snake River canyon commonly form large bars that stretch for a half mile or more along the floor of the canyon. These mixed lithology deposits were lain down by

Pleistocene Cataclysmic Floods (Missoula Floods and Bonnevile Flood) that periodically inundated the Snake River Canyon and its tributaries. The Missoula Floods also deposited the well bedded, silt and sand (referred to as Touchet Beds) commonly seen in Snake River tributary canyons throughout the project area.

Suprabasalt sediment aquifer system: The suprabasalt sediment aquifer system is found predominantly in valley filling alluvial gravel and Pleistocene Cataclysmic Flood sand and gravel. This aquifer system generally consists of multiple, local, unconfined groundwater-bearing zones that are less than 5 to 40 feet below ground surface, less than 50 feet thick. The distribution of this system is controlled by the physical extent of the deposits and the location of bedrock in and adjacent to the valleys the aquifer is found in. Generally there is little or no hydrologic continuity between the parts of this aquifer system located in different stream valleys. However, this aquifer probably does typically have a high degree of hydrologic continuity with nearby streams, both discharging to and receiving discharge from them. Given the generally uncemented character of the sand and gravel which seems to host this aquifer system it is inferred generally to have high porosity.

Columbia River basalt

The middle to late Miocene (17,500,000 to 6,500,000 years) Columbia River Basalt Group is the main geologic unit underlying the project area. It is the product of several hundred huge volcanic eruptions which inundated the region under thousands of feet of basalt lava flows. Most CRBG basalt flows occur as sheet flows which form laterally widespread, planar-tabular sheets (or layers). Each basalt flow has a top and bottom where porous and permeable rock is found. The interiors of these flows generally consist of dense, glassy basalt which has low to no porosity and permeability unless disturbed by deformation or erosion. While widespread, these sheet flows do terminate. Their lateral extent is controlled by erosion, faulting, and the original extent of the basalt flow. A small number of CRBG basalt flows where emplaced in and filled pre-existing canyons and valleys and form narrow, elongate, ribbons which are referred to as intracanyon flows. The CRBG is subdivided into multiple units which are summarized below.

Saddle Mountains Basalt: This is the youngest (13,500,000 to 6,500,000 years) and aerially most limited CRBG unit in the project area. Eight Saddle Mountains units are present in the Asotin area where they occur as very small sheet flows and/or as intracanyon flows. Elsewhere in the project area, Saddle Mountains units only occur as intracanyon flows which are generally restricted to the vicinity of the Snake River canyon.

Wanapum Basalt: The Wanapum Basalt consists predominantly of sheet flows subdivided into the Roza Member (1 flow), Frenchman Springs Member (3 to 6 flows), and Eckler Mountain Member (3 or more flows). Wanapum sheet flows are found across much of the area. However, they have limited lateral continuity because the modern drainage has cut canyons which erode completely through the Wanapum in many areas. Where it has not been removed by erosion in the project area, the Wanapum Basalt usually is several hundred feet thick. Feeder dikes for the eruptions that feed at least the Roza Member are present in the Asotin drainage.

Grande Ronde Basalt: The Grande Ronde Basalt, which underlies the Wanapum Basalt, is the most widespread and voluminous CRBG unit, underlying almost the entire project area and comprising over 85% of the CRBG although it was emplaced in a relatively short period of time (15,600,000 to 14,500,000 years). In the project area it consists of dozens of flows subdivided into 4 magnetostratigraphic units (from top to bottom, N_2, R_2, N_1, and R_1).The depth of erosion into the Grande Ronde Basalt generally increases upstream on the Snake River and its tributaries (including the Asotin, Tucannon, and Pataha drainages). Grande Ronde sheet flows typically become more widespread and thicker away from the crest of the Blue Mountains. In the project area the Grande Ronde Basalt usually is several thousand feet thick. Feeder dikes for eruptions that feed many Grande Ronde flows are present in the Asotin drainage.

Imnaha Basalt: The Imnaha Basalt, the oldest CRBG unit, is not exposed at the Earth's surface in the project area. Beneath the project area it is inferred to consist of several sheet flows that buried an irregular, pre-existing land surface.

Ellensburg Formation: The Ellensburg Formation consists of thin claystone, mudstone, sandstone, and conglomerate interbedded between some CRBG units, especially in the Saddle Mountains Basalt. Ellensburg units are most common in the Asotin area where they crop out on canyon walls.

Folds and faults: The CRBG (and Ellensburg Formation) is deformed by folding and faulting. Throughout the project area CRBG layers generally dip to the north, northwest, and northeast off the crest of the Blue Mountains towards the Snake River. In the Asotin Creek drainage this general dip is interrupted by a series of north-south faults in the area where the creek forks and by several low amplitude anticlines and synclines in the lower part of the drainage. To the west, in the Pataha and Tucannon drainages, the generally north-northeast trending Hite fault system cuts through and offsets CRBG units by hundreds of feet.

CRBG aquifers: Groundwater within the CRBG generally is found in flow tops and flow bottoms, with the top of one flow and the bottom of the overlying flow referred to as an interflow zone. These interflow zones are separated by dense flow interiors which essentially block significant movement of groundwater between successive interflow zones. Consequently, groundwater in the CRBG generally occurs in multiple, stacked, confined aquifers which have limited hydrologic continuity. CRBG aquifers can be very productive (having very high hydraulic conductivity and transmissivity), although they can be easily depleted (because of very low storativity) if pumping exceeds recharge. Groundwater flow direction within an interflow zone generally is in the down-dip direction of the zone. Given the regional dip of the CRBG in the project area, off the Blue Mountains towards the Snake River, groundwater flow in CRBG aquifers generally is towards the Snake River.

Interflow zone aquifers are as widespread as the geologic units they belong to. Consequently, potential aquifers in the Saddle Mountains basalt (dominated by intracanyon flows) are narrow and elongate whereas those in the sheet flow dominated Wanapum and Grande Ronde Basalts are thin, but potentially laterally extensive. The lateral continuity of potential Wanapum and Grande Ronde aquifers in the project area is largely controlled by depth of erosion, flow edges, faults, and feeder dikes. The more each of these features are overprinted on the Wanapum and Grande Ronde, the more restricted lateral continuity of potential aquifer becomes. Erosion appears to be the predominant control on the lateral continuity of Wanapum aquifers. Faults and feeder dikes may affect the lateral continuity of Grande Ronde aquifers.

Because flow interiors are relatively impermeable, recharge to CRBG interflow aquifers occur where the interflow zone crops out at the Earth's surface. These locations have to be where surface water and/or precipitation are present and can infiltrate into the ground. Conversely, discharge from these aquifers generally has to be where these interflow zones terminate at or near the surface (such as in deeply eroded canyons) or other aquifers. Based on the extent of interflow zone aquifers in the various CRBG units with respect to potential recharge areas, lateral continuity, and location Saddle Mountains and Wanapum aquifers are inferred to be of limited extent and low, sustainable productivity (<100 gpm). Grande Ronde aquifers should be more productive, but the relative lack of deep, high capacity, water production wells in the project areas makes any prediction of Grande Ronde aquifer production premature.

Pre-CRBG rocks

The rocks underlying the CRBG crop out in small areas in the bottoms of several canyons in the project area. These rocks consist of metamorphic volcanic and sedimentary rocks having limited porosity. Pre-CRBG rocks probably are not a source of significant groundwater in the project area.

Conceptual Groundwater Model

The suprabasalt aquifer system typically contains the shallowest groundwater in the project area. However, this system generally is localized in stream valleys and canyons, relatively thin (only a few tens of feet), and usually in direct hydrologic continuity with nearby streams. Consequently, impacts to one (increased pumping, decreased recharge, etc.) will affect the other. Groundwater flow in this system is inferred to be relatively rapid and directly influenced by bedrock topography in the valley bottom.

The CRBG aquifer system essentially consists of a series of inclined, stacked, confined aquifers. These aquifers generally dip off the crest of the Blue Mountains towards the Snake River. The degree of hydrologic continuity between these aquifers is limited to areas where erosion, faulting, and/or flow edges terminate the flow interiors which separate aquifers.

Most Saddle Mountains and Wanapum interflow zone aquifers crop out on relatively arid canyon walls within the project area, suggesting relatively little recharge to these potential aquifers. This, coupled with their limited lateral continuity, suggests groundwater production from most aquifers hosted by these units is limited. The well records examined for this assessment, which show must wells in these units produce less than 150 gpm, support this conclusion.

Many Grande Ronde interflow zones crop out in well watered canyons and higher precipitation areas of the Blue Mountains. Given this, these potential aquifers may see significant recharge. Discharge from individual Grande Ronde aquifers is inferred to be limited to deep canyons that cut each aquifer and generally non-existent from Grande Ronde aquifers which are not truncated by deep erosion in down gradient areas. Consequently, discharge from the Grande Ronde to the Snake River is inferred to be limited to absent. The combination of potentially good recharge and limited discharge suggests Grande Ronde aquifers have the potential to yield large volumes of water. However, the presence of feeder dikes and faults cross-cutting these aquifers has the potential to limit there continuity, and hence potential production. In addition, so few large volume production wells tap these aquifers that any conclusion regarding their production potential is premature.

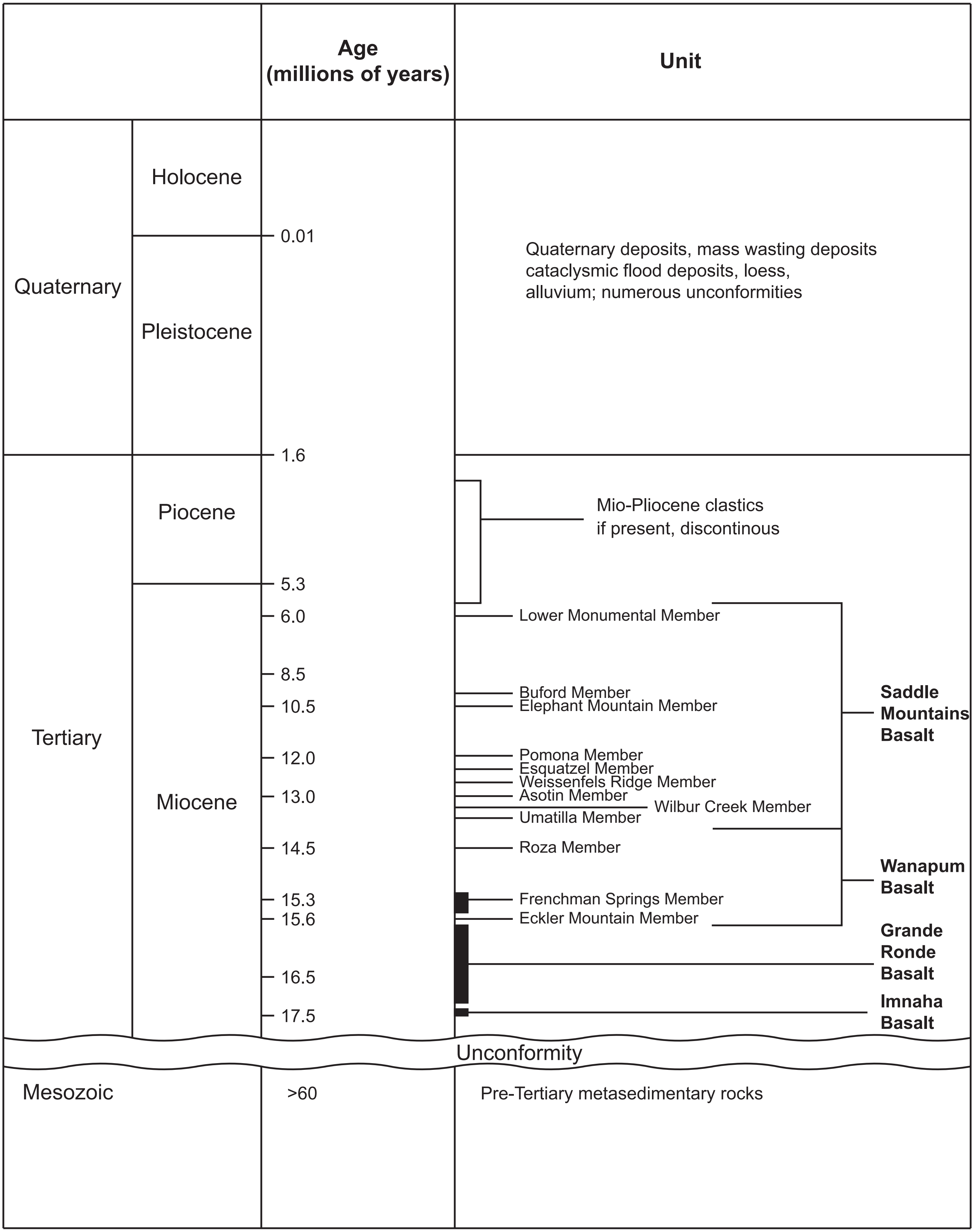

Figure E-1. General stratigraphic chart and main aquifer hosting geologic units for project area.

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Section 1: Introduction

This report presents a hydrogeologic assessment of the portion of WRIA 35 generally lying within the drainages of Asotin Creek, the Tucannon River, and Pataha Creek, in southeastern Washington (Figure 1). The purpose of this assessment is to summarize basic geologic and hydrogeologic conditions within this area to the extent possible using the available data and information. The types of geologic information summarized include basic stratigraphy, physical geology, and structure. Hydrogeologic information summarized in this assessment includes the nature and characteristics of the main aquifers, groundwater levels and flow directions, water well pumping information, and water quality. For the remainder of this report the combined Asotin Creek, Tucannon River, and Pataha Creek drainages are collectively referred to as the project area.

This assessment is based almost entirely on previously published and readily available information. This information includes reports the team has on-file or could get access to from various agencies and libraries, geologic maps, water well reports in the Department of Ecology website, and water level information available from the U.S. Geological Survey website (http://NWIS.waterdata.usgs.gov/MWIS/gwlevels). Water well information summarized for this report is compiled in Appendix A. A two-day field reconnaissance was conducted for the project to review basic area surface conditions. No invasive subsurface investigation was done for this project.

The information summarized in this report is organized into sections describing:

1. Study area geologic setting, including suprabasalt sediments, Columbia River basalt, and structural features

2. Study area hydrogeologic setting, including suprabasalt sediment aquifers and basalt aquifers

3. Conclusions, including a basic conceptual hydrogeologic model

The project area encompasses much of the northern portions of Asotin (exclusive of the Clarkston area), Columbia, and Garfield Counties (Figure 1). It is generally bounded on the north, east, and west by the Snake River and on the south by the crest of the Blue Mountains. This hydrogeologic assessment focuses on the Asotin Creek, Tucannon River, and Pataha Creek drainages. Headwaters for each of these drainages generally are found in the northern part of the Blue Mountains. Asotin Creek generally flows to the east-northeast to the Snake River. The Tucannon River and Pataha Creek generally flows northwest towards the Snake River. Pataha Creek flows into the Tucannon River, which in turn flows into the Snake River.

In the upper reaches of these streams, the landscape is mountainous, with peaks and ridges rising to elevations over 5500 feet above sea level. Asotin Creek, the Tucannon River, and Pataha Creek, and their tributaries, occupy canyons cut hundreds to over 1,000 feet into this mountainous terrain. This mountainous terrain dominates the southern quarter of the project area. For this assessment the Blue Mountains portion of the project area generally is defined as that part of the area covered by wooded ridges, valleys, and peaks and lying within the Umatilla National Forest.

The central, northern, and eastern parts of the project area consists of a generally north, northwest, and northeast sloping upland surface that decreases in elevation towards the Snake River. This upland surface is covered by a hilly topography and cut by numerous ravines and canyons which form the area's drainage. These canyons and ravines can be hundreds of feet, to over one thousand feet, deep. The Snake River, which occupies a deep canyon cut into this upland surface, forms base level for all area streams and marks the northern and eastern edges of the project area.

The Kennedy/Jenks Consultants project team was lead by Dr. Kevin Lindsey, L.Hg. and included Mr. Terry Tolan, L.Hg. and Mr. Jon Travis. Dr. Lindsey was the lead hydrogeologist. Mr. Tolan provided additional hydrogeology support and Mr. Travis provided technical support, including compilation of well data.

Section 2: Geologic Setting

Physical geology exerts a fundamental influence on the hydrologic properties of aquifers and hence the movement and distribution of groundwater. Therefore, a basic understanding of area geology is fundamental to providing a basic framework for understanding groundwater occurrence and aquifer properties. The purpose of this section is to present a review of the geology of the Asotin Creek, Tucannon River, and Pataha Creek drainages and provide this basic physical framework for understanding area groundwater and aquifer conditions.

Geologic mapping of the WRIA 35 region has been conducted by a number of investigators over the years (e.g., Huntting, 1942; Hammatt and Blinman, 1977; Kienle, 1980; Swanson and others, 1979a, 1980; Hooper and Webster, 1982; Hooper, 1985; Hooper and others, 1985; Swanson and Wright, 1978; Stoffel, 1984; Schuster and others, 1997; Gulick, 1994). The Washington Division of Geology and Earth Resources has compiled and published 1:100,000 scale geologic maps (Schuster, 1994; Gulick, 1994) that cover the WRIA 35 region. Major stratigraphic units found within the WRIA 35 area, from oldest to youngest, are (Figure 2):

- Isolated pre-Tertiary igneous and metamorphic rock inliers in bottom of the Snake River, Tucannon River, and Menatchee Creek canyons;
- Middle to late Miocene flood basalt flows and feeder dikes of the Columbia River Basalt Group (CRBG) and interbedded continental sediments (Ellensburg Formation);
- Miocene to Pleistocene gravels found along the Snake River and Grande Ronde River canyons and in the Lewiston Basin;
- Pleistocene Cataclysmic Flood deposits (Missoula and Bonneville Floods) found along the Snake River canyon and some of the larger tributary canyons (e.g., Tucannon River) below the 1,200 ft elevation;
- Pleistocene to Holocene loess of the Palouse Formation;
- Pleistocene to Holocene mass-wasting deposits consisting of talus and landslide deposits;
- Late Pleistocene to Holocene alluvium deposited by rivers and creeks in valley bottoms.

The general physical characteristics of these stratigraphic units within the project area are summarized in the following sections. Surface soils are not discussed in this assessment because of its regional emphasis and the relatively minor role soils play in groundwater occurrence and distribution in the project area. The following discussion generally proceeds from the youngest to oldest units.

2.1 Quaternary deposits

Quaternary deposits consist of a variety of basic units. For the purpose of this review these strata are referred to as: (1) Pleistocene Cataclysmic Flood deposits, (2) loess of the Palouse

Formation, (3) mass-wasting deposits, and (4) alluvium. The basic characteristics of these strata are summarized in the following sections.

2.1.1 Pleistocene Cataclysmic Flood Deposits

Largely uncemented, typically poorly indurated, well-stratified interbedded silt and sand, sand, gravelly sand, and pebble to boulder gravel is present in the Snake River canyon and tributary valleys, (Bretz and others, 1956; Rigby and others, 1979; Myers and Price, 1979, 1981; Waitt, 1985; Fecht and others, 1987; US DOE, 1988; Kiver and others, 1989; McDonald and Busacca, 1989; Baker and others, 1991). These strata have been interpreted as having been deposited by the Pleistocene Cataclysmic Floods that were released from glacial Lake Missoula periodically between approximately 1,000,000 and 12,000 years ago and glacial Lake Bonneville less than 10,000 years ago (Bretz and others, 1956; Baker and Nummedal, 1978; Rigby and others, 1979; Myers and Price, 1979, 1981; Webster and others, 1982; Waitt, 1985; Fecht and others, 1987; US DOE, 1988; Kiver and others, 1989; McDonald and Busacca, 1989; Baker and others, 1991).

Where present, Pleistocene Cataclysmic Flood deposits range from a few feet (<1 m) thick to more than 200 feet (+60 m) thick (Grolier and Bingham, 1971, 1978; Myers and Price, 1979, 1981; Fecht and others, 1987; USDOE, 1988; Baker and others, 1991; Lindsey and others, 1994). Pleistocene Cataclysmic Flood deposits are commonly divided into three basic sediment types (facies) which commonly form the basis for subdividing the flood deposits into map units. These facies include the following:

- Intercalated, well stratified silt and fine- to coarse-grained sand forming normally graded (fining upwards) beds that range from inches (few centimeters) to several feet (tens of centimeters) thick (Figure 3).
  - This facies, also known as Touchet beds, is found predominantly on highland surfaces (ridges) and localized in valleys tributary to the Snake River.
- Laminated to massive, uncemented, felsic to basaltic, fine- to very coarse-grained sand. These sands can contain thin, lenticular silt to fine gravel interbeds. Where the silt content is low, a well-sorted and open-framework texture is common. Where the basalt content in these deposits is high, they are often referred to as “black sands” because of the dark gray to black color caused by the high basalt content.
  - This facies appears to be relatively rare in the project area. If present, it is inferred to comprise some of the large flood deposited bars found downstream of the mouth of the Palouse River in the Snake River canyon and near the mouths of tributary canyons.
- Well-stratified to massive, uncemented, unweathered, mixed lithology (although basalt content is usually high) pebble to boulder gravel (Figure 4). Interstitial matrix in this facies generally ranges from absent to predominantly coarse sand and granules. Where these strata contain little or no matrix sand they commonly have an open-framework texture where open intergranular pores are readily apparent to the unaided eye. This

facies may be locally muddy, although such fine content does not appear to be widespread.

- Flood-deposited gravel is found intermittently in the Snake River canyon and in the lowermost reaches of tributary streams. In the Snake River canyon these deposits commonly form large gravel terraces and bars in the bottom of the canyon that may be capped by large-scale "mega-ripples". Flood deposited gravel also is found forming terraces in tributary canyons and on the west sides of ridges protruding into the Snake River canyon several hundred feet above the current river level. A number of these features are found near the mouth of the Tucannon River and on the Snake River opposite and downstream of the City of Asotin.

Another feature common to the flood deposits is clastic dikes (Black, 1979; Myers and Price, 1981, Fecht and others, 1999). Clastic dikes usually consist of alternating vertical to subvertical layers of silt, sand, and granule gravel less than 0.5 in (~1 cm) up to 6 ft (2 m) thick (Figure 5). Clastic dikes typically cross-cut bedding, although they do locally parallel bedding. Where dikes intersect the ground surface, a polygonal feature visible from the air and known as patterned ground is observed. Clastic dikes are generally best developed in the interstratified silt and sand facies and to a lesser extent in the sand-dominated facies.

2.1.2 Loess

The surface materials covering much of the upland surface between the Snake River canyon and the Blue Mountains commonly consists of massive to poorly stratified, light colored, silt and very fine sand (also called loess), (Figure 6) (Grolier and Bingham, 1971; Rigby and others, 1979; Kiver and others, 1989; McDonald and Busacca, 1989; Baker and others, 1991; Busacca and others, 1992; Busacca and McDonald, 1994; Berger and Busacca, 1995; Schuster and others, 1997). Loess commonly is pedogenically altered (e.g., display evidence of soil forming processes, including animal burrows and rooting), in some areas contains air fall ash, and can display evidence of multiple, stacked and superimposed soil horizons reflecting subtle changes in climate and erosion conditions in the region during the Quaternary. Caliche can be present in the loess. This loess also is referred to on some maps and in some reports as the Palouse Formation or Palouse loess.

Loess generally is thought to consist of glacial "rock flour". The source of this rock flour is interpreted to be the Cordilleran and Continental ice sheets. Rock flour derived from glacial erosion is thought to have been reworked (transported) and deposited by wind across much of the region during the Pleistocene (Rigby and others, 1979; Swanson and others, 1979a, 1980; Stoffel and others, 1991; Baker and others, 1991; Busacca and McDonald, 1994). Air fall ash found intermittently within the loess came from volcanic eruptions in the Cascade Range. Caliche, where found in the loess, suggests semi-arid conditions periodically occurred in the region in the Quaternary.

Across the study area loess generally covers unforested upland surfaces but is thin to absent from the modern active river and stream valleys and most tributary valleys which are cut into underlying basalt bedrock. Loess deposits may range from less than 1 foot to more than 100 feet thick (Rigby and others, 1979; Stoffel and others, 1991; Busacca and McDonald, 1994; Schuster and others, 1997). In the Columbia Basin, Baker and others (1991) identify multiple loess units that range in age from more than 1 million years in age to less than 10,000 years in age. Based on mapped trends loess appears to predominantly overlie basalt bedrock. This contact is disconformable, although the extent of incision, if any, into underlying basalt bedrock is not well known.

2.1.3 Quaternary alluvium and mass wasting deposits

Uncemented and nonindurated sandy to gravelly strata is found in many of the stream valleys and canyons which cross the project area. These gravely deposits generally are basaltic, have a silty to sandy matrix, and contain thin silty to sandy interbeds. Reviewing driller's information on water well logs suggests these strata are very variable in thickness, ranging from less than 1 foot to several tens of feet thick.

These basaltic clastic strata are inferred to have been deposited in two main ways. Well stratified occurrences of moderately to well rounded gravel represent stream deposition in the stream cut valleys and canyons which transect the area. Massive, generally more matrix-rich occurrences of these gravels, occurring at the base of slopes and in alluvial fans at the mouths of tributary canyons are interpreted as mass-wasting and as debris flow deposits from storm generated flash flood events. The mass wasting deposits may be locally well cemented (usually with caliche) while stream deposited gravels generally display little or no cement. These uncemented and nonindurated gravels are interpreted to record deposition in local streams incised into the area and streams draining off the adjacent Blue Mountains.

The age of these sand and gravel deposits is not well constrained. In some parts of the region these strata are found underlying loess and Touchet Beds. In the modern stream drainages these gravelly sediments are interpreted to be actively deposited and they may be contemporaneous with other Quaternary deposits. Based on these stratigraphic relationships Quaternary alluvium and mass wasting deposits predate, are contemporaneous with, and post-date Pleistocene cataclysmic flooding, giving these deposits ages of as little as a few thousand, hundreds, or even tens of years old to as old as 1 million years or more.

2.2 Mio-Pliocene suprabasalt sediments

Compilation geologic maps of the project area suggest the presence of indurated coarse clastics on localized terraces in and adjacent to the Snake River canyon. If present, these strata would likely be equivalent to Mio-Pliocene conglomerate found in the nearby Walla Walla Basin and more distant Pasco Basin. In the Pasco Basin these strata are known as the Ringold Formation. For this assessment we could not find any information describing the presence of these deposits outside of the Snake River Canyon. If they are present elsewhere in the project area, one would expect to find them occurring as thin, discontinuous terraces in tributary valleys and buried beneath loess on upland surfaces.

2.3 Columbia River Basalt Group (CRBG)

The predominant stratigraphic unit underlying the project area is the Columbia River Basalt Group (CRBG). Collectively, the CRBG consists of a thick sequence of more than 300 continental tholeiitic flood basalt flows that cover an area of more than 164,000 km^2 in

Washington, Oregon, and western Oregon (Tolan and others, 1989). The CRBG virtually underlies the entire project area except, where pre-CRBG rocks crop out in deeply incised canyons in the Blue Mountains. The total estimated volume for the CRBG is greater than 174,000 km^3 (Tolan and others, 1989), with the maximum thickness of over 3.2 km occurring in the Pasco Basin area, based on geophysical and deep hydrocarbon exploration well data (Reidel and others, 1982; 1989a). CRBG flows were erupted during a period from about 17 to 6 million years ago (Ma) from long (10 to >50 km), north-northwest-trending linear fissure systems located in eastern Washington (WRIA 35 area), northeastern Oregon, and western Idaho. Although CRBG eruptive activity spanned an 11-million-year period, most (>96 volume %) of the CRBG flows were emplaced over a 2.5-million-year period from 17 to 14.5 Ma (Swanson and others, 1979b; Tolan and others, 1989).

The following sections summarize CRBG physical characteristics and stratigraphy.

2.3.1 Physical characteristics of CRBG flows

2.3.1.1 Mode of emplacement─sheet vs. compound flows and intracanyon flows

Rate and volume of lava erupted, lava composition/temperature (rheology), vent geometry, topography, and environmental conditions all play significant roles in the eruption dynamics and overall geometry of individual basalt lava flows or flow fields (Shaw and Swanson, 1970; Beeson and others, 1989; Reidel and Tolan, 1992; Reidel and others, 1994; Hon and others, 1994; Keszthelyi and Self, 1996; Self and others, 1996; Reidel, 1998). There are two basic types of flow geometries, compound and sheet.

A compound flow develops when a lava flow advances away from its vent in a series of distinct and separate lobes (flows) of flowing lava. Each lobe is subsequently covered by later lava lobes as the emplacement of lava continues. This results in the accumulation of elongated bodies of basalt with numerous, local, discontinuous, and relatively thin layers of basalt lava.

In comparison, a sheet flow results when lava is erupted at a high rate and is able to advance away from the vent as a single, uniform, moving sheet of lava. This type of flow consists of a relatively extensive, single layer or "sheet" of lava. Each successive sheet flow will create a similar layer, with the flow boundaries being delineated by distinct vesicular flow tops and flow bottoms. Individual, large-volume CRBG flows (especially Wanapum and Grande Ronde Basalts) display characteristics consistent with sheet flows (Swanson and others, 1979b; Beeson and others, 1985, 1989; Tolan and others, 1989; Reidel and others, 1989b; Beeson and Tolan, 1990, 1996; Reidel and Tolan, 1992; Reidel and others, 1994; Reidel, 1998). CRBG flows typically exhibit the complex features associated with compound flows only at their flow margins or proximal to their vents (Beeson and others, 1989; Reidel and Tolan, 1992; Reidel and others, 1994; Beeson and Tolan, 1996; Reidel, 1998).

A much less common mode of emplacement for CRBG flows is as an intracanyon flow. In this case, an advancing CRBG sheet flow encounters a major river canyon that serves to channel the lava into a ready-made conduit to the west. These paleoriver canyons allowed some CRBG flows to travel significantly greater distances than they might have as sheet flows. A number of Saddle Mountains Basalt flows within the project area occur as intracanyon flows (Swanson and others, 1980; Ross, 1989).

2.3.1.2 Rate of emplacement

Two differing models have been suggested for the emplacement of huge-volume CRBG flows: (1) rapid emplacement, on the order of weeks to months per flow (Shaw and Swanson, 1970; Swanson and others, 1975; Wright and others, 1989; Reidel and Tolan, 1992; Reidel and others, 1994; Beeson and Tolan, 1996; Reidel, 1998); or (2) slow emplacement, on the order of many years to centuries per flow (Self and others, 1991, 1993, 1996; Long and others, 1991; Finneamore and others, 1993; Murphy and others, 1997). Both field evidence and laboratory evidence to date (Swanson and others, 1975; Mangan and others, 1986; Wright and others, 1989; Reidel and Tolan, 1992; Reidel and others, 1994; Beeson and Tolan, 1996; Ho and Cashman, 1997; Reidel, 1998; Ho, 1999) appear to favor a rapid, laminar-flow model. Evidence supporting the rapid emplacement model includes the following:

- The internal structure of CRBG flows (discussed in the next section) is relatively simple. The slow emplacement model requires low lava discharge that would produce very distinctive flow features such as lava tubes and lava inflation structures, resulting in a relatively complex internal arrangement of flow structures (Chitwood, 1994; Hon and others, 1994; Self and others, 1996). These complex flow features are rarely found within a CRBG flow except at the margins of flows. The pervasive presence of simple internal flow structures in CRBG flows supports a rapid emplacement model (Reidel and Tolan, 1992; Reidel and others, 1994; Beeson and Tolan, 1996; Reidel, 1998).

- Petrographic examination of quenched CRBG lava (e.g., rinds from pillow lava) from medial to distal parts of the flows has shown that the crystallinity is no greater than that of the glassy selvage zones of feeder dikes. This indicates that little or no crystal nucleation and growth occurred from the time the lava was erupted to when it reached its most distal point–distances ranging from 200 to >500 km (Shaw and Swanson, 1970; Swanson and others, 1975; Mangan and others, 1986; Wright and others, 1989; Ho and Cashman, 1997; Ho, 1999). These observations are not consistent with a very long duration (slow) emplacement model and instead support the huge-volume, rapid emplacement model.

- A basalt glass composition-based geothermometry study has been conducted for the Ginkgo flow (Frenchman Springs Member, Wanapum Basalt) along its 500-km length to provide a quantitative estimate of heat loss (Ho and Cashman, 1997; Ho, 1999). Results suggest cooling rates of 0.02 to 0.04 ^{o}C/km for the Ginkgo flow, which are substantially lower than cooling rates observed in active and historic basalt flows (Ho and Cashman, 1997). These data favor a rapid emplacement model over a slow emplacement model that would require extreme thermal efficiencies to produce these cooling rates (Ho and Cashman, 1997, p. 405).

- The lack of extensive pillow/hyaloclastite complexes along the length of CRBG intracanyon flows favors a rapid emplacement model (Reidel and others, 1994; Beeson and Tolan, 1996).

If CRBG intracanyon flows were emplaced over very long periods (years to centuries), dammed-off rivers would have overtopped the lava dams in a period of a few months and reestablished their presences within their canyons years before the flows reached their most distal points. This situation would result in rivers encountering the advancing flow fronts, causing the continuous creation of large quantities of hyaloclastic debris and pillow lava. Features consistent with this aspect of a slow emplacement model are not found along the length of CRBG intracanyon flows.

2.3.1.3 Intraflow structures

Examination of vertical exposures through the CRBG reveal that they all generally exhibit the same basic three-part internal arrangement of intraflow structures (Figure 7). These features originated either during the emplacement of the flows or during the cooling and solidification of the lava after it ceased flowing. Intraflow structures are generally referred to as the flow top, flow interior, and flow bottom. The combination of a flow top of one flow and the flow bottom of the overlying flow is commonly referred to as an “interflow zone” (Figure 7).

Flow Tops: The flow top is the crust that formed on the top of a molten lava flow. Flow tops commonly consist of glassy to very fine-grained basalt that is riddled with countless spherical and elongated vesicles. Vesicles represent gas bubbles that were trapped (frozen) as the flow solidified. These gases were originally dissolved within the magma, but reduction in pressure (and subsequent decrease in temperature) as the magma reached the surface allowed these gases to come out of solution. CRBG flow tops can display a wide range of variation in both their physical character and thickness (U.S. Department of Energy, 1988).

The physical character of flow tops falls between two basic end-members: (1) a flow top breccia (Figure 8) and (2) a simple vesicular flow top (Figure 9). There characteristics are summarized as follows:

- A flow top breccia (Figure 8) consists of angular, scoriaceous to vesicular fragments of basaltic rubble that lie above a zone of nonfragmented, vesicular to vuggy basalt. Flow top breccias can be very thick (over half the flow thickness, which can be more than 30 m) and laterally extensive (U.S. Department of Energy, 1988). There are two models for the origin of CRBG flow top breccias: (1) the scoria (breccia) was originally produced along the linear fissure system and subsequently rafted away on top of the flowing lava, and (2) an autobrecciation process similar to that which creates aa flows in Hawaii occurred. In either case, laterally extensive flow top breccias are relatively common features within the CRBG.

- A simple vesicular flow top (Figure 9) commonly consists of glassy to fine-grained basalt that displays a marked increase in the density of vesicles toward the top of the flow (U.S. Department of Energy, 1988; McMillian and others, 1989). Vesicles may be isolated or interconnected, resulting in lower or higher permeability and effective porosity, respectively (U.S. Department of Energy, 1988). Tensional cooling joints related to flow top formation/flow emplacement can augment the overall permeability of this feature.

Flow Interiors: CRBG flow interiors typically consist of dense, nonvesicular, glassy to crystalline basalt that contains numerous contraction joints (termed “cooling joints”) that formed when the lava solidified. CRBG cooling joints most often form regular patterns or styles, with the two most common being columnar-blocky jointing (Figure 10) and entablature-colonnade (Figure 11).

- Columnar-blocky jointing (Figure 10) is usually associated with thinner (more fluid) flows and typically displays mostly vertical, poorly to well-formed polygonal columns that can range from 0.5 m to >3 m in diameter. The vertical columns are often cut by horizontal to subhorizontal cooling joints.

- Entablature-colonnade jointing (Figure 11) is usually observed in thicker (more viscous) flows and displays a more complex pattern than that forming within a single flow. The entablature portion displays a pattern of numerous, irregular-jointed small columns to randomly oriented cooling joints that abruptly overlie a thinner zone displaying well-developed columnar jointing. The transition zone between the entablature and the basal colonnade may be very narrow, generally less than a centimeter in width. Typically the entablature is thicker than the basal colonnade, often making up at least two-thirds of the total flow thickness. The entablature is assumed to form due to cooling from the top of the flow downward, and the colonnade forms due to cooling from the bottom upward. Another characteristic of entablatures is that the basalt of which they are composed contains a very high percentage of glass (50 to 95%) in contrast to the colonnade (Long and Wood, 1986; U.S. Department of Energy, 1988). While entablature-colonnade jointing style is commonly observed in CRBG flows, it is actually a very uncommon jointing pattern for lava flows elsewhere in the world. The origin of entablature-colonnade jointing has been the subject of much speculation and conjecture (e.g., Long and Wood, 1986; Reidel and others, 1994) but has not been resolved.

Regardless of the jointing style of an individual CRBG flow, it is important to note that in the subsurface 70 to 90 percent of all joints are filled by secondary minerals (Lindbergh, 1989). These minerals most commonly are clays and zeolites. In addition, it is equally important to remember that the open joints so typical of outcrops largely are a manifestation of the release of confining pressure associated with the exposure of these rocks at the Earth's surface. In the subsurface, where these rocks are under lithostatic loads, well videos reveal that joints are only rarely open.

Flow Bottoms: The physical characteristics of CRBG flow bottoms are largely dependent on the environmental conditions molten lava encountered as it was emplaced (Mackin, 1961; Swanson and Wright, 1978, 1981; U.S. Department of Energy, 1988; Beeson and others, 1989; Reidel and others, 1994; Beeson and Tolan, 1996). For example:

- If the advancing CRBG lava encountered relatively dry ground conditions, the flow bottom that resulted typically consists of a narrow (<1-m thick) zone of sparsely vesicular, glassy to very fine-grained basalt (Figure 12). This type of flow bottom structure is very common within the CRBG.

- If, on the other hand, advancing lava encountered lakes, rivers, and/or areas of water-saturated, unconsolidated sediments, far more complex flow bottom structures formed (Mackin, 1961; Bentley, 1977; Grolier and Bingham, 1978; Byerly and Swanson, 1978; Swanson, and Wright, 1978, 1981; Swanson and others, 1979b; Beeson and others, 1989; Bentley and others, 1980; Camp, 1981; Stoffel, 1984; Tolan and Beeson, 1984; Ross, 1989; Pfaff and Beeson, 1989; Reidel and others, 1994; Beeson and Tolan, 1996). Where advancing lava encountered a lake, a pillow lava complex (Figure 13) would be created as the lava flowed into the lake. A pillow complex consists of elongated to spherical lobes of basalt (pillows) set in a matrix of glassy basalt fragments (hyaloclastite). The pillows represent subaqueous pahoehoe flow lobes that advanced down the front of the pillow lava delta. Studies of the active formation of basaltic pillow lavas in Hawaii (e.g., Moore, 1975) indicate that molten lava can smoothly flow into the ocean without thermal disruption (phreatic brecciation) as long as a thin film of highly insulating steam protects the lava. This process allows for the formation of subaqueous lava tubes (pahoehoe flow lobes that advance and grow in a manner similar to those observed on land (Swanson, 1973; Hon and others, 1994). Disruption of this insulating steam barrier (e.g., wave action, currents, and gas explosions within the lava lobe) allows water to come into direct contact with molten lava, resulting in the production of glassy debris (hyaloclastite) by phreatic brecciation. CRBG pillow lava complexes and hyaloclastites are not uncommon features, but their occurrence and distribution reflect the paleodrainage pattern that existed at the time of their emplacement (Tolan and Beeson, 1984; Fecht and others, 1987; Beeson and others, 1989; Reidel and others, 1994; Beeson and Tolan, 1996).

A trip through any of the many canyons that are eroded into the project area will reveal examples of all of the intraflow structures noted here.

2.3.2 Stratigraphy

The CRBG has been divided into a host of regionally mappable units (Figures 2 and 14), based on stratigraphic position and variation in physical, chemical, and paleomagnetic properties of flows and packets of flows (Swanson and others, 1979b; Beeson and others, 1985; Bailey, 1989; Reidel, and others, 1989). The CRBG underlying the project area has been subdivided into four formations, which are, from oldest to youngest, Imnaha Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt (Swanson and others, 1980). These formations have been further subdivided into members defined, as are the formations, on the basis of a combination of unique physical, geochemical, and paleomagnetic characteristics. These members can be, and often are, further subdivided into flow units (e.g., Beeson and others, 1985). From youngest to oldest, the following sections (based on existing reports and geologic maps cited earlier) provide a brief review of the major CRBG units that are present in the project area.

2.3.2.1 Saddle Mountains Basalt

The Saddle Mountains Basalt was erupted between approximately 6 million and 13.5 million years ago from vents in eastern Washington and western Idaho. The time that elapsed between eruptions ranged from 250,000 to 1,500,000 years, allowing ridges to be uplifted and rivers to erode canyons. Consequently, Saddle Mountains Basalt flows were generally emplaced as intracanyon flows that filled existing river canyons and aerially restricted sheet flows that filled structural basins that formed between adjacent fault and fold uplifted highlands. Both types of flows are found in the Saddle Mountains Basalt in the project area.

Eight of the ten member subdivisions of the Saddle Mountains Basalt, the Lower Monumental, Buford, Elephant Mountain, Pomona, Weissenfels Ridge, Asotin, Wilbur Creek, and Umatilla Members, are present in the project area. All of these units are found in the vicinity of the lower part of Asotin Creek. In this area these units all accumulated as at least localized sheet flows that filled a topographic low present in this area during their eruption, between 14.5 and 6 million years ago. This topographic low, formed as folds and faults uplifted ridges all around it is known as the Lewiston Basin.

Outside of the Lewiston Basin, in the western part of the project area in the Snake River canyon where the Tucannon River meets the Snake River, only the Lower Monumental, Elephant Mountain, and Pomona Members are shown on compilation geologic maps. South of the project area the Umatilla Member also occurs in the area now occupied by the crest of the Blue Mountains. Where these units occur they are interpreted to have been emplaced as intracanyon basalt flows that at least partially filled paleocanyons incised into and through the Wanapum Basalt and the upper part of the Grande Ronde Basalt. The other Saddle Mountains units noted above to occur in the Asotin Creek drainage also may be present in this same area, they simply are not shown on the compilation geologic maps reviewed for this report.

2.3.2.2 Wanapum Basalt

The Wanapum Basalt, ranging from 14.5 to approximately 15.5 million years in age, disconformably underlies the Saddle Mountains Basalt. Where present in the project area, Wanapum Basalt flows are typically sheet flows, recording emplacement over a relatively flat surface that dipped away from the area now occupied by the Blue Mountains and to the west, into the Columbia Basin. The paleocanyons and uplifted highs revealed by the distribution of the younger Saddle Mountains Basalt units were not as well developed during emplacement of the Wanapum Basalt because of the much shorter period of time (less than a few hundred thousand years) between Wanapum flows limiting the time for these features to develop.

Wanapum flows are present across most of the project area, except in the south-central and southeastern areas where they may have been largely removed by post-uplift erosion (Hooper and Swanson, 1990). Geologic cross sections prepared for this report (Figures 15, 16, 17, 18, 20, 21, and 22) show the basic distribution of Wanapum Basalt units in the project area. They generally are found on the upper parts of ridges, being completely eroded through in most of the larger, deeper canyons. In the project area, the Wanapum Basalt is formally divided into four members.

Of the uppermost two Wanapum Basalt members, the Roza Member and Priest Rapids Member, only the Roza is shown on compilation maps. Interpreting the distribution of the Roza Member shown on these maps, it originally covered most of the project area, although today much of it has been removed by erosion. In the upland areas between the Snake River and Blue Mountains crest, especially in the Tucannon River and Pataha Creek drainages, the Roza Member is inferred be buried beneath loess on many of the ridges and highland areas separating canyons.

The most widespread Wanapum Basalt member in the project area is the Frenchman Springs Member. It occurs underlying almost all upland surfaces from the Snake River, well into the Blue Mountains within the Tucannon River and Pataha Creek drainages (Beeson and others, 1985; Gulick 1994; Schuster, 1994). The available geologic mapping reviewed for this project does not indicate whether or not the Frenchman Springs Member occurs within the Asotin Creek drainage. In the project area the Frenchman Springs Member may be as much as 300 feet and it can be subdivided into three subunits, each consisting of one or two flows.

The oldest Wanapum basalt unit, the Eckler Mountain Member (Swanson and others, 1979b) generally crops out on ridges across most of the central to east part of the project area. Based on compilation geologic mapping the Eckler Mountain Member may be the only widespread Wanapum unit in the Asotin Creek drainage. The Eckler Mountain Member is further subdivided into three subunits containing one or more flows.

2.3.2.3 Grande Ronde Basalt

The Wanapum Basalt is disconformity underlain by the thickest and most widespread CRBG unit, the Grande Ronde Basalt. The Grande Ronde Basalt consists of a thick sequence of fine- to medium-grained, rarely to sparsely plagioclase phyric flows that were erupted from approximately 16.5 to 15.6 Ma (Reidel and others, 1989b). The Grande Ronde Basalt comprises approximately 85% of the total volume of the CRBG, individual flow units generally cover several thousand square miles, but yet the entire formation was all erupted and emplaced within approximately 900,000 years (Reidel and others, 1989b). Given this, the time between individual eruptions may have only been a few hundred to a few tens of thousands of years. The oldest Grande Ronde flows may have been emplaced across an at least locally irregular land surface developed on pre-existing pre-CRBG rocks. The landscape across which younger Grande Ronde Basalt flows was emplaced probably was generally a flat, gently west-dipping surface with little in the way of organized stream drainage and valleys.

The top of the Grande Ronde Basalt typically is marked by a saprolite developed on the uppermost basalt flow and/or a sedimentary interbed (Vantage Member of the Ellensburg Formation). Grande Ronde Basalt units underlie the entire project area, with the upper 1,000 to 3,500 ft of the unit exposed in the deeper river and stream valleys found in this WRIA. The Grande Ronde Basalt is thought to reach its maximum thickness, 6,000 to greater than 8,000 feet, beneath the western portion of the project area (Reidel and others, 1989b). Grande Ronde flows typically display sheet flow geometries except proximal to their feeder dike/vent systems (Reidel and Tolan, 1992). Sedimentary interbeds are rarely found within the Grande Ronde Basalt (Hooper and others, 1979). Feeder dikes and vents for the Grande Ronde Basalt have been found throughout the project area (Swanson and others, 1980; Reidel and others, 1989b; Reidel and Tolan, 1992). The type locality for the Grande Ronde Basalt is located within WRIA 35 near the mouth of the Grande Ronde River (Swanson and others, 1979b).

The Grande Ronde Basalt originally was subdivided into four magnetostratigraphic units (Swanson and others, 1979b). These units are referred to, from the top downwards as the N_2, R_2, N_1, and R_1 units. All four magnetostratigraphic units are exposed in the project area (Swanson and others, 1980; Schuster, 1994). More recently, Reidel and others (1989b) subdivided the Grande Ronde Basalt into a number of members based on a combination of stratigraphic, lithologic, geochemical, and magnetic polarity criteria (Figure 14). Wide-scale geologic mapping that employs this Grande Ronde member nomenclature has not been undertaken within the project area.

Based on the available compilation geologic mapping reviewed for this project the distribution of the four Grande Ronde Basalt magnetostratigraphic units is summarized as follows:

- The uppermost Grande Ronde Basalt unit, N_2, is the only Grande Ronde unit to not underlie essentially the entire project area. While it is exposed in the Tucannon River and Pataha Creek valleys, as well as many of their tributary valleys, it is not found in the lower part of the Asotin Creek valley. N_2 Grande Ronde Basalt is absent from the lower reaches of the Asotin Creek valley below where the creek changes its course towards the Snake River from a generally northeast flowing to an east flowing direction.

- The R_2 Grande Ronde Basalt (as well as the N_1 and R_1) does underlie the entire project area except where older, pre-CRBG rocks crop out at the Earth's surface.

Generally in the project area, as one goes upstream, towards the Blue Mountains, stream valleys cut deeper into the Grande Ronde Basalt section. In the middle Tucannon River valley (Figures 15 and 16) and Asotin Creek valley (Figure 17) erosion has completely cut through the N_2, into the underlying R_2 Grande Ronde Basalt. Further upstream in these valleys the R_2 is completely eroded through and the underlying N_1 is exposed on canyon walls (Figures 15, 16, and 17).

2.3.2.4 Imnaha Basalt

The Imnaha Basalt is the oldest CRBG formation and consists of a series of coarse-grained, plagioclase phyric flows that were erupted between approximately 17.5 to 16.5 Ma (Hooper and others, 1979). The Imnaha Basalt is inferred to underlie most of the project area, have a collective thickness ranging from less than 300 feet to more than 1,000 feet (Hooper and others, 1979; Tolan and others, 1989), and probably was emplaced on an older, irregular, pre-existing topographic surface. It conformably underlies the Grande Ronde Basalt.

Exposed Imnaha flows tend to display sheet flow geometries and often weather to grus. It is not uncommon for the vesicles within flow tops to be completely filled with secondary minerals (zeolites/calcite) (Hooper and others, 1979). Sedimentary interbeds are rarely found within the Imnaha Basalt. Exposures of the feeder dike system that erupted these earliest CRBG flows are found south and southeast of the southern boundary of project area, although is believed that Imnaha feeder dikes may be present beneath the project area (Hooper and Swanson, 1990).

Based on stratigraphic, lithologic, and geochemical criteria, Hooper and others (1979) subdivided the Imnaha Basalt into the American Bar and Rock Creek units. Flows of the American Bar unit dominate the lower portion of the Imnaha section while flows of the Rock Creek unit dominate the upper portion of the Imnaha Basalt. However flows belonging to these two units interfinger through the entire Imnaha Basalt section (Hooper and others, 1979).

Exposures of Imnaha Basalt are limited within the WRIA 35 area, and absent in the project area. Imnaha Basalt is exposed within the core of the Lewiston Structure and in the southeastern corner of WRIA 35 in the Snake River canyon.

2.3.2.5 Ellensburg Formation

A number of sediment interbeds are found interbedded between several CRBG basalt units. Collectively the interbeds belong to the Ellensburg Formation (Mackin, 1961; Schmincke, 1964; Grolier and Bingham, 1978; Swanson and others, 1979b; Fecht and others, 1987; USDOE, 1988; Smith and others, 1989) (Figure 2). While existing Ellensburg nomenclature is widely used and accepted throughout the Columbia Plateau region, it does have problems that can create confusion. Individual Ellensburg sediment units are defined on the basis of the basalt flows that overlie and underlie them and that the defining basalt units in one area are not always present in other areas. As a result, beyond the terminus of any individual basalt flow, one Ellensburg "member" can merge into, and become part of another Ellensburg member or become part of the suprabasalt sediment section.

Although detailed mapping is incomplete within the project area with respect to identifying Ellensburg Formation units, it is still possible to identify units likely to be present in the project area based on the available information. The following Ellensburg sediment interbeds are known to be, or may be, present in the project area:

- North Lewiston gravel, interbed between the Lower Monumental Member and Buford Member, Saddle Mountains basalt.

- Rattlesnake Ridge Member, interbed between the Elephant Mountain Member and Pomona Member, Saddle Mountains basalt.

- Selah Member, interbed below Pomona Member, Saddle Mountains Basalt, may include several un-named interbeds and the Sweetwater Creek interbed, all sediment interbeds below the Pomona Member and overlying the Umatilla Member, Saddle Mountains Basalt. May be mapped as undifferentiated Miocene continental deposits in the lower part of the Saddle Mountains Basalrt (silt, sand, and gravel).

Ellensburg interbeds within the project area display a variety of lithologies, including siltstone and claystone paleosols and lake deposits and river deposited arkosic to quartzose sand and conglomerate.

2.4 Pre-CRBG rocks

Pre-Tertiary rocks are inferred to underlie the entire WRIA 35 area and are unconformably overlain by the CRBG (Swanson and others, 1980). Pre-Tertiary rocks are exposed at several locations within the WRIA, including:

- In the Tucannon River and Menatchee Creek valleys, small isolated inliers of metasedimentary and metavolcanic rocks have been found, but the exact age of these rocks has not been established (Swanson and others, 1980).

- Along the Snake River, upstream of Lower Granite Dam, an inlier of Cretaceous-age granodiorite is exposed.

- South of the Town of Asotin along the Snake River, several inliers of Triassic-age metasedimentary and metavolcanic rocks belonging to the Seven Devils Group are exposed.

2.5 Structural geology

The predominant structural feature in the project area is the generally north to northwest and northeast dip of the CRBG off the Blue Mountains crest towards the Snake River and into the

Columbia Basin. This regional dip is imparted to the CRBG because the Blue Mountains were being uplifted both during and after CRBG emplacement. Given this though, there are several major differences between the structural setting of the Asotin Creek drainage and the Tucannon River and Pataha Creek drainages.

2.5.1 Tucannon River and Pataha Creek areas

As a result of regional dip, strata (N_1 Grande Ronde Basalt) exposed in the bottom of the deeper canyons incised into the Blue Mountains in the upper parts of these drainages are not exposed down-dip in the northern part of the project area. Instead, these units occur hundreds of feet below the bottom of the Snake River (Figures 15 and 16). Conversely, the only widespread Grande Ronde Basalt unit exposed in the bottom of the Snake River Canyon in this part of the project area (upper part of the N_2 Grande Ronde Basalt), occurs well above the bottom of the upper Tucannon River valley (and tributaries) as one moves upstream towards the Blue Mountains, in the up-dip direction (Figures 15, 16, 20, 21, and 22). In addition, because the Blue Mountains were being uplifted during CRBG emplacement, Grande Ronde Basalt and Wanapum Basalt units generally are thinner in the Blue Mountains and thicker to the north in the Columbia Basin (Figures 15, 16, 20, 21, and 22).

The Tucannon and Pataha portion of the project area is cut by several major fault systems as well as many small faults. The largest major fault system that transects the area is the Hite Fault system (Figure 19) (Newcomb, 1965, 1969; Kienle, 1980; Swanson and others, 1980; USDOE, 1988; Tolan and Reidel, 1989). The Hite fault is normal displacement fault with the down side being to the northwest. Studies of the Hite Fault system (Kienle, 1980; WPPSS, 1981; USDOE, 1988) also have found that it displays evidence of extensive sinistral (left-lateral) oblique-slip movement. Numerous subsidiary faults and folds are associated with the Hite Fault. Given the local tectonic regime within the region, localized areas of transtension (horst and graben structures) and transpression (anticlines and synclines) are expected to be created along, and between, subsidiary faults. The general location of the Hite Fault system and several other major faults that transect the project area are shown on Figure 19. Smaller, localized faults are not shown, but they are likely present in parts of the project area. Note, the northeast oriented fault shown on Figure 19 west of the Hite Fault is shown on some maps to be a monocline, not a fault. We show it to be a fault here because the most recent Washington State compilation maps show it to be a normal fault.

Several low amplitude, northwest trending folds, also are present in this part of the project area (Figure 19). The largest of these shown on compilation geologic maps of the area is a syncline that generally follows the course of the lower Tucannon River. Other folds are mapped along the Snake River canyon upstream of the mouth of the Tucannon River (Figure 19).

2.5.2 Asotin Creek area

In the Asotin Creek drainage regional dip of CRBG strata off the Blue Mountains crest towards the Snake river is oriented in a more northerly to northeastern direction. Given this however, there are some significant differences between the Asotin Creek valley and the rest of the project area.

The Asotin Creek drainage is transected by a series of generally north-south oriented faults that cross the creek in the vicinity of it's confluence with Charley Creek. These faults, and several associated monoclines, are down to the east. Additional faults probably are present in the Asotin Creek drainage, although they are not shown on compilation geologic maps.

Unlike the Tucannon River and Pataha Creek drainages, several large folds cross-cut the Asotin Creek drainage. These folds include: (1) anticlines and synclines parallel to the North Fork Asotin Creek, (2) a low amplitude syncline/anticline pair near where Maguire Gulch enters the creek (Figure 17), and (3) a large anticline along the drainage divide between the Asotin Creek drainage and the Grande Ronde River (Figure 18). A large syncline is found south of this anticline, generally parallel to the Grande Ronde River (Figure 18).

Section 3: Hydrogeologic Setting

Groundwater in the study area occurs in two principal aquifer systems: (1) the suprabasalt sediment (or overburden, or alluvial) aquifer system which is primarily hosted by “alluvial gravels” and Pleistocene Cataclysmic Flood deposits and (2) the underlying CRBG aquifer system. Very little direct study of these aquifers has been undertaken in the project area. Consequently, Newcomb's (1965) hydrogeology study of the nearby Walla Walla Basin becomes a primary reference, supplemented by other Walla Walla Basin (Barker and Mac Nish, 1976; Mac Nish and Barker, 1976; Pacific Groundwater Group, 1995) and regional studies (Bauer and Vaccaro, 1990). This section summarizes the general hydrogeologic setting, aquifer recharge, hydraulic continuity, and water quality of the aquifer systems beneath the project area.

3.1 Suprabasalt sediment hydrogeology

As noted above, little direct information about suprabasalt aquifer conditions in the project area is available. Therefore, the following summary of the suprabasalt sediment aquifer is based in large part on informed conjecture based on regional information, surficial geology, and our experience with similar hydrogeologic conditions in other areas, especially the Walla Walla and Pasco Basins.

The suprabasalt sediment aquifer system found in the project area occurs as multiple, localized water-bearing sand and gravel aquifers in stream valleys. Where present, predominantly in the Snake River Canyon and tributary valleys, including Asotin Creek, Tucannon River, and Pataha Creek, the suprabasalt aquifer generally is hosted by Quaternary alluvial gravel and Pleistocene Cataclysmic Flood deposits. The suprabasalt aquifer generally is unconfined. The Geologic cross sections prepared for this report (Figures 15, 16, 17, 18, 20, 21, and 22) show how little of the project area is underlain by the various Quaternary sediment units which could potentially host this aquifer. Given the geographic distribution of these materials, the suprabasalt sediment aquifer in the project region is generally small and localized.

Very little hydraulic property information is available for the suprabasalt aquifer. However, based on work in the nearby Walla Walla Basin (Newcomb, 1965; Barker and Mac Nish, 1976) one can infer some general hydrologic properties for suprabasalt sediment aquifers in the project area.

- In the Walla Walla Basin average effective porosity of older, indurated gravel is interpreted to be approximately 5 percent. In the project area, most gravelly strata which potentially hosts a suprabasalt aquifer is inferred to be nonindurated to poorly indurated. Given this, the alluvial gravel and flood deposits inferred to host the suprabasalt aquifer in the project area is inferred to have a higher average effective porosity.

- Estimates of hydraulic conductivity and transmissivity for the older indurated sediment found in the Walla Walla Basin range from $1.5x10^{-4}$ feet/second to $7.6x10^{-3}$ feet/second and 10,000 $feet^2$/day to 60,000 $feet^2$/day, respectively. As with effective porosity in the previous bullet, we suspect hydraulic conductivity and transmissivity would be higher in the saturated alluvial gravel and flood deposits we infer dominate the suprabasalt aquifer where it occurs in stream valleys and canyon in the project area.

Groundwater flow directions in the suprabasalt aquifer in the study area generally will be down valley, roughly in the same direction as stream flow. However, locally, depending on stream channel conditions, valley and stream morphology, and the location and depth to bedrock beneath valley fill alluvium, groundwater flow direction in the suprabasalt sediment aquifer may be quite variable.

Water table elevation within the suprabasalt sediment aquifer probably will vary seasonally in response to changes in stream discharge. Generally, the suprabasalt aquifer water table will lie a few feet to tens of feet below the ground surface and mimic valley floor topography. Again however, the position and depth of bedrock highs will influence water table elevations at least locally in this aquifer.

Suprabasalt aquifer recharge is inferred to be from surface water leakage from irrigation ditches, applied irrigation water, stream loss to the aquifer, direct precipitation, and to a lesser extent leakage from the CRBG aquifer system (Newcomb, 1965; Barker and Mac Nish, 1976; Pacific Groundwater Group, 1995). Discharge from the suprabasalt aquifer occurs in a number of ways, including direct discharge to streams, springs and seeps, pumped water wells, evapotransporation, and localized leakage to the CRBG aquifer system (Newcomb, 1965; Barker and Mac Nish, 1976; Pacific Groundwater Group, 1995).

Recharge to, and discharge from, the suprabasalt aquifer system probably is a very localized. On this local scale both are inferred to be controlled by such things as local stream gradient, depth of incision (including depth to bedrock below valley fill sediment), width of the valley, channel position in the valley, and stream flow. In addition, seasonal changes in water budget probably have a role in this, with aquifer recharge most common during winter and spring high flows, and aquifer discharge (as baseflow) most common in the summer and early autumn dry seasons.

Another factor to consider with respect to recharge to, and discharge from, this aquifer is its potential interaction with underlying basalt aquifers. Intermittently throughout the length of any of the canyons cutting the project area, aquifer hosting interflow zones will be in direct physical contact with the valley fill gravel of the suprabasalt aquifer. Depending on the potentiometric heads in these confined interflow aquifers, they could be recharging the sediment aquifer or be locations for discharge from the sediment aquifer.

Of the three drainages emphasized for this report the Asotin Creek drainage is interpreted to be the most effected by bedrock highs, especially above the City of Asotin. Significant reaches of this stream appear to have a bedrock channel bottom. Where this occurs, the suprabasalt aquifer will be absent. Within the confines of the City of Asotin the suprabasalt aquifer is inferred to be in direct hydraulic connection with the Snake River.

No up-to-date groundwater quality data for the suprabasalt aquifer in the study area has been found.

3.2 CRBG hydrogeology

CRBG flows host the major (semi-confined to confined) aquifer system utilized within the project area (Newcomb, 1965). The behavior of groundwater within the CRBG is governed by the physical characteristics of the CRBG flows, presence of interbedded sediments, and the effects of secondary processes that modify these physical characteristics (Newcomb, 1965, 1969; USDOE, 1988; Lite and Grondin, 1988; Wozniak, 1995; Tolan and others, 2000). Generally, groundwater is localized in interflow zones that act as aquifers while the dense interior portion of CRBG flows are typically impermeable creating confined conditions (Newcomb, 1969; USDOE, 1988; Wozniak, 1995; Tolan and others, 2000). Given the areal extent of CRBG flows, interflow zones that serve as aquifers are often laterally extensive (miles to tens of miles) and occur as a series of "stacked", confined aquifers. Commonly, CRBG aquifers are identified and grouped together based on which formation hosts aquifers (e.g., Saddle Mountains, Wanapum, and Grande Ronde Basalt aquifers).

The following sections review hydrologic properties, groundwater occurrence, and groundwater movement in CRBG aquifers both regionally, and in the project area. A discussion of CRBG aquifer water quality and temperature in the project area is not included because no information describing these conditions within the project area was found for this assessment.

3.2.1 Hydrologic properties

Based on investigations conducted in the central Columbia Plateau, a range of hydraulic properties for CRBG aquifers and interbedded sediments have been measured (USDOE, 1988; Whiteman and others, 1994; Hansen and others, 1994; Wozniak, 1995; Packard and others, 1996; Sabol and Downey, 1997). Generally:

- Hydraulic conductivity of CRBG flow tops range from 1×10^{-6} to 1,000 feet per day (feet/day), average 0.1 feet/day, and flow tops serve as the primary conduit for lateral groundwater flow (USDOE, 1988). Flow top transmissivity ranges from 4×10^{-1} to 6×10^{4} feet^2/day. Effective porosity of flow tops have been estimated to range from 1% to greater than 20%.

- Horizontal hydraulic conductivity of dense basalt flow interiors range from 1×10^{-9} to 1×10^{-3} feet/day, or approximately 5 orders of magnitude less than flow tops (USDOE, 1988). Estimated vertical hydraulic conductivity of the flow interiors range from 1 to 3 times the horizontal hydraulic conductivity determined for flow interiors, or as much as 3×10^{-9} to 3×10^{-3} feet/day (USDOE, 1988).

- Ellensburg formation interbeds have been determined to have horizontal hydraulic conductivities ranging from 1×10^{-6} to 1 feet/day, averaging 0.01 to 0.1 feet/day for various interbeds (USDOE, 1988). Values of 1×10^{-6} to 100 feet/day were reported for interbeds measured in the Pasco Basin (Sabol and Downey 1997). These sediment interbeds are relatively rare in the project area.

- Vertically averaged lateral hydraulic conductivities were estimated in Whiteman and others (1994) to range from 7×10^{-3} to 1,892 feet/day for the Saddle Mountains, 7×10^{-3} to 5,244 feet/day for the Wanapum, and 5×10^{-3} to 2,522 feet/day for the Grande Ronde aquifers. The values of hydraulic conductivity reported in Whiteman and others (1994) rely heavily on driller data from many wells that are open to multiple aquifers. These lateral conductivities integrate values over the entire depth of a given CRBG formation and therefore, reflect the contribution from inter-layer vertical movement of groundwater past lava flow pinchouts, faulting, and other discontinuities in individual flow layers.

Specific information on the hydraulic properties of the CRBG aquifer beneath the project area is limited. Estimates of CRBG aquifer hydraulic properties for use in a digital simulation of the CRBG aquifer in the nearby Walla Walla Basin were made by Mac Nish and Barker (1976). Estimates used for the hydraulic properties of the confined CRBG aquifer beneath the Walla Walla Basin in that study were:

- Transmissivity - available data from aquifer tests indicated transmissivity of 6.2×10^{-1} $feet^2$/second to 4.4×10^{-1} $feet^2$/second for CRBG aquifers. For their model, the CRBG aquifer in most of the Walla Walla Basin was assigned a range of 5.0×10^{-2} $feet^2$/second to 4.0×10^{-1} $feet^2$/second.

- Storage Coefficient - available data from aquifer tests indicate a storage coefficient of approximately 0.0002. For their model, the storage coefficient for the CRBG aquifer in most of the Basin ranged between 0.00047 and 0.00009.

Figure 23 illustrates the basic distribution of hydrologic properties through a sequence of multiple basalt flows and their intraflow zones.

Based on the available information collected for the preparation of this assessment report, it is difficult to determine what the hydrologic properties of the various basalt units present in the project area are. As noted earlier, we did not find any direct measurements. Because of that we attempted to estimated basic hydrologic conditions from pumping and draw down data listed on well logs for some of the wells drilled in the project area (Appendix A). Using this data we calculated specific capacity of a number of wells to qualitatively assess possible aquifer conditions. Based on the results of that effort we found specific capacities ranging from less than 1 gallon per minute pumped per foot drawdown (gpm/ftdd) to greater than 100 gpm/ftdd. However, most specific capacity calculations are less than 5 gpm/ftdd from wells pumping less than 150 gpm. Given this, one must suspect that CRBG aquifers in the project area generally have hydrologic properties at the lower end of the data ranges reviewed in the preceding bullets.

Such a conclusion may be premature because data describing the presence of high yield aquifers is simply lacking. Most well records for the project area are for low production, domestic wells and only a few large capacity irrigation or water system supply wells are present. The well logs for the domestic wells do not provide a good picture of high yield aquifer conditions because these wells typically are built as small low yield wells that do not stress an aquifer to the extent necessary to evaluate true aquifer properties. In addition, domestic wells generally are drilled only deep enough to produce a few tens of gpm. In many cases such production can be acquired from shallow, low yield aquifers and it is not necessary to drill to deeper, potentially higher yield aquifers. In fact, a few well logs reviewed for this assessment suggest that deeper, potentially high yield aquifers underlie the project area, both near the Snake River and closer to the Blue Mountains. Given the presence of these few wells, one cannot discount the possibility that high yield aquifers underlie some or all of the project area. If such aquifers are present, they would occur in strata that can be physically traced to areas of higher recharge and not deeply incised by modern stream drainages.

3.2.2 Factors effecting CRBG groundwater occurrence and movement

Generally, regional groundwater flow within CRBG aquifers is assumed to be toward the Columbia and Snake rivers (Whiteman and others, 1994; Hansen and others, 1994; Packard and others, 1996), and locally towards tributary streams (Newcomb, 1965; Mac Nish and Barker, 1976; Whiteman and others, 1994; Hansen and others, 1994). However, groundwater occurrence and movement within CRBG aquifers is dependent on the presence and extent of both intrinsic and external factors and other features associated with the CRBG flows. The potential affect and impact of these factors on the CRBG groundwater system can range from benign to profound. Understanding the impact and influence of these factors on CRBG aquifer is critically important to accurately interpreting the behavior of CRBG groundwater systems. These factors are discussed below.

3.2.2.1 Stratigraphic relationships

In relatively undisturbed, intact CRBG rocks the primary aquifer hosting strata are interflow zones at the contacts between successive flood basalt flows. In such cases, dense flow interiors are impermeable, or nearly so, making them effective barriers to groundwater movement between successive interflow zones. They are effective barriers to groundwater movement between interflow zones because, although jointed, the joints are effectively closed by secondary clay and zeolite mineralization and lithostatic pressure. Because these aquifers and aquicludes (or aquitards) are controlled by stratigraphic layering one must consider the extent and orientation of these layers when considering the occurrence and movement of groundwater through CRBG aquifers.

The following bullets review factors that effect the extent and orientation of stratigraphic layers, and hence aquifers and aquicludes, in CRBG aquifers.

- First, CRBG stratigraphic units are only rarely perfectly horizontal. Almost everywhere they occur these units (or layers) are inclined by at least one degree (commonly more) from horizontal. Interflow zones (aquifers) and flow interiors (aquicludes) within these units are oriented the same way as the stratigraphic units. Any inclination from horizontal of CRBG layers (and the aquifers within them) will impart a dip which influence up gradient and down gradient movement controls on any groundwater within these zones. In effect, groundwater confined within CRBG interflow zones will move down-dip through these layers in response to gravity and the inclination of the interflow zone pathway.
    - This has a profound impact on potential groundwater movement in the project area because the uplift of the Blue Mountains has imparted a pronounced north to northwest oriented dip in all CRBG layers in the project area (Figures 15, 16, and 17).
- Although CRBG flows are laterally widespread, they do eventually terminate because the molten lava from which they form always has a finite extent. Where basalt flows end

(e.g., flow edges) the dense flow interior which separates overlying and underlying interflow zones terminates, allowing hydrologic connection between these successive layered aquifers.

  - On the stratigraphic member level available mapping allows us identify the location of flow edges in the project area and location of areas where successive layered aquifers may be in hydrologic connection. One such area is in Asotin Creek where the uppermost Grande Ronde Basalt unit, N_2, pinches out.

- Incision into and through CRBG flows, forms “erosional windows” into deeper CRBG flows. These windows disrupt the lateral continuity of flow interiors, allowing the creation of potential flow pathways connecting successive interflow zone aquifers. These erosional windows also act to terminate lateral continuity of interflow zones, limiting the extent of aquifers hosted by them.

  - Erosional windows are common throughout the project area, being formed by the many deep canyons incised into and through the upland surfaces lying between the Blue Mountains and the Snake River (Figures 15, 16, 17, and 18). The orientation and depth of these canyons will have a profound effect on the lateral continuity of shallower aquifers and the locations of potential recharge and discharge areas from CRBG aquifers.

- Presence of interbedded sediments (e.g., members of the Ellensburg Formation) may locally influence the direction and rate of groundwater flow. The physical characteristics and lateral extent (facies relationships) of the sediments within these interbeds may allow the interbed to act as either an aquifer or aquitard.

  - These sediment interbeds are relatively rare in the Tucannon River and Pataha Creek drainages and consequently, not expected to exert a significant influence on groundwater movement and occurrence. However, they are common in the Saddle Mountains Basalt (upper CRBG) in the Asotin Creek drainage and may exert an important influence of groundwater occurrence and distribution in this area.

3.2.2.2 Folds

Folds (primarily anticlinal and monoclinal folds) have been noted to affect the occurrence and movement of groundwater through CRBG aquifers (e.g., Newcomb 1965, 1969; Gephart and others, 1979; Lite and Grondin, 1988; USDOE, 1988; Packard and others, 1996). In many cases, folds have been identified as groundwater barriers or impediments that either block or restrict lateral groundwater movement through the CRBG aquifer system (e.g., Newcomb, 1969; USDOE, 1988). During the process of folding, slippage parallel to the layers (CRBG flows) will occur, in part, to accommodate structural shortening. An analogy for this process is seen when a deck of playing cards are flexed and the individual cards slip past one another to accommodate the flexure. The tighter the flexure, the greater the “intercard” slippage. In folds, this type of flexural slip typically occurs within CRBG interflow zones (Newcomb, 1969; Price, 1982; Anderson, 1987) which are the mechanically weakest “layers” in the CRBG. The effects of this flexural slip on CRBG interflow zones range from minor shearing to nearly complete destruction (production of fault shatter breccia/gouge material) and is directly related to the intensity and magnitude of deformation (Price, 1982; Anderson, 1987). This process also impacts the original hydraulic characteristics of interflow zones, reducing or even destroying the permeability of these features (Newcomb, 1969).

The available geologic mapping for the project area suggests that folds in the immediate vicinity of the Asotin Creek, Tucannon River, and Pataha Creek drainages are typically broad, open, gentle structures. Therefore, we infer that these folds do not generally form significant barriers to groundwater movement. However, as noted earlier a very large amplitude anticline separates the headwaters area of Asotin Creek from the Grande Ronde River drainage. This fold may form a barrier to groundwater movement between the two drainages.

3.2.2.3 Faults

The presence of faults in the CRBG has been identified as a feature that can potentially impact groundwater movement (Newcomb 1960; 1961, 1965, 1969; Gephart and others, 1979; Oberlander and Miller, 1981; Lite and Grondin, 1988; U.S. DOE, 1988; Johnson and others, 1993; Packard and others, 1996). Faults can impact CRBG aquifers in a number of ways, including:

- Forming barriers to the lateral and vertical movement of groundwater
- Providing vertical pathways (of varying length) for groundwater movement allowing otherwise confined CRBG aquifers to be in direct hydrologic communication
- Exposing CRBG interflow zones, creating local opportunities for aquifer recharge and/or discharge.

The ability of faults to affect CRBG aquifers in a variety of ways reflects the potential for both lateral and vertical heterogeneities in the physical characteristics of fault zones. For example, the degree of secondary alteration and mineralization along a fault zone may vary. Complete alteration and/or mineralization of fault shatter breccias and gouge zones would “heal” these features and produce rock of very low permeability. Variations in the completeness of this process would produce hydrologic heterogeneities along the trace of the fault. Even if a fault zone is completely healed by secondary alteration and mineralization, renewed movement (displacement) on the fault could produce new permeability within the healed shatter breccia (e.g., USDOE, 1988; Johnson and others, 1993). Therefore depending on the physical characteristics of the fault zone, a fault can be a barrier to, or a pathway for, groundwater movement through the CRBG.

A number of both local and regional faults cross-cut the project area, especially in the Blue Mountains and adjacent uplands. From the information compiled to-date for this assessment, it is not clear if any of these faults affect groundwater movement and occurrence. However, in the nearby Walla Walla Basin a number of faults mapped in the eastern portion of the Basin (e.g., College Place, Mill Creek, Reser, Promontory Point Faults) are known to influence the behavior of CRBG aquifers by generally forming barriers to flow (Newcomb, 1965; CH2M HILL, 1997, 1999). It seems likely that at least portions of the faults mapped in the project area have the potential to influence groundwater movement.

3.2.2.4 Feeder dikes

Source vents for many CRBG lava flows are located in the project area, being especially common in the Asotin Creek drainage. Studies of the exposed portions of CRBG vents (Swanson and others, 1975; Camp, 1981; Reidel and Tolan, 1992; Reidel and others, 1994; Self and others, 1997) have found that CRBG lava flows were erupted from 6 to +30 mile-long (10 to +50 km-long) linear fissure systems. The surface expressions of vent features associated with CRBG fissure systems are relatively small in comparison to the enormous size of CRBG flows.

Erosion has exposed portions of the subsurface "plumbing" of these linear fissure systems. CRBG fissures commonly have a near vertical orientation and are filled with solidified lava. This feature is referred to as a dike or feeder dike. CRBG dikes range from <5ft to > 100ft- wide (Swanson and others, 1975, 1979a, 1979b). The basalt which solidified within a dike often displays horizontal columnar jointing, with the columns bending upward in the center of wider dikes producing a "herring-bone" pattern. Dike margins are typically marked by a narrow (0.1 ft to 0.2 ft-wide) glassy selvage.

CRBG dikes found within the project area are most common above the forks in Asotin Creek. In this area dikes for the upper Grande Ronde basalt and the Roza Member of the Wanapum Basalt are the most common. They generally have a north-south to northwest-southeast orientation. Because of their large lateral extent (extending many miles across country), their great depth (going entirely through the CRBG), and their being filled by basalt having the physical characteristics of dense flow interiors, dikes may form significant barriers or impediments to lateral groundwater movement because they extend across large areas.

3.2.2.5 Secondary alteration

Secondary alteration and mineralization of CRBG interflow zones can radically change their physical characteristics which, consequently, can degrade their ability to serve as aquifers. The most common form of secondary alteration are paleosols developed on CRBG flow tops. If a sufficiently long hiatus occurred between emplacement of CRBG flows, weathering and chemical breakdown of the glassy vesicular flow top will occur and lead to soil formation (paleosol). This process typically alters and destroys the original physical texture of a portion of the flow top as well as most of its original permeability. The extent of the flow top involved, and degree to which these paleosols are developed varies tremendously. Factors controlling their development are thought to be duration of interval before flow top is covered by the next CRBG flow, absence of sediment cover, and environmental conditions (e.g., climate, vegetation, paleogeography, etc.). After the emplacement and burial of the CRBG flows, secondary minerals (e.g., silica, cryptocrystalline quartz, calcite, zeolite, pyrite, clay minerals, etc.) can partially to completely fill existing void spaces within interflow zones. Process(es) by which precipitation of these minerals occurs can be very complex and is dependent on a host of variables including groundwater hydrochemistry, groundwater mobility/mixing rates, groundwater residence time, and local geothermal regime (USDOE, 1988). The net effect of secondary mineralization on CRBG interflow zones is a reduction, ranging from slight to total, in the permeability of these zones.

3.2.3 Potentiometric levels

Potentiometric (water level) maps for individual CRBG aquifers or groups of aquifers within the Columbia Basin and project area are available, but problematic. Maps prepared by the USGS for regional studies, while useful in providing general potential flow directions, are limited because they are compiled from well data collected from wells open to different parts of the aquifer system and/or from wells open to multiple aquifers. In fact, in the nearby Walla Walla Basin, both Newcomb (1965) and Mac Nish and Barker (1976) cautioned that the validity of some of the water level data used to generate potentiometric maps was suspect due to well construction. They found that the most common problem in measuring water levels in the region was the fact that most wells are open to multiple aquifers, and therefore water level data from them represents a composite (or average) of all aquifers the well is open to.

Given this limitation on the available mapping, one can still use the maps compiled to-date to at least identify general groundwater flow directions in CRBG aquifers underlying the project area. From these maps it is clear that groundwater in these aquifers generally flows from the Blue Mountains to the north and northwest into the Columbia Basin. Groundwater flow in the shallower aquifers, especially those hosted by the upper N_2 Grande Ronde and and Wanapum Basalt will be effected by canyons which cut into and through these shallower aquifers. When this occurs, these canyons may deflect groundwater flow to discharge points in these canyons. In some cases these canyons also may act as recharge points for CRBG aquifers (interflow zones) present on, or just below, the canyon floors. Deeper N_2 Grande Ronde, and other deeper Grande Ronde aquifers may not be effected by these canyons except in headwater areas where these geologic units crop out.

3.2.4 Recharge and discharge

This section presents a brief review of likely recharge and discharge conditions for the aquifers underlying the project area. Note, this is largely informed speculation as little or no direct work has been done to address this in the project area.

Shallow (a few tens up to approximately 1000 feet thick) basalt aquifers occurring beneath the uplands lying between the Blue Mountains and the Snake River probably receive little significant recharge. Comparing geomorphology to basalt interflow distribution shows that if one traces the interflow zones which host groundwater in the shallower basalts underlying these uplands in an up-dip direction (generally to the south and southeast) one will find them truncated by canyons and ravines before these strata reach higher elevation, higher precipitation, areas in the Blue Mountains. By cropping out in lower precipitation areas, on essentially semiarid canyon walls, one would suspect little or no significant recharge of these shallow, upland aquifers. Discharge from these low yield aquifers will most likely occur in spring lines on canyon walls. Typically these springs will form where canyons truncate an inclined, water-bearing interflow zone which is dipping towards the canyon. Generally these aquifers are hosted by the Wanapum Basalt, and to a lesser degree the upper part of the N_2 Grande Ronde Basalt.

Basalt units which generally are at or below the most deeply eroded canyons, those of the Tucannon River and Pataha Creek are inferred to be recharged where their hosting interflow zones project up-dip and either crop out in the bottoms of major perennial stream valleys or in the well watered Blue Mountains highlands. Generally these aquifers are hosted by the lower part of the N_2 Grande Ronde Basalt, the R_2 Grande Ronde Basalt, and the N_1 Grande Ronde basalt. Water which enters these aquifers as recharge moves down-dip away from the Blue Mountains. Depending on depth of incision and local structural uplifts (folds or faults) aquifers in the upper part of this Grande Ronde aquifer system (most likely N_2) may at least locally discharge to streams, or the suprabasalt aquifer in deeply incised canyons. Except where such features occur though, we infer that once water gets into these deeper aquifers there is little or no opportunity for it to naturally discharge from these deeper aquifers. Faults probably affect groundwater occurrence and movement in this system. Unfortunately little or no information has been found yet (if it even exists) upon which we can draw any specific conclusions.

3.2.5 Water quality and temperature

Up-to-date water quality data for the CRBG aquifer system in the project area was not found for this assessment. However, based on trends summarized in USDOE (1988) sodium, calcium, chloride, sulfate, fluoride, and iron (to name some of the main constituents of CRBG aquifer waters) as well as dissolved gases are expected to increase with depth below ground surface. Water quality constituent concentrations also are expected to be relatively higher in parts of the aquifer system where lateral aquifer continuity is limited and/or where recharge is slow. One of the main dissolved gases found in the CRBG west of the project area, methane, is not expected to be common in the project area because of the inferred absence of the source rocks for methane, early Tertiary (55 to 40 million years old) sediments, beneath the CRBG in the project area.

An up-to-date set of CRBG aquifer water temperature data also was not found during this assessment. However, like water quality data, water temperature also is expected to increase with depth below the ground surface. The geothermal gradient for the Columbia Basin is at least 1^{o} F increase per 50 feet of depth over the mean annual temperature. In addition, the geothermal gradient may be higher near at least some of the faults cross-cutting the project area and where deeper, pre-CRBG rocks are found at or near the surface.

3.2.6 Ellensburg Formation sediment interbeds

Each of the Ellensburg members can be considered as a hydrostratigraphic unit because they do influence groundwater occurrence and movement (e.g., Gephart and others, 1979; USDOE, 1988; Whiteman and others, 1994; Hansen and others, 1994; Wozniak, 1995; Packard and others, 1996). However, like the Ringold Formation hydrostratigraphic unit, the Ellensburg hydrostratigraphic units are highly variable, displaying a range of physical properties which potentially effect aquifer conditions. Where they are composed of coarse-grained epiclastic sediments they can potentially host significant, usable quantities of groundwater. However, were an Ellensburg unit consists of fine-grained sediments, it may form an aquitard. Future work could refine the distribution of fine- and coarse-grained sediments within individual Ellensburg Formation hydrostratigraphic units.

Section 4: Conclusions

4.1 Conceptual model

Based on our review of the limited hydrologic data available, geologic mapping, well characteristics, and our general knowledge of Columbia Basin hydrogeology we can construct a general conceptual model of aquifers underlying the project area. Using the information presented herein, this conceptual groundwater model consists of three basic components: (1) an geographically limited suprabasalt sediment aquifer system that displays a high degree of continuity with surface water, (2) basalt aquifers isolated by deeply incised canyons and restricted to upland areas, and (3) more widespread basalt aquifers generally lying below the bottoms of the most deeply incised canyons. These systems are summarized in the following bullets and diagrammatically on Figure 24.

- The suprabasalt aquifer system generally is interpreted to be a very localized flow system. Since it largely is restricted to relatively narrow canyons and valleys, groundwater flow through it is limited to those same valleys. Depending on local stream gradient, depth of incision, channel position, and stream flow we suspect that water movement back and forth between the suprabasalt aquifer and surface streams is relatively common. In addition, we suspect that there probably is a component of seasonality to flow in this aquifer, with aquifer recharge (from surface waters) most common during winter and spring high flows, and aquifer discharge (as baseflow to streams) most common in the summer and early autumn dry seasons. Additional controls on where streams contribute to suprabasalt aquifer recharge and gain water back from this aquifer probably also includes depth to bedrock below valley fill sediment, width of the valley, and channel position in the valley. Possible interaction between this aquifer and underlying basalt aquifers is reviewed below.
    - Yields from wells in this aquifer vary widely, but generally seem to be less than 200 gpm.
    - The one notable exception to this will likely be in the immediate vicinity of the City of Asotin where the suprabasalt aquifer is likely hosted by coarse, permeable, Pleistocene Cataclysmic Flood deposits
- The available well data suggests there are multiple, low yield basalt aquifers occurring beneath the uplands lying between the Blue Mountains and the Snake River. Comparing geomorphology to basalt interflow distribution shows that probable recharge of these low yield aquifers is small, which is probably why they are low yield.
    - Basically, if one traces the interflow zones which host groundwater in the shallower basalts underlying these uplands in an up-dip direction (generally to the south and southeast) one will find them truncated by canyons and ravines before these strata reach higher elevation, higher precipitation, areas in the Blue Mountains.
    - By cropping out in lower precipitation areas, on essentially semi arid canyon walls, one would suspect little or no significant recharge of these shallow, upland aquifers.

Consequently, aquifers occurring in these strata will not contain significant volumes of groundwater, being low yield aquifers.

- To identify the depths of new wells that will likely tap into these low recharge, low yield aquifers one should simply examine topographic conditions south and southeast of the well. Generally, the well should be drilled and open to depths below the deepest canyon in that direction to minimize the chances of building a low yield low recharge well.

- Discharge from these low yield aquifers will most likely occur in spring lines on canyon walls. Typically these springs will form where canyons truncate an inclined, water-bearing interflow zone which is dipping towards the canyon.

Based on the available geologic maps and well pumping information, wells in upland areas generally less than 500 feet to as much as 1000 feet deep are interpreted to tap into these low yield aquifers (Figure 24). The specific depths of these aquifers will depend on the depth of canyon incision in up-dip directions. These low yield aquifers generally are hosted by the Wanapum Basalt and the upper few hundred feet of the N2 Grande Ronde Basalt. These aquifers rarely yield more than 50 to 100 gpm.

- The third basic aquifer system in the project area is interpreted to be associated with basalt units which generally are found at and below the most deeply eroded canyons, those of Asotin Creek, the Tucannon River, and Pataha Creek. Generally these aquifers are:

  - Hosted by the lower part of the N_2 Grande Ronde Basalt (if present, it is absent from the lower part of Asotin Creek), the R_2 Grande Ronde Basalt, and the N_1 Grande Ronde basalt.

  - Inferred to be recharged where their hosting interflow zones project up-dip and either crop out in the bottoms of major perennial stream valleys or in the well watered Blue Mountains highlands (Figure 24). Water which enters these aquifers as recharge then moves down-dip away from the Blue Mountains. Depending on depth of incision and local structural uplifts (on folds or faults) aquifers in the upper part of this Grande Ronde aquifer system (most likely N_2) may at least locally discharge to streams, or the suprabasalt aquifer in deeply incised canyons. Except where such features occur though, we infer that once water gets into these deeper aquifers there is little or no opportunity for it to naturally discharge from these deeper aquifers.

  - Faults and feeder dikes may affect groundwater occurrence and movement in this system. Unfortunately little or no information has been found yet (if it even exists) upon which we can draw any specific conclusions about which faults potentially act as barriers to groundwater flow, which might act as pathways to groundwater flow, and which, if any, might facilitate the movement of deep warm water to the surface.

  - The anticline located along the southern edge of the Asotin Creek drainage may form at least a partial hydrologic barrier, separating this area from the adjacent Grande Ronde River valley. If so, potential deep aquifer water production in this area also may be limited because this structure could restrict or limit potential recharge to these aquifers.

This aquifer system may be capable of sustaining wells which can produce in excess of 500 gpm. However, since only a few high yield wells penetrate it in the project area it is difficult to predict with any certainty how this aquifer would respond to increased development. Also, in the absence of much deep well information there is essentially no information available upon which to assess deep aquifer water quality and temperature.

Of these three basic aquifer systems we infer the later one to offer the most potential for long-term sustainable development. This is because it probably is being recharged in the Blue Mountains. However, given that, it might still be possible to pump parts of this aquifer at rates greater than natural recharge can sustain. The shallower part of the basalt aquifer system, the part broken up by canyons incised into the uplands areas, has little potential for significant recharge. The suprabasalt aquifer system, although relatively small, probably sees significant amounts of recharge because of its close proximity to surface waters. However, that proximity also suggests that it rapidly discharges to these same surface streams. Given that, future use of these shallow sediment aquifers will have to be done in such a manner so as to not have an adverse impact on stream flows.

4.2 Recommendations

This section presents some basic recommendations for filling data gaps identified during the course of the assessment and possible approaches to future aquifer recharge efforts done as part of future groundwater storage efforts.

4.2.1 Filling data gaps

The available data, while providing a good basis for an initial assessment of project area hydrogeologic conditions, lacks some of the detail necessary to provide a basis for comprehensive planning and management and for site specific projects. Additional geologic information is needed to better constrain subsurface geology, including identifying the distribution of geologic units and aquifers. CRBG aquifer hydrologic property data also is generally lacking and needs to be collected.

For the shallower parts of the aquifer system the most cost effective way to begin filling gaps in our understanding of aquifers underlying the project area is to work with well owners (public and private) to collect information from existing and/or new wells. Examples of how this could work include:

- Encourage individual land and well owners (private and public) to have well drillers collect drill cuttings during water well drilling when these drillers are drilling wells for these owners. An experienced CRBG geologist, logging these cuttings, would be able to identify specific units present. As this data is compiled a far better interpretation of subsurface CRBG aquifer distribution and continuity would be developed, including identifying the major water-bearing aquifers and physical geologic features (folds, faults, dikes, etc.) that may limit them.

- As with the previous bullet, the most cost effective way to collect aquifer property data is to encourage individual well owners (private and public) to have pump test data collected following construction of new wells and/or when pumps are being rehabilitated. WRIA staff and/or consultants could provide well owners using basic data collection guidelines and begin to compile this data in an effort to better understand aquifer properties.

- Again, using existing wells, and working with cooperative well owners, a comprehensive screening of aquifer water quality and temperature conditions could be implemented. This data will allow better delineation of aquifer continuity and recharge, including in conjunction with surface water data, evidence for surface water-groundwater continuity.

For each of these activities a parallel effort focusing on mapping the distribution of the major aquifer hosting units in the subsurface should be implemented. This subsurface mapping would be based on existing information, limited field mapping, and updated as new information (as outlined in the bullets above) is collected. The benefit of this mapping is that it can be used to place all aquifer data collected into a common framework. This framework gives watershed planners a common baseline for identifying aquifer conditions, allows them to differentiate between different parts of the aquifer system, and forms the fundamental scientific basis for interpreting areas of aquifer recharge, discharge, groundwater flow paths, and barriers to groundwater flow.

Filling gaps in our understanding of the deeper Grande Ronde parts of the aquifer system can be, at least in part, done with the same approach noted above. However, given that there currently are few users of this system opportunity for working with well owners may be limited. If planning efforts in a specific area require deeper aquifer knowledge it may become necessary at some point in the future to build a well(s) to collect that information. This would be a very expensive effort. To control the cost of such a project the preparers of this report would encourage WRIA planners to define a very specific set of goals and objectives before going down this road.

4.2.2 Groundwater storage

Based on the review of hydrogeologic information presented herein, the opportunities for shallow alluvial aquifer storage in the suprabasalt aquifer system probably are limited. This is because this aquifer system is so limited in volume and extent (probably including available potential storage that could be used), that there simply are not that many locations where it could be implemented and have an effect. There may be some opportunity for shallow aquifer storage in the various drainages covered in this assessment, such as tributary canyon runoff capture and field flooding in the winter, but collection of the site-specific information needed to ascertain this was beyond the scope of this assessment and can only be addressed in site specific investigations. Based on our initial observations we suspect that cost effective shallow alluvial aquifer storage opportunities may be better addressed as part of other floodplain and near stream riparian restoration activities that would include some sort of recharge effort as a component of an overall approach.

Storage in deeper basalt aquifers is problematic for any but the largest water users (probably municipalities) because of the cost of injecting water into these aquifers. Such users, if they also have a source of surface water available at least seasonally to use for storage, may be able to develop long-term storage and recovery activities that provide for stable water supplies. For other deep aquifer water users (current and future), future efforts looking at ways to more effectively use deep aquifers should probably focus on identifying those aquifers that appear to be able to support long-term pumping. These efforts would include identifying appropriate well construction for promoting sustainable production and evaluating water production rates that targeted aquifers can sustain. If such aquifers are identified, they may offer opportunities for switching surface water withdrawals in areas of limited supply to groundwater withdrawals.

References Cited

Anderson, J.L., 1987, The structure and ages of deformation of a portion of the southwest Columbia Plateau, Washington and Oregon: Los Angeles, Calif., University of Southern California, Ph.D. dissertation, 272 p.

Bailey, M.M., 1989, Revisions to the stratigraphic nomenclature of the Picture Gorge Basalt Subgroup, Columbia River Basalt Group, *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. 67-84.

Baker, V.R., Bjornstad, B.N., Busacca, A.J., Fecht, K.R., Kiver, E.G., Moody, U.L., Rigby, J.G., Stradling, D.F., and Tallman, A.M., 1991, Quaternary geology of the Columbia Plateau, *in* Morrison, R.B., ed., Quaternary geology of the conterminous United States: Boulder, Colo., Geological Society of America, Geology of North America, v. K-2, p. 215-238.

Baker, V.R., and Nummedal, eds., 1978, The Channeled Scabland—a guide to the geomorphology of the Columbia Basin: Washington, U.S. National Aeronautics and Space Administration, 186 p.

Bauer, H.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: U.S. Geological Survey Water-Resources Investigations Report 88-4108.

Barker, R.A., and Mac Nish, R.D., 1976, Digital model of the gravel aquifer, Walla Walla River Basin, Washington and Oregon: Washington Department of Ecology Water-Supply Bulletin 45, 49 p.

Beeson, M.H., Fecht, K.R., Reidel, S.P., and Tolan, T.L., 1985, Regional correlations within the Frenchman Springs Member of the Columbia River Basalt Group—new insights into middle Miocene tectonics of northwestern Oregon: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 47, no. 8, p. 87-96.

Beeson, M.H., and Tolan, T.L., 1990, The Columbia River Basalt Group in the Cascade Range—a middle Miocene reference datum for structural analysis: American Geophysical Union Journal of Geophysical Research, v. 95, no. B12, p. 19,547-19,559.

Beeson, M.H., and Tolan, T.L., 1996, Field trip guide to Columbia River Basalt intracanyon flows in western Oregon and Washington—Ginkgo, Rosalia, and Pomona flows: Cordilleran Section Meeting of the Geological Society of America, Portland, Oreg., 35 p.

Beeson, M.H., Tolan, T.L., and Anderson, J.L., 1989, The Columbia River Basalt Group in western Oregon—geologic structures and others factors that controlled emplacement patterns, *in* Reidel. S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River Flood Basalt Province: Boulder, Colo., Geological Society of America Special Paper 239, p. 223-246.

Bentley, R.D., 1977, Stratigraphy of the Yakima basalts and structural evolution of the Yakima ridges in the western Columbia Plateau, *in* Brown, E.H., and Ellis, R.C., eds., Geological excursions in the Pacific Northwest: Ellensburg, Wash., Central Washington University, p. 339-390.

Bentley, R.D., Anderson, J.L., Campbell, N.P., and Swanson, D.A., 1980, Stratigraphy and structure of the Yakima Indian Reservation, with emphasis on the Columbia River Basalt Group: U.S. Geological Survey Open-File Report 80-200, 86 p.

Berger, G.W., and Busacca, A.J., 1995, Thermoluminescence dating of late Pleistocene loess and tephra from eastern Washington and southern Oregon and implications for the eruptive history of Mount St. Helens: Journal of Geophysical Research, v. 100, no. B11, p. 22.361-22.374.

Black, R.F., 1979, Clastic dikes of the Pasco Basin, southwestern Washington: Richland, Wash., Rockwell Hanford Operations, RHO-BWI-C-64, 64 p.

Bretz, J.H., Smith, H.T.U., and Neff, G.E., 1956, Channeled Scabland of Washington—new data and interpretations: Geological Society of America Bulletin, v. 67, p. 957-1049.

Busacca, A.J., and McDonald, E.V., 1994, Regional sedimentation of late Quaternary loess on the Columbia Plateau—sediment source areas and loess distribution patterns, *in* Lasmanis, R., and Cheney, E.S., eds., Regional geology of Washington state: Washington Department of Natural Resources, Division of Geology and Earth Resources Bulletin 80, p. 181-190.

Busacca, A.J., Nelstead, K.T., McDonald, E.V., and Purser, M.D., 1992, Correlation of distal tephra layers in loess in the Channeled Scabland and Palouse of Washington state: Quaternary Research, v. 37, no. 3, p. 281-303.

Byerly, G., and Swanson, D.A., 1978, Invasive Columbia River basalt flows along the northwestern margin of the Columbia Plateau, north-central Washington (abs.): Boulder, Colo., Geological Society of America Abstracts with Programs, v. 10, no. 3, p. 98.

CH2M HILL, 1997, Aquifer Storage and Recovery Task Report: Consultants report prepared for City of Walla Walla.

CH2M HILL, 1999, City of Walla Walla Aquifer Storage and Recovery Project Pilot Test Report: Consultants report prepared for City of Walla Walla.

Camp, V.E., 1981, Geologic studies of the Columbia Plateau; Part 2, Upper Miocene basalt distribution, reflecting source locations, tectonism, and drainage history in the Clearwater embayment, Idaho: Boulder, Colo., Geological Society of America Bulletin, Part 1, v. 92, no. 9, p. 669-678.

Chitwood, L.A., 1994, Inflated basalt lava—examples of processes and landforms from central and southeast Oregon: Oregon Department of Geology and Mineral Industries, Oregon Geology, v. 56, no. 1, p. 11-21.

Fecht, K.R., Lindsey, K.A., Bjornstad, B.N., Horton, D.G., Last, G.V., and Reidel, S.P., 1999, Clastic injection dikes of the Pasco Basin and vicinity: Richland, Wash., Bechtel Hanford, Inc., BHI-01103.

Fecht, K.R., Reidel, S.P., and Tallman, A.M., 1987, Paleodrainage of the Columbia River system on the Columbia Plateau of Washington state—a summary, *in* Schuster, J.E., ed., Selected papers on the geology of Washington state: Washington Department of Natural Resources, Division of Geology and Earth Resources Bulletin 77, p. 219-248.

Finneamore, S.L., Self, S., and Walker, G.P.L., 1993, Inflation features in lava of the Columbia River basalts: American Geophysical Union, EOS, v. 74, no. 43, p. 555.

Gephart, R.E., Arnett, R.C., Baca, R.G., Leonhart, L.S., and Spane, F.A., Jr., 1979, Hydrologic studies within the Columbia Plateau, Washington—an integration of current knowledge: Richland, Wash., Rockwell Hanford Operations, RHO-BWI-ST-5, 547 p.

Grolier, M.J., and Bingham, J.W., 1971, Geologic map and sections of part of Grant, Adams, and Franklin Counties, Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-589, scale 1:62,500.

Grolier, M.J., and Bingham, J.W., 1978, Geology of parts of Grant, Adams, and Franklin Counties, east-central Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Bulletin 71, 91 p.

Gulick, C.W., 1994, Geologic map of the Pullman 1:100,000 quadrangle, Washington-Idaho: Washington State Department of Natural Resources, Division of Geology and Earth Resources Open File Report 94-6, 22 p.

Hammett, H.H., and Blinman, E., 1977, Late Quaternary geology of the lower Granite Reservoir area, lower Snake River, Washington: Geological Society of America Map and Chart Series MC-18, 1 sheet, scale 1:24,000.

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

Ho, A.M., 1999, Emplacement of a large lava flow – the Ginkgo flow of the Columbia River Basalt Group: University of Oregon, Eugene, Ph.D Dissertation, 188 p.

Ho, A.M., and Cashman, K.V., 1997, Temperature constraints on a flow of the Columbia River Basalt Group: Geology, v. 25, p. 403-406.

Hon, K., Kauahikaua, J., Denlinger, R., and Mackay, K, 1994, Emplacement and inflation of pahoehoe sheet flows—observations and measurements of active lava flows on Kilauea volcano, Hawaii: Geological Society of America Bulletin, v. 106, p. 351-370.

Hooper, P.R., 1985, A case of simple magma mixing in the Columbia River Basalt Group: the Wilbur Creek, Lapwai, and Asotin flows, Saddle Mountains Formation: Contributions to Mineralogy and Petrology, v. 91, no. 1, p. 66-73.

Hooper, P.R., and Swanson, D.A., 1990, The Columbia River Basalt Group associated volcanic rocks of the Blue Mountains province. *In* Walker, G.W., editor, Geology of the Blue Mountains region of Oregon, Idaho, and Washington – Cenozoic geology of the Blue Mountains region: U.S. Geological Survey Professional Paper 1437, p. 63-99.

Hooper, P.R., and Webster, G.D., 1982, Geology of the Pullman, Moscow West, Colton and Uniontown 7 ½ minute quadrangles, Washington and Idaho: Washington State Department of Natural Resources, GM-26, scale 1:62500.

Hooper, P. R.; Knowles, C. R.; Watkins, N. D., 1979, Magentostratigraphy of the Imnaha and Grande Ronde basalts in the southeast part of the Columbia Plateau: American Journal of Science, v. 279, no. 7,p. 737-754

Hooper, P. R.; Webster, G. D.; Camp, V. E., 1985, Geologic map of the Clarkston 15 minute quadrangle, Washington and Idaho: Washington Division of Geology and Earth Resources Geologic Map GM-31, 11 p., 1 plate, scale 1:48,000.

Huntting, M. T., 1942, Geology of the middle Tucannon area: State College of Washington Master of Science thesis, 33 p.

Johnson, V.G., Graham, D.L., and Reidel, S.P., 1993, Methane in Columbia River Basalt aquifers—isotopic and geohydrologic evidence for deep coal-bed source in the Columbia Basin, Washington: American Association of Petroleum Geologists Bulletin, v. 77, no. 7, p. 1192-1207.

Kienle, C.F., 1980, Geologic reconnaissance of parts of the Walla Walla and Pullman, Washington and Pendleton, Oregon 1x2 degree AMS quandrangles: Seattle, Washington, Consultants Report to the U.S Army Corps of Engineers, Seattle District, 76 p., 3 plates, scale 1:250000.

Keszthelyi, L., and Self, S., 1996, Some thermal and dynamical considerations for the emplacement of long lava flows: American Geophysical Union Chapman Conference on long lava flows, Abstract Volume, p. 36-38.

Kiver, E.P., Rigby, J.G., Strandling, D.F., Breckenridge, R.M., McDonald, E.V., and Busacca, A.J., 1989, The Channeled Scabland—Lake Missoula floods and sediments and loess stratigraphy, *in* Joseph, N.L., and others, eds., Geologic guidebook for Washington and adjacent areas: Washington Department of Natural Resources, Division of Geology and Earth Resources Information Circular 86, p. 305-346.

Lindbergh, J.W., 1989, A numerical study of cooling joint width and secondary mineral infilling in four Grande Ronde Basalt flows of the central Columbia Plateau, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 169-185.

Lindsey, K.A., Reidel, S.P., Fecht, K.R., Slate, J.L., Law, A.G., and Tallman, A.M., 1994, Geohydrologic setting for the Hanford site, south-central Washington, *in* Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest: Geological Society of America Annual Meeting, Seattle, Washington, p. 1C.1-1C.16.

Lite, K.E., Jr., and Grondin, G.H., 1988, Hydrogeology of the basalt aquifers near Mosier, Oregon—a ground water resources assessment: Oregon Department of Water Resources Ground Water Report 33, 119 p.

Long, P.E., Murphy, M.T., and Self, S., 1991, Time required to emplace the Pomona flow, Columbia River basalt: American Geophysical Union EOS, v. 72, no. 44, p. 602.

Long, P.E., and Wood, B.J., 1986, Structures, textures, and cooling histories of Columbia River basalt flows: Geological Society of America Bulletin, v. 97, p. 1144-1155.

Mac Nish, R.D., and Barker, R.A., 1976, Digital simulation of a basalt aquifer system, Walla Walla River Basin, Washington and Oregon: Washington Department of Ecology Water-Supply Bulletin 44, 51 p.

Mackin, J.H., 1961, A stratigraphic section in the Yakima Basalt and Ellensburg Formation in south-centra Washington: Washington Division of Mines and Geology Report of Investigations 19, 45 p.

Mangan, M.T., Wright, T.L., Swanson, D.A., and Byerly, G.R., 1986, Regional correlations of Grande Ronde Basalt flows, Columbia River Basalt Group, Washington, Oregon, and Idaho: Geological Society of America Bulletin, v. 97, p. 1300-1318.

McDonald, E.V., and Busacca, A.J., 1989, Record of pre-late Wisconsin floods and of late Wisconsin flood features in the Cheney-Palouse Scabland—Trip C, *in* Joseph, N.L., and others, eds., Geologic guidebook for Washington and adjacent areas: Washington Department of Natural Resources, Division of Geology and Earth Resources Information Circular 86, p. 337-346.

McMillan, K., Long, P.E., and Cross, R.W., 1989, Vesiculation in Columbia River basalts, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 157-168.

Moore, J.G., 1975, Mechanism of formation of pillow lava: American Scientist, v. 63, p. 269-277.
Moore, J.G., Phillips, R.L., Grigg, R.W., Peterson, D.W., and Swanson, D.A., 1973, Flow of lava into the sea, 1969-1971, Kilauea volcano, Hawaii: Geological Society of America Bulletin, v. 84, no. 2, p. 537-546.

Murphy, M.T., Self, S., and Long, P.E., 1997, The lava-flow-front morphology and textures of the Columbia River basalt (abs.): Geological Society of America Abstracts with Programs, v. 29, no. 6, p. 137.

Myers, C.W., and Price, S.M., eds., 1979, Geologic studies of the Columbia Plateau: a status report: Richland, Wash., Rockwell Hanford Operations, RHO-BWI-ST-4.

Myers, C.W., and Price, S.M., eds., 1981, Subsurface geology of the Cold Creek syncline: Richland, Wash., Rockwell Hanford Operations, RHO-BWI-ST-14.

Newcomb, R.S., 1960, Storage of groundwater behind subsurface dams in the Columbia River basalt, Washington, Oregon, and Idaho: U.S. Geological Survey Open-File Report, 31 p.

Newcomb, R.C., 1961, Structural barrier reservoirs of groundwater in the Columbia River basalt: U.S. Geological Survey Professional Paper 424-B, p. B213-B215.

Newcomb, R.C., 1965, Geology and ground-water resources of the Walla Walla River Basin, Washington and Oregon: Washington Department of Conservation, Division of Water Resources Water-Supply Bulletin 21, 151 p, 3 plates.

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

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

Pacific Groundwater Group, 1995, Initial watershed assessment water resources inventory area 32 Walla Walla River watershed: Washington Department of Ecology Open-File Technical Report 95-11, 47 p.

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

Pfaff, V.J., and Beeson, M.H., 1989, Miocene basalt near Astoria, Oregon; geophysical evidence for Columbia Plateau origin, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 143-156.

Price, E.H., 1982, Structural geology, strain distribution, and tectonic evolution of Umtanum Ridge at Priest Rapids Dam, and a comparison with other selected localities within the Yakima Fold Belt structures, south-central Washington: Richland, Wash., Rockwell Hanford Operations, RHO-BWI-SA-138, 197 p.

Reidel, S.P., 1998, Emplacement of Columbia River flood basalt: American Geophysical Union Journal of Geophysical Research, v. 103, no. B11, p. 27,393-27,410.

Reidel, S.P., and Tolan, T.L., 1992, Eruption and emplacement of a flood basalt—an example from the large-volume Teepee Butte Member, Columbia River Basalt Group: Geological Society of America Bulletin, v. 104, no. 12, p. 1650-1671.

Reidel, S.P., Campbell, N.P., Fecht, K.R., and Lindsey, K.A., 1994, Late Cenozoic structure and stratigraphy of south-central Washington, *in* Lasmanis, R., and Cheney, E.S., eds., Regional geology of Washington state: Washington Department of Natural Resources, Division of Geology and Earth Resources Bulletin 80, p. 159-180.

Reidel, S.P., Fecht, K.R., and Cross, R.W., 1982, Constraints on tectonic models for the Columbia Plateau from the age and growth rates of Yakima folds: Proceedings, the 33rd Alaska Scientific Conference, Arctic Division, American Association for the Advancement of Science, v. 12, p. 131.

Reidel, S.P., Fecht, K.R., Hagood, M.C., and Tolan, T.L., 1989a, Tectonic development of the central Columbia Plateau, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 247-264.

Reidel, S.P., Tolan, T.L., Anderson, J.L., Beeson, M.H., Fecht, K.R., Bentley, R.D., and Hooper, P.R., 1989b, The Grande Ronde Basalt, Columbia River Basalt Group—stratigraphic 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: Boulder, Colo., Geological Society of America Special Paper 239, p. 21-53.

Rigby, J.G., Othberg, K.L., Campbell, N.P., Hanson, L.G., Kiver, E.P., Stradling, D.F., and Webster, G.D., 1979, Reconnaissance surficial geologic mapping of the late Cenozoic sediments of the Columbia Basin, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Open File Report 79-3, 94 p., 7 plates, scale 1:250,000.

Ross, M.E., 1989, Stratigraphic relationships of subaerial, invasive, and intracanyon flows of Saddle Mountains Basalt in the Troy Basin, Oregon and Washington, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 131-142.

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

Schmincke, H., -U., 1964, Petrology, paleocurrents, and stratigraphy of the Ellensburg Formation and interbedded Yakima Basalt flows, south-central Washington [Ph.D. thesis]: Baltimore, Maryland, The Johns Hopkins University, 426 p.

Schuster, J.E., 1994, Geologic map of the Clarkston 1:100000 quadrangles: Washington Department of Natural Resources, Division of Geology and Earth Resources, Open-File Report 93-4.

Schuster, J.E., Gulick, C.W., Reidel, S.P., Fecht, K.R., and Zurenko, S., 1997, Geologic map of Washington—southeast quadrant: Washington Department of Natural Resources, Division of Geology and Earth Resources Geologic Map GM-45, 20 p., scale 1:250,000.

Self, S., Finnemore, S., Thordarson, T., and Walker, G.P.L., 1991, Importance of compound lava and lava-rise mechanisms in emplacement of flood basalts: American Geophysical Union EOS, v. 72, no. 44, p. 566-567.

Self, S., Thordarson, T., Keszthelyi, L., Walker, G.P.L., Hon, K., Murphy, M.T., Long, P.E., and Finnemore, S., 1996, A new model for the emplacement of Columbia River basalt as large, inflated pahoehoe lava sheets: Geophysical Research Letters, v. 23, p. 2689-2692.

Self, S., Walker, G.P.L., and Thordarson, T., 1993, How are flood basalt lavas emplaced? A case of the tortoise and the hare (abs.): Canberra, Australia, IAVCEI Abstracts Volume, p. 98.

Shaw, H.R., and Swanson, D.A., 1970, Eruption and flow rates of flood basalts, *in* Gilmour, E.H., and Stradling, D., eds., Proceedings of the second Columbia River basalt symposium: Cheney, Wash., Eastern Washington College Press, p. 271-299.

Smith, G.A., Bjornstad, B.N., and Fecht, K.R., 1989, Neogene terrestrial sedimentation on and adjacent to the Columbia Plateau; Washington, Oregon, and Idaho, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 187-198.

Stoffel, K.L., 1984, Geology of the Grande Ronde lignite field, Asotin County, Washington: Washington Department of Natural Resources, Division of Geology and Earth Resources Report of Investigations 27, 79 p.

Stoffel, K.L., Joseph, N.L., Waggoner, S.J., Gulick, C.W., Korosec, M.A., and Bunning, B.B, 1991, Geologic map of Washington—northeast quadrant: Washington Department of Natural Resources, Division of Geology and Earth Resources Geologic Map GM-39, 36 p., 3 pl.

Swanson, D.A., 1973, Pahoehoe flows from the 1969-1971 Mauna Ulu eruption, Kilauea volcano, Hawaii: Geological Society of America Bulletin, v. 84, no. 2, p. 615-626.

Swanson, D.A., and Wright, T.L., 1978, Bedrock geology of the northern Columbia Plateau and adjacent areas, *in* Baker, V.R., and Nummedal, D., eds., The Channeled Scablands—a guide to the geomorphology of the Columbia Basin, Washington: Washington, D.C., NASA Office of Space Science, Planetary Geology Program, p. 37-57.

Swanson, D.A., and Wright, T.L., 1981, The regional approach to studying the Columbia River Basalt Group, *in* Subbarao, K.V., and Sukheswala, R.N., eds., Deccan volcanism and related basalt provinces in other parts of the World: Geological Society of India Memoir 3, p. 58-80.

Swanson, D.A., Anderson, J.L., Bentley, R.D., Camp, V.E., Gardner, J.N., and Wright, T.L., 1979a, Reconnaissance geologic map of the Columbia River Basalt Group in Washington and adjacent Idaho: U.S. Geological Open-File Report 79-1363, scale 1:250,000.

Swanson, D.A., Wright, T.L., Camp, V.E., Gardner, J.N., Helz, R.T., Price, S.M., Reidel, S.P., and Ross, M.E., 1980, Reconnaissance geologic map of the Columbia River Basalt Group, Pullman and Walla Walla Quadrangles, southeast Washington and adjacent Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1139, scale 1:250,000.

Swanson, D.A., Wright, T.L., and Helz, R.T., 1975, Linear vent systems and estimated rates of magma production and eruption for the Yakima Basalt on the Columbia Plateau: American Journal of Science, v. 275, p. 877-905.

Swanson, D.A., Wright, T.L., Hooper, P.R., and Bentley, R.D., 1979b, Revisions in the stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Tolan, T.L., and Reidel, S.P., 1989, Structure map of a portion of the Columbia River flood-basalt province, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, plate 1, scale 1:500,000.

Tolan, T.L., Campbell, N.P., and Lindsey, K.A., 2000, Exploring the hydrogeology of the Columbia River Basalt Group - a field guide to selected localities in the Columbia Plateau, Washington: Third Washington State Hydrogeology Symposium, October 14-15, 2000, Tacoma, Washington, 66 p.

Tolan, T.L., Reidel, S.P., Beeson, M.H., Anderson, J.L., Fecht, K.R., and Swanson, D.A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Boulder, Colo., Geological Society of America Special Paper 239, p. 1-20.

Tribble, G.W., 1991, Underwater observations of active lava flows from Kilauea volcano, Hawaii: Geology, v. 19, no. 6, p. 633-636.

U.S. Department of Energy (USDOE), 1988, Consultation draft site characterization plan: Washington D.C., Office of Civilian Radioactive Waste Management, U.S. Department of Energy DOE/RW-0164, v. 1-9.

Waitt, R., 1985, Case for periodic, colossal jokuhlaups from Pleistocene glacial Lake Missoula: Geological Society of America Bulletin, v. 96, no. 10, p. 1271-1286.

Washington Public Power Supply System (WPPSS), 1981, Final Safety Analysis Report—WPPSS nuclear project no. 2: Richland, Wash., Washington Public Power Supply System, v. 1-3.

Webster, G.D., Kuhns, M.J.P., and Waggoner, G.L., 1982, late Cenozoic gravels in the Hells Canyon and Lewiston basin, Washington and Idaho, *in* Bonnichsen B. and Breckinridge, R.M., eds., Cenozoic geology of Idaho: Boise, Idaho, Idaho Bureau of Mines and Geology Bulletin 26, p. 669-683.

Whiteman, K.J., Vaccaro, J.J., Gonthier, J.B., and Bauer, H.H., 1994, Hydrological framework and geochemistry of the Columbia Plateau aquifer system in parts of Washington, Oregon, and Idaho: U.S. Geological Survey Professional Paper 1413-B, 73 p.

Wozniak, K.C., 1995, Chapter 2—Hydrogeology, *in* Hydrogeology, groundwater chemistry, and land uses in the lower Umatilla Basin Groundwater Management Area, northern Morrow and

Umatilla Counties, Oregon—Final Review Draft: Salem, Oregon, Oregon Department of Environmental Quality Report, p. 2.1-2.80.

Wright, T.L., Mangan M.T., and Swanson, D.A., 1989, Chemical data for the flows and feeder dikes of the Yakima Basalt Subgroup, Columbia River Basalt Group, Washington, Oregon, and Idaho: U.S. Geological Survey Bulletin 1821, 71 p.

Figures

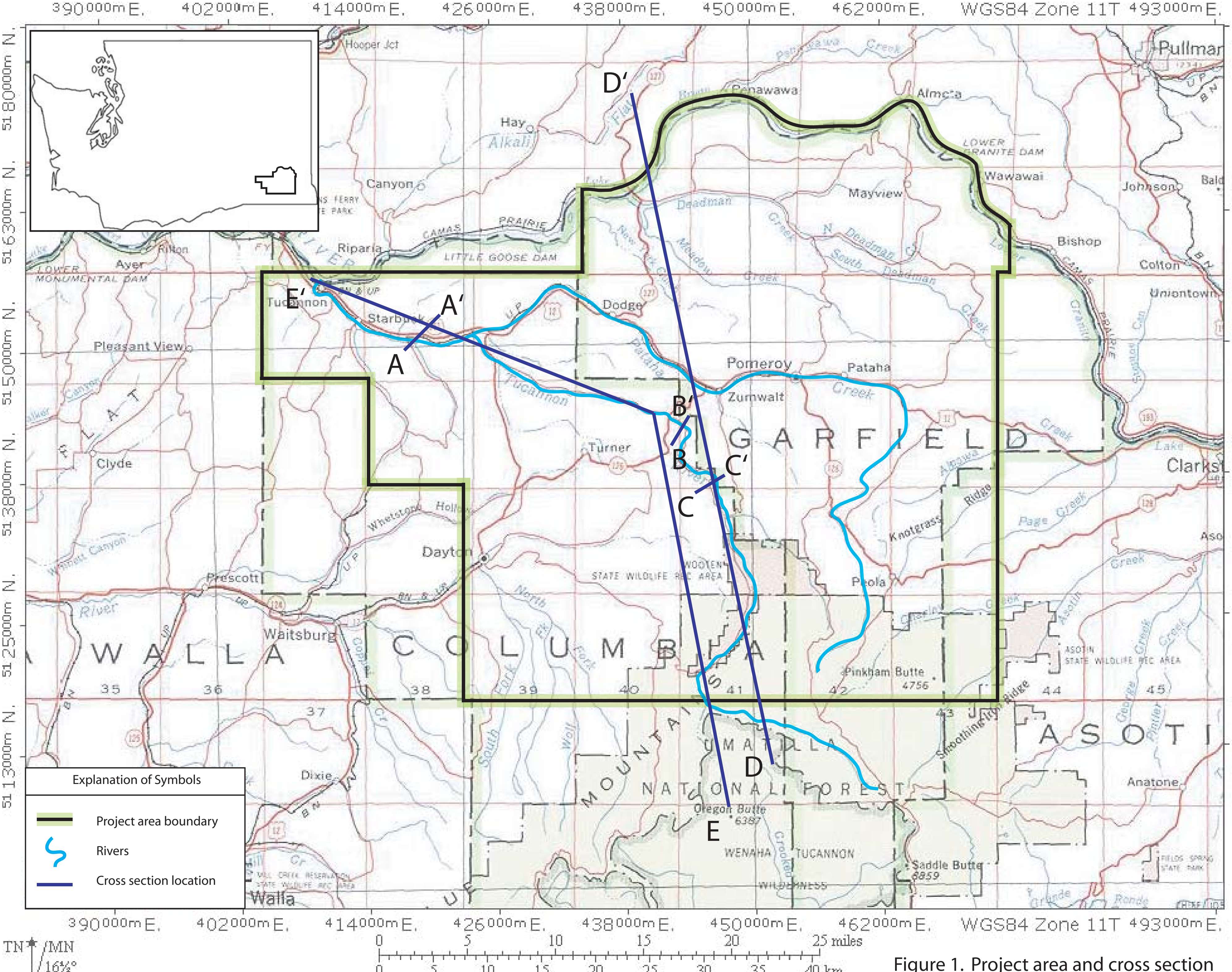


Figure 1. Project area and cross section location map.

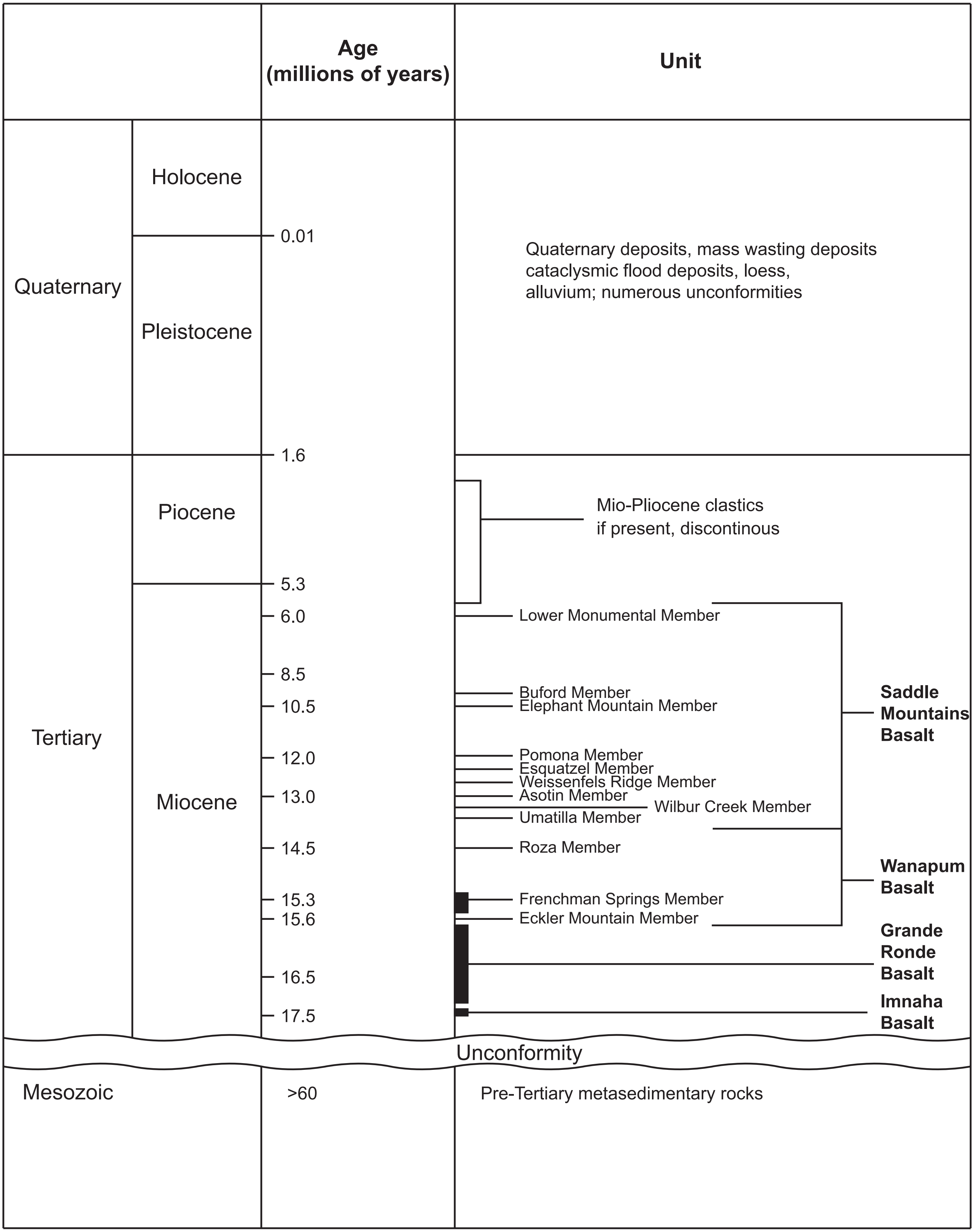


Figure 2. General stratigraphic chart for project area.

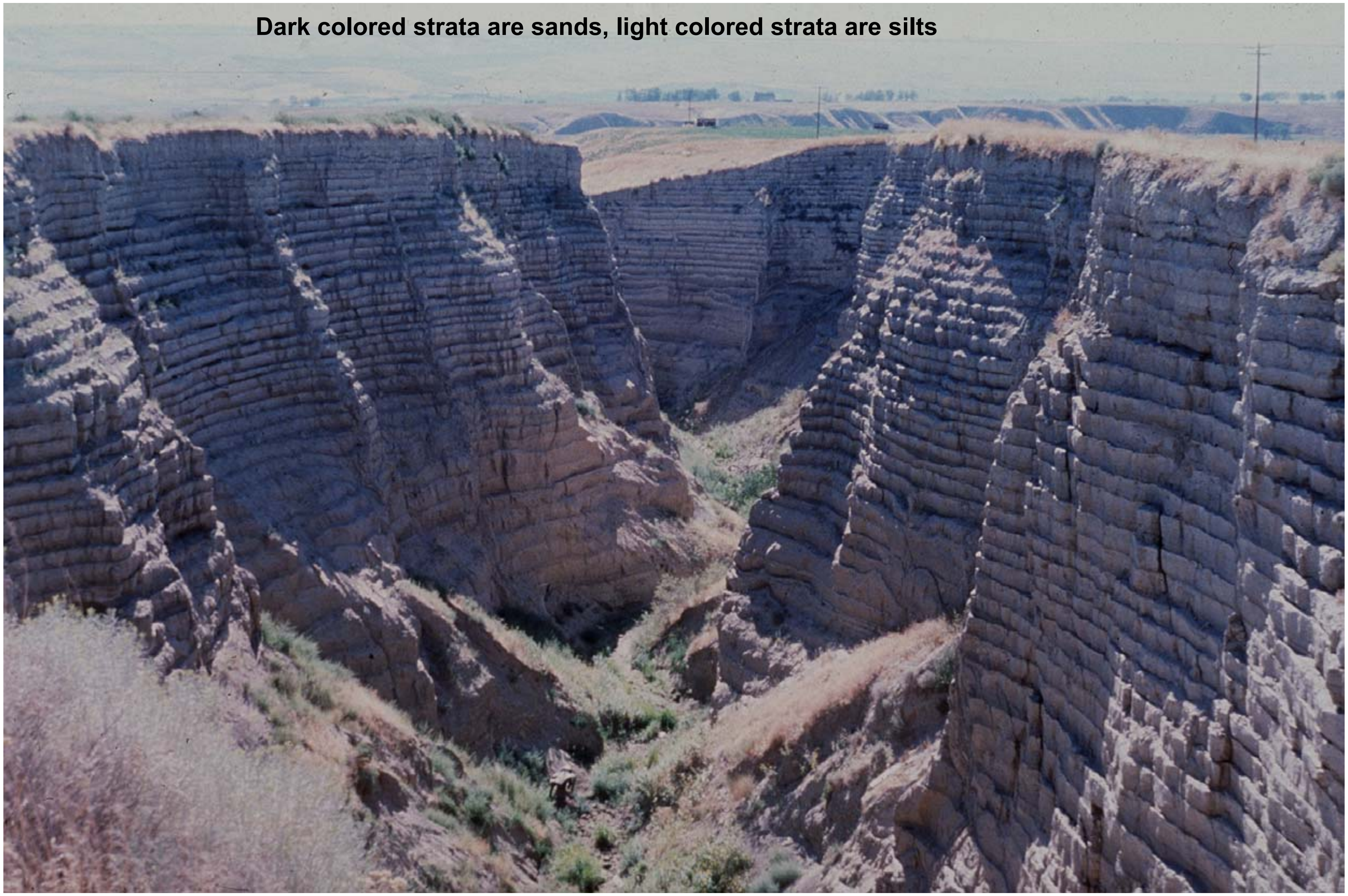


Figure 3. Photograph of Touchet beds showing their well stratified nature.

Figure 4. Photograph of large outcrop of cataclysmic flood gravel.

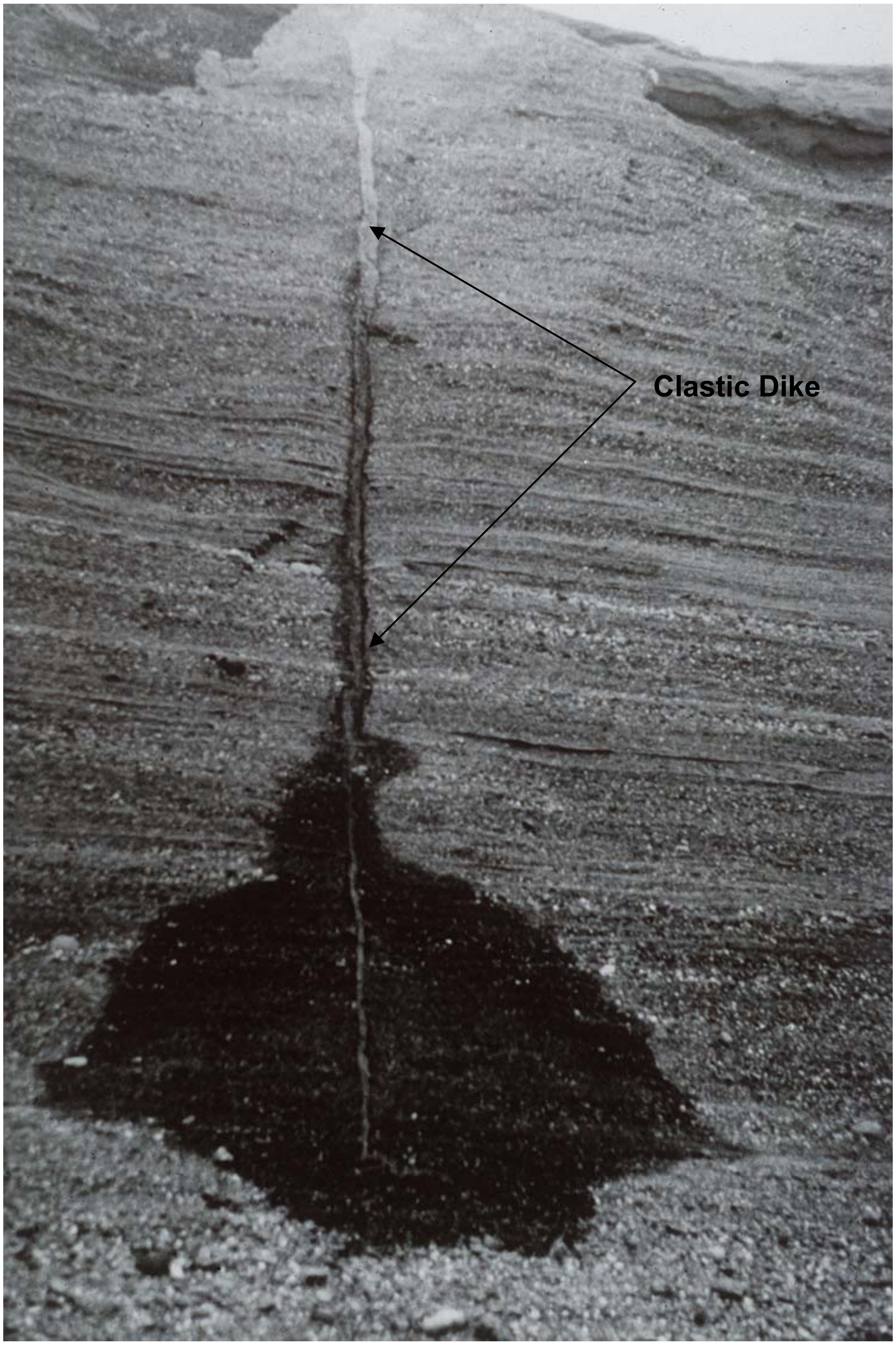


Figure 5. Photograph of clastic dike.

Figure 6. Photograph of loess showing basic massive structure.

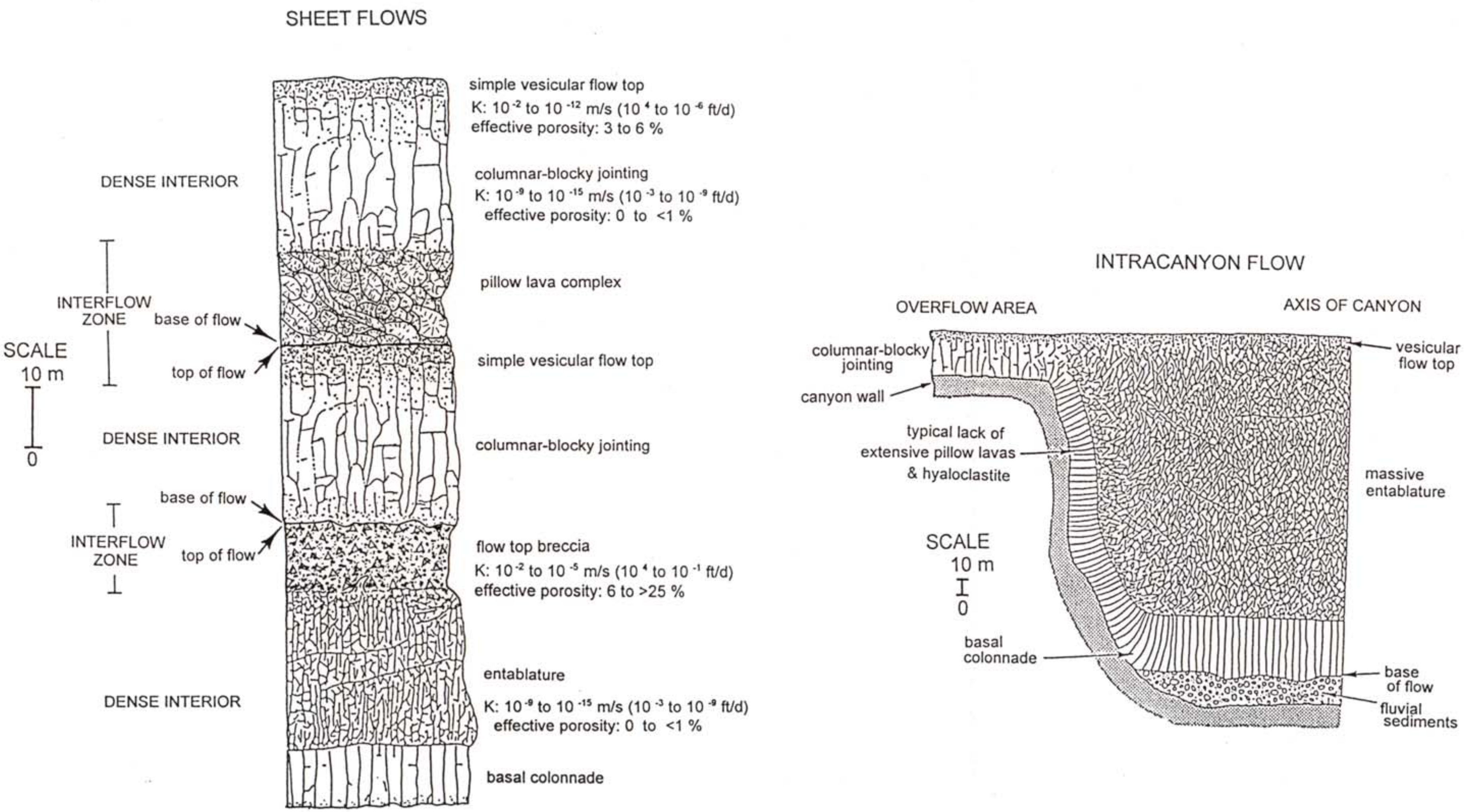


Figure 7. Drawing showing arrangement of major intraflow structures in CRBG sheet and intracanyon flows.

Figure 8. Photograph of typical flow top breccia.

Figure 9. Photograph of regular flow top.

Figure 10. Photograph of columnar jointed flow interior.

Figure 11. Photograph of entablature-colonade jointed flow interior.

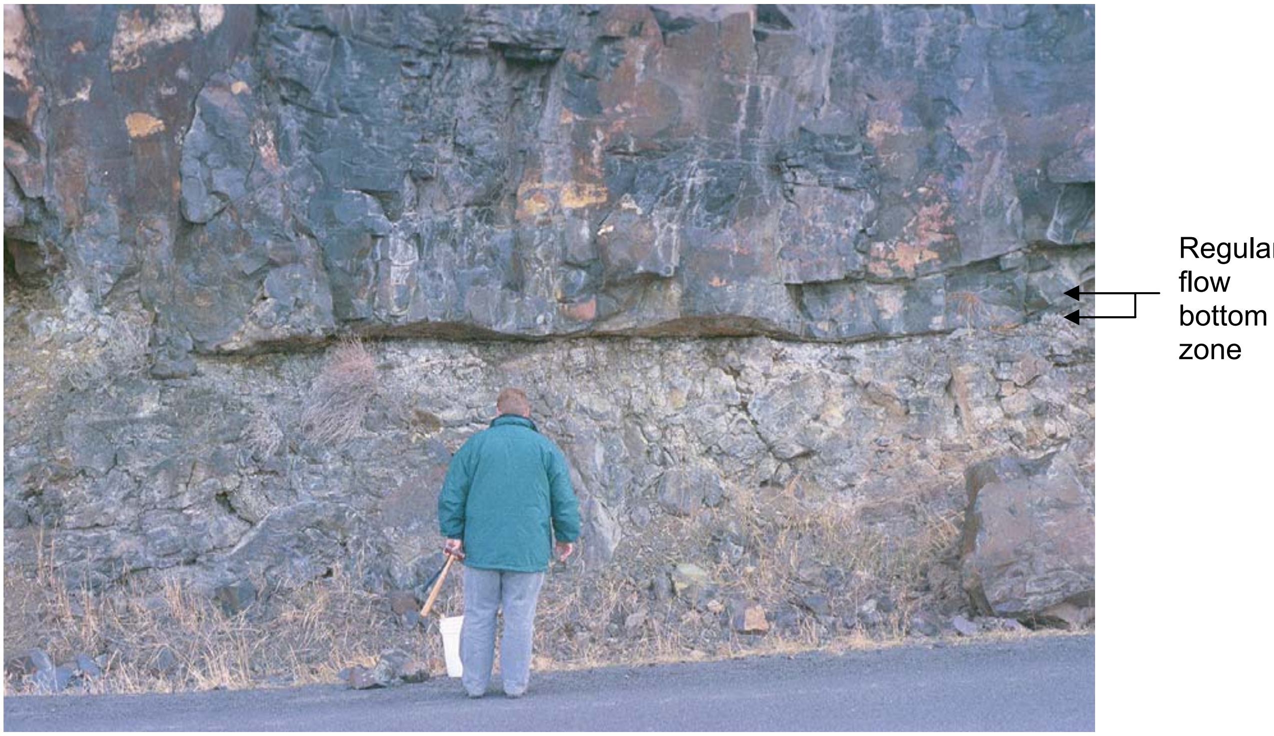


Figure 12. Photograph of regular flow bottom overlying a thin flow top breccia.

Figure 13. Photograph of pillow basalt complex at the base of a CRBG flow.

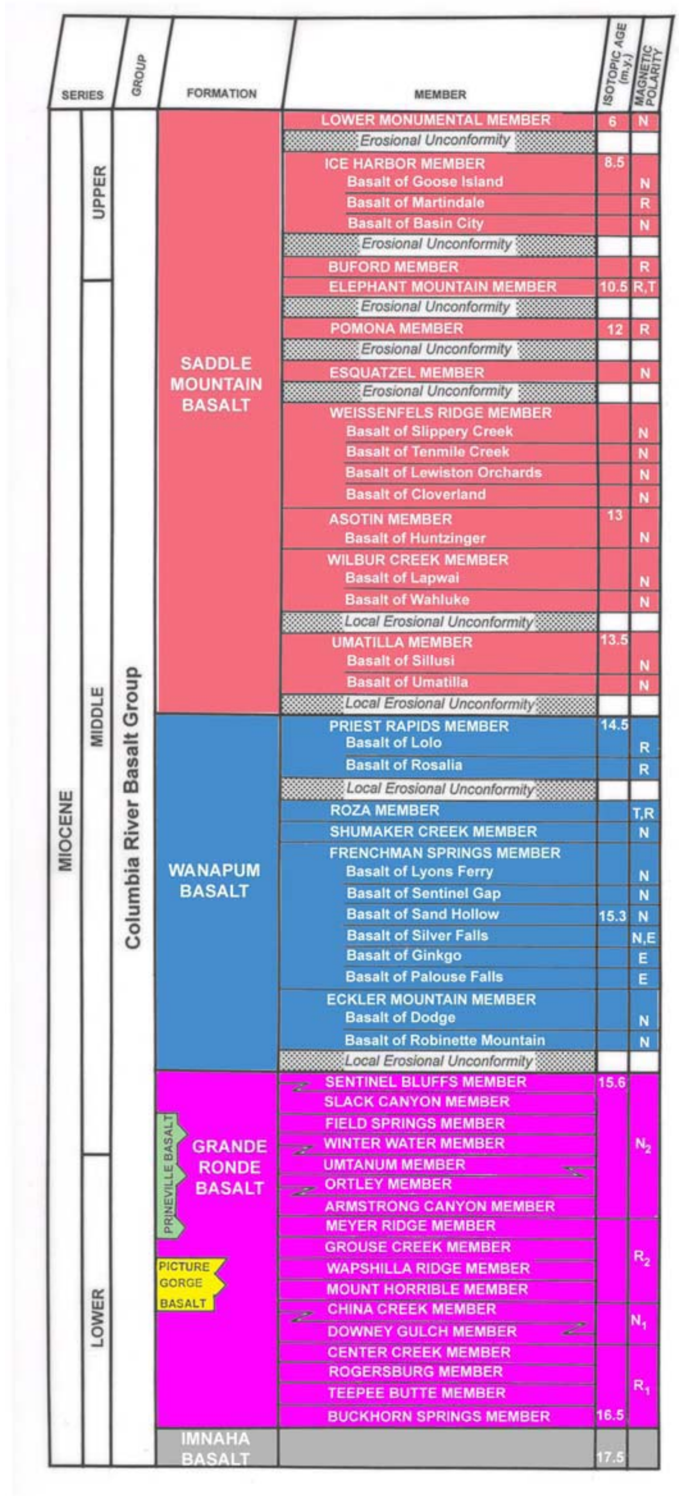
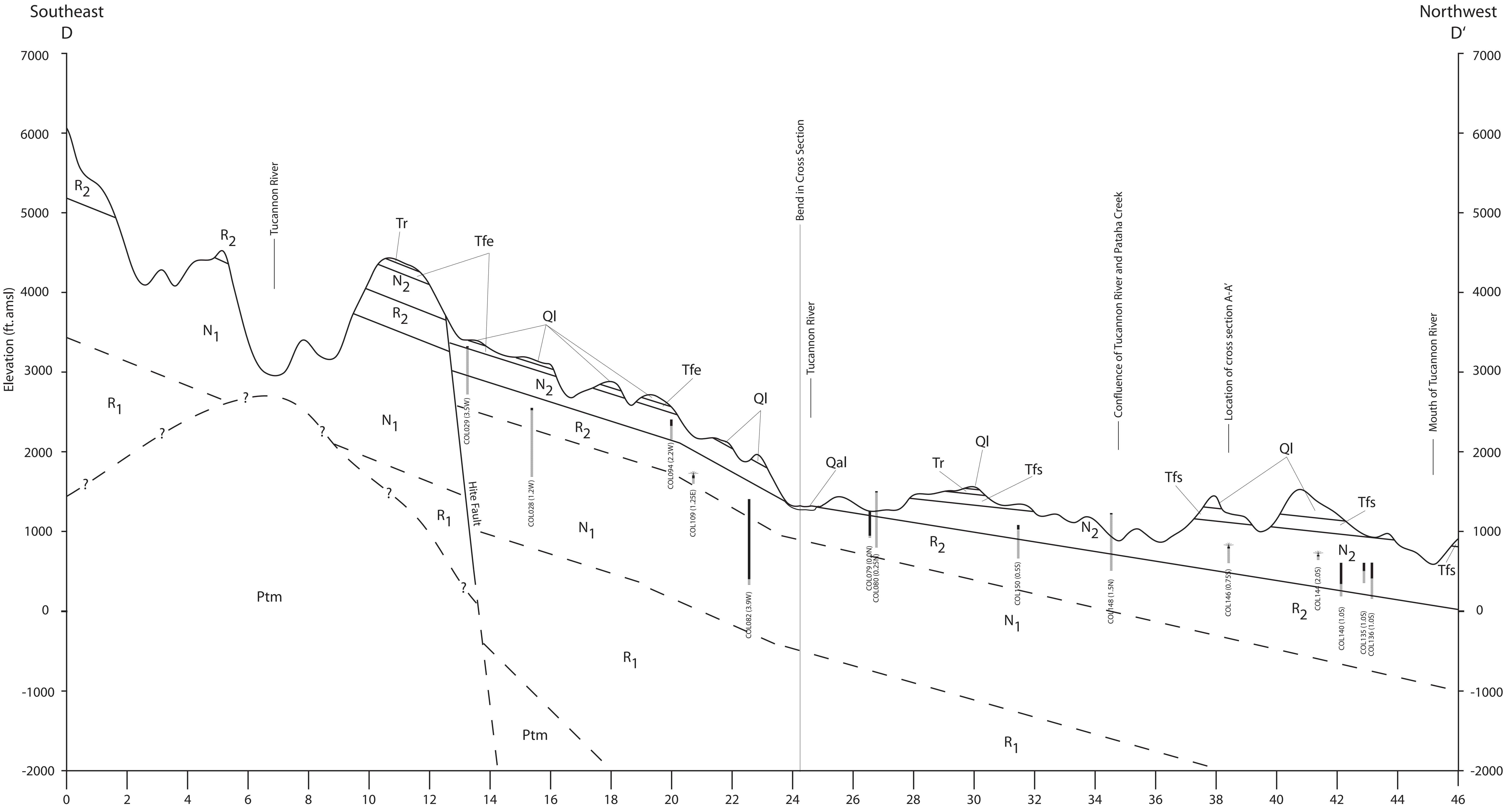


Figure 14. Stratigraphic chart for the Columbia River Basalt Group.

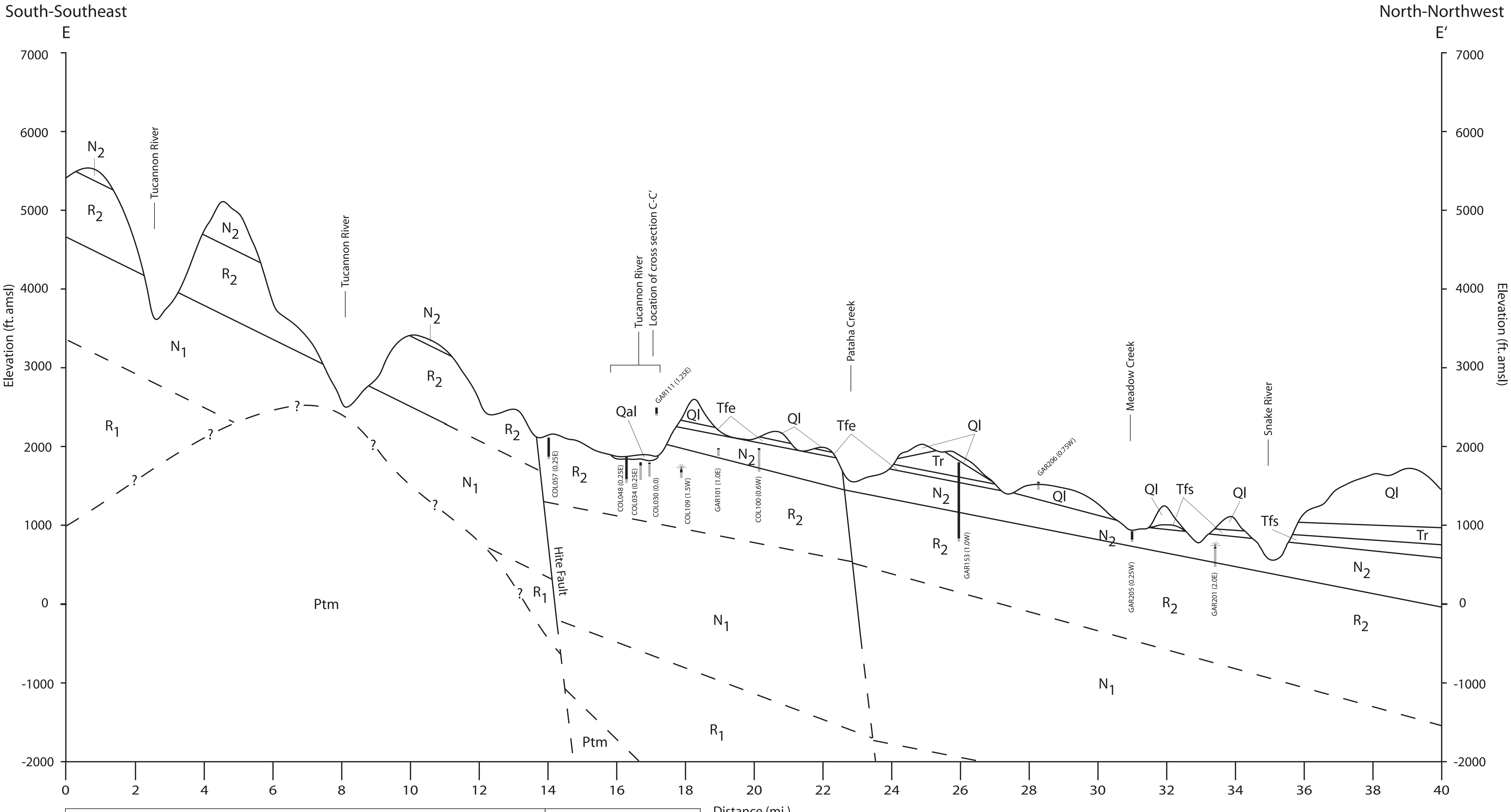


Explanation of Units			
Qal	Quaternary alluvium	R_2	R_2, Grande Ronde Basalt
Ql	Loess	N_2	N_2, Grande Ronde Basalt
Tr	Roza Member, Wanapum Basalt	R_1	R_1, Grande Ronde Basalt
Tfe	Eckler Mountian Member, Wanapum Basalt	N_1	N_1, Grande Ronde Basalt
Tfs	Frenchman Springs Member, Wanapum Basalt	Ptm	Pre-Tertiary Metamorphic

Explanation of Symbols
flowing well
Well casing showing open interval

Vertical Exaggeration = 6.9x

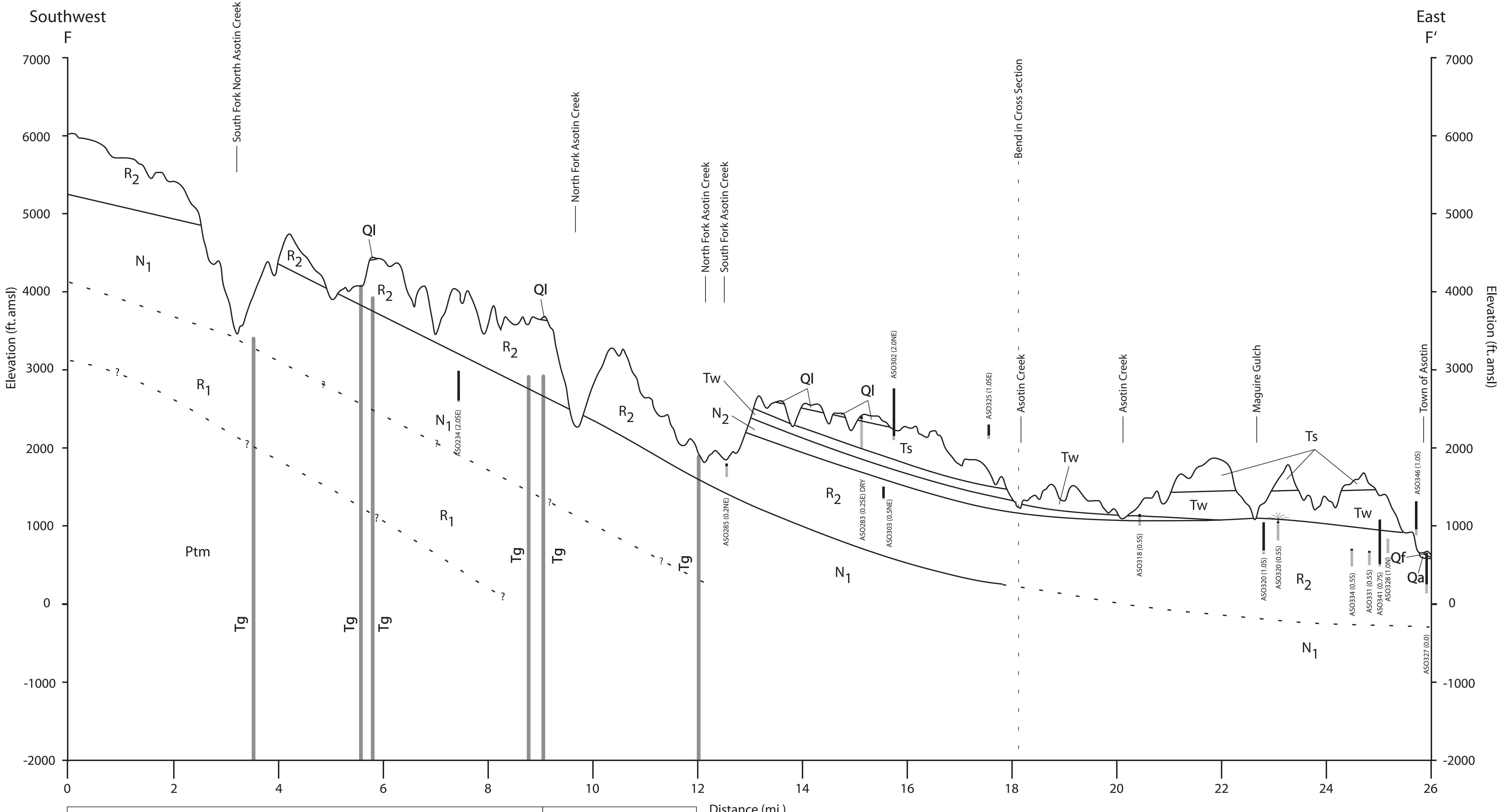
Figure 15. Regional geologic cross section generally following the Tucannon River drainage.



Explanation of Units				Explanation of Symbols
Qal	Quaternary alluvium	R_2	R_2, Grande Ronde Basalt	
Ql	Loess	N_2	N_2, Grande Ronde Basalt	flowing well
Tr	Roza Member, Wanapum Basalt	R_1	R_1, Grande Ronde Basalt	
Tfe	Eckler Mountian Member, Wanapum Basalt	N_1	N_1, Grande Ronde Basalt	Well casing showing open interval
Tfs	Frenchman Springs Member, Wanapum Basalt	Ptm	Pre-Tertiary Metamorphic	

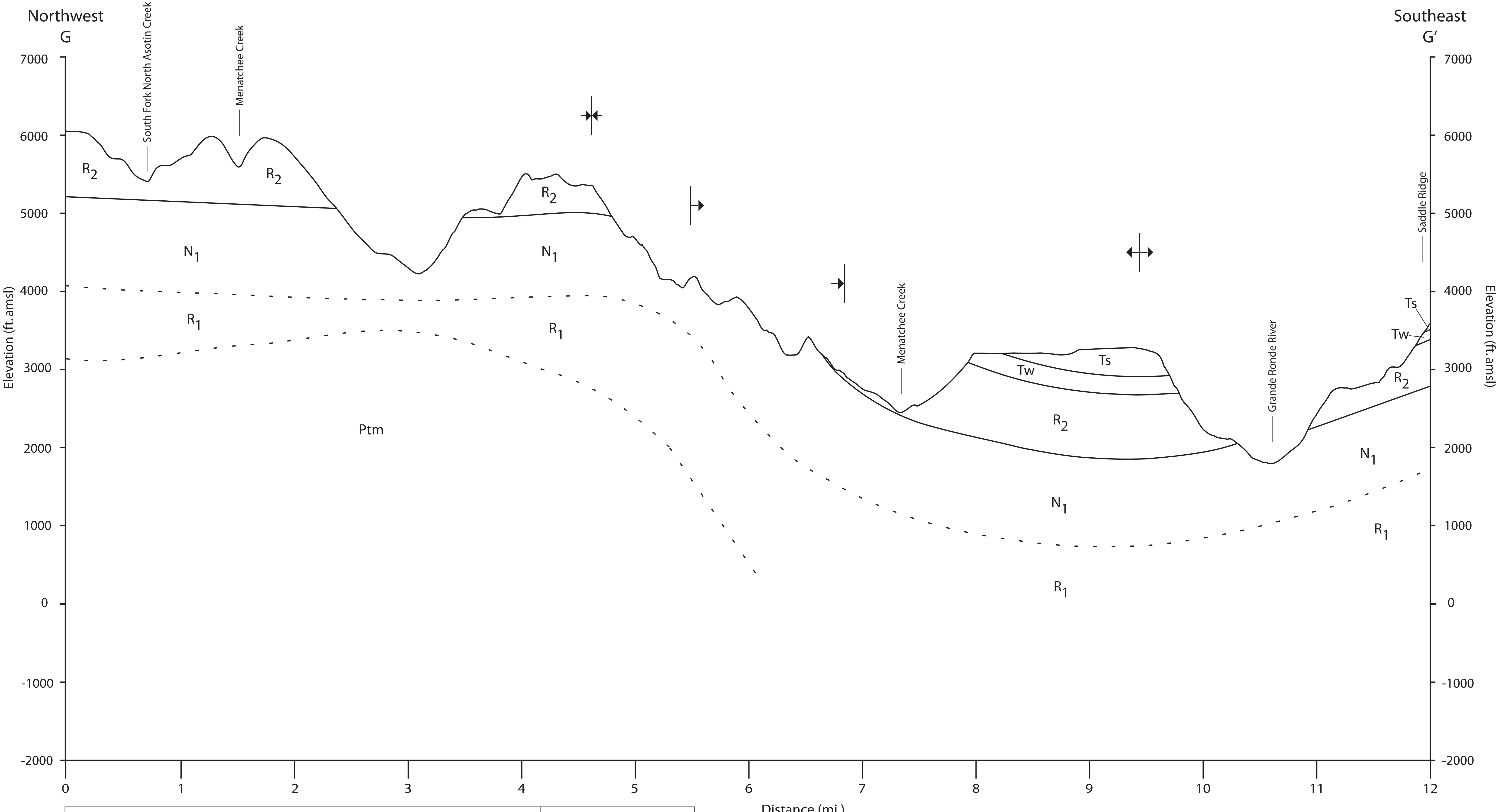
Vertical Exaggeration = 6.2x

Figure 16. Regional geologic cross section from the headwaters of Pataha Creek to the Snake River.



Explanation of Units				Explanation of Symbols
Qal	Quaternary alluvium	R_2	R_2, Grande Ronde Basalt	flowing well
Ql	Loess	N_2	N_2, Grande Ronde Basalt	Well casing showing open interval
Ts	Saddle Mountains Basalt, Undivided	R_1	R_1, Grande Ronde Basalt	
Tw	Priest Rapids Member, Wanapum Basalt	N_1	N_1, Grande Ronde Basalt	
Tg	Grande Ronde Basalt, Feeder Dike Undivided	Ptm	Pre-Tertiary Metamorphic	

Figure 17. Regional geologic cross section form the headwaters of Asotin Creek to the Snake River.



Explanation of Units				Explanation of Symbols
Qal	Quaternary alluvium	R_2	R_2, Grande Ronde Basalt	Syncline
Ql	Loess	N_2	N_2, Grande Ronde Basalt	Monocline, arrow on steeper side
Ts	Saddle Mountains Basalt, Undivided	R_1	R_1, Grande Ronde Basalt	
Tw	Priest Rapids Member, Wanapum Basalt	N_1	N_1, Grande Ronde Basalt	Anticline
Tg	Grande Ronde Basalt, Feeder Dike Undivided	Ptm	Pre-Tertiary Metamorphic	

Figure 18. Regional geologic cross section from the headwaters of Asotin Creek to the Grande Ronde River.

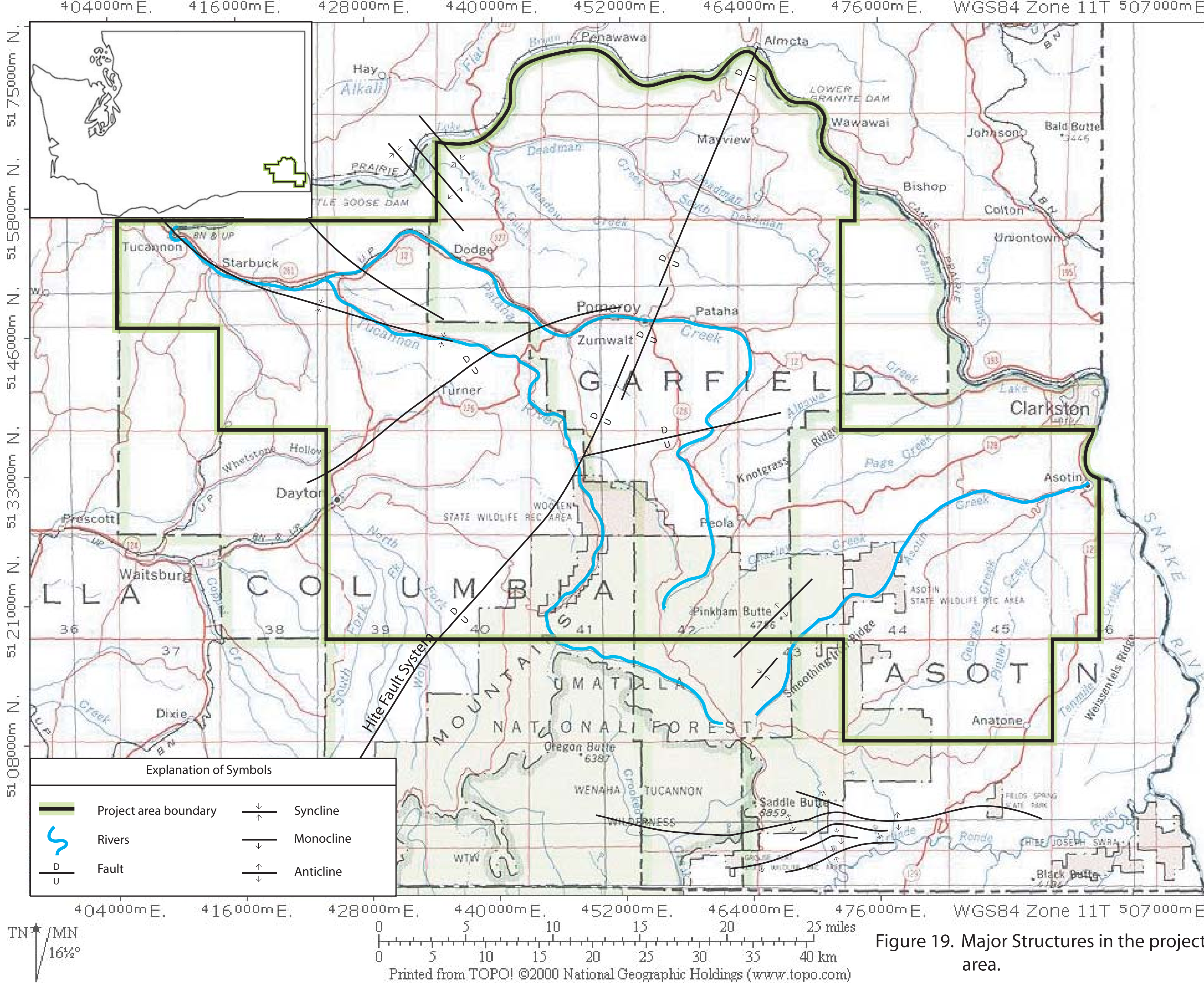


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Figure 19. Major Structures in the project area.

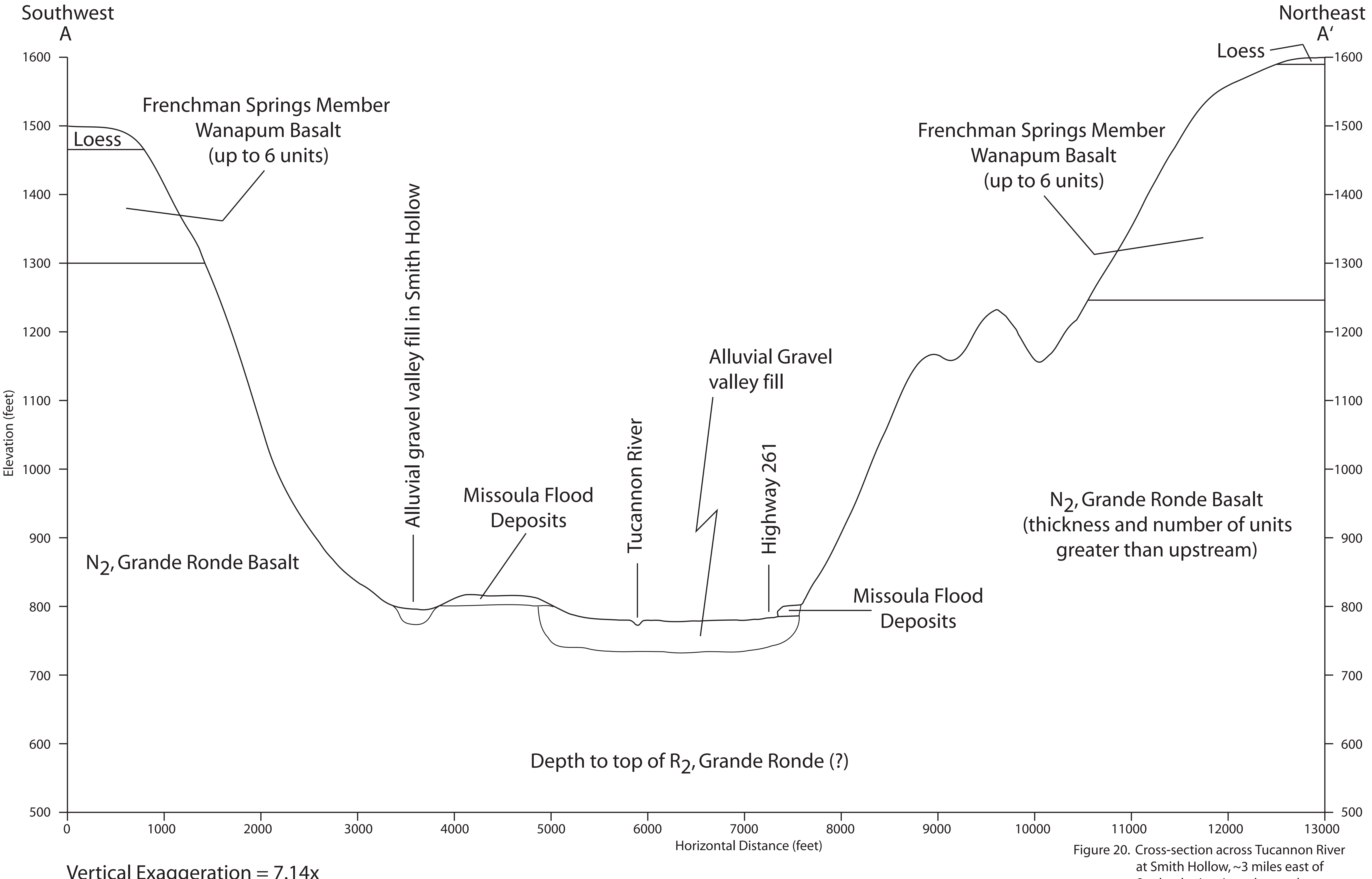


Figure 20. Cross-section across Tucannon River at Smith Hollow, ~3 miles east of Starbuck, view is to the northwest.

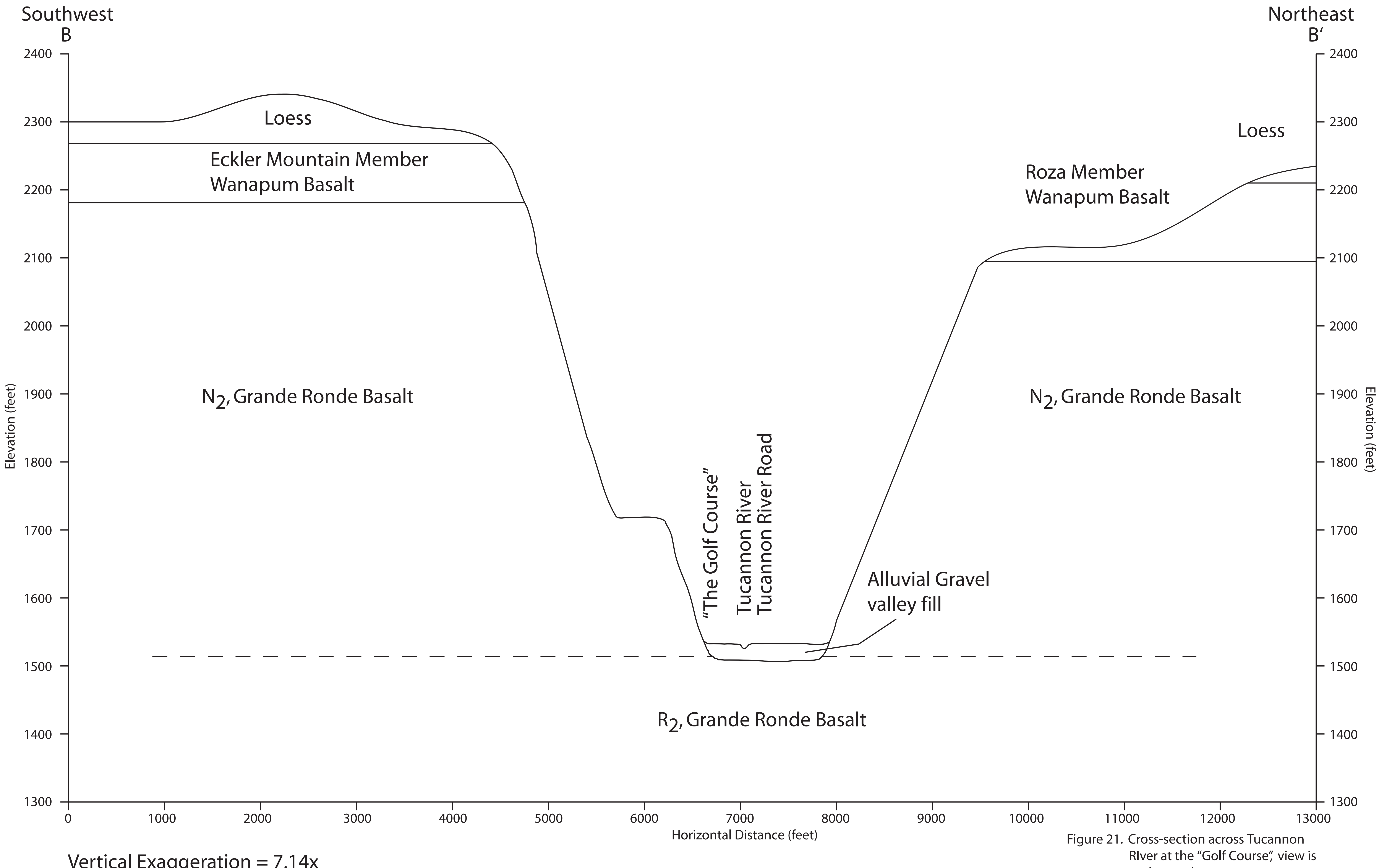


Figure 21. Cross-section across Tucannon RIver at the "Golf Course", view is to the northwest.

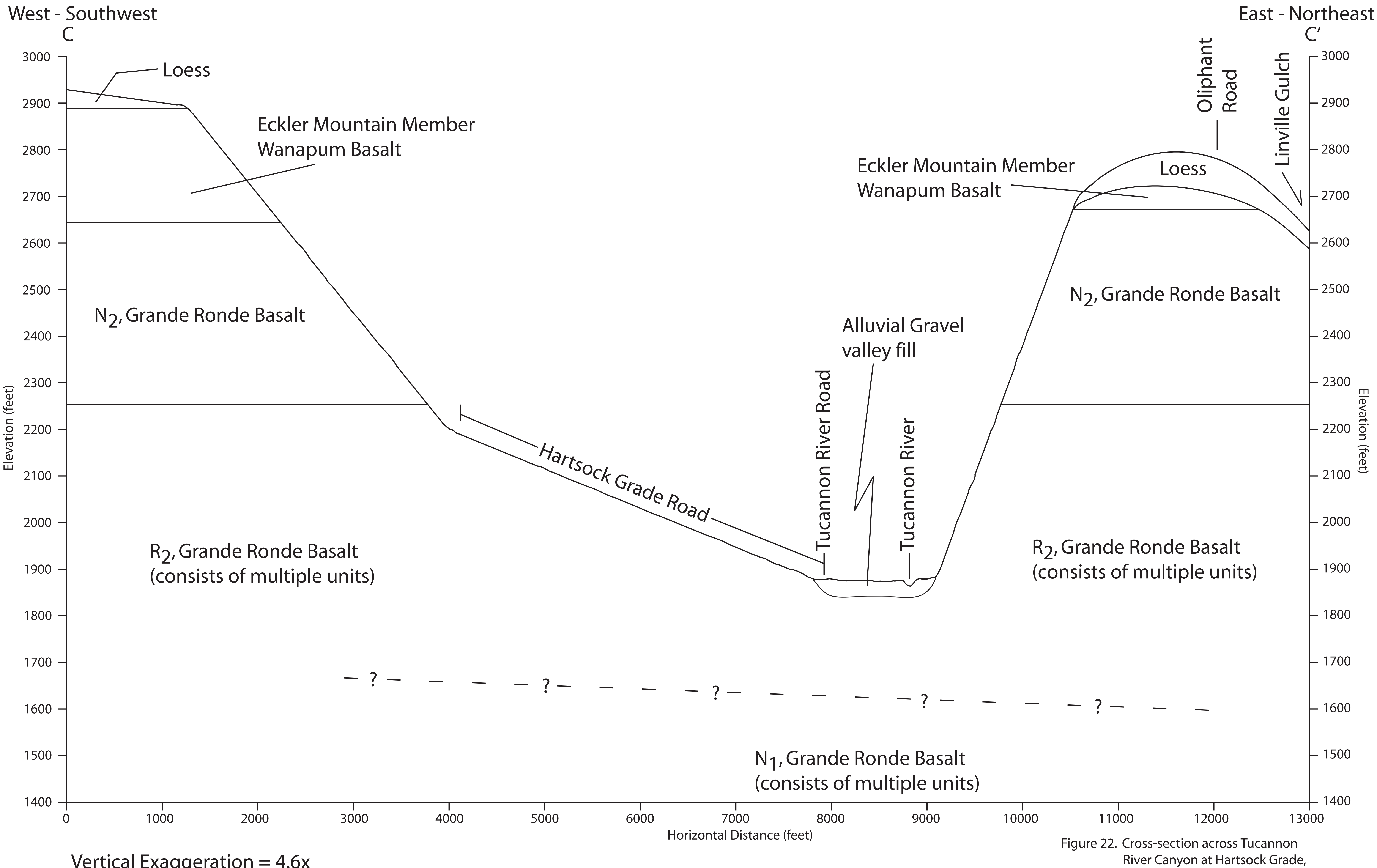


Figure 22. Cross-section across Tucannon River Canyon at Hartsock Grade, view is to the north.

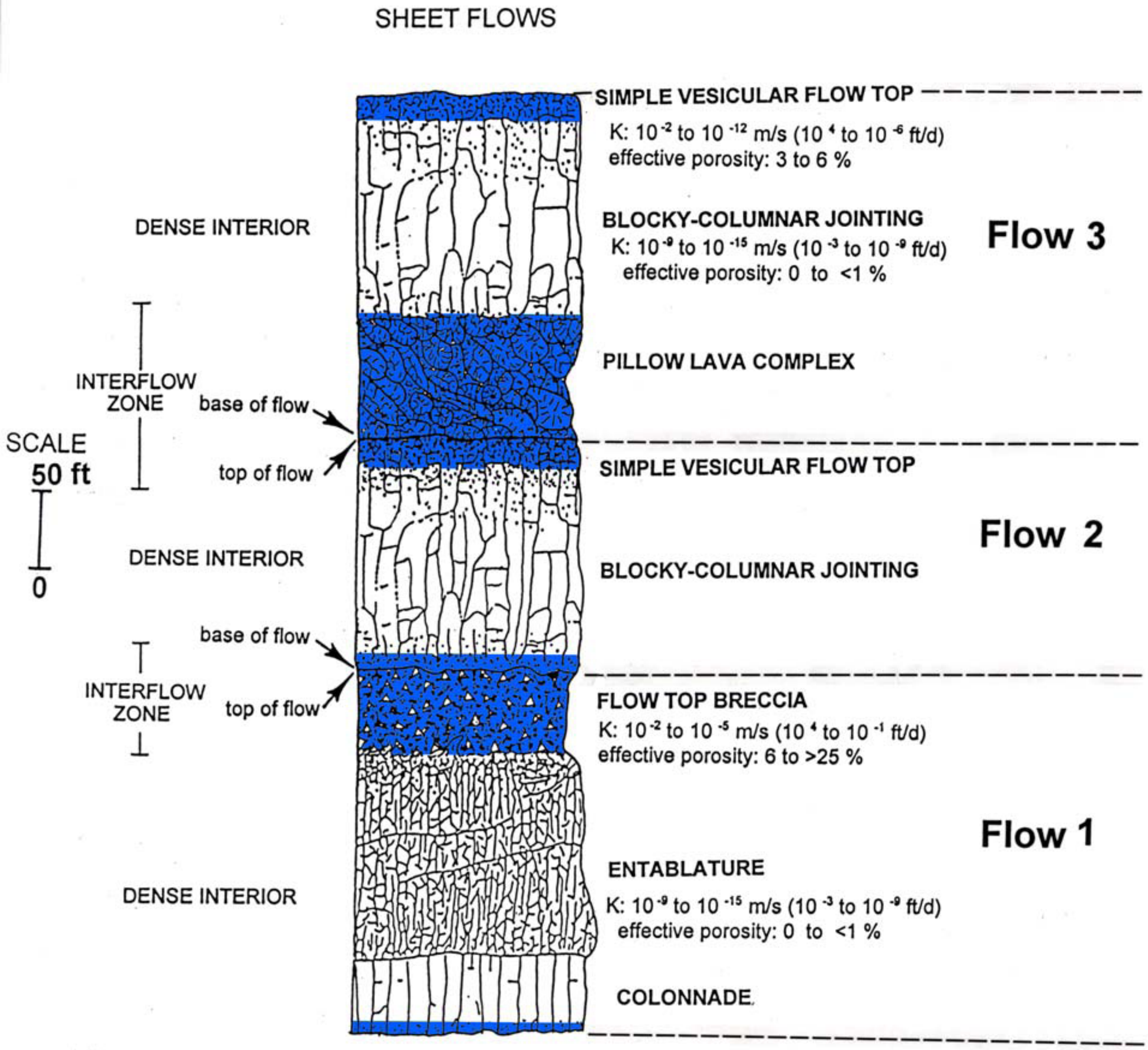


Figure 23. Drawing showing the distribution of basic hydrologic properties for CRBG intraflow zones.

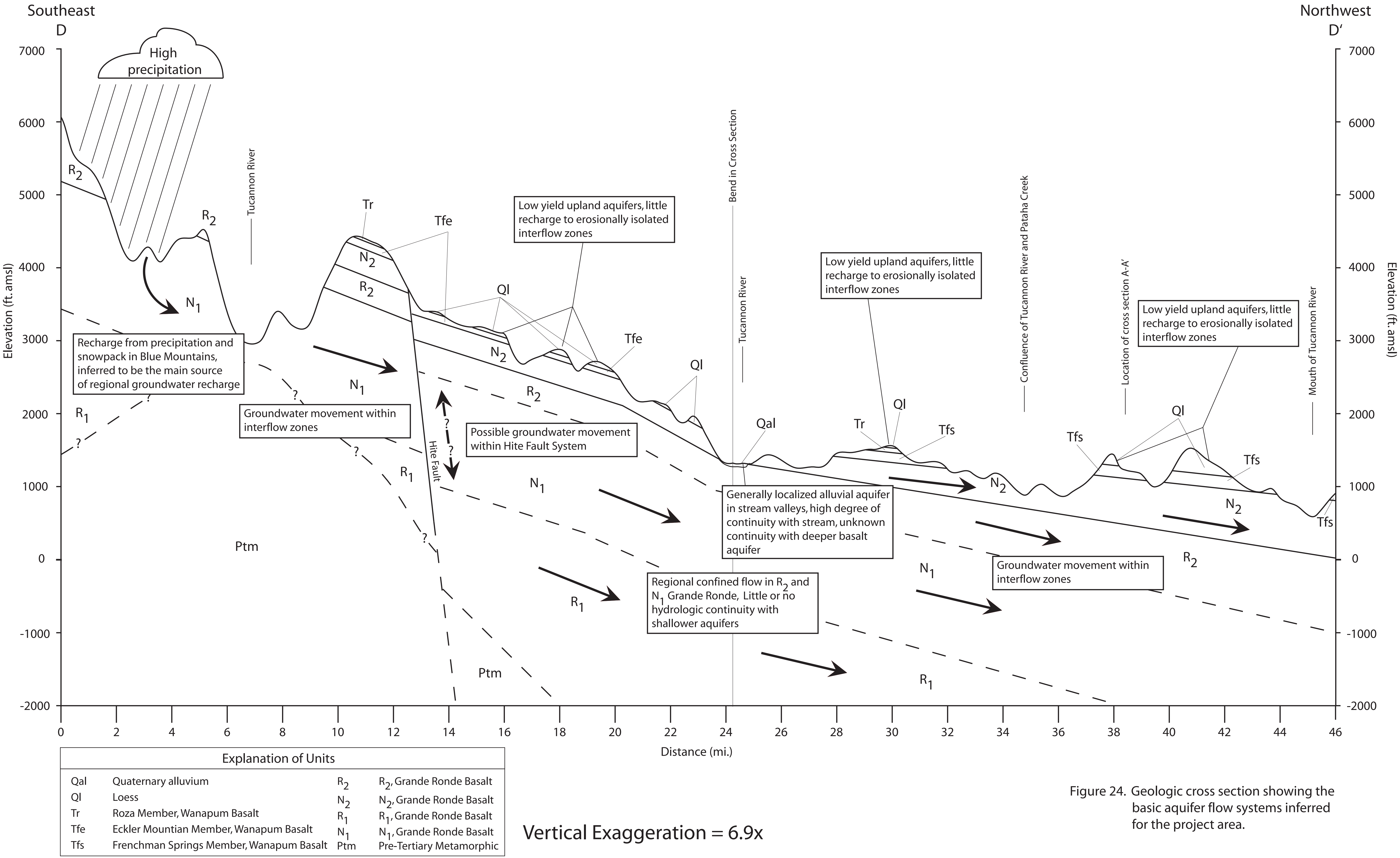


Figure 24. Geologic cross section showing the basic aquifer flow systems inferred for the project area.

Appendix A

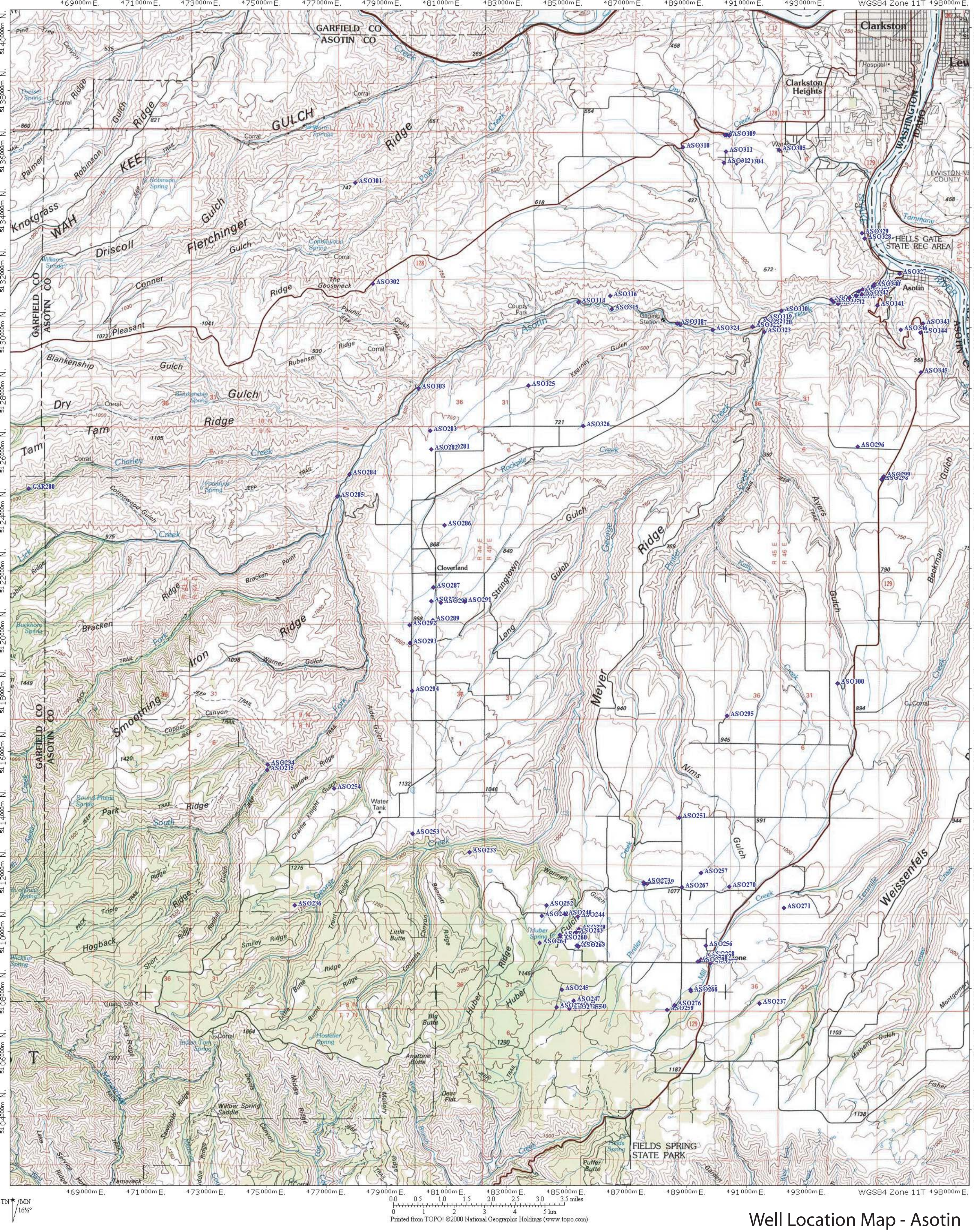
Well Construction and Hydrologic Information Compiled for Selected Wells in the Project Area

		Location			M/Y	ft. amsl	Total Depth		Casing		Seal		Open Interval Range		Open to:			°F	Water Level(s)			Pumping Info.				
Well ID#	River Valley/Uplands	sec.	T	R	Date drilled	Surface Elev.	Depth	Elev.	Depth	Elev.	Depth	Elev.	Top	Bottom	Sediment	Basalt	Sed/Basalt	Water Temp.	Depth	Elev.	Date	Pump Rate (gpm)	draw down (ft.)	specific capacity	Type of Test (B,A,P)	Comments
ASO069	Upland	12	10	43	Nov-01	1388	610	778	570	818			570	610		*		51	200	1188	Nov-01	1			A	no surface seal
ASO070	Upland	12	10	43	Sep-03	1306	190	1116	18	1288	18	1288	18	190		*										dry? no mention of water on log
ASO071	Upland	23	10	43	Oct-86	1338	61	1277	19	1319	19	1319	19	61		*			25	1313	Oct-86	10			A	
COL001	Upland	6	10	39	Aug-92	2102	160	1942	42	2060	20	2082	42	160			*		flowing well		Aug-96				none	
COL002	Upland	9	10	39	Nov-95	1978	250	1728	27	1951	27	1951	27	250		*			122	1856	Nov-95	30			A	
COL003	Upland	11	10	39	Jun-96	2290	120	2170	32	2258	32	2258	32	120		*			50	2240	Jun-96	60			A	
COL004	Upland	12	10	39	Dec-93	1706	400	1306	32	1674	18	1688	32	400		*			320	1386	Dec-93	51			A	
COL005	Upland	18	10	39	Sep-84	2059	152	1907	37	2022	37	2022	37	152		*			51	2008	Sep-84				none	
COL006	Upland	18	10	39	Sep-84	2047	127	1920	51	1996	48	1999	51	127		*			60	1987	Sep-84	40	25	1.60	A	
COL007	Upland	19	10	39	Apr-97	1624	100	1524	70	1554	20	1604	70	100		*			36	1588	Apr-97	70			A	
COL008	Upland	19	10	39	Jun-40	1627	942	685	33	1594			33	942		*			420	1207	Jun-40	700	436	1.61	P	no surface seal
COL009	Upland	22	10	39	Apr-96	2251	920	1331	37	2214			37	920		*						2			A	no surface seal
COL010	Upland	28	10	39	Aug-97	1841	280	1561	240	1601	18	1823	240	280		*			180	1661	Aug-97	20			A	
COL011	Touchet	29	10	39	Sep-00	1644	337	1307	52	1592	18	1626	52	337		*			193	1451	Sep-02	7			A	
COL012	Touchet	29	10	39	Sep-82	1653	365	1288	96	1557	80	1573	96	365		*			250	1403	Aug-82	7			P	
COL013	Touchet	30	10	39	Jun-79	1617	484	1133	39	1578	30	1587	39	484		*			250	1367	Jul-79	10			A	
COL014	Touchet	30	10	39	Jul-94	1614	825	789	150	1464	150	1464	150	825		*			525	1089	Jul-94	75			A	
COL015	Touchet	30	10	39	Jun-69	1629	10	1619	2	1627			2	10	*			cold	4	1625	Jun-69	75	5	15.00	P	no surface seal
COL016	Touchet	30	10	39	Apr-36	1625	1250	375	24	1601			24	1250		*			420	1205	Apr-36	700			P	no surface seal
COL017	Touchet	32	10	39	Oct-81	1647	1180	467	700	947	700	947	700	1180		*			541	1106	Oct-81				P	Ladd Irrigation has pumptest results, Moses Lake
COL018	Touchet	32	10	39	Jul-81	1644	1445	199	707	937	707	937	707	1445		*			613	1031	Jul-81				P	Ladd Irrigation has pumptest results, Moses Lake
COL019	Upland	32	10	39	Jan-87	1755	500	1255	30	1725	30	1725	30	500		*									none	
COL020	Upland	33	10	39	Nov-92	1855	652	1203	18	1837			18	652		*			515	1340	Nov-92	5			A	no surface seal
COL021	Upland	5	10	40	Jun-94	2480	900	1580	67	2413	18	2462	67	900		*			800	1680	Jun-94	8			A	
COL022	Upland	16	10	40	Dec-90	2211	403	1808	400	1811	22	2189	400	403		*			330	1881	Dec-90				none	questionable casing depth
COL023	Upland	16	10	40	Aug-98	2196	800	1396	19	2177	18	2178	19	800		*						15			A	
COL024	Upland	16	10	40	Oct-90	2245	200	2045	30	2215	18	2227	30	200		*									none	water at 91' and 104'
COL025	Upland	19	10	40	Sep-95	2033	380	1653	380	1653	24	2009	380	380		*			360	1673	Sep-95	12			A	open only at bottom
COL026	Upland	20	10	40	Sep-86	2134	150	1984	32	2102	20	2114	32	150		*			47	2087	Aug-90	80	46	1.74	P	160 gpm airtest
COL027	Upland	22	10	40	Sep-76	2491	12	2479	0	2491	0	2491	0	12	*				3	2488	Sep-75				none	perforated 0-12'
COL028	Upland	23	10	40	Oct-98	2545	875	1670	29	2516	22	2523	29	875		*			660	1885	Oct-98	10+			A	
COL029	Upland	33	10	40	Jun-96	3405	610	2795	20	3385	18	3387	20	610		*									none	"no water encountered what so ever"
COL030	Tucannon	4	10	41	Oct-92	1910	177	1733	19	1891	18	1892	19	177		*						60			A	
COL031	Tucannon	4	10	41	Jul-75	1920	29	1891	26	1894	19	1901	26	29		*			12	1908	Jul-75	45	1	45.00	A	
COL032	Tucannon	4	10	41	Sep-94	1847	140	1707	120	1727	20	1827	120	140		*			40	1807	Sep-94	20			A	
COL033	Tucannon	5	10	41	Apr-05	1901	100	1801	80	1821	18	1883	80	100		*			35	1866	Apr-05	50			A	
COL034	Tucannon	9	10	41	Jun-94	1910	225	1685	43	1867	43	1867	43	225		*			35	1875	Jun-94	30			A	
COL036	Tucannon	9	10	41	Sep-95	1969	202	1767	162	1807	18	1951	162	202		*			75	1894	Sep-95	15			A	
COL037	Tucannon	9	10	41	Sep-94	2030	240	1790	220	1810	20	2010	220	240		*			100	1930	Sep-94	10			A	
COL038	Tucannon	9	10	41	Sep-98	1904	300	1604	220	1684	19	1885	220	300		*		57	116	1788	Sep-98	35			A	
COL039	Upland	9	10	41	Dec-04	2065	204	1861	65	2000	18	2047	65	204		*			59	2006	Dec-04	12			A	
COL041	Tucannon	9	10	41	Sep-02	1940	78	1862	63	1877	63	1877	63	78		*			15	1925	Sep-02	45			A	
COL042	Tucannon	9	10	41	Nov-98	1962	150	1812	130	1832	29	1933	130	150		*		56	95	1867	Nov-98	30			A	
COL043	Tucannon	9	10	41	Sep-94	1965	180	1785	140	1825	20	1945	140	180		*			50	1915	Sep-94	20+			A	
COL044	Tucannon	9	10	41	Sep-98	1979	300	1679	280	1699	18	1961	280	300		*		57	280	1699	Sep-98	15			A	
COL045	Tucannon	9	10	41	Sep-98	1922	175	1747	135	1787	20	1902	135	175		*		57	40	1882	Sep-98	40			A	
COL046	Tucannon	9	10	41	Mar-00	1944	180	1764	160	1784	30	1914	160	180		*			19	1925	Mar-00	30			A	
COL047	Tucannon	9	10	41	Jul-01	1898	225	1673	82	1816	19	1879	82	225		*		55	35	1863	Jul-01	40			A	
COL048	Tucannon	9	10	41	Sep-98	1977	325	1652	285	1692	23	1954	285	325		*		57	220	1757	Sep-98	35			A	
COL049	Tucannon	9	10	41	Dec-78	1942	35	1907	35	1907	20	1922	35	35	*				17	1925	Dec-78	15	0.1	150.00	B	open only at bottom
COL056	Tucannon	9	10	41	Jun-94	1926	225	1701	43	1883	43	1883	43	225		*			35	1891	Jun-94	30			A	
COL057	Upland	16	10	41	Mar-96	2102	275	1827	245	1857	19	2083	245	275		*			235	1867	Mar-96	4			A	
COL058	Upland	24	10	41	Feb-03	3899	140	3759	18	3881	18	3881	18	140		*			93	3806	Feb-03	12			A	
COL059	Upland	31	10	41	Oct-93	4488	425	4063	18	4470	18	4470	18	425		*									none	"no water encountered"
COL073	Upland	25	11	38	Jul-95	1929	325	1604	82	1847	18	1911	82	325		*						15			A	no swl on log
COL074	Upland	25	11	38	Sep-92	1938	152	1786	78	1860	78	1860	78	152		*			98	1840	Sep-92	15			A	
COL075	Upland	27	11	38	Mar-67	1757	117	1640	60	1697	21	1736	60	117		*			22	1735	Mar-67	30	3	10.00	B	
COL076	Upland	32	11	38	Jun-67	1962	191	1771	88	1874	88	1874	88	191		*			115	1847	Jun-67	30	0.1	300.00	B	
COL077	Upland	34	11	38	Mar-93	1932	200	1732	160	1772	19	1913	160	200		*			65	1867	Mar-93	17			A	
COL078	Tucannon	1	11	39	Nov-74	1144	162	982	30	1114	25	1119	30	162		*			45	1099	Nov-74	30	40	0.75	P	
COL079	Tucannon	5	11	40	Sep-95	1328	324	1004	320	1008	18	1310	320	324		*			223	1105	Sep-95	24			A	
COL080	Upland	5	11	40	Nov-95	1565	715	850	19	1546	19	1546	19	715		*						15			A	Hickam's own well and no swl
COL081	Upland	6	11	39	Apr-02	1633	200	1433	18	1615	18	1615	18	200		*			163	1470	Apr-02	25			A	
COL082	Upland	16	11	39	Jun-93	1388	1190	198	1120	268	985	403	1120	1190		*		65	970	418	Jul-93	200	0.1	2000.00	P	Dept of Corrections - good conpletion diagram
COL083	Upland	16	11	39	Jun-90	1306	604	702	580	726	18	1288	580	604		*						6			A	no swl on log
COL084	Upland	16	11	39	Oct-96	1338	700	638	20	1318	20	1318	20	700		*						4			A	no swl on log
COL085	Upland	19	11	39	Apr-65	1518	109	1409	21	1497			21	109		*			12	1506	Apr-65	50	52	0.96	P	seal exists but no depth on log
COL086	Upland	19	11	39	Oct-95	1801	200	1601	37	1764	18	1783	37	200		*			120	1681	Oct-95	20			A	
COL087	Upland	21	11	39	Nov-02	1483	84	1399	44	1439	28	1455	44	84		*			41	1442	Nov-02	25			A	
COL088	Upland	32	11	39	Sep-94	2153	250	1903	41	2112	18	2135	41	250		*			150	2003	Sep-94	30			A	
COL089	Upland	33	11	39	Sep-96	1944	125	1819	85	1859	20	1924	85	125		*			50	1894	Sep-96	17			A	
COL090	Upland	35	11	39	Jul-99	2084	160	1924	58	2026	20	2064	58	160		*			43	2041	Jul-99	25			A	
COL091	Upland	35	11	39	Jul-94	2024	180	1844	36	1988	20	2004	36	180		*						15			A	no swl on log
COL092	Upland	19	11	40	Dec-02	2175	410	1765	47	2128	18	2157	47	410			*		330	1845	Dec-02	25			A	
COL093	Upland	24	11	40	May-77	1999	159	1840	35	1964			35	159		*			5	1994	Jun-77	20			B	no surface seal
COL094	Upland	28	11	40	May-93	2455	250	2205	83	2372	18	2437	83	250		*			110	2345	May-93	2			A	
COL095	Upland	30	11	40	Aug-94	2197	300	1897	22	2175	18	2179	22	300		*						15			A	no swl on log
COL100	Upland	18	11	41	Aug-03	1997	300	1697	24	1973	18	1979	24	300		*			40	1957	Aug-03	10			A	
COL109	Tucannon	30	11	41	May-97	1715	105	1610	38	1677	18	1697	38	105		*			flowing well		May-97	40			A	25gpm artesian
COL110	Tucannon	32	11	41	Sep-82	1834	51	1783	30	1804			30	51		*			4	1830	Sep-82	190	14	13.57	P	log says there is not a seal yet cement was used to make seal?
COL135	Tucannon	11	12	37	Oct-92	595	259	336	104	491			104	259		*			36	559	Oct-92				none	seal exists but no depth on log
COL136	Tucannon	11	12	37	Jun-93	589	457	132	199	390			199	457		*			35	554	Jun-93	1125			A	WB zones 270-286, 308-317, 442-455
COL137	Tucannon	13	12	37	Oct-01	623	85	538	32	591	34	589	34	85		*			13	610	Oct-01	75			A	
COL138	Upland	13	12	37	Nov-65	640	93	547	40	600			40	93		*									none	main water from 65' to 85'
COL139	Tucannon	13	12	37	Jan-29	640	33	607	33	607			33	33	*				22	618	Jan-29	100	4	25.00	P	brick casing, dug well
COL140	Upland	13	12	37	Jan-85	1217	424	793	270	947	42	1175	270	424		*			100	1117	Jan-85	361	174	2.07	P	town of Starbuck

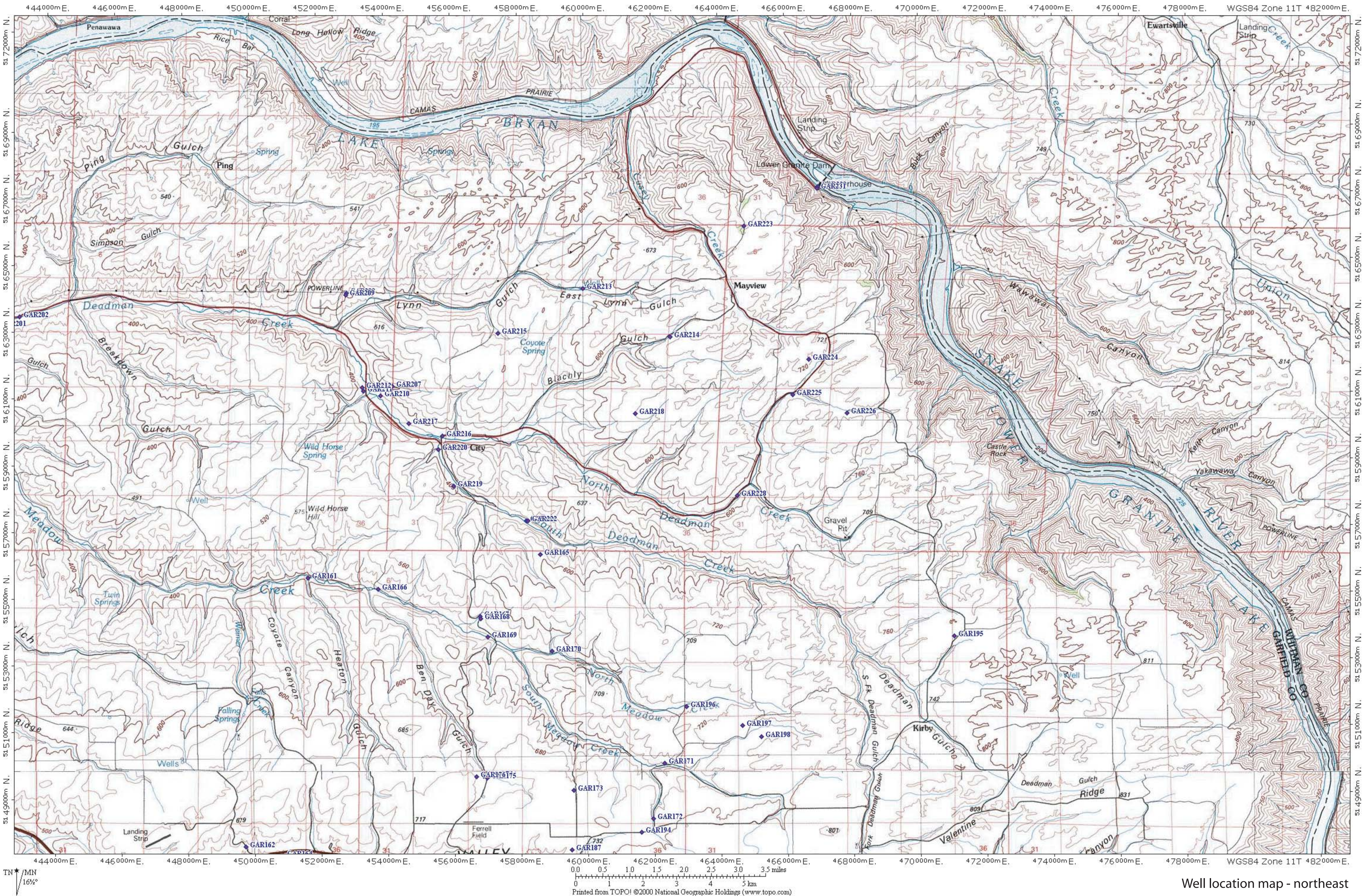
		Location			M/Y	ft. amsl	Total Depth		Casing		Seal		Open Interval Range		Open to:			°F	Water Level(s)			Pumping Info.				
Well ID#	River Valley/Uplands	sec.	T	R	Date drilled	Surface Elev.	Depth	Elev.	Depth	Elev.	Depth	Elev.	Top	Bottom	Sediment	Basalt	Sed/Basalt	Water Temp.	Depth	Elev.	Date	Pump Rate (gpm)	draw down (ft.)	specific capacity	Type of Test (B,A,P)	Comments
COL141	Upland	15	12	37	Apr-92	1217	803	414	800	417	18	1199	800	803		*						20			A	no swl on log
COL142	Upland	1	12	38	Jul-85	1712	113	1599	32	1680	32	1680	32	113		*			13	1699	Jul-85	30	4	7.50	A	
COL143	Upland	17	12	38	Feb-94	1459	172	1287	38	1421	38	1421	38	172		*			-1	1460	Feb-94	150			A	water level at TOC 1' above ground surface
COL144	Tucannon	18	12	38	Feb-94	769	65	704	20	749	18	751	20	65		*			flowing well		Feb-94				A	40 psi artesian pressure
COL145	Upland	22	12	38	Dec-02	1256	90	1166	38	1218	18	1238	38	90		*			27	1229	Dec-02	25			A	
COL146	Tucannon	22	12	38	Dec-02	786	208	578	25	761	18	768	25	208		*			flowing well		Dec-02	70			A	11 psi artesian pressure
COL148	Upland	18	12	39	Dec-02	1402	730	672	18	1384	18	1384	18	730		*			550	852	Dec-02	15			A	
COL149	Tucannon	19	12	39	Aug-78	905	88	817	22	883			22	88		*			45	860	Aug-78	30	4	7.50	A	seal exists but no depth on log
COL150	Tucannon	34	12	39	Sep-93	1070	420	650	59	1011	18	1052	59	420		*			225	845	Sep-93	200			A	
COL199	Upland	27	13	38	Dec-63	722	381	341	330	392	330	392	330	381		*		74	17	705	Dec-63	280	36	7.78	P	little goose dam water well #1
COL200	Upland	27	13	38	Sep-65	690	399	291	337	353	1	689	337	399		*		75	flowing well		Jul-72	473	0.1	4730.00	P	little goose dam water well #2 / 27psi. Artesian pressure
GAR060	Upland	4	10	42	May-81	3328	237	3091	32	3296	20	3308	32	237		*									none	dry? no mention of water on log
GAR061	Upland	12	10	42	Oct-04	3445	700	2745	19	3426	18	3427	19	700		*			510	2935	Oct-04	2			A	
GAR062	Upland	27	10	42	May-98	3777	370	3407	330	3447	18	3759	330	370		*			150	3627	May-98	1			A	
GAR063	Upland	28	10	42	Oct-81	4267	300	3967	10	4257	10	4257	10	300		*									none	dry
GAR064	Upland	29	10	42	Jul-79	4163	214	3949	25	4138	25	4138	25	214		*			178	3985	Jul-78	0.5			B	
GAR065	Upland	33	10	42	Jul-95	4419	539	3880	20	4399	18	4401	20	539		*									none	dry
GAR066	Upland	33	10	42	Jul-95	4444	200	4244	18	4426	18	4426	18	200		*									none	dry
GAR067	Upland	34	10	42	Jul-84	4331	460	3871	39	4292	39	4292	39	460		*									none	dry
GAR068	Upland	34	10	42	Oct-80	3953	143	3810	23	3930	20	3933	23	143		*									none	dry? no mention of water on log
GAR072	Upland	30	10	43	Jul-77	4006	161	3845	23	3983	18	3988	23	161		*									none	dry
GAR096	Pataha	4	11	41	May-89	1616	134	1482	94	1522	14	1602	94	134		*						2			A	no swl on log
GAR097	Upland	9	11	41	Apr-80	1695	155	1540	26	1669		1695	26	155		*						10			B	no swl on log / seal exists but no depth on log
GAR098	Upland	13	11	41	Jan-64	2645	203	2442	135	2510			135	203		*		56	150	2495	Jan-64	60	40	1.50	P	no mention of seal / unusable water 165 and down?
GAR099	Upland	16	11	41	Nov-03	1783	945	838	18	1765	18	1765	18	945		*			835	948	Nov-03	35			A	
GAR101	Upland	21	11	41	Aug-94	2023	100	1923	18	2005	18	2005	18	100		*			46	1977	Aug-94	20			A	
GAR102	Upland	23	11	41	Jul-68	2094	277	1817	277	1817			277	277		*		60	flowing well		Jul-68	150	100	1.50	P	15gpm artesian
GAR103	Upland	24	11	41	Oct-79	2192	140	2052	25	2167	25	2167	25	140		*		52	35	2157	Oct-79	20	10	2.00	B	
GAR104	Upland	25	11	41	Jul-77	2384	142	2242	30	2354	25	2359	30	142		*				2384		60	20	3.00	P	no swl on log
GAR105	Upland	26	11	41	Oct-81	2277	92	2185	20	2257	10	2267	20	92		*				2277		40	20	2.00	B	water at 66' and 81'
GAR106	Upland	26	11	41	Mar-75	2327	92	2235	27	2300			27	92		*			1	2326	Mar-75	60	85	0.71	P	seal exists but no depth on log
GAR107	Upland	26	11	41	May-59	2206	60	2146					0	60		*		48	17	2189	Jun-59	100	0.1	1000.00	P	no casing details
GAR108	Upland	26	11	41	Aug-77	2128	80	2048	31	2097	25	2103	31	80		*				2128		67			P	no swl on log
GAR111	Upland	33	11	41	Apr-03	2502	100	2402	80	2422	18	2484	80	100		*			12	2490	Apr-03	50			A	
GAR112	Upland	35	11	41	Jun-79	2328	128	2200	69	2259	20	2308	69	128		*			25	2303	Jun-79	40	45	0.89	P	
GAR113	Pataha	1	11	42	Feb-97	2185	190	1995	170	2015	19	2166	170	190		*			40	2145	Feb-97	50			A	
GAR114	Pataha	1	11	42	Oct-66	2192	108	2084	30	2162	30	2162	30	108		*			40	2152	Oct-66				none	
GAR115	Pataha	2	11	42	Apr-64	2131	211	1920	23	2108			23	211		*			60	2071	Apr-64	200	100	2.00	P	no surface seal
GAR116	Pataha	2	11	42	May-68	2111	92	2019	27	2084			27	92		*			20	2091	May-68	250	0.1	2500.00	P	"Balsalt!"
GAR117	Pataha	2	11	42	May-64	2080	98	1982	24	2056			24	98		*		58	15	2065	May-64	300	19	15.79	P	no surface seal
GAR118	Pataha	3	11	42	Oct-79	2026	60	1966	23	2003	21	2005	23	60		*		57	8	2018	Oct-79	50			A	
GAR119	Upland	4	11	42	Apr-94	2250	325	1925	26	2224	18	2232	26	325		*						30			A	no swl on log
GAR120	Pataha	4	11	42	May-74	2006	224	1782	81	1925	81	1925	81	224		*		57	80	1926	May-74	150			A	
GAR121	Upland	8	11	42	Jul-67	2239	101	2138	9	2230			9	101		*			4	2235	Jul-67	40			A	seal probably exists but no depth on log
GAR122	Upland	20	11	42	Jul-68	2900	130	2770	23	2877	18	2882	23	130		*			100	2800	Jul-68	25			A	
GAR123	Upland	20	11	42	Oct-94	2783	300	2483	40	2743	40	2743	40	300		*		56	30	2753	Oct-94	15			A	
GAR124	Upland	24	11	42	Apr-92	2842	95	2747	70	2772	40	2802	70	95		*		51	46	2796	Apr-92	17			A	
GAR125	Upland	31	11	42	Aug-79	3292	103	3189	19	3273	18	3274	19	103		*			30	3262	Aug-79	18	?		P	
GAR126	Pataha	6	11	43	Mar-69	2252	154	2098	37	2215			37	154		*		54	40	2212	Mar-69	300	70	4.29	P	no surface seal
GAR127	Upland	7	11	43	Nov-78	2583	138	2445	24	2559	18	2565	24	138		*			70	2513	Nov-78	11	60	0.18	P	
GAR128	Pataha	7	11	43	Mar-77	2339	155	2184	31	2308	25	2314	31	155		*		50	20	2319	Mar-77	50	100	0.50	P	
GAR129	Upland	8	11	43	Dec-94	2646	660	1986	19	2627	19	2627	19	660		*									none	0gpm for airtest but no mention if dry, could be?
GAR130	Upland	8	11	43	Jan-67	2624	231	2393	84	2540	84	2540	84	231		*		54	215	2409	Jan-67	12			none	
GAR131	Upland	16	11	43	Nov-68	2766	575	2191	298	2468			298	575		*		60	474	2292	Nov-68	62	38	1.63	P	seal exists but no depth on log
GAR132	Upland	26	11	43	Nov-71	1904	208	1696	60	1844	26	1878	60	208		*		45	70	1834	Oct-71	10	100	0.10	B	
GAR133	Upland	26	11	43	Feb-03	2304	360	1944	18	2286	18	2286	18	360		*			180	2124	Feb-03	4			A	
GAR134	Upland	26	11	43	Feb-03	1970	125	1845	49	1921	18	1952	49	125		*			33	1937	Feb-03	250			A	
GAR151	Pataha	7	12	40	Mar-45	1182	122	1060	118	1064			118	122		*			42	1140	Mar-45	50	33	1.52	P	
GAR152	Pataha	8	12	40	Oct-03	1206	39	1167	20	1186	18	1188	20	39			*		17	1189	Oct-03	20			A	
GAR153	Upland	14	12	40	Oct-74	1895	1015	880	980	915	23	1872	980	1015		*		70	880	1015	Feb-84	9	0.1	90.00	P	deepened 3 times start: drill date / end: WL date
GAR154	Pataha	16	12	40	Apr-03	1278	345	933	300	978	29	1249	300	345		*			206	1072	Apr-03	3			A	
GAR155	Pataha	16	12	40	Nov-94	1301	331	970	271	1030	33	1268	271	331		*			198	1103	Nov-94	15			A	
GAR156	Pataha	17	12	40	May-75	1249	295	954	255	994	40	1209	255	295		*		54	240	1009	Sep-75	75			A	
GAR157	Pataha	17	12	40	Apr-75	1246	295	951	250	996	41	1205	250	295		*		50	265	981	Apr-75	20	0.1		P	
GAR158	Pataha	22	12	40	Dec-80	1354	165	1189	28	1326	23	1331	28	165		*			80	1274	Dec-80	2			P	
GAR159	Pataha	22	12	40	May-91	1331	250	1081	211	1120	46	1285	211	250		*		59	180	1151	May-91	30+			A	
GAR160	Upland	28	12	40	Oct-78	1985	255	1730	30	1955	30	1955	30	255		*		58	190	1795	Oct-78	3.5	180	0.02	B	
GAR161	Meadow	1	12	41	Sep-04	1273	140	1133	120	1153	20	1253	120	140		*			35	1238	Sep-04	20			A	
GAR162	Upland	34	12	41	Oct-98	1873	725	1148	24	1849	18	1855	24	725		*						10+			A	no swl on log
GAR163	Pataha	35	12	41	Mar-79	1721	400	1321			18	1703	18	400		*			355	1366	Mar-79				none	no casing depth or pummping info.
GAR164	Pataha	35	12	41	Oct-66	1744	137	1607	40	1704	30	1714	40	137		*			100	1644	Oct-66	15	25	0.60	B	
GAR165	Upland	3	12	42	Jun-96	1936	300	1636	280	1656	19	1917	280	300		*			136	1800	Jun-96	40			A	
GAR166	Meadow	6	12	42	Apr-79	1341	110	1231	18	1323	18	1323	18	110		*		50	20	1321	Apr-79	20	50	0.40	B	
GAR167	Upland	9	12	42	Aug-95	1652	270	1382	31	1621	31	1621	31	270		*			90	1562	Aug-95	20			A	
GAR168	Upland	9	12	42	Aug-00	1651	110	1541	80	1571	30	1621	80	110		*			15	1636	Aug-00	100			A	
GAR169	Meadow	9	12	42	Dec-67	1557	274	1283	80	1477	1	1556	80	274		*		58	47	1510	Nov-74	374	156	2.40	P	
GAR170	Meadow	10	12	42	Aug-85	1718	335	1383	322	1396			322	335		*		64	230	1488	Aug-85	85			A	no swl or seal depth on log
GAR171	Meadow	24	12	42	May-95	2102	232	1870	18	2084	18	2084	18	232		*			150	1952	May-95	15	0.1	150.00	P	
GAR172	Upland	25	12	42	Apr-96	2318	175	2143	115	2203	18	2300	115	175		*			50	2268	Apr-96	60			A	
GAR173	Upland	27	12	42	Oct-97	2393	270	2123	230	2163	38	2355	230	270		*		50				20			A	no swl on log
GAR174	Upland	28	12	42	Aug-66	2166	116	2050	21	2145			21	116		*			15	2151	Aug-66	25	106	0.24	P	
GAR175	Upland	28	12	42	Jun-05	2138	301	1837	19	2119	17	2121	19	301		*						60			A	no swl on log
GAR176	Upland	28	12	42	Apr-94	2277	75	2202	19	2258	18	2259	19	75		*						7			A	no swl on log
GAR177	Pataha	31	12	42	Feb-55	1857	997	860	69	1788			69	997		*			400	1457	Feb-55	500	29	17.24	P	
GAR178	Pataha	32	12	42	Oct-79	1928	110	1818	70	1858	70	1858	70	110		*		58	35	1893	Oct-79	300			A	
GAR179	Upland	33	12	42	Nov-86	1983	175	1808	75	1908			75	175		*		60	15	1968	Nov-86	40			A	
GAR180	Upland	33	12	42	May-82	2008	103	1905	37	1971	24	1984	37	103		*		58	20	1988	May-82	35	48	0.73	P	

		Location			M/Y	ft. amsl	Total Depth		Casing		Seal		Open Interval Range		Open to:			°F	Water Level(s)			Pumping Info.				
Well ID#	River Valley/Uplands	sec.	T	R	Date drilled	Surface Elev.	Depth	Elev.	Depth	Elev.	Depth	Elev.	Top	Bottom	Sediment	Basalt	Sed/Basalt	Water Temp.	Depth	Elev.	Date	Pump Rate (gpm)	draw down (ft.)	specific capacity	Type of Test (B,A,P)	Comments
GAR181	Pataha	33	12	42	Dec-72	1980	130	1850	130	1850	36	1944	130	130		*		57	70	1910	Dec-72	40			B	
GAR182	Pataha	33	12	42	Nov-64	1996	132	1864	25	1971	25	1971	25	132		*		52	32	1964	Nov-64	100	68	1.47	P	
GAR183	Pataha	33	12	42	Jun-94	1991	150	1841	30	1961	30	1961	30	150		*			30	1961	Jun-94	120			A	
GAR184	Pataha	33	12	42	Aug-53	1948	134	1814	17	1931			0	134			*		0	1948	Aug-53	115	24	4.79	P	the 17' of casing is perforated
GAR185	Pataha	33	12	42	Jan-77	1972	184	1788	31	1941	20	1952	31	184		*			25	1947	Jan-77	35			P	
GAR186	Pataha	34	12	42	Dec-63	2086	70	2016	65	2021			65	70		*			30	2056	Nov-63	45	10	4.50	P	seal exists but no depth on log
GAR187	Upland	34	12	42	Jan-04	2408	520	1888	480	1928	18	2390	480	520		*			280	2128	Jan-04	20+			A	
GAR188	Upland	34	12	42	Jun-77	2002	62	1940					0	62					20	1982	Jun-77	45	3	15.00	B	cased and sealed but no details
GAR189	Pataha	34	12	42	Aug-97	2046	108	1938	88	1958	24	2022	88	108		*		57	4	2042	Aug-97	80			A	
GAR190	Pataha	34	12	42	Nov-56	2055	93	1962	31	2024			31	93		*			11	2044	Nov-56	605	76	7.96	P	
GAR191	Pataha	34	12	42	Mar-77	2046	108	1938	80	1966	20	2026	80	108		*						60	10	6.00	P	no swl on log
GAR192	Upland	34	12	42	Nov-49	2064	57	2007	23	2041			23	57		*		54	14	2050	Nov-49	32	0.1	320.00	P	gravel packed to 18' and no seal
GAR193	Upland	34	12	42	Oct-84	2014	164	1850	100	1914	160	1854	160	164		*		55	75	1939	Oct-84	85			A	sealed to 160' and perforated 100' -160'?
GAR194	Upland	36	12	42	Nov-74	2431	161	2270	121	2310	40	2391	121	161		*			84	2347	Nov-74	30	20	1.50	B	
GAR195	Upland	12	12	43	Jun-57	2571	189	2382	63	2508			63	189		*		55	71	2500	Jun-57	94	79	1.19	P	
GAR196	Meadow	18	12	43	Apr-74	2199	172	2027	27	2172	27	2172	27	172		*			60	2139	Apr-74	8	60	0.13	P,B	
GAR197	Upland	20	12	43	May-74	2484	207	2277	95	2389	30	2454	95	207		*			117	2367	May-74	35			P	
GAR198	Upland	20	12	43	May-74	2461	207	2254	134	2327	60	2401	134	207		*			140	2321	May-74	25	35	0.71	P	
GAR201	Deadman	11	13	40	Dec-67	686	250	436	17	669	17	669	17	250		*			flowing well		Dec-67	400			P	log says 103 psi. artesian pressure and 103 swl?
GAR202	Deadman	12	13	40	May-71	730	368	362	12	718			12	368		*									none	
GAR203	Deadman	14	13	40	Aug-75	794	50	744	25	769			25	50		*			30	764	Aug-75	25	10	2.50	P	seal exists but no depth on log
GAR204	Deadman	14	13	40	Oct-73	721	250	471	27	694	27	694	27	250		*			80	641	Oct-73	460	8	57.50	P,B	
GAR205	Upland	26	13	40	Mar-94	752	130	622	110	642	20	732	110	130		*			70	682	Mar-94	55			A	
GAR206	Upland	27	13	40	Jun-76	1198	100	1098	23	1175	23	1175	23	100		*			89	1109	May-76				none	
GAR207	Deadman	11	13	41	Apr-68	1278	125	1153	16	1262			16	125		*				1278		200			P	sealed with cement but no depth on log / no swl either
GAR208	Upland	12	13	41	Jul-02	1384	90	1294	18	1366	18	1366	18	90		*			55	1329	Jul-02	35			A	
GAR209	Upland	12	13	41	Jul-02	1377	170	1207	37	1340	20	1357	37	170		*			90	1287	Jul-02	60			A	
GAR210	Deadman	24	13	41	Dec-69	1122	177	945	177	945			177	177		*			30	1092	Dec-69	450	3	150.00	P	no surface seal
GAR211	Deadman	24	13	41	Oct-03	1189	140	1049	33	1156	18	1171	33	140		*			23	1166	Oct-03	200+			A	
GAR212	Deadman	24	13	41	Oct-58	1185	85	1100	64	1121			64	85		*		54	35	1150	Oct-58				none	water encountered 75-85'
GAR213	Upland	10	13	42	1966	1772	19	1753	19	1753			19	19	*				4	1768	1966				none	6' casing
GAR214	Upland	13	13	42		2120	118	2002	118	2002			118	118		*				2120					none	no dates / no swl
GAR215	Upland	17	13	42	May-85	1637	350	1287	62	1575			62	350		*		66	118	1519	May-85	41			P	seal exists but no depth on log
GAR216	Deadman	12	13	42	Dec-69	1212	80	1132	20	1192	12	1200	20	80		*			23	1189	Dec-69	100			P	
GAR217	Deadman	19	13	42	Mar-69	1164	195	969	40	1124	20	1144	40	195		*			62	1102	Mar-69	250	2	125.00	P	
GAR218	Deadman	23	13	42	Mar-04	2232	200	2032	18	2214	18	2214	18	200		*			56	2176	Mar-04	30			A	
GAR219	Deadman	29	13	42	Jun-84	1302	400	902	80	1222			80	400		*		58	185	1117	Jun-84	27			P	water level inferred from pumptest on log
GAR220	Deadman	30	13	42	Jun-78	1224	55	1169	23	1201	18	1206	23	55		*			20	1204	Jun-78	60	3	20.00	P	
GAR221	Deadman	33	13	42	Jul-73	1383	200	1183	23	1360	22	1361	23	200		*				1383		100			A	no swl on log
GAR222	Deadman	33	13	42	Jun-84	1394	155	1239	90	1304	89	1305	90	155		*		68	60	1334	Feb-85	18			A	water level inferred from pumptest on log
GAR223	Upland	6	13	43	May-71	2247	184	2063	100	2147			100	184		*				2247		31	0.1	310.00	P	no swl on log or seal info
GAR224	Upland	17	13	43	Nov-93	2423	125	2298	40	2383	18	2405	40	125		*				2423		50			A	no swl on log
GAR225	Upland	20	13	43	Jul-89	2131	279	1852	37	2094	37	2094	37	279		*			145	1986	Jul-89	20			A	
GAR226	Upland	21	13	43	Jun-84	2292	150	2142	90	2202	25	2267	90	150		*		54	flowing well		Jun-84	25			A	12 psi. artesian pressure
GAR228	Upland	30	13	43	Oct-03	1868	160	1708	140	1728	18	1850	140	160		*			12	1856	Oct-03	18			A	
GAR229	Upland	32	13	43	Jun-74	743	350	393	295	448		743	295	350		*		59	20	723	Jun-74	257	36	7.14	P	lower granite dam water well
GAR231	Upland	32	13	43	Aug-74	863	220	643	34	829	33	830	34	220		*		59	26	837	Aug-74	240	55	4.36	P	lower granite dam water well
ASO233		13	8	44	Jun-75	3401	594	2807	30	3371		3401	30	594		*				3401						no water
ASO234		5	8	44	Jul-95	3002	405	2597	380	2622	18	2984	380	405		*		52	340	2662	Jul-95	40			A	
ASO235		8	8	44	Jul-95	2961	445	2516	18	2943		2961	18	445		*		51	395	2566	Jul-95	0.5			A	
ASO236		21	8	44	Dec-79	4360	165	4195	35	4325	35	4325	35	165		*		57	25	4335	Dec-79	10			A	
ASO237		36	8	45	Sep-56	3629	66	3563	27	3602	27	3602	27	66		*		48		3629		45	6.83	6.59	P	possibly artesian
ASO238		32	8	45	Jul-94	3960	128	3832	44	3916	44	3916	44	128		*			42	3918	Jul-94	4			A	
ASO239		29	8	45	Dec-86	3614	323	3291	120	3494	18	3596	120	323		*			120	3494	Dec-86	10			A	
ASO240		29	8	45	Nov-86	3595	315	3280	20	3575	20	3575	20	315		*				3595						no water plug and abandoned
ASO241		29	8	45	Nov-86	3616	400	3216	70	3546	70	3546	70	400		*				3616						no water
ASO242		29	8	45	Apr-92	3642	840	2802	19	3623	18	3624	19	840		*				3642						no water
ASO243		29	8	45	Apr-92	3620	1155	2465	19	3601	19	3601	19	1155		*				3620						no water
ASO244		29	8	45	Nov-76	3570	575	2995	25	3545	20	3550	25	575		*			82	3488	Nov-76	27	30	0.90	P	
ASO245		32	8	45	Oct-02	3890	126	3764	45	3845	45	3845	45	126		*			92	3798	Oct-02	12			A	
ASO246		29	8	45	Aug-92	3591	76	3515	55	3536	18	3573	55	76		*		55	50	3541	Sep-92				P	cant read pump test numbers
ASO247		32	8	45	Oct-02	3976	157	3819	137	3839	57	3919	137	157		*			24	3952	Oct-02	6			A	
ASO248		22	8	45	Apr-87	3442	213	3229	37	3405	37	3405	37	213		*			33	3409	Apr-87	30			A	
ASO249		22	8	45	Jul-90	3461	160	3301	160	3301		3461	160	160		*			flowing well		Jul-90	30			A	13psi artesian pressure, casing is perforated depth unknown
ASO250		32	8	45	Oct-02	4006	160	3846	140	3866	62	3944	140	160		*			60	3946	Oct-02	4			A	
ASO251		15	8	45	Oct-97	3298	90	3208	70	3228	18	3280	70	90		*		49	flowing well		Oct-97	70			A	15psi / 20gpm artesian pressure
ASO252		20	8	45	Jul-71	3590	155	3435	18	3572	18	3572	18	155		*		51	80	3510	Jul-71	5			A	
ASO253		14	8	45	Sep-81	3610	275	3335	172	3438	29	3581	172	275		*			178	3432	Sep-81					
ASO254		9	8	45	Nov-79	3662	160	3502	18	3644	18	3644	18	160		*		59	71	3591	Nov-79	25			A	
ASO255		32	8	45	Oct-02	3984	160	3824	56	3928	56	3928	56	160		*			58	3926	Oct-02	6			A	
ASO256		26	8	45	Nov-79	3580	95	3485	18	3562	18	3562	18	95		*			25	3555	Nov-79	25			A	
ASO257		23	8	45	Jun-86	3475	99	3376	36	3439	36	3439	36	99		*			15	3460	Jun-86	2			A	
ASO258		26	8	45	Mar-56	3577	100	3477	80	3497	80	3497	80	100		*		42	2	3575	Mar-56	10	70	0.14	B	log says 5psi pressure but not flowing?
ASO259		34	8	45	Jul-90	3779	90	3689	38	3741	38	3741	38	90		*			50	3729	Jul-90	42			A	
ASO260		29	8	45	Jun-79	3664	50	3614	18	3646	18	3646	18	50		*			16	3648	Jun-79	0.5			A	
ASO261		29	8	45	Jun-79	3671	176	3495	110	3561	18	3653	110	176		*			16	3655	Jun-79	2			A	
ASO262		29	8	45	Jun-79	3658	50	3608	18	3640	18	3640	18	50		*			15	3643	Jun-79	0.5			A	
ASO263		29	8	45	Jun-79	3684	162	3522	137	3547	137	3547	137	162		*			35	3649	Jun-79	150			A	
ASO264		34	8	45	Jun-86	3739	78	3661	27	3712	27	3712	27	78		*			53	3686	Jun-86	100+			A	
ASO265		35	8	45	Aug-95	3659	485	3174	265	3394	19	3640	265	485		*		54	100	3559	Aug-95	1			A	
ASO266		35	8	45	Aug-95	3673	203	3470	163	3510	32	3641	163	203		*		54	110	3563	Aug-95	50			A	
ASO267		23	8	45	Aug-04	3540	205	3335	185	3355	19	3521	185	205		*		56	27	3513	Aug-04	50			A	
ASO268		26	8	45	Jun-69	3625	200	3425	91	3534	91	3534	91	200		*			38	3587	Jun-69	75			A	
ASO270		24	8	45	Jan-85	3439	460	2979	168	3271	168	3271	168	460		*		64	240	3199	Jan-85	15			A	
ASO271		19	8	45	May-97	3369	270	3099	24	3345	18	3351	24	270		*			22	3347	May-97	3			A	
ASO272		26	8	45	Dec-79	3604	110	3494	18	3586	18	3586	18	110		*		54	19	3585	Dec-79	30			A	
ASO273		22	8	45	Sep-98	3430	90	3340	19	3411	19	3411	19	90		*			8	3422	Sep-98	50+			A	

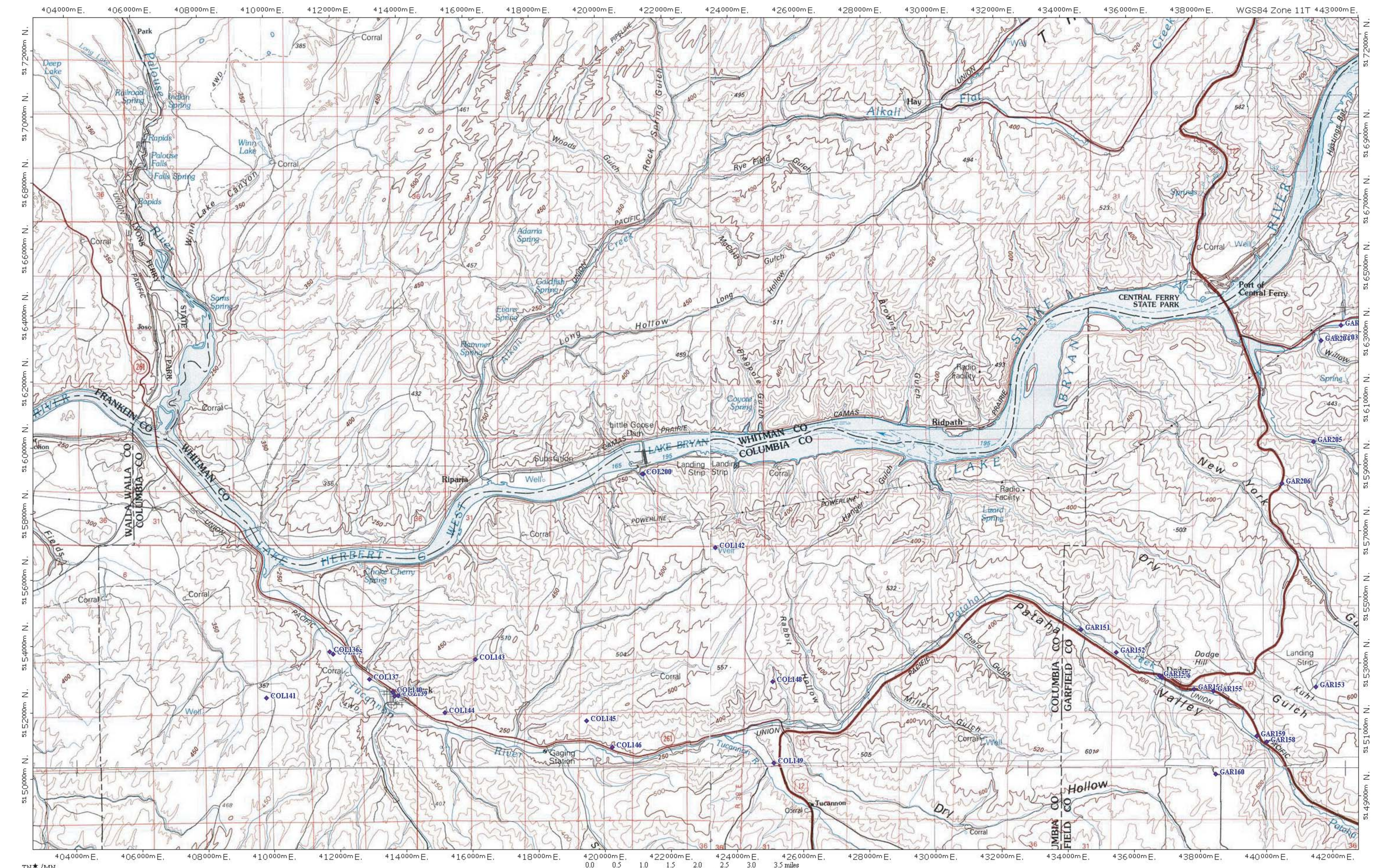
		Location			M/Y	ft. amsl	Total Depth		Casing		Seal		Open Interval Range		Open to:			°F	Water Level(s)			Pumping Info.				
Well ID#	River Valley/Uplands	sec.	T	R	Date drilled	Surface Elev.	Depth	Elev.	Depth	Elev.	Depth	Elev.	Top	Bottom	Sediment	Basalt	Sed/Basalt	Water Temp.	Depth	Elev.	Date	Pump Rate (gpm)	draw down (ft.)	specific capacity	Type of Test (B,A,P)	Comments
ASO274		32	8	45	Oct-02	3971	112	3859	92	3879	42	3929	92	112		*			45	3926	Oct-02	5			A	
ASO275		32	8	45	Sep-02	3974	138	3836	47	3927	18	3956	47	138		*			97	3877	Sep-02	30			A	
ASO276		34	8	45	Aug-84	3724	129	3595	31	3693	31	3693	31	129		*			15	3709	Aug-84	3			A	
ASO277		35	8	45	Aug-68	3571	164	3407	70	3501	70	3501	70	164		*		60	20	3551	Aug-68	25	63	0.40	P	
ASO278		26	8	45	May-92	3613	132	3481	19	3594	19	3594	19	132		*			8	3605	May-92	6			A	
ASO279		26	8	45	Jun-03	3634	160	3474	70	3564	18	3616	70	160		*			16	3618	Jun-03	2			A	
ASO281		1	9	44	Jul-79	2566	192	2374	152	2414	18	2548	152	192		*		50	135	2431	Jul-79	12			A	
ASO282		2	9	44	Jul-79	2587	245	2342	18	2569	18	2569	18	245		*				2587						no water
ASO283		2	9	44	Dec-79	2511	460	2051	36	2475	18	2493	36	460		*				2511						no water
ASO284		3	9	44	Dec-01	1791	94	1697	74	1717	31	1760	74	94		*			28	1763	Dec-01	12			A	
ASO285		10	9	44	Mar-64	1861	179	1682	39	1822	18	1843	39	179		*			18	1843	Jan-64	20	140	0.14	P	
ASO286		13	9	44	Mar-95	2772	382	2390	288	2484	30	2742	288	382		*			225	2547	Mar-95	20			A	
ASO287		23	9	44	Jul-95	2964	129	2835	22	2942	22	2942	22	129		*			75	2889	Jul-95	10			A	
ASO288		23	9	44	Dec-95	3026	120	2906	60	2966	18	3008	60	120		*			60	2966	Dec-95	12			A	
ASO289		23	9	44	Dec-95	3112	129	2983	69	3043	22	3090	69	129		*			40	3072	Dec-95	12			A	
ASO290		24	9	44	Jun-97	3023	454	2569	263	2760	18	3005	263	454		*			240	2783	Jun-97	3			A	
ASO291		24	9	44	Jul-95	2978	304	2674	19	2959	19	2959	19	304		*			265	2713	Jul-95	20			A	
ASO292		26	9	44	Sep-90	3205	660	2545	34	3171	18	3187	34	660		*				3205						no water
ASO293		26	9	44	Oct-93	3272	157	3115	142	3130	18	3254	142	157		*			96	3176	Oct-93	60			A	
ASO294		35	9	44	May-92	3422	196	3226	19	3403	19	3403	19	196		*			182	3240	May-92	6			A	
ASO295		35	9	45	Jan-97	2969	165	2804	110	2859	18	2951	110	165		*		52	60	2909	Jan-97	5			A	
ASO296		5	9	46	Sep-92	2257	446	1811	446	1811	25	2232	446	446		*			325	1932	Sep-92	4.5			A	
ASO297		9	9	46	Sep-96	2339	525	1814	30	2309	30	2309	30	525		*				2339						now water
ASO298		9	9	46	Sep-96	2343	530	1813	490	1853	38	2305	490	530		*		51	180	2163	Oct-96	10			A	
ASO299		9	9	46	Jul-00	2337	605	1732	585	1752	18	2319	585	605		*			380	1957	Jul-00	4.5			A	
ASO300		32	9	46	Apr-95	2819	303	2516	79	2740	79	2740	79	303		*			80	2739	Apr-95	2			A	
ASO301		3	10	44	Aug-95	2313	186	2127	184	2129	18	2295	184	186		*			145	2168	Aug-95	10			A	
ASO302		22	10	44	May-02	2827	650	2177	610	2217	18	2809	610	650		*		55	490	2337	May-02	10			A	
ASO303		35	10	44	Jun-97	1594	175	1419	145	1449	33	1561	145	175		*			120	1474	Jun-97	35			A	
ASO304		1	10	45	Dec-97	1510	489	1021	355	1155	18	1492	355	489		*			305	1205	Dec-97	70			A	
ASO305		1	10	45	Feb-00	1481	160	1321	150	1331	18	1463	150	160		*		56	90	1391	Feb-00	20			A	
ASO306		2	10	45	Jun-96	1249	250	999	143	1106	143	1106	143	250		*			60	1189	Jun-97	6			A	
ASO307		2	10	45	Nov-97	1258	172	1086	112	1146		1258	112	172		*			116	1142	Nov-97	9			A	
ASO308		2	10	45	Aug-97	1267	200	1067	170	1097	18	1249	170	200		*			130	1137	Aug-97	12			A	
ASO309		2	10	45	Aug-97	1242	225	1017	170	1072	18	1224	170	225		*			130	1112	Aug-97	12			A	
ASO310		2	10	45	Apr-03	1670	125	1545	185	1485		1670	185	125		*		55	85	1585	Apr-03	30			A	
ASO311		2	10	45	Jul-97	1487	175	1312	155	1332	38	1449	155	175		*			41	1446	Jul-97	70			A	
ASO312		2	10	45	Nov-97	1624	260	1364	240	1384	23	1601	240	260		*			200	1424	Nov-97	100			A	
ASO313		20	10	46	Oct-93	823	98	725	78	745	18	805	78	98		*			56	767	Oct-93	40			A	
ASO314		20	10	45	Sep-90	1327	90	1237		1327	18	1309	18	90		*			10	1317	Sep-90					
ASO315		21	10	45	Jul-03	1204	77	1127	41	1163	41	1163	41	77		*			8	1196	Jul-03	25			A	
ASO316		21	10	45	Jul-87	1469	160	1309	34	1435	34	1435	34	160		*		63	51	1418	Jul-87	51			A	
ASO317		22	10	45	Aug-78	1074	50	1024	20	1054	20	1054	20	50		*		cold	8	1066	Aug-78	12			A	
ASO318		22	10	45	Nov-74	1095	150	945	36	1059	20	1075	36	150		*			70	1025	Nov-74	40			A	
ASO319		24	10	45	Nov-72	945	100	845	87	858	37	908	87	100		*			35	910	Jan-73	30			A	
ASO320		24	10	45	Nov-95	997	228	769	18	979	18	979	18	228		*			flowing well		Nov-95	90			A	15psi artesian pressure
ASO321		24	10	45	Oct-94	988	76	912	36	952		988	36	76		*			16	972	Oct-94	40			A	
ASO322		24	10	45	Apr-89	1087	60	1027	18	1069	18	1069	18	60		*			16	1071	Apr-89	30			A	
ASO323		25	10	45	Nov-00	994	401	593	360	634	19	975	360	401		*		54	330	664	Nov-00	30			A	
ASO324		26	10	45	Oct-01	1018	90	928	46	972	46	972	46	90		*			20	998	Oct-01	35			A	
ASO325		31	10	45	Apr-02	2309	190	2119	140	2169	88	2221	140	190		*		50	120	2189	Apr-02	50			A	
ASO326		32	10	45	Jul-03	2330	175	2155	135	2195	18	2312	135	175		*		55	115	2215	Jul-03	2			A	
ASO327		16	10	46	May-61	780	522	258	401	379		780	401	522		*		65	33	747	May-61	599			P	
ASO328		17	10	46	Mar-66	916	181	735	6	910	6	910	6	181		*			131	785	Mar-66	25	0.01	2500.00	B	
ASO329		17	10	46	Sep-85	930	285	645	44	886		930	44	285		*				930		40			A	
ASO330		19	10	46	Jul-94	927	150	777	110	817	18	909	110	150		*			8	919	Jul-94	40			A	
ASO331		20	10	46	Mar-95	837	175	662	115	722	22	815	115	175		*			97	740	Mar-95	200+			A	
ASO332		20	10	46	Mar-95	847	175	672	115	732	18	829	115	175		*			83	764	Mar-95	40			A	
ASO333		20	10	46	Jul-69	773	100	673		773		773	0	100			*	59	48	725	Jul-69	50			P	
ASO334		20	10	46	Mar-64	872	220	652	16	856		872	16	220		*		58	43	829	Mar-64	50	12	4.17	P	
ASO335		20	10	46	Mar-88	859	90	769	70	789	23	836	70	90		*			46	813						
ASO336		20	10	46	Aug-98	828	175	653	155	673	18	810	155	175		*		57	95	733	Aug-98	50			A	
ASO337		20	10	46	May-74	818	170	648	29	789		818	29	170		*			83	735	May-74	100			A	
ASO338		20	10	46	Oct-93	829	115	714	95	734	20	809	95	115		*		48	64	765	Oct-93	30			A	
ASO339		20	10	46	Nov-90	812	160	652	18	794	18	794	18	160		*			84	728	Nov-90	40			A	
ASO340		20	10	46	Oct-00	788	156	632	126	662	18	770	126	156		*		56	30	758	Oct-00	70			A	
ASO341		20	10	46	Feb-02	1043	610	433	570	473	56	987	570	610		*		57	540	503	Feb-02	30			A	
ASO342		20	10	46	Sep-89	810	100	710	27	783	20	790	27	100		*			48	762	Sep-89	40			A	
ASO343		21	10	46	Oct-02	1701	650	1051	610	1091	18	1683	610	650		*		56	520	1181	Oct-02	20			A	
ASO344		28	10	46	May-04	1727	750	977	700	1027	18	1709	700	750		*		56	520	1207	May-04	2			A	
ASO345		28	10	46	Mar-91	1923	220	1703	78	1845	22	1901	78	220		*			160	1763	Mar-91					
ASO346		28	10	46	May-01	1374	435	939	357	1017	23	1351	357	435		*		56	156	1218	May-01	30			A	
GAR280		6	9	43	Sep-91	3134	415	2719	19	3115	19	3115	19	415		*		60	375	2759	Oct-91	1.5	20	0.08	B	



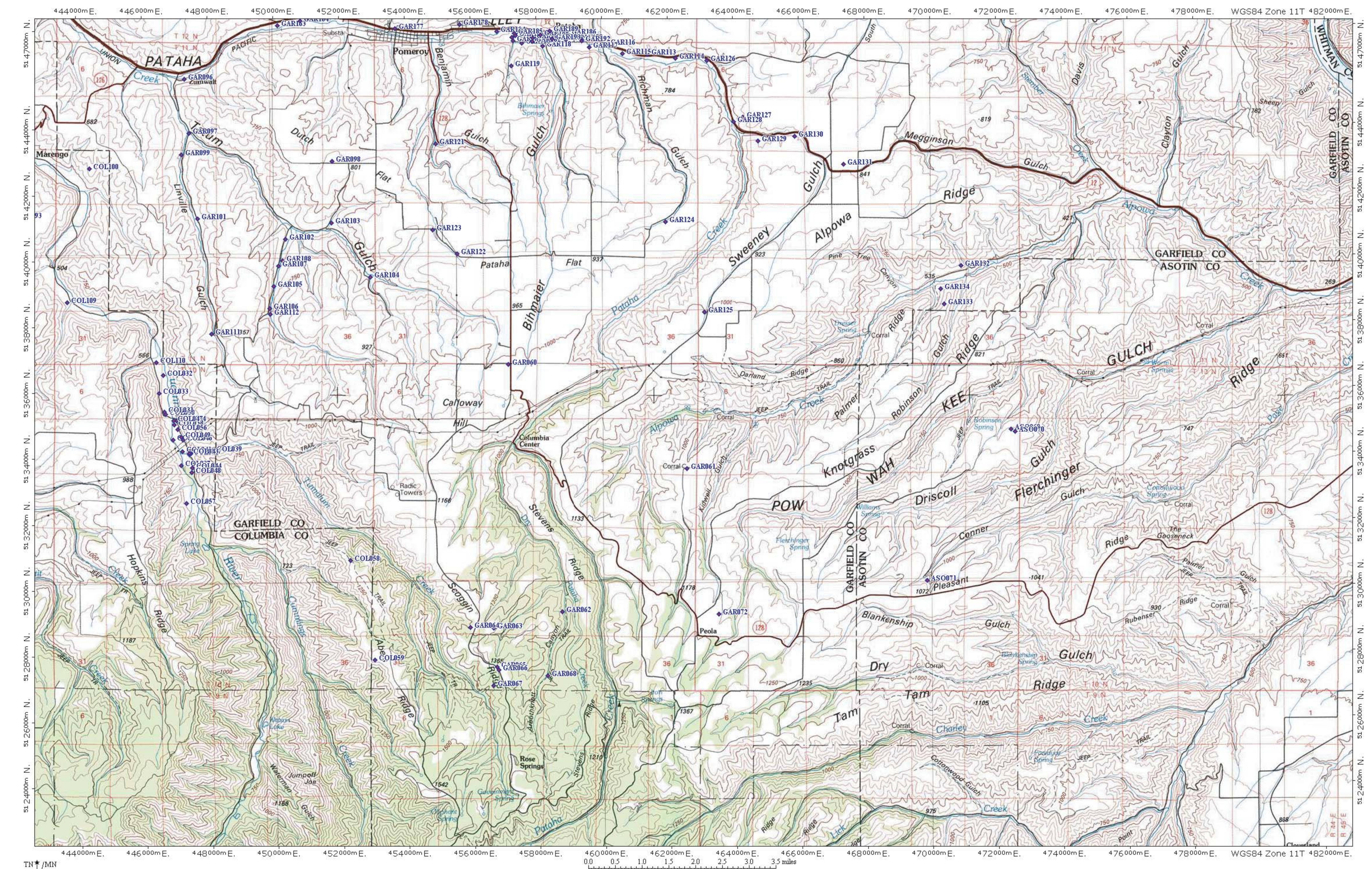
Well Location Map - Asotin



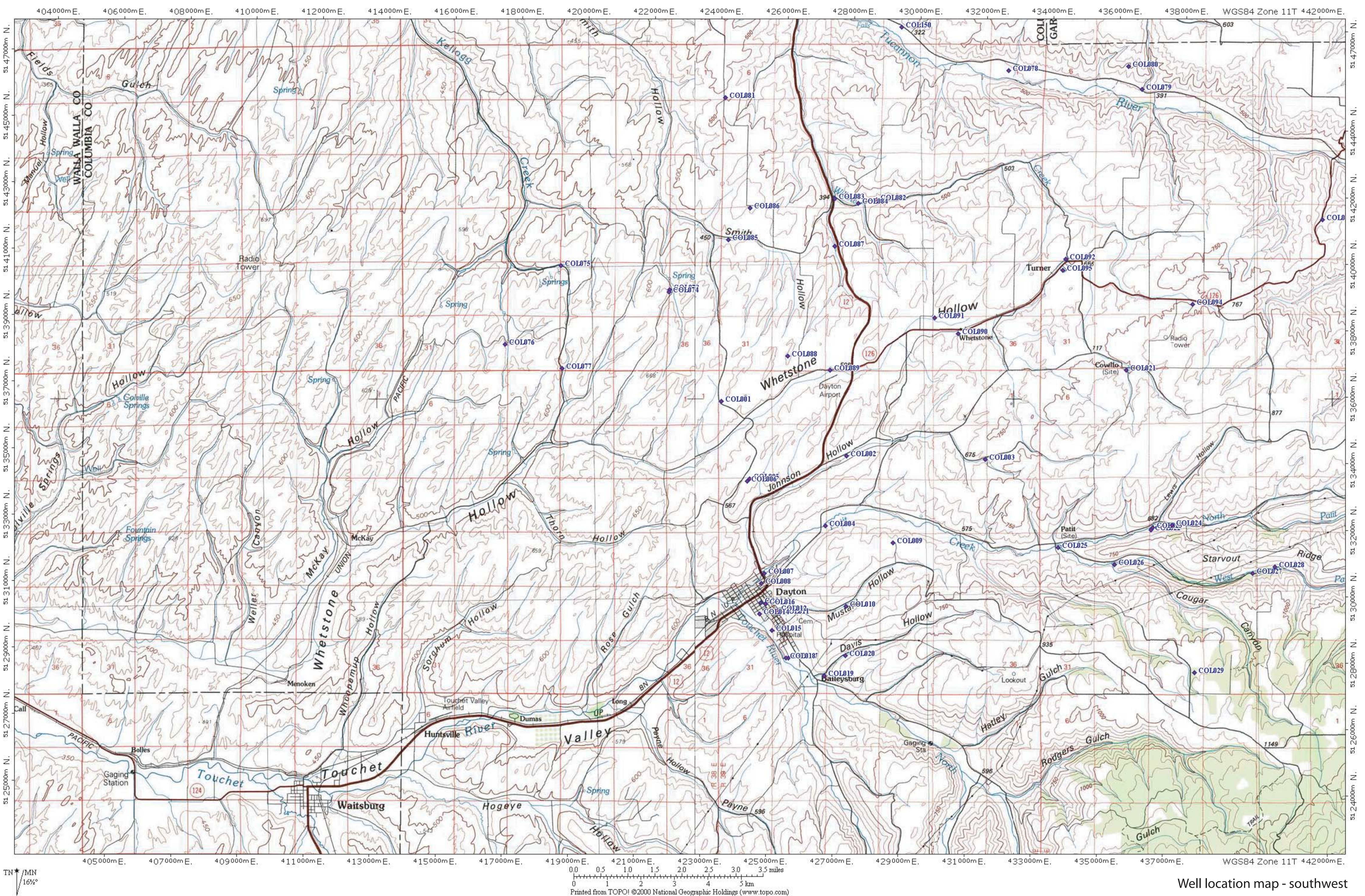
Well location map - northeast



Well location map - northwest



Well location map - southeast



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Well location map - southwest