Hydrogeologic Sub-Basins in
The Palouse area of Idaho and Washington.

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Eddy W. Teasdale

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Major Professor: John H Bush, Ph.D.

AUTHORIZATION TO SUBMIT THESIS

This thesis of Eddy W. Teasdale, submitted for the degree of Master of Science with a major in Geology and titled "Hydrogeologic Sub-Basins in the Palouse area of Idaho and Washington" has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor ____John Bush____ Date April 8/02
Dr. John H. Bush

Committee Members ____James L. Osiensky____ Date 4-8-02
Dr. James L. Osiensky

____John E. Hammel____ Date 4/20/02
Dr. John E. Hammel

Department Administrator ____________ Date 4/22/02
Dr. Dennis J. Geist

Discipline's College Dean ____________ Date 4/22/02
Dr. Earl H. Bennett

Final approval and acceptance by the College of Graduate Studies

____Charles R. Hatch____ Date 4/25/2002
Charles R. Hatch

ABSTRACT

The study area referred to as "the Palouse area" encompasses approximately 408 square miles, and includes portions of northern Idaho and eastern Washington. The Palouse area relies almost entirely on ground water for its supply of municipal, domestic and institutional water. The majority of ground water comes from two aquifers in the Miocene basalts of the Columbia River Basalt Group (CRBG) with associated interbedded gravel, sand, silt and clay. The upper aquifer is in the Priest Rapids Member of the Wanapum Formation and the deeper aquifer is in the Grande Ronde Formation. Decline in water levels in both aquifers has been the focus of considerable research into the hydrogeology of the system since the early 1970's. Ground water research has added to the general overall understanding of the region but no geologic or hydrogeologic model has adequately predicted or explained the system. Little geologic research has been conducted at scales less than 1:250,000. Previous investigations of rare outcrops along with sporadic detailed lithologic well data suggested that the basalt units are undeformed and nearly horizontal.

Several isopach and structural contour maps were constructed for the basalt and sedimentary units. These maps indicate that the rock units are not horizontal and undeformed. A review of old and new geologic data supports the conclusion that the basalts are not horizontal, and that in places they are folded into narrow anticlinal ridges separated by wide synclinal troughs. These structural features

divide the Palouse area into at least two different sub-basins. Drainage pattern differences in the Palouse area also suggest different sub-basins. In places, stream patterns can be related to structures identified on sub-surface maps and/or existing geologic maps.

Selective hydrogeological data were re-interpreted, and can be related to these sub-basins. These data consist of: ground water chemistry, carbon-14 and oxygen isotopes; ground water pump tests; static ground water levels and hydrographs. The combination of the structural contour and isopach maps, geological trends, drainage patterns, and re-interpreted hydrogeological data strongly indicate that the Palouse area is subdivided into at least two ground water sub-basins with identifiable subsurface structural features.

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INTRODUCTION

Statement of the Problem

The study area, locally referred to, as "The Palouse area" is located in southeastern Washington and northern Idaho (Figure 1). The area includes the two communities of Moscow, Idaho and Pullman, Washington, both of which have major state universities, the city of Colfax, the city of Palouse, and portions of Latah and Whitman counties. The Palouse area depends on ground water for the majority of its municipal, domestic and industrial needs. Primarily the ground water comes from two aquifers in basalt flows of the Columbia River Basalt Group (CRBG). The upper aquifer is in the Wanapum Formation, and the deeper main aquifer, is in the Grande Ronde Formation. Decline in ground water levels in both aquifers has been the focus of considerable hydrogeological research over the last thirty years.

Previous geologic and hydrogeologic research has focused on localized areas, with emphasis near the towns of Moscow and Pullman and their associated universities. Several agencies have sponsored ground water modeling studies to be used as predictive tools, and to help forecast ground water development within the Palouse area. For example, Smoot and Ralston's model (1987) suggested that if the Palouse area could stabilize their ground water pumpage, the Grande Ronde Aquifer would be able to supply enough water without a

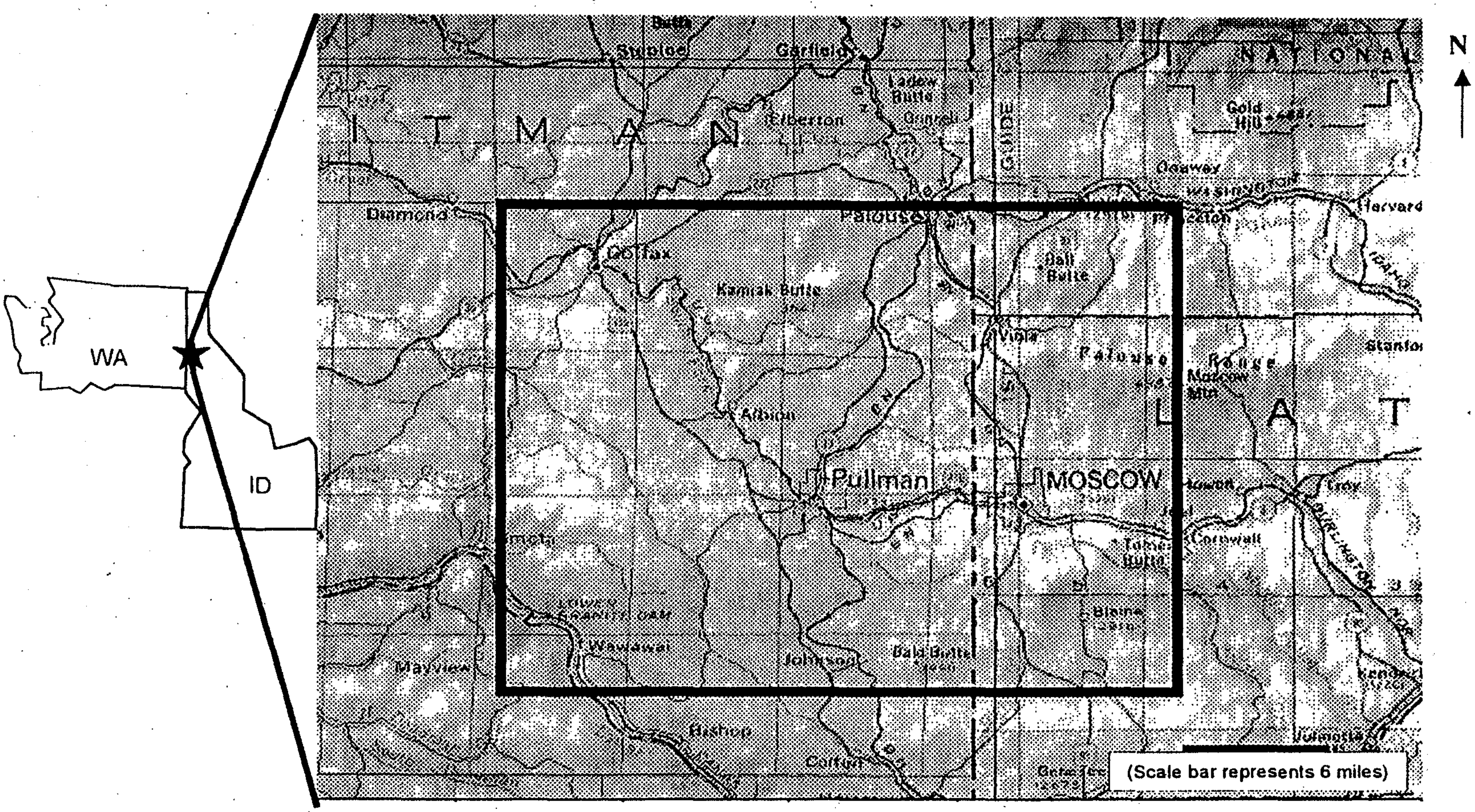

Figure 1. Location map of the Palouse area.

significant amount of decline in ground water levels. However, ground water levels continued to decrease, with constant usage, indicating that one or more parameters of the predictive model were not correct. The long-term decline of ground water levels is still a major issue.

The geologic parameters in the Palouse area may not be defined well enough for hydrogeologic modeling on a small scale. The most detailed geologic maps (1:24,000) in the area focus primarily around the cities of Moscow and Palouse (Bush and others, 2000; Bush and others, 1998a, b; Bush and Provant 1998, Duncan 1998, Pierce 1998, and Bush, 1996). The Pullman area was mapped at a scale of 1:62,000 by Hooper and Webster (1982). The remainder of the Palouse area has been mapped at a reconnaissance scale of 1:250,000 (Swanson and others, 1980a). In summary, some detailed geologic mapping has been done, but it has been limited to specific areas within the Palouse area. Overall detailed geologic mapping encompassing the whole "Palouse area" has not been done. In addition, very little detailed subsurface geologic data have been collected.

Numerous aspects of the geologic parameters of the Palouse area need to be studied. The purpose of this study was to help understand the ground water resource problems in the Palouse area. The study is a preliminary investigation of the subsurface geology and of the effects the geology has on influencing and controlling the ground water resources of the Palouse area.

Purpose and Objectives

The specific purpose of this study was to better understand the subsurface geology of the "Palouse area" and its relationship and potential control over local ground water. The primary goal of this study was to produce isopach and structural contour maps of specific stratigraphic units and horizons that could be used to assist in the delineation of regional structural trends. Geological Survey (USGS) topographic 7 ½ minute quadrangle maps were used as a base. The quadrangles used were as follows: Diamond, Colfax North, Elberton, Wilcox, Colfax, Albion, Almota, Ewartsville, Palouse, Viola, and Moscow West.

Specific objectives of the study include:

1. Compile and tabulate geologic and hydrogeologic data for wells located within the Diamond, Colfax North, Elberton, Wilcox, Colfax, Albion, Almota, and Ewartsville 7 ½ minute USGS quadrangles of southeastern Washington.
2. Compile and tabulate data for wells located within the Palouse, Viola, and Moscow West 7 ½ minute quadrangles of western Idaho.
3. Construct a structural contour map of the top of the Grande Ronde Basalt for the Palouse area.
4. Construct a structural contour map of the top of the Wanapum Basalt for the Palouse area.
5. Construct an isopach map of the Wanapum Basalt for the Palouse area.
6. Construct a structural contour map of the top of the Vantage Member for the Palouse area.
7. Construct an Isopach map of the Vantage Member for the Palouse area.

8. Determine potential structural features and different sub-basins from the three structural contour and two isopach maps for the Palouse area.

9. Relate stream patterns to potential structures and sub-basins in the Palouse area.

10. Review selected ground water data and compare these data to potential structures and sub-basins in the Palouse area.

Previous Research

Geology

Regional geology of the Columbia River Basalt Group (CRBG) was investigated by Swanson and others (1979,1980b). They presented the first comprehensive stratigraphic framework for the CRBG. Reidel and others (1989) provided a complete stratigraphic framework of the Grande Ronde Formation. Hooper (1982), Hooper and others (1984), and Hooper (1997) discussed regional trends and emplacements of the basalts.

Local geology was investigated by Johnson and Myrene (1929), Tullis (1940, 1944), Carmichael (1956), Crosby and Cavin (1960), Hosterman and others (1960), Ross (1965), Lin (1967), Ringe (1968), Brown (1976), Rember and Bennett (1979). Hooper and Webster (1982) produced a 1:62,000 geologic map of the Pullman quadrangle. Anderson (1991) investigated the geology and completed a structural analysis of Tomer Butte, Middle Potlatch Creek and Little Potlatch Creek areas. Gulick (1994) compiled a 1:100,000 geologic map of the Pullman area. Provant (1995) investigated the geology and hydrogeology of the Viola and Moscow West quadrangles. Pierce (1998) investigated the geology and hydrogeology of the Moscow East and Robinson Lake quadrangles. Four bedrock geologic maps at 1:24,000 (Bush and Provant, 1998; Bush and others 1998a, b; and Bush and others, 2000) and two surficial maps of the Moscow area have been completed by the Idaho Geologic Survey (Othberg, 1982; Othberg and Breckenridge, 2001)

Crosby and Cavin (1960) applied general geophysical methods to define thickness, and stratigraphic boundaries in the basalt sequences. Klein and others (1987) using geophysical methods estimated the thickness of the Grande Ronde Formation in the area. Surficial deposition, general topography and local climate as well as general soil types were discussed by Agee and others (1917), Fryxell and Cook (1965), Baker and others (1991 and 1989), Othberg (1982), and Othberg and Breckenridge (2001).

Hydrogeology

Russell (1897) compiled the first documented ground water information in the Palouse area. Russell (1897) noted that in 1890, 10 of 14 wells drilled in the Wanapum Basalt of the Palouse area were flowing artesian, but by 1896 water levels in those wells had declined an average of 8-9 feet. Laney and others (1923), Foxsworthy and Washburn (1963), Ross (1965), and Jones and Ross (1972) investigated the basic hydrogeology within the Moscow-Pullman area. Crosthwaite (1975) studied local effect of the geology on local ground water systems. Water well logs and well construction schematics were correlated to develop a general overview of the geology and hydrogeology. Lin (1967) and

Williams and Allman (1969) investigated the amount of recharge coming into the basin.

Several numerical and mathematical models were produced. These ground water models were used as a predicative management tools to model ground water in the Palouse area (Jones and Ross, 1972; Barker, 1979; Smoot and Ralston, 1987; Lum and others, 1990; and Brown, 1991). Baines (1992) and Kopp (1994) investigated the upper Wanapum Aquifer. Li (1991) used borehole geophysics and multiple pump tests to characterize the University of Idaho Ground Water Research site. Kopp (1994) performed aquifer tests at the University of Idaho Aquaculture site. Heinemann (1994) investigated the relationship of streams to ground water in the western portion of the Moscow-Pullman area. The Palouse Basin Aquifer Committee (PBAC), which was formed in the late 1960's, has published several annual reports on the overall water usage of the Moscow-Pullman area (Gill, 1999; and McKenna, 2000 and 2001).

Method of Study

A literature review of previous work, and a data search for well logs was begun in September of 1999. Several hundred well logs have been compiled for this study, resulting in a database (Figure 2, and Appendix A and B) of approximately 250 wells. Some of the well data including locations were obtained from previous work of Heinemann, 1994; Provant, 1995; Duncan, 1998; Beck, 2000, personnel communication; and Bush and others, 2001. The remaining data points were obtained from water well logs and plotted on standard 1:24,000 topographic maps. Well logs were not used if the descriptions were not clear and/or the geological terminology was misleading. The following list the assumptions and criteria used for determing stratigraphic units:

1. All well logs were cross-referenced with existing geological maps to determine stratigraphic units.
2. The Wanapum Formation was not subdivided into members, although in places it consists of both the Priest Rapids and the Roza Members.
3. In areas where the Saddle Mountains Basalt is known to exist, stratigraphic determinations where made based on major lithological breaks and the Wanapum Basalt was assumed to occur beneath the first encountered Saddle Mountain Basalt. The two basalt units are generally separated by a sedimentary interbed.
4. The first interbed beneath the Wanapum Basalt, that was greater than five feet in thickness, was considered to be part of the Vantage Member.
5. The basalts underlying the Vantage Member were assumed to be part of the Grande Ronde Formation.

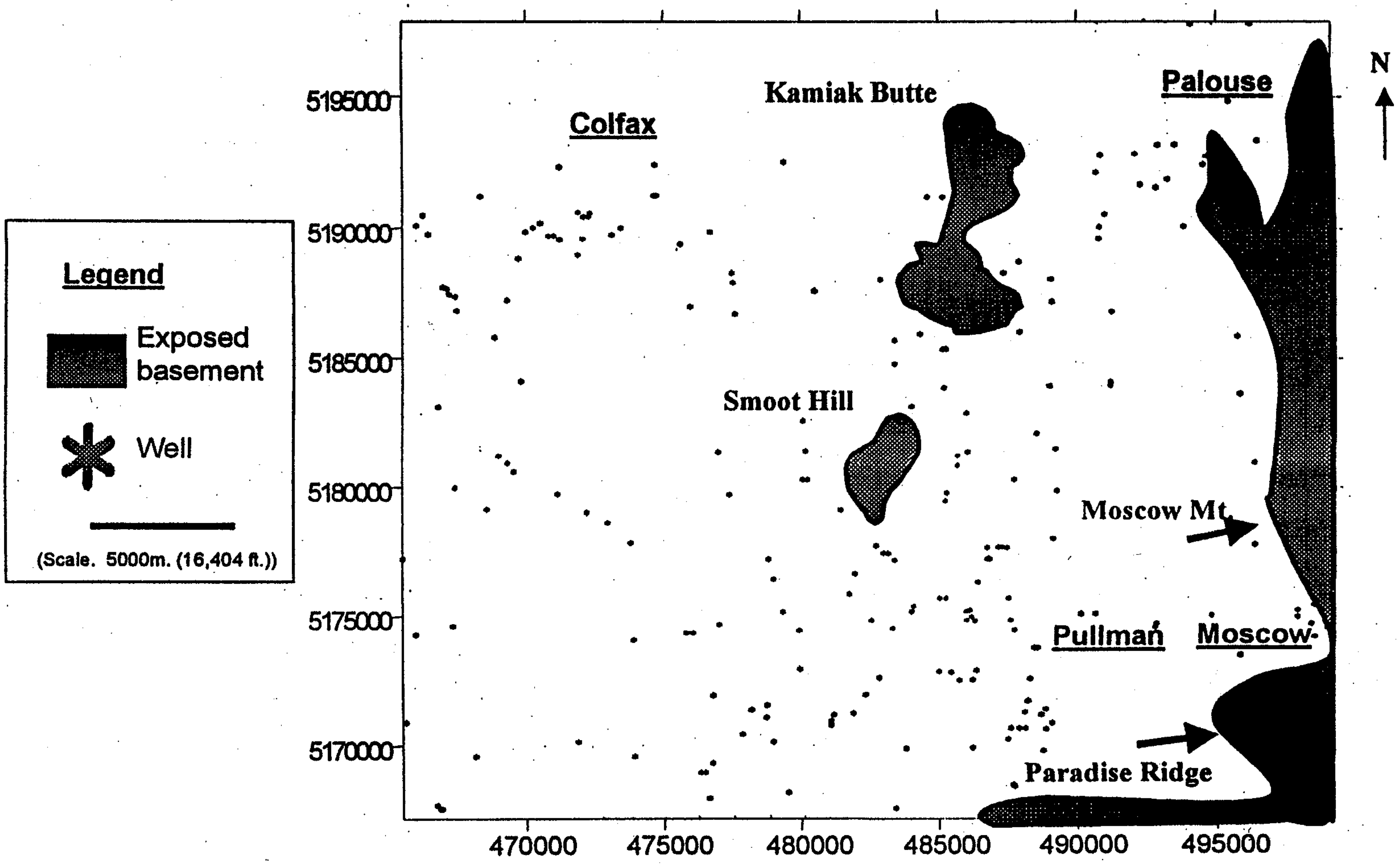

Figure 2. Location map of wells researched in the Palouse area.

Surface elevations were determined from 1:24,000 topographic maps and/or a combination of several different additional independent sources (Heinemann, 1994; Provant ,1995; Duncan,1998; Beck, 2000, personnel communication; and Bush and others, 2001). Several subsurface maps were generated from the well data. Elevations for the top of Grande Ronde, Wanapum and Vantage were used to construct structural contour maps. Isopach maps were constructed for the Wanapum and Vantage. It was more efficient to initially use a computer software package to generate individual isopach and structural contour maps because of the large number of data points. These maps where then manually modified to account for exposed basement rock.

The structural contour maps were compared to other information to help locate potential structures. For example, regional and local stream patterns were examined and compared to trends noted on the subsurface maps as well as a compiled 1:100,000 geologic map by Gulick (1994). In addition, geologic data from previous research by Brown (1976), and Bush and others (2001) were used to aid in interpreting the subsurface features in the basalts. Hydrogeologic data from previous researchers; (Foxsworthy and Washburn (1963), Beck (2001), and Larson and others, (2000)) included ground water levels, isotope chemistry and pump test data. These hydrogeologic data where used along with the subsurface maps, geologic data, and geomorphic data to aid in the identification of potential sub-basins within the Palouse area. From all the data, it is suggested that structural features may form partitions within and between those sub-basins.

GEOLOGIC SETTING

Regional Geology

The Columbia River Basalt Group (CRBG) forms the Columbia River Plateau. These Miocene basalts erupted from NNW linear fissure systems (Swanson and others, 1975) varying in length from tens to hundreds of kilometers (Figure 3). Most of the dikes have been thought to be fed by the Chief Joseph Dike Swarm located near the Idaho, Washington and Oregon borders (Hooper, 1997). The extent of the CRBG has been the topic of numerous debates, but total volumes have been estimated to vary between 174,000 km^3. (Reidel and others, 1989) and 222,400Km^3 (Camp, 2000)

The Imnaha Formation (17.5 Ma) was the first of a sequence of basalts to be erupted from these feeder dikes (Figure 4) and makes up 5.4% by volume of the CRBG (Tolan and others, 1989). The Grande Ronde Basalt was subsequently emplaced (16.5- 15.5 Ma) and makes up 87% by volume of all the CRBG (Reidel and others, 1989). Grande Ronde Basalt is typically fine-grained, aphyric and tholeiitic in composition. The Grande Ronde flows were erupted during two normal and two reversed magnetic polar events (Swanson and others, 1979). Magnetic polarity orientations have traditionally been used to distinguish the Grande Ronde units in the field and have been designated from oldest to youngest as R_1, N_1, R_2, and N_2. Up to 17 different units are thought to exist

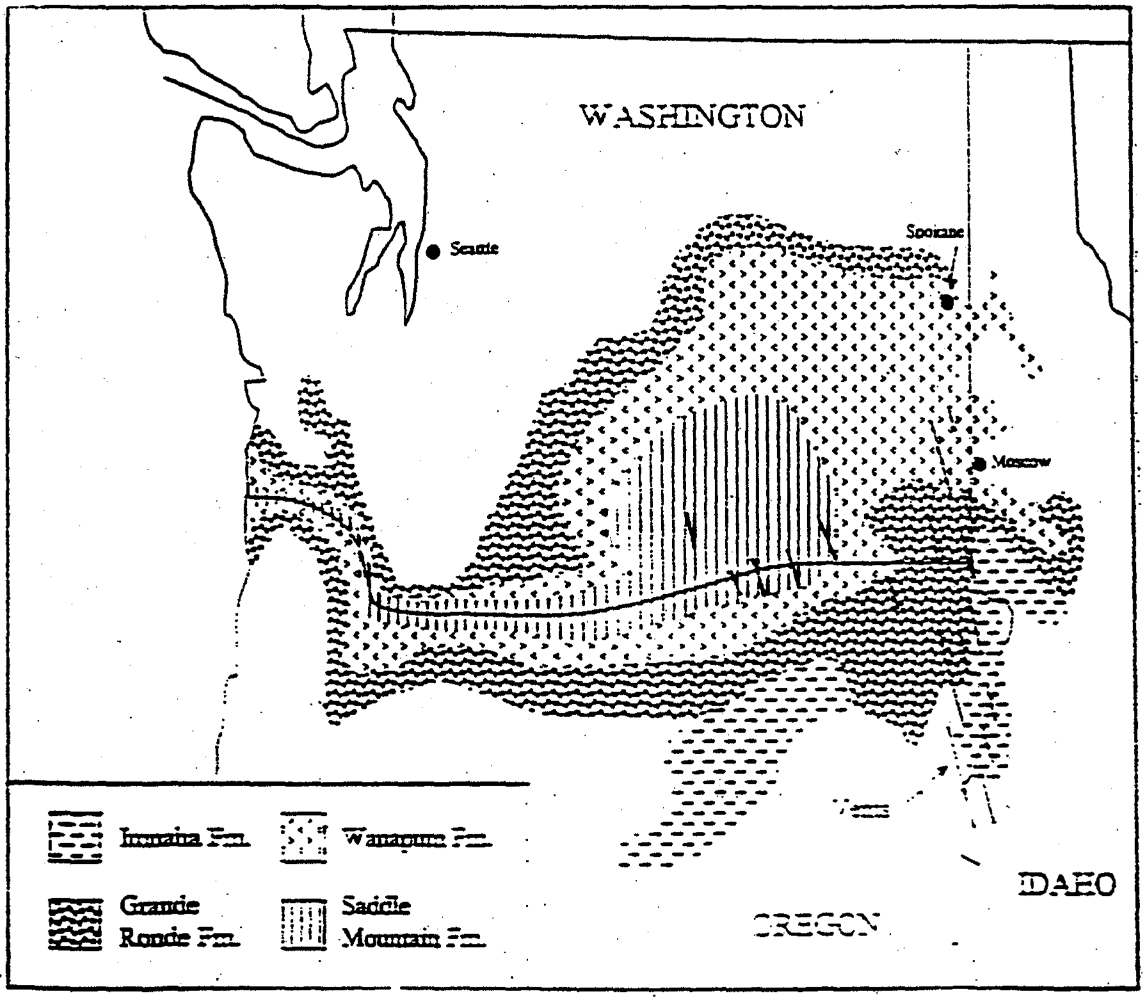

Figure 3. Generalized distribution of the Columbia River Basalts (modified from Provant, 1995).

GROUP	SUB-GROUP	FORMATION	MEMBER	MAGNETIC POLARITY	DATE (M.Y)
COLUMBIA RIVER BASALT	YAKIMA BASALT	SADDLE MOUNTAIN BASALT	LOWER MONUMENTAL	N	6
			ICE HARBOR	N,R	8.5
			BUFORD	R	
			ELEPHANT MOUNTAIN	N,T	
			POMONA	R	12
			ESQUATZEL	N	
			WEISSENFELS RIDGE	N	
			ASOTIN	N	13
			WILLOW CREEK	N	
			UMATILLA	N	
		WANAPUM BASALT	PRIEST RAPIDS	R	14.5
			ROZA	T,R	
			FRENCHMAN SPRINGS	N	15.3
			ECKLER	N	
		GRANDE RONDE	BASALT	N2	15.5
		PICTURE GORGE BASALT		R2	
				N1	
				R1	16.5
		IMNAHA BASALT		T N R	17.5

Figure 4. Generalized stratigraphic terminology of the Columbia River Basalt Group
N= Normal mangnetic polarity, T= transitional magnetic polarity, R= Reversed magnetic polartiy
(Modified from Provant 1995).

within the Grande Ronde Basalt; however, they are distinguishable only through precise geochemical, stratigraphic and paleomagnetic analysis.

The Wanapum Formation began emplacement approximately 15.3 Ma and make up about 6% of the CRBG (Tolan and others, 1989). The Wanapum Basalt is divided into four members; from the base upward they are the Eckler Mountain, Frenchman Springs (15.3 Ma), Roza, and Priest Rapids (14.5 Ma, Swanson and others, 1979). The overlying basalts of the Saddle Mountains Formation were extruded up to 6 Ma (Tolan and others, 1989). The Saddle Mountains Formation has been divided into approximately 19 different flows and makes up about 1.4% by volume of the CRBG (Tolan and others, 1989).

Local Geology

The Palouse area can be subdivided into five major geologic units. These units are as follows: the pre-Cretaceous metamorphic rocks, Cretaceous granitoid rocks, Miocene Columbia River Basalt Group, the Miocene Latah Formation, and the Pleistocene Palouse Loess.

The pre-Cretaceous rocks are comprised of phyllite, quartzite, schist, and gneiss (Gulick, 1994; Lewis and others, 2001). The oldest units are the Proterozoic Syringa metamorphic sequence (Lewis and others, 2001). Paradise Ridge and other high topographic areas in the Palouse area are considered to belong to this sequence. Other ridges and buttes such as Kamiak Butte and Smoot Hill are considered to belong to the pre-Cretaceous metasediments of the Belt-Supergroup (Gulick, 1994). Underlying and intruding the pre-Cretaceous units is the intrusive granite (55-67 Ma). This granite intrusion is related to the Idaho batholith and makes up most of the Palouse Range. Several areas in the Palouse area have pre-basalt units exposed at the surface (Figure 5).

The CRBG overlies the pre-Cretaceous and granitoid rocks. The CRBG in the Palouse area can be divided into four formations. These formations from oldest to youngest are: Imnaha, Grande Ronde, Wanapum, and Saddle Mountains formations. Imnaha Basalt has only been identified at the bottom of Washington State University well number 7 (Bush and others, 2001). Bush and others (2001)

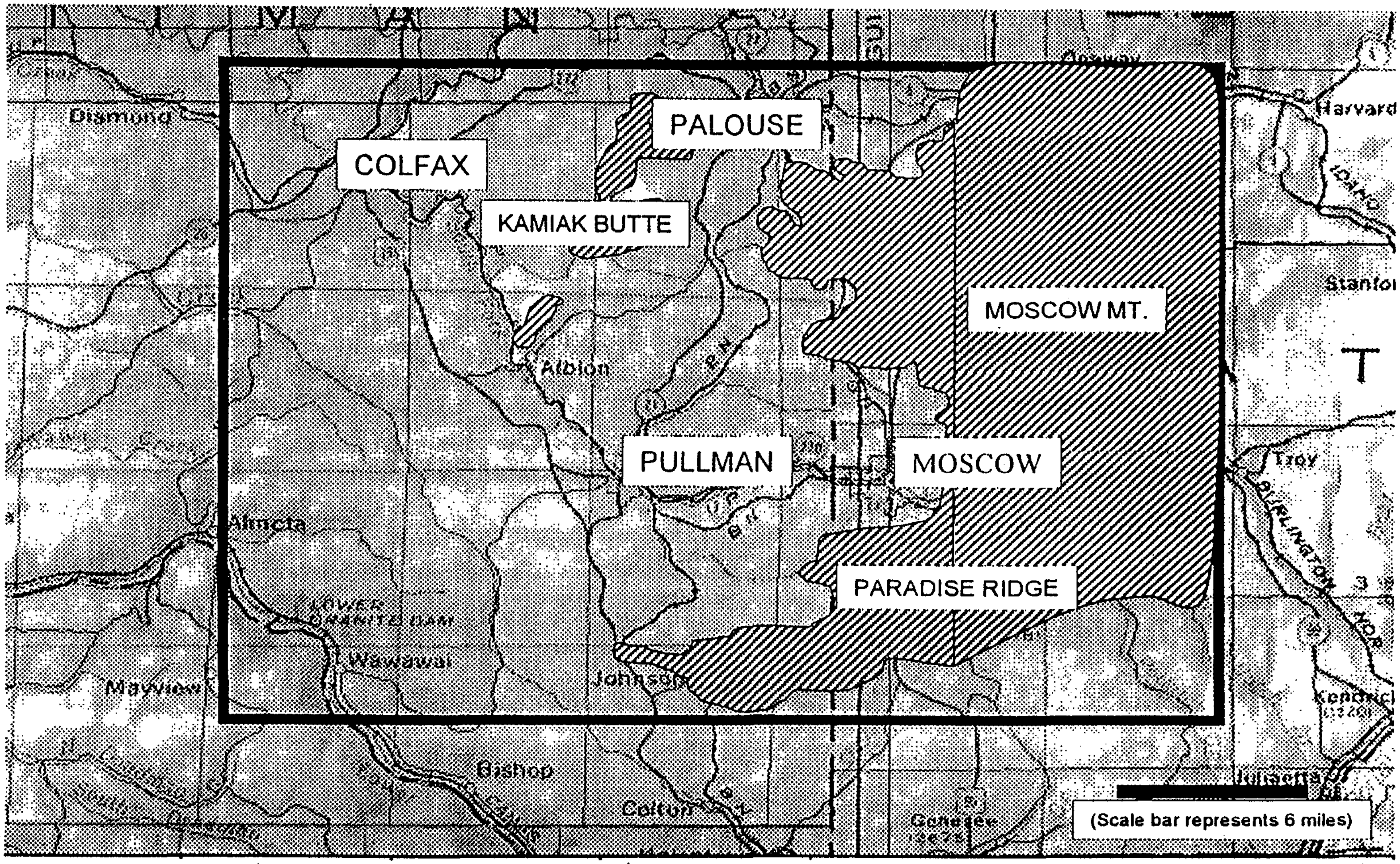

Figure 5. Map showing distribution of pre-basalt units in the Palouse area.
Striped areas have exposed pre-basalt rocks at the surface.

believe that all four units (R_1, N_1, R_2, and N_2) of the Grande Ronde Basalt exist in the Pullman area. The Roza and the Priest Rapids are the only known members of the Wanapum Formation to occur in the study area. The Roza Member is exposed at locations in Colfax, on Almota Grade, and in Glenwood Canyon. The Priest Rapids is the youngest Wanapum flow and is also the most widespread basalt flow represented in the Palouse area. Three members of the Saddle Mountain Basalt are known to exist in the southwest part of the study area. These members are the Umatilla, Wilbur Creek and the Asotin.

The basalt flows are in places separated by sand, silt and clay interbeds. Miocene sediments also overlie the basalt flows in the Moscow area. As a group, the sediments and interbeds belong to the Latah Formation. The Latah Formation has been subdivided from oldest to youngest into three members as follows: the sediments of Moscow, the Vantage and the sediments of Bovill (Bush and others, 1998a). The total thickness of all the sediments vary between 600-900' in the Moscow subsurface (Bush and others, 1998a).

The oldest Latah unit, the sediments of Moscow, occurs as several sedimentary layers separating individual Grande Ronde Basalt flows (Bush and Provant, 1998). These sediments formed as a result of basalt flows damming westward flowing streams, subsequently causing deposition on flood plains, in small lakes and as deltas. This damming process would have occurred numerous times, resulting in the formation of several sediment lenses (Bush personnel communication, 1999).

The Vantage Member of the Latah Formation separates the Wanapum Formation from the Grande Ronde Formation. Some parts of these sediments are thought to have formed similar to the interbeds between the Grande Ronde Basalt flows. However, the Vantage is more laterally extensive than the other interbeds (Siems and others, 1974). Garwood (2001) and Bush and others (2001) note that away from basement margins these types of interbeds are deposited in deformation lows and are not always caused by basalt dams.

The sediments of Bovill of the Latah Formation overlie the Wanapum Basalt. The origins of these sediments include fluvial, lacustrine, bog, and deltaic environments. The majority of these sediments are believed to have deposited in fluvial environments. These sediments range up to 300 ft. in thickness and cover much of the Wanapum in the Moscow area (Pierce, 1998).

Pleistocene Loess of the Palouse Formation overlies all the bedrock units in the Palouse area. These wind-blown sediments range in thickness from 0-200 ft. in the study area and are thought to have originated from sources southwest of the Palouse area (Othberg and Breckenridge, 2001).

Miocene Folds, Dikes and Faults

Background Discussion

The study area is located on what is called the Palouse slope which is generally considered to lack subsurface deformation features (Watkinson and Hooper, 2000). The premise of this study is that the Palouse area is more deformed than previously believed. It is assumed that the area contains folds, faults and dikes that are not easily detectable at the land surface. Linear brecciated zones that occur within the fold axes or along fault traces could also be common in the Palouse subsurface.

Three types of brecciated zones were found to occur within the folds in south central Washington; (1) shattered, (2) anastomosing, and (3) shear zone breccias (Price and Watkinson, 1989). Shatter breccias tend to maintain the original internal columnar structure. Fractures occur on the order of millimeter to centimeter scale. Anastomosing breccias are non-tabular in appearance without systematic orientation. Secondary mineral growth within the lenticular fractures of the breccia has cemented the breccias into a lithologic unit that is resistant to weathering such that the breccias are commonly found standing out in relief. The third type, shear zone breccia, is a direct result of faulting occurring within the basalt. Fine-grained fault gouge material was also detected on the slip surfaces of the shear zone breccias in the Priest Rapids Member of the Wanapum Basalt (Price and Watkinson, 1989).

Folds

Newcomb (1969 and 1970) investigated the regional tectonic deformation of the CRBG in Washington, Oregon and Idaho. He illustrated numerous large-scale anticlines and synclines over much of the Columbia River Plateau. Several secondary, parasitic folds or groups of folds were identified within the primary folds in northeastern Oregon (Newcomb, 1969).

Locally, Brown (1976) correlated well data between Moscow and Pullman, and showed a downwarp in the Grand Ronde Basalt east of Pullman. In the Priest Rapids Member of the overlying Wanapum Basalt, Brown (1976) noted that a possible anticlinal structure could exist just east of Pullman. Brown (1976) further suggested that the basalts west of Pullman could also be folded. Foxsworthy and Washburn (1963) had earlier suggested that the basalts in the Moscow-Pullman area were folded. Bush and others (2001) correlated well data between Pullman, Moscow and the city of Palouse and suggested that northwest plunging folds may exist. Bush and others (2001) agreed with Brown (1976) about the presence of a synclinal warp in the upper Grande Ronde Basalt between Moscow and Pullman.

Northwest folds have been suggested in the Palouse area by surface mapping. Swanson and others (1980b) mapped two northwest trending folds southwest of the Pullman area. Southeast of the Palouse area, near Lewiston Idaho, Garwood (2001) documents numerous northwest trending folds. In addition, Bush and others (2001) noted northwest trending folds along the Snake River, approximately 15 miles southwest of Pullman. It is suggested here in that similar northwest trending folds likely exist in the Palouse area.

Dikes and Faults

North and northwest trending dikes have been documented on the Palouse slope southwest of Pullman since 1975 (Swanson and others, 1975). These Roza dikes are located approximately 12 miles southwest of Pullman. Hooper and Webster (1982) mapped Priest Rapids dikes within the city limits of Pullman. Grande Ronde dikes crop-out along the north side of the Snake River, approximately 15 miles southwest of Pullman. The perimeter of these dikes are glassy, fine-grained and rapidly decompose to clays.

The basalts in the Palouse area rarely crop-out and generally, only portions of the uppermost Wanapum are exposed. Therefore, detection of Wanapum dikes is difficult and detection of Grande Ronde dikes is not likely. Determination of dikes from drilling is not possible without detailed sampling and chemical analysis. It is certain that there are more dikes present in the Palouse area than depicted on existing maps.

Major faults have not been documented in the Palouse area. However, with the lack of exposures the presence of faulting with breccias and gouge cannot be ruled out. Elevation differences noted for the Wanapum flows both at the surface and subsurface could be explained by faulting. Weathered zones between fractures in the Wanapum are dominated by clay. Clays are common in exposures between Moscow and Pullman. Some of these may be faults, but no major movement has been documented.

STRUCTURAL CONTOUR AND ISOPACH MAPS

Results

Three structural contour maps and two isopach maps were constructed to help interpret the subsurface geology of the Palouse area. The structural contour maps illustrate: (1) the top of the Grande Ronde Basalt, (2) the top of the Wanapum Basalt and (3) the top of the Vantage Member. The isopach maps illustrate the thickness of the Wanapum Basalt and the Vantage sediments.

Grande Ronde Basalt

Elevation data for the top of the Grande Ronde Basalt were used to create a structural contour map (Figure 6). The top of the Grande Ronde in the western half of the Palouse area varies in elevation from 2500 feet. approximately 6 miles southwest of Pullman, to 2300-2400 feet. in Pullman and decreases to 2000 feet. in the Colfax area (Figure 6). The Grande Ronde surface west of Pullman, between the Pullman and Colfax area, slopes to the northwest. East of Pullman, the surface of the Grande Ronde slopes toward Moscow (Figure 6). The elevation of the top of the Grande Ronde in the Moscow area varies from 2100-2300 feet. The Grande Ronde surface increases to 2400 feet. near the city of Palouse. The slope of the basalt east of Kamiak Butte is toward the city of

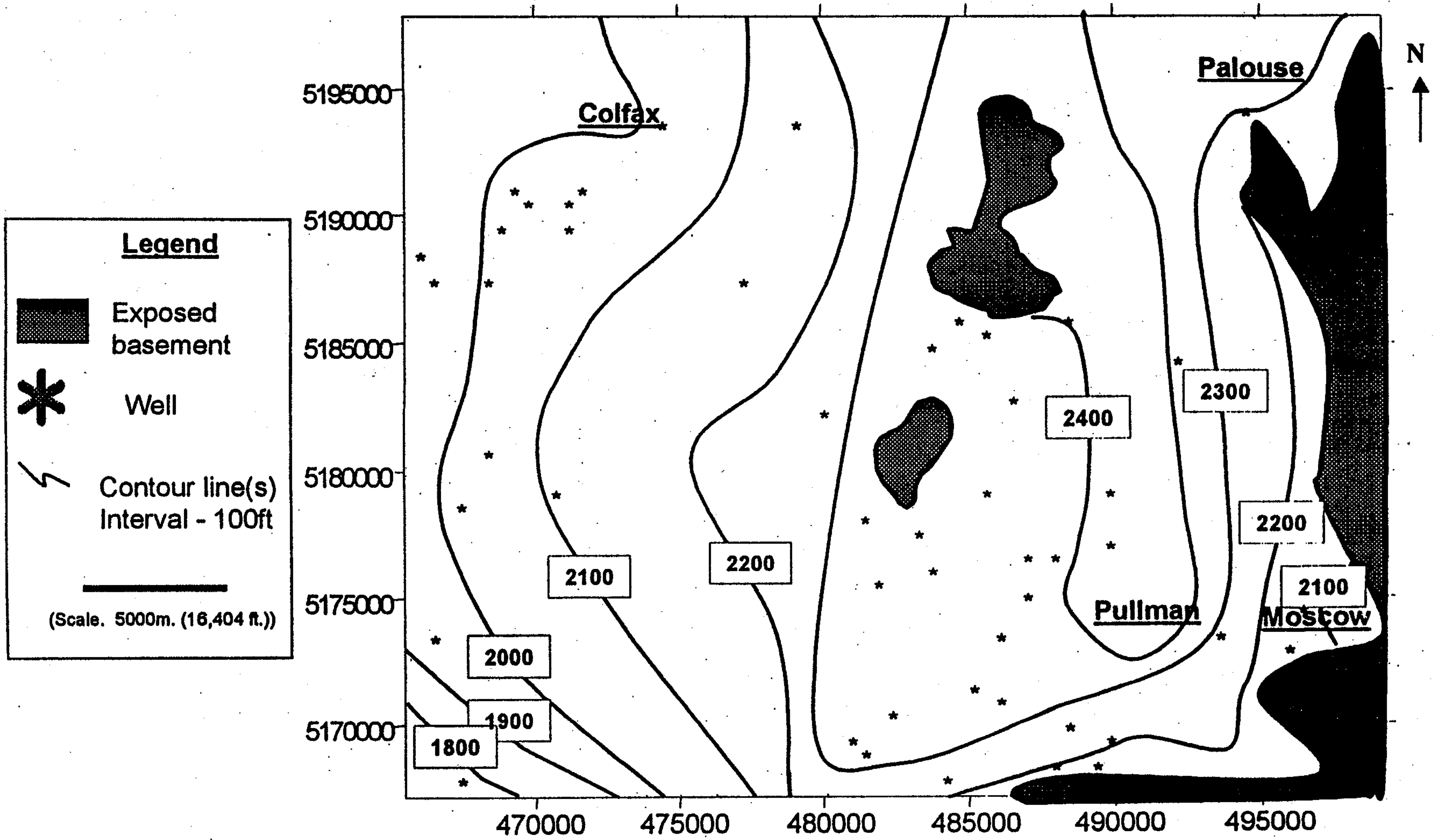

Figure 6. Structural contour map of the top of the Grande Ronde in the Palouse area.

Palouse. The difference in elevation between the Pullman area and Moscow area agrees with previous work of Brown (1976).

Wanapum Basalt

Two sub-surface maps were constructed for the Wanapum Basalt. Figure 7 is a structural contour map of the upper most surface and Figure 8 is an isopach map of the Wanapum. The top of the Wanapum averages approximately 2450 feet. in the Moscow area, 2400-2500 feet in the Pullman area, 2150feet in Colfax area, and 2450-2500 feet in the Palouse area. West of Pullman, the surface of the Wanapum dips to the northwest. The Wanapum Basalt increases in thickness from the Pullman area toward the Moscow area. Along the eastern most boundary including the Moscow area and northward towards the city of Palouse, the thickness of the Wanapum varies between 160 and180 feet. The thickness of the Wanapum decreases towards Pullman and northwest towards the city of Colfax.

Vantage Member

Two sub-surface maps were constructed for the Vantage sediments. Figure 9 is a structural contour map of the upper most surface and Figure 10 is an isopach map of the Vantage. The thickness of the Vantage Member (Figure 10) appears to be consistent (20-40 feet) throughout much of the study area. There are three

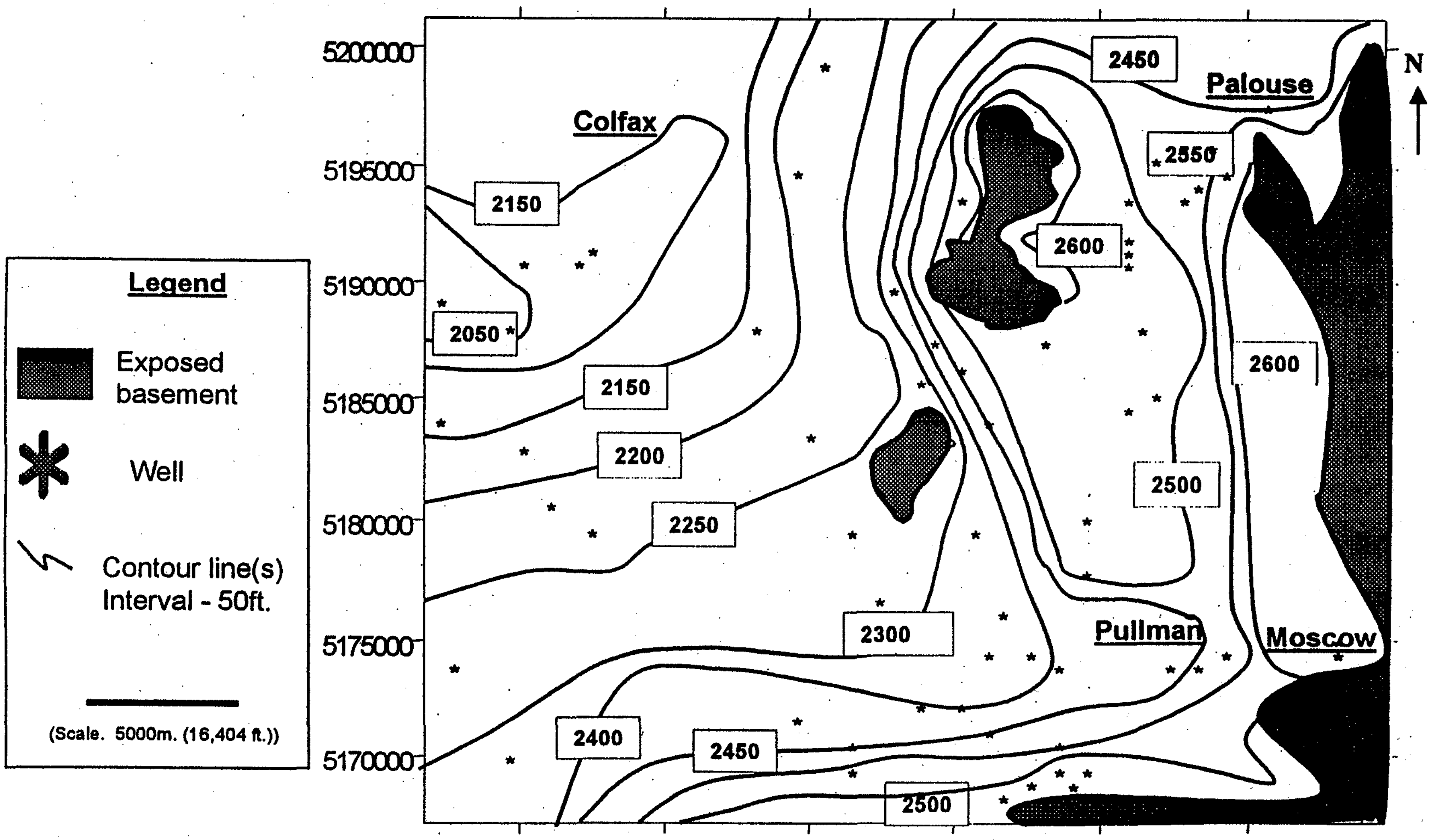

Figure 7. Structural contour map of the upper surface of the Wanapum Basalt In the Palouse area.

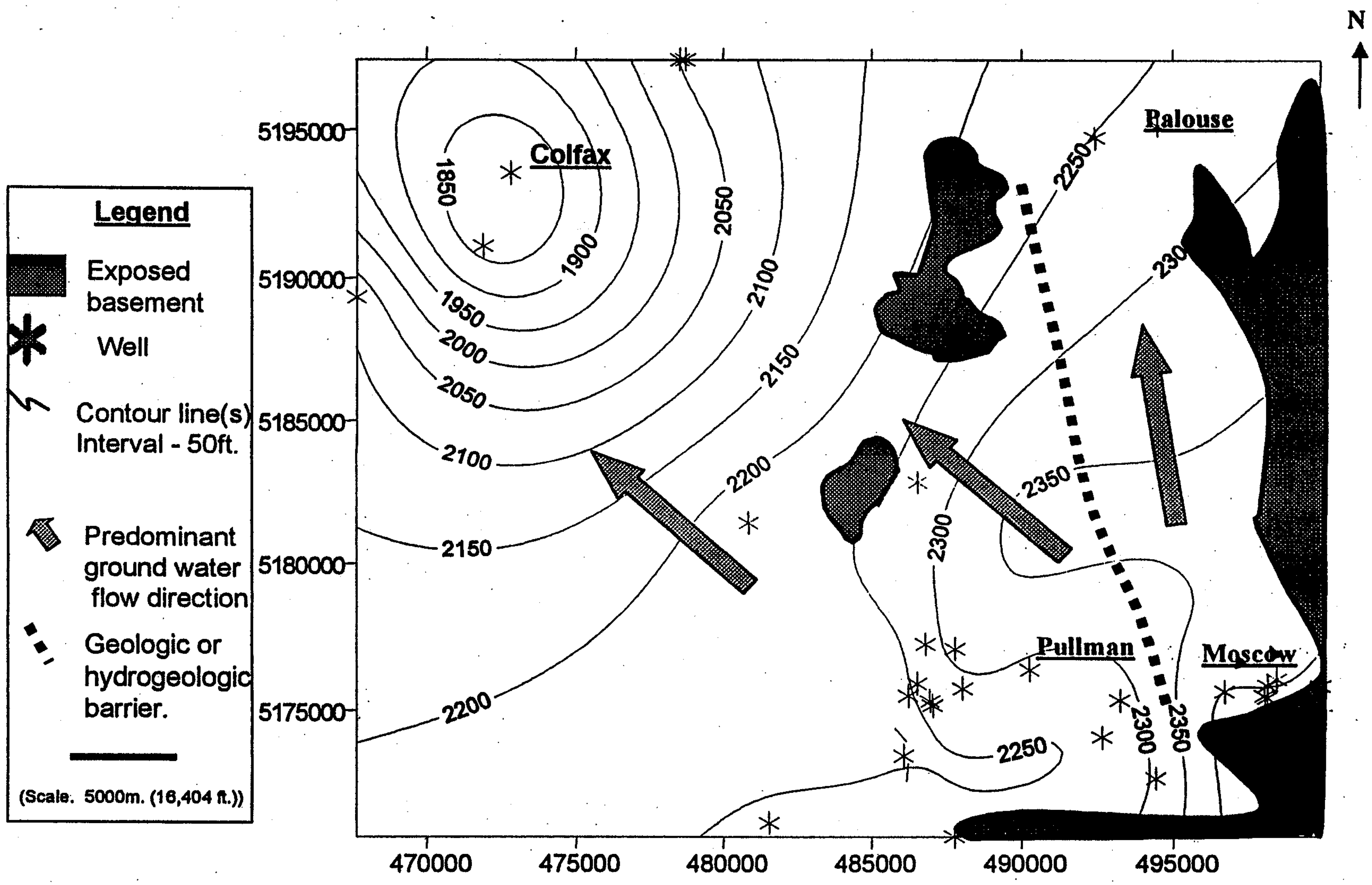

Figure 23. Ground water contour map of water elevations for wells completed in the Grande Ronde. In the Palouse area. Note two general trends of ground water flow direction.

Pump Tests

Recent ground water pump test data suggest that there is a hydraulic connection between Moscow and the city of Palouse (Beck, 2001) in the Grande Ronde Aquifer. Two Aquifer tests were conducted, one in Moscow and one in Pullman. The study entailed that all municipalities would not pump ground water, except for the city performing the test. Transducers (monitor ground water pressure changes) were installed at various monitoring points throughout the area (Colfax, Pullman, city of Palouse, and Moscow), and ground water levels in the Grande Ronde Aquifer were monitored for a 24-hour period.

After several hours of pumping the city of Moscow's wells, the only noticeable drawdown was in the Moscow area and the Washington Department of Ecology (WADOE) Well (Figure 24). The hydrograph for the city of Palouse well and the WADOE Well (Figure 25) showed similar ground water trends. This drawdown in ground water levels and hydrograph information could suggest that there is a hydraulic connection between Moscow, the WADOE and Palouse wells. The north-south syncline structure, noted in the structural contour map, could be acting as a possible ground water conduit between Moscow and the city of Palouse.

During the Pullman pumping tests, some drawdown was noted in surrounding wells, but no drawdown was noted in the city of Palouse, the Moscow area or the

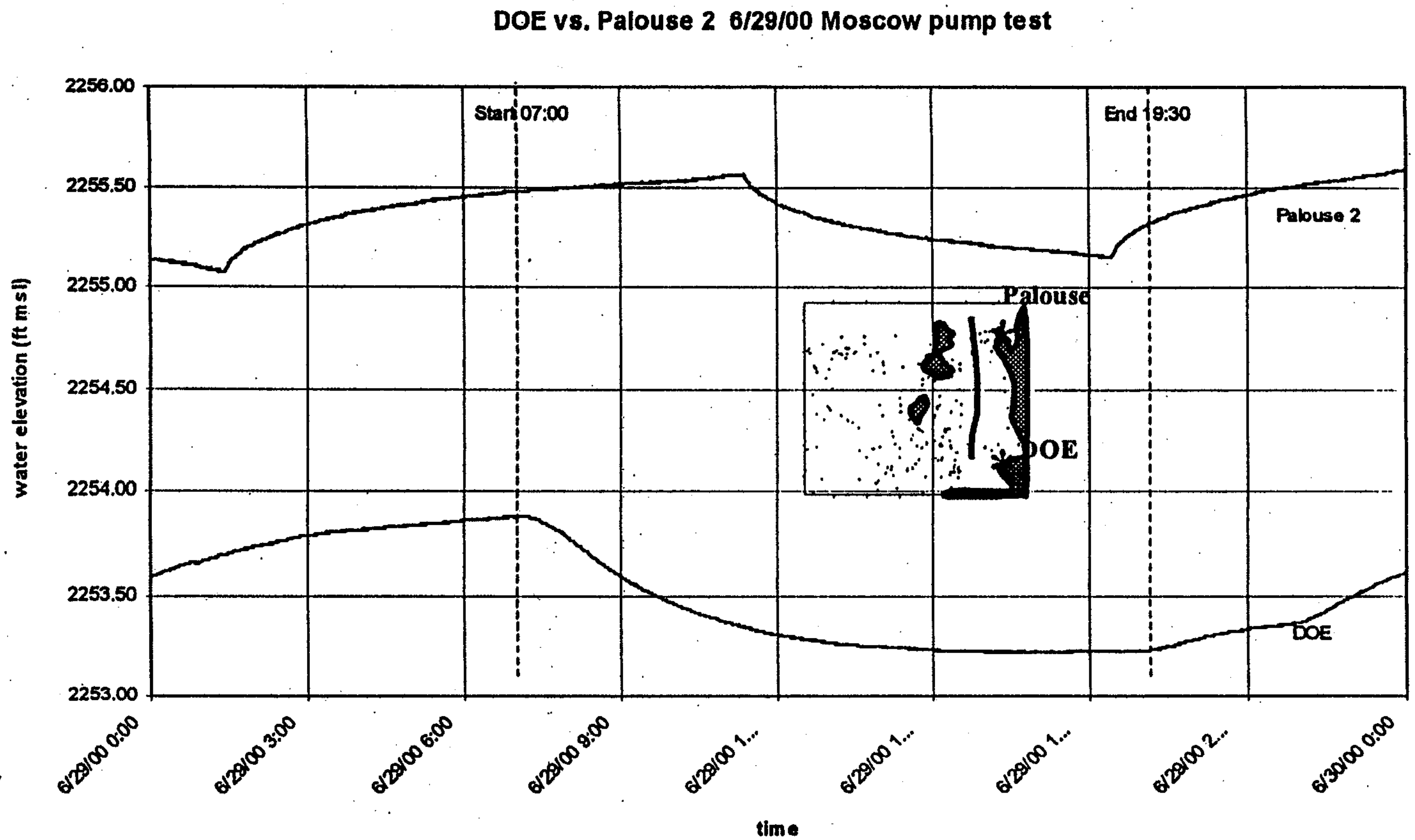

Figure 24. Comparison between Moscow well (DOE) and Palouse well (Palouse #2) pump test (Modified from Beck, 2001)

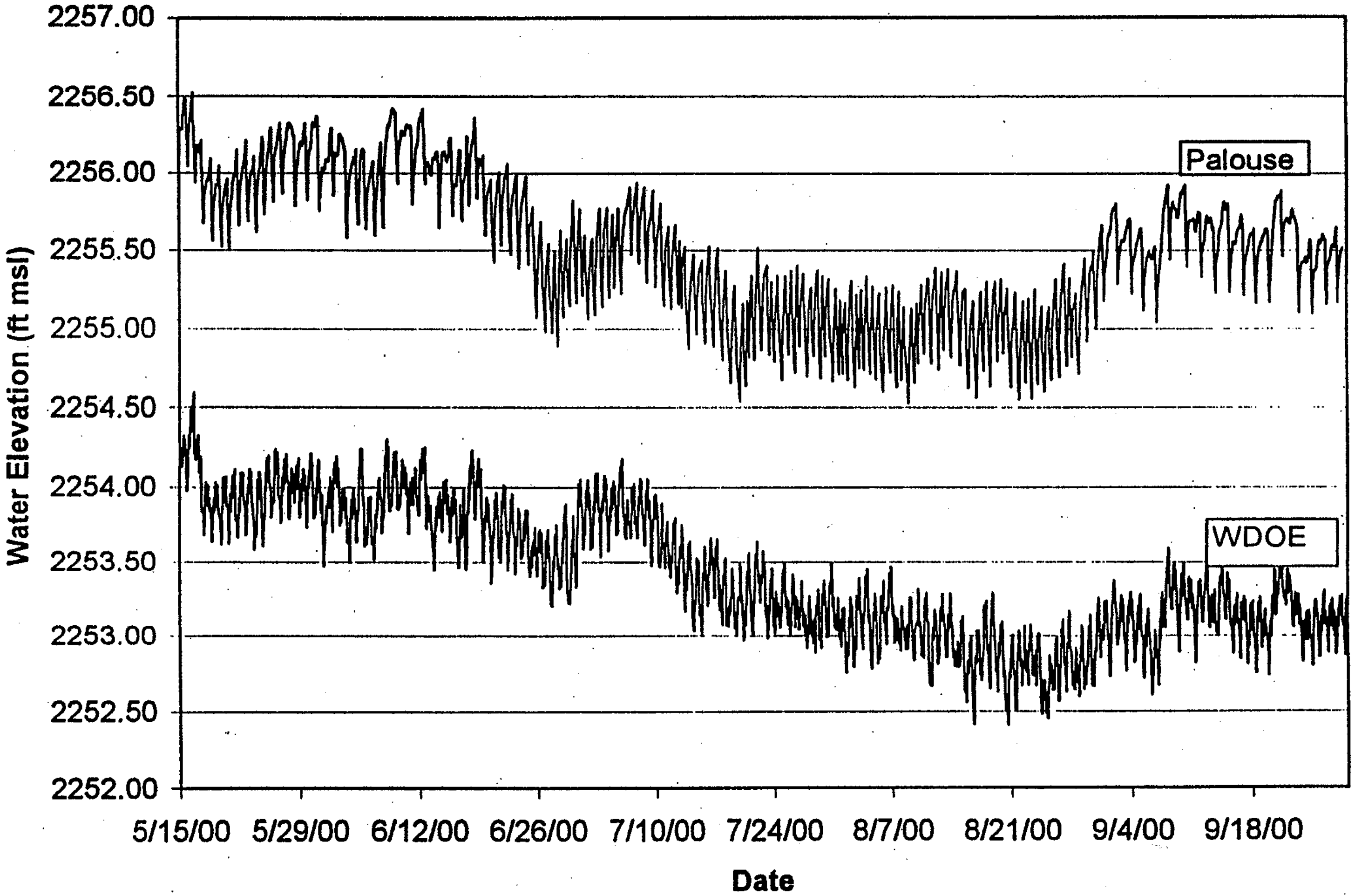

Figure 25. Hydrograph comparison between WDOE and City of Palouse 2.

Washington Department of Ecology Well. The Pullman pump test suggests that there is a hydraulic or potential geologic barrier between Grande Ronde wells in Pullman and Moscow (Beck, 2001). This geologic barrier could be the anticline that exists in the Grande Ronde Basalt just west of the Moscow area (Figure 11).

SUMMARY

The completion of structural contour and isopach maps provides a better geological and hydrogeological understanding of the Palouse area. Several conclusions and discoveries were made during the course of this study. A summary of the completed research, conclusions and discoveries are listed below.

1. Compiled and tabulated a database of over 250 well logs. The database consists of well locations, associated surface elevations, individual formation thickness and stratigraphic elevations.

2. Constructed three structural contour maps and two isopach maps. The structural contour maps were for the Grande Ronde and Wanapum Basalts, and the Vantage Formation. The isopach maps were for the Wanapum and Vantage.

3. Identified two potential structural features in the Grande Ronde from structural contour maps. A north-south anticlinal feature east of Pullman that extends and develops into a syncline structure in the Moscow and Palouse areas. Geologically, this structure would create two separate sub-basins. West of Pullman, the surface of the Grande Ronde slopes northwest towards the city of Colfax. This northwest structure is being interpreted to be related to the northwest folds that exist throughout the Columbia River Plateau area.

4. Examined stream patterns from 1:24,000 USGS topographic maps that were compiled from regional maps scale 1:100,000, and local geologic maps to detect the presence of folds in the Wanapum and Grande Ronde Basalts.

5. Constructed a ground water contour map for the Grande Ronde Aquifer in the Palouse area.

6. The ground water contour map shows two distinct flow directions, (1) west of Pullman, ground water flows northwest towards the city of Colfax, and (2) east of Pullman, ground water flows north from Moscow towards the city of Palouse.

7. Re-interpreted previous hydrogeologic information including isotope data, limited pump test data, water chemistry information, and ground water level data. This information was used as supporting evidence for the geologic data and suggests that there are at least two sub-basins in the Grande Ronde aquifer in the Palouse area. Potentially, Moscow and the city of Palouse wells are in one Grande Ronde Aquifer system, and the city of Pullman and the city of Colfax are in the second Grande Ronde Aquifer system.

8. Presented strong evidence for the presence of a folded subsurface throughout the Palouse area.

RECOMENDATIONS FOR FUTURE WORK

1. In order to thoroughly understand the dynamics of the Palouse area and precisely locate these potential basalt barriers, detailed field mapping and (1:24,000), accurately recording and inspecting all well logs throughout the area needs to be completed. This work has been recommended by several previous investigators, but as of to date, only a limited amount of actual field mapping has been done. This new current data does indicate that the basalts do to some degree control ground water behavior in both the upper and lower aquifer.

2. The potential for these structural barriers to influence or limit the migration of local ground water needs to be investigated. Simple pump tests around these barriers might help delineate the ground water control dynamics.

3. Individual reaches of local streams need to be gauged. Finding out which areas gain and loose water to the surrounding basalts will only add to the potential for understanding the amount of overall recharge that is occurring to the area.

4. Investigate ground water levels in the Wanapum Basalt to see if there is any evidence suggesting that ground water from this aquifer is shared by Pullman and Moscow.

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APPENDIX A

	Reference	X	Y	Elevation to Vantage (top)	V thick	W Thick	DTW	GPM	swl	top GR
16.45										
	14	489426.19	5185571.43				290	6	183	
	7	485523.81	5185500.00				270	15	224	
	11	485595.24	5187166.67	2166	27	123	135	30	54	2139
	15	488333.33	5187904.76	2406		89	90	20	12	2317
	1	489523.81	5189238.10				40	18	27	
	12	489476.19	5190214.29				70	1	46	
	18	488309.52	5190952.38					30	40	
	13	487738.10	5190476.19				190	20	82	
	3	484904.76	5193738.10				73	30	43	
	5	485476.19	5193738.10	2683	17	163		12	172	2666
16.44										
	3	479595.24	5195214.29	2030	30	47	235	55	156	2000
	4	476833.33	5192238.10				200	50	84	
	6	475714.29	5191714.29				240	30	147	
	5	477642.86	5190476.19				60	30	17	
	7	477690.48	5190047.42				80	40		
	8	480690.48	5189690.48				dry	dry	dry	
	9	480738.10	5189690.48					5	50	
	2	476095.24	5189000.00				250	5	93	
	13	477761.90	5188690.48	2193	7	60	290	0.5	210	2186
	10	483166.67	5190190.48	2399		70		12	41	
	11	484642.86	5187809.52	2277	18	10		10	30	2259
	12	483690.48	5187547.62	2235			210	24	82	
	1	483690.48	5186523.81	2348	134	20	250	40	84	2214
15.45	2	486380.95	5184404.76	2349	16	97	220	20	170	2333
	6	488952.38	5183500.00					20	300	
	13	489642.86	5182833.33	2408				30	60	
	5	486428.57	5182690.48					30	126	
	4	486047.62	5182523.81					13	60	
	3	486047.62	5182095.24					100	70	
	9	489714.29	5181000.00	2418	6	131	350	15	310	2412
	10	488142.86	5181476.19	2351				15	210	
	11	485642.86	5180904.76	2297				30	65	
	14	489547.62	5178880.95	2513	20	84	80	10	260	2493
	20	487857.14	5178500.00				285	30	145	
	19	487142.86	5178500.00	2353	24	74		30	63	2329

	16	487190.48	5178047.62	2324	12	72		90	155	2312
	17	487142.86	5178000.00	2363				100	117	
	18	487238.10	5178000.00	2335	25	95		400	171	2310
	23	486809.52	5177000.00	2341	32	59		1500	132	2309
	21	485595.24	5176309.52					100	55	
	22	485357.14	5176309.52					396	23	
	25	486357.14	5175738.10	2362				1000	9	
	24	486476.19	5175785.71	2351						
	26	487928.57	5176309.52					50	180	
		0.00	0.00							
14.45	37	488119.05	5168119.05				140	12	69	
	38	488071.43	5168190.48					20	7	
	33	489166.67	5169690.48	2354	74	93		15	35	2280
	32	487880.95	5170190.48	2360	44	112		20	78	2316
	31	486595.24	5169809.52	2539		44		6	35	
	29	489261.90	5171476.19	2440	2	120	200	30	67	2438
	28	489261.90	5170619.05							
	27	489095.24	5171238.10	2377	52	100		40	110	2277
	40	488619.05	5171833.33	2275	17	176		340	173	2258
	20	488500.00	5171333.33	2448			200	12	54	
	24	488523.81	5170666.67	2205	65	163		40	230	2140
	26	488000.00	5170666.67	2295						
	25	488285.71	5170666.67	2310	20	120		25	150	2290
	17	488690.48	5172809.52	2280	23	148	365	50	295	
	16	486738.10	5173166.67	2296			351	300	200	
	41	486095.24	5172738.10	2363	40	72		148	1799	2253
	15	485785.71	5173095.24					75	20	
	46	485333.33	5173119.05	2316	30	148		110	150	2286
	10	488976.19	5174142.86	2351	29	32	181	25	152	2322
	11	488857.14	5174142.86	2360	25	23		10	40	2335
	13	488142.86	5174928.57	2280	10	121		7	154	2270
	12	486904.76	5175380.95							
	44	486666.67	5175333.33							
	14	486357.14	5175357.14					55	6	
	45	486595.24	5172761.90	2371					235.5	
	Pullman#7	486547.62	5175500.00	2300	40	32				2340
	wsu #6	487976.19	5175357.14	2370	1	150				2371
	Pullman Test Well	493333.33	5175200.00	2394	10	85				2384
14.44	21	484095.24	5169785.71	2522	27			10	80	2495
	27	481309.52	5170809.52	2304	10	180		329	236	2294
	14	481309.52	5171000.00				200	58	30	

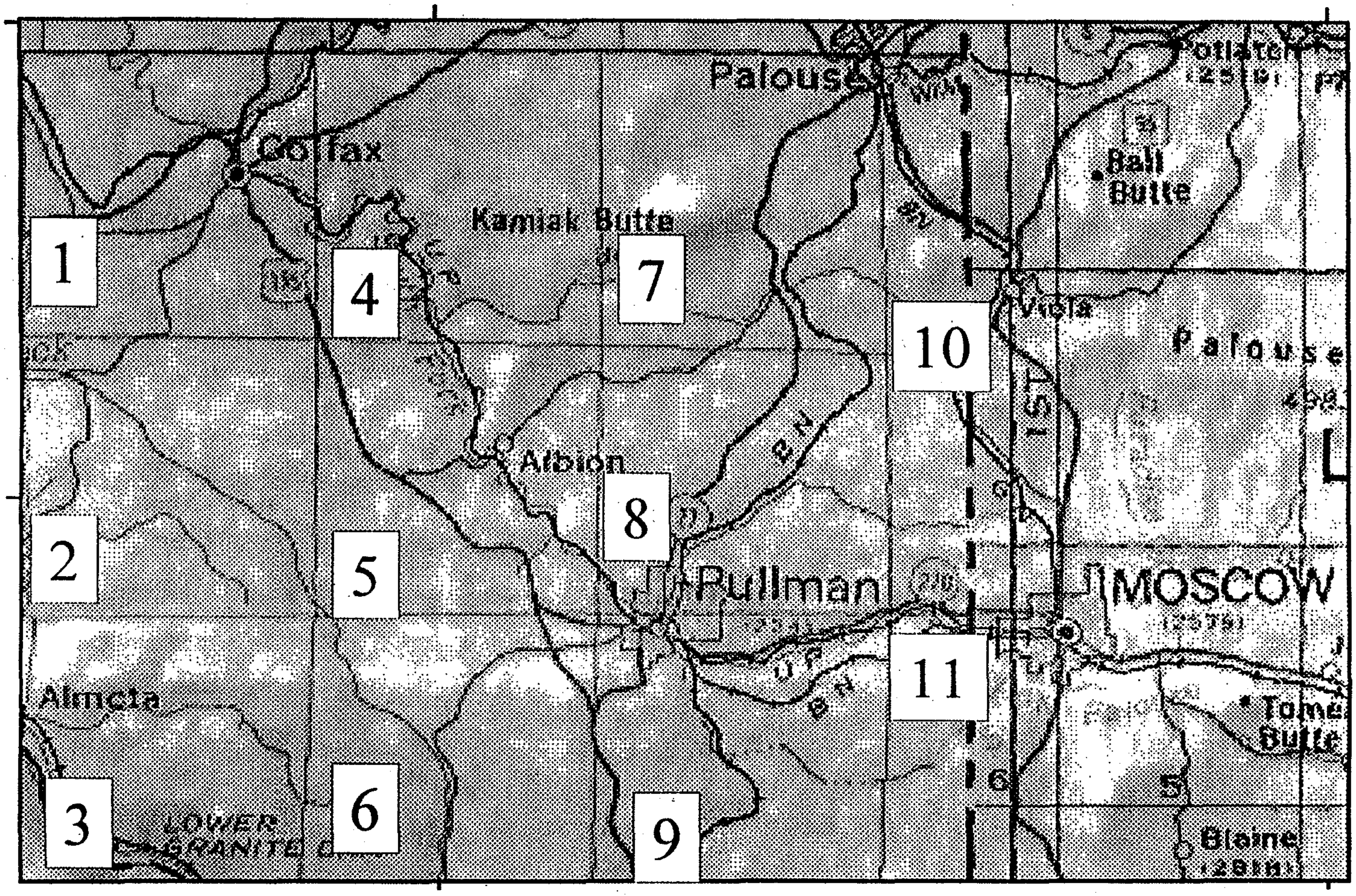
	15	481404.76	5171261.90	2325	25	155		120	285	2300
	10	482142.86	5171309.52						300	
	9	482619.05	5172119.05	2320	35	155	271	15	362	2285
	8	483119.05	5172857.14				225	13	127	
	1	483619.05	5175000.00				145	12	47	
	2	482809.52	5175357.14				90	30	14	
	23	476785.71	5167595.24				130	15	19	
	22	479714.29	5167857.14					100	0	
	24	476476.19	5168761.90				215	50	155	
	25	476619.05	5168761.90					50	70	
	17	476904.76	5169166.67							
	19	478000.00	5170428.57					20	32	
	20	479166.67	5170095.24					40	10	
	11	478357.14	5171476.19	2208		169		60	130	
	12	478904.76	5171142.86					60	116	
	13	478928.57	5171666.67	2292		99	120	20	22	
	18	476928.57	5172095.24				60	40	39	
	3	480142.86	5174928.57				140	10	37	
	4	477166.67	5175166.67				222	18		
	6	476190.48	5174809.52					75	15	
	5	475952.38	5174809.52				84	30	52	
	7	480166.67	5173238.10					25	150	
	26	483714.29	5167142.86	2637	7	29		60	3	2630
		0.00 -								
15.44	15	479523.81	5175714.29				60	0.5	6	
	16	479190.48	5177119.05							
	17	482000.00	5176500.00					500	86	
	18	484309.52	5175714.29					60	140	
	19	484380.95	5175952.38					15	20	
	14	479000.00	5178000.00				198	20	133	
	7	477571.43	5180833.33					15	115	
	5	480285.71	5181476.19				100	25		
	6	480452.38	5181476.19					70	16	
	4	480380.95	5182738.10				245	10	105	
	3	477142.86	5182690.48				384	18	290	
	2	480285.71	5184071.43	2164	20	22	200	6	119	2144
	11	482238.10	5177357.14	2350	2	158	165	20	52	2192
	13	483452.38	5178238.10	2197	50	68		25		2129
	12	483000.00	5178595.24	2310	23	87	182	15	45	2223
	10	483285.71	5178261.90	2348	3	27		12	21	2321
	9	483690.48	5177952.38	2274	3	116	220	75	165	2158
	8	481690.48	5180166.67	2253	3	29				2250

	1	484333.33	5184690.48	2291	88	61	170	6	87	2230
		0.00	0.00							
15.43	6	468523.81	5180190.48				370	60	250	
	1	465404.76	5178000.00					15	15	
	5	467333.33	5181119.05					12	57	
	9	471142.86	5180857.14	2023	20	71		7.5	139	2003
	2	469523.81	5181833.33	2017	38	77	240	30	92	1979
	3	469285.71	5182214.29	1913	15	75		30	54	1898
	8	468952.38	5182523.81	1918	8	65		25	22	1910
	7	466714.29	5184666.67	1786		59		25	22	
	12	473857.14	5178714.29					50	10	
	10	473000.00	5179595.24					75		
	11	472214.29	5180047.62				100	120	30	
	4	469285.71	5182214.29					24	81	
		0.00	0.00							
14.43	3	466833.33	5167142.86					200	26	600
	12	466761.90	5167142.86					300	26	600
	2	466642.86	5167285.71					260	20	650
	1	465500.00	5170928.57							651
	4	468071.43	5169452.38							1688
	11	467238.10	5175119.05	2110	17	168			301	2093
	7	465857.14	5174738.10	1793	1	78			50	1882
	5	471880.95	5170095.24				360	40	300	
	9	473952.38	5174500.00	2347	39				60	
	10	473976.19	5169452.38					20	54	
		0.00	0.00							
16.43	18	471880.95	5191238.10	1954	25	128			90	1929
	14	472071.43	5191928.57	2130	10	65	223	15	80	2120
	16	473166.67	5192095.24				70	50	40	
	12	473500.00	5192404.76				250	50	30	
	11	474809.52	5193785.71				175	6	37	
	14	474714.29	5193785.71							
	9	471904.76	5193071.43				125	20	100	1980
	10	472095.24	5192880.95				498	711	180	1960
	8	472285.71	5192880.95							1980
	7	472333.33	5193023.81				164	30	15	2000
	1	474785.71	5195095.24					5	43	2048
	34	469785.71	5185761.90					50	7	
	32	468809.52	5187666.67					50	12	
	33	467380.95	5188809.52					70	1	
	31	469261.90	5189261.90	2132	16	67	230	52	32	2116
	29	467333.33	5189404.76					60	15	

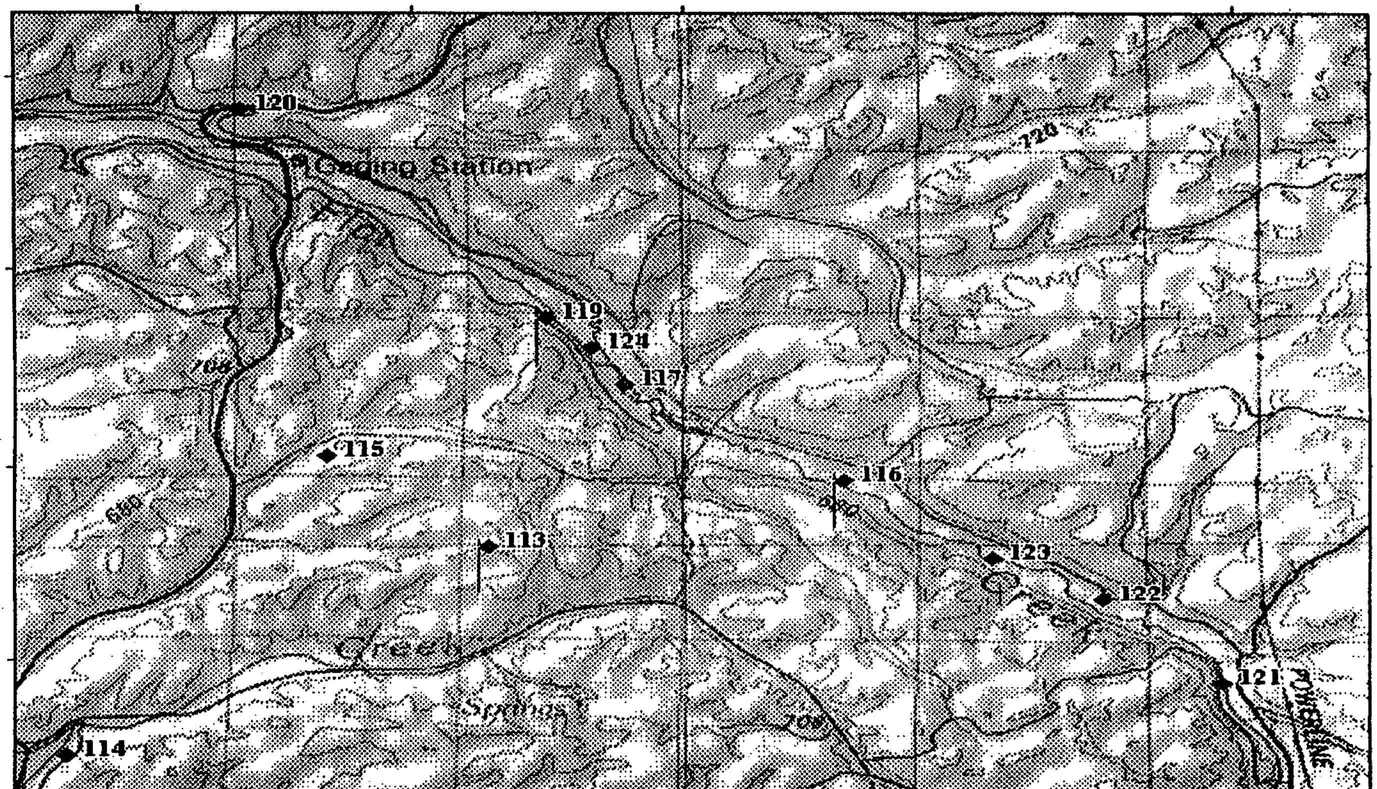
	28	467119.05	5189500.00	2082	45		160	30	38	2037
	30	467023.81	5189761.90	2075		41	230	52	32	
	27	466880.95	5189833.33	2004	26	77	220	12	157	1978
	23	469690.48	5191071.43	2156	11	91	80	20	32	2145
	25	465904.76	5192500.00				125	50	13	
	24	466333.33	5192119.05				80	30	12	
	22	469952.38	5192214.29					12	60	
	5	470238.10	5192404.76				91	10	32	2054
	6	470500.00	5192595.24				370	10	179	2054
	21	470809.52	5192047.62	1929	10	161		0.75	118	1919
	19	471000.00	5192047.62	2138	13	61		30	43	2125
	20	471214.29	5191904.76				350	15	305	
	3	466142.86	5192928.57					55	12	
	4	468261.90	5193738.10				230	20	67	
	2	471214.29	5195000.00					12	223	
	13	474714.29	5193785.71							
Albion	A6	485476.00	5187167.00	2321	19	27				2302
	A18	485571.00	5180548.00	2410	13	25				2397
	A22	487690.00	5178524.00	2349	27	107				2322
	A23	487548.00	5178524.00	2349	24	74				2325
DEQ	DEQ	493293.00	5175037.00	2304	16	44				2288
pullman #4		486611.00	5175601.00							
Guy Street	Near Maint Yard	485278.00	5176151.00	2260	20					2240
Glennwood	ROZA/GR	478812.00	5196555.00							2100
Glennwood	PR/ROZA - meet at	479106.00	5195982.00							
Colfax	GR/VAN	472305.00	5192853.00	2000	10					1990
Colfax	ROZA/PR - 2226	473555.00	5194548.00							
Almota	ROZA/GR 1655	462935.00	5174459.00							1655
Albion	Quart/PR - 2365	479690.00	5181980.00							
Albion	Roza/PR - 2301	481360.00	5180533.00							
Palouse										
	57	491262	5192476.2	2382		0			157	
	55	493333.3	5194166.7	2374		0			33.2	
	56	493404.8	5195976.2	2345		2346				
	46	492571.4	5195571.4	2366		2360			97	

	47	491309.5	5195523.8						37	
	54	491142.9	5194809.5						3	
	63	494023.8	5196000	2292		0				
	53	497047.6	5196166.7						3	
	38	499119	5199047.6						25	
	40	499952.4	5203500						6	
	60	495476.2	5194404.8						92	
	58	496285.7	5194476.2	2394						
	50	495071.4	5195142.9	2380					120	
	65	492761.9	5194285.7						39.1	
	62	496000	5197809.5						24	2265
	52	496642.9	5201190.5	2324					47	
	51	494619	5201023.8	2292					81	
	48	494333.3	5192500	2336					84	
	49	495190.4	5195476.2	2312					172	
	61	486000	5195309.5	2370					92	
	Palouse #2	493761.90	5194500.00		207					
Vilola										
	V1	491666.67	5185761.90	2346	41	171				2305
	V2	491666.67	5185600.71	2360	21	144				2339
	V3	491714.29	5188785.71	2328		181				
Moscow	2 (uoi #3)	498476.19	5175500.00	2392	331	148		2400	256	2061
	3(moscow #2)	499904.76	5175500.00	2381	30	152		1200	100	2351
	4 (Bestway Carpets	499547.62	5175142.86	2332	10	180		40	76	just granit
	10	499642.86	5169166.67	2547	22	169		5	101	granite at
	14 (moscow City #2	499904.76	5175500.00	2344	336	147				(double ch
	15 (uoi #1)	499095.24	5174630.95	2235		207				
	16 (Uoi #2)	498928.57	5175190.48	2287	70	154				granite @
	18 (moscow #7)	499071.43	5176000.00	2221	307	199				1914

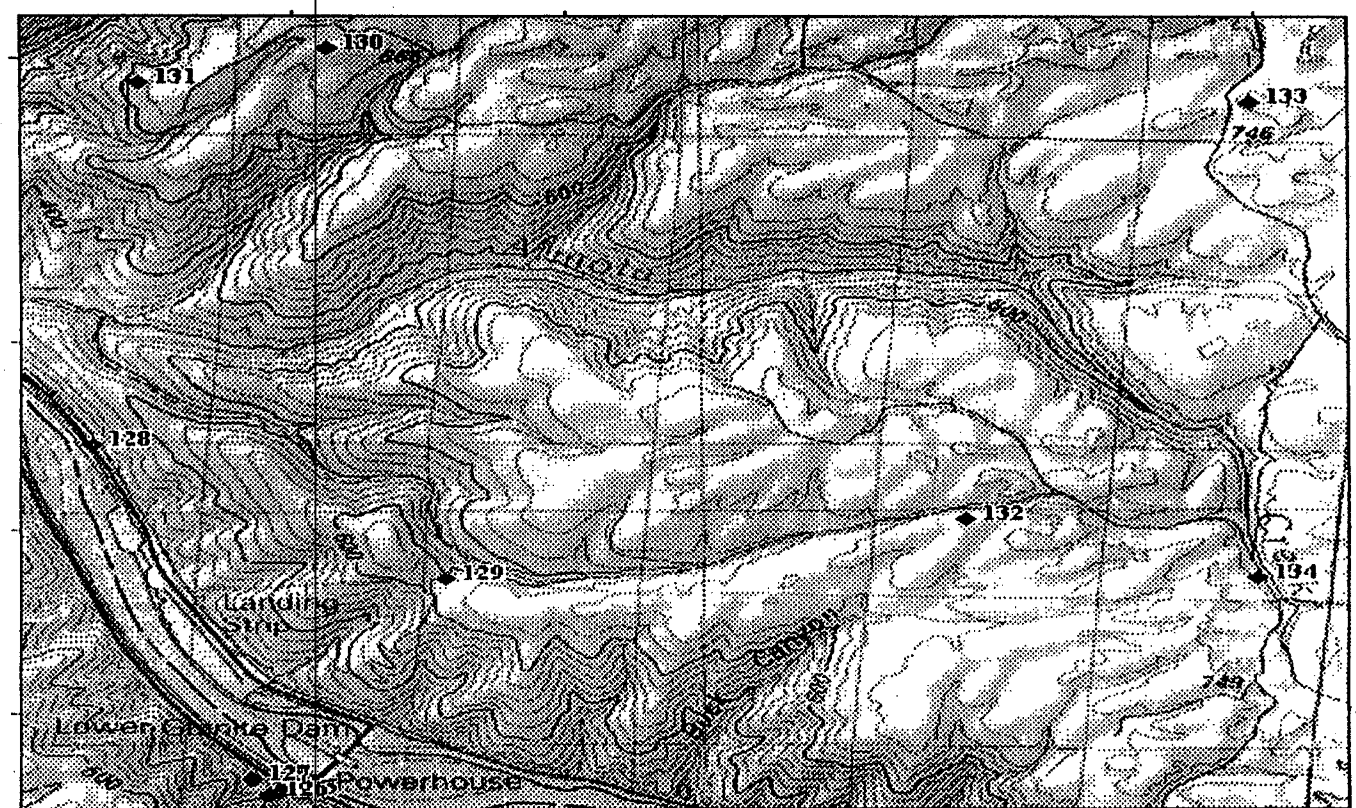
APPENDIX B



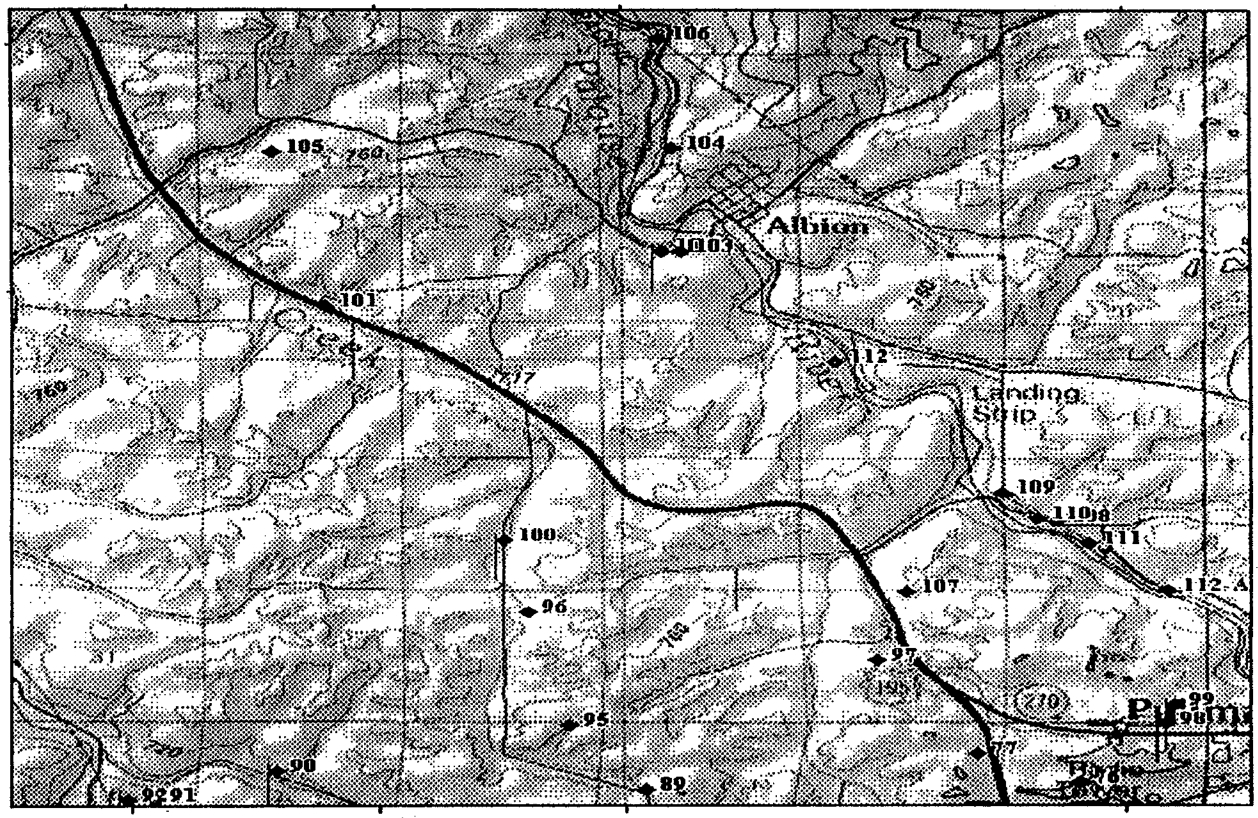
Appendix B. Site index map. For individual well locations, refer to the individual inset map number noted on this map. All maps (1-12) have a referenced number of their individual well. Individual well descriptions can be found in Appendix A.



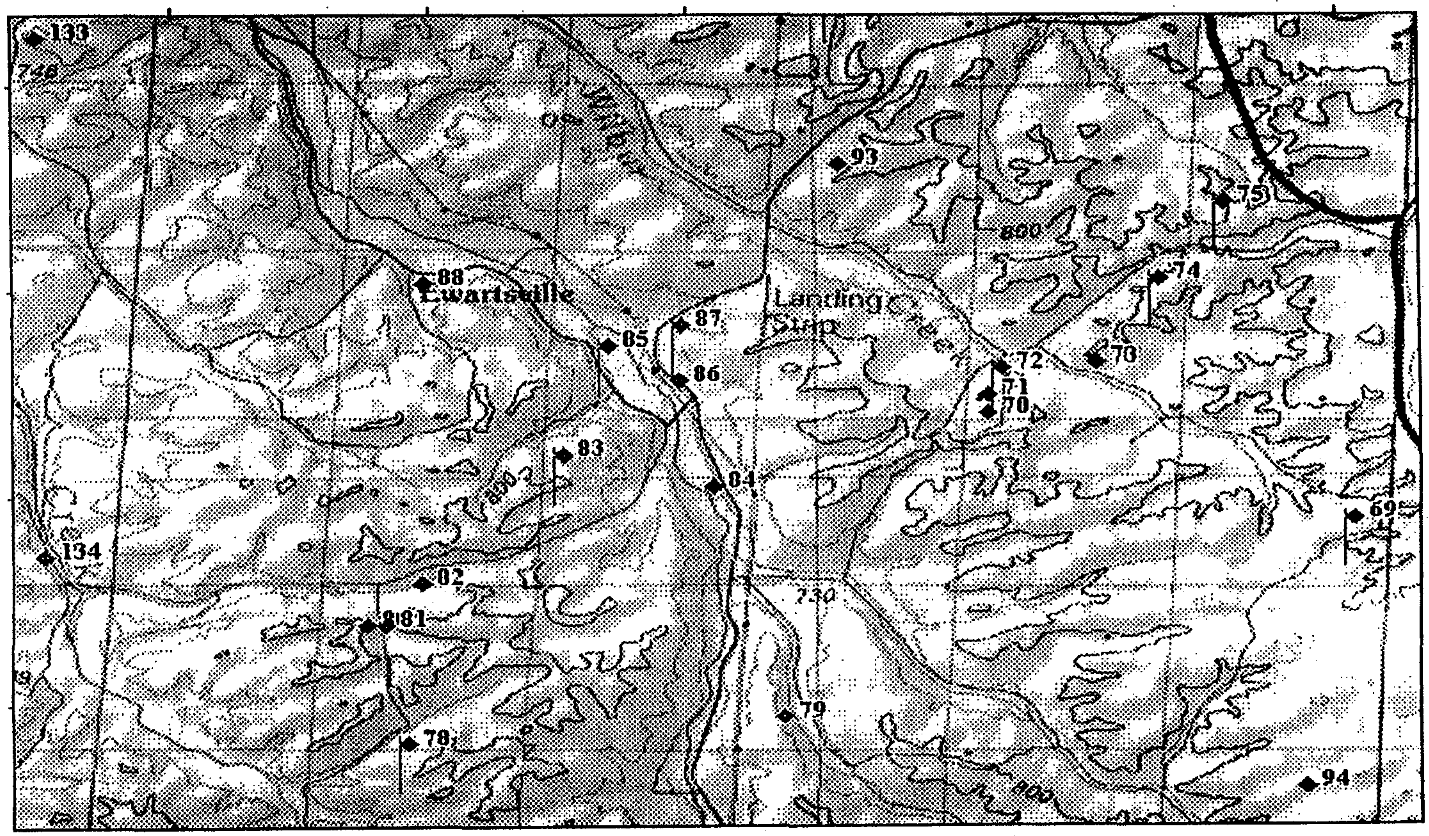
Appendix B-2. Location map of wells located on inset map 2 (see Appendix B)



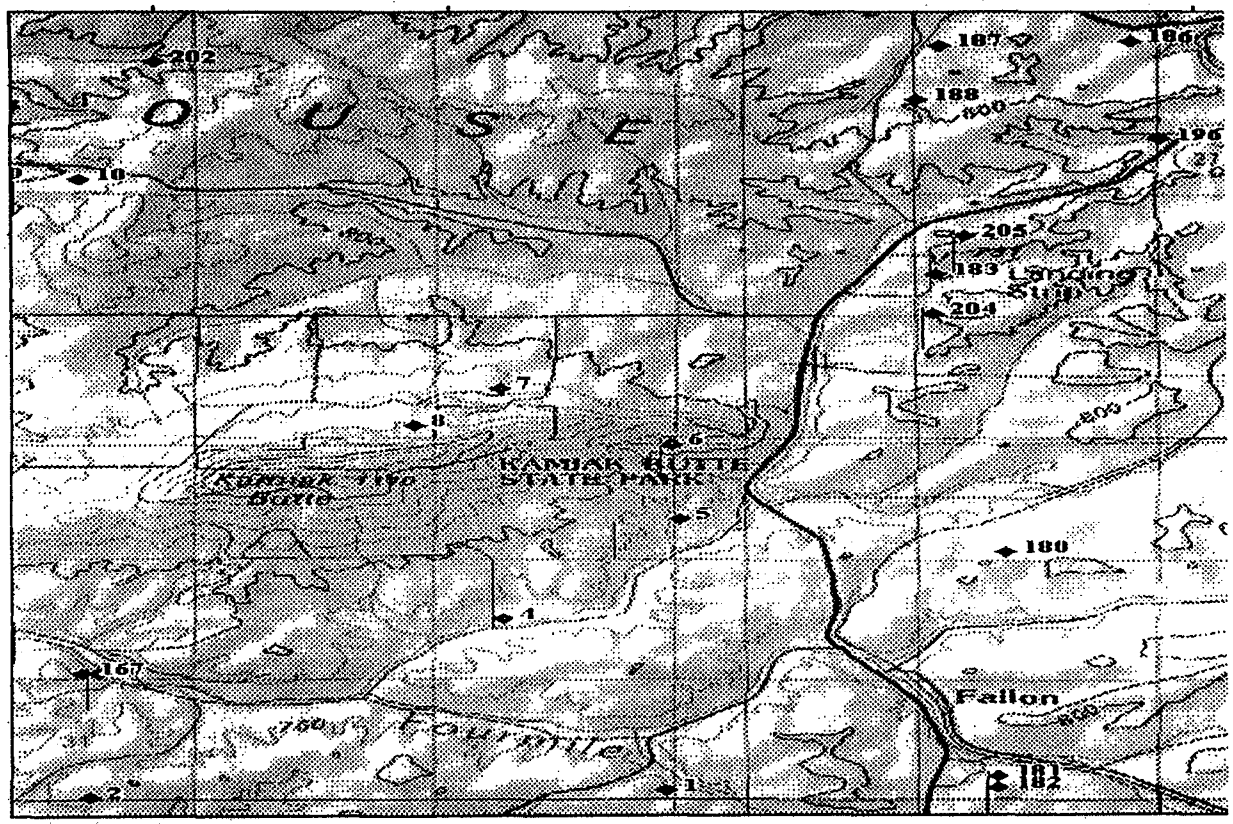
Appendix B-3. Location map of wells located on inset map 3 (see Appendix B)



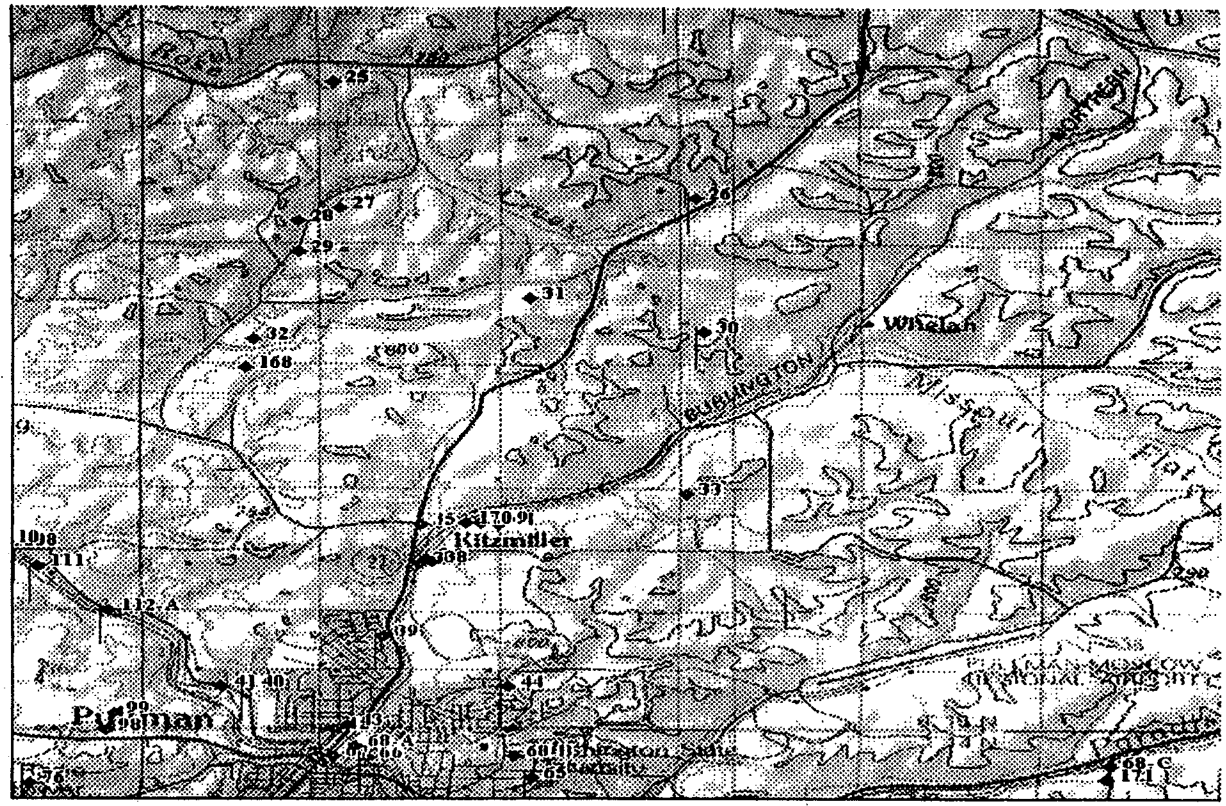
Appendix B-5. Location map of well located on inset map 5 (see Appendix B)



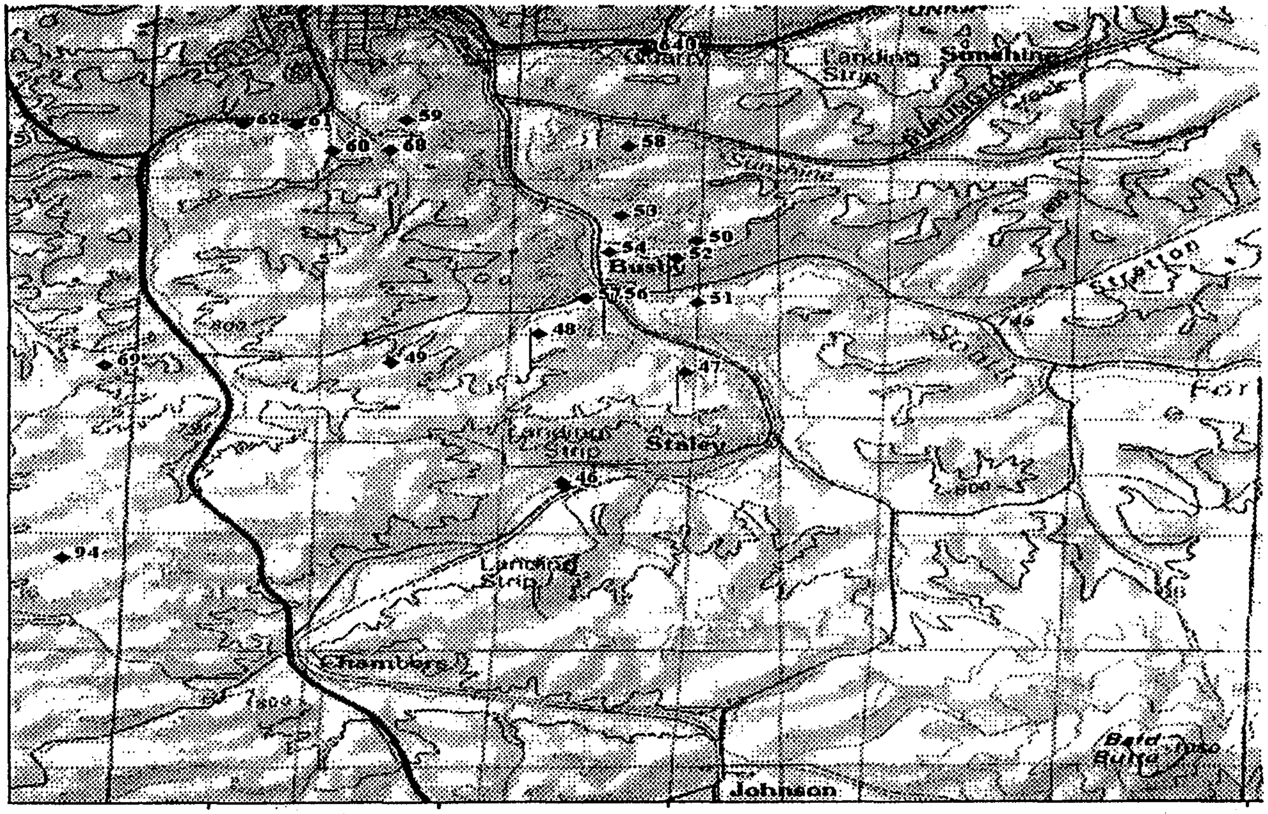
Appendix B-6. Location map of wells located on inset map 6 (see Appendix B)



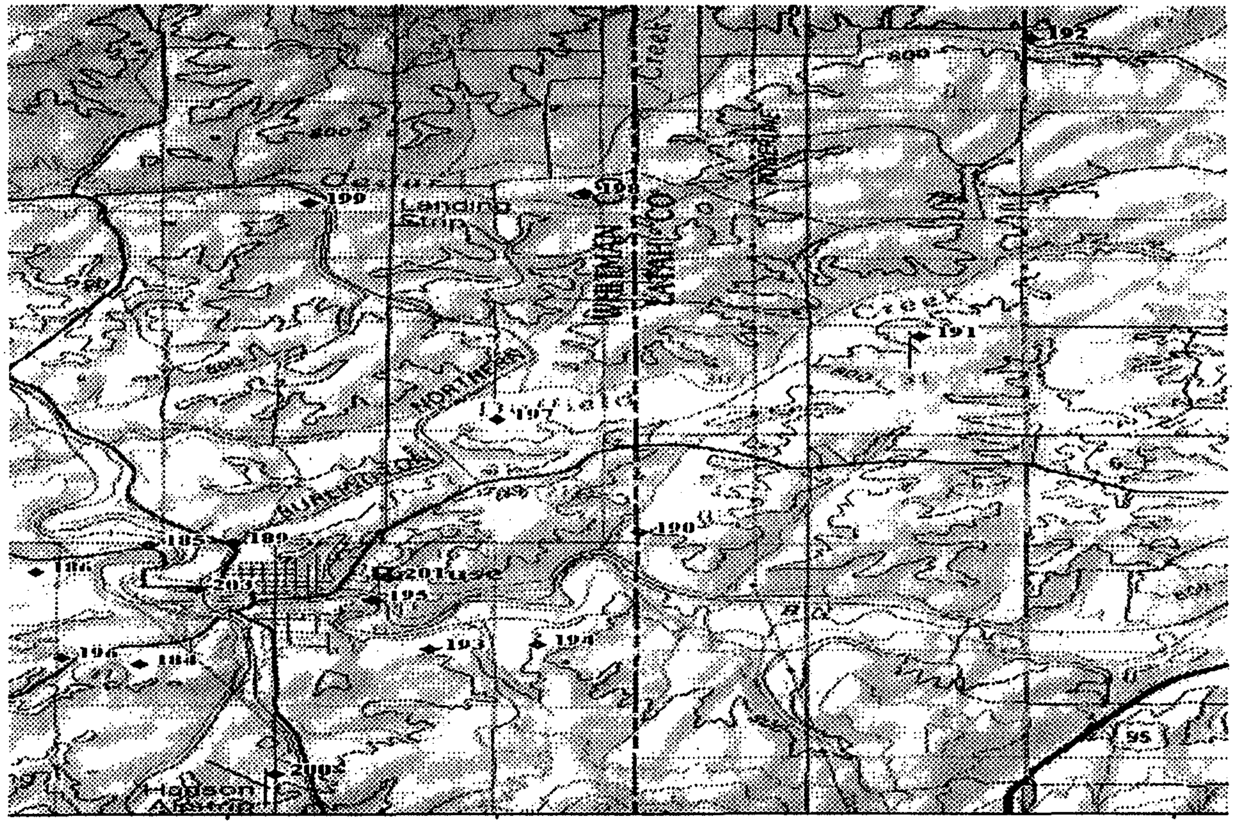
Appendix B-7. Location of wells located on inset map 7 (see Appendix B)



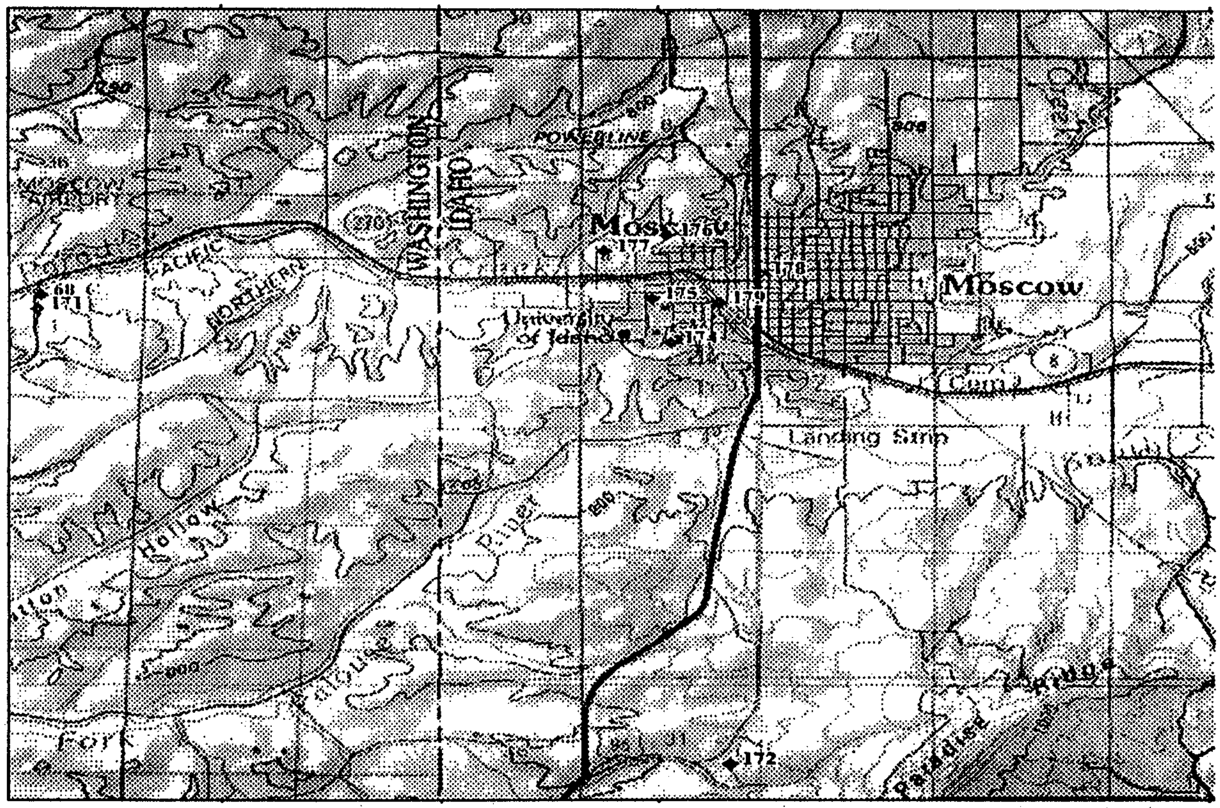
Appendix B-8. Location of wells located on insert map 8 (see Appendix B)



Appendix B-9. Location of wells located on inset map 9 (see Appendix B)



Appendix B-10. Location map of well located on inset map 10 (see Appendix B)



Appendix B-11. Location of wells located on inset map 11 (see Appendix B)

APPENDIX C

Grande Ronde Wells	Static Water Level	X	Y	Date Measured	Water level Reference Point
Albion #3	2246.51	480832	5181433	3/17/00	2380.10
Appaloosa Horse Club	2479.77	496689	5175631	6/4/01	2559.32
Boyd	2253.76	487765	5170642	3/17/01	2488.19
Brandt	2502.10	487778	5177063	6/4/01	2643.89
Brawdy	2275.68	494415	5172669	6/4/01	2578.14
Colfax Fairview	1771.17	472808	5193565	5/8/02	2111.17
Colfax Clay	1777.60	471887	5191100	6/16/02	1964.60
Colfax Glenwood #1	2064.89	478536	5197462	3/17/00	2072.28
Colfax Glenwood #2	2067.40	478726	5197461	3/17/00	2074.79
DOE	2253.70	493229	5175325	6/4/01	2492.64
Howell	2251.75	486539	5182868	6/5/00	2499.55
McGreevy	2387.20	489865	5181689	3/17/00	2532.25
Moscow #2	2400.50	499830	5175784	12/31/00	2569.44
Moscow #3	2501.00	499830	5175815	12/31/00	2569.70
Palouse #1	2259.55	494500	5195234	3/17/00	2437.64
Palouse #2	2255.01	492426	5194804	6/4/01	2507.23
Paulson	2252.65	492655	5174060	6/4/01	2598.01
Pullman #3	2252.47	486225	5175492	2/27/01	2340.27
Pullman #4	2253.09	486523	5175892	2/27/01	2345.29
Pullman #5	2259.32	486072	5173424	2/27/01	2446.82
Pullman #6	2143.14	486802	5177219	3/17/00	2424.14
Terrace Gardens	2542.81	499448	5173562	3/11/00	2566.99
UI #3	2269.12	498408	5176032	12/31/00	2567.45
UI #4	2255.66	498111	5175816	11/27/00	2554.10
UIGRS D 19D	2503.63	498005	5175476	6/29/00	2543.97
UIGRS INEEL	2486.26	498090	5175414	6/29/00	2546.71
Whitman Co. Shop	2129.81	467643	5189331	6/5/01	2181.07
WSU #1	2255.71	486946	5175305	3/1/00	2364.21
WSU #3	2255.77	486946	5175305	3/1/00	2364.77
WSU #5	2259.87	490259	5176348	3/1/00	2505.87
WSU #6	2252.78	488030	5175735	3/1/00	2535.78
WSU #7	2238.98	487031	5175150	3/1/00	2414.98
WSU Dairy #1	2257.85	481542	5171121	3/15/00	2561.43
WSU Test Well	2251.76	486946	5175305	6/4/01	2363.90

Appendix C. Grande Ronde ground water levles for various well in the Palouse area.
Note: all X, and Y locations are in meters, and static water levels are in feet
(Data modified from Beck, 2001 unfinished thesis).