Boundaries of the "Palouse Basin" Aquifer System in the Moscow-Pullman Area, Idaho and Washington

John H. Bush, Steve Robischon, and Pamela Dunlap

March 21, 2022

INTRODUCTION AND GOALS

The term "Palouse Basin" has been used in the Moscow-Pullman area for at least three decades to refer to the size and nature of its aquifer systems within Columbia River Basalt Group (CRBG) lava flows and associated sediments of the Latah Formation. The primary pumping centers are in Moscow and Pullman. Historic yearly water level declines have caused concerns since the late 1940s and hundreds of studies have been conducted on the geology and hydrology of the area. A portion of these studies are site specific, but most included parts or all of an aquifer system that has become known as the "Palouse Basin."

A problem has evolved in that many of the studies do not use the same boundaries. A committee formed from political and municipal entities has used the name "Palouse Basin Aquifer Committee" (PBAC) since the early 1990s. Four groundwater models and characterizations of the "Palouse Basin" (Barker, 1979; Lum et al., 1990; Leek, 2006; Medici et al., 2021) each have used data within different boundaries. PBAC illustrations continue to show boundaries (Figure 1) that were introduced by Leek (2006).

The purpose of this report is to review the illustrated and defined boundaries used for the term "Palouse Basin" and propose an updated version (Figure 2). The basic assumption followed in our review is that PBAC, scientists, engineers and the public have the same goal which is to determine the extent and nature of the aquifers connected to or affected by the pumping centers in Moscow and Pullman.

There are two major aquifers in the Moscow and Pullman area which are referred to as the lower (Grande Ronde) and upper (Wanapum) aquifers. Water level separation between the two aquifers is generally greater than 100 ft (30 m). The upper aquifer has variable water levels and production capabilities with limited hydrological connections over large areas of the Moscow-Pullman area. The connection between the upper and lower aquifer is considered to be minor (Bennett, 2009). Moscow is the only community where large production wells in the upper aquifer have been used for municipal purposes.

Presently, lower aquifer wells are the only sources being used for municipal water in Moscow and Pullman. Most domestic wells drilled between the two cities during the past two decades are located in the lower aquifer. All lower aquifer wells have similar water levels which indicate connections within the same aquifer system. Considerable pump test data exist to help evaluate the nature of these connections (Fielder, 2009; Moran, 2011; Folnagy, 2012). The extent of similar water levels in the lower aquifer was used as the primary basis in this review for determination of boundary locations for the "Palouse Basin." Geologic information on lower aquifer rocks was evaluated in concert with the focus on similar water levels. Modern stream patterns (Figure 3) were also used because they often reflect the tilt (slope) of the subsurface rocks which in turn control the direction of groundwater flow. For example, note the change from east-west-trending streams to northwest-trending streams in Pullman and the Union Flat Creek area. The rocks tilt to the northwest and the groundwater is considered to be flowing northwest in the Union Flat Creek area.

The terms "Grande Ronde aquifer" and "lower aquifer" have been used for the same aquifer in the Moscow-Pullman area. Aquifer names throughout the Columbia River flood basalt province typically have been derived from the formal geologic name of the basalt flows present in the system from which groundwater is obtained. The use of the same geologic name in two different locales does not mean that the aquifers have the same hydrologic characteristics and(or) are significantly interconnected.

MOSCOW-PULLMAN BASIN

Moscow and Pullman have some of the highest production wells from the Grande Ronde Basalt in the entire Columbia River flood basalt province. These wells, with similar water levels, are in the geographic area defined as the Moscow-Pullman Basin (MPB, Figure 4). The MPB has been considered by all researchers to be part of the aquifer system called the "Palouse Basin." Boundaries for the MPB were drawn where the basalts and associated sediments are in contact with the older, nearly impermeable rocks such as quartzite and granite. The lack of outcrops requires the use of water well reports which are based on drill cuttings for more precise contact determinations. Boundaries of basalt with quartzite are easy to locate because drill chips of basalt are dark colored and quartzite chips are light colored. Where sediments are present between basalt and quartzite, they tend to be quartz rich and well sorted. Determination of boundaries between granite and sediment however has been a problem in some places.

The contacts between the basalt, sediment and granite have been illustrated on four published geologic maps of the Moscow-Pullman area.[1] The authors of these maps relied on water well reports to establish contacts due to the rarity of outcrops. It is now apparent that both drillers and professionals for decades often had reported granite when they actually had encountered sediment. Drill cuttings from granite are very similar to cuttings from poorly-sorted sediments

[1] Four geologic maps of the Viola, Moscow East, Moscow West, and Robinson Lake 1:24,000 scale quadrangles are available from the Idaho Geological Survey (Bush et al., 1998a,b; Bush and Provant, 1998; Bush et al., 2000).

derived from nearby weathered granite. Grader (2012) used the available geologic maps and was the first to note that the contacts, in places, had not been correctly located. For this report, the proposed boundaries for the "Palouse Basin" near granitic areas are based on estimates of where the basalts end and the sediments and(or) granites begin. Some adjustments from the MPB boundaries of Bush et al. (2016) were made and additional minor ones are expected in the future.

The proposed boundaries in granitic areas for the lower aquifer are accurate enough for hydrological research. It should be noted that recharge into the lower aquifer via sediments and weathered granites does occur from higher elevations above and beyond the extent of the basalt flows (Dijksma et al., 2011; Candel et al., 2016; Duckett et al., 2019; Behrens et al., 2021).

The older impermeable rocks rise above lower aquifer rocks and define the semi-circular MPB. There are three gaps which make the boundaries discontinuous. These gaps are where the basalts and associated sediments extend between the older rocks and out of the MPB. The Fourmile and Kamiak Butte gaps on the northwest and north are narrow at approximately 1 mi (1.5 km) and 2.5 mi (4 km) across, respectively. The third gap, 10.5mi (16 km) across, is located along a line extending from the southern end of Smoot Hill at Albion (north of Pullman) to Chambers (south of Pullman).

A geologic cross-section, extending west from eastern Moscow through Pullman and out of the MPB into the Union Flat Creek area, illustrates the general geologic framework of the aquifer system of the "Palouse Basin"(Figure 5). There are three different geologic subsurface segments of the lower aquifer (Figure 5). Segment A, beneath Moscow, is dominated by fine- and coarse-grained sediments in close proximately to mountain highs. Segment B, the central area between Moscow and Pullman, is dominated by a vertical sequence of horizontal basalt flows which extend from near the Idaho-Washington state line westward to the eastern edges of Pullman. Segment C, beneath western Pullman and the Union Flat Creek area, is dominated by a stack of slightly deformed basalt flows that tilt (slope) to the northwest. There are hydrological differences in the lower aquifer across the Moscow-Pullman-Union Flat Creek area. Hydrological analyses by Fielder (2009), Moran (2011), and Folnagy (2012) concluded that the lower aquifer is very compartmentalized. The northwest tilted block and its associated structures in Segment C are believed to cause groundwater movement to change from a primarily east-to-west flow direction in segment B to a primarily northwest direction in Segment C (Foxworthy and Washburn, 1963; Leek, 2006). In spite of these cited differences, lower aquifer water levels are similar across all three segments and indicate connections beyond the western boundary of the MPB and into the Union Flat Creek area.

UNION FLAT CREEK AREA

The Union Flat Creek area west of Pullman is considered to be part of the "Palouse Basin." The basalts and sediments in the Union Flat Creek area that overlie the Grande Ronde Basalt include flows that are not present in Pullman and Moscow. Most domestic wells are in Wanapum Basalt and(or) Saddle Mountains Basalt, and there is a lack of deep wells into the lower aquifer. Three DOE test wells, completed in the lower aquifer, show that the uppermost Grande Ronde Basalt flows are the same as those at the top of the Grande Ronde in Pullman (Conrey et al., 2013). However, the upper Grande Ronde surface is much lower in elevation than in Pullman. For example, the top of the Grande Ronde in the DOE Landfill well is 220 ft (66 m) (Conrey et al., 2013) lower in elevation than an outcrop of the same surface along the South Fork of Palouse River near the two DOE City Yard wells in Pullman (Bush et al., 2016). This difference in elevation for the lower aquifer rocks requires the presence of a structural feature or features between the two areas.

Conrey et al. (2013) determined that there is a gentle rise in elevation of basalt contacts toward Pullman from the DOE Grange well to the DOE Flat Creek well located on the southwestern limb of an upfold in Pullman. The crest (top) of that fold corresponds to the outcrops along the South Fork of Palouse in western Pullman (Bush et al., 2016). In spite of the geological differences, the DOE wells have similar lower aquifer water levels as those in the MPB, which verifies that lower aquifer waters in the Union Flat Creek area are in some manner connected to the MPB area.

The southwest boundary of the Union Flat Creek area with the Snake River follows the crest of a northwest-trending upfold (anticline) on the north side of the river where basalt units dip (slope) into a northwest-trending downfold (syncline) that roughly follows Union Flat Creek (Swanson et al., 1980; Bush, 2008). Walters and Glancy (1969), Heinemann (1994) and Leek (2006) reported that deep wells near the north side of the Snake River are basically unproductive and that groundwater flows away from the river. Large springs are conspicuously lacking along canyon walls (Walters and Glancy, 1969) where more than 1,400 ft (427 m) of lower aquifer rocks are exposed. Barker (1979) produced a water level map that shows water levels decreasing in elevation with increasing distance away from the Snake River; these water levels are tracking the downward descent of basalt and sediment contacts of the northeast limb of the northwest-trending upfold (anticline). Our conclusion is that the upfold along the northeast side of the Snake River is a sharp groundwater boundary for the Palouse Basin. Leek (2006), Moran (2011), TerraGraphics Environmental Engineering, Inc. and Ralston Hydrologic Services (2011), and Folnagy (2012) all agree on this boundary.

The western boundary of the Union Flat Creek area was drawn west of the creek at the approximate structural change from basalts that tilt northwest to basalts that tilt southwest.

However, the deep well data base is sparse for large areas west of Union Flat Creek and until new well data are obtained, the western boundary of the "Palouse Basin" is considered to be debatable.

COLFAX AREA

The City of Colfax and areas north along the Palouse River have been considered to belong in the "Palouse Basin" by some researchers. We present several reasons, listed below, why we do not include the city and the areas north of the city in our proposed "Palouse Basin." They represent a combination of outcrop information, well comparisons, drillers reports, and hydrological analyses.

1) City of Colfax wells 2 and 3 are 600 (182.9) and 723 ft (220.4 m) deep, respectively, in Grande Ronde Basalt and associated sediments, and they produce about 600–711 gpm which is about one-third the production rate of the deep Grande Ronde wells in Pullman. Gravel sequences in both wells were dry and sealed off.

2) Lower aquifer rocks drop 340 ft (104 m) in elevation from Pullman outcrops to those in Colfax. The difference in elevation of the Grande Ronde rocks shows that there must be a structural feature or features between Colfax and Pullman. In contrast to the Union Flat Creek area where the lower aquifer water levels are similar to those in Pullman; the water levels in Colfax City wells are approximately 252 ft (83 m) lower than those in Pullman wells.

3) North of Colfax the Palouse River flows for 3 mi (4.8 km) on top of the uppermost Grande Ronde Basalt which dips to the southwest (Bush et al., 2016), but wells up to 500 ft (153 m) in depth near the river have variable water levels and generally only provide low yields. Wells in the lower aquifer between the river and Smoot Hill also have variable water levels and low production capacities. Folnagy (2012) reported low production lower aquifer wells in the Parvin area between Albion and Colfax.

4) Colfax is located on the southern end of a block of basalt flows that tilts to the southwest in contrast to the Union Flat Creek area which is located on a block of basalt flows that tilts to the northwest.

5) Lower aquifer interflow zones in the Colfax area are rarely traceable between wells. Dense parts of individual basalt flows show considerable changes in thicknesses from well to well.

6) Barker (1979) considered the area north and east of Colfax to be a barrier to groundwater flow from the Moscow-Pullman Basin.

7) Water level maps show a very steep gradient from Albion north to Colfax. Folnagy (2012, p. 99) stated this relatively large gradient "suggests that the long-term westward groundwater

flow out of the Palouse groundwater basin is slow." Porcello et al. (2009) noted that such steep gradients in CRBG aquifers may indicate the presence of a groundwater barrier.

8) Water level declines for the Clay Street well (Colfax City well 2) in Colfax (0.04 m/year) were much smaller than those in Pullman (1.18 ft/year, or 0.36 m/year) for the same 60-year period (Moran, 2011, p. 46).

The evidence indicates that the City of Colfax should not be included in the Palouse Basin. However, its location is near the border with the Union Flat Creek area; therefore, it should not be overlooked in any future studies. It is suggested that any groundwater modeling studies that include Colfax should at least lower the connection to the MPB by at least 70 percent and that areas north, northwest, and northeast of Colfax not be included in any iteration of the "Palouse Basin."

FOURMILE GAP

CRBG and associated sediments extend west out of the MPB between older rocks where Fourmile Creek flows westward between Smoot Hill and Kamiak Butte north of Albion. The Rod Mclntosh well, in the approximate center of the gap, is 235 ft (71.6 m) deep and encountered 140 ft (42.7 m) of Grande Ronde rocks. Basalt flows were emplaced from the west. One flow of the Roza Member of the Wanapum Basalt and one flow of the uppermost Grande Ronde Basalt both thin and pinch out east of the gap. Clay was deposited in front of and on top of these flows. Interflow zones generally are not traceable between low-production deep wells on either the east or west sides of the gap. The slope of the uppermost surface of the Grande Ronde surface dips steeply to the west toward the Palouse River indicating the presence of a structural feature west of the gap. Groundwater level maps show a steep downward gradient west of the gap for the lower aquifer. The drop in water level, the presence of clay between flows, the lack of traceable interflow zones and the existence of low-production wells west and east of the Fourmile gap has led to the conclusion that groundwater flow across the gap probably is not significant.

KAMIAK BUTTE GAP AND THE PALOUSE CITY AREA

The Kamiak Butte gap is important in that undeformed upper and lower aquifer rocks are believed to extend across this area (Bush et al., 2016) and connect the MPB with the Palouse city area. The upper aquifer north and south of the gap consists of the basalt of Lolo and the Vantage Member of the Latah Formation. The Grande Ronde was encountered at an elevation of 2,110 ft (643.1 m) in Palouse City well 3 where a high-production (about 800 gpm) lower aquifer well was established in 1999 and completed in 2000 (Ralston, 2000). In the DOE Butte Gap well, about 3.5 mi (5.8 km) south-southwest of Palouse, the top of the Grande Ronde was encountered at an elevation of 2,192 ft (668 m).

The 2000 city well replaced an older city well which was also completed in the upper Grande Ronde. Ralston (1996) noted that water level decline records for the older well appeared small for the withdrawal rates and concluded that there was a connection between the lower aquifer system in the Palouse city area and the pumping centers in Moscow and Pullman. Conrey et al. (2013) noted that the uppermost Grande Ronde Basalt in the DOE Butte Gap well belongs to the Meyer Ridge Member which is the same member as reported for the upper Grande Ronde in the Palouse City well 3 (Bush and Dunlap, 2018). Dale Ralston (written commun. to Kevin Gardes, 23 April 2013) stated that the information obtained from the DOE Butte Gap well indicated that the lower aquifer is continuous between the cities of Pullman, Moscow, and Palouse. Bush et al. (2016) illustrated (Figure 6) and discussed the geologic similarities between the Butte Gap well and Palouse City well 3. Bush et al. (2018) used palegeographic reconstructions to show that the ancestral Palouse River once flowed through the Kamiak Butte gap connecting the MPB with the Palouse city area. Piersol and Sprenke (2014) conducted an analysis of geophysical data across Kamiak Butte gap and concluded that the Grande Ronde basalts are in excess of 100 m (328 ft) thick and are likely continuous across the gap.

The water levels in Palouse City well 3 and DOE Butte Gap well are similar to those in the MPB which indicates that the Palouse area needs to be included within the boundaries of the "Palouse Basin." The lack of deep wells prohibits determination of the extent of the lower aquifer in the Palouse area. Aquifer test data from the Palouse City well 3 suggest that there are boundaries to groundwater flow probably due to the presence of older rocks that nearly encircle the city (Ralston, 2000). It is also possible that the Grande Ronde Basalt is restricted to canyon walls of the paleo-Palouse River.

Pump test analyses have been used to determine the possibility of lower aquifer connections between Palouse and the MPB to the south. Owsley (2003), McVay (2007), and Moran (2011) reported likely connections between Moscow, Pullman, and Palouse city wells. Folnagy (2012) believed this connection was questionable based on different seasonal water level trends in Palouse than those at pumping centers in Moscow and Pullman. These differences in seasonal trends are believed to be caused by the fact these cities are located in basins that have different configurations connected by a narrow gap.

The lack of deep wells makes it difficult to determine the precise depth and extent of the lower aquifers in the City of Palouse area. However, the evidence for a groundwater connection between MPB and Palouse via the Kamiak Butte gap is extensive. The Palouse city area is considered to be within the proposed boundaries of the groundwater "Palouse Basin."

SUMMARY

Research since the first regional map of the "Palouse Basin" by Leek (2006) shows that an updated map of the lower aquifer extent should be utilized by PBAC. The proposed boundaries presented herein are primarily based on research supported by PBAC and represent a smaller areal extent than the boundaries presently in use. The primary basis for a revised boundary at any location was where proven groundwater connections within the lower aquifer terminated. Our review indicates that the lower aquifer in the Colfax area is not, or at least not significantly, connected to the Moscow-Pullman pumping centers; however, it does show that the Palouse city area is likely connected. The lack of deep wells in the Union Flat Creek and Palouse city areas prohibits precise boundary locations in places, and adjustments are expected in the future as additional data becomes available. The boundaries presented in this proposal encompass an area that is defendable as one groundwater basin.

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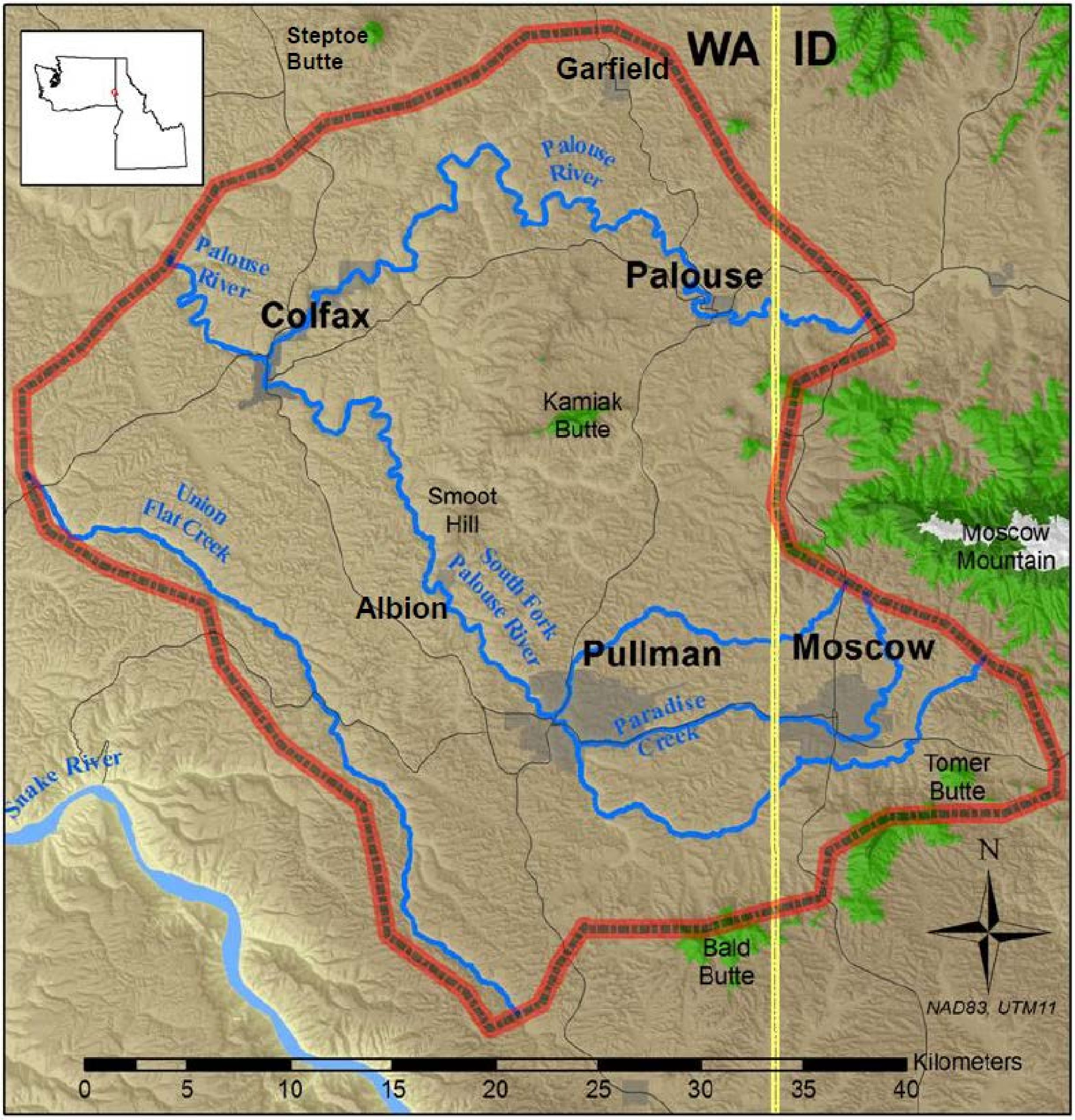

Figure 1. Map illustrating boundary of Palouse Basin (inside red highlighted dashed line) as presently used by Palouse Basin Aquifer Committee (from Moran, 2011).

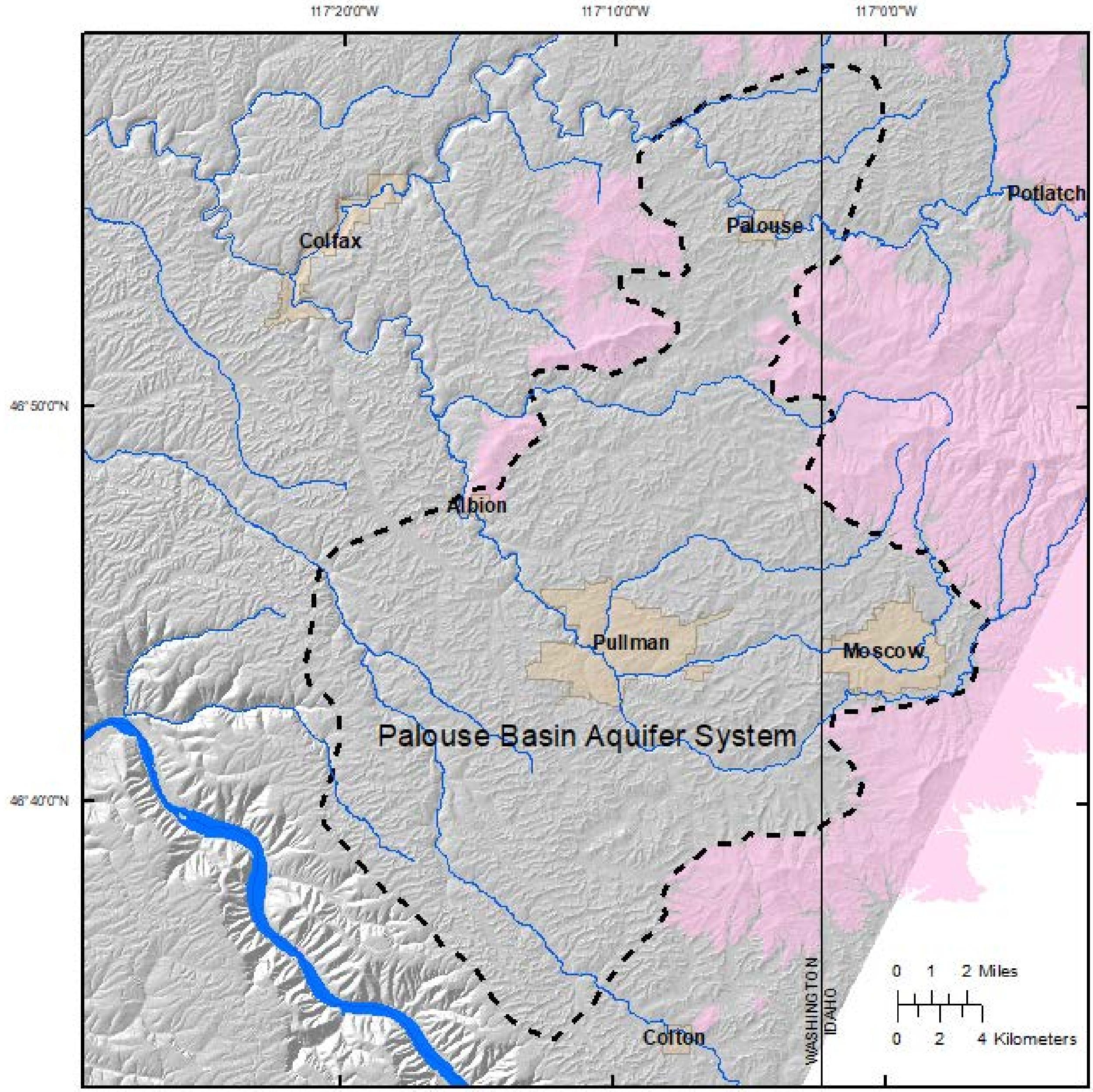

Figure 2. Physiographic map showing revised extent of the Palouse Basin aquifer system (inside black dashed line); Columbia River Basalt Group (gray), pre-Columbia River Basalt Group basement rocks (pink).

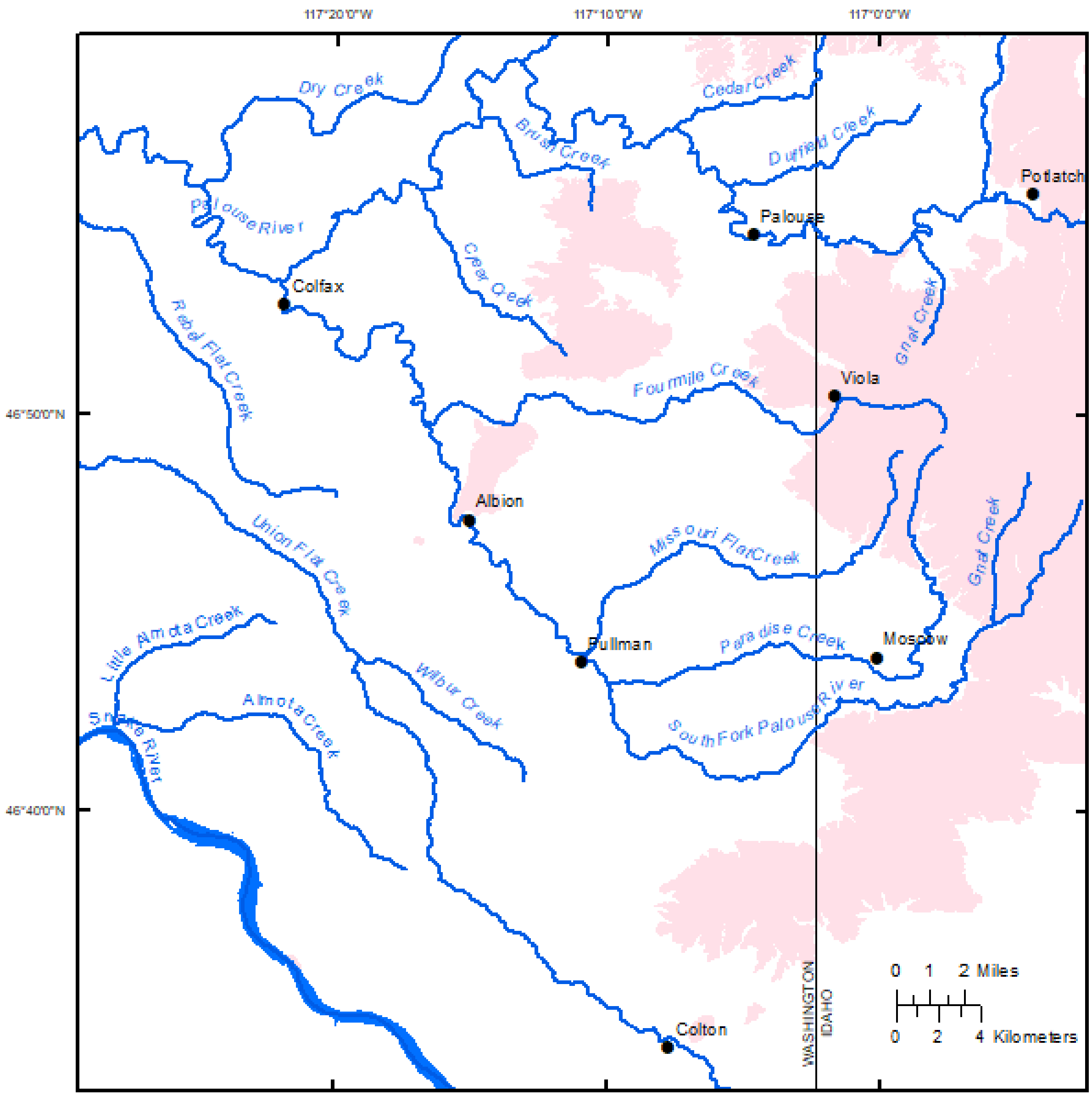

Figure 3. Map showing rivers and streams in the greater Moscow-Pulllman area; towns (black dots), basement rocks (pink). Note the northwest-trending streams west of Pullman; they are flowing in the direction of regional dip of the rocks.

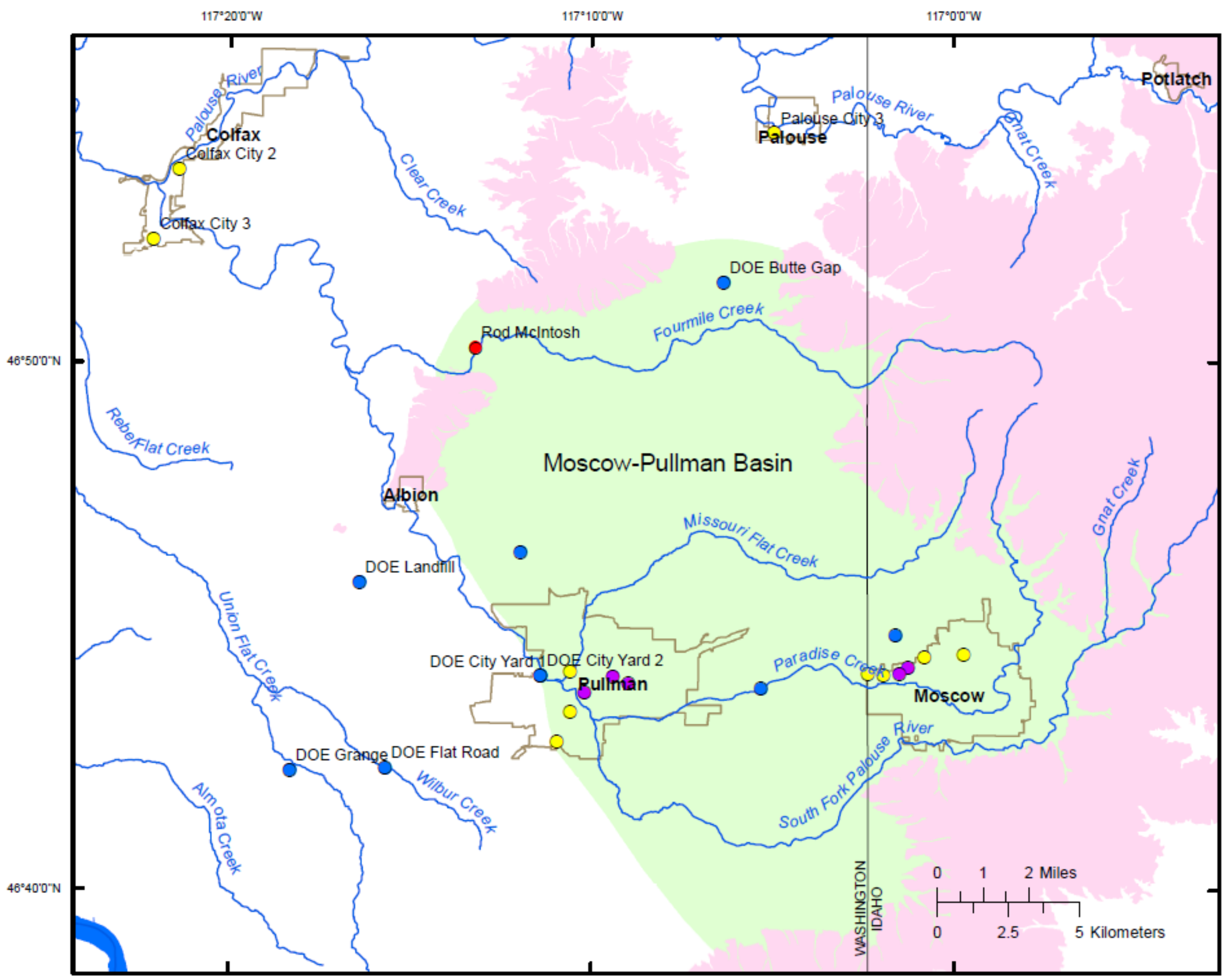

Figure 4. Map showing extent of the Moscow-Pullman Basin (green) as defined by Bush et al. (2018) and being made up of basalts and sediments; pre-Columbia River Basalt Group basement rocks (pink); wells (dots), domestic (red), municipal (yellow), test (blue), university (purple).

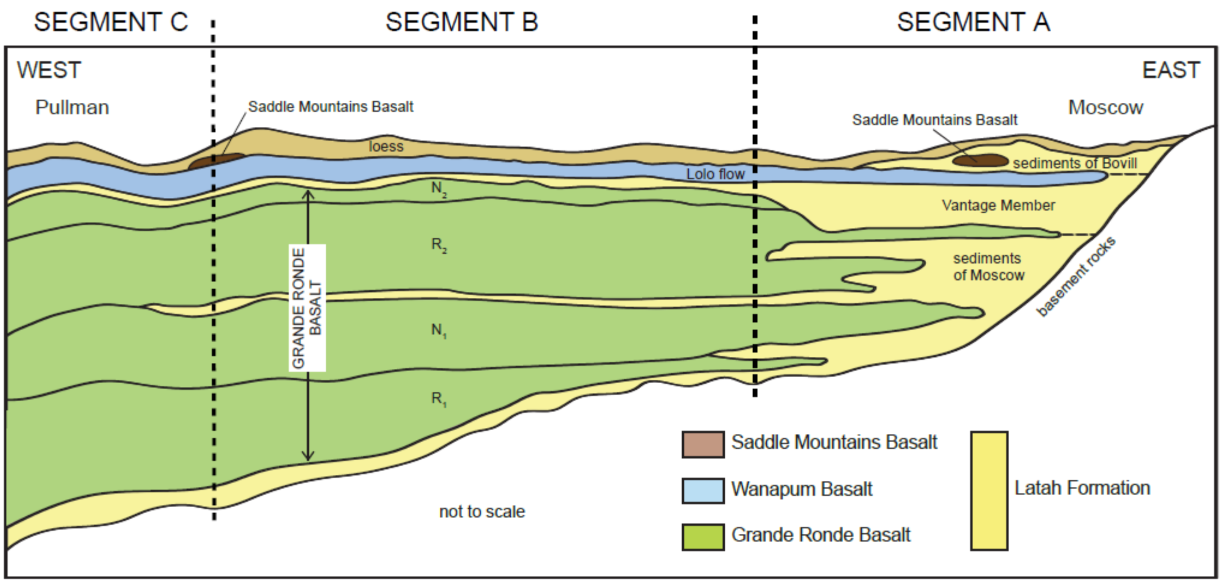

Figure 5. Geohydrologic segments A, B, and C of the Moscow-Pullman subsurface; cross-section from Bush et al. (2018).

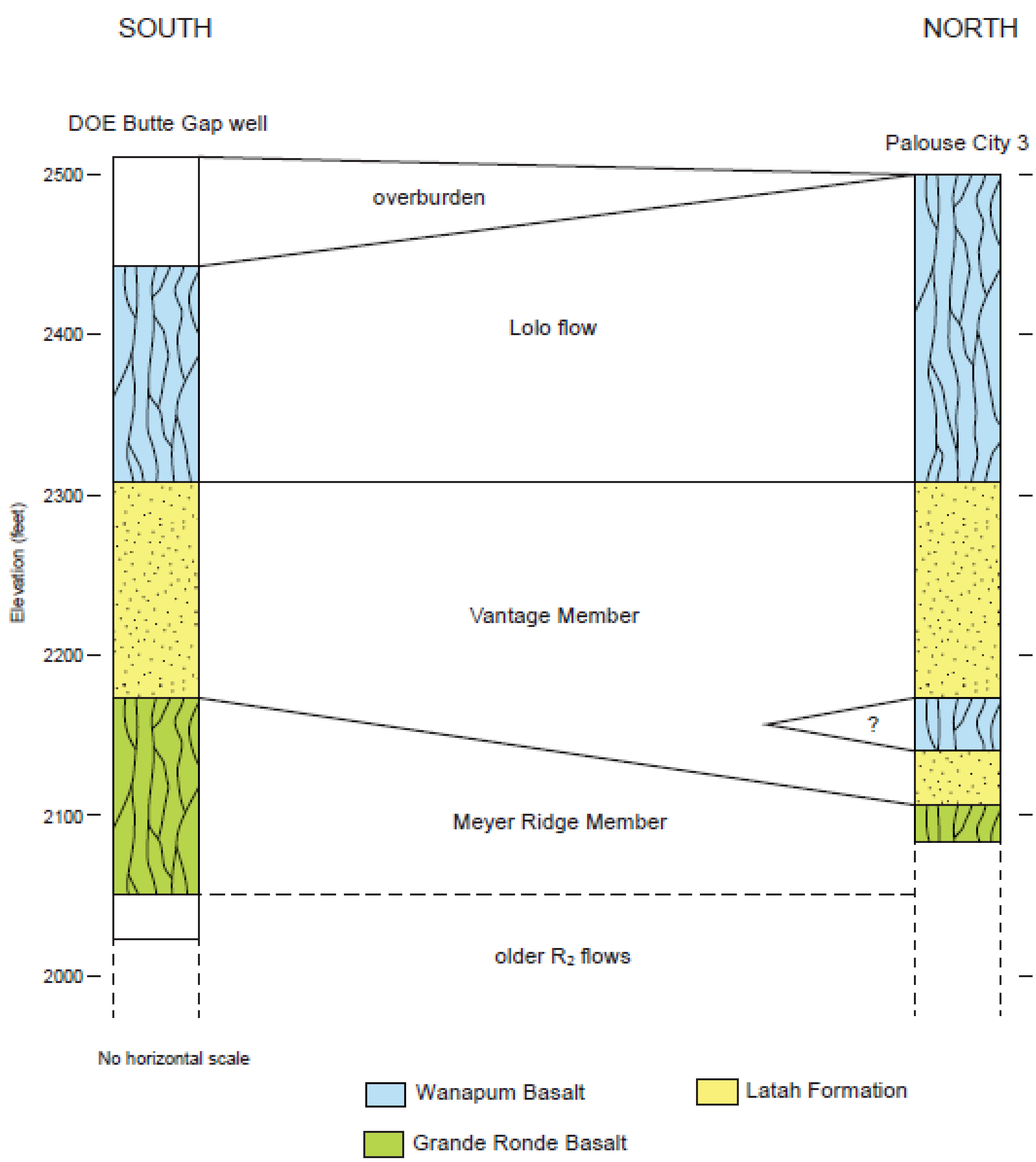

Figure 6. Comparison of DOE Butte Gap well to Palouse City well 3 (modified from Bush et al., 2016).