



*Kennewick Irrigation District*

*Badger Coulee Recapture of  
Artificially-stored Project Water Report*

*December 2015*



Prepared by RH2 Engineering, Inc.

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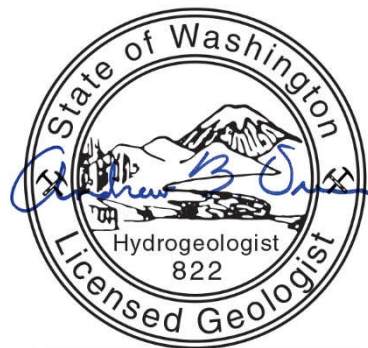
*December 2015*

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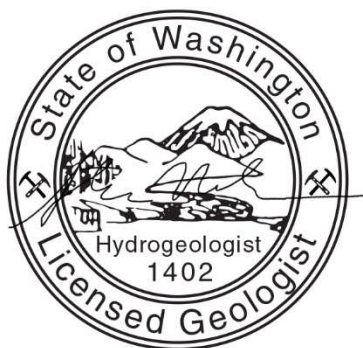
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Kennewick Irrigation District  
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# **Kennewick Irrigation District Badger Coulee Recapture of Artificially-stored Project Water Report**

## **Executive Summary**

The Kennewick Irrigation District (District) has an opportunity to recapture artificially-stored groundwater within the District boundary for beneficial use. Since 1957, when the District began to divert and transmit water from the Yakima River within Badger Coulee, groundwater levels within Badger Coulee have risen by 100 to 150 feet due to the recharge of groundwater directly associated with water leaking from District canals and laterals, as well as irrigation return flow.

The volume of project water that has been artificially stored in the subsurface within Badger Coulee is at least 132,000 acre-feet (af), with 85,000 af occurring within the Yakima groundwater subbasin, and 47,000 af occurring within the Columbia groundwater subbasin.

This water is stored in, and can be pumped from, the Pasco Gravel unit, which occurs at depths of approximately 50 to 240 feet below the coulee and is bounded both laterally and beneath by basalt bedrock. This unit ranges from 75 to 150 feet thick and is composed of coarse gravel. Any recapture wells would need to be drilled from 140 to 240 feet deep to reach the bottom of the Pasco Gravel unit and maximize available drawdown.

Groundwater within Badger Coulee flows from beneath the canals and irrigated fields toward the center of the coulee and then flows either toward the Yakima or Columbia Rivers. The groundwater elevation near the flow divide is approximately 600 feet. The groundwater flow divide appears correlative to the maximum elevation of the base of the Pasco Gravel unit, as opposed to being coincident with the topographic divide.

Six potential exploration sites have been identified for recapture wells. Four of these sites are located on the Yakima River side of the groundwater flow divide, while two sites are located on the Columbia River side of the groundwater divide.

Properly designed wells completed in the Pasco Gravel unit should produce approximately 1,000 gallons per minute (gpm). However, one well in the coulee is reported to have pumped up to 3,000 gpm.

Drilling and testing of a single recapture well should cost approximately \$150,000. Planning-level cost estimates to develop four wells at one location and to connect the wells to the canal system range from \$2.1 to \$2.8 million (M).

If the District elects to proceed, the next steps would include selecting a site, and drilling and testing the initial well; estimating the capacity and configuration of a well field; and refining the costs to construct and operate the well field.

## **Background**

The District is an irrigation district within the United States Bureau of Reclamation's Yakima Project that diverts water from the Yakima River at Prosser Dam. The District routes the water through miles of canals that ultimately pass through Badger Coulee (**Figure 1**) within the District's service area. Incidental canal leakage and a portion of irrigation water that infiltrates below the root zone

seeps into unconsolidated geologic units below the canals within Badger Coulee. Much of that water has accumulated and been stored over time in the aquifer, while a portion of the water discharges as seepage to surface drains, wetlands, and stream channels. The District is interested in recovering the artificially recharged and stored water in the sand and gravel aquifer to put the water to beneficial use within the District service area.

The District retained RH2 Engineering, Inc., (RH2) to perform a groundwater investigation of Badger Coulee to identify one or more target aquifers, and to identify potential well locations within the aquifers to allow the District to pump project water that has been artificially stored in the subsurface due to seepage from canals and irrigation return flow.

Badger Coulee is a long and narrow geomorphic feature with a relatively flat bottom that is underlain by unconsolidated sediments and is bounded by basalt bedrock hills on either side. The coulee runs from the south side of the Yakima River, near the community of Kiona (Kiona), on a sinuous path, until the valley widens as it reaches the City of Richland (Richland) on the right bank of the Columbia River (**Figure 1**). Within this report, Badger Coulee between Kiona and Interstate 82 (I-82) is referred to as the study area (**Figure 1**).

## **Geologic Setting**

### **Regional Geology**

The Yakima River valley and Pasco Basin are underlain by the Columbia River Basalt Group (CRBG), a series of Miocene-age basalt flows that subsequently experienced significant northwest-southeast trending folding and faulting to form the Yakima Fold Belt. Within the folded depressions of the basalt, alluvial sediments have been deposited and reworked by fluvial mechanisms. These sediments range in thickness from a few feet near bedrock outcrops to hundreds of feet in the center of the depressions. A generalized stratigraphic section is shown in **Figure 2**.

During glacial episodes of the Late Wisconsin age (13 to 15 thousand years ago), the area was inundated more than 40 times by large catastrophic glacial flooding, known as the Missoula Floods (Waitt, 1985). These flooding events eroded the existing sediments and basalt, as well as deposited numerous new sediment layers ranging in size from clay to boulders. It was these large flood events that deposited the sediments underlying Badger Coulee.

The upper sediments of Badger Coulee are composed of laminated silts and fine sands, and is known as the Touchet Beds; one of two units comprising the Hanford Formation. These fine-grained sediments were deposited within temporary impoundments created by the bottlenecking of the Missoula flood waters at the Wallula Gap, located southeast of the Tri-Cities (Reidel, 2004). As the floodwaters slowed, they deposited the suspended sediment and bed load. These temporary lakes impounded a large portion of the Pasco Basin and Yakima and Walla Walla River valleys. The overall thickness of the Touchet Beds is typically less than 50 feet, but may attain 200 feet within Badger Coulee. These fine-grained sediments act as an aquitard, restricting some vertical migration of groundwater into the underlying sediment. In this study, all sediments that contain a silt, clay, or fine-sand matrix are considered to be part of the Touchet Beds. Some unsorted coarse-grained landslide and alluvial fan deposits may interfinger with the fine-grained units.

Below the fine-grained Touchet Beds is a coarse-grained gravel unit, referred to as the Pasco Gravel (Reidel, 2004), with clasts ranging in size from gravel to boulders, and generally less than 15-percent

fine sediment. These gravels correspond to high energy deposition during the floods (Reidel, 2004). Thicknesses range from 0 to 150 feet, and, throughout much of the Pasco Basin, these gravels are at or near the ground surface covered by only a thin veneer of windblown sand or alluvium, except within Badger Coulee (Drost, 1997). It is difficult to distinguish between the Pasco Gravels and the underlying middle and lower sections of the Ringold Formation (pre-flood gravel deposits); therefore, within Badger Coulee, all gravel underlying the Touchet Beds are assigned to Pasco Gravels, although a significant portion may be Ringold Formation (Drost, 1997).

The Pasco Gravels often have an open texture and lack a fine-grained matrix (Reidel, 2004). It is this open texture and high porosity and permeability that makes the Pasco Gravels such a productive aquifer (Drost, 1997) and the primary target for recapturing artificially-stored project water.

The sediments within Badger Coulee are bounded both vertically and laterally (except at each end of the coulee) by the CRBG. In this area, the CRBG consists of three formations; from youngest to oldest they are the Saddle Mountain Basalt, the Wanapum Basalt, and the Grande Ronde Basalt, (Drost, 1997). Each formation is composed of many members or lava flows, which range in thickness from 10 feet to more than 300 feet. Total thickness of the CRBG is greater than 15,000 feet (Drost, 1997). The flows formed during the Miocene Epoch 17.3 to 6 million years ago from a north-northwest trending fissure system in southeastern Washington, Idaho, and Oregon (Schuster et al, 1997). The flows are fine- to coarse-grained, often exhibiting columnar (cooling joints) or blocky fractures. Flows tend to have numerous vertical fractures within each flow. The top and bottoms of flows are often more vesicular than the center of the flow and are highly fractured. Thin layers or lenses of sediments are often found between the flows; the sediments compose the Ellensburg Formation (Drost, 1997). The sediments are the same ages as the basalt flows and are composed of various sizes of grains from clay to cobbles of varying compositions. The deformation that formed the Yakima Fold Belt occurred concurrently with the eruptions of basalt (Reidel, 2004).

## **Local Geology**

The geology of the Badger Coulee area, as described within this report, is derived from a detailed review of the existing geologic documentation on the area, including, but not limited to, regional mapping and reporting by the United States Geological Survey, Washington State Department of Natural Resources, the Northwest Geological Society, and studies commissioned on the Badger Coulee area. This existing documentation was augmented by review of available water well reports that were either drilled within, or in proximity to Badger Coulee (**Appendix A**).

Geology within Badger Coulee consists of two units of Missoula Flood-deposited sediment, together referred to as the Hanford Formation, that overlie CRBG bedrock (Reidel, 2004). The actual folded depression, or coulee, (i.e., Badger Coulee), was either formed by erosion from the Yakima River prior to the floods, or was eroded during the floods (Brown, 1979) (**Figure 3**).

Subsurface data was collected and organized using the following methodology. Water well reports were obtained from the Washington State Department of Ecology's (Ecology) Well Log Viewer (<https://fortress.wa.gov/ecy/waterresources/map/WCLSWebMap/>) for all sections included within the study area: p

- T8N, R27E – Section 1
- T8N, R28E – Sections 1, 2, 6, 7, 8, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, and 23
- T9N, R27E – Sections 19, 20, 26, 27, 28, 29, 33, 34, 35, and 36
- T9N, R28E – Sections 31 and 36

Given the narrow extent of the aquifer within Badger Coulee, only well logs that could be associated with a well on a specific parcel were utilized. Association with a specific parcel was possible when the parcel number itself or an address was included on the water well report. When an address was included, the parcel number was obtained using the Benton County Assessor property search site (<http://bentonpropertymax.governmaxa.com/propertymax/rover30.asp>). While the exact location of the well within the parcel is still unknown, this level of accuracy is reasonable for the typical parcel size (2.5 to 5 acres) in relation to the width of the coulee.

One exception to the methodology above was for well logs associated with water rights that have the point of withdrawal mapped in Ecology's Water Resources Explorer (<https://fortress.wa.gov/ecy/waterresources/map/WaterResourcesExplorer.aspx>). In these situations, the identified point of withdrawal locations were used.

The approximate well locations were plotted using Geographic Information Systems (GIS). Approximate ground surface elevation for each well site was obtained using Google Earth.

Utilization of GIS allowed for information to be plotted and analyzed, including features such as the base of the Pasco Gravel aquifer elevation (**Figure 4**), the Pasco Gravel aquifer saturated thickness (**Figure 5**), and the approximate water level elevation (**Figure 6**). The stratigraphy contained on the well log was interpreted and the information was recorded in a spreadsheet (**Appendix B**). The information was then plotted to allow for analysis and contouring of the attributes previously discussed.

## **Groundwater Conditions**

For this study, the floor of Badger Coulee that is underlain by the Pasco Gravel aquifer is an area that includes approximately 7,750 acres. As will be discussed in more detail later in this report, the coulee has been divided in two at a location assumed to be consistent with the groundwater divide, which separates groundwater flowing toward the Yakima River (5,000 acres) from groundwater flowing toward the Columbia River (2,750 acres) (**Figure 7**). Even though the distinction is made in this report, it is strictly hydrogeologic in nature since all of the water is still Yakima Project water that falls within the project boundaries and is available for recapture and beneficial use by the District.

## **Groundwater Occurrence**

Artificially-recharged groundwater percolating from the surface fills the pore spaces of the unconsolidated Touchet Beds and Pasco Gravels, and possibly even enters the aquifers within the CRBG in places. The most productive wells within the coulee are completed in the Pasco Gravels. The Pasco Gravels are first encountered at a depth of approximately 50 to 200 feet below ground surface and the unit can be up to 150 feet thick in places (**Figure 6**).

Where the Touchet Beds are saturated, the water table is typically higher than the top of the Pasco Gravels. However, the fine grained Touchet Beds are too fine-grained to support a production well and are considered to be an aquitard.

Within Badger Coulee, the target aquifer for the recapture of artificially-stored groundwater is the Pasco Gravels. **Figures 5** and **6** show the anticipated extent of this aquifer within the coulee, the elevation of the bottom of the gravel unit where it usually lies directly on bedrock, and also the saturated thickness of the aquifer.

## **Groundwater Elevation and Flow Direction**

Drost (1997) and Brown (1979) suggest that regional groundwater flow in the CRBG aquifers, in Badger Coulee, is generally to the northeast toward the Columbia River. The Columbia River is generally considered to be the regional discharge point for all groundwater in the area. Groundwater within the Pasco Gravel aquifer within Badger Coulee ultimately flows parallel to the axis of the valley and either flows toward the Yakima River near Kiona, or flows toward the Columbia River at Richland.

CH2M Hill (1983) estimated that the groundwater flow divide between the Yakima and Columbia Rivers is located to the southeast of Badger Station (approximately Section 7, Township 8 North, Range 28 East W.M.). The groundwater flow divide occurs in a location where there are few wells, so it is an approximate boundary. The groundwater elevation at the divide is approximately 600 feet (**Figure 7**). The groundwater divide is not coincident with the topographic divide, which is located approximately 1.5 miles farther to the north (**Figure 4**), but instead appears to coincide with the highest elevation of the base of the Pasco Gravel aquifer (**Figure 5**). For all water balance calculations in this report, calculations will be made separately for water on each side of this groundwater divide.

CH2M Hill (1983) measured water levels in wells and created a groundwater elevation map that showed the general direction of groundwater flow in the coulee. Special attention was paid to the area around Sections 15, 16, 21, and 22, Township 8 North, Range 28 East W.M., where the general groundwater flow direction was to the northeast. CH2M Hill noted a rapid change in groundwater level near Sections 15 and 22, Township 8 North, Range 28 East W.M. CH2M Hill attributed this discrepancy in water level to the Badger Coulee Fault, which cuts northwest-southeast across the coulee through the study area (**Figure 3**). CH2M Hill speculated that either groundwater could be elevated upgradient of the fault due to the faulting action grinding down sediment to form a vertical zone of lower-permeability sediments that could impede lateral groundwater flow, or that a drop in bedrock elevation across the fault is being mimicked by the groundwater level elevation. An additional reason for the water level drop could be that the mouth of the coulee widens past this point, which would allow groundwater to spread out laterally as it moves toward the Columbia River.

The District's canals typically occur near the edge of the flat-bottom portion of the coulee. Drost (1997) provided water level measurements from wells in Badger Coulee over time during 1986 and 1987. The hydrographs show that the groundwater level measured in wells closer to the canals rise and fall more dramatically than in wells near the center of the coulee. The rise of the groundwater level occurs shortly after the start of the irrigation season when water fills the canals and begins to leak. The drop in groundwater level occurs shortly after the irrigation season has ended and the canals are dry, which cuts off that source of recharge to the aquifer. During periods of groundwater recharge through canal seepage, groundwater flows from the canals on the margin of the coulee toward the center.

## **Artificial Rise of the Groundwater Level**

Past investigators have looked at the impact on the water level within the Pasco Gravel aquifer of the artificial storage of water in the Badger Coulee. Drost (1997) estimated that between 1957 (when the District's canals began to provide irrigation water and associated seepage to the groundwater system), and 1986, the groundwater level rose between 100 and 150 feet in Badger Coulee from a starting elevation of approximately 450 feet. Over that 29-year period, that is an average water level

rise of between 3.4 and 5.2 feet per year. CH2M Hill (1983) compared the water level measured in wells in September 1982 with the water level when the wells were drilled, and calculated an average rise of 4.3 feet per year. Brown (1979) suggested that the rise in the groundwater level had been on the order of 5 feet per year.

Comparison of the elevation of the base of the Pasco Gravel unit with the approximate pre-1957 groundwater elevation of 450 feet (Drost, 1997) shows that very little of the Pasco Gravel unit was saturated historically and those areas were where the base of the unit is lower than elevation 450 feet (**Figure 5**). Ecology's Water Resources Explorer was reviewed for water rights utilizing sources of groundwater within the Badger Coulee study area. The only state-issued groundwater right in the study area that was issued prior to 1957 was GWC 2594-A, issued to the Yakima Sheep Company. This water right utilized a well completed in the basalt aquifer beneath the unconsolidated sediments. The water well log indicated that a 33-foot-thick gravel and sand unit (likely the Pasco Gravel) was encountered at a depth of 175 to 208 feet (**Appendix A**). However, no water was noted in this unit and the well driller proceeded to drill into the basalt before water was encountered. The elevation of the base of the Pasco Gravel is approximately 471 feet at this well, which indicates that the static groundwater level was deeper than the gravel unit at this location prior to the introduction of project water. The lack of pre-1957 groundwater rights also suggests that groundwater was not physically present in much of Badger Coulee in the Pasco Gravel unit before the importation of irrigation water by the District.

Most investigators suggest that by the mid-1980s, an equilibrium had been reached between the inputs (primarily canal seepage and irrigation return flow) and outputs (well pumping, discharge to springs, wetland, and wasteways, evaporation from wetlands, subsurface percolation into bedrock, and subsurface discharge to the Yakima and Columbia Rivers).

Therefore, the groundwater system has equilibrated to the introduction of substantially more recharge than under natural conditions. In the future, a long-term drop in water level might signal either a reduction in inputs (such as less canal seepage due to efforts to line the canal or irrigation efficiencies), or an increase in discharge (pumping from wells).

## **Recharge Sources**

There are two types of recharge to the target aquifer. Recharge that is naturally occurring (precipitation) and recharge that is artificial (seepage from the District's canals and irrigation return flow). Badger Coulee receives approximately 8 to 10 inches of precipitation each year (CH2M Hill, 1983) with less than 1 inch contributing to groundwater recharge (Drost, 1997). Over the study area of 7,750 acres, this equals an annual natural groundwater recharge of, at most, 646 acre-feet per year (afy), with 417 afy on the Yakima River side of the groundwater divide and 229 afy on the Columbia River side of the groundwater divide. Drost (1997) estimated that for irrigated land within Badger Coulee, the anticipated deep percolation beyond the root zone is equal to approximately 7.9 inches per year. The recharge under irrigated fields is calculated to be 8 times greater than unirrigated areas.

CH2M Hill (1983) used multiple methods to estimate the rate at which water was being added to storage in the groundwater system between Badger Station and the Badger Coulee Fault (an area of approximately 2,500 acres) on an annual basis (**Figure 3**). In one method they estimated the influx of water necessary to produce an average water level rise of between 4.3 and 5.3 feet per year. In the report they used a storage coefficient of 0.2, which is equivalent to a soil porosity of 20 percent and a reasonable estimate for the Pasco Gravel. They assumed that the introduced water is trapped within the coulee without any subsurface outflow and did not account for water lost to other

groundwater wells. This estimation suggests that there was 2,100 to 2,800 afy being added to groundwater storage each year over the period of 1957 through 1986 to account for the rise. Total groundwater recharge in this area was estimated to be 4,500 afy, which is a distributed recharge rate of approximately 1.8 feet per year, which is at least 22 times greater than the natural recharge rate.

The District performed monitored flow in the canal shortly before the CH2M Hill report (1983) and estimated that the main canal was losing 1.06 cubic feet per second (cfs) per mile based on differences in the measurement of flow from Chandler Siphon to Amon Pump. CH2M Hill concluded that there was approximately 6.1 cfs introduced over the 5.75-mile length of the main canal between Badger Station and the Badger Coulee Fault. Over the course of the 180-day irrigation season, this equates to about 2,200 afy being introduced into the groundwater system in that area.

The calculations previously mentioned suggest that the volume of water that has been added to storage to cause the 100- to 150-foot rise in the static water level for the 29 years between 1957 and 1986 was between 60,900 af and 81,200 af for the area between Badger Station and the Badger Coulee Fault.

Since 1983, the District has lined portions of its canals between the Chandler Siphon and Amon Wasteway in Badger Coulee. In 1983, the entire length of main canal and East Badger lateral was unlined, which is a total of 25.9 miles of canal within the RH2 study area. As of 2015, only 14.3 miles of canal within the Badger Coulee study area remains unlined (**Figure 8**). Currently, the District is planning on lining additional portions of the main canal in Badger Coulee. Unlined canals constructed in the Touchet Beds are estimated to leak at a rate that is 2 to almost 60 times higher than lined canals (Drost, 1997). The District's lining program will lead to a reduction in artificial groundwater recharge from canal seepage and will most likely cause groundwater levels to drop as the groundwater system adjusts to the reduced recharge rate.

## **Discharge Areas**

### **Wetlands, Springs, and Wasteways**

The reason the District contracted with CH2M Hill to perform the 1983 groundwater study was because landowners were complaining about shallow groundwater levels in the vicinity of the SE ¼ Section 16 and the NW ¼ Section 22, Township 8 North, Range 28 East W.M. near the intersection of E Badger Road and S 918 Private Road SE (**Figure 8**). The only reason there is shallow groundwater in this area is due to the introduction of project water into the subsurface. Within Badger Coulee, these wetlands now form the headwaters of the East Badger Drain, which is tributary to the Amon Wasteway in the vicinity of Meadow Springs (Section 36, Township 9 North, Range 28 East W.M.). Prior to the construction of the irrigation system, there were no perennial waterways in what is now the East Badger Drain and Amon Wasteway.

### **Springs**

CH2M Hill (1983) reported that a spring had developed over time in the northwestern part of the coulee and that water from it flows down into the Yakima River near the community of Kiona. This spring was reported to have started as a seep or wet spot in about 1973, and the flow steadily increased until it was observed to be flowing at 0.4 to 0.6 cfs in September 1983. Drost (1997) estimated the mean annual discharge from this spring to be 0.4 cfs. At this rate, there is 290 afy discharging from groundwater at the spring.

### **Subsurface Discharge**

It has been established that groundwater flows from eastern Badger Coulee toward the Columbia River. This flow is entirely in the subsurface, and CH2M Hill (1983) estimated that this annual groundwater flow is equal to approximately 1,350 afy and is controlled by the Badger Coulee fault.

No estimates have been made regarding the subsurface groundwater discharge to the Yakima River.

### **Aquifer Yield and Pumping Rates**

Brown (1979) indicated that transmissivities calculated from specific capacity of wells produced a range of 3,000 to 30,000 gallons per day per foot (gpd/ft) with an average of approximately 15,000 gpd/ft. He noted that the wells were concentrated near the east end of the coulee and might not be representative of the entire coulee. Drost (1997) suggests that the hydraulic conductivity of the Pasco Gravels in Badger Coulee is lower than elsewhere within the unit, and indicates that the median hydraulic conductivity of the unit, based on 16 wells, was 320 ft/day. Conservatively, assuming a 50-foot-thick saturated thickness for the Pasco Gravel aquifer, then the transmissivity would be 16,000 ft<sup>3</sup>/day (120,000 gpd/ft), which is approximately 10 times greater than estimated by Brown (1979). On a short-term basis, at least one well completed in the target aquifer was reported to pump up to 3,000 gpm (Goose Hill Orchards Well, Section 28, Township 9 North, Range 27 East W.M.). Based on the specific capacities for the larger production wells and the sediments describe on the water well reports, it is anticipated that the transmissivity of the aquifer will be shown to be closer to the higher value if the wells are properly designed and constructed.

For planning purposes, each new, properly designed, and appropriately located well should be able to produce approximately 1,000 gpm from the Pasco Gravel unit.

### **Groundwater Quality**

Groundwater within the unconsolidated sediments (Touchet Beds and Pasco Gravels) often contains elevated nitrate concentrations. The source of the nitrate in the groundwater appears to be a combination of nitrate-rich irrigation water return flow and leaching of naturally-occurring nitrates from the Touchet Beds (Ebbert, 1995). Wells tapping the deeper underlying basalt aquifers do not typically have elevated nitrate concentrations, which suggests that groundwater does not move vertically from the unconsolidated sediments into the basalt aquifers in Badger Coulee. However, Brown (1979) suggests that the coulee is a major recharge area for the aquifers in the upper part of the Wanapum Basalts, so it is possible that there is percolation from the Pasco Gravels to the Columbia River Basalt Group aquifers beneath the coulee.

Groundwater with elevated nitrate should not present a problem for the District since this water is intended to be used for irrigation.

### **Groundwater Use**

The density of groundwater development in the target aquifer varies depending on location. There are some larger irrigation water rights, as well as private single-family residence wells, that tap the target aquifer. **Figure 9** identifies the density per square mile of wells, as reported on Ecology's Well Log Viewer. This figure also shows some of the larger wells associated with water right documents.

In many areas, as discussed previously, the groundwater within the target aquifer contains elevated nitrate concentration that is above the maximum contaminant limit (MCL) for drinking water. This has led to a number of wells being cased through the target aquifer so that the well can be

completed in the underlying basalt aquifers, which usually contain water that has a lower nitrate concentration.

## **Estimate of Artificially-stored Water**

Drost (1997) suggests that the storage coefficient for the Pasco Gravels is between 0.15 and 0.20, while the storage coefficient for the Touchet Beds is lower at about 0.08. If it is assumed that the average water level rise across the study area was 100 feet, and of that rise, there was an average of 75 feet of water level rise in the Pasco Gravels at a storage coefficient of 0.2, and 25 feet of rise in the Touchet Beds at a storage coefficient of 0.08, that volume on the Columbia River side (2,750 acres) is equal to approximately 47,000 af. If the District begins to pump the artificially-stored water, they will be able to pump more than the 47,000 af since pumping will cause a reduction in evapotranspiration from wetlands and discharge to ditches and wasteways. As long as the static water level elevation does not drop below an elevation of 450 feet, then all of the water pumped will be artificially-stored water as opposed to naturally-occurring groundwater. The estimate of the volume of water in storage is a fixed volume. Short-term pumping that reduces the volume of water in storage must be managed against the recharge to the aquifer (historically estimated as 4,500 afy), which can be impacted by changes in irrigation methods and canal lining.

If a well is able to be operated continuously over the irrigation season of April 1 through October 31 at 1,000 gpm, it will be capable of pumping 941 af of water. This volume of water is approximately 2 percent of the artificially-stored water. Assuming that the first reduction in storage would occur in the Touchet Beds, with their reduced storage coefficient (0.08), the static water level would be lowered by an average of, at most, 4.3 feet on the Columbia River side of the groundwater divide if all water was taken from storage. However, as long as water continues to be introduced to the aquifer from canal leakage and irrigation return flow, these inputs will help to buffer the removal of water from storage during the initial phase of development.

## **Proposed Exploration Areas**

In order to capture the artificially-stored groundwater, the District will need to construct recovery wells. A well tapping the Pasco Gravel could be completed almost anywhere in Badger Coulee. To refine the sites, RH2 reviewed the study area for several criterion related to groundwater availability, property ownership and access, distance and pipeline route to the nearest canal, groundwater use in the area, and whether the proposed pipeline alignment would need to cross the railroad tracks. RH2 compared these criterion for each site to assist the District with identifying one or more preferred exploration areas for further investigation. **Table 1** summarizes the comparison criterion and **Figure 10** shows the potential exploration areas. The criterion included in **Table 1** are described in the following section.

## **Hydrogeologic Criteria**

### **Aquifer Saturated Thickness**

The greater the aquifer saturated thickness, the potentially higher aquifer transmissivity and potential pumping rate of a well. Within the potential exploration areas, the aquifer saturated thickness is anticipated to range from 75 to 150 feet.

### **Anticipated Well Depth**

This criterion shows the variability in the thickness of the unconsolidated sediments anticipated between the sites. Within the potential exploration areas, the well depth necessary to reach the bottom of the Pasco Gravels is anticipated to range from 140 to 240 feet.

### **Anticipated Depth to Static Water Level**

This criterion identifies at approximately what depth below ground surface the static (non-pumping) water level will be for each area. Within the potential exploration areas, the anticipated depth to static water level should range from 20 to 100 feet.

### **Anticipated Available Drawdown**

This criterion helps with determining how much drawdown a particular well site can handle based on the pumping rate. For this criterion, it is assumed that the District would not want to draw the water level down farther than half of the distance between the bottom of the Pasco Gravels and static water level. This limitation will allow for a sufficient length of well screen to be exposed to the aquifer to maximize efficiency when pumping. Within the potential exploration areas, the range of available drawdown is estimated to be 55 to 75 feet.

### **Density of Wells in Section**

This criterion informs the District of the number of well logs on file with Ecology for each legal section that contains a potential exploration area. There are likely more wells than are identified due to wells being drilled before recordkeeping was required (1971). Within the potential exploration areas, the density of identified well logs range from 1 to 31 wells per square mile.

### **Groundwater Basin**

This criterion identifies which side of the groundwater flow divide each site is located. While the District has a right to recover project water anywhere within the project boundary, this helps to identify which stakeholders might be the most interested in each potential exploration area.

### **Site Information**

Site information is included so that the District can determine if the target property is either owned by the District, or if an agreement will need to be reached with a property owner.

### **Distance to E Badger Road**

This measurement was included as a possible surrogate for the distance to provide power to the wellfield.

### **Distance to Larger User Pumping from Gravel Aquifer**

This criterion was included to understand the proximity of the most likely source of interference drawdown to a well located in the potential exploration area.

### **How Far the Site is from E Badger Road**

This distance was included because it could be a surrogate for the distance to a power source, assuming that adequate power exists at E Badger Road for the pumps that will be used.

### **Well to Canal Information**

Information is included on the distance to both the Main and Badger Lateral, ownership for the anticipated pipeline alignment, if there is a railroad crossing, and the approximate pumping lift. Distances to the main canal ranged from 0.5 miles to 1.1 miles. Distances to the Badger Lateral ranged from 0 to 2.1 miles. Anticipated pumping lifts to the main canal range from 170 to 195 feet, while the anticipated pumping lift to the Badger Lateral range from 145 to 175 feet.

### **Planning-level Cost Estimates**

Planning-level cost estimates to develop four wells at one location and to connect the wells to the canal system ranges from \$2.1 to \$2.8M (**Appendix C**). At this point, none of the sites are clearly more cost effective than the others, based on the uncertainty that still needs to be refined through additional work, such as discussion with property owners, well drilling, and well testing.

Preliminary results of this work were discussed in a meeting on August 20, 2015, with RH2 and District staff. District staff directed RH2 to focus on potential exploration areas 5 and 6, which are east of the apparent groundwater divide within the Columbia River groundwater basin, and have a high potential for well yield. Based on the water budget calculations, wells constructed at sites 5 and 6 could recover up to a maximum combined 47,000 af from storage (which would lower the water table by approximately 100 feet). In addition, the wells could capture, at most, up to an additional 4,500 afy if that water is not allowed to discharge via springs, wasteways, or subsurface flow toward the Columbia River.

## **Conclusions and Recommendations**

Badger Coulee represents an opportunity for the District to recapture project water that is being artificially stored within the coulee and can be readily accessed through pumping from the Pasco Gravel aquifer.

### **Accessing Artificially-stored Project Water**

It has been calculated that there has been between 100 and 150 feet of groundwater level rise in the coulee due to the introduction of artificially-stored project water. The volume of artificially-stored project water within the coulee ranges from 132,000 to 232,000 af. Of this, approximately 47,000 af is stored in the portion of the aquifer that appears to be discharging toward the Columbia River. As long as the District does not pump the static groundwater level down to an elevation below 450 feet, no natural groundwater will be withdrawn since the artificial recharge of project water is what has caused the water level to rise to its present elevation. However, it is likely that there are many individual wells that tap this same aquifer and are likely pumping the District's artificially-stored project water. The potential impact to these individual wells will be better understood once a well has been constructed and tested.

It is recommended that development of the artificially-stored project water be undertaken in phases. With each phase of development, monitoring should occur to allow for refinement of water budget estimates, including how much artificially-stored project water is in storage, how much water is recharged to the aquifer over the course of the irrigation season, and how effective the wells are at capturing that water.

### **Site Characterization**

The District should identify property owners within the identified potential exploration areas that may be willing to consider utilization of at least a portion of their property for a recapture facility owned and operated by the District. Obtaining properties that currently contain project water-fed wetlands will allow the wells to be placed where the aquifer discharges and could have the added benefit of reducing the area suffering from high groundwater levels.

The District should secure a well driller to construct a 16-inch-diameter test well, which would accommodate a well casing, screen, and pump of sufficient capacity to efficiently yield 800 to 3,000 gpm.

After drilling of the well, the well screen assembly should be designed by a licensed hydrogeologist or professional engineer experienced with designing well screen assemblies. After screen installation, the well should be developed to remove any fine-grained material from the portion of the aquifer adjacent to the screened interval.

After development, a temporary pump should be installed and the well should be pump tested at a rate no less than the desired design pumping rate for a period not shorter than 24 hours. The test water must be discharged in a manner such that it will not recirculate back to the aquifer and interfere with test results. During the pumping test, the water level in nearby wells completed in the Pasco Gravels should be monitored to improve the quality of the analysis. The pumping test will allow for aquifer properties to be calculated, which will allow for better decision making regarding individual well pumping rates, production well spacing, anticipated interference drawdown in neighboring wells, and potential well field seasonal yield.

Drilling and testing of a single recapture well should cost approximately \$150,000. Planning-level cost estimates to develop four wells at one location and to connect the wells to the canal system ranges from \$2.1 to \$2.8M.

## **Water Level Monitoring**

The District should start to monitor the groundwater level within wells located in Badger Coulee. This monitoring will provide the District with a better understanding of trends in groundwater level over time. This will be especially critical if the District begins to recapture project water.

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