City of Pasco, Washington

Initial Feasibility Study Report

Aquifer Storage and Recovery Feasibility Study

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Abbreviations and Acronyms

afy	acre-feet per year
ASR	Aquifer Storage and Recovery
bgs	below ground surface
cm	centimeters
City	City of Pasco, Washington
CRBG	Columbia River Basalt Group
DBPs	disinfection byproducts
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
gpm	gallons per minute
Golder	Golder Associates, Inc.
GSI	GSI Water Solutions, Inc.
h	available buildup
ID	identification
K	hydraulic conductivity
Kh	horizontal hydraulic conductivity
Kv	vertical hydraulic conductivity
MCL	maximum contaminant level
µS/cm	microSiemens per centimeter
mg/L	milligrams per liter
mg/L-$CaCO_3$	milligrams per liter as calcium carbonate
mg/L-N	milligrams per liter as nitrogen
MGD	million gallons per day
MG	million gallons
M&I	municipal and industrial
MOA	memorandum of agreement
MSA	Murray, Smith, and Associates, Inc.
Murraysmith	Murraysmith, Inc.
NAD27	North American Datum of 1927
n_e	effective porosity
OCR	Office of the Columbia River
Off-season	November through March
Peak-season	May through September
Q	flow rate
QCWR	Quad City Water Right
Quad Cities	Cities of Kennewick, Pasco, Richland, and West Richland
R	Range
RAW	Rattlesnake-Wallula alignment
RH2	RH2 Engineering, Inc.
SMB	Saddle Mountains Basalt
s.u.	standard units
S	storativity
SMCL	secondary maximum contaminant level
SCBID	South Columbia Basin Irrigation District
T	Township
T	transmissivity
TDS	total dissolved solids

TSS	total suspended solids
TTH	trihalomethanes
UGA	Urban Growth Area
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDOE	United States Department of Energy
USGS	United States Geological Survey
V	volume
WTP	Water Treatment Plant
WB	Wanapum Basalt
WAC	Washington Administrative Code
WPWTP	West Pasco Water Treatment Plant

Executive Summary

The City of Pasco, Washington (City) is evaluating the feasibility of developing an aquifer storage and recovery (ASR) program that would allow storing surplus water available from their existing supply sources in aquifers beneath the City for use during periods of peak-season demand. ASR is a water management tool that municipalities throughout Washington and Oregon use to help manage and optimize their water supply resources. The concept for a Pasco ASR program would include withdrawing water from existing supply sources during the winter months when demands for water are low, injecting and storing that water in an aquifer system beneath the City using a well or series of wells, and recovering (pumping) the stored water from those same wells to meet peak summer demands. This would allow the City to augment peak-season demand needs and help meet projected demand shortfalls without increasing permitted withdrawals from the Columbia River during the low-flow summer months. A successful ASR program would allow the City to optimize use of their portion of the Quad City water right permit and to increase the sustainability and resiliency of their existing water supply sources.

This report presents initial findings from a targeted reconnaissance-level investigation of the feasibility of Pasco developing a future ASR program. The following sections summarize major findings from the study.

Future Water Demands

The City is projected to experience significant growth in population and demands on their water systems over the next 15 years, particularly in the northwest portion of the City and future urban growth boundary areas. By year 2036, the City's potable and irrigation water systems are projected to have a combined peak-season (May through September) capacity shortfall of approximately 5,700 gallons per minute (gpm) and a peak-season firm capacity[1] shortfall of roughly 10,800 gpm. During the 153-day peak demand season, this equates to a total capacity shortfall of approximately 3,850 acre-feet of water (1,255 million gallons)[2] and firm capacity shortfall of approximately 7,300 acre-feet (2,380 million gallons)[3].

Water Rights

The City has an extensive portfolio of water rights that gives them legal access to water to supply both their potable and irrigation water systems. The City's current portfolio of rights however, is not enough to cover the 15-year future water demand needs without offsetting the impacts from using those systems on minimum instream flow requirements on the Columbia River. Conjunctive use of ASR with the Quad City water right permit however, provides an opportunity for the City to address the legal and physical water availability constraints of the resource by storing water diverted under the permit during off-peak times when minimum instream flows on the river are met, and recovering the stored water during high demand periods when the instream flow protections may not be met. Together they would allow the City to (1) shift seasonal water availability to correspond better with demands on the City's irrigation and potable systems, (2) reduce future impacts on the Columbia River during summer low-flow periods, and (3) reduce or eliminate the need to mitigate any impacts to the river as described by provisions of the permit.

[1] Firm capacity is defined as the capacity of a water production facility with the largest pump out of service, due to damage or routine maintenance, for example.

[2] Total peak-season capacity shortfall of approximately 32 million gallons (98 acre-feet) for the potable system and 1,223 million gallons (3,752 acre-feet) for the irrigation system.

[3] Firm peak-season capacity shortfall of approximately 495 million gallons (1,519 acre-feet) for the potable system and 1,885 million gallons (5,781 acre-feet) for the irrigation system.

ASR Potential in the Pasco Basin

Findings from this initial feasibility study suggest that development of a Pasco ASR program appears feasible. The City is situated in a geologic region where the vast majority of operational ASR systems in the Pacific Northwest are located, including active ASR facilities currently operated by the cities of Kennewick, Walla Walla, and Pendleton. The Umatilla Member of the Saddle Mountains Basalt and the Frenchman Springs Member of the Wanapum Basalt have been identified as potential storage aquifers for a Pasco ASR program. The storage capacity of these aquifers underlying the City is estimated at approximately 17,000 acre-feet (5,600 MG), and is estimated to be greater than the total predicted shortfall for both the potable and irrigation systems. The storage volume estimate however, could vary depending on the actual hydrogeologic characteristics of the aquifers beneath candidate ASR development sites. No groundwater quality concerns were identified for these potential storage aquifers, though future water quality investigations are recommended to be completed as a future feasibility phase.

Candidate ASR Development Areas

Preferred locations where ASR could help address future demand growth for the potable and irrigation systems have been identified in the northwest portion of the City. Findings suggest that the hydrogeologic conditions beneath that portion of the City are most favorable. Hydrogeologic conditions in the southern half or eastern portion of the City however, are less favorable.

Source of Water for Aquifer Recharge

The City's potable water system does have access to the interruptible portion of the Quad Cities water right permit during the off-season months via their West Pasco and Butterfield Intakes when minimum instream flow provisions on the Columbia River are met. Based on the number of days that water is historically available (uninterrupted) for withdrawal under the water right permit and existing infrastructure capacity constraints, an estimated 3,146 acre-feet (1,025 MG) of water could be diverted and treated by the West Pasco WTP for use as source water for ASR storage. An additional 951 acre-feet (310 MG) of water could be pumped from the Columbia River Intake irrigation source for ASR supply, though would require filtration and disinfection prior to recharge to meet groundwater anti-degradation criteria and to reduce or eliminate the potential for plugging or biofouling of the ASR well(s). Additional or alternative ASR supply sources (e.g., collector wells or riverbank filtration wells) could add to the amount of water available for storage and reduce treatment needs/costs compared to the existing sources.

ASR Wells

A conceptual ASR wellfield design was developed for the candidate ASR development sites based on historic source water availability using the Quad Cities water right permit and existing infrastructure capacity constraints. Because source water available for ASR supply would be interruptible during the off-season when minimum instream flows on the river are not met, the ASR wellfield must be designed and capable of recharging water at the maximum rate of 6,000 gpm when it becomes available. This would require an estimated four ASR wells designed to recharge at 1,500 gpm each, with one identified as the City's irrigation ASR well and the remaining three reserved for potable water. The actual number and configuration of the ASR wellfield wells will depend on site-specific aquifer characteristics determined as part of a future work phases should the City decide to pursue an ASR program and could be adjusted or expanded if dedicated ASR supply sources are developed.

The purpose of designating one of the ASR wells as an irrigation ASR well, in addition to offsetting the irrigation system supply deficit, is partially based upon eliminating the need for treating all of the water recovered from storage and partially based upon still being able to use the recovered water if the ASR water quality is less desirable as drinking water due to secondary contaminants or aesthetic concerns (*e.g.*, taste, odor, temperature).

Water Recovered from Storage

Some loss of source water stored in the target storage aquifers is likely and will limit full recovery of the volume of water recharged. Using an estimated 10 percent loss factor for planning purposes, this means that of the 3,146 acre-feet (1,025 MG) estimated to be available for ASR supply, an estimated 2,831 acre-feet (922 MG) will be available for recovery and beneficial use. The estimated 2,831 acre-feet is enough to cover the entire year 2036 projected shortfall for the potable system, but only a portion of the year 2036 projected shortfall for the irrigation system. As a result, additional sources of water, either for direct use or seasonal storage, would be needed to meet the peak-season shortfall remaining for the irrigation system.

Recommendations

Additional work is recommended to better understand ASR feasibility given the general lack of specific data on the target storage aquifers at the candidate ASR development sites. Recommended next steps include (1) reconnaissance surveys of key basalt wells in the area, (2) water quality sampling and analyses, (3) a geocompatibility assessment to evaluate for potential adverse geochemical reactions between ASR supply water and groundwater, and (4) an evaluation of potential alternative ASR supply sources, including City stand-alone water rights. Additional work could include other physical sources including but not limited to municipal and industrial (M&I) water from U.S. Bureau of Reclamation or treated water from the City's Process Water Reuse Facility.

SECTION 1: **Introduction**

Competing uses for water are continuing to increase demands on surface water and groundwater resources in the Pasco Basin. These increasing demands, coupled with constraints on developing new supply sources, are factors the City of Pasco (City) faces when planning, developing, and maintaining safe and reliable sources of water for its customers. Meeting these demands can be challenging, as the City is constrained by the legal and/or physical availability of the resource:

- Water rights may not be available, and if they are, they may be subject to seasonal-use provisions or require mitigation and capital investment to secure.
- The seasons during which water is available do not correspond with the City's demand patterns.
- Existing groundwater resources are fully allocated.

Aquifer storage and recovery (ASR) is a water management tool that municipalities throughout Washington and Oregon are using to help manage and optimize their water rights and water supply resources. The general ASR concept involves withdrawing water from an existing supply source during the winter months when water is more readily available and demands are seasonally low, injecting and storing that water in a deep aquifer system using a well or series of wells, and recovering that stored water using those same wells to meet peak-summer demands.

The City is conducting an ASR feasibility study to evaluate the possibility of using ASR to optimize the use of existing water rights, and to increase the sustainability and resiliency of its water supply to meet projected future demands given that new water supply sources may not be available. This would allow the City to augment peak-season demand needs and help meet projected demand shortfalls without increasing permitted withdrawals from their Columbia River supply sources during the low-flow summer months.

1.1 Purpose and Scope

The purpose of this study is to evaluate the feasibility of using and storing off-season water available from the City's existing water supply sources in storage aquifers beneath the City for use during the high-demand period.

The City entered into a grant agreement (Agreement No. WROCR-1921-Pasco-00015) with the Washington State Department of Ecology (Ecology) Office of Columbia River (OCR) to complete the ASR feasibility study. The Agreement outlined a phased approach for completing the study using existing and available information. The Agreement defined four tasks:

- **Task 1: Project Administration/Management** – This task is reserved for City staff to administer the project.
- **Task 2: Hydrogeologic Feasibility Assessment** – Identify locations and characteristics of potential aquifer storage zones beneath the City that may be suitable for aquifer storage and recovery.
- **Task 3: Source Option Analysis** – Evaluate when, where, and how much source water is available for ASR recharge, considering legal and physical water availability and water system conveyance and treatment constraints.
- **Task 4: Initial Feasibility Study Report** – Synthesize results from Tasks 2 and 3 to rank and prioritize various ASR development options. Results from this report will be the basis for assessing whether source water availability and the hydrogeological setting in the Pasco area suggest that ASR may be feasible (*focus of this report*).

Tasks 2 and 3 have already been completed. This Task 4 Initial Feasibility Study Report (1) provides background information on the City's water systems and future supply needs, (2) presents pertinent information gathered from active ASR systems operating in the region, (3) summarizes results from the Hydrogeologic Feasibility Assessment (Task 2; GSI, 2020a) and Source Option Analysis (Task 3; RH2, 2021) work, (4) provides an initial (preliminary) determination regarding the feasibility of ASR in Pasco, (5) recommends areas and aquifers that appear hydrogeologically suitable for ASR based on available information, and (6) provides future work considerations and recommended next steps. Additional details regarding the hydrogeologic feasibility and potential ASR supply source options are reported under separate cover by GSI (2020a) and RH2 (2021), respectively.

1.2 Geographic Setting

Pasco is located at the southern margin of Franklin County and is one of four cities that make up the Quad-City[4] area of southeast Washington (**Figure 1-1**). The Columbia River forms the City's western and southern boundaries, while the Snake River and its conflux with the Columbia River border the City to the east. To the north, the City transitions from an urban setting to extensive agricultural land. The area north of the City is sometimes referred to as the Pasco Greenbelt (Brown, 1979) because of widespread irrigation and farming. Land surface elevations generally rise gradually from low-lying areas south along the Columbia River (350-390 feet NAD27)[5] to agricultural areas north (500-525 feet NAD27).

1.2.1 Study Area

The project study area is located in the southern portion of the Pasco Basin, a south-central subbasin of the intermontane Columbia Basin, and includes the City of Pasco and future urban growth area (**Figure 1-2**). The eastern extent of the approximately 60 square mile study area (Study Area) is bounded partially by the Snake River and includes the City's Process Water Reuse Facility and Farm Circles, while the southern and western extents are bounded by the Columbia River. The northern border encompasses the City's recently adopted 20-year urban growth area and immediate surrounding areas.

1.3 Recharge Objectives

The primary recharge objective for a City of Pasco ASR program is to realign supply availability with peak-season (May through September) potable and irrigation demand needs by seasonal storage and recovery of water. The ASR concept for the City would withdraw water from the Columbia River using the City's existing infrastructure and treatment facilities (and/or possibly new riverbank filtration wells in hydraulic connection with the river) during the off-season winter months, store it in an aquifer system beneath the City, and recover the stored water to augment peak-season demands. This would allow the City to supplement peak-season demand needs and help meet projected demand shortfalls without increasing permitted withdrawals from the Columbia River during the low-flow summer months, providing instream flow benefits and allowing more efficient use of existing water rights. Environmental and economic benefits from such a program would:

- Reduce environmental effects of surface water diversions during periods of high demand by shifting water withdrawals from the Columbia River from the summer months when flows in the river are at their lowest to the winter months when flows are highest

[4] The Quad-Cities are made up of Kennewick, Pasco, Richland, and West Richland
[5] North American Datum of 1927

- Optimize the City’s potable and irrigation supply system infrastructure without having to make costly improvements to existing supply sources and treatment plants to meet all of the projected peak-season demand shortfalls
- Reduce or eliminate costs associated with mitigating impacts to the Columbia River from usage of the Quad City Water Right during periods of low instream flows

SECTION 2: **City Water System and Supply Needs**

The City supplies its ratepayers with potable water sourced from two Columbia River surface diversions and water treatment plants. The City also operates a separate non-potable water system to serve water to customers for irrigating residential landscaping, parks, and sports fields. The City forecasts increasing demands on their irrigation and potable systems and the need for additional source capacity to meet those demands (MSA, 2013; Murraysmith, 2019). Near- and long-term population growth and demands on the water systems are anticipated to be focused in the northwest portion of the Study Area.

2.1 Potable System

The City's potable water system (potable system) is sourced by two Columbia River diversions and water treatment plants (WTP): Butterfield Intake and West Pasco Intake (**Figure 2-1**). The existing potable system has an approximate total capacity of 22,800 gallons per minute (gpm) (or 32.8 million gallons per day; MGD), and a firm capacity of 20,700 gpm (29.8 MGD). The firm capacity of the potable system assumes that the high service pump or a membrane train in the West Pasco Water Treatment Plan (WPWTP) is out of service.

The City currently is designing improvements at the WPWTP to increase its total capacity by an additional 8,333 gpm (12 MGD), which will increase its firm capacity by 8,333 to 10,415 gpm (increasing capacity by 12 MGD to a 15 MGD firm capacity at the WPWTP). The City is also currently implementing improvements at the Butterfield WTP, which may increase its total capacity by additional 695 to 2,080 gpm (increasing capacity by 1 to 3 MGD depending on improvements implemented). For the purposes of this study, the improvements to the WPWTP and the Butterfield WTP together are assumed to increase the City's firm source capacity by 8,333 gpm (12 MGD). With the completion of these improvements, the potable system is projected to have a slight source capacity deficiency in 2036 of approximately 145 gpm (0.2 MGD) based on the system's total capacity, and a capacity deficiency of approximately 2,245 gpm (3.2 MGD) based on the system's firm capacity (**Table 2-1**).

Table 2-1. 2036 Peak Season Potable System Supply Capacity Summary

Description	Total Capacity (gpm)	Firm Capacity (gpm)
Source Capacity		
Existing Source Capacity(1)	22,800	20,700
Additional WPWTP Capacity	8,333	8,333
Total Source Capacity	**31,133**	**29,033**
Demands		
Maximum Day Demand (MDD)	29,056	29,056
UGA Expansion Area MDD	2,222	2,222
Total Demands	**31,278**	**31,278**
Surplus (or Deficient) Source Capacity		
Surplus (or Deficient) Source Capacity	**(145)**	**(2,245)**

Notes: Adapted from RH2 (2021). (1) Total capacity of existing sources: Butterfield WTP = 18,633 gpm (26.8 MGD) and West Pasco WTP = 4,167 gpm (6 MGD)

The City's projected year 2036 potable system demands are based on the City's Water System Plan (WSP) (see Table 6-2 in Murraysmith, 2019) and are assumed to include both infill demands and the demands projected for the City's expanded urban growth area (UGA). The City's Water System Plan (WSP) however, presents a population increase by the year 2036 that is approximately 10,000 people less than the City's

2020 draft Comprehensive Plan (City of Pasco, in preparation). If the WSP is underestimating the projected 2036 water service population by approximately 10,000 people, approximately 2,222 gpm (3.2 MGD) of additional source capacity will be required. For the purposes of this study, the additional 10,000 people are included in the year 2036 demand projections shown in **Table 2-1**.

2.2 Irrigation System

The City owns and operates an irrigation water system (irrigation system) separate from the potable system. The irrigation system is supplied by groundwater from 11 wells and surface water pumped from the Columbia River Intake, located near the I-182 Bridge (**Figure 2-1**). The City's irrigation wells range between 135 and 245 feet deep and are completed in an unconfined alluvial aquifer consisting mainly of sand and gravel (*i.e.*, suprabasalt aquifer). The reported production capacities of the wells range between 450 and 2,500 gpm. Surface water from the Columbia River is pumped directly to the irrigation distribution system via a river intake and booster station. The City uses the irrigation system annually from April through October to avoid using treated drinking water as a source for irrigation. Source water for the irrigation system is not treated or disinfected.

The City's existing irrigation system has an approximate total supply capacity of 17,750 gpm (25.5 MGD) (**Table 2-2**; RH2, 2021). The irrigation system heavily relies on all existing sources operating to meet peak demands, including the system's largest source (the Columbia River Intake) operating at its existing 3,000 gpm (4.3 MGD) capacity. The existing irrigation system has an existing firm capacity of 14,750 gpm (21.2 MGD; **Table 2-2**) if the Columbia River Intake source is out of service or unavailable due to minimum instream flow regulations. Intake and groundwater pumping capacity improvements described by RH2 (2021) could increase irrigation source capacity by 6,000 gpm (8.7 MGD; **Table 2-2**).

Table 2-2. 2036 Peak Season Irrigation System Supply Capacity Summary

Description	Total Capacity (gpm)	Firm Capacity (gpm)
Source Capacity		
Existing Source Capacity	17,750	14,750
Additional Intake Pumping Capacity	5,400	5,400
Additional Groundwater Pumping Capacity	600	600
Total Source Capacity	**23,750**	**20,750**
Demands		
MDD	15,090	15,090
Infill Demand Projection (MDD)(1)	907	907
Expansion Area (PHD)(1)	13,301	13,301
Total Demands	**29,298**	**29,298**
Surplus (or Deficient) Source Capacity		
Surplus (or Deficient) Source Capacity	**(5,548)**	**(8,548)**

Notes: Adapted from RH2 (2021). (1) Existing system storage is slightly deficient for existing demands. If no additional storage is constructed, peak hour demand (PHD) is recommended to be considered future demand projections, or a reduction in service pressures will occur in system during PHD events.

Growth within the irrigation system is anticipated to take place as infill within the existing irrigation system footprint, with an estimated 907 gpm (1.3 MGD) of infill growth anticipated prior to 2036. Additional growth is anticipated within the City's UGA expansion area in the northwestern portion of the City. A portion of the UGA expansion area is located at higher elevations than the existing irrigation system customers and likely will require additional booster station facilities and/or storage facilities. Currently, no additional storage facilities are planned in the UGA expansion area. Consequently, future irrigation system supply facilities must be capable of meeting the peak hour demand (PHD) in the UGA expansion area. The City's existing maximum day demand (MDD), projected infill demand on an MDD basis, and projected UGA expansion area demand on a PHD basis are defined in **Table 2-2** for year 2036.

Based on the capacity evaluation summarized in **Table 2-2**, the irrigation system is estimated to have a 2036 supply deficiency of approximately 5,548 gpm (12.4 MGD) based on the system's total capacity, and approximately 8,548 gpm (19.0 MGD) based on the system's firm capacity.

SECTION 3: **Hydrogeologic Feasibility Assessment**

The Columbia River Basalt Group (CRBG) hosts a regional aquifer system that is an important groundwater resource for portions of Washington, Oregon, and Idaho. In many cases, CRBG aquifers serve as the only supply source for domestic, municipal, industrial, and agricultural uses throughout the Columbia Plateau (CRGWMA, 2009). Since the late 1990s, CRBG aquifer systems also have become important reservoirs for storing excess winter water from alternative supply sources (e.g., surface water[6], springs[7], and shallow alluvial groundwater[8]) for recovery during summer periods of high demand.

This section of the report describes the hydrogeologic conditions of the Pasco Basin (**Section 3.1**) and presents a summary of active ASR systems being operated by other municipalities in the region (**Section 3.2**). The hydrogeologic conditions of the Pasco Basin presented in **Section 3.1** are based on work completed as part of Task 2. More detailed information on the geologic and hydrogeologic conditions of the Pasco Basin is presented in the Task 2 Hydrogeologic Feasibility Assessment report (GSI, 2020a and Tolan, 2020). **Sections 3.3** and **3.4** recommend preferred hydrogeologic settings for ASR within Pasco and ranks areas and aquifers identified in the Study Area with respect to ASR suitability.

3.1 Pasco Basin Hydrogeology

The Study Area is located within the Pasco Basin, a topographic and structural low located near the eastern edge of the Yakima Fold Belt structural sub-province within the Columbia River Flood Basalt Province. The Pasco Basin is geologically defined by the following features (**Figure 3-1A**):

- On the west by the northwest-trending anticlinal folds and faults that define the Rattlesnake-Wallula alignment (RAW) (**Figure 3-1A** and **3-1B**).
- On the north by the east-west-trending portion of the Saddle Mountains, which is a Yakima Fold Belt anticlinal ridge.
- On the east by the combination of the westward-dipping Palouse Slope-Jackass anticline/monocline and the north-northwest-trending Columbia River Basalt Group (CRBG) dike swarm (**Figure 3-1B**).

The bedrock geology of the Pasco Basin (**Figure 3-2**) is dominated by the flood-basalt flows of the middle-to-late Miocene CRBG and the interbedded sediments of the Ellensburg Formation. The CRBG flows are overlain by suprabasalt sediments, including the late Miocene-Pliocene sediments of the Ringold Formation, the Quaternary-age Hanford formation, and Holocene-age sediments (**Figure 3-2**). The CRBG (and interbedded Ellensburg Formation sediments) and suprabasalt sediments are the major hydrostratigraphic units that host significant aquifers and serve as important sources of groundwater throughout much of this region. The characteristics and distribution of each of these stratigraphic units are summarized in the following section and detailed further by Tolan (2020; see Attachment A in GSI, 2020a).

The primary stratigraphic units for the purposes of this ASR feasibility study can be divided into two main types: suprabasalt sediments and the underlying basalt sheet flows of the CRBG. Collectively, these units form a general three-dimensional framework of the aquifers that they may host beneath the greater Pasco area. The general relationships and thicknesses of each of these units are illustrated on west-east and north-south geologic cross-sections through the Study Area (**Figures 3-3** through **3-5**). The suprabasalt sediment and CRBG unit contacts depicted on the cross-sections are largely derived from isopach and

[6] For example, the cities of Kennewick, Walla Walla, and White Salmon, Washington; and the cities of Beaverton, Salem, Tigard, and Pendleton, Oregon.
[7] For example, City of Lafayette, Oregon.
[8] For example, Madison Farms, Oregon; and McCarty Ranch, Oregon

structure-contour maps of these stratigraphic units mapped over the four-county Columbia Basin Groundwater Management Area (CBGWMA). The methodologies used to develop these stratigraphic unit surfaces and isopachs are described in Lindsey et al. (2007) and Tolan et al. (2007). The stratigraphic unit contacts from the CBGWMA regional maps were refined on **Figures 3-4** and **3-5** using available borehole logs within and adjacent to the Study Area (Tolan, 2020; see Attachment A in GSI, 2020a). Confidence levels associated with the contacts and thicknesses of the units depicted generally decreases with increased depth within the lower Saddle Mountains and Wanapum Basalts because very few wells in the Study Area have been drilled deep enough to penetrate these stratigraphic units.

3.1.1 Suprabasalt Sediment Aquifer System

The suprabasalt sediments in the greater Pasco Basin are collectively defined as all of the sediment deposits that overlie the CRBG to the ground surface. These sediments can be subdivided (from youngest to oldest) into Holocene (recent) deposits, Hanford formation, and Ringold Formation (**Figure 3-2**; Tolan, 2020; see Attachment A in GSI, 2020a):

- **Holocene Deposits** – Dominantly consist of relatively unconsolidated, wind-deposited silt (*i.e.*, loess) and sand (active and stabilized sand dunes) that unconformably overlie the Hanford formation. In the greater Pasco area, these deposits can range from less than 2 feet to greater than 15 feet thick and typically do not host any groundwater.
- **Hanford formation** – Consists of unconsolidated deposits of silt, sand, and gravel that were deposited by a series of cataclysmic flood events due to failures of large, glacial ice-dammed lakes from around 1.6 million years until about 13,000 years ago. Within main channel floodwater pathways through the Study Area, these deposits are predominately unconsolidated, massive to bedded, open framework, coarse gravel and sand, with only very minor amounts of silt present. The thicknesses of the Hanford formation in the greater Pasco area collectively ranges from roughly 40 to 300 feet or more.
- **Ringold Formation** – Consists of interbedded, unconsolidated to cemented, clay, silt, sand, and gravel deposited by rivers, and within lakes, associated with the ancestral Columbia River system. Two of three informally-designated members of the Ringold Formation[9] have been removed from the Study Area by cataclysmic flood erosion, leaving only poorly-consolidated to well-cemented river (fluvial) gravel deposits with minor interbedded sand and overbank (silt and clay) deposits inferred to belong to the Wooded Island member. The thickness of the Ringold Formation beneath the Study Area is highly variable, ranging from absent to greater than 200 feet.

The suprabasalt sediment aquifer is defined for this study to consist of the catastrophic flood sediments of the Hanford formation, and the older Ringold conglomerate facies of the Wooded Island member where present. Combined they host an unconfined (*i.e.*, water table) sedimentary aquifer that overlies the CRBG and is present throughout the Study Area. Because the Hanford formation flood sediments are considerably more permeable and thicker than the Ringold sediments (Tolan, 2020; see Attachment A in GSI, 2020a), the flood sediments host a significant portion of the unconfined aquifer and account for the bulk of groundwater flow in this system. High-capacity wells are reported to have yields between approximately 1,000 and 3,000 gpm, including the City's irrigation supply wells. Well yields in the underlying, lower permeability Wooded Island member however, normally produce a few hundreds of gallons per minute (Brown, 1979).

[9] Savage Island, Taylor Flats, and Wooded Island Members, as defined by Lindsey et al. (2007). A comparison of these three members against other Ringold Formation deposits described in other hydrogeologic studies in or near the eastern Pasco Basin are presented by Heywood et al. (2016).

The suprabasalt sediment aquifer system is the primary developed source of groundwater within the Study Area. Of the 840 well logs identified (GSI, 2020a), over 90 percent were classified as suprabasalt wells, most of which are understood to be for domestic or irrigation purposes. Suprabasalt wells are reported to produce between 15 and 3,000 gpm (MSA, 2013; Brown, 1979). Many of the high-producing wells are for irrigation purposes. Depths to water are reported to range between approximately 25 and 175 feet below ground surface (bgs) with seasonal groundwater level fluctuations estimated to range between 2 and 25 feet. Suprabasalt groundwater levels are generally deeper in the northern portion of the Study Area and shallower in the south (GSI, 2020a) due to land-surface elevation differences.

3.1.1.1 Groundwater-Surface Water Interaction

The suprabasalt aquifer system is generally understood to be in direct hydraulic connection with surface water bodies in the Pasco Basin (Brown, 1979). Though groundwater in the suprabasalt sediments ultimately discharges to the Columbia River in the Study Area (GSI, 2020a), the river can also recharge the unconfined aquifer when river (*i.e.*, Lake Wallula) stage is higher than water table elevations in the vicinity of the river (Brown, 1979). During changing river elevations, the interaction between surface water and groundwater takes place as bank storage. The extent of the bank storage zone exchange and the time lag for river stage changes to affect suprabasalt aquifer levels will depend on the degree of hydraulic connectedness between the two systems, magnitude of changes in hydraulic gradient between the two systems resulting from changing river stages, and hydraulic characteristics of the aquifer system.

Extensive irrigation over the years has led to rising groundwater levels, drainage problems, and dewatering needs in this aquifer system in some parts of the Pasco Greenbelt and Study Area (Brown, 1979; Drost et al., 1997). The United States Army Corps of Engineers (USACE) installed above- and below-ground levees in places along the Columbia River to protect low-lying areas from Lake Wallula as part of the McNary Dam project. Suprabasalt groundwater draining toward the Columbia River in these areas is collected by ditches constructed behind the levees and pumped into the river to manage shallow groundwater levels and ponding. Consequently, the downgradient movement of groundwater towards the river in some portions of the suprabasalt sediment aquifer system is affected and redirected by a network of agricultural drains, mostly located north of the Study Area (Heywood et al., 2016), and by levees, collection ditches and pump stations in low-lying areas along the Columbia River. Groundwater elevation contours of the unconfined suprabasalt aquifer, areas of shallow unconfined groundwater, and locations of levees and drains are presented by Drost et al. (1997).

3.1.1.2 Groundwater Quality

Groundwater quality of the suprabasalt aquifer system is characterized as a magnesium-bicarbonate type water to bicarbonate type water with no dominant cation (Golder, 2021; see Appendix A in RH2, 2021). The Groundwater quality data compiled from available sources meets primary drinking water criteria with the exception of nitrate. Nitrate concentrations are typically higher than Columbia River water, with concentrations ranging from below detection to 20-70 mg/L-N. Additional groundwater quality conditions of the suprabasalt aquifer system are summarized in **Section 4.2.1**.

3.1.1.3 Summary

Because of the drainage and dewatering needs and unconfined aquifer conditions, the suprabasalt aquifer system is expected to have a very limited storage capacity for ASR supply water. Recharge to the suprabasalt aquifer could contribute to ponding in low-lying areas and impact active management of shallow groundwater levels. The aquifer's direct hydraulic connection with the river also could contribute to losses of stored water to the river and significantly limit the volume of ASR supply water available for recovery.

Expectedly low storage capacity and recovery volume and active drainage and dewatering needs preclude the suprabasalt aquifer as a potential ASR storage aquifer.

3.1.2 CRBG Aquifer System

The CRBG and associated sediment interbeds of the Ellensburg Formation, host confined aquifers that may be suitable ASR storage zones. The vast majority of the operational ASR systems in the Pacific Northwest use CRBG aquifers as compartments for storing excess municipal supply water, including the cities of Kennewick, Walla Walla and Pendleton (see **Section 3.2**). The City of Yakima has developed an ASR system in sediments of the upper Ellensburg Formation, which is essentially equivalent to, but far thicker than, the Ringold Formation in the Pasco Basin.

The CRBG consists of a regionally extensive series of more than 350 continental flood basalt sheet flows that cover a 77,220 square mile portion of Washington, Oregon, and western Idaho (**Figure 3-1A**). The maximum thickness of the CRBG is inferred to occur beneath the Pasco Basin area where it is estimated to be greater than 10,000 feet thick. The sheet flows exhibit a series of distinct three-part internal structures consisting of a flow top, a dense interior, and a flow bottom (Tolan, 2020; see Attachment A in GSI, 2020a), all of which play important roles in defining aquifers and confining layers within the CRBG aquifer system:

- **Flow Tops** – Generally consist of vesicular basalt, or scoriaceous to vesicular fragments of basaltic rubble (flow top breccias), and is often the most permeable of the intraflow structures. Flow top breccias can be very thick (over half the flow thickness to more than 100 feet thick) and laterally extensive (Tolan et al, 2009). Flow top breccias host some of the most highly transmissive and productive aquifers in the CRBG.
- **Flow Interior** – Generally consists of massive, dense basalt containing cooling joints that formed during the slow cooling and contraction of the flow interior. The cooling joints have been found to be typically 77- to nearly 100-percent filled with secondary minerals (e.g., clay, silica, zeolite). Void spaces that are present are typically not interconnected. Flow interiors generally have very low hydraulic conductivities and typically function as confining units within CRBG aquifer systems.
- **Flow Bottom** – The most common is a *simple flow bottom*, which consists of a thin (< 2 feet) zone of sparsely vesicular basalt produced when an advancing CRBG lava encountered relatively dry ground. Simple flow bottoms are typically poorly transmissive. A *pillow lava complex* flow bottom was produced if the advancing CRBG lava encountered water (*e.g.*, lakes, rivers, and/or areas of water-saturated, unconsolidated sediments). Pillow complexes may be thick and generally host highly transmissive and productive aquifers.

Groundwater is typically present within an interflow or several combined interflows. An *interflow* is the space between a flow top and the stacked overlying flow bottom (and any Ellensburg Formation sediment that might be present). Water-bearing interflows are commonly the groundwater supply sources and aquifer storage zones within the CRBG.

The Saddle Mountains, Wanapum, and Grande Ronde Basalt aquifer systems are present beneath the Study Area (**Figures 3-4** and **3-5**). The primary focus of this ASR feasibility study is on the two uppermost CRBG formations, consisting of the Saddle Mountains and Wanapum Basalts. Suitable storage aquifers also may be present within the deeper basalt flows of the Grande Ronde Basalt. The Grande Ronde Basalt however, is considered a lower priority target option for this study because of poor groundwater quality conditions, need for deep ASR well completion and seal depths (> 2,000 feet), and greater facility development costs compared to shallower comparable CRBG aquifers (GSI, 2020a).

3.1.2.1 Physical Characteristics

The physical characteristics of this three-part structure and the underlying geologic structure (*e.g.*, faults and folds) of a particular area control the occurrence and movement of groundwater within the CRBG aquifer system. Faults can (1) form barriers to the lateral movement of groundwater and a series of faults can create hydrologically isolated areas (*i.e.*, compartments), (2) provide a potential pathway for vertical groundwater movement interconnecting otherwise confined interflows, and (3) expose interflow zones creating areas of CRBG aquifer recharge and/or discharge. Folds can impact the original hydraulic characteristics of interflow zones by shearing or damaging mechanically weaker interflows and greatly reducing their ability to transmit groundwater. CRBG feeder dikes, which once served as long, linear vertical conduits that supplied the magma to the ground surface that produced individual basalt flows, can form vertical sheet walls composed of dense basalt that impede groundwater flow. Where interflows are laterally extensive and not crossed by permeable faults or open boreholes, there is little vertical hydraulic connectivity between interflows.

Faults, folds, and the CRBG feeder dike swarm are structural boundaries that make up the Richland Subbasin within the Pasco Basin (Reidel et al., 2020; and Reidel and Tolan, 2013). The Richland Subbasin is geologically defined by the following features (**Figure 3-6**):

- Umtanum-Gable anticline on the north
- Ice Harbor Dike system on the east
- Wallula Fault zone on the south
- Horn Rapids anticline and May Junction fault on the west

Where not fractured by faults and folds, the basalts typically exhibit high horizontal and vertical hydraulic conductivities in the vesicular/brecciated and weathered zones associated with the permeable interflows, and low horizontal and vertical hydraulic conductivities in the dense flow interiors. An overall range of hydraulic conductivity values reported for CRBG features by USDOE (1988), Whiteman et al. (1994), and Sabol and Downey (1997) are summarized in **Table 3-1**. The hydraulic conductivities reported by Whiteman et al. (1994) rely heavily on data reported on drillers' logs from many wells that are open to multiple flow tops within individual basalt formations.

Table 3-1. Reported Hydraulic Conductivity Ranges for CRBG Aquifer Features

Feature		Hydraulic Conductivity (feet/day)	Reference	Comments
Flow tops	K_h	1x10^{-6} to 1,000	USDOE, 1988	Mean = 0.1 feet/day
	K_v	3x10^{-9} to 3x10^{-3}	USDOE, 1988	--
		1x10^{-5} to 1x10^{-1}	Sabol and Downey, 1997	Measured near Lind, WA
Flow interiors	K_h	1x10^{-9} to 1x10^{-3}	USDOE, 1988	Approx. 5 orders of magnitude < flow tops
	K_v	3x10^{-9} to 3x10^{-3}	USDOE, 1988	--
		1x10^{-5} to 1x10^{-1}	Sabol and Downey, 1997	Measured near Lind, WA
Flow tops	K_h	7x10^{-3} to 1,892	Whiteman et al., 1994	Vertically averaged for Saddle Mountains Basalt
	K_h	7x10^{-3} to 5,244		Vertically averaged for Wanapum Basalt
	K_h	5x10^{-3} to 2,522		Vertically averaged for Grande Ronde Basalt

Ellensburg Formation interbeds	K_h	$1x10^{-6}$ to 1	USDOE, 1988	Mean for various interbeds = 0.01 to 0.1 feet/day
	K_h	$1x10^{-6}$ to 100	Sabol and Downey, 1997	Measured for interbeds in the Pasco Basin

Notes: Reproduced from Tolan et al. (2009); K_h is horizontal hydraulic conductivity; K_v is vertical hydraulic conductivity; CRBG is Columbia River Basalt Group; USDOE is U.S. Department of Energy

3.1.2.2 CRBG Wells

Most of the basalt wells in the Study Area are completed in the Ice Harbor, Elephant Mountain, or Pomona Members of the Saddle Mountains Basalt and appear to be for domestic and/or irrigation purposes (GSI, 2020a). Well logs report pumping rates to range between 10 and 650 gpm when the wells were tested after drilled and constructed. Depths to water reported on the logs ranged between 0 and 250 feet, and are generally deeper in the northern portion of the Study Area and shallower in the south. The groundwater level for one 400-foot deep basalt well located in the south-central portion of the Study Area near the Columbia River was reported as artesian after drilled in 1989 (Well Log ID: 438115). This well appears completed in the Ice Harbor and Elephant Mountain Members. In the northern portion of the Study Area, groundwater levels are reported to range between 130 and 185 feet bgs. Seasonal groundwater level fluctuations are estimated to range up to 20 feet. Long-term declining antecedent groundwater levels ranging between 2 and 4 feet per year have been observed at the Kennewick ASR-1 well (pre-ASR operations) and at two other known basalt wells located roughly 8 miles northwest of ASR-1 (GSI, 2017).

The only wells identified within the Study Area that appear completed in the Wanapum Basalt are two wells drilled circa 1943 for the U.S. Government Naval Air Station. The wells are approximately 1,050-feet deep and were installed near the Tri-Cities Airport (Tolan, 2020; see Attachment A in GSI, 2020a). Based on their total depths, the wells appear completed in the Priest Rapids or Roza Members of the Wanapum Basalt, or possibly the upper portion of the Frenchman Springs Member. No construction diagrams or pumping information were discovered for these wells and their current status is unknown.

3.1.2.3 Groundwater-Surface Water Interaction

CRBG aquifers in the Study Area do not appear to be in direct hydraulic connection with the Columbia River (**Figures 3-4** and **3-5**). Natural groundwater discharge to and potential exchange with the river would likely take place where confining units are absent, and/or in areas where surficial drainages have incised into basalt interflow zones. Dense basalt flow interiors and low-permeability CRBG interbeds are widespread throughout the area and act to confine groundwater in interflow zones. CRBG outcrops are present near Ice Harbor Dam on the Snake River, though the outcrop is in the same place as the Ice Harbor Dike system, which likely functions as a flow-limiting or no-flow boundary condition.

3.1.2.4 Groundwater Quality

Regional (Steinkampf, 1989) and local (Golder, 2001, 2012b, 2014, and 2020) groundwater quality data reviewed as part of this study indicate that groundwater characteristics of the Saddle Mountains and Wanapum Basalt aquifers are calcium-magnesium-bicarbonate to sodium-bicarbonate type waters (Golder, 2020; see Attachment C in GSI, 2020a). The former groundwater-type is typically found in upgradient (in the Columbia Plateau), shallow wells (< 400 feet) while the latter type is generally found in downgradient and deeper (> 400 feet) wells near the Columbia River. Groundwater quality is near-circum pH to alkaline in the Saddle Mountains Basalt and near-circum pH in the Wanapum Basalt (see **Tables A-1** and **A-2** in **Attachment A**). Saddle Mountains Basalt wells generally have higher concentrations of dissolved oxygen and nitrates compared to the Wanapum wells (**Table A-1** in **Attachment A**), indicating oxidized groundwater conditions. In Wanapum Basalt wells, the presence of iron, manganese, methane, and low levels of dissolved oxygen indicate reducing, anoxic groundwater conditions (**Table A-2** in **Attachment A**). Water temperatures are expected to be elevated in the Wanapum, based on previous observed ranges of 24 to 28 °C. Overall, drinking water quality standards are met for all primary and secondary constituents (Golder, 2020; see Attachment C in GSI, 2020a), with a few exceptions for iron, manganese, and fluoride that were detected at or slightly above their respective secondary maximum contaminant levels (SMCLs). Sodium can also be expected above the state advisory level of 20 mg/L for both the Saddle Mountains and Wanapum Basalts.

The USDOE (1988) reports groundwater quality data for the Saddle Mountains Basalt at the Hanford site. The concentration range for each reported analyte is consistent with the range reported for some private domestic wells (**Table A-1** in **Attachment A**), though concentrations of sulfate and magnesium in some of the domestic wells are somewhat higher. The USDOE (1988) data also are generally consistent with the regional data, though the maximum concentrations for chloride, sulfate, calcium, and magnesium reported by Steinkampf (1989) are considerably higher.

Table A-2 in **Attachment A** provides basalt groundwater quality data from City of Walla Walla Wells 1, 2, 4, and 6 prior to the start of ASR pilot testing and operations (Golder, 2009b). The wells are thought to be completed in the Wanapum Basalt, but this interpretation is not definitive from the Golder (2009b) report. The concentration range for each coinciding monitored analyte is near the average or low-end range values reported for the Wanapum Basalt by regional studies completed by Steinkampf (1989) and Steinkampf and Hearn (1996). Compared to the more local Kennewick and Willowbrook ASR feasibility studies (Golder, 2001, 2012b, and 2014) however, concentrations reported for the City of Walla Walla wells are generally within and/or near the low-end ranges observed, with the exception of calcium.

Groundwater quality data reported by the USDOE (1988) for the Wanapum Basalt at the Hanford site is summarized in **Table A-2** in **Attachment A**. The concentration range for each reported analyte is generally consistent with the range reported for the local studies (Golder, 2001, 2009b, 2012b, and 2014) and with the average or low-end values reported by the regional studies (Steinkampf, 1989; Steinkampf and Hearn, 1996).

3.2 Local ASR Systems

Municipalities throughout Washington and Oregon have been using ASR to store excess treated drinking water in CRBG-hosted aquifers since the mid-to-late 1990s as a means to help optimize their water right portfolios and manage their water supply resources. The City of Salem, Oregon began pilot-testing their ASR system in 1997 using treated surface water from the North Santiam River as the ASR supply source. Salem currently operates four ASR wells completed in the CRBG aquifer system, and to date has successfully stored more than 1,900 acre-feet (620 MG) annually for subsequent recovery and beneficial use. Salem is currently considering adding additional ASR wells and expanding their ASR program.

The City of Walla Walla, Washington began its ASR program in 1998 and is authorized to annually store up to 11,750 acre-feet of treated Mill Creek surface water in three structurally-bounded CRBG aquifer storage blocks. Walla Walla currently operates two ASR wells capable of a combined annual recharge capacity of between approximately 1,840 and 2,760 acre-feet (or between 600 and 900 MG per year).

Examples of other active municipal ASR programs utilizing the CRBG aquifer system as a storage reservoir for treated drinking water include the cities of Kennewick, White Salmon, and Yakima, Washington; and the cities of Beaverton, Cornelius, Dallas, Pendleton, Tigard, and Tualatin, Oregon.

This section presents a summary of active ASR systems being operated by three municipalities in the Pasco region: Kennewick, Walla Walla, and Pendleton. Emphasis has been placed on Kennewick's ASR system because it is the closest active system to Pasco. Additional information on these ASR systems is available from various reservoir permitting documents through Ecology for Kennewick (permit# R4-35237) and Walla Walla (permit# R3-30526) and from the Oregon Water Resources Department for Pendleton (ASR Limited License# 006).

3.2.1 City of Kennewick ASR

The City of Kennewick, Washington has been operating its ASR-1 facility and putting water recovered from basalt aquifer storage to beneficial use since 2014. The ASR-1 facility recharges and stores treated drinking water from the City's municipal system in a CRBG aquifer during the winter and spring months, and recovers that water for beneficial use during the summer and fall. The facility contains a single ASR well (ASR-1; well tag ID: ALM 112), which functions as both the recharge and recovery well, and is permitted for use under reservoir permit R4-35237. ASR-1 is authorized to recharge up to 1,458 acre-feet per year (afy) (475 MG) at a maximum injection rate of 1,800 gpm and to recover up to 92 percent of the recharge volume at a maximum withdrawal rate of 2,080 gpm.

3.2.1.1 Feasibility Study

Kennewick began investigating the feasibility of developing an ASR program in 2009 to help meet growing storage and capacity demands in parts of their water system and to optimize the use of existing water rights. The feasibility investigation included (1) preparing an application and supporting information for underground artificial storage and recovery (Golder, 2009a; GSI, 2018a), (2) drilling and testing of an ASR test well (Golder, 2012a), (3) developing a conceptual hydrogeologic storage model (Golder, 2012b), (4) completing a geocompatibility assessment of ASR supply water and native groundwater quality (Golder, 2012c), (5) conducting an AKART[10] analysis (HDR, 2012), and (6) preparing an environmental assessment and analysis report (Golder, 2012d; GSI, 2015a). Installation and testing of a basalt monitoring well (ASR-MW-1; well tag ID: AAR 980) was completed in 2013 (Golder, 2014) and the ASR facility fully constructed in early 2014.

The ASR-1 well was drilled to a depth of 1,173 feet below ground surface (bgs) during the summer of 2011. The well is cased and sealed to a depth of 961 feet bgs to limit the potential for interference with shallow groundwater users and surface water bodies, and is open to four water-bearing interflow zones: two within the Priest Rapids Member and two within the Frenchmen Springs Member. Both members are within the Wanapum Basalt Formation of the CRBG. The combined thickness of the interflow zones is approximately 108 feet. In the ASR-1 project area, the Wanapum Basalt is a confined aquifer and is isolated from the overlying Saddle Mountains Basalt by tuffaceous claystone, siltstone and sandstone of the Mabton interbed. The Wanapum Basalt is separated from the underlying Grande Ronde Basalt by the Vantage interbed. The Mabton and Vantage interbeds are understood to be present throughout much of the region.

The ASR-MW-1 monitoring well is located approximately 1,300 feet east of ASR-1 and was drilled to a depth of 1,165 feet bgs. ASR-MW-1 is cased and sealed in basalt to 947 feet bgs and is open to the same members of the Wanapum Basalt as ASR-1.

ASR-1 well yields from the upper interflow zone in the Priest Rapids Member estimated during drilling and development ranged between 50 and 100 gpm and progressively increased to greater than 2,000 gpm (cumulative of all four interflow zones) at total depth. The bottom 43 feet of ASR-1 is open to an interflow zone in the Frenchman Springs Member and yielded the most water. Results from a 35-hour constant-rate pumping test at 950 gpm produced a near-borehole transmissivity of over 80,000 square feet per day (feet^2/day). A maximum drawdown of 13.65 feet was observed by the end of the pumping test, resulting in a

[10] Available and reasonable methods of prevention, control and treatment

35-hour specific capacity of nearly 70 gpm/foot of drawdown. The pre-test static water level measured 356.90 feet bgs. The hydrogeologic conceptual model (Golder, 2012b) estimated a storage capacity of between 190 and 19,000 acre-feet (60 and 6,200 MG) using storativity values typical of confined basalt aquifers (1×10^{-3} to 1×10^{-5}) (Price, 1960; Tanaka et al., 1974; Livesay, 1986; USDOE, 1988). The aquifer's hydraulic response to ASR-1 operational-scale activities observed at ASR-MW-1 indicates that the storativity value is at the high-end of the basalt range (1.1×10^{-3} to 1.5×10^{-3}), which would suggest that the storage capacity is likely near the mid- to high-end range estimated.

Background groundwater quality from ASR-1 prior to beginning ASR activities met Washington State drinking water and groundwater quality criteria with the exception of arsenic. Arsenic concentrations in samples collected from the well measured 0.4 and 0.5 micrograms per liter (µg/L) and were greater than the groundwater criterion of 0.05 µg/L, but well below the drinking water maximum contaminant level (MCL) of 10 µg/L. The background aquifer water temperature measured 27 degrees Celsius (°C) and is warmer than the upper range of temperature desired for a municipal drinking water supply source. Additional groundwater quality details from samples collected from the well pre-ASR and post-storage are provided by Golder (2012a) and summarized by GSI (2020b).

Results from the drilling and testing program at ASR-1 (Golder, 2012a) indicated that aquifer conditions, well performance, and water quality were suitable for ASR pilot testing. Based on these results it was recommended that an ASR pilot testing program be developed for ASR-1. A project operations and monitoring work plan was developed for the ASR pilot testing program (GSI, 2014).

3.2.1.2 Pilot-Scale Testing

The first year of ASR pilot testing at the City's ASR-1 facility was completed during 2014 (GSI, 2015b). This first year of testing consisted of a series of three short-term successive cycles of the same rate and duration (Cycles 1–3) and one longer operational-scale cycle (Cycle O1). The three brief repetitive Cycles 1–3 were conducted to assess the rate of thermal recovery efficiency improvement over each successive cycle and potential for developing a thermal storage zone within the basalt aquifer, capable of storing and recovering cooler water for municipal use. The longer-scale test (Cycle O1) was an expansion of the previous three cycles and conducted to assess larger-scale storage zone development and thermal conditioning.

The source water for ASR-1 recharge is treated drinking water from the City's municipal water supply system, appropriated under authorization of the City's existing surface water and groundwater rights (S4-25479C and G4-*04539WRIS). The City's water system is supplied by two Ranney Collector Wells (Ranney Collector No. 4 and No. 5; RC4 and RC5) and a filtration Water Treatment Plant (WTP) that treats water withdrawn directly from the Columbia River. ASR-1 recharge operations uses water from both the surface water and collector well sources in different proportions at different times. The variable source blending has been the normal condition for the City's ASR operations. Source water is supplied to the ASR-1 facility via a water main extending along Ridgeline Drive from the City's distribution system.

ASR water stored in the basalt aquifer initially is pumped at startup of recovery to an onsite infiltration basin until clear (turbidity less than 1 NTU). After purging the well, recovered water is then chlorinated and delivered to the City's distribution system for municipal use.

The Year 1 testing program was very successful, and clearly demonstrated the viability of Kennewick's ASR-1 project (GSI, 2015b). The ASR-1 pilot testing results did not identify any hydraulic limitations to ASR operations and there was no evidence of well or aquifer clogging. Year 1 results also demonstrated that thermal storage zone development to manage recovered water temperature was easily achieved, and that source and recovered water quality samples met all drinking water quality criteria.

3.2.1.3 Operational-Scale Testing

Subsequent operational-scale tests (Cycles 02 through 06) each involved upscaling from the previous cycle (GSI, 2017; GSI, 2018b; GSI, 2019a; GSI, 2020b), with the goal of progressively working towards testing at full-scale rates and volumes to evaluate the feasibility of long-term ASR recharge and storage operations. The water year 2020 ASR-1 recharge volume of 737 acre-feet (240 MG) was slightly greater than the volume stored during Cycle 06 and the largest stored volume to date (GSI, 2021).

No evidence of ASR-1 well clogging or diminished well performance have been observed during ASR-1 recharge or recovery activities. ASR-1 well performance measures are summarized below:

- Injection specific capacity[11] measured more than 32 gpm per foot of water-level buildup after recharging continuously at 1,200 gpm for a period of 50 days
- Pumping specific capacity[12] measured approximately 40 gpm per foot of drawdown after pumping continuously at 1,500 gpm for a period of over 70 days.

The aquifer's hydraulic response to ASR-1 activities from year-to-year repeatedly exhibits an increased rate of head buildup at approximately 10,000 minutes (7 days) into the recharge phase despite a constant recharge rate. The increase in the rate of buildup most likely results from a flow-limiting aquifer boundary condition associated with fault/fold structures mapped to the north and south of ASR-1. It was initially conceptualized that these fault/fold structures have compartmentalized the basalt aquifer system creating hydraulic barriers to groundwater flow (Golder, 2012b). The aquifer's hydraulic response to ASR pilot testing supports this concept of flow-limiting boundaries and suggests a limited potential for loss of stored water during ASR operations.

It is not anticipated that long-term ASR-1 recharge operations will be limited by the apparent boundary condition. Based on observed trends, head buildup during recharge is projected to remain within the total available buildup capacity (340 feet) under full-scale operations (1,458 acre-feet; 475 MG). The water-level buildup in ASR-1 observed at 1,600 gpm recharge rate predicts recharge water levels to be less than 60 feet above the pre-recharge static water level after recharging 1,458 acre-feet (475 MG), well under the available buildup capacity of 340 feet. The predicted recharge buildup water level however, assumes the late-time rate of buildup (>10,000 minutes recharge) remains consistent over longer recharge periods.

Water-level buildup observed at ASR-MW-1 in response to ASR-1 operations has ranged between 2 and 7 feet after recharging between approximately 30 and 737 acre-feet (10 and 240 MG) at rates ranging between 1,000 and 1,600 gpm. Drawdown observed at ASR-MW-1 in response to ASR-1 recovery operations has ranged between 2 and 8 feet after recovering between approximately 55 and 678 acre-feet (18 and 220 MG) at rates between 600 and 1,800 gpm.

The City has been monitoring (and continues to monitor) source water and groundwater quality since pilot testing operations first began in 2014. Concentrations of all monitored constituents in source water have been in compliance with primary and secondary drinking water standards. No exceedances of established MCLs or SMCLs have been observed. Minor variability in source water quality has been observed and is likely attributed to variable blending of the City's municipal supply sources and/or seasonal water quality fluctuations in the Columbia River. Concentrations of all monitored constituents in water recovered from storage exhibited concentrations below their established contaminant levels as defined for drinking water systems (Chapter 246-290-310 WAC). Based on water quality testing results, drinking water recovered from storage in the basalt aquifer system is suitable for the City's water distribution system and municipal uses.

[11] Injection specific capacity is the recharge injection rate divided by water-level buildup above pre-recharge static water level
[12] Pumping specific capacity is the recovery pumping rate divided by drawdown below the static water level post-storage

Some improvements in recovered water have been observed during ASR-1 operations (*e.g.*, disinfection byproduct removal, denitrification, and temperature decrease). Analytical test results from water quality samples indicate that disinfection by-products (DBPs) in injected water are attenuated in the subsurface and DBPs are not formed during storage (*i.e.*, concentrations in recovered water are well below source water concentrations and drinking water MCLs). For many constituents, the recovered water quality appears to be the result of simple mixing between pre-recharge groundwater and source water, indicating minimal advection of stored water.

Some fluctuations in constituent concentrations appear to originate from minor interactions between recharge water, native groundwater and aquifer solids. Though concentrations of some redox-sensitive metals such as arsenic, iron, manganese, and molybdenum have been developed in somewhat greater concentrations than observed in native groundwater and/or source water samples, none have been detected above MCL or SMCL regulatory drinking water criteria levels. Concentrations of these constituents are expected to decrease over successive cycles under similar operational conditions, though may increase temporarily with further conditioning of the aquifer from larger storage volumes and longer residence times.

DBPs have not been detected at ASR-MW-1 and no exceedances for established MCLs or SMCLs for other monitored constituents have been observed.

Positive results have been obtained from all operational-scale cycles and operation of the ASR-1 facility has been beneficial to the City's management of its water resources. Results to date have not identified any hydraulic, well performance, or thermal storage zone development limitations to ASR operations, and water recovered from storage has met all established drinking water quality criteria.

3.2.2 City of Walla Walla ASR

The City of Walla Walla, Washington implemented ASR pilot testing activities starting in 1998 as a means of managing its water supply during periods of surplus and limited surface water availability. Walla Walla operates their ASR program by recharging treated Mill Creek surface water into two ASR wells completed in two structurally-bounded basalt aquifer storage blocks (Golder 2006): Well #1 (Block I) and Well #6 (Block II). Surface water treatment at the Mill Creek WTP consists of sedimentation, ozonation, and chlorination to maintain a disinfectant residual throughout the distribution system.

Wells #1 and #6 are understood to be completed in the Wanapum Formation of the CRBG (Golder, 2006) and are constructed and authorized to function as both recharge and recovery wells. Under reservoir permit R3-30526, Walla Walla is authorized to inject up to 1,650 afy at a maximum injection rate of 1,300 gpm at Well #1 and up to 2,200 afy at a maximum injection rate of 1,600 gpm at Well #6. Up to 60 percent of the volume of water recharged at each well is available for recovery at a maximum withdrawal rate of up to 2,500 gpm at Well #1 and 2,600 gpm at Well #6. The authorized recovery percentage is based on storage loss estimates from groundwater modeling results and mass balance data presented in the reservoir permit application (Golder, 2006).

ASR operations at Well #1 generally takes place intermittently throughout the year, with short cycles of recharge and recovery between late-summer and late-spring followed by recovery during the summer. Water-level monitoring at Well #1 observed over the last five years indicate a stable water-level trend and suggests that the volume of water added to Block I, either through natural or artificial recharge mechanisms, is equal to or greater than the volume of water removed by pumping (EA, 2021). Prior to ASR operations, water levels in Block I were declining (Golder, 2005).

Recharge at Well #6 is intermittent and generally takes place under pressurized conditions between early-fall and early-summer. During the last two water years, recharge at Well #6 has decreased due to flood damage and repairs to the surface water diversion system, and was only rarely pumped (EA, 2021). During this time, static water levels in Block II have declined to below artesian levels, though remain within the operational range observed during previous years. No overall declining trend is apparent and water levels are expected to recover to previous levels when normal ASR operations are resumed.

Walla Walla noted that there were no adverse geochemical interactions between the recharge water and the background groundwater or changes in water quality attributable to geochemical reactions during the ASR pilot test or ongoing ASR operations (Golder, 2011). During pilot testing, total trihalomethane (THM) concentrations were high (ranging between 10 and 33 µg/L) during storage and recovery due to elevated chlorine dosages applied to the source water because of operational testing at the Mill Creek WTP. During ASR operations between 2001 and 2009, total THM concentrations were lower than those observed during pilot testing and THM concentrations decreased as recovery progressed. This effect was attributed to mixing of source water with native groundwater and degradation of THMs.

The water year 2020 annual ASR report (EA, 2021) states that no monitored analytes exceeded their applicable standards and no water quality issues were detected. Total THM concentrations were detected in water quality samples collected from both ASR wells during recovery operations (ranging between 7.1 and 26.8 µg/L), though at concentrations within the low-end range of quarterly THM samples collected in the City's distribution system (8.7 to 48.0 µg/L). Walla Walla does not monitor for haloacetic acids in water recovered from storage.

No operational or environmental issues related to ASR operations are known and Walla Walla continues to monitor the potential for flowing artesian wells, ponding, or land erosion in accordance with provisions of their reservoir permit (EA, 2021).

3.2.3 City of Pendleton ASR

The City of Pendleton, Oregon has been operating its ASR program since pilot testing first began in 2004 to store excess treated surface water from the Umatilla River in the basalt aquifer system, help meet seasonal water-demand needs, and manage the sustainability of the groundwater resource. Pendleton's ASR program consists of five ASR wells and is the largest ASR program in the Pacific Northwest. The wells are completed to depths ranging between 500 and 1,086 feet bgs and are interpreted to be completed in the Grande Ronde Basalt Formation of the CRBG (CH2M HILL, 2002).

The City's ASR program is being performed under ASR Limited License #006 issued by the Oregon Water Resources Department. The ASR limited license authorizes the City to store up to 9,903 acre-feet (3,200 MG) in the basalt aquifer system using up to seven ASR wells at a maximum combined recharge rate of 14,400 gpm. The maximum recharge rate for individual wells ranges between 1,000 and 3,000 gpm. The City is allowed to recover up to 95 percent of the total annual recharge volume at a maximum combined pumping rate of 16,800 gpm. The maximum recovery pumping rate for individual wells ranges between 1,000 and 3,000 gpm. The City typically stores well over 2,455 acre-feet (800 MG) of water per year and can pump approximately 6,250 gpm (9 MGD).

Pendleton's membrane water filtration plant (WFP) filters water obtained from the Umatilla River and is the source of recharge water used for ASR. In winter months, excess treated drinking water from the WFP is recharged into the basalt aquifer system beneath the City via the ASR wells, temporarily stored, and recovered to the water system during the high demand period later in the water year (GSI, 2019b). Recharge operations typically begin mid-December and continue through May of each year. Recovery of the stored water generally occurs during the highest demand months, which typically are June through September. Source water availability is dependent on both Umatilla River levels and municipal demand. Recharge operations take place under unpressurized conditions and only during periods of low demand and elevated river levels.

The City began pilot testing its ASR system in 2004 at three existing municipal production wells: Byers Well #1 (UMAT 531), Stillman Well #5 (UMAT 530), and Well #14 (UMAT 54072). The first year of pilot testing consisted of two ASR cycle tests (Cycles 1 and 2), each consisting of a recharge, storage, and recovery phase. The pilot-scale tests were designed to (1) assess ASR system operations, (2) evaluate well performance and the aquifer's hydraulic response to ASR activities, and (3) monitor for potential changes in recovered groundwater quality. Subsequent operational-scale ASR cycles conducted during Years 2 through 16 (2005 through 2019) typically consisted of 120–180 days of recharge, 0–30 days of storage, and 120–180 days of recovery. In 2012 (Year 9 testing), the City added two wells to its ASR program: Hospital Well #4 (UMAT 55619) and Prison Well #8 (UMAT 554). Addition of ASR wells was made possible because of expanded production at the WFP.

With the exception of Stillman Well #5, water recovered from storage is pumped from the ASR wells directly to the City's water supply distribution system. Given a history of air entrainment problems during recovery pumping, water recovered from storage at Stillman Well #5 is pumped to an 80,000-gallon storage tank equipped with a diffuser. This allows time for entrained air to come out of solution before the recovered water is delivered to the water supply system. Air-entrainment in the recovered water at Stillman Well #5 is thought to result from operations, originating from frequent on/off cycling of the well during recharge activities (GSI, 2016).

Total annual recharge volumes have ranged between 723 and 2,172 acre-feet (235 and 710 MG) during the last 16 years of City ASR program operations. The maximum recharge rate amongst the ASR wells during the City's most recent operational-scale test (Year 16, 2019 operations) ranged between 1,066 and 1,832 gpm (GSI, in preparation). Including year-to-year carryover storage volumes, the City has banked over 8,020 acre-feet (2,600 MG) of water in basalt storage. Up to 95 percent of the banked storage is available for recovery. The maximum recovery pumping rate amongst the wells during Year 16 (2019) operations ranged between 596 and 2,091 gpm (GSI, in preparation). All of the City's ASR wells are equipped with downhole flow-control valves capable of electrical generation and produce power during ASR recharge activities to offset a portion of the system's electrical utility bill.

All source water for ASR supply passes through the City's surface water filtration plant, which is designed to treat water to Safe Drinking Water Act (SDWA) water quality standards. No synthetic organic compounds (SOCs) or volatile organic compounds (VOCs) have been detected in the source water. Concentrations of other regulated contaminants have been either below detection limits or below action levels for ASR in Oregon.

No SOCs or VOCs have been detected in recovered water, with the exception of certain DBPs (trihalomethanes), which have been detected at levels below drinking water standards. Concentrations of other recovered water constituents have been either below detection limits or below drinking water standards. Comparison of major ionic compositions of source water and recovered water has yielded consistent results during ASR pilot testing:

- There is little variation in source water ionic composition
- Major ion concentrations are lower in source water than in recovered water
- Recovered water composition indicates a simple mixture of source water and native groundwater
- There is no indication of adverse chemical reactions taking place in the basalt aquifer system as a result of ASR

Before implementation of Pendleton's ASR program, the groundwater level in the basalt aquifer system was observed to be dropping at a rate of more than 3 feet per year (CH2M HILL, 2002; GSI, 2016). At that time, the City derived approximately 60 percent of its supply from groundwater and roughly 40 percent from the City's former spring sources (*i.e.*, a series of collector galleries located in the alluvium next to the Umatilla River). Since the ASR program began, the City has been able to increasingly reduce its use of groundwater and now relies primarily on storage of surface water available during the winter and spring months when flows are high and demand is low.

The City's water system operations have resulted in a reduction in the rate of water level decline in the basalt aquifer by more than half and have provided a significant benefit to the groundwater resource by reducing withdrawals of native groundwater. The City's overall conservation of groundwater through the use of ASR provides a benefit to the local basalt aquifer and improves the sustainability of the City's future water supply. The City continues to explore the feasibility of expanding its ASR program and anticipates adding two new ASR wells within the next 2–5 years. The City has not fully determined the storage capacity of the basalt aquifer system or whether additional recharge or recovery wells are needed to optimize the operation of full-scale ASR system.

3.3 Potential ASR Storage Aquifers

The primary objective of this evaluation is to recommend preferred hydrogeologic settings for ASR within the Pasco Study Area. Based on results from the Task 2 Hydrogeologic Feasibility Assessment (GSI, 2020a), this section presents a ranked list of potential ASR storage aquifers within the Study Area. The categories and criteria that were evaluated for meeting this objective consisted of the following:

- **Hydrogeologic Conditions:** Favorable hydrogeologic conditions means the presence of suitable aquifers for source water storage and recovery, while minimizing the potential loss of stored water.
- **Background Groundwater Quality[13]:** Adequate groundwater quality would require only disinfection with little to no additional treatment and little to no aquifer conditioning for buffer zone development to separate the stored ASR supply water from the surrounding ambient groundwater.
- **Interference with Existing Users:** ASR wells may interfere with other existing groundwater users due to the composite water-level buildup or drawdown of closely spaced wells.

3.3.1 Evaluation Scoring

Each of the potential ASR storage aquifers were evaluated against the three categories outlined above, with rating scores assigned to criteria defined for each category to aid in comparing the storage zones. The methodology for scoring included assigning one of the following three scores to each criteria within each category:

Positive (+)	Favorable attributes are present, and/or minimal challenges are anticipated
Neutral (0)	Favorable attributes are accompanied by unfavorable attributes, moderate challenges are anticipated, and/or some information is not available

[13] Geocompatibility between the waters was not assessed as part of this phase of the feasibility study. A geochemical evaluation as part of a subsequent phase should be conducted to assess that ASR supply water and ambient groundwater are compatible and that precipitation or adverse reactions will not take place.

Negative (-)	Unfavorable attributes are present, and/or significant challenges are anticipated

Each of the three categories and related criteria are defined in more detail in **Attachment B**.

3.3.2 Results

Candidate aquifers identified as being favorable for potential ASR storage are listed and ranked in **Table 3-2**. The maximum score a potential storage aquifer can achieve is 7(+), based on the categories and criteria outlined above and in **Attachment B**.

Table 3-2. Ranking of Potential Storage Aquifers

	Scoring Results (1)				
Potential Storage Aquifer	Hydrogeologic Conditions	Background Groundwater Quality	Interference with Existing Users	Total Score	Data Gaps (1)
Umatilla Member, Saddle Mountains Basalt	4(+)	1(+)	1(+)	**6(+)**	C-D
Frenchman Springs Member, Wanapum Basalt	4(+)	1(+)	1(+)	**6(+)**	C-D
Roza Member, Wanapum Basalt	3(+)	1(+)	1(+)	**5(+)**	C-D
Priest Rapids Member, Wanapum Basalt	2(+)	1(+)	1(+)	**4(+)**	C-D
Ice Harbor Member, Saddle Mountains Basalt	(0)	1(+)	(0)	**1(+)**	C-D
Elephant Mountain Member, Saddle Mountains Basalt	(0)	1(+)	(0)	**1(+)**	C-D
Pomona Member, Saddle Mountains Basalt	(0)	1(+)	(0)	**1(+)**	C-D
Esquatzel Member, Saddle Mountains Basalt	(0)	1(+)	(0)	**1(+)**	C-D
Ellensburg Formations	(0)	(0)	1(+)	**1(+)**	C-D
Grande Ronde Basalt	2(+)	2(-)	1(+)	**1(+)**	C-D
Suprabasalt Sediments	2(-)	2(-)	1(-)	**5(-)**	B

Notes: (1) See **Attachment B** for descriptions of scoring methodology, criteria, and data gap sub-ranks. Sub-ranks A-D identify a grade level assigned to data gaps identified as part of this feasibility study. A sub-rank grade of "A" indicates that data gaps are negligible and that future work needed to address any data gaps is not required. Conversely, a sub-rank grade of "D" indicates major data gaps and that future work will be required. Additional information is provided in **Attachment B**.

The top two potential ASR storage aquifers each scored a total of 6(+), and include the Umatilla Member of the Saddle Mountains Basalt and the Frenchman Springs Member of the Wanapum Basalt. The least favorable was the suprabasalt sediment aquifer. Results are summarized in the subsections below.

3.3.2.1 Umatilla Member, Saddle Mountains Basalt

The Umatilla Member scored positively for all scoring evaluation categories (**Table 3-2** and **Attachment B**). The Umatilla Member in the Pasco Basin area typically consists of two units that are each represented by a single sheet flow. Based on the geologic log for the Welch's well (Tolan, 2020; see Attachment A in GSI, 2020a), both Umatilla units are likely present beneath the Study Area. Total thickness of the Umatilla Member is variable, ranging from 40 to more than 270 feet thick within the Pasco Basin area. The thickness of the member beneath the Study Area is inferred to range from as low as approximately 40 feet in the eastern portion to as high as 280 feet in the western portion (**Figures 3-4 and 3-5**).

In portions of the Pasco Basin area where Umatilla Member interflow zones consist of simple vesicular flow tops/flow bottoms, groundwater yields are often less than 50 gpm. Where flow top or flow bottom breccia zones are present however, groundwater yields can be many times greater. The ability of flow breccia zones to produce high groundwater yields is documented in the Welch's well, which was drilled in 1981 and located in Kennewick, across from Pasco near the Columbia River[14]. Based on the geologist and driller's logs, the Welch's well penetrated an interflow zone within the Umatilla Member that consisted of a flow bottom breccia/flow top breccia that was approximately 50 feet thick and capable of very high groundwater yields (the well was tested at 1,390 gpm with 100 feet of drawdown), suggesting that the Umatilla Member is a good candidate to evaluate as a target storage aquifer.

Groundwater quality conditions are unknown, though the quality of area wells completed in the Saddle Mountains Basalt met primary drinking water standards for all monitored constituents (Golder, 2020; see Attachment C in GSI, 2020a). Groundwater quality data from the area wells suggest that the background aquifer water temperature may be somewhat elevated (13 to 21 °C, or 55 to 70 °F), and may require minor conditioning of the storage aquifer to develop a buffer zone to separate the cooler stored ASR supply water from the warmer surrounding ambient groundwater.

No existing groundwater users were identified in this CRBG member within the Study Area.

Limited available data and moderate to major data gaps indicates that future work is suggested or required to address uncertainties and further address ASR feasibility of this potential storage aquifer. Recommended future work considerations are outlined in **Section 7**.

3.3.2.2 Frenchman Springs Member, Wanapum Basalt

The Frenchman Springs Member scored positively for all scoring evaluation categories (**Table 3-2** and **Attachment B**). In the greater Pasco Basin area, the Frenchman Springs Member consists of between 9 to 14 sheet flows that have been subdivided into five separate units. All five of the Frenchman Springs Member subunits are inferred to be present beneath the Study Area (Tolan, 2020; see Attachment A in GSI, 2020a). Though there are no direct subsurface information on the Frenchman Springs Member beneath the Study Area, geologic logs from two deep Hanford Site wells suggest that more than half of the Frenchman Springs Member flows present in each well have flow top breccias that comprise from 10 to more than 40 percent of the individual flow thickness. Beneath the Study Area, the total thickness of the Frenchman Springs Member is estimated to range between 700 and 800 feet (**Figures 3-4 and 3-5**).

The potential for the presence of multiple flow top breccias within the Frenchman Springs Member section beneath the Study Area and information obtained from the City of Kennewick's ASR-1 feasibility study suggest that one or more of these interflow zones might be capable of very high groundwater yields (1,000 to more than 2,000 gpm). The ASR storage zone in the City of Kennewick's ASR well consists primarily of flow top breccia in the shallower flows of the Frenchman Springs Member and is capable of recharging at

[14] 550-foot deep water supply well located within the Richland Subbasin in Kennewick along the Columbia River (NW¼ of the NW¼, Section 6, T8N, R30E) (Tolan, 2020; see Attachment A in GSI, 2020a). The current status of the well (*e.g.*, present and active, abandoned, decommissioned) is unknown.

rates greater than 1,600 gpm and pumping at greater than 2,000 gpm, indicating that the interflow zones within the Frenchman Springs Member are high priority candidates to evaluate for ASR in the Study Area.

Two old naval air station wells were drilled near the Tri-Cities Airport (Tolan, 2020; see Attachment A in GSI, 2020a), though their current status (*e.g.*, present and active, abandoned, decommissioned) and well completion details are unknown. Based on their reported depths, these wells may be completed in the Priest Rapids or Roza Members of the Wanapum Basalt, or possibly the upper portion of the Frenchman Springs Member. No other existing groundwater users were identified in this CRBG member within the Study Area.

Groundwater quality conditions are not well known, though the quality of area wells completed in the Wanapum Basalt met primary drinking water standards for all monitored constituents (Golder, 2020; see Attachment C in GSI, 2020a). Groundwater quality data from one of the naval air station wells (Well BF002 in CBGWMA, 2009; summarized in **Table A-2** in **Attachment A**) are generally within the range of data observed from the Kennewick and Willowbrook ASR feasibility studies (Golder, 2001; Golder, 2012a; Golder, 2012c; HDR, 2012; Golder, 2014), with the exception of sodium and specific conductance. The concentration of sodium is reported at 115 mg/L and the specific conductivity measured 506 µS/cm, and are both comparatively elevated. Groundwater quality data from the area wells suggest that the background aquifer water temperature may be elevated (24 to 28 °C, or 75 to 82 °F), and may require some aquifer conditioning to separate the cooler stored ASR supply water from the warmer surrounding ambient groundwater.

Limited available data and moderate to major data gaps indicates that future work is suggested or required to address uncertainties and further address ASR feasibility of this potential storage aquifer. Recommended future work considerations are outlined in **Section 7**.

3.3.2.3 Roza and Priest Rapids Members, Wanapum Basalt

The Roza and Priest Rapids Members both scored positively for all scoring evaluation categories and scored a total of 5(+) and 4(+), respectively (**Table 3-2** and **Attachment B**). The Roza Member scored less than the top two potential ASR storage aquifers because its production capacity depends on whether it possess a thick (30 to 50 feet) flow top breccia beneath the Study Area. The Roza Member (originally interpreted to be present at Kennewick's ASR-1 well; Golder, 2012a), was reinterpreted by Golder (2014) to be absent, whereas the Priest Rapids Member is instead present. The subsurface extent of the Roza Member within the Study Area is inferred based on work completed by Tolan et al. (1989), Martin (1989), and Reidel et al. (2013). Limited available data and moderate to major data gaps indicates that future work is suggested or required to address uncertainties and further address ASR feasibility of the Roza Member (see **Section 7**).

The estimated production capacity and storage potential of the Priest Rapids Member are considered low because the Lolo flow beneath the Study Area may have either a thin (less than 10 feet thick) flow top breccia or a thin simple vesicular flow top, and a thin vesicular flow bottom (Tolan, 2020; see Attachment A in GSI, 2020a).

3.3.2.4 Other CRBG Members

The remaining CRBG members identified in the Study Area[15] each scored a total of 1(+) (**Table 3-2** and **Attachment B**). All scored positively for background groundwater quality and neutrally for hydrogeologic conditions and interference with existing users, with the exception of the Grande Ronde Basalt. The Grande Ronde Basalt scored positively for hydrogeologic conditions and interference with existing users and

[15] Ice Harbor, Elephant Mountain, Pomona, and Esquatzel Members of the Saddle Mountains Basalt; and the Grande Ronde Basalt.

negatively for groundwater quality. Poor groundwater quality concerns (GSI 2020) and greater well completion depths render development of an ASR system using Grande Ronde Basalt-hosted aquifers more costly than development of comparably-productive and better water quality aquifers in the shallower basalt units. Consequently, the Grande Ronde Basalt is considered a lower priority target for ASR beneath Pasco.

3.3.2.5 Ellensburg Formation Interbeds

The Ellensburg Formations presumed present beneath the Study Area[16] scored a total of 1(+) (**Table 3-2** and **Attachment B**). The Ellensburg Formations scored positively for interference with existing users and neutrally for hydrogeologic and groundwater quality conditions. These interbeds are relatively thin, typically consist of semi-indurated silt/clay and fine sand, and are unlikely to have suitable hydraulic characteristics to target as ASR storage aquifers (Tolan, 2020; see Attachment A in GSI, 2020a).

3.3.2.6 Suprabasalt Sediment Aquifer

The least favorable of the potential storage aquifers was the suprabasalt sediment aquifer (**Table 3-2** and **Attachment B**). The suprabasalt sediment aquifer scored negatively for all scoring evaluation categories. Because of its unconfined aquifer conditions and drainage and dewatering needs (GSI, 2020a), the suprabasalt aquifer system is expected to have a very limited storage capacity. Recharge to this unconfined aquifer could contribute to ponding in low-lying areas and impact active management of shallow groundwater levels. The aquifer's direct hydraulic connection with the river also could contribute to losses of stored water to the river and significantly limit the volume of ASR supply water available for recovery. This aquifer is highly utilized in and around the Study Area and adverse impacts to existing users from ASR activities are anticipated.

Groundwater quality meets primary drinking water criteria with the exception of nitrate. Nitrate concentrations are typically higher than Columbia River water (Golder, 2021; see Attachment X in RH2, 2021), with concentrations ranging from below detection to 20-70 mg/L-N. Based on available groundwater quality data, iron and manganese concentrations are variable and often higher than concentrations in the Columbia River and both have been measured above their SMCLs of 0.3 and 0.05 mg/L, respectively. Additional water quality characteristics are provided in **Section 4.2**.

Expectedly low storage capacity and recovery volume, anticipated impacts to existing groundwater users, and active drainage and dewatering needs preclude the suprabasalt aquifer as a potential ASR storage aquifer.

3.4 Potential ASR Development Areas

The Umatilla and Frenchman Springs Members are widespread throughout the Study Area, though findings from the hydrogeologic feasibility assessment indicate that the northwest portion of the City is the overall preferred ASR development area (GSI, 2020a). This area is where the Umatilla Member is interpreted to be thickest (approximately 280 feet), and where the apparent hydrogeologic conditions most suitable for ASR within the Study Area overlap with areas where increased water needs from near- and long-term growth are anticipated (RH2, 2021). Candidate ASR development sites within this area are identified in **Section 6** and further described by RH2 (2021).

In the northeastern portion of the Study Area, the thickness of the Umatilla Member is estimated to be 50 feet or less. Areas where the Umatilla is thin may limit recharge and recovery rates and volumes and prevent

[16] Levey, Rattlesnake Ridge, Selah, Cold Creek, Mabton, Quincy, Squaw Creek, and Vantage Members.

stacking of adjacent ASR wells in separate aquifer storage zones to maximize the ASR capacity at an individual site.

The thickness of the Frenchman Springs Member appears to be relatively uniform across the Study Area. ASR facilities targeting storage only in the Frenchman Springs Member would be most economically favorable in the northern and eastern portions of the Study Area, where the top of the member is interpreted to be shallowest (900 to 1,200 feet bgs). In the preferred northwest portion of the Study Area, the top of the Frenchman Springs Member is estimated to range between 1,300 and 1,500 feet bgs.

Hydrogeologic conditions in the southern portion of the Study Area are comparatively less favorable. Because of apparent shallower basalt groundwater levels (GSI, 2020a), ASR development areas along the southern portion of the Study Area compared to the north may have less storage potential without having to seal wellheads and recharge under pressurized conditions.

SECTION 4: **Source Option Analysis**

This section summarizes the legal and physical availability and general water quality conditions of the surface water and groundwater sources, with the objective of recommending a preferred and alternative source water option for ASR supply. This section also identifies potential treatment requirements of the recommended source water option pre- and post-storage. Potential ASR site development options and planning-level costs to develop are provided in **Section 6** of this report.

The City's current primary sources of water include surface water from the Columbia River and groundwater from the suprabasalt sediment aquifer system. The City's potable system is sourced by two Columbia River diversions and WTPs: Butterfield Intake and West Pasco Intake. The City's separate irrigation system is supplied by suprabasalt groundwater from 11 wells and surface water pumped from the Columbia River Intake. These sources, the potable and nonpotable (irrigation) systems, and current and future capacities and demand needs are described in RH2 (2021) and summarized in **Section 2** of this report. The locations of the sources are shown on **Figure 2-1**.

4.1 Water Rights

The City currently holds water rights for its regional irrigation system, water rights for stand-alone systems such as individual park irrigation and supplemental irrigation water for disposal of effluent at the Pasco Process Water Reuse Facility, and water rights for its regional potable system. Additional details on the City's existing water rights and pending water right applications for both systems are provided by RH2 (2021).

4.1.1 Irrigation System

The City currently holds 24 water rights for its existing irrigation system (RH2, 2021). These water rights total 17,608 gpm (25.36 MGD) and 7,216.7 acre-feet per year (2,350 MG). The irrigation system water rights currently are pumped from 11 wells (First Place, Desert Sunset, Island Estates, Sirocco, Road 52, Village of Pasco Heights, Northwest Commons, Desert Estates, Linda Loviisa, I-182, and Powerline Road) and one surface water diversion (Columbia River Intake) (**Figure 2-1**). The period of use of the irrigation system water rights are variable, and some are unspecified or general in nature (i.e., *seasonal*).

Each of the irrigation system wells and the surface water diversion has a source meter installed. Metering data from 2015 through 2020 are summarized in **Table 4-1**, and indicates that water use from the irrigation system has exceeded the annual water right limit since 2015. Ecology is aware of the situation and the City is actively working toward a resolution through pending water right change applications (**Section 4.1.2**) and through coordination with the South Columbia Basin Irrigation District (SCBID) and U.S. Bureau of Reclamation (USBR) to acquire additional irrigation water. Consequently, no water rights are available from the irrigation system that could be used for ASR supply.

Table 4-1. Irrigation System Water Use (2015 through 2020)

Irrigation Season	Water Right Limit (afy)	Annual Volume Used (afy)	Difference (afy)
2015	7,216.7	9,665.6	-2,448.9
2016	7,216.7	8,514.6	-1,297.9
2017	7,216.7	8,215.7	-999.0
2018	7,216.7	9,211.2	-1,994.5
2019	7,216.7	9,074.1	-1,857.4
2020	7,216.7	9,768.4	-2,551.7

4.1.2 Stand-Alone Systems

The City currently has 43 pending water right change applications before the Franklin County Water Conservancy Board (RH2, 2021). The water right total for all of the water rights proposed to be changed is 39,142 gpm (56.36 MGD) and 16,368.6 afy (5,330 MG). This includes all of the irrigation system water rights summarized in **Section 4.1.1**, plus 21,534 gpm (31.01 MGD) and 9,152 afy (2,980 MG) from other water rights. Source metering data would need to be analyzed to determine how much water might be unused under the other water rights that could be available to meet future demands.

The change applications were filed in either 2016 and amended in 2020 (seven change applications) or were filed in 2020 (36 change applications). Most water rights are in the City's name, but some are in others. The 2020 change applications request to add all existing points of withdrawal and points of diversion to all water rights (33 in total), make the period of use year round, make the purpose of use municipal, and make the place of use the area served by the City.

If these water rights can be changed as requested, it could add significantly to the rate and volume of water available for direct use and/or for ASR supply. Since the change applications are still pending however, these stand-alone system water rights and sources were not reviewed further as part of this phase of the feasibility study.

4.1.3 Potable System

This section summarizes the City's water rights portfolio for its potable system, which consists of both uninterruptible and interruptible water rights. Additional information is provided by RH2 (2021).

4.1.3.1 Uninterruptible Water Rights

The City currently holds 10 uninterruptible water rights for its existing potable system (RH2, 2021). These water rights total 32,223 gpm (46.40 MGD) and 19,655.75 afy (6,400 MG). The potable system water rights can be used year round and the place of use is the City's water service area, which can be changed through updates of its water system plan.

Water use from the regional potable system is expected to exceed the current water rights by approximately 2030, leaving a projected deficit of 2,713 afy (885 MG) in the year 2036 (**Figure 4-1**). Therefore, there are no uninterruptible water rights available from the potable system that could be used for ASR supply.

4.1.3.2 Interruptible Water Right

The City is presumed to be one-quarter holder of the Quad Cities water right permit (S4-30976) based on the Quad Cities and the Office of Columbia River Memorandum of Agreement (MOA; see **Attachments C** and **D**). A MOA Water Committee comprised of the Public Works Directors of all four cities meets quarterly to review and accept accumulative water allocations as use patterns and needs change. It is up to each individual member to secure mitigation and additional diversion authority under the permit. The Quad Cities water right permit was initially issued for 178 cubic feet per second (cfs) (79,892 gpm; 115 MGD) and 96,619 afy (31,483 MG). The City's presumed portion of this water right equals 44.5 cfs (19,973 gpm; 28.76 MGD) and 24,154.75 afy (7,870 MG). Ecology provided mitigation that allowed the Quad Cities to utilize the first increment from the water right on an uninterruptible basis. Each city's portion of that first increment was 1,122 gpm (1.6 MGD) and 1,806.75 afy (589 MG).

The undeveloped portion of the Quad Cities water right remaining after the first increment was 168 cfs and 89,392 afy, of which one-quarter[17] is the City's portion.

Water rights S4-33044(A) and S3-30852 issued to the City utilize the Lake Roosevelt Incremental Storage Release Water as mitigation, offered by the Office of Columbia River. These water rights add 10,000 afy (3,258 MG) to the City's water rights portfolio and their approvals contain the following provision: "In accordance with the MOA Section 5 (b)(ii), equal annual use under permit S4-30976P shall be reduced in equal amount in exchange for developing water supplies with mitigation requirements under…" these two permits.

Subtracting the 10,000 afy (3,258 MG) from the City's portion of the undeveloped portion of the Quad Cities water right leaves 18,850 gpm (27.1 MGD) and 12,348 afy (4,023 MG) that is available to the City under this water right, but that is currently interruptible since it is unmitigated.

A description of the Quad City water right permit provisions are provided by RH2 (2021).

This undeveloped portion of the Quad Cities water right is subject to minimum instream flow limitations as specified in the permit provisions and summarized in **Figure 4-2**. Using the BiOp Compliance Plan contained within the January 2016 *Regional Water Forecast and Conservation Plan* (RH2, 2016), the probability of water being available each month over the period of water years 2005 through 2019 is summarized in **Table 4-2**.

Table 4-2. Quad Cities Interruptible Water Right Water Availability (Water Years 2005 through 2019)

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Days Water Available	25/31	17/30	26/31	28/31	24/28	27/31	18/30	22/31	19/30	11/31	2/31	22/30
% Water Available	83	58	85	91	88	88	62	73	64	38	9	76

Notes: Table adapted from RH2 (2021).

Over a typical ASR recharge season (November through March), the probability that water under the Quad Cities water right will be available (provisioned minimum flows are met) ranges between 58 and 91 percent.

This interruptible water right currently represents the City's best option for using off season (*i.e.*, surplus) water from the City's potable system for ASR supply.

If the City can add the Columbia River Intake as an additional point of diversion under the Quad City water right permit, it could utilize both the potable and irrigation systems to pump water from the Columbia River to the ASR storage sites. Some form of treatment of the irrigation source pre-recharge however, will be needed to meet groundwater anti-degradation criteria (Chapter 173-200-040 WAC) and to reduce or eliminate the potential for ASR well plugging or biofouling.

4.2 Water Quality

This section summarizes general water quality characteristics of the surface water (treated and untreated) and groundwater (untreated) source options based on available water quality data and published reports.

[17] 42 cfs (18,850 gpm; 27.15 MGD) and 22,348 afy (7,280 MG)

Details, data sources, and water quality summary tables are provided by Golder (2021; see Appendix A in RH2, 2021).

4.2.1 Suprabasalt Sediment Aquifer

Groundwater from City wells completed in the suprabasalt sediment aquifer system provides some of the supply for the City's irrigation system. Groundwater quality data from former City municipal supply wells completed in the suprabasalt sediments available from the Washington State Department of Health (WDOH) are tabulated by Golder (2021; see Appendix A in RH2, 2021). Water quality results indicate compliance with Washington State Drinking Water Criteria (Chapter 246-290-310 WAC), with the following exceptions:

- Nitrate ranged between 14 and 17 milligrams per liter as nitrogen (mg/L-N) in six samples collected between 1993 and 1994
- Single conductivity (760 µmhos/cm) exceedance of the SMCL in 1993 (SMCL of 700 µmhos/cm)
- Single iron (0.34 mg/L) exceedance of the SMCL in 1993 (SMCL of 0.3 mg/L)
- Single manganese (0.06 mg/L) exceedance of the SMCL in 1993 (SMCL of 0.05 mg/L)
- Single TDS (510 mg/L) exceedance of the SMCL in 1993 (SMCL is 500 mg/L)
- Sodium ranged between 28 and 47 mg/L in all six samples collected between 1988 and 1997, exceeding the advisory limit of 20 mg/L
- No alkalinity, dissolved oxygen, or pH data were available for review

Nitrate concentrations in City irrigation wells were reported to range between 22 and 28 mg/L-N in samples collected during July 2005 (MSA, 2013). Nitrate concentrations in suprabasalt wells located within and adjacent to the Study Area reported in Ecology's Environmental Information Management (EIM) database as part of the Washington State Agricultural Chemicals Pilot Study have been reported up to approximately 40 mg/L-N. Nitrate concentrations in 70 suprabasalt wells located in the Pasco Basin ranged from non-detect (< 0.01 mg/L) to 70.4 mg/L with a median value of 9.7 mg/L and a mean of 12.3 mg/L (SSPA, 2008).

Other groundwater quality data from suprabasalt wells located at the Pasco Bulk Fuels Site (Ecology site ID# 579) are tabulated by Golder (2021; see Appendix A in RH2, 2021) and summarized below:

- Arsenic concentrations have ranged between 0.0009 and 0.005 mg/L when detected above reported limits
- Iron was detected at low concentrations (up to 0.18 mg/L) during two sampling events
- Nitrate concentrations have been consistently below the analytical reporting limits (< 0.01 to < 0.07 mg/L-N) in one well, consistently below the MCL in another well (3.2 to 9.4 mg/L-N), and ranged between 13 and 18 mg/L-N in the remaining three wells
- Sodium concentrations ranged between 4.9 and 54 mg/L
- The mean total dissolved solids (TDS) concentration was 375 mg/L, though some samples reported values that exceeded drinking water and Washington Groundwater Anti-Degradation Criteria (Chapter 173-200-040 WAC) criteria of 500 mg/L

4.2.2 Columbia River

Treated water from the Columbia River is the sole water supply source for the City's potable system while untreated water from the river supplies a portion of the irrigation system. The general water quality characteristics for both treated and untreated Columbia River water are summarized in the following sections.

4.2.2.1 Treated

According to the City's Comprehensive Water System Plan (Murraysmith, 2019), water treatment at the West Pasco and Butterfield WTPs includes the addition of coagulants (alum) and chlorine. The West Pasco WTP water is then strained, filtered, and fluoridated prior to storage and distribution. The Butterfield WTP includes flocculation and sedimentation basins, a mixed-media filter, and a second addition of coagulants and chlorine prior to storage and distribution. Post-treatment (finished) water quality data from the WDOH are summarized for the most recent 10-year period of record by Golder (Golder, 2021; see Appendix A in RH2, 2021). Findings and observations from a review of the data are summarized below:

- All volatile and synthetic organic compounds (VOCs and SOCs) were consistently reported as below detection
- Radionuclide concentrations were either below detection or detected at concentrations below drinking water criteria
- Nitrate concentrations ranged between 0.3 and 1 mg/L-N
- Most measured metals were consistently below detection
- Iron concentrations were consistently below detection (< 0.1 mg/L) and manganese concentrations were low (< 0.01 mg/L)
- Total organic carbon (TOC) concentrations ranged between 0.6 and 1.8 mg/L
- Meets the state drinking water criteria for all analyzed constituents
- Meets the groundwater anti-degradation criteria for all analyzed inorganic constituents, with the exception of arsenic and silver (for which compliance with anti-degradation criteria could not be assessed)[18] and disinfection byproducts (DBPs) bromodichloromethane and chloroform
- Water quality results are similar for the two WTPs
- Notable data gaps in the finished water quality data set include some major ions (*e.g.*, alkalinity), dissolved oxygen, and pH

4.2.2.2 Untreated

Untreated (and unfiltered) surface water from the Columbia River Intake provides some of the supply for the City's irrigation system. Raw water quality data available from the West Pasco and Butterfield WTPs pre-treatment are assumed to represent water quality conditions of the irrigation system expected from the Columbia River Intake. The raw water quality data were obtained from the WDOH for the most recent 10-year period of record, and included analytical test results for fluoride, nitrate and TOC:

- Fluoride concentrations ranged between 0.07 and 0.11 mg/L from 12 samples collected between 2016 and 2020
- Nitrate concentrations ranged between 0.3 and 0.7 mg/L-N from two samples, one from each WTP collected in 2010 and 2013
- TOC concentrations ranged between 0.6 and 2.5 mg/L, with a mean concentration of approximately 1.3 mg/L from 86 samples collected between 2010 and 2020

Raw Columbia River water quality data previously compiled and evaluated as part of the Kennewick ASR-1 feasibility study (Golder 2012c) are tabulated by Golder (2021; see Appendix A in RH2, 2021) and provide

[18] Both arsenic and silver were reported as below detection. Their respective analytical reporting limits however, were higher than the anti-degradation criteria. Arsenic was not detected (< 0.003 to < 0.001 mg/L); the anti-degradation criterion is 0.00005 mg/L. Silver was not detected (< 0.1 mg/L); the anti-degradation criterion is 0.05 mg/L.

results for additional analytes. Select findings and observations from a review of the data are summarized below:

- TDS was approximately 200 mg/L
- Alkalinity ranged between approximately 30 and 90 mg/L as calcium carbonate ($CaCO_3$)
- Nitrate concentrations were less than 1 mg/L
- Sulfate concentrations were approximately 10 mg/L
- Sodium concentrations were less than 5 mg/L
- Total iron and manganese concentrations were low (< 0.1 mg/L and < 0.05 mg/L, respectively)
- Meets groundwater anti-degradation criteria for all analyzed inorganic constituents, with the exception of arsenic and silver, for which compliance could not be assessed[19]

4.2.3 Summary

Columbia River water is classified as a calcium-magnesium-bicarbonate type water with circum-neutral to alkaline pH and moderate alkalinity concentrations. Nitrate, iron, and manganese concentrations are relatively low and all reported parameters meet drinking water criteria (Chapter 246-290-310 WAC) based on the data sets reviewed for this phase of the feasibility study. DBPs were detected below drinking water criteria, but above the groundwater anti-degradation criteria (Chapter 173-200-040 WAC) in treated Columbia River water from the Pasco and Kennewick WTPs. Total suspended solids (TSS) data were not available for raw or treated Columbia River water. Based on the design of the City WTPs, it is assumed that raw Columbia River water likely contains TSS. Elevated TSS in ASR supply water may adversely affect injection well performance.

Groundwater in the suprabasalt sediment aquifer is characterized as a magnesium-bicarbonate type water to bicarbonate type water with no dominant cation. The water quality meets primary drinking water criteria with the exception of nitrate based on the data sets reviewed for this phase of the feasibility study. Nitrate concentrations are typically higher than Columbia River water, with concentrations ranging from below detection to as high as 20-70 mg/L-N. Iron and manganese concentrations are variable and often higher than concentrations in the Columbia River and both iron and manganese have been measured above their SMCLs. The available metals data indicate a potential for arsenic to be present at low (part per billion) concentrations. Baseline arsenic concentrations may therefore exceed the anti-degradation criterion of 0.00005 mg/L. Concentrations of major ions and metals are generally higher compared to the Columbia River.

Treated drinking water from the City's potable water system is considered the best candidate for ASR supply. Treated source water provides the benefits of filtration and disinfection, which helps to reduce or eliminate plugging and biofouling of the ASR well during recharge from elevated TSS concentrations and microbial contaminants that are otherwise present in untreated and unfiltered surface water. DBPs including trihalomethanes (THMs) and haloacetic acids (HAAs) formed during chlorine disinfection of drinking water however, will likely violate water quality standards for groundwater (Ecology, 2005). Results from several ASR programs that store treated drinking water in basalt-hosted aquifers however, have demonstrated DBP attenuation in the subsurface (Golder, 2011), including the City of Kennewick's ASR-1 program (GSI, 2021).

[19] Both arsenic and silver were reported as below detection. Their respective analytical reporting limits however, were higher than the anti-degradation criteria. For one sample, a lower reporting limit was achieved for silver and result indicated compliance with anti-degradation criterion.

Chlorine compounds lower than 1 mg/L in ASR supply water can help control biological growth in the ASR well and prevent clogging of the well screen and aquifer formation (Pyne, 2005).

Groundwater from existing City irrigation wells completed in the suprabasalt sediment aquifer is considered the least favorable of the ASR supply options evaluated because of high nitrate and groundwater anti-degradation concerns. Though elevated nitrate concentrations in ASR supply water may not persist within the CRBG during storage (Nelson and Melady, 2014), nitrate present in source water will likely reduce to nitrogen or ammonia as a result of denitrification during storage and recovery periods (Mirecki, 2004) and possibly contribute to pH increases (Pyne, 2005).

4.3 Physical Capacity

Of the City's two points of diversion from the Columbia River (West Pasco Intake and Butterfield Intake) for its potable system, the West Pasco Intake and WTP are the closest diversion to where near- and long-term growth is anticipated to be focused, and thus is the only point of diversion considered in this analysis. The irrigation system includes 11 wells and one surface water diversion from the Columbia River (Columbia River Intake) in proximity to the West Pasco WTP. For the irrigation system, only the capacity of the Columbia River Intake is considered in this section, since groundwater produced by the wells is high in nitrate and because the wells are not listed as authorized points of withdrawal under the Quad City permit.

4.3.1 Irrigation System

If the Columbia River Intake for the irrigation system is added as a point of diversion to the Quad City water right permit, then that point of diversion would allow the irrigation system to also be used to convey water during the off-season (November through March) from the Columbia River to a treatment facility and then to candidate ASR development sites for ASR supply. The off-season firm capacity surplus of the Columbia River Intake and associated transmission main is limited by the capacity of the transmission main at 1,764 gpm (2.54 MGD) in 2036. Using the off-season firm capacity and the monthly average percent of the time that the minimum flows are met (**Table 4-2**), an estimated 951 acre-feet (310 MG) of water could be pumped from the Columbia River Intake for use as source water for ASR storage.

4.3.2 Potable System

The firm capacity of an intake structure is defined as the capacity of the facility with the largest pump out of service (such as due to damage or routine maintenance). The off-season firm capacity surplus of the West Pasco WTP in 2036 is forecast to be 5,835 gpm (8.4 MGD). Using the off-season firm capacity and the monthly average percent of the time that the minimum flows are met (**Table 4-2**), an estimated 3,146 acre-feet (1,025 MG) of water could be pumped from the West Pasco WTP for use as source water for ASR storage.

4.3.3 Combined Systems

The combined off-season firm capacity to move water from the Columbia River using both the potable and irrigation systems to the northwest portion of the City where near- and long-term growth is anticipated is nearly 7,600 gpm (10.94 MGD). Using the combined off-season firm capacity rate and the monthly average percent of the time that the minimum flows are met, an estimated 4,097 acre-feet (1,335 MG) of water could be pumped from the Columbia River for use as source water for ASR storage.

Chlorine disinfection and filtration of water produced by the Columbia River Intake however, would be needed pre-recharge to meet groundwater anti-degradation criteria and to reduce or eliminate the potential for plugging or biofouling of the ASR well. An alternative to engineered filtration could be to develop an alternative supply source (*e.g.*, collector well or riverbank filtration wells; **Section 4.6**) that is in hydraulic connection with the river and capable of naturally pre-filtering water prior to recharge. This alternative will require application and approval from Ecology for the water rights change.

4.4 ASR Supply Availability

The projected future demands on the potable water system (Murraysmith, 2019) suggest that the City does not have enough uninterruptible water right annual volume to meet future potable demands or that could be used for aquifer recharge during the off-season. Current demands on the irrigation system exceed the existing irrigation system water rights, leaving no excess water that could be used as source water for ASR. An estimated 951 afy (310 MG) of water however, could be pumped from the Columbia River Intake through the irrigation supply system for use as an ASR supply source if the source could be added as a point of diversion to the Quad City permit. The lack of treatment and filtration at the Columbia River Intake however, currently prevents it from being a source suitable for ASR in its current configuration.

The City's potable water system does have access to the interruptible portion of the Quad Cities water right via their West Pasco and Butterfield Intakes when instream flow provisions on the Columbia River are met. The 5,835 gpm (8.4 MGD) firm capacity of the WPWTP during the off-season compared against the number of days that water is historically available (uninterrupted) for use under the QCWR, results in an estimated 1,025 MG of water available for storage during the November through March off-season. The potable supply sources are filtered and treated, and no water quality limitations are anticipated to reduce the off-season firm capacity estimate from the WPWTP for ASR.

The recommended source water for ASR supply is treated surface water from the Columbia River, diverted using City-owned infrastructure when instream flow provisions are met utilizing the Quad Cities water right permit. An alternative to this source is discussed in **Section 4.6**. Tracking and managing diversions under this interruptible permit as well as the City's non-interruptible water rights is conducted by a MOA Water Committee. The MOA Water Committee reports diversions and return flows quarterly and develops an Annual Report demonstrating how the mitigated water is shaped and quantified based upon the instream flows at McNary and Bonneville dams and subject to the required minimum instream flow targets throughout the calendar year.

4.5 Potential Treatment Needs

In order to preserve water quality and protect existing and beneficial uses of groundwater, an ASR project must comply with the groundwater anti-degradation policy stated in Chapter 173-200-040 WAC. All contaminants proposed for discharge into groundwaters shall be provided with all known, available, and reasonable methods of prevention, control, and treatment (AKART).

If a Pasco ASR facility uses potable water as the ASR supply source, it may need to be treated prior to recharge to remove or reduce DBPs, arsenic and potentially silver, as identified by Golder (2021; see Appendix A in RH2, 2021). If arsenic in the ASR source water is higher than groundwater, then arsenic treatment may be required prior to recharge to the aquifer. This likely would be in the form of pyrolusite or GreensandPlus media filtration, and a pilot study would need to be conducted to verify treatment effectiveness and estimate capital costs.

If a Pasco ASR facility uses the irrigation system as the ASR supply source, the water would need to be filtered and disinfected, and possibly treated to remove or reduce DBPs, arsenic and potentially silver. Suspended solids removal should occur prior to recharge to avoid clogging the wellbore and negative impacts to the well and aquifer performance. Chlorination can occur before recharge to inactivate bacteria and viruses, but this may contribute to the formation of DBPs. The disinfection process will be further refined at a later stage of this project. DBPs in ASR supply water may not be a concern since other municipal ASR systems which store treated drinking water in basalt-hosted aquifers have demonstrated DBP attenuation in the subsurface. A 2.8 MGD treatment facility for suspended solids removal and chemical feed may cost on the order of $3 million.

When the ASR supply water is withdrawn from storage, it would need to be re-chlorinated and possibly re-fluoridated to match distribution water if used for potable purposes. If the water recovered from storage will be used for irrigation purposes, then it is presumed that the City would not have to modify or further condition this water and can reuse it for irrigation as needed.

The chlorination and dechlorination chemicals can be stored in a chemical storage tank within a new building with metering pumps to flow pace to the withdrawal rate. This infrastructure may cost on the order of $100,000 for the chemical tanks, metering pumps, chemical injection piping, and facility structure. If DBPs form and become an issue, then a granulated activated carbon, reverse osmosis, or aeration system can be implemented to reduce these contaminants. Further alternatives analyses would be required to estimate the costs and effectiveness of these technologies, but they would be at least an order-of-magnitude higher than a dechlorination and chlorination facility.

A comprehensive water quality analyses should be conducted to characterize treated and untreated Columbia River water, evaluate for potential temporal trends, and identify other potential treatment needs. Results from this analyses should be compared against groundwater quality conditions of potential ASR storage aquifers to assess geocompatibility between source water and receiving groundwater and to identify a need for additional treatment of water recovered from storage prior to potable distribution or irrigation. Future work considerations are provided in **Section 7**.

4.6 Alternative ASR Supply Source

Future source capacity for ASR recharge could potentially include an alternative groundwater supply source in hydraulic connection with the Columbia River to provide natural filtration and reduce or preclude specialized treatment. The alternative groundwater supply source could be a riverbank filtration wellfield consisting of conventional vertical wells and/or a collector well system. The advantages of a dedicated ASR supply source include the ability to operate autonomously from the existing potable system, the potential for reduced treatment costs since the water would not be used directly for potable supply, decoupling from seasonal demands on the potable system, and potentially greater recharge rates and storage volumes depending on the actual capacity of the alternative source. The disadvantage is that the City currently does not have or operate any collector wells or wellfields adjacent to the Columbia River and would require significant capital expenditures to identify a suitable location and construct such a facility (**Section 4.6.4**).

The hydrogeologic conditions of the shallow aquifer in connection with the river would need to be favorable for an alternative ASR supply source or multiple sources to meet the storage requirements (**Section 5.1**). In addition, the water quality would need to be more characteristic of river water than suprabasalt groundwater. If the water quality is closer to suprabasalt groundwater based on characteristics from upgradient wells and has high nitrate, then the ongoing treatment cost of the alternative supply sources could be similar or higher than for the potable system.

It should be feasible to add one or multiple collector wells or conventional wellfields as points of withdrawal to the Quad Cities water right, through the water right change application process, if desired by the City and agreed to by the other Quad Cities, based on the following:

- RCW 90.03.570(2)(c) authorizes the proposed water right change to an unperfected surface water permit, since the water right currently is subject to minimum instream flow requirements and would continue to be after the change.
- RCW 90.03.380 authorizes the change in point of diversion and application will be made for any new points of withdrawal consistent with both RCW 90.03.395 and 90.03.397.
- The City of Kennewick is already authorized to use collector wells under the water right.

While the City should be able to add a collector well to the Quad City permit under a plain reading of RCW 90.03.570(2)(c), since the water right is interruptible based on provisioned minimum stream flows, the City will need to confirm with Ecology to make sure that this is correct.

4.6.1 Potential Locations

A preliminary review of possible locations for a riverbank filtration wellfield or collector well system includes five candidate sites within the City. These locations are shown in **Figure 4-3** and listed below:

- Location No. 1 – Adjacent to Butterfield WTP Intake
- Location No. 2 – Wade Park (south end of Road 54)
- Location No. 3 – Chiawana Park
- Location No. 4 – Adjacent to WPWTP Intake
- Location No. 5 – Adjacent to Harris Road or Shoreline Road

Preliminary review and consideration of these five possible alternative source locations suggest that candidate Location Nos. 4 and 5 are most favorable if a riverbank filtration wellfield or collector well system is considered as an alternative ASR supply source option and pursued in future planning efforts.

4.6.2 Hydraulic Connection with Columbia River

In order to have a riverbank filtration wellfield or collector well approved as a point of withdrawal under the interruptible portion of the Quad City water right permit, the City will have to demonstrate through aquifer characterization and testing, that the impacts due to pumping the wells can be considered the same as a direct surface water diversion. If groundwater pumping from a well leads to long lags in impact to the Columbia River, then that well is not a good candidate to be used under an interruptible water right because its pumping and associated impacts will not be able to be managed on a daily basis and impairment of the minimum flows will occur after pumping has ceased, but while the impact remains. Any new point of withdrawal will require application and approval in accordance with RCW 90.03.380, 90.03.395 and 90.03.397.

4.6.3 Water Quality

ASR supply water for Kennewick ASR-1 is treated drinking water from their municipal water supply system. Kennewick's water system is supplied by two Ranney Collector Wells (RC4 and RC5), and from a filtration WTP that treats water withdrawn directly from the Columbia River. The collector wells are installed in suprabasalt sediments adjacent to the Columbia River (HDR, 2012) and are considered an initial proxy for water quality conditions of a similar alternative ASR supply source for Pasco. The water quality data from RC4 and RC5 are provided by Golder (2012c and 2020) and summarized for select analytes below:

- Alkalinity concentrations were variable, ranging from 1 to 257 mg/L as CaCO3
- Nitrate ranged from 0.15 to 4.3 mg/L-N

- Sulfate ranged from 20 to 42 mg/L
- Sodium ranged from 15 to 25 mg/L
- Iron ranged from <0.01 to 0.44 mg/L. There has been only one exceedance of the iron drinking water SMCL of 0.3 mg/L reported at both RC4 and RC5 over the period of record evaluated
- Arsenic generally ranged between 0.001 and 0.005 mg/L with one sample measured at the drinking water limit (0.01 mg/L) on a single occasion at RC5. Arsenic concentrations therefore have exceeded the anti-degradation criterion of 0.00005 mg/L.

4.6.4 Estimated Cost

Significant capital expenditures are anticipated to construct a riverbank filtration wellfield or collector well system and the several miles of transmission main necessary to convey the water to the northwest portion of the City where near- and long-term growth is anticipated. Five potential collector well or wellfield locations were identified, but only the closest two (Site Nos. 4 and 5) were considered feasible given their proximity to the anticipated growth areas. The capital cost for developing a collector well at one of these two sites is estimated at $4 million to $5 million, though potentially less for a wellfield depending on the size and number of wells. The capital cost of a dedicated transmission main is estimated to be $6 million or $7 million from the WPWTP Intake (Site No. 4) or Harris/Shoreline Road (Site No. 5) sites to the candidate ASR Recharge/Recovery Site No. 1 (see **Section 6.2**), or to the existing irrigation system where that system has sufficient capacity to transmit the water. The total capital cost of this option is estimated to range between $11 million and $12 million.

SECTION 5: **Conceptual ASR Storage Model**

This section presents a conceptual ASR storage model for Pasco based on the top two preferred storage aquifers and their estimated hydraulic characteristics along with observations from nearby and relevant ASR programs. The conceptual model was used to estimate aquifer storage capacity, reservoir storage radius, and region potentially affected by anticipated ASR operations based on source water availability, storage volume requirements, and conceptualized ASR wells. This conceptual model, including the ASR well concepts and designs and candidate storage areas, will need to be refined and updated as further data are gathered during subsequent work activities.

5.1 Storage Requirements

Peak-season (May through September) firm-capacity demand shortfalls of 2,245 gpm (1,498 acre-feet) and 8,548 gpm (5,704 acre-feet) are respectively predicted for the potable and irrigation systems by year 2036 (**Tables 2-1** and **2-2**), which equates to a total shortfall of 10,793 gpm (7,202 acre-feet).

Of the 3,146 acre-feet (1,025 MG) of total volume available for off-season recharge identified from the potable system (**Section 4.3.2** and **Table 5-1**), 2,831 acre-feet (922 MG) is estimated to be available for recovery and beneficial use during the peak-season, assuming a 10 percent loss factor (or 90 percent recovery) during aquifer storage (**Table 5-1**). The 10 percent loss factor is based on a range of recovery percentages for permitted systems in Washington and Oregon that use the CRBG aquifer system for ASR[20], and will need to be assessed as part of future phases of the project.

Table 5-1. Source Water Availability and Storage Volume Requirements

Offseason Recharge Month	**(1) % Water Historically Available for Recharge**	**Days Water Historically Available for Recharge**	**(2) Total Water Available for Recharge from WPWTP** (acre-feet)	**(3) Additional Source Water Needed for Recharge** (acre-feet)	***Total Source Water Needed for Recharge to Achieve 2036 Demand Shortfalls*** *(acre-feet)*
NOV	58	17	438	677	*1,115*
DEC	85	26	671	1,035	*1,706*
JAN	91	28	722	1,115	*1,837*
FEB	88	24	619	956	*1,575*
MAR	88	27	696	1,075	*1,771*
TOTAL AVAILABLE FOR RECHARGE (acre-feet)			**3,146**	**4,858**	***8,004***
(4) TOTAL AVAILABLE FOR RECOVERY (acre-feet)			**2,831**	**4,372**	***7,204***

Notes: (1) From **Table 4-2**; (2) Off-season firm capacity estimate of 5,835 gpm; (3) 9,010 gpm of additional off-season firm capacity needed; and (4) assumes 10 percent loss factor during aquifer storage, leaving only 90 percent of the volume of water recharged during the off-season available for recovery and beneficial use during the peak season.

The estimated 2,831 acre-feet (922 MG) of water available from storage is enough to meet the 2036 projected peak-season shortfall for the potable system, leaving 1,333 acre-feet (434 MG) of storage volume available to help meet the projected peak-season shortfall for the irrigation system. An additional 9,010 gpm

[20] City or water purveyor (recovery percentage) for permitted ASR systems in Washington and Oregon: City of Kennewick (92%), City of White Salmon (95%), McCarty Ranch (98%), City of Baker City (85 to 95%), McNulty Water Public Utility District (95%), and Hillsboro School District (95%). City of Walla Walla (60%) is anomalous and was not considered. The loss factor is the difference between 100 percent and the permitted recovery percentage.

(4,858 acre-feet) of off-season capacity would be needed to make up the remaining storage volume needed to achieve the total 2036 demand shortfall for both systems.

The City's remaining portion from the QCWR (**Section 4.1.3.2**) is enough to cover the additional source water needed to meet the remaining 9,010 gpm (4,858 acre-feet) shortfall for the irrigation system. Though source water available for recharge under the QCWR is interruptible, off-season source capacity from the WPWTP is the primary factor limiting the volume of water available for recharge and storage. Either additional off-season source capacity (e.g., Butterfield WTP, Columbia River Intake or an alternative source option) is needed to achieve the 4,858 acre-feet storage volume shortfall, or additional peak-season irrigation source water (e.g., U.S. Bureau of Reclamation/South Columbia Basin Irrigation District) is needed to reduce the projected 2036 irrigation deficit, or possibly some combination thereof.

5.2 Aquifer Storage Capacity Estimates

A basic estimation of the available aquifer storage capacity (acre-feet) can be calculated as follows:

$$Volume = SAh$$

where *S* is the storativity (dimensionless), *A* is the aquifer extent or area (acres), and *h* is the available head buildup in the aquifer (feet). The total available buildup is estimated to be 130 feet (GSI, 2020a), assuming that groundwater levels in the upper portion of the Saddle Mountains Basalt in the northwestern portion of the Study Area are similar to the water levels in the lower portion of the Wanapum Basalt (Drost et al., 1997). The aquifer extent (330,000 acres) was estimated as the Richland Subbasin region bounded by several faults and folds (**Figure 3-6**). Using storativity values typical of confined basalt aquifers (1×10^{-3} to 1×10^{-5}), the available aquifer storage capacity could range between approximately 430 and 43,000 acre-feet (or between approximately 140 and 14,000 MG). Using a basalt storativity of 4×10^{-4} calculated from data collected during Kennewick ASR-1 pilot testing (GSI, 2020b), the available aquifer storage capacity is estimated at 17,160 acre-feet (5,600 MG).

The storage capacity estimates assume however, that the aquifer characteristics remain the same over both time and distance, and that no flow-limiting boundary conditions significantly affect the rate of buildup during recharge. The folds and faults mapped in the area may create barriers to groundwater flow, and the extent to which these potential boundary conditions affect piezometric pressure in the basalt aquifer system during recharge will need to be evaluated as part of future work activities.

5.3 Recharge/Recovery Well Concepts

A conceptual ASR wellfield design for this phase of the feasibility study was developed to accept a maximum recharge rate of approximately 5,835 gpm (8.4 MGD), consistent with the off-season firm capacity rate available from the WPWTP. Because ASR supply water availability is interruptible during the off-season, the ASR wellfield must be designed and capable of recharging water at the maximum rate when it becomes available to meet storage volume requirements. This would require an estimated four ASR wells designed to recharge at 1,500 gpm each to achieve a combined recharge capacity of 6,000 gpm.

Results from the hydrogeologic feasibility assessment (GSI, 2020a) suggests the possibility of stacking storage in the two top preferred ASR storage aquifers at candidate ASR development sites. One ASR well pair could be located at one site and a second pair at another. Each pair would consist of one ASR well completed in the Umatilla Member of the Saddle Mountains Basalt and one in the Frenchman Springs Member of the Wanapum Basalt. The final number and configuration of wells required to achieve the approximate 6,000 gpm recharge rate will depend on site-specific aquifer characteristics determined as part of a subsurface proof-of-concept exploration program should the City decide to pursue an ASR program, and could be adjusted or expanded if dedicated ASR supply sources are developed.

Stacking ASR storage aquifers is not only cost-effective by reducing the number of ASR facilities and piping needed to connect them, but also minimizes ASR wellfield interference affects. Instead of distributing ASR wells over large areas to reduce potential interference affects from closely-spaced, mutually pumping (or recharging) wells completed in the same storage aquifer, the ASR wells can be stacked and completed in two different storage aquifers at the same site, reducing property acquisition; facility construction, operations, and maintenance; and piping and pumping costs.

The recovery pumping rate for each individual well is recommended to be greater than its recharge rate to help maintain optimal well performance. Assuming a 10 percent loss factor during aquifer storage, 2,831 acre-feet (922 MG) is estimated to be available for recovery and beneficial use during the 153-day peak-demand season. This equates to an average recovery rate of approximately 4,200 gpm (6 MGD) and individual well pumping rates of up to 2,100 gpm for two recovery wells operating simultaneously. Carousel pumping (*i.e.*, rotating production between wells) amongst the four ASR wells would be recommended to reduce idle times between when the wells are in operation.

5.4 Recharge Reservoir Radius

The radius of the recharge reservoir (*i.e.*, distance from an ASR well that source water will displace native groundwater, sometimes referred to as the bubble radius) depends on the total recharge volume and the hydraulic characteristics of the aquifer, and can be estimated as:

$$Recharge\ Reservoir\ Radius = \sqrt{\frac{43{,}560 * V}{\pi * b * \mathrm{n_e}}}$$

where, V is the volume of water recharged (acre-feet), π is 3.14159, b is the cumulative thickness of the interflow zones (feet), and n_e is the effective porosity (dimensionless). The recharge reservoir radius is inversely proportional to b and n_e, so the greater b and n_e, the smaller the radial distance source water will displace native groundwater away from the well during recharge. The storage radius assumes plug flow with no mixing or differential flow as recharge source water displaces background groundwater.

The recharge reservoir radius was developed for two scenarios (**Table 5-2**) to estimate the extent of the recharge reservoir by recharging two ASR concept wells. The first scenario (Scenario A) assumes that all four ASR wells are located in close proximity to each other, and are all completed across the same 150 feet of interflows within one basalt unit (estimated based on interflow thicknesses of the Frenchman Springs Members of the Wanapum Basalt). The storage radius for this scenario is estimated to range between 1,200 and 3,200 feet (**Table 5-2**), using effective porosities of 0.25, 0.15, and 0.03.

Table 5-2. Recharge Reservoir Radius Estimates

Scenario	Potential ASR Storage Aquifer	Recharge Storage Radius, Radial Distance (feet) from Conceptual ASR Wellfield		
		n_e = 0.25	n_e = 0.15	n_e = 0.03
Scenario A: 4-Well ASR wellfield, all wells completed in same storage aquifer	Frenchman Springs	1,200	1,400	3,200

Scenario B: 2x2 ASR wellfield, with two wells stacked in different storage aquifers at two different locations	Umatilla	1,000	1,200	2,700
	Frenchman Springs	600	700	1,600

Notes: n_e is effective porosity (LaSala and Doty, 1971; Livesay, 1986; USDOE, 1988; and Tolan et al, 2009).

Scenario B assumes that two well pairs will be stacked at two different locations, with one well at each location completed in the Umatilla Member and the other in the Frenchman Springs (**Table 5-2**). The estimated storage radius for each Umatilla ASR well ranges between 1,000 and 2,700 feet (based on an assumed interflow thickness of 50 feet). The estimated storage radius for each Frenchman Springs ASR well ranges between 600 and 1,600 feet. This indicates that even given a relatively large storage volume, the basalt aquifer will store most of the recharge water within a short distance of a proposed ASR wellfield.

5.5 Region Potentially Affected by ASR Operations

The amount and areal extent of water level buildup or drawdown in a storage aquifer depends primarily on its physical characteristics. In aquifers with high transmissivity and low storativity, groundwater level changes in response to ASR recharge or recovery spread rapidly over large areas. The Saddle Mountains and Wanapum Basalts are laterally extensive in the Pasco Basin except where faults and folds may have compartmentalized the basalt aquifer, and even if compartmentalized, the aquifer may be able to transmit a significant amount of water.

Because the aquifer's hydraulic response to ASR activities will propagate much further than the actual movement of ASR supply water during recharge, the region potentially affected by ASR operations was estimated by predicting changes in groundwater level (s, in feet) at a distance from the ASR well (or wellfield) (*r*, in feet) using the modified non-equilibrium equation for confined aquifers (Cooper and Jacob, 1946) and aquifer parameters estimated from available literature and the observations from the Kennewick ASR-1 program:

$$s = \frac{2.303Q}{4\pi T}\log\frac{2.25Tt}{r^2S}$$

where, *Q* is the pumping rate (feet^3/day), *T* is aquifer transmissivity (feet^2/day), *t* is pumping time (days), and *S* is storativity (dimensionless). For this analysis, both the anticipated rate and duration for ASR recharge[21] and recovery pumping[22] were estimated to evaluate the aquifer's hydraulic response to anticipated ASR activities, for both a 4-well wellfield and for two sets of stacked ASR well pairs (2x2 wellfield). A range in transmissivity of 6,700 to 67,000 feet^2/day was used to account for the variability in published values for the Wanapum Basalt members in the vicinity of the Study Area[23]. A transmissivity value of 3,700 feet^2/day was assigned to the Umatilla Member based on information from the Welch's well (Tolan, 2020; see Attachment A in GSI, 2020a).

[21] Average of 4,800 gpm (924,000 feet^3/day) recharge for 151 days to meet the 3,146 acre-feet (1,025 MG) storage volume requirement.
[22] Pumping rate of 4,200 gpm (808,500 feet^3/day) for 153 days split between two wells to recover 90 percent of the volume of water recharged. Recovery pumping rates are recommended to be greater than recharge rates to maintain optimal well performance.
[23] Transmissivity values are based on existing wells within the Pasco Basin, including the Kennewick ASR-1 well, Kennewick's Willowbrook well, and packer tests completed at the Hanford Site (GSI, 2020b, Golder, 2001, Tolan, 2009, Guzowski et. al., 1984, and Strait and Mercer, 1987).

The anticipated influence due to both recharge and recovery pumping activities for the 4-well wellfield or 2x2-wellfield is summarized in **Table 5-3**. These estimates were calculated for both ASR well concepts to evaluate the ability to reduce the hydraulic pressure response within the aquifer(s) by stacking ASR wells. Due to the recovery rates necessary to provide water over the demand season, Scenario A assumes that only two wells will pump simultaneously (for a combined rate of approximately 4,200 gpm) from the Frenchman Springs. Scenario B assumes that one of the stacked wells will pump from the Umatilla storage aquifer and the other from the Frenchman Springs.

The predicted hydraulic response during anticipated ASR operations for a 4-well wellfield completed in the Frenchman Springs (Scenario A in **Table 5-3**) is estimated to range between 51 and 58 feet at a radial distance of 1 mile from the wellfield and between 6 and 7 feet at a distance of 2 miles. The predicted hydraulic response is reduced if the ASR storage aquifers are stacked. The predicted hydraulic response during anticipated ASR operations for two wells completed in the Umatilla Member (Scenario B in **Table 5-3**) is estimated to range between 41 and 47 feet at a radial distance of 1 mile and between 29 and 33 feet at a distance of 2 miles. The predicted response for two wells completed in the Frenchman Springs (Scenario B in **Table 5-3**) is estimated to range between 26 and 29 feet at a radial distance of 1 mile and approximately 3 feet at a distance of 2 miles. The magnitude and areal extent of water level buildup during injection or drawdown during pumping in a storage aquifer for each scenario is expected to increase if a flow-limiting hydraulic boundary condition (*e.g.*, impermeable rock) is encountered during ASR activities and decrease if a recharge boundary (*e.g.*, river or canal) is encountered. Intercepting a recharge boundary during ASR activities is not anticipated due to the deep and confined nature of the potential ASR storage aquifers.

Table 5-3. Summary of Hydraulic Influence from ASR Operations

Well Siting Options	Potential ASR Storage Aquifer	ASR Operation	Distance from ASR wells (miles)	Estimated Influence (feet)
Scenario A: 4-Well ASR wellfield completed in same storage aquifer; 4 wells operating during recharge and two during pumping	Frenchman Springs	Recharge	1 - 2	7 - 58
		Recovery	1 - 2	6 - 51
Scenario B: 2x2 ASR wellfield, with stacked ASR well pairs completed at two locations; all wells operating during recharge and one pair during pumping	Umatilla	Recharge	1 - 2	33 - 47
		Recovery	1 - 2	29 - 41
	Frenchman Springs	Recharge	1 - 2	3 - 29
		Recovery	1 - 2	3 - 26

Notes: Influence calculated using assumed transmissivity values of 3,700 feet^2/day for the Umatilla Member and a range of 6,700 to 67,000 feet^2/day for the Wanapum Basalt; storativity of 4.0 x 10^{-4}; injection duration of 151 days; recovery duration of 153 days.

The majority of the groundwater users in the Pasco Basin utilize groundwater from the suprabasalt sediment aquifer. Few wells in the Study Area are completed in the CRBG aquifer system and none appear completed below the Pomona Member of the Saddle Mountains Basalt (GSI, 2020a). As a result, recharge- or pumping-related influences on existing basalt groundwater users from ASR wells completed in the Umatilla or Frenchman Springs Members are anticipated to be minimal to absent. Two deep (~1,050 feet) basalt wells drilled circa 1943 for the old naval air station near the Tri-Cities Airport (Tolan, 2020; see Attachment A in GSI, 2020a) may be completed in the upper portion of the Wanapum Basalt. No construction diagrams however, were discovered for these wells and their current status is unknown. As documented by the Kennewick ASR-1 program (GSI, 2015b; Golder, 2012a), the CRBG aquifers in the Study Area are confined by low-permeability Ellensburg Formations and/or dense basalt flow interiors, and no hydraulic response to ASR operations were observed in CRBG aquifer units overlying the storage zone.

SECTION 6: **Candidate ASR Development Sites**

This section recommends candidate ASR development sites within the Study Area based on future anticipated growth areas and the preferred hydrogeologic settings for ASR within Pasco (**Section 3**). The preferred locations within the Study Area where ASR could help address future demand growth for the potable and irrigation systems have been identified as ASR Recharge/Recovery Areas A through D on **Figure 6-1** (RH2, 2021). Findings through the course of this study suggest that the hydrogeologic conditions beneath Areas A through C are most favorable, with no apparent advantages or disadvantages across the three areas (GSI, 2020a).

Three potential ASR recharge/recovery sites were identified (Site Nos. 1 through 3 shown on **Figure 6-2**), one in each of the three preferred ASR Recharge/Recovery Areas A–C (RH2, 2021):

- Candidate ASR Recharge/Recovery Site Nos. 1 and 2
- Candidate ASR Recharge/Recovery Site Nos. 2 and 3
- Candidate ASR Recharge/Recovery Site Nos. 1 and 3

This feasibility study assumes that an ASR facility will be constructed at two of these three locations, each having two ASR wells: one completed in the Umatilla Member and one in the Frenchman Springs. No ASR recharge/recovery sites are proposed within ASR Recharge/Recovery Area D.

Conceptual ASR well designs for the preferred candidate ASR recharge/recovery sites are presented and discussed in **Section 6.1.** The planning-level improvements to supply water to, convey water from, and store water at the preferred sites are shown on **Figure 6-2** and summarized in **Section 6.2.** Planning-level cost estimates associated with the capital improvement needs are provided in **Section 6.3**. Potential acquisition of each of the three candidate sites are discussed in **Section 6.4**. Capital improvement needs for all candidate ASR development sites shown on **Figure 6-2** are detailed further by RH2 (2021).

6.1 ASR Well Prognosis

Conceptual well designs were developed for two prototype ASR wells: one targeting completion in the Umatilla Member of the Saddle Mountains basalt and the other within the Frenchman Springs Member of the Wanapum basalt. The conceptual design for each well was developed using the general hydrogeologic conditions identified during this desktop feasibility study in the area of potential ASR development sites and an assumed pump size capable of producing 2,000 gpm. Both designs are for combination recharge and pumping wells, each used to recharge and store water during the off-season when surplus water is available and to pump and recover the stored water when needed. The resulting conceptual design for each basalt ASR well is shown on **Figure 6-3**, and includes the key design elements/assumptions listed in **Table 6-1**.

6.2 Capital Improvement Needs

It is assumed that two ASR locations will be paired with the ASR supply source to utilize a larger spatial area of the aquifers for storage and to provide redundancy within the system in case of unexpected or expected interruptions. It is assumed that a single wellhouse will be constructed at each site with each wellhouse containing two ASR wells: one well completed in the Umatilla Member and the other completed in the Frenchman Springs. Each well is assumed capable of recharging at 1,500 gpm and pumping at 2,000 gpm.

The water main segments shown on **Figure 6-2** are proposed to connect the existing irrigation and potable systems with the candidate ASR recharge/recovery sites. These segments are approximately consistent with future potable Zone 3 transmission main identified in the West Pasco WTP Expansion Proposed

Improvements and Design Criteria Technical Memorandum (RH2, 2020) that are necessary for future transmission between the WPWTP and the Zone 3 distribution system, as well as a future Zone 3 tank site along Road 68 approximately between Powerline Road and Kau Trail. As such, the water main Segments A through D shown on **Figure 6-2** are long-term transmission main projects for the City, and the construction of these water main segments for ASR recharge/recovery purposes is anticipated to serve multiple purposes for the City's water system.

Table 6-1. Conceptual Design Elements for Saddle Mountains and Wanapum Basalt ASR Wells

	Descriptions	
Conceptual Design Element	**Umatilla Member, Saddle Mountains Basalt**	**Frenchman Springs Member, Wanapum Basalt**
Static water level (est.)	130 feet bgs	130 feet bgs
Well depth (1)	1,000 feet bgs	1,750 feet bgs
Surface casing	20-inch nominal diameter, low-carbon steel casing with 0.375-inch wall thickness to 30 feet bgs	20-inch nominal diameter, low-carbon steel casing with 0.375-inch wall thickness to 30 feet bgs
Surface seal	2-inch annular surface cement grout seal consisting of type I, II or III Portland cement from 0 to 30 feet bgs	2-inch annular surface cement grout seal consisting of type I, II or III Portland cement from 0 to 30 feet bgs
Intermediate production casing (1)	16-inch nominal diameter, low-carbon steel casing with 0.375-inch wall thickness, from surface to 700 feet bgs	16-inch nominal diameter, low-carbon steel casing with 0.375-inch wall thickness, from surface to roughly 1,350 feet bgs
Intermediate seal (1)	1½-inch annular intermediate cement grout seal consisting of type I, II or III Portland cement from 0 to 700 feet bgs	1½-inch annular intermediate cement grout seal consisting of type I, II or III Portland cement from 0 to roughly 1,350 feet bgs
Open borehole	15-inch nominal diameter open borehole extending from base of intermediate casing/seal to total well depth	
Liner casing	12-inch nominal diameter, low-carbon steel casing with 0.375-inch wall thickness	
Liner screen	12-inch pipe-size diameter, stainless steel, continuous wire-wrap screen with 0.100-inch slot size, strength-rated to depth of 2,000 feet	

Notes: (1) The confidence level associated with the contacts and thicknesses of the CRBG units in the Study Area generally decreases with depth within the lower Saddle Mountains and Wanapum members because few wells in the Study Area have been drilled deep enough to penetrate these stratigraphic units. Consequently, the estimated well depths and depths for the intermediate production casings and seals could vary significantly in one direction or another. Exploratory drilling and testing (see Section 7.2.2.1) is recommended to address data gaps associated with basalt stratigraphy, actual unit thicknesses, and presence and actual thickness of interflow zones beneath the candidate ASR development sites.

The capital improvements recommended if candidate ASR development Site Nos. 1 and 2 are selected are shown on **Figure 6-2** and summarized below:

- Potable Water Main Segments A, B, and C
- Irrigation Water Main Segment E
- Two wells drilled and developed in the Umatilla Member of the Saddle Mountains Basalt
- Two wells drilled and developed in the Frenchman Springs Member of the Wanapum Basalt
- One ASR facility at each of the candidate ASR development sites (Nos. 1 and 2)

Water main segments A, B, C, and E (**Figure 6-2**) are necessary to be completed to connect the existing potable and irrigation systems with the candidate ASR development Site Nos. 1 and 2. It is recommended that Site No. 1 be designed for recharge from both the City's irrigation system and the City's potable water system, and Site No. 2 designed for recharge from only the City's potable water system. The use of the City's USBR/Harris Road BPS in the off season will provide approximately 1,750 gpm, with consideration for a 5 feet per second velocity limitation, which is viable to approximately recharge one ASR well and is recommended to be the City's dedicated ASR irrigation well. With two ASR wells proposed to be constructed at each site, and the treatment requirements associated with using irrigation supply as ASR recharge (as described in **Section 4.5**), it is unlikely that irrigation supply will be available to be conveyed beyond Site No. 1. Consequently, no additional dedicated irrigation transmission to Site No. 2 is recommended.

6.3 Planning-Level Cost Estimates

Planning-level, order-of-magnitude costs for the improvements recommended in **Section 6.2** are provided in **Table 6-2**. Treatment-related improvements and costs are based on irrigation supply being treated for recharge and recovered without treatment at one ASR well, and potable supply being treated for both recharge and recovery at three ASR wells. Capital improvement requirements for the other two combinations of ASR recharge/recovery sites (*i.e.*, Site Nos. 2 and 3 and Site Nos. 1 and 3) are identified by RH2 (2021). Capital improvements and related costs associated with these combinations are also shown on **Figure 6-2** and summarized in **Table 6-2**.

Table 6-2. ASR Transmission Main Planning-Level Cost Estimates

				Candidate ASR Development Sites[1]		
Improvement	**Description**	**Quantity**	**Unit Cost**	**Site Nos. 1 and 2**	**Site Nos. 2 and 3**	**Site Nos. 1 and 3**
Water Main Segments						
Segment A (Potable)[2]	30-inch	2,600 LF	$700/LF	$0	$0	$0
Segment A (Potable)[2]	24-inch	7,700 LF	$575/LF	$0	$0	$0
Segment B (Potable)	24-inch	4,500 LF	$575/LF	$2,587,500	$2,587,500	$2,587,500
Segment C (Potable)	24-inch	9,300 LF	$575/LF	$5,347,500	$5,347,500	$5,347,500
Segment D (Potable)	24-inch	9,500 LF	$575/LF	---	$5,462,500	$5,462,500
Segment E (Irrigation)	12-inch	4,500 LF	$350/LF	$1,575,000	$1,575,000	$1,575,000
Segment F (Irrigation)	12-inch	7,800 LF	$350/LF	---	$2,730,000	---
			Water Main Totals	***$9,510,000***	***$17,702,500***	***$14,972,500***
ASR Wells						
Umatilla Drilling and Developing	950 feet bgs	2	$1,200/foot	$2,280,000	$2,280,000	$2,280,000
Frenchman Springs Drilling and Developing	1,750 feet bgs	2	$1,200/foot	$4,200,000	$4,200,000	$4,200,000
Equip ASR Wells (Pump, Motor, Column Pipe)	2,000 gpm	4	$400,000 per well	$1,600,000	$1,600,000	$1,600,000
ASR Facility Mechanical, Structural, Treatment, Electrical Controls, Site Work	50-ft x 50-ft facility	2	$2,000,000 per site	$4,000,000	$4,000,000	$4,000,000
			ASR Well Totals	***$12,080,000***	***$12,080,000***	***$12,080,000***
Irrigation Recharge Treatment						
Irrigation Recharge Treatment	Expanded ASR facility at one location	1	$3,000,000	$3,000,000	$3,000,000	$3,000,000
			COMBINED TOTALS	**$24,590,000**	**$32,782,500**	**$30,052,500**

Notes: Adapted from RH2 (2021). (1) Shown as ASR Recharge/Recovery Sites on **Figure 6-1**; (2) The 24- and 30-inch proposed water main comprising Segment A is required to be constructed as part of the City's capacity upgrades at the West Pasco WTP, and is therefore not shown as an additive cost specific to future ASR wells. Segments B, C, and D are also planned as long-term transmission projects by the City within Zone 3, but are included in this table. Additional information on the capital improvements are provided by RH2 (2021).

6.4 Site Acquisition

Each of the two ASR facilities is anticipated to require approximately a one-acre site for the wellhouse, miscellaneous site improvements, and a 100-foot sanitary control radius for each ASR well. Property acquisition is not anticipated to be onerous within any of the candidate ASR development site options.

The vicinity of candidate ASR Site No. 1 includes agricultural and undeveloped acreage, with platting of portions of this land beginning in 2020, and development in this location anticipated to begin as early as 2021. Opportunities for the City to purchase the land necessary for an ASR facility in the vicinity of candidate site No. 1 are likely available in 2021 and should remain available for a number of years.

The vicinity of candidate ASR development Site No. 2 includes agricultural and undeveloped acreage, as well as a number of single-family homes on ½- and 1-acre lots. The City is believed to be evaluating site acquisition in this vicinity for a future Zone 3 tank site in the coming years, and it is anticipated that an ASR facility can be located at the same site as the future tank. Opportunities for the City to purchase the land are likely available in 2021 and should remain available for a number of years.

The vicinity of candidate ASR development Site No. 3 includes agricultural acreage. Developers representing these property owners have been in contact with the City regarding utility service for future development of this land. This site is currently outside of the City's urban growth boundary, but is anticipated to be within the City's future urban growth boundary as shown in the City's draft Comprehensive Plan update, which is anticipated to be adopted and approved in 2021. As such, development is expected within the vicinity of this candidate site within the next 10 years, and opportunities for the City to purchase the land necessary for an ASR facility in this location likely will be available as early as 2022 or 2023.

6.5 Recommendations

If each of three candidate ASR recharge/recovery sites remain viable from a hydrogeologic perspective, candidate ASR Site Nos. 1 and 2 are recommended for implementation, with one ASR well identified as the City's irrigation ASR well, and three ASR wells reserved for potable water. The purpose of designating one of the ASR wells as an irrigation ASR well, in addition to offsetting the irrigation system supply deficit, is partially based upon eliminating the need for treating all of the water recovered from storage and partially based upon still being able to use the recovered water if the ASR water quality is less desirable as drinking water due to secondary contaminants or aesthetic concerns (*e.g.*, taste, odor, temperature).

Benefits of Site Nos. 1 and 2 compared to the other configurations include the following:

- Least cost configuration, as shown in **Table 6-2**
- Proximity of sites to future City growth areas
- The ASR facility at Site No. 2 can share a site with the City's future Zone 3 tank along Road 68

The recommendations are based on the firm capacity surplus of the City's WPWTP during the off-season for ASR recharge at three ASR wells at a rate of approximately 1,500 gpm (2.2 MGD) per well. The fourth ASR well can be recharged with the City's irrigation USBR/Harris Road BPS to recharge a dedicated irrigation ASR well at approximately 1,500 gpm (2.2 MGD). If a dedicated irrigation ASR well is not desired by the City, the City would have capacity in year 2036 to recharge four potable water ASR wells based on the future maximum capacity (18 MGD) of the WPWTP in the off season. Relying on the WPWTP to operate at its future maximum capacity (18 MGD) for extended periods or year-round is not recommended due to the lack of redundancy and stress that this operating condition would place on the facility's infrastructure; therefore, three potable water ASR wells and one irrigation water ASR well are recommended. The Columbia River Intake is recommended to be used for the irrigation portion of the ASR supplies to avoid operating the WPWTP at maximum capacity for both reliability and redundancy purposes. Filtration and disinfection of ASR supply water sourced from the Columbia River Intake would be required at one of the two ASR facilities pre-recharge.

Other ASR configurations and treatment options could be considered if an alternative source is developed and dedicated for ASR supply.

SECTION 7: **Data Gaps and Future Work Considerations**

Data gaps may require additional research, further investigation, and/or monitoring to better address related uncertainties for future phases of the project. This section identifies data gaps and recommends future work needed to address the identified data gaps.

7.1 Data Gap Summary

This section presents a summary of data gaps identified by the consultant team as part of this Task 2 – Hydrogeologic Feasibility Assessment (GSI, 2020) and Task 3 – Source Option Analysis (RH2, 2021) work. The data gaps pertain to geologic and hydrogeologic data, water quality, treatment needs, and cost estimates for expanding existing source capacity compared to costs associated with developing dedicated ASR supply source option alternatives. The data gaps are identified and described below, and have been deemed as having significant effects on future work that might take place following completion of this phase of the ASR feasibility study.

7.1.1 Geologic and Hydrogeologic Information

The primary geologic and hydrogeologic data gaps consist of geologic characterization data, site-specific aquifer hydraulic characteristics, and groundwater levels. Limited data are available to characterize the depth, thickness, and characteristics of the basalt aquifer units in the Study Area and near candidate ASR development sites, including whether faults, folds, and other structural features function as barriers to groundwater flow and compartmentalize the potential CRBG storage aquifers. Less than 10 percent of the wells identified within the Study Area are basalt wells, most of which appear to penetrate only the upper portion of the Saddle Mountains Basalt. Consequently, the number, thickness, and hydraulic characteristics of the water-bearing interflow zones; presence and thickness of sedimentary interbed units; and productivity of the interflow zones are not well known at or in the vicinity of the candidate ASR development sites.

The degree of hydraulic connectedness between groundwater in the suprabasalt sediments and the river is not known at the potential alternative ASR supply locations. Further analyses and water right application process would be needed should the City decide to develop an alternative ASR supply source at one of these sites to understand whether pumping impacts can be regulated the same as a direct surface water diversion and demonstrate that there will be no impairment of the provisioned minimum instream flows due to its operation. This approach would require application to Ecology for a change in point of withdrawal.

7.1.2 Water Quality

Some of the source water and groundwater quality datasets evaluated are more than a decade old and therefore may not be representative of current water quality conditions. The available datasets did not include comprehensive analyses of untreated water from the City Columbia River Intake (irrigation supply) or untreated and treated Columbia River from Pasco's WTPs. Both surface water and groundwater, particularly shallow groundwater in the suprabasalt sediments depending on the degree of hydraulic connection with the river, may exhibit seasonal variation in water quality. The available datasets were insufficient to evaluate temporal trends in water quality.

There are insufficient water quality data to fully characterize groundwater in the suprabasalt sediments. The groundwater quality data available for the City's former shallow supply wells were limited to regulated constituents. Similarly, water quality data for the City's irrigation wells are limited to nitrate and a few DBP samples from an uncertain source.

There are no current or site-specific native groundwater quality data available for the two potential ASR storage aquifers in the preferred ASR development areas. Available native groundwater quality in the area can be variable with respect to water type and geochemical conditions, but is likely within the regional range reported by Steinkampf (1989), Steinkampf and Hearn (1996), and USDOE (1988) for most overlapping constituents monitored. It is currently assumed that the native groundwater quality in the Saddle Mountain and Wanapum Basalt units in the Pasco area will be similar to the groundwater quality in the Kennewick area.

7.1.3 Geocompatibility

Geocompatibility between the waters was not assessed as part of this phase of the feasibility study. A geochemical evaluation as part of a subsequent phase is recommended to assess that source water for ASR supply and native groundwater in the potential ASR storage aquifers are compatible and that precipitation or adverse reactions are unlikely to take place. Analyzing rock cuttings obtained from exploratory drilling also is recommended to characterize geochemistry of the aquifer solids, and to evaluate the potential for adverse rock-water geochemical reactions to take place during ASR operations and how these may affect groundwater quality or the quality of water recovered from storage.

7.1.4 ASR Supply Capacity Expansion Costs

Cost estimates for expanding capacity at the West Pasco Intake beyond what the City is currently planning to increase off-season water available for ASR supply compared to constructing dedicated collector or riverbank filtration wells were not developed as part of this phase of the feasibility study. The current WPWTP facility footprint and transmission piping are factors limiting expansion of the facility beyond its planned 12-18 MGD capacity expansion range. Significant upgrades to the treatment plant, pumping system, and transmission piping would be needed to expand its capacity beyond 18 MGD.

7.2 Future Work Considerations

The following future work considerations are recommended to address the data gaps identified in the preceding section and to provide data that are needed for subsequent project tasks. The critical data gaps and the actions to fill them are outlined in a phased approach below.

7.2.1 Phase II ASR Feasibility Assessment

In order to better understand ASR feasibility and to guide work for potential future phases, the next phase of the feasibility assessment should consider completing the following next steps.

7.2.1.1 Key Well Reconnaissance Surveys

Conduct investigations of the Welch's well (Umatilla well) and old naval air station wells (Wanapum wells) to determine their current status, well construction, existing conditions, and availability for video surveying, groundwater level monitoring, pump testing, geophysical logging (e.g., gamma, caliper, water quality profiling, heat pulse, and acoustic televiewer), and water quality sampling. Information obtained could potentially be used as a first, low-cost approach to fill some hydrogeologic and water quality data gaps for the two potential ASR storage aquifers. Findings from the investigation however, may not eliminate the need for an exploratory drilling and testing program (Phase III, see **Section 7.3.1**) because of the wells' distances from the preferred ASR development areas and potential lateral variability in aquifer characteristics.

Conduct a survey of suprabasalt sediment wells that may be completed along the riverbank. This would include a review of well logs and existing/available data and published literature prior to conducting any site-specific field investigations. Available information could be used to better understand (1) the hydrogeologic and water quality conditions at potential alternative/dedicated ASR supply source option sites, and (2) model/predict whether pumping impacts can likely be regulated the same as a direct surface water diversion.

7.2.1.2 Water Quality Characterization and Geocompatibility Assessment

Collect water quality samples from the West Pasco WTP, Columbia River Intake, and a suprabasalt well near one of the candidate alternative source locations (Location Nos. 4 and 5; see **Section 4.6.1** and **Figure 4-3**) for comprehensive analyses. Water quality samples could be collected at times during the anticipated recharge season (November through March) to characterize water quality conditions and evaluate for potential temporal trends in water quality of the potential source water options.

Results from the analyses could be compared against water quality (and mineralogical and whole-rock composition data of the aquifer solids) from the City of Kennewick ASR-1 feasibility study (and information obtained from the Welch's and/or old naval station wells) to complete a preliminary geocompatibility assessment. The geocompatibility assessment would evaluate the effect of potential geochemical reactions resulting from interactions between source water, receiving groundwater, and aquifer solids on well performance and on the quality of the native groundwater and source water recovered from storage.

The recommended analytical suite for source and receiving groundwater characterization would be determined following additional project evaluations. At minimum, the samples should be analyzed for major ions, pH, reduction-oxidation potential (redox), dissolved oxygen, trace metals (total and dissolved), nutrients, TOC, TSS, TDS, and possibly redox-dependent species. Selection of analytical methods to achieve analytical reporting limits below all applicable standards, in particular groundwater anti-degradation standards, should be considered during the planning stages of an analytical program, and include at minimum the *Recommended Analyte List for Aquifer Storage and Recovery Testing* (Ecology, 2017).

7.2.1.3 Stand-Alone Systems Evaluation:

In addition to the water rights held by the City for their potable and irrigation water systems, the City also has water rights for stand-alone systems, such as individual park irrigation and supplemental irrigation water for disposal of effluent at the Pasco Process Water Reuse Facility. These rights could potentially serve one or more of several needs: (1) offset the peak-season shortfall remaining for the irrigation system, (2) reduce the need for additional source water for ASR supply, (3) serve as an alternative supply source for ASR, or (4) reduce the need for municipal and industrial (M&I) water from USBR/SCBID.

ASR generally involves injecting and storing treated drinking water into an aquifer system for later recovery and municipal use. Alternative applications however, are rapidly expanding beyond municipal uses, including for non-potable uses (*e.g.*, industrial and irrigation) and environmental benefits (*e.g.*, groundwater replenishment), and as alternative source options, such as reclaimed water and stormwater. The City produces 2,000 acre-feet (650 MG) of treated industrial process water annually that could potentially be reclaimed for use as source water for aquifer recharge or to offset the unmet irrigation demand. The reclaimed water rule (Chapter 173-219 WAC) describes specific allowable beneficial uses of reclaimed water, and the required level of treatment for each use. A reclaimed water ASR project would be authorized by the rule, though additional work would be needed to understand the feasibility of using the City's treated industrial water for direct groundwater recharge and recovery. Among other required elements, the feasibility assessment would require (1) a preliminary water right impairment analysis, (2) hydrogeologic evaluation meeting the requirements established in the *Criteria for Sewage Works Design*, Section E3-4 Groundwater Quality Standards Checklist (Ecology Publication No. 98-37), and (3) a water quality evaluation.

7.2.1.4 Cost Comparison of Source Capacity Expansion Options

Because of the costs and uncertainties associated with drilling and constructing new collector or riverbank filtration wells, demonstrating their hydraulic connection with the Columbia River, adding them as new points of withdrawal to the Quad City water right permit, and constructing new transmission piping, it may be more cost effective to expand capacity at the WPWTP. Additional work is recommended to assess and compare costs, particularly for expanding capacity at the WPWTP. Costs opinions for facility and transmission piping design and construction, treatment, and operations and maintenance associated with expanding capacity at the WPWTP should be developed and compared against costs for developing dedicated ASR supply source alternatives to better assess options for increasing off-season source capacity for ASR supply.

7.2.2 Phase III ASR Feasibility Assessment

Given the general lack of specific hydrogeologic and groundwater quality data on the potential ASR storage aquifers (**Section 3.3.2**) or alternative ASR supply source (**Section 4.6**), drilling and testing programs would be needed to further assess ASR feasibility. The primary purpose of drilling and testing would be to fill site-specific data gaps regarding the geologic conditions, aquifer hydraulic characteristics, groundwater levels, groundwater quality, and geochemical characteristics of (1) the potential storage aquifers in the preferred ASR development areas or (2) a potential riverbank filtration source (**Section 4.6**) at candidate locations should an alternative ASR supply source be considered for further evaluation.

7.2.2.1 Exploratory Drilling and Testing – Candidate ASR Development Sites

A drilling and testing program is recommended to assess the feasibility of developing potential ASR storage aquifers in the preferred ASR development areas:

- Drilling and testing a small-diameter (8- to 10-inch) exploratory borehole to address a few key data gaps (*e.g.*, groundwater level, basalt stratigraphy and unit thicknesses, presence and thickness of interflow zones, mineralogy and whole-rock composition of target interflow zones, and groundwater quality).
- Conducting borehole geophysical logging (e.g., caliper log, gamma log, video log, acoustic televiewer log, water quality profile log, and heat pulse meter) to identify clay-bearing zones that could potentially impact recovered water quality and to aid in the determination of basalt stratigraphy, water quality, location and thickness of interflow zones, zones of relatively higher flows, and pre-design of full-size ASR well(s).
- Completing step- and constant-rate pumping tests to determine well performance, aquifer productivity, and aquifer hydraulic characteristics in the vicinity of the ASR test well. Conducting a step-injection test is recommended also to characterize the water level response in the ASR test well under recharging conditions. An 8- to 10-inch diameter borehole would only allow pumping up to an estimated 300-700 gpm depending on lift. ASR feasibility however, is best confirmed from a full-size ASR well designed for its purpose.
- Completing interval step- and constant-rate tests to assess the hydraulic and groundwater quality characteristics of multiple potential storage zones within the Saddle Mountains and Wanapum aquifer units. This would provide information to assess the potential for stacking ASR storage zones. Stacking the storage zones at a single ASR development site can save site acquisition and facility costs and construction and operation costs for a larger piping network.
- Complete the exploratory boreholes as observation wells for future groundwater level and/or groundwater quality monitoring.

- Collecting and analyzing samples from groundwater produced during the pumping tests to characterize baseline groundwater quality conditions of the target storage zone(s).
- Analyzing drill cuttings obtained from the exploratory well to identify basalt stratigraphy, characterize geochemistry of the aquifer solids, and evaluate the potential for water-water and rock-water interactions. These data can then be used for predictive geochemical modeling (*e.g.*, PHREEQC) to evaluate the potential for geochemical reactions in target storage zones during ASR operations and how they may affect groundwater quality or the quality of water recovered from storage.

The conceptual ASR storage model, ASR well prognosis, and preliminary geocompatibility assessment results would be reassessed based on results from the drilling and testing program.

7.2.2.2 Exploratory Drilling and Testing – Alternative/Dedicated ASR Supply Source

A drilling and testing program is recommended to assess the feasibility of developing a riverbank filtration wellfield or collector well system if the project pursues development of an alternative/dedicated ASR supply source in hydraulic connection with the Columbia River:

- Drill and test a new or existing well completed in the suprabasalt aquifer system at one or two preferred alternative ASR supply locations along the Columbia River.
- Conduct step- and constant-rate pumping tests to estimate production capacities, aquifer hydraulics, and collect groundwater quality samples.
- Characterize timing and lag of impact to Columbia River from groundwater-level and river stage monitoring, and/or from pumping of a new or existing well.
- Conduct comprehensive analysis of water quality parameters for geochemical modeling and to characterize water quality conditions and spatial and temporal trends in groundwater quality. Results could be used to inform a decision on the feasibility and location of an alternative ASR supply source.
- File and have processed a water right change application on the Quad Cities water right requesting to add one or multiple riverbank filtration wells or collector well locations as points of withdrawal should results of the drilling and testing program be favorable.

7.2.3 Future Task – AKART Analysis

After source water and receiving groundwater quality have been adequately characterized and geocompatibility evaluated, the next step would be to conduct an AKART (all known, available, and reasonable methods of prevention, control, and treatment) analysis.

The anti-degradation policy (Chapter 173-200-030 WAC) requires that existing and future beneficial uses be maintained and protected, and degradation shall not be allowed of high quality groundwaters. In evaluating the best approach to reduce or eliminate constituents that might violate the anti-degradation policy, an AKART analysis of the best methods and cost will be required. For each pollutant, or similar groups of potential pollutants such as disinfection byproducts (DBPs) or arsenic, the reservoir permit applicant must evaluate available treatment technologies, the degree of pollutant reduction provided by each treatment, and the capital and operating expenses of each treatment technology.

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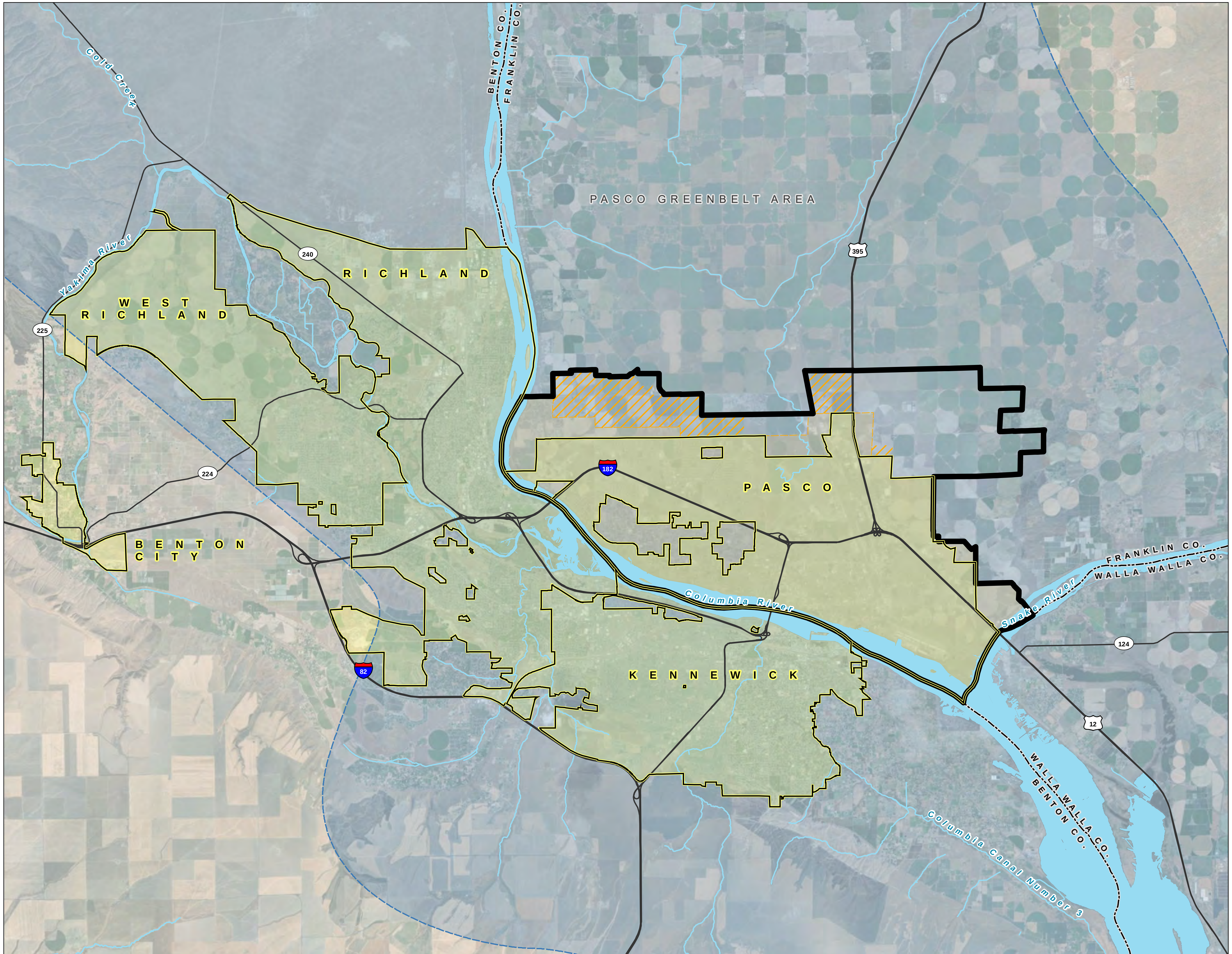
Figures

FIGURE 1-1

Overview Map

Aquifer Storage and
Recovery Feasibility Study
City of Pasco, Washington



LEGEND

- Study Area
- Pasco Basin
- City Boundary
- Urban Growth Boundary (UGB)
- Expanded 20-Year UGB
- Major Road
- Watercourse
- Waterbody

N

0 6,000 12,000 18,000
Feet

Date: April 28, 2021
Data Sources:

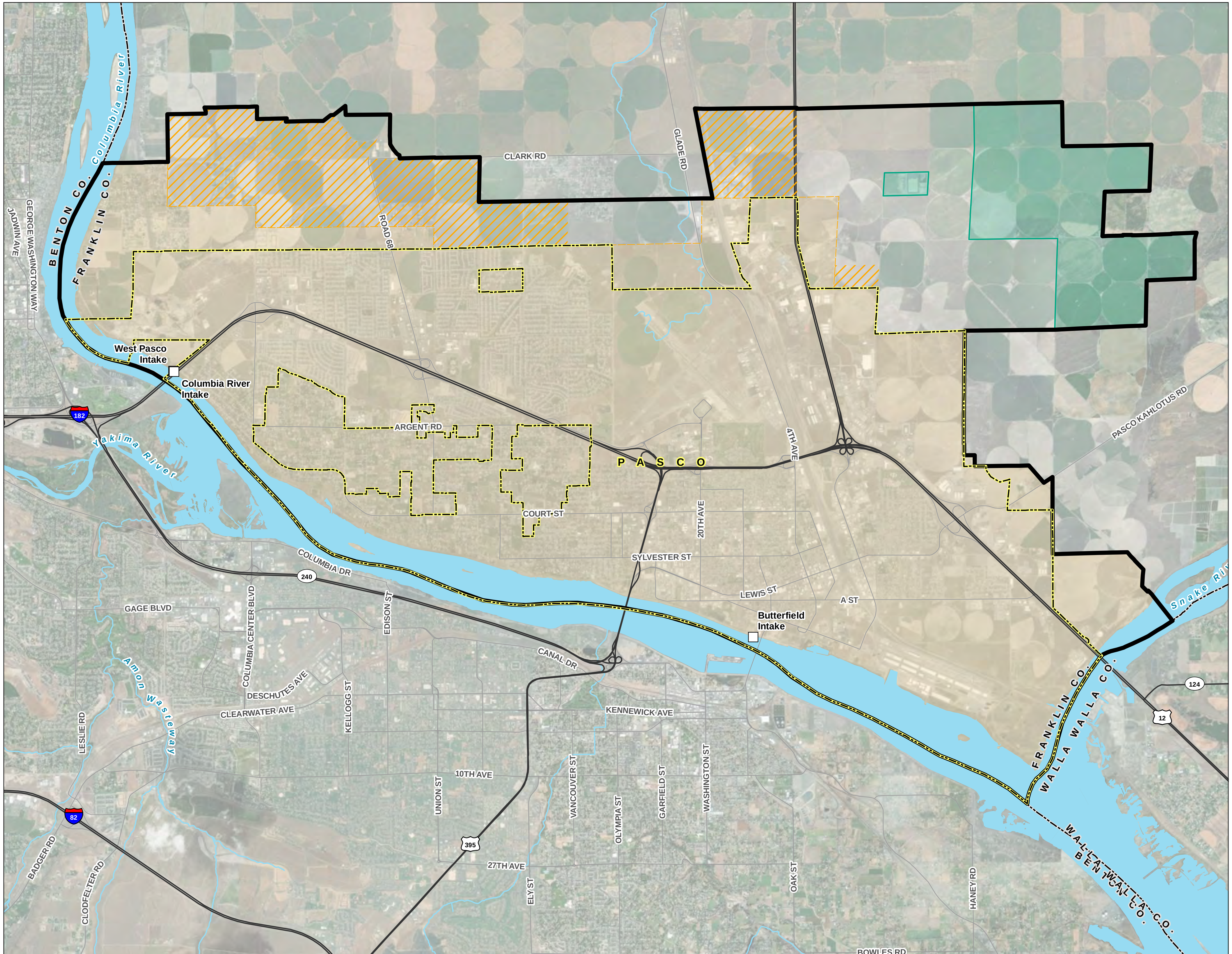


FIGURE 1-2

Study Area

Aquifer Storage and Recovery Feasibility Study

City of Pasco, Washington

LEGEND

- Intake
- Study Area
- City of Pasco
- Urban Growth Boundary (UGB)
- Expanded 20-Year UGB
- City Process Water Reuse Facility and Farm Circles
- Major Road
- Watercourse
- Waterbody

N

0 3,000 6,000 9,000

Feet

Date: April 28, 2021

Data Sources:

GSI Water Solutions, Inc.

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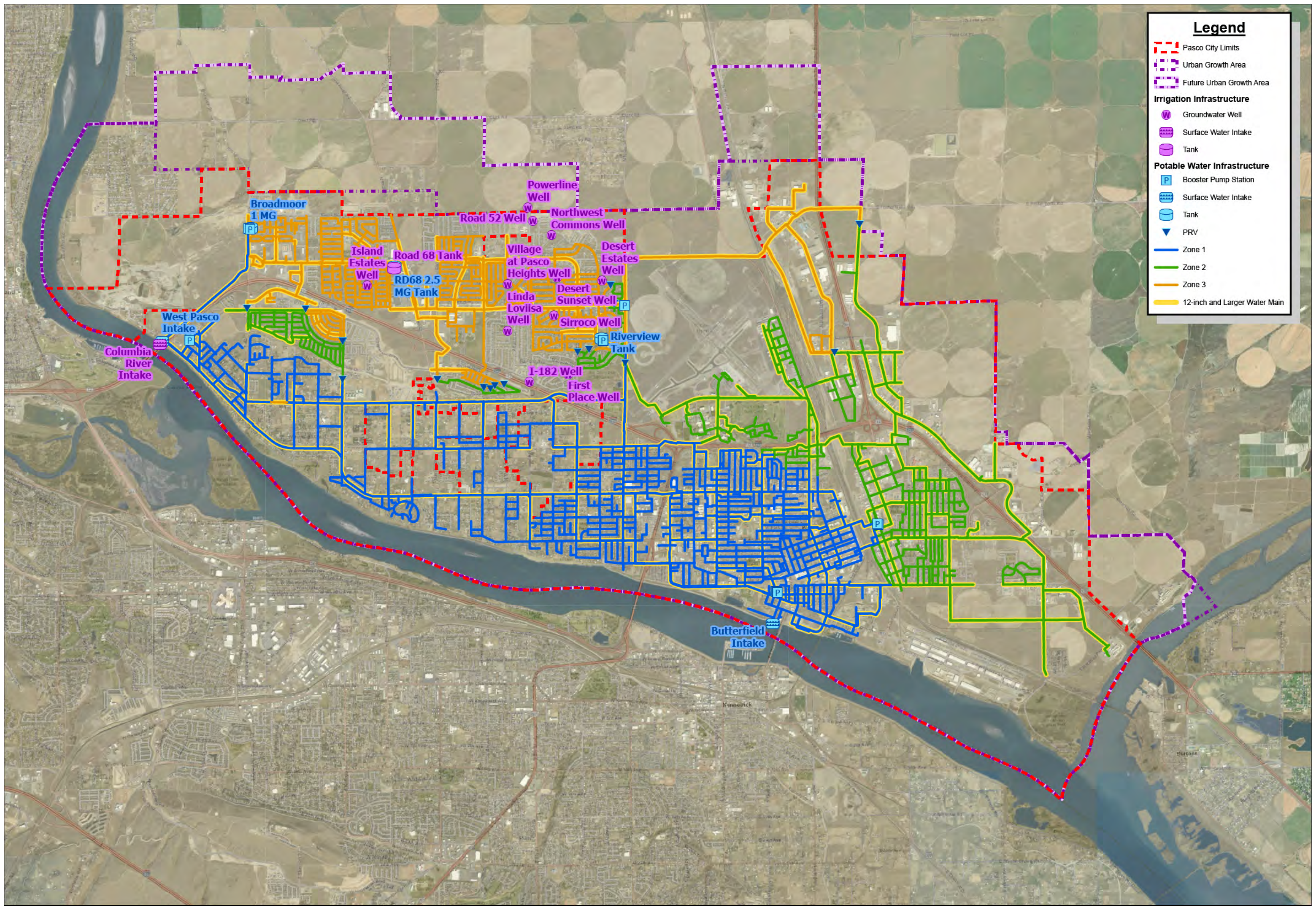

NORTH

1,250 2,500 5,000
Feet

FIGURE 2-1

Existing Potable Water and Irrigation System Infrastructure

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

LEGEND

Pasco City Limits

Urban Growth Area

Future Urban Growth Area

Irrigation Infrastructure

Groundwater Well

Surface Water Intake

Tank

Potable Water Infrastructure

Booster Pump Station

Surface Water Intake

Tank

PRV

Zone 1

Zone 2

Zone 3

12-inch and Larger Water Main

NOTE
Developed by RH2

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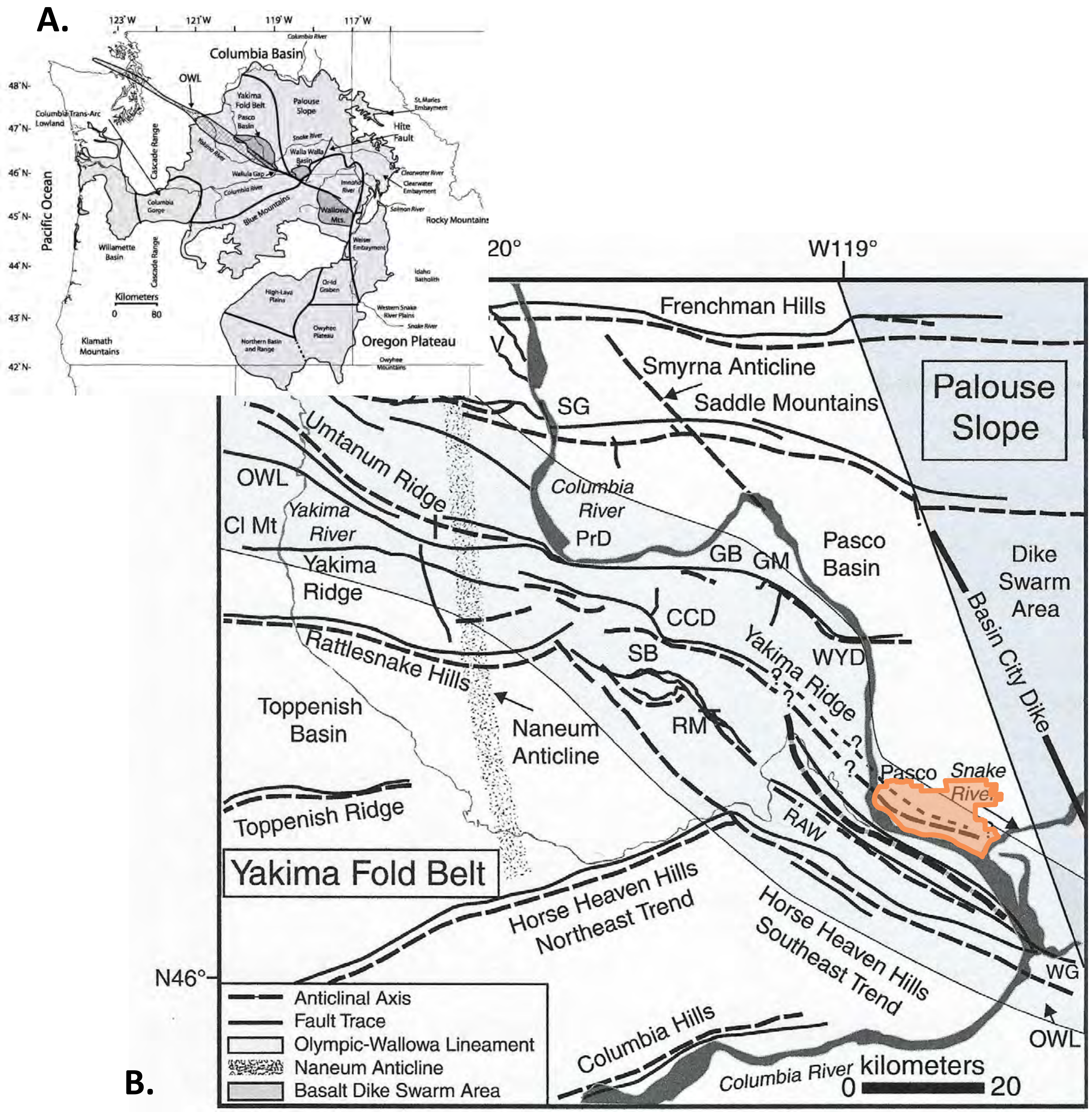

FIGURE 3-1

Geologic Setting

Hydrogeologic Feasibility Assessment, Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

LEGEND

Study Area (approximate)

NOTES

A. Map showing the location of the Pasco Basin in relation to geologic structural sub-provinces and the extent of the Columbia River Flood Basalt Province. From Reidel et al. (2020, Figure 1).

B. Major geologic features of the Pasco Basin area and vicinity. V-Vantage; SG-Sentinel Gap; PrD-Priest Rapids Dam; OWL-Olympic Wallowa lineament; Cl Mt- Cleman Mt.; GM-Gable Mtn.; GB-Gable Butte; CCD-Cold Creek depression; WYD- Wye Barricade depression; RM-Rattlesnake Mtn.; RAW-Rattlesnake-Wallula alignment; WG-Wallula Gap. From Reidel et al. (2013, Figure 8).

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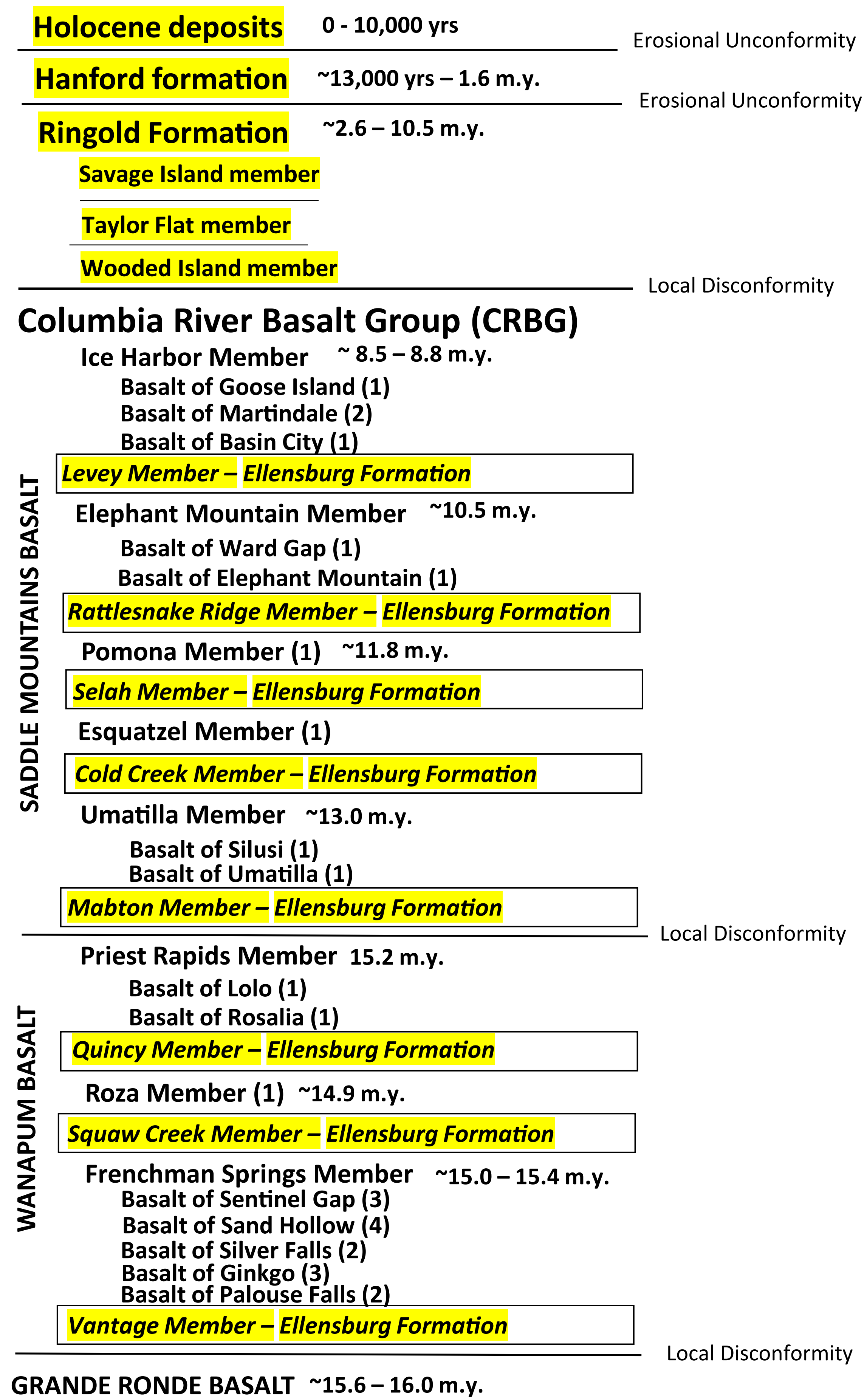


FIGURE 3-2

Stratigraphic Column, Major Units of the Pasco Area

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

NOTES

Chart showing the major stratigraphic units found in the greater Pasco, Washington, area. Yellow highlight denotes sedimentary unit. Number in parentheses to the right of CRBG unit names denotes the number individual basalt flows likely present beneath this area. Ages of units are approximate. "yrs. = years for present; "m.y." = millions of years before present. Modified from Tolan et al. (2007) and Reidel et al. (2013).

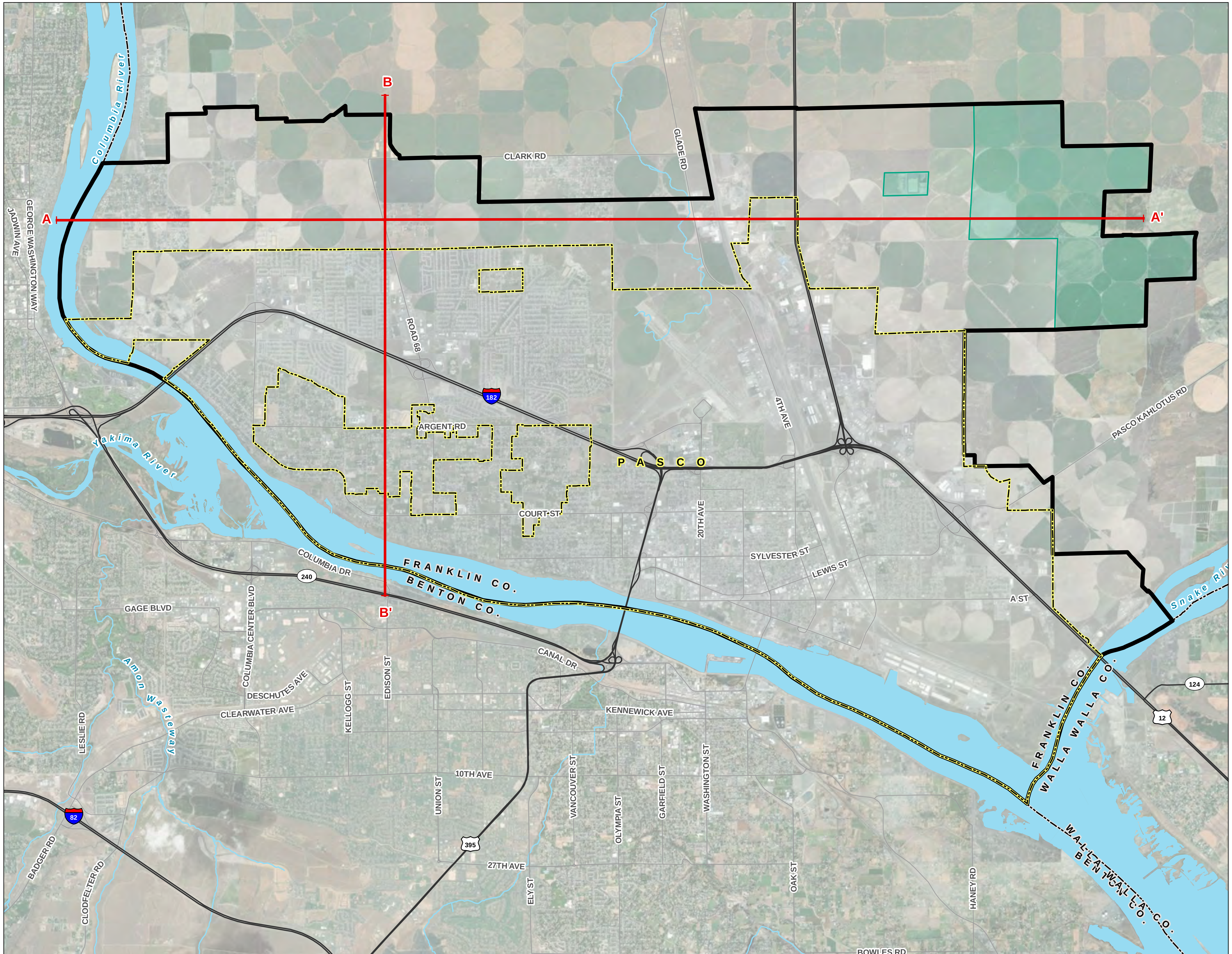
Due to cataclysmic flood erosion, it is likely that the Wooded Island Member is the only unit of the Ringold Formation present within the Study Area.

GSI Water Solutions, Inc.

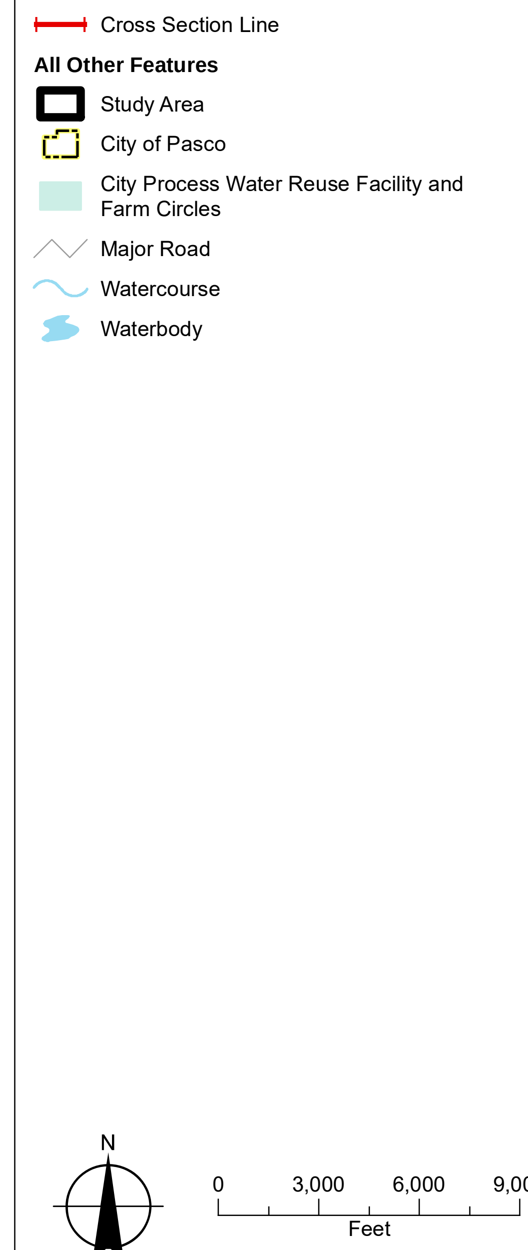
FIGURE 3-3

Cross Section Overview

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington



LEGEND



Date: April 28, 2021
Data Sources:

GSI Water Solutions, Inc.

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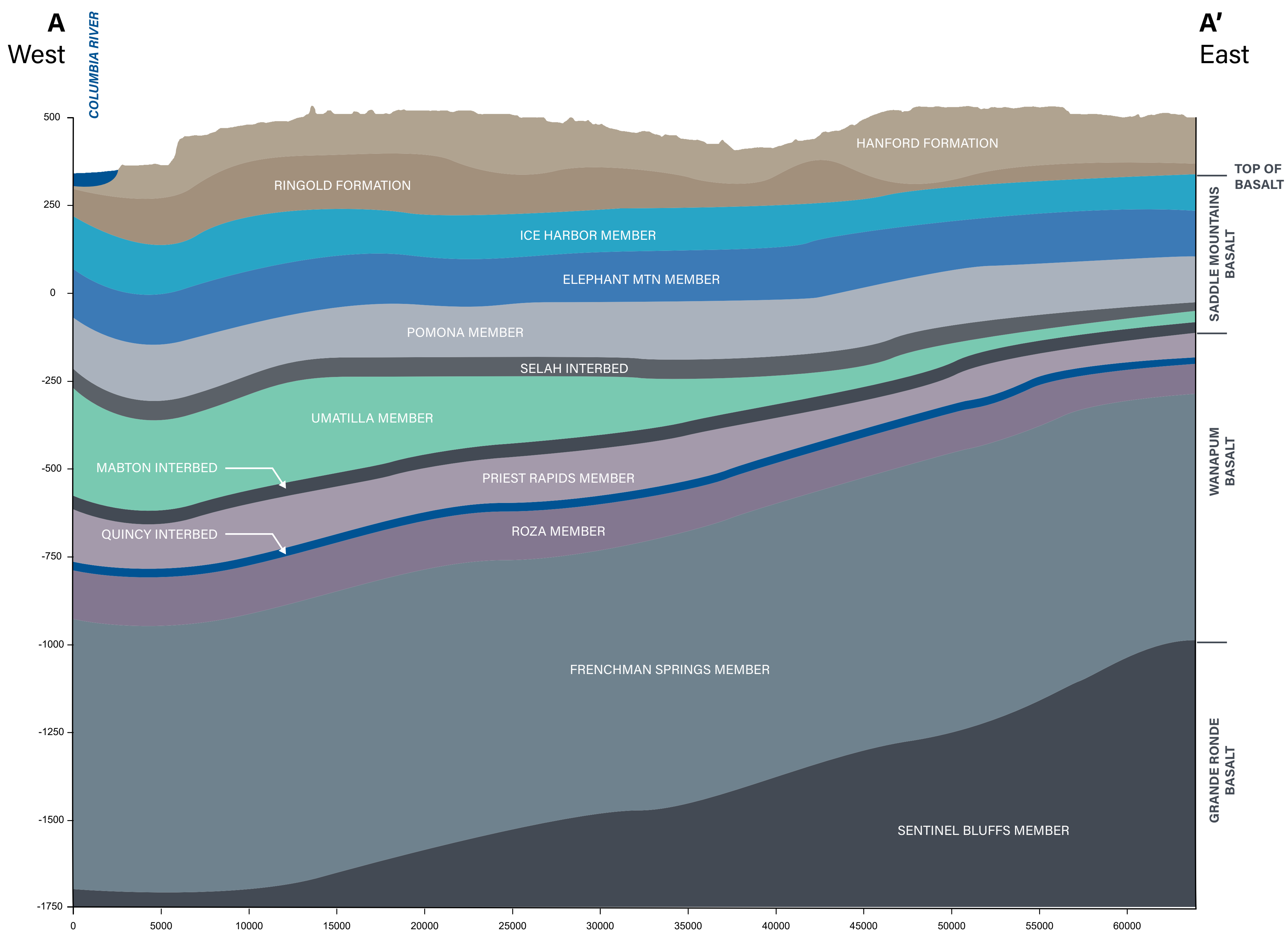

FIGURE 3-4

Cross Section A

Aquifer Storage and
Recovery Feasibility Study
City of Pasco, Washington

LEGEND

- Hanford Formation
- Ringold Formation

Columbia River Basalt Group (CRBG)

- Ice Harbor Member
- Elephant Mtn Member
- Pomona Member
- Selah Interbed
- Umatilla Member
- Mabton Interbed
- Priest Rapids Member
- Quincy interbed
- Roza Member
- Frenchman Springs Member
- Sentinel Bluffs Member

NOTE

Additional interbeds are expected to be present, but are too thin to depict in the cross section. These interbeds include the sedimentary units of the Ellensburg Formation (Levey, Rattlesnake, Cold Creek, Squaw Creek, and Vantage Members)

GSI Water Solutions, Inc.

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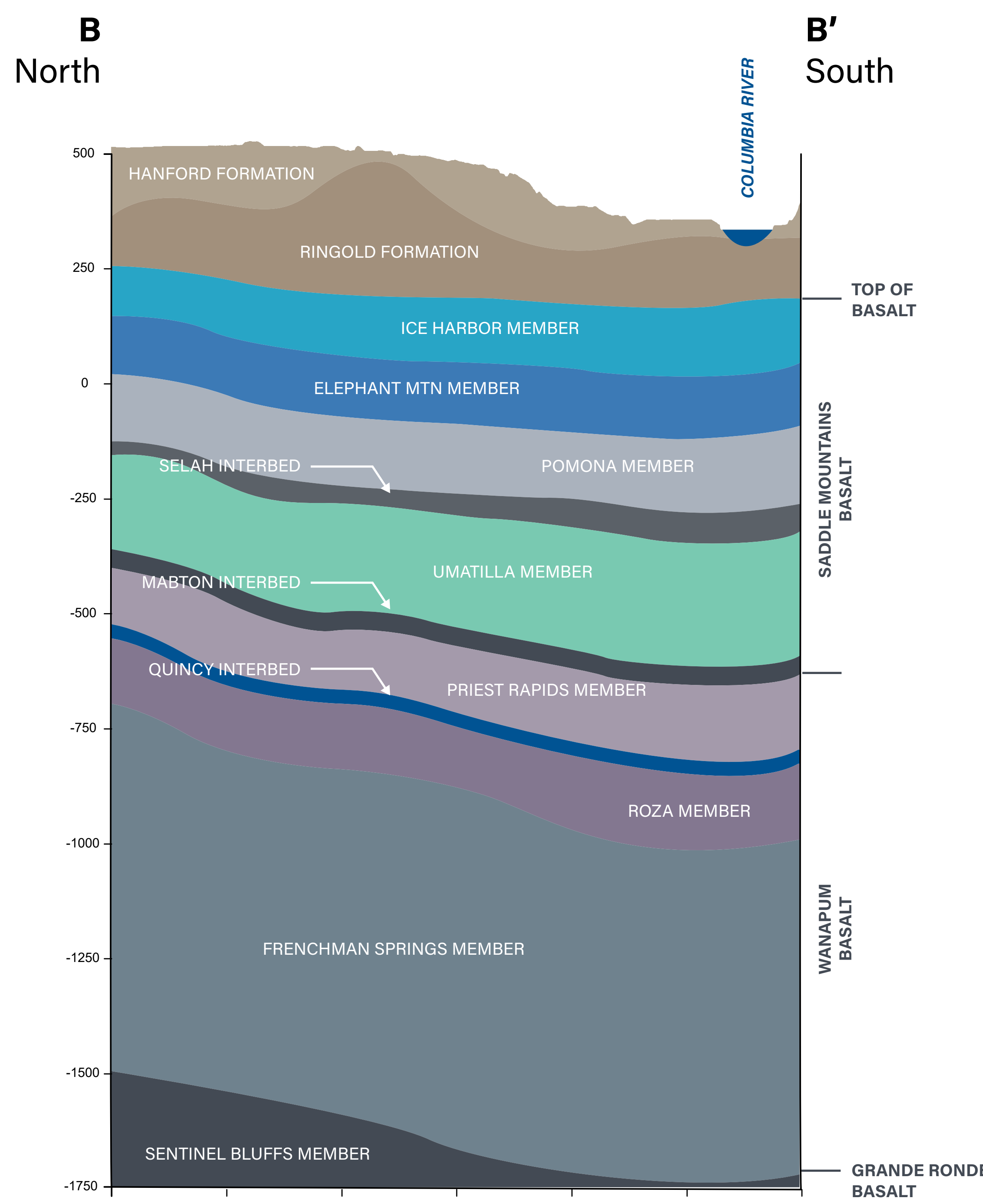
FIGURE 3-5

Cross Section B

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington



LEGEND

- Hanford Formation
- Ringold Formation

Columbia River Basalt Group (CRBG)

- Ice Harbor Member
- Elephant Mtn Member
- Pomona Member
- Selah Interbed
- Umatilla Member
- Mabton Interbed
- Priest Rapids Member
- Quincy interbed
- Roza Member
- Frenchman Springs Member
- Sentinel Bluffs Member

NOTE

Additional interbeds are expected to be present, but are too thin to depict in the cross section. These interbeds include the sedimentary units of the Ellensburg Formation (Levey, Rattlesnake, Cold Creek, Squaw Creek, and Vantage Members)

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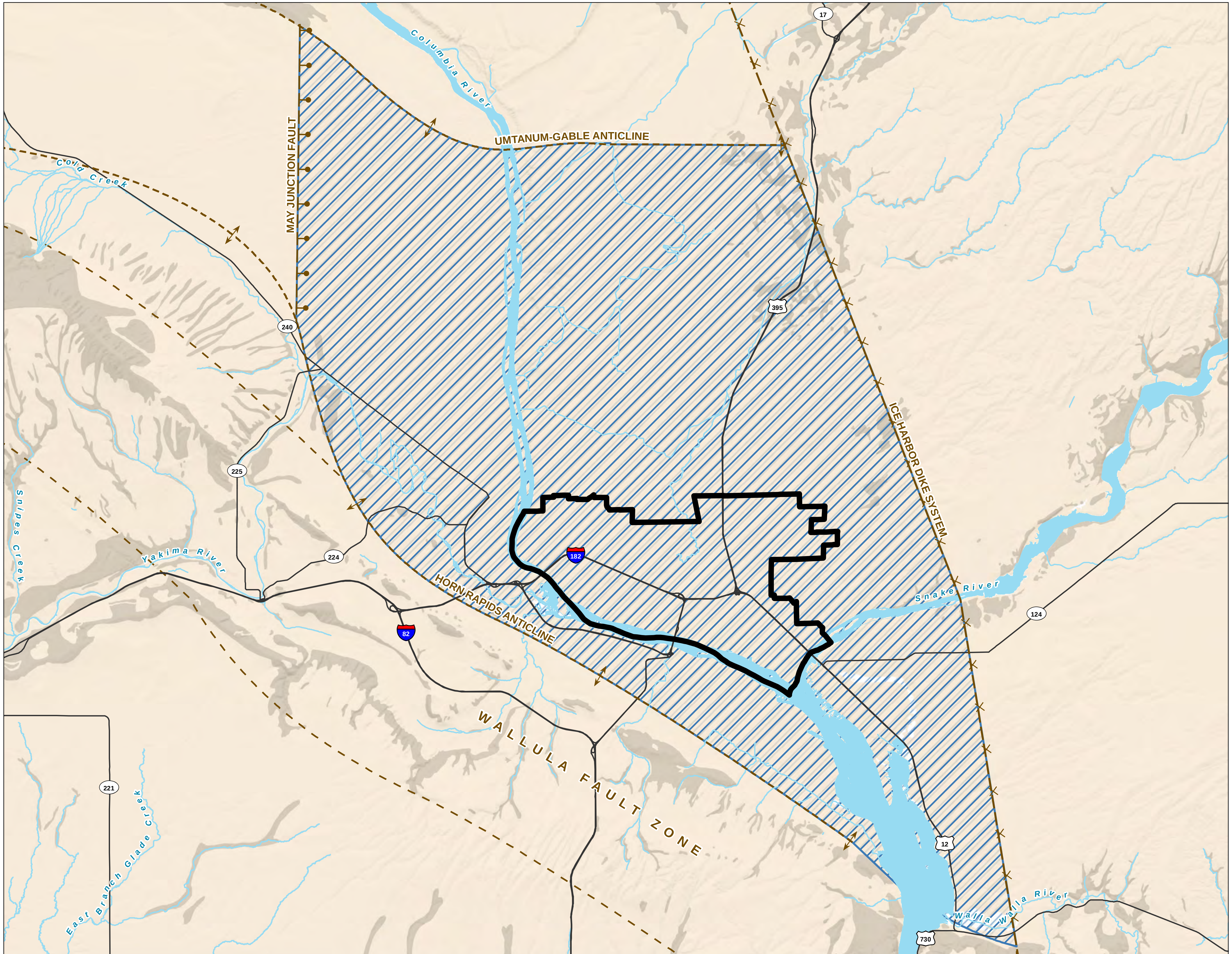

FIGURE 3-6

Geologic Structural Map and Extent of the Richland Subbasin

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

LEGEND

Study Area

Richland Subbasin, Approximately 330,000 acres

Wallula Fault Zone

Geologic Features, Approximate

Dike

Fault, Bar and Ball on Downthrown Side

Fold, Anticline

Geologic Units

Suprabasalt Sediments

Columbia River Basalt Group (CRBG)

All Other Features

Major Road

Watercourse

Waterbody

SOURCES

Reidel and Tolan, 2010.
Schuster, J.E., Geologic map of the Walla Walla 1:100,000 quadrangle, Washington, USGS Open File Report 94-3

N

0 10,000 20,000 30,000
Feet

Date: April 27, 2021
Data Sources: DNR, ESRI, ODOT, USGS, Aerial Photo 2018

GSI Water Solutions, Inc.

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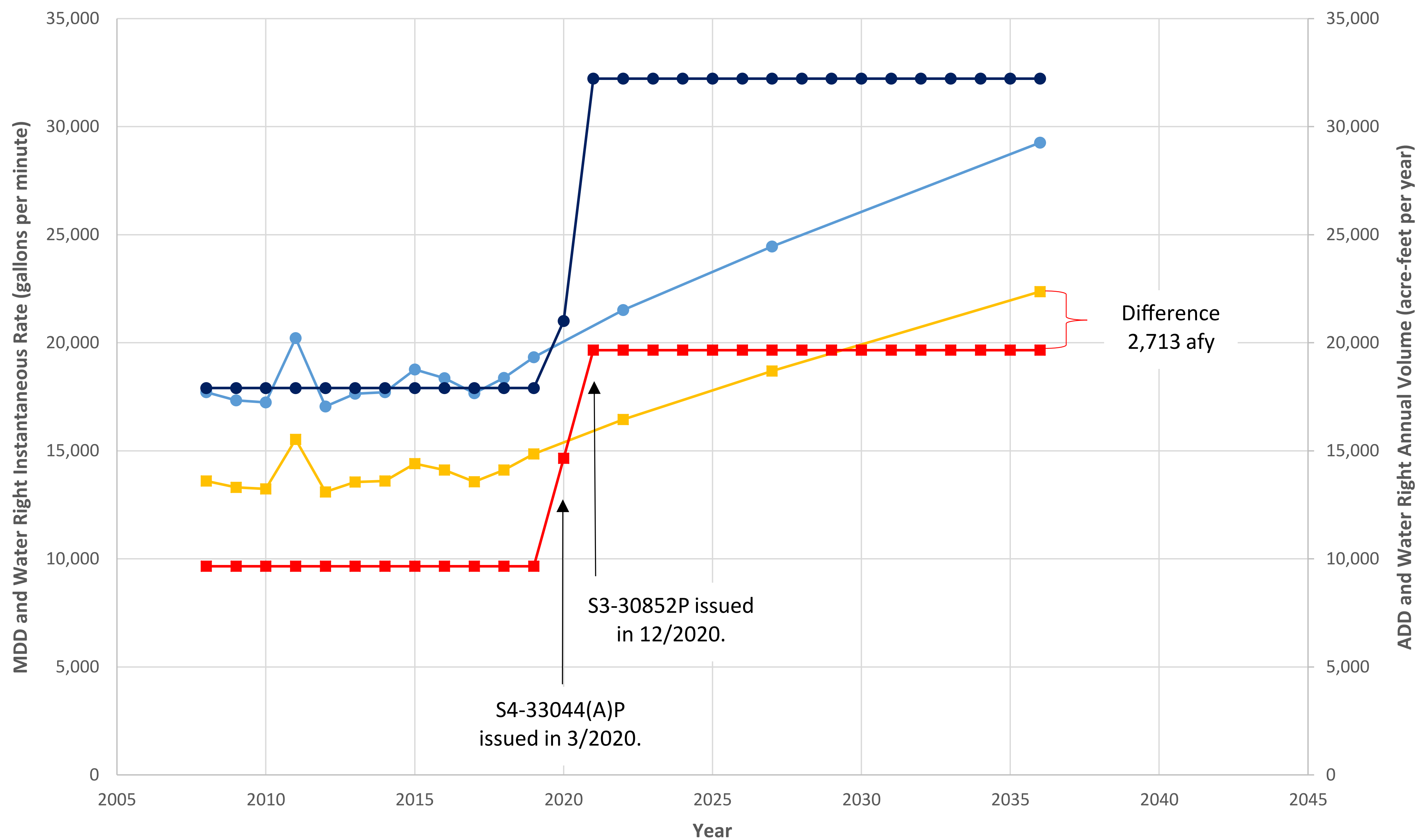

FIGURE 4-1

Demand vs. Uninterruptible City-Held Potable System Water Rights

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

LEGEND

- MDD (gpm)
- Water Rights Qi (gpm)
- ADD (afy)
- Water Rights Qa (afy)

NOTE
Developed by RH2

RH2 GSI Water Solutions, Inc.

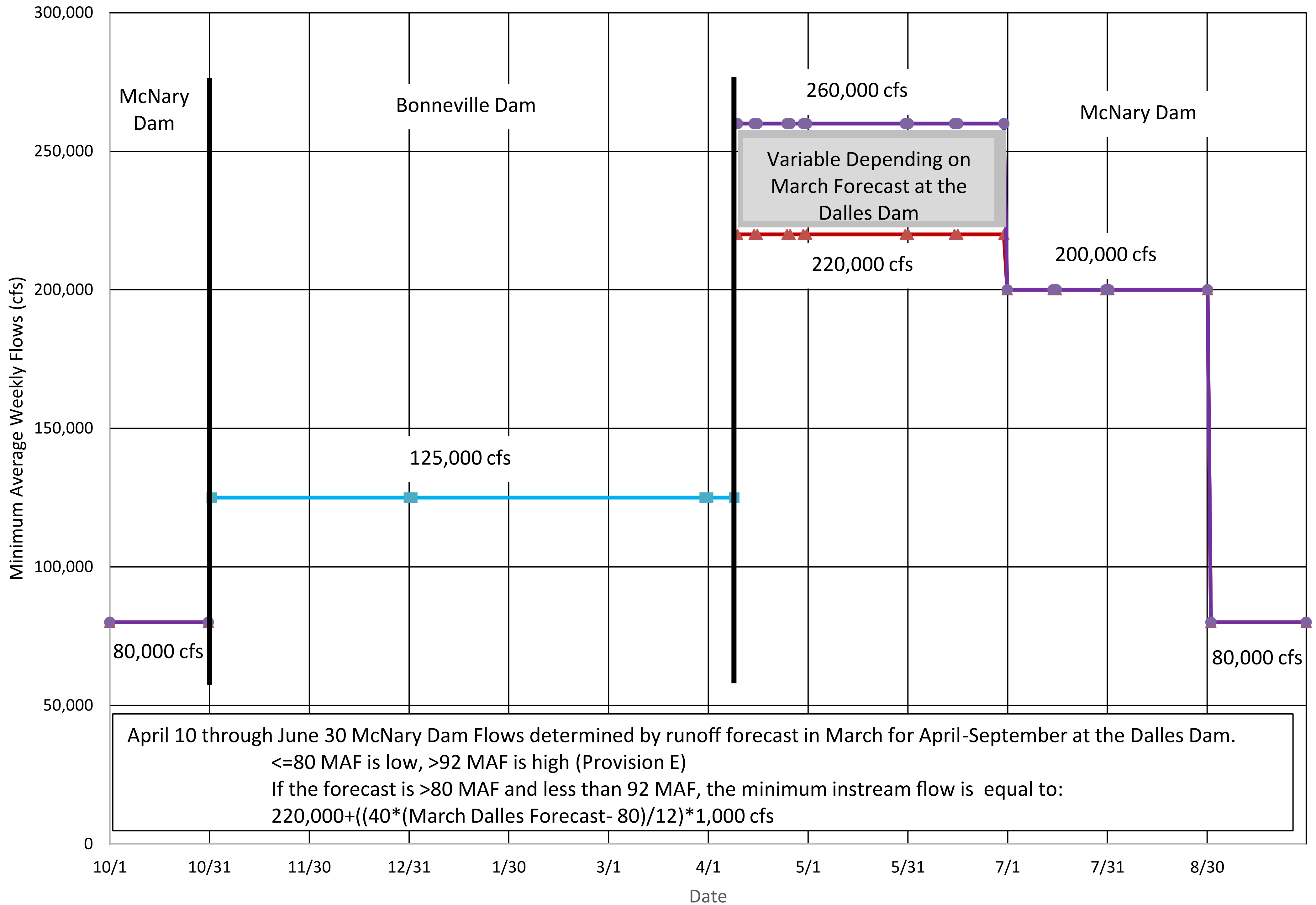

FIGURE 4-2

Columbia River Minimum Flows

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

LEGEND

- Provision E McNary Low
- Provision E McNary High
- Provision E Bonneville Low

NOTE
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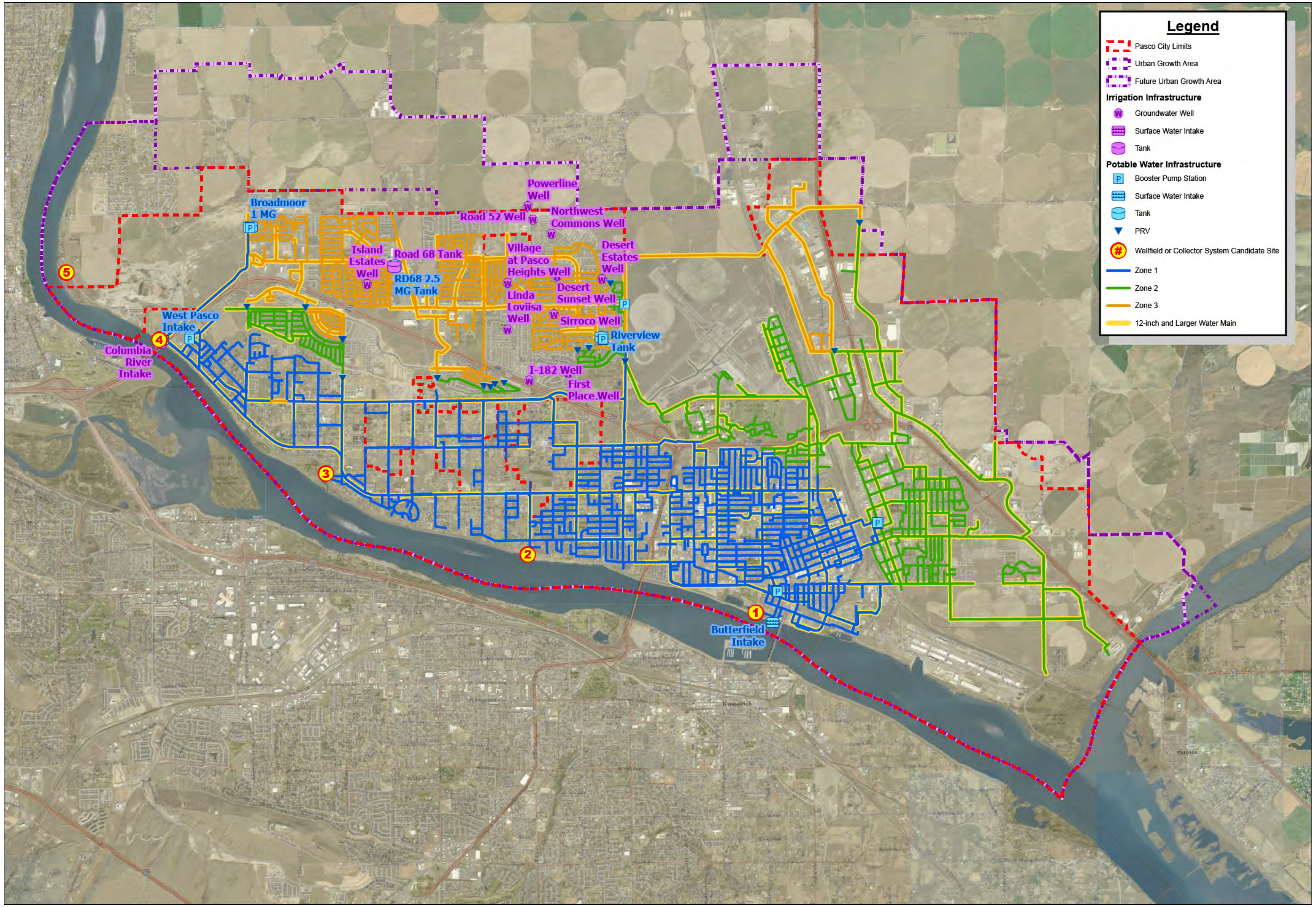
FIGURE 4-3

Wellfield or Collector System Candidate Sites for Alternative ASR Supply Source

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington



RH2

NORTH

1,250 2,500 5,000 Feet

LEGEND

Pasco City Limits

Urban Growth Area

Future Urban Growth Area

Irrigation Infrastructure

Groundwater Well

Surface Water Intake

Tank

Potable Water Infrastructure

Booster Pump Station

Surface Water Intake

Tank

PRV

Wellfield or Collector System Candidate Site

Zone 1

Zone 2

Zone 3

12-inch and Larger Water Main

NOTE
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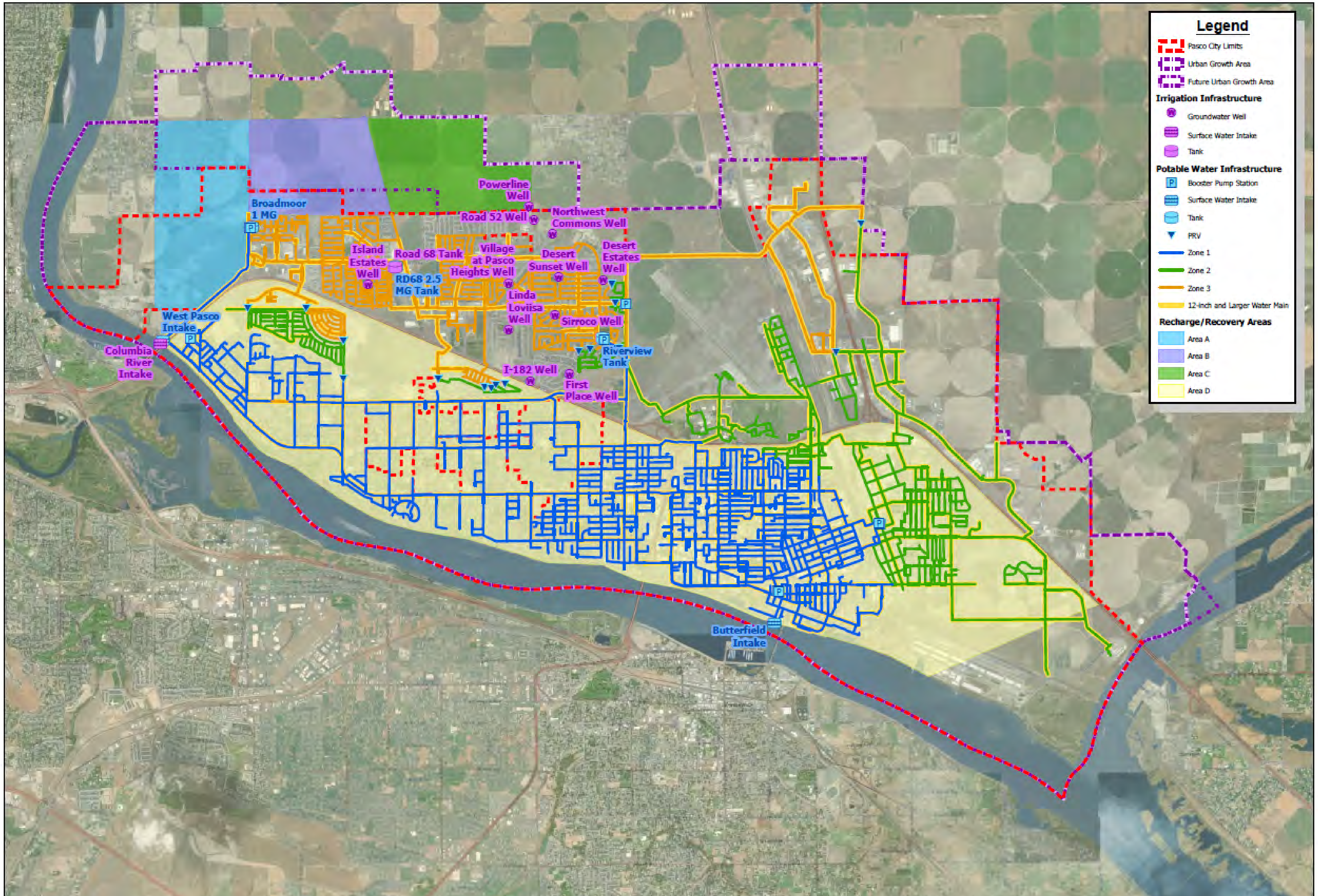
FIGURE 6-1

Candidate ASR Recharge/Recovery Areas

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington



NORTH

1,250 2,500 5,000 Feet

LEGEND

- Pasco City Limits
- Urban Growth Area
- Future Urban Growth Area

Irrigation Infrastructure

- Groundwater Well
- Surface Water Intake
- Tank

Potable Water Infrastructure

- Booster Pump Station
- Surface Water Intake
- Tank
- PRV
- Zone 1
- Zone 2
- Zone 3
- 12-inch and Larger Water Main

Recharge/Recovery Areas

- Area A
- Area B
- Area C
- Area D

NOTE
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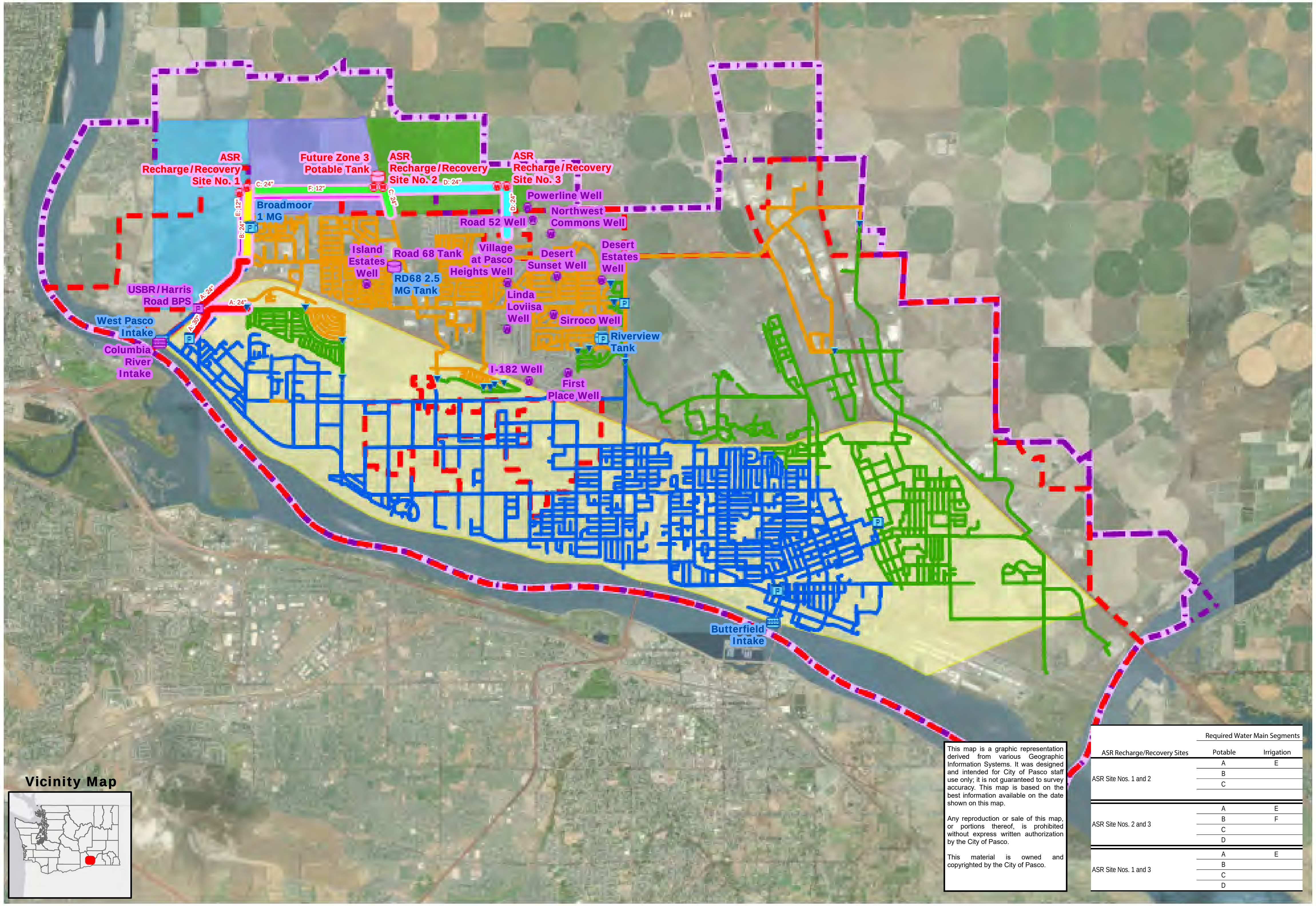

This map is a graphic representation derived from various Geographic Information Systems. It was designed and intended for City of Pasco staff use only; it is not guaranteed to survey accuracy. This map is based on the best information available on the date shown on this map.

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ASR Recharge/Recovery Sites	Required Water Main Segments	
	Potable	Irrigation
ASR Site Nos. 1 and 2	A	E
	B	
	C	
ASR Site Nos. 2 and 3	A	E
	B	F
	C	
	D	
ASR Site Nos. 1 and 3	A	E
	B	
	C	
	D	

FIGURE 6-2

Proposed ASR Improvements and Infrastructure

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington

LEGEND

- Pasco City Limits
- Urban Growth Area
- Future Urban Growth Area

Irrigation Infrastructure

- Booster Pump Station
- Groundwater Well
- Surface Water Intake
- Tank

Potable Water Infrastructure

- Booster Pump Station
- Surface Water Intake
- Tank
- PRV
- Zone 1
- Zone 2
- Zone 3

Recharge/Recovery Areas

- Area A
- Area B
- Area C
- Area D

Proposed Recharge/Recovery Site

- Groundwater Well

Proposed Potable Water Main

- Segment A
- Segment B
- Segment C
- Segment D

Proposed Irrigation Main

- Segment E
- Segment F

NOTE
Developed by RH2

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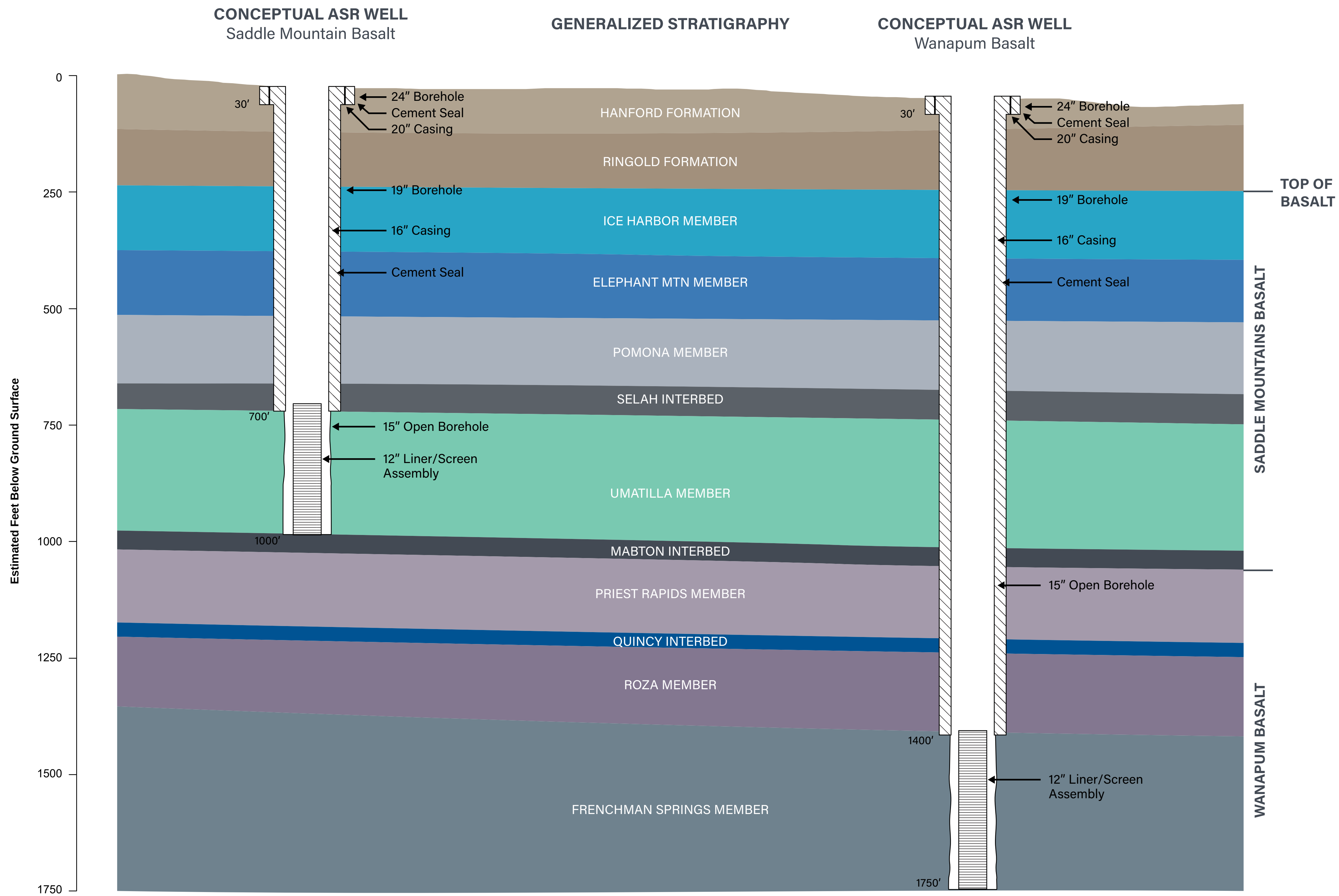
FIGURE 6-3

Conceptual Schematic Design ASR Wells

Aquifer Storage and Recovery Feasibility Study
City of Pasco, Washington



LEGEND

- Hanford Formation
- Ringold Formation

Columbia River Basalt Group (CRBG)

- Ice Harbor Member
- Elephant Mtn Member
- Pomona Member
- Selah Interbed
- Umatilla Member
- Mabton Interbed
- Priest Rapids Member
- Quincy interbed
- Roza Member
- Frenchman Springs Member
- Sentinel Bluffs Member

NOTES

Final depths will be determined based on conditions encountered during drilling.

The Wanapum Basalt well will target completion in either the Roza or Frenchman Springs Member based on results obtained from a drilling and testing program.

GSI Water Solutions, Inc.

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ATTACHMENT A

Water Quality Data Summary

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Table A-1. Saddle Mountains Basalt Water Quality Data Summary

ANALYTE GROUP / Analyte	Units	Drinking Water MCL/SMCL (WAC 246-290-310)	Saddle Mountains Basalt: Steinkampf (1989) [1] Maximum	Steinkampf (1989) [1] Mean	Steinkampf (1989) [1] Minimum	Domestic Wells (Golder, 2001; 2020) Pratt	Michel	Bettinghouse	KID#3	Powers	Westcoast	Maxfield	USDOE (1988) Various Hanford Wells
Alkalinity	mg/L as $CaCO_3$	--	--	--	--	159	116	172	164	142	181	183	< 50 to < 250
Ammonia	mg/L as N	--	--	--	--	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	--
Bicarbonate	mg/L as $CaCO_3$	--	392	195	108	--	--	--	--	--	--	--	--
Bromide	mg/L	--	--	--	--	0.16	0.08	0.52	0.52	0.08	0.10	0.20	--
Chloride	mg/L	250	130	24	1.3	22	10	68	68	9.7	12	71	< 50 to < 150
Fluoride	mg/L	2 (SMCL), 4 (MCL)	2.9	0.6	0.2	0.29	0.32	0.44	0.34	0.56	0.32	0.43	< 4 to < 12
Nitrate	mg/L as N	10	--	--	--	3.5	1.1	6.8	9.8	2.1	< 0.03	7.0	--
Nitrate + Nitrite	mg/L as N	10 (nitrate) / 1 (nitrite)	54	4.8	0.1	--	--	--	--	--	--	--	--
Silica as SiO_2	mg/L	--	72	56	36	--	--	--	--	--	--	--	--
Sulfate	mg/L	250 (SMCL)	490	53	0.2	66	27	230	210	45	13	130	< 20 to < 120
Boron	mg/L	--	--	--	--	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	--
Calcium	mg/L	--	98	38	1.9	45	27	78	91	31	24	78	< 5 to < 95
Iron	mg/L	0.3 (SMCL)	0.8	0.030	0.003	ND	ND	ND	ND	0.33	ND	ND	--
Magnesium	mg/L	--	62	19	0.3	29	12	47	40	32	13	50	< 1 to < 19
Manganese	mg/L	0.05 (SMCL)	0.890	0.021	0.001	ND	ND	ND	ND	0.014	0.091	ND	--
Potassium	mg/L	--	13	6.9	1.5	ND	ND	9.3	6.9	7.6	10	9.1	> 4 to < 16
Selenium	mg/L	0.05	--	--	--	< 0.003	< 0.003	0.007	0.004	< 0.003	< 0.003	< 0.003	--
Sodium	mg/L	20 (advisory level)	100	35	7.3	18	18	66	56	21	35	31	< 5 to < 125
TDS (calculated)	mg/L	500	890	340	140	--	--	--	--	--	--	--	--
pH	pH units	6.5 to 8.5 (SMCL)	8.7	7.0	7.7	7.62	7.27	7.47	7.66	7.66	7.55	7.33	> 7 to < 10
Eh	mV	--	--	--	--	393	359	360	349	350	411	367	--
Specific Conductance	µS/cm	700 (SMCL)	1,460	498	175	172	196	492	469	304	294	430	--
Temperature	°C	--	26	18	8.6	13	17	16	17	18	21	17	--
Turbidity	NTU	--	--	--	--	0.1	0.2	0.3	0.2	2.4	3.6	0.3	--
Dissolved Oxygen	mg/L	--	10	4.5	0.1	9.0	4.5	9.5	5.4	2.2	1.1	7.2	--

Notes: (1) 131 samples; shaded cells identify exceedances of applicable MCL, SMCL, or advisory level (sodium); -- not applicalble or not analyzed

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Table A-2. Wanapum Basalt Water Quality Data Summary

ANALYTE GROUP / Analyte	Units	Drinking Water MCL/SMCL (WAC 246-290-310)	Wanapum Basalt: Steinkampf (1989) [1] Maximum	Mean	Minimum	Steinkampf and Hearn (1996) Maximum	Mean	Minimum	City of Walla Walla (Golder, 2009b) Well 1	Well 2	Well 4	Well 6	City of Kennewick (Golder, 2012b; 2014) ASR-1 (Initial Testing)	ASR-1 (Pre-ASR)	ASR-MW-1 (Pre-ASR)	Willowbrook Well (Golder, 2001) 6/21/1991	4/11/1996	6/27/1996	9/25/2000	USDOE (1988) Various Hanford Wells	CBGWMA (2009) BF002
Alkalinity	mg/L as CaCO3	--	--	--	--	--	--	--	94	96	NA	120	212	208	207	--	--	--	74	> 75 to < 200	244
Bicarbonate	mg/L as CaCO3	--	406	177	53	246	192.7	86	--	--	--	--	210	208	207	--	--	--	--	--	--
Carbonate	mg/L as CaCO3	--	21	12.3	6	0	0	0	--	--	--	--	ND	ND	ND	--	--	--	--	--	--
Hardness	mg/L as CaCO3	--	--	--	--	--	--	--	83	91	70	71	70	64	--	--	--	--	--	--	--
Bromide	mg/L	--	--	--	--	0.15	0.08	0	--	--	--	--	--	--	--	--	--	--	0.03	--	--
Chloride	mg/L	250	300	19.5	1.1	28	12.5	1.2	1.5	1.9	2.2	2.3	11.7	12.5	11.7	10	--	14	6	< 50 to < 500	15
Fluoride	mg/L	2 (SMCL), 4 (MCL)	3.4	0.4	0	2.2	1.0	0.4	0.3	ND	0.9	0.7	0.87	0.92	0.83	1.5	2.0	2.2	0.3	< 4 to < 28	1.8
Nitrate+Nitrite (total N)	mg/L as N	10 (nitrate) / 1 (nitrite)	35	4.4	0	--	--	--	--	--	--	--	ND	ND	ND	--	--	--	--	--	--
Nitrate-N	mg/L as N	10	--	--	--	0.2	0.2	0.2	0.9	2.2	<0.5	<0.01	ND	ND	ND	<0.2	<0.2	<0.01	0.031	--	0
Silica (as SiO2)	mg/L	--	72	46.5	5.8	63	56	48	47	45	NA	30	--	66.6	80.3	--	--	--	--	--	54
Sulfate	mg/L	250 (SMCL)	290	32.8	0	45	16.6	0.7	2.9	3.4	5.0	5.5	0.5	0.2	ND	--	--	<0.1	19	< 20 to < 40	0
Aluminum	mg/L	0.05 to 0.2 (SMCL)	--	--	--	0.007	0.002	0	--	--	--	--	ND	ND	ND	--	--	--	<0.2	--	--
Barium	mg/L	2	--	--	--	0.059	0.028	0.018	0.0038	0.0008	0.0350	<0.1	0.0540	0.0514	0.0795	<0.25	--	0.036	0.037	--	--
Boron	mg/L	--	--	--	--	0.2	0.1	0.0	--	--	--	--	--	--	--	--	--	--	<0.5	--	0.1
Calcium	mg/L	--	180	35.3	1.1	39	17.9	3.2	18.0	20.0	--	17.5	15	13.9	14	--	--	3.5	15	< 5 to < 25	1.9
Iron	mg/L	0.3 (SMCL)	1.1	0.024	0.003	0.081	0.028	0.003	ND	ND	<0.010	<0.05	0.044	0.018	0.030	<0.1	--	<0.05	<0.1	--	0.04
Lithium	mg/L	--	--	--	--	0.029	0.015	0.005	--	--	--	--	--	--	--	--	--	--	--	--	< 0.020
Magnesium	mg/L	--	75	15.9	0.06	16	7.8	0.6	9.0	10.0	NA	7.3	7.66	7.1	6.9	--	--	0.5	3.7	< 1 to < 13	0.5
Manganese	mg/L	0.05 (SMCL)	0.890	0.021	0.001	0.014	0.006	0.001	ND	ND	<0.010	0.011	0.030	0.027	0.017	<0.01	--	0.011	0.014	--	< 0.020
Potassium	mg/L	--	22	4.5	0.9	13	7.7	2.1	NA	NA	NA	5.0	12.9	11	13.9	--	--	--	<5	> 4 to < 36	11.0
Sodium	mg/L	20 (advisory level)	130	27.6	5	100	48	7.7	10	7.4	26.4	24.0	62	55	70	65	--	93	22	< 5 to < 325	115
Strontium	mg/L	--	--	--	--	0.200	0.089	0.026	--	--	--	--	--	--	--	--	--	--	--	--	< 0.050
Zinc	pH units	5	--	--	--	--	--	--	--	--	--	--	0.0005	0.0067	0.00624	< 0.2	--	< 0.02	0.01	--	< 0.01
pH	pH units	6.5 to 8.5 (SMCL)	9.4	7.6	6.1	8.8	7.9	7.2	7.77	7.39	7.96	7.70	8.0	8.0	7.9	--	7.82	--	7.51	> 7 to < 10.5	8.6
Specific Conductance	µS/cm	700	1,970	420	159	--	--	--	NA	NA	207	230	424	376	421	350	--	410	167	--	506
Total Dissolved Solids	mg/L	500 (SMCL)	1,100	275	130	--	--	--	130	160	192	NA	324	308	280	--	--	330	130	--	354
Temperature	°C	--	24.5	14.4	6.2	--	--	--	--	--	--	--	27.2	27.3	26.1	--	23.4	--	21.1	--	21.0
Dissolved Oxygen	mg/L	--	10.6	5.5	0.1	--	--	--	--	--	--	--	0.32	0.17	3.7	--	--	--	0.36	--	--

Notes: (1) 410 samples; shaded cells identify exceedances of applicable MCL, SMCL, or advisory level (sodium); NA is not available; -- not applicalble or not analyzed

ATTACHMENT B

Potential ASR Storage Aquifer Scoring Methodology, Criteria, and Results

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Hydrogeologic Conditions

The hydrogeologic conditions of each potential storage aquifer are critical for estimating the amount of available storage. To compare the hydrogeologic characteristics of each potential storage aquifer, the following criteria were considered:

- Confined/Compartmentalized: Potential storage aquifers that are confined and conceptualized to be completely or partially compartmentalized by fault/fold barriers will limit the potential loss of stored water and are scored more favorably than storage zones that are unconfined.
- Groundwater-surface water interaction: For this criterion, potential storage aquifers not in hydraulic connection with surface water bodies are scored more favorably than those that are understood to be hydraulically connected.
- Aquifer Storage Potential: Aquifer storage potential is determined largely by macrogeologic conditions of the potential storage aquifer, such as lithology, hydraulic parameters, extent, and hydraulic boundary conditions. Conceptually, for aquifers with relatively homogenous compositions, larger available water-level buildup capacities and aquifer extents generally correspond to greater storage potentials. For this criterion, potential storage aquifers having presumably larger storage potentials are scored more favorably than aquifers with smaller storage potentials.
- Estimated Production Capacity: The production capacity of each potential storage aquifer was based on findings reported by GSI (2020a). For this criterion, potential storage aquifers scored positively for anticipated groundwater yields greater than 1,000 gpm (1.4 MGD). Neutral scores were given to groundwater yields estimated between 500 and 1,000 gpm and negative scores for yields estimated to be less than 500 gpm.

Using the scoring methodology in conjunction with the four criteria, the maximum score a candidate site can achieve for this category is 4(+), based on a positive (+) score for each of the four criteria.

Background Groundwater Quality

Adequate groundwater quality would require only disinfection with little to no additional treatment and would have characteristics similar to source water quality. Potential storage aquifers having groundwater quality characteristics that are significantly different than the anticipated ASR supply source may require conditioning for development of a buffer zone to separate the stored ASR supply water from the surrounding ambient groundwater. The following criteria were considered for this category:

- Groundwater Quality: Potential storage aquifers with high quality water are scored more favorably than storage aquifers having poor water quality conditions.
- Conditioning/Buffer Zone Development: Potential storage aquifers with groundwater quality characteristics similar to the characteristics of the anticipated ASR supply source are scored more favorably than storage aquifers having significant water quality differences.

The maximum score a candidate site can achieve for this category is 2(+), based on a positive (+) score for each of the two criteria.

Mixing and geocompatibility between the two waters were not assessed as part of this first phase of the feasibility study. A geochemical evaluation as part of a subsequent phase should be conducted to assess that ASR supply water and native groundwater are compatible and that precipitation or adverse reactions will not take place.

Interference with Existing Users

Pumping interference during ASR recovery activities has the potential to reduce the available drawdown and production capacity of a neighboring well. Similarly, injection interference during ASR recharge operations has the potential to cause water levels to rise in neighboring wells and cause flowing conditions. Either generally takes place when ASR wells are too closely spaced to existing groundwater users with wells that share the same aquifer system. The following criterion was considered for this category:

- Presence of Existing Users: Aquifers in the Study Area utilized as primary supply sources by existing groundwater users are scored less favorably than aquifers that are less utilized.

The maximum score a potential storage aquifer can achieve for this category is 1(+), based on a positive (+) score for the single criterion.

Data Gaps

Another factor to consider in assessing potential ASR storage aquifers is the availability of data used for this feasibility study. Though the amount and quality of the data available are important in that it defines the level of assessment that can be done, the absence or presence of available data should not govern the priority ranking of potential ASR storage aquifers or candidate ASR development sites. Rather than a scored criterion, a sub-ranking is incorporated to identify the data available for this study. The available data sub-ranking will then be included in the overall priority ranking without changing the overall rank. The value of this sub-ranking is that it assists in further scoping of future work considerations by identifying major and minor data gaps identified as part of this feasibility study.

Each potential ASR storage aquifer was assigned one of the following sub-ranks to identify the data available for evaluation and overall level of uncertainty, and to help with scoping and costing future work considerations:

Sub-Rank	Data Available	Data Gaps	Future Work Needed to Address Uncertainty
A	Substantial	Negligible	Not Required
B	Partial	Minor	Optional
C	Very Limited	Moderate	Suggested
D	None	Major	Required

Table B-1: Potential ASR Storage Aquifer Evaluation Categories and Results

Potential Storage Aquifers	Potential Storage Aquifer Evaluation Categories [1]						Total Score	Data Gaps [1]	Observations/Comments
	Hydrogeologic Conditions		Background Groundwater Quality		Interference with Existing Users				
	Criteria	Rating	Criteria	Rating	Criteria	Rating			
Umatilla Member, SMB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (+) Estimated production capacity > 1,000 gpm (+) Moderate to high aquifer storage potential	4(+)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the SMB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning and buffer zone development needs are unknown	1(+)	(+) No existing groundwater users were identified in this CRBG member	1(+)	6(+)	C-D	• The Welch's well (Tolan, 2020; see Attachment A in GSI 2020a) penetrated an interflow zone within the Umatilla Member that consisted of a flow bottom breccia/flow top breccia that was approximately 50 feet thick and capable of very high groundwater yields (tested at 1,390 gpm with 100 feet of drawdown)
Frenchman Springs Member, WB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (+) Estimated production capacity > 1,000 gpm (+) Moderate to high aquifer storage potential	4(+)	(+) Groundwater quality conditions are not well known though the quality of area wells completed in the WB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning needs are unknown, though elevated groundwater temperatures may require minimal buffer zone development	1(+)	(+) Minimal impacts anticipated because only two Wanapum Basalt wells were discovered within the Study Area	1(+)	6(+)	C-D	• Two old naval air station wells were identified near the Tri-Cities Airport, though their current status (e.g., present and active, abandoned, decommissioned) and well completion details are unknown
Roza Member, WB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (0) Estimated production capacity > 1,000 gpm (+) Moderate to high aquifer storage potential	3(+)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the WB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning needs are unknown, though elevated groundwater temperatures may require minimal buffer zone development	1(+)	(+) Minimal impacts anticipated because only two Wanapum Basalt wells were discovered within the Study Area	1(+)	5(+)	C-D	• Production capacity estimated to be > 1,000 gpm if this member possess a 30- to 50-foot thick flow top breccia beneath the Study Area • Two old naval air station wells were identified near the Tri-Cities Airport, though their current status (e.g., present and active, abandoned, decommissioned) and well completion details are unknown
Priest Rapids Member, WB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (0) Estimated production capacity < 500 gpm (0) Low to moderate aquifer storage potential	2(+)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the WB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning needs are unknown, though elevated groundwater temperatures may require minimal buffer zone development	1(+)	(+) Minimal impacts anticipated because only two Wanapum Basalt wells were discovered within the Study Area	1(+)	4(+)	C-D	• The estimated production capacity and storage potential are likely low because the Lolo flow beneath the Study Area may have either a thin flow top breccia or thin simple vesicular flow top, and a thin vesicular flow bottom • Two old naval air station wells were identified near the Tri-Cities Airport, though their current status (e.g., present and active, abandoned, decommissioned) and well completion details are unknown
Ice Harbor Member, SMB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (-) Estimated production capacity < 500 gpm (-) Low aquifer storage potential	(0)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the SMB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning and buffer zone development needs are unknown	1(+)	(0) Moderately-utilized groundwater source	(0)	1(+)	C-D	• Groundwater yields in this CRBG member are commonly low, ranging from 20 to 50 gpm, and unlikely to have suitable hydraulic characteristics to target as an ASR storage aquifer
Elephant Mountain Member, SMB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (-) Estimated production capacity < 500 gpm (-) Low aquifer storage potential	(0)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the SMB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning and buffer zone development needs are unknown	1(+)	(0) Moderately-utilized groundwater source	(0)	1(+)	C-D	• While this CRBG member is potentially more productive than the overlying Ice Harbor Member, the potential for encountering suitable hydraulic characteristics to target it as an ASR storage aquifer is low
Pomona Member, SMB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (-) Estimated production capacity < 500 gpm (-) Low aquifer storage potential	(0)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the SMB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning and buffer zone development needs are unknown	1(+)	(0) Moderately-utilized groundwater source	(0)	1(+)	C-D	• Similar to the Elephant Mountain Member, the potential for encountering hydraulic characteristics in the Pomona Member suitable for ASR storage is relatively low
Esquatzel Member, SMB	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (-) Estimated production capacity is unknown, but presumed to be low (-) Aquifer storage potential is unknown, but presumed to be low	(0)	(+) Groundwater quality conditions are unknown, though the quality of area wells completed in the SMB met primary drinking water standards for all monitored constituents (GSI, 2020) (0) Aquifer conditioning and buffer zone development needs are unknown	1(+)	(0) Moderately-utilized groundwater source	(0)	1(+)	C-D	• The estimated production capacity and storage potential are unknown, though presumed low because the distribution of this member is low and may not be fully present within the Study Area (GSI, 2020)
Ellensburg Formations	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (-) Estimated production capacity < 500 gpm (-) Low aquifer storage potential	(0)	(0) Groundwater quality conditions are unknown (0) Aquifer conditioning and buffer zone development needs are unknown	(0)	(+) No existing groundwater users are known or were discovered	1(+)	1(+)	C-D	• Organic matter (if present) could contribute to the development of disinfection byproducts during ASR recharge and storage activities (e.g., City of Yakima; reservoir permit R4-34552)

Potential Storage Aquifers	Potential Storage Aquifer Evaluation Categories [1]						Total Score	Data Gaps [1]	Observations/Comments
	Hydrogeologic Conditions		Background Groundwater Quality		Interference with Existing Users				
	Criteria	Rating	Criteria	Rating	Criteria	Rating			
Grande Ronde Basalt	(+) Confined and compartmentalized (+) Not hydraulically connected with surface water (0) Estimated production capacity is unknown (0) Aquifer storage potential is unknown	2(+)	(-) Groundwater quality tends to be warmer and more geochemically evolved than the shallower basalt units, with higher mineral content (-) Aquifer conditioning and buffer zone development anticipated becase of poor groundwater quality conditions	2(-)	(+) No existing groundwater users are known or were discovered	1(+)	**1(+)**	C-D	• Poor water quality concerns and greater well completion depths render development of an ASR system using Grande Ronde Basalt-hosted aquifers more costly than development of comparably-productive and better water quality aquifers in the shallower basalt units
Suprabasalt Sediments	(-) Unconfined with shallow water-level conditions in some areas (-) Hydraulically connected with the Columbia River (+) Estimated production capacity > 1,000 gpm (-) Low aquifer storage potential	2(-)	(-) Fair-to-poor groundwater quality (-) Aquifer conditioning and buffer zone development likely needed	2(-)	(-) Highly-utilized groundwater source	1(-)	**5(-)**	B	• Because of drainage and dewatering needs, unconfined aquifer conditions, and hydraulic connection with the Columbia River, the suprabasalt aquifer system is expected to have a very limited storage capacity and could siginifcantly limit the volume of ASR supply water available for recovery

Notes: See **Attachment B** for descriptions of scoring methodology, criteria, and data gap sub-ranks; SMB is Saddle Mountains Basalt; WB is Wanapum Basalt

(+)	Favorable attributes are present, and/or minimal challenges are anticipated
(0)	Favorable attributes are accompanied by unfavorable attributes, moderate challenges are anticipated, and/or some information is not available
(-)	Unfavorable attributes are present, and/or significant challenges are anticipated

ATTACHMENT C

Quad Cities and the Office of Columbia River, Memorandum of Agreement: Securing New Water Supplies for the Cities of Kennewick, Pasco, Richland, and West Richland

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Quad Cities and the Office of Columbia River

Memorandum of Agreement (MOA): Securing New Water Supplies for the City of Kennewick, City of Pasco, City of Richland, and City of West Richland

Summary

1. Purpose
    a. Coordinate Water Supply Development Projects
    b. Resolve remaining uncertainty in the 2003 Settlement Agreement
2. Buckley Season of Use Transfer
    a. Upon written request of the Quad Cities, Ecology will modify the rights to restore the historic season of use
3. Agreement on Trust Water Holdings for Mitigation of First 10 cfs under S4-30976
    a. The Parties agree that Ecology's obligation is to mitigate total 8 cfs and 5,781.6 acre-feet.
    b. The Parties agree the appropriate amount of mitigation for the first increment of growth is 6 cfs and 4,336.2 acre-feet (60% consumptive use).
    c. The remaining 2 cfs and 1,445.4 acre-feet are available to the Quad Cities as mitigation for the future increments of growth.
    d. Responsibility for costs are divided between Ecology (6 cfs portion) and Quad Cities (2 cfs portion).
4. Fulfillment of Ecology's obligation to provide 8 cfs and 5,781.6 acre-feet.
    a. The difference between Ecology's Buckley and Byerly trust water holdings and the 8 cfs and 5,781.6 acre-feet described above, is 1 cfs and 4,014.37 acre-feet.
    b. Ecology agrees to make 13.25 cfs and 4,014.37 acre-feet available from Lake Roosevelt Project to fulfill its mitigation obligations.
    c. The Parties agree that the Lake Roosevelt water provides equivalent benefit to the McNary Pool per the 2003 Settlement Agreement
5. Filing of New Applications
    a. City-specific applications may be filed that address specific projects.
    b. Coordinated application shall be filed for regional growth needs. OCR may issue new rights as mitigation for S4-30976, or in substitution of S4-30976 if preferred by Quad Cities.
6. OCR and Quads will coordinate on future water supply projects to meet growth.
7. Pasco and West Richland pre-settlement "holes" are resolved.

Quad Cities and the Office of Columbia River

Memorandum of Agreement (MOA): Securing New Water Supplies for the City of Kennewick, City of Pasco, City of Richland, and City of West Richland

Parties: The undersigned Parties, the City of Kennewick, City of Pasco, City of Richland, and City of West Richland (Quad Cities) and the Washington State Department of Ecology (Ecology), acting through the Office of Columbia River (OCR), jointly support this Memorandum of Agreement (2011 Quads MOA).

Purpose: The undersigned Parties are committed to the following objectives:

1. Coordinate on water supply development projects that will assist the Quad Cities in meeting the mitigation requirements of Water Right Permit S4-30976P, or provide alternate, equivalent means of serving the projected growth for the Quad Cities.
2. Reach a common understanding of issues of uncertainty contained in the 2003 Stipulation, Settlement Agreement and Order of Dismissal of PCHB Appeal No. 02-216 (2003 Settlement Agreement), relating to Water Right Permit S4-30976P.

Recitals:

- Whereas OCR has a statutory mandate to pursue developing water supplies to meet pending municipal needs and develop sources of supply for interruptible water users on the Columbia River;

- Whereas Water Right Permit S4-30976P is subject to interruption associated with minimum instream flow requirements on the Columbia River.
- Whereas both Ecology and the Quad Cities are parties to the 2003 Settlement Agreement[1];
- Whereas Ecology and the City of Kennewick are partnering on an Aquifer Storage and Recovery (ASR) project, subject to a 2008 Memorandum of Understanding (2008 Kennewick MOU).
- Whereas Ecology and the City of Pasco are partnering on a water supply project, subject to a 2011 Memorandum of Understanding (2011 Pasco MOU).
- Whereas there is a need to coordinate future water supply development projects consistent with the terms of Water Right Permit S4-30976P.

Now, therefore, the Parties acknowledge and agree to the following:

1. **Buckley and Byerly Water Right Trust Transfers:** In partial fulfillment of obligations of the 2003 Settlement Agreement, Ecology acquired and placed water rights into the State Trust Program (RCW 90.42), termed the "Buckley" and "Byerly" water rights. Collectively, these water rights total 7 cfs and 1,767.23 acre-feet. A summary of the Buckley and Byerly water rights held in trust under the 2003 Settlement Agreement is provided in Appendix A.

   The 2003 Settlement Agreement (Page 3) states in part that "*the intent . . . is*

[1] The Center for Environmental Law and Policy (CELP) is also a party to the 2003 Settlement Agreement. CELP is not a party to this MOA and is unaffected by its terms and conditions.

that trust water rights used for mitigation shall be from McNary Pool and of equivalent quantity and period as shown in Table 5 of the ROE" (referring to Table 5 of the Report of Examination, or ROE, for Permit S4-30976P). The referenced table identified the historic Buckley season of use as year-round, with water right specific quantities for each season (i.e., summer, fall and winter/spring). However, Ecology's 2002 ROE for the Buckley water rights altered the season of use inconsistent with Table 5 in response to comments from the Washington Department of Fish and Wildlife.

Under RCW 90.42.040, Ecology may modify a trust water certificate providing it does not impair existing water rights. Upon written request of the Quad Cities, Ecology will process a modification to the subject rights to return the season of use consistent with the historic exercise thereof, and with the terms and conditions of Table 5 of the ROE for Permit S4-30976P. While Ecology cannot prejudge this decision, a return to the historic season of use is not expected to impair existing water rights. In the event that Ecology's impairment analysis introduces constraints to the Quad-Cities' requested trust water certificate modifications other than a return to the historic season of use, Ecology shall 1) consult with the Quad-Cities to set the modified certificate to the Quad Cities' maximum benefit; and 2) consult with the Fish Flow Advisory Group to determine whether the available Lake Roosevelt mitigation can be used to offset such constraints.

2. **<u>Trust Water Mitigation for the First 10 cfs of Diversions Under S4-30976P:</u>** The 2003 Settlement Agreement contains several statements that are unclear as to Ecology's obligation to hold trust water rights as mitigation for diversions under the first 10 cfs of Permit S4-30976P.

First, the 2003 Settlement Agreement (Page 4) states: "*To determine the amount of perpetual mitigation for the first increment of water use, Ecology has used an 80 percent consumptive use estimate". Permit S4-30976P identifies the first increment of water use as 10 cfs and 7,227 acre-feet. 80 percent of the first increment is 8 cfs and 5,781.6 acre-feet..*

Second, the 2003 Settlement Agreement (Page 3) references Table 5 of the ROE for Permit S4-30976P as "*the two groups of water rights Ecology intends to use as mitigation for the first increment of Quad Cities' water use*". Table 5 identified diversions for a suite of water rights (Buckley and Simplot) ranging from 11 cfs to 20.8 cfs and totaling 6,476.7 acre-feet.

Third, the 2003 Settlement Agreement (Page 4) stated that concurrent with each 6-year Quad Cities planning update, Ecology "*will assure that the appropriate amount of water-for-water mitigation is in place*". In 2008, the Quad Cities completed its 2008 Regional Water Forecast and Conservation Plan Update, which identified an annual consumptive use percentage of 48%, significantly less than the 80% assumption. The "appropriate amount of water-for-water mitigation" based on 48% consumptive use to offset the first increment under Permit S4-30976P would be 4.8 cfs and 3,469 acre-feet.

The Parties agree that Ecology's obligations to mitigate for the first increment of water use total 8 cfs and 5,781.6 acre-feet. The Parties further agree that, while consumptive use must be calculated during each 6-year planning effort, and while consumptive use may vary from year-to-year, that the 80% consumptive use assumption for the first 10 cfs is likely to be significantly higher than the Quad Cities' actual consumptive use, even during drought years.

The Parties desire to maximize the trust water holdings for the benefit of the Quad Cities municipal uses. The trust water holdings will be maximized if 1) sufficient trust water holdings are maintained to offset consumptive uses in the first increment across a range of potential water years; and 2) if trust water holdings surplus to that objective, but within the 8 cfs and 5,781.6 acre-feet held for such purpose, are made available to the Quad Cities as mitigation to offset future increments of growth. To that end, the Parties agree "that the appropriate amount of water-for-water mitigation" for the first increment of growth is 6 cfs and 4,336.2 acre-feet (60% consumptive use). The remaining 2 cfs and 1,445.4 acre-feet are available to the Quad Cities as mitigation for the future increments of growth.

The Parties agree that Ecology is responsible for developing the 8 cfs and 5,781.6 acre-feet of water for the first increment. The Parties agree that Ecology is responsible for costs associated with the 6 cfs and 4,336.2 acre-feet of water for the first increment. The Parties agree that Quad Cities is responsible for costs associated with the 2 cfs and 1,445.2 acre-feet of water beyond the first increment. However, in the event that consumptive use in the future increases above 60%, Ecology agrees to assume responsibility for costs associated with that quantity. The Parties further agree that in the event that a future planning document estimates consumptive use above 60%, the Parties will meet and negotiate how such data will affect future increments of growth for which mitigation has already been secured. The Parties further agree that in the event that a future planning document estimates consumptive use at a percentage less than the percentage used to acquire mitigation that the Parties will negotiate a new and expanded permitted diversion amount commensurate with the lower consumptive use percentage.

3. **Simplot, Byerly and Lake Roosevelt Trust Water Rights:** When the ROE for Permit S4-30976P issued, Table 5 contained a summary of six water rights Ecology was negotiating with Mr. Buckley to acquire and three water rights that Ecology was negotiating to acquire from the Simplot Corporation. The Buckley water rights were secured, totaling 1,536.58 acre-feet. However, negotiations between Simplot and Ecology broke down and those rights were

not acquired.

Since that time, Ecology has acquired two water rights termed the "Byerly" water rights, totaling 230.65 acre-feet, bringing Ecology's trust water holdings to 7 cfs and 1,767.23 acre-feet. The difference between Ecology's Buckley and Byerly trust water holdings and the 8 cfs and 5,781.6 acre-feet described in Section 2 above, is 1 cfs and 4,014.37 acre-feet.

OCR is beginning a permitting effort for water made available through its Lake Roosevelt Incremental Storage Release Projects. Ecology holds 25,000 acre-feet of water in trust for municipal, domestic, and industrial purposes. Mitigation water is available from this project from April to August. Ecology agrees to make 13.25 cfs and 4,014.37 acre-feet available to fulfill its mitigation obligations under the Quad Cities permit. These quantities are shown in Appendix B. While permits issued based on the mitigation provided by the Lake Roosevelt project are permanent, the mitigation supply is not; Ecology must replace its 25,000 acre-feet of trust water holdings in the future with another supply source. In that event, Ecology will notify Quad Cities of opportunities to participate in the permitting and environmental review for such decisions. The Parties agree to amend Section 3 and Appendix B of this MOA at that time to reflect the change in mitigation source, and potentially the timing of availability; however, the quantities agreed to herein are expected to remain unchanged.

4. **McNary Pool Defined:** The 2003 Settlement Agreement (Page 3) states that the Buckley water rights and Simplot water rights (if acquired) place of use were to be modified to "the McNary Pool of the Columbia River". Further, if the Simplot rights were not acquired, then "other water rights from the McNary Pool" were to be acquired and put into trust. The Buckley and Byerly rights acquired to-date (and Simplot water not acquired) were originally diverted from the Walla Walla River, in a location such that the trust water benefit to McNary Pool accrued on the order of days later. The Parties agree that the Lake Roosevelt water described above provides equivalent benefit to the McNary Pool as contemplated in the 2003 Settlement Agreement. Lake Roosevelt authorizations used for Quad Cities mitigation will reflect delivery of water to the McNary Pool of the Columbia River from approximately River Mile 292 to River Mile 346.

5. **New Water Right Applications:** Section 9 (Page 5) of the 2003 Settlement Agreement required the Quad Cities to "*withdraw all pending applications for new water rights except for certain groundwater applications that are for supplemental rights for alternate places of withdrawal*". However, since execution of the 2003 Settlement Agreement, the legislature passed RCW 90.90 and formed the Office of Columbia River, which created water supply development and permitting options not originally contemplated by the

Parties.

Under this 2011 Quads MOA, the Parties agree on the following framework for the submittal of new water right applications:

- **a.** **<u>Project-Specific Applications:</u>** Any individual city may file:
    - **i.** A project-specific water right application associated with a joint City-OCR water supply development partnership. An example of a project of this nature is the City of Kennewick – OCR Aquifer Storage and Recovery project, for which a reservoir application has been filed and a preliminary permit issued. In the event that new water supply is made available from such a project, such quantity in acre-feet shall be allocated in the same manner as for Non-Project-Specific Applications below.
    - **ii.** A new water right application for additional instantaneous capacity only (no additive annual allocation) without affecting annual allocations amongst the Quad Cities.
- **b.** **<u>Non-Project-Specific Applications:</u>** Unless partnering with OCR on specific projects or filing for source redundancy applications in Section 5a above, the Quad Cities shall file new water right applications jointly and consistent with the planning demands outlined in the Regional Water Forecast and Conservation Plan updates, and the 2000 Final Supplemental Environmental Impact Statement. As part of the

negotiation of this MOA, the Quad Cities will file the first of such applications. The Quad Cities shall reserve the right to allocate water awarded under such applications amongst themselves consistent with the planning objectives outlined in the Regional Water Forecast and Conservation Plan updates. If Project-Specific Applications for individual cities are also granted, then the Quad Cities shall coordinate how such individual water right permits affect regional water availability. Non-Project-Specific Applications are subject to the following guidelines:

i. **<u>Mitigation Water:</u>** A new water right may be granted to provide mitigation water for consumptive use impacts associated with Permit S4-30976P. Such water right may be in the form of a new water right permit, a trust water certificate, a reservoir permit, or other appropriate authorization for the project.

ii. **<u>In-Lieu Water:</u>** Ecology may develop water supplies with mitigation requirements that are deemed "superior" to those in Permit S4-30976P. In such cases, the Quad Cities may receive a permit in exchange for the voluntary cancellation of an equal amount of Permit S4-30976P.

iii. **<u>Priority Date:</u>** Consistent with RCW 90.03.340, the priority date of such applications filed by the Quad Cities or individual cities that are a party to this 2011 Quads MOA is the date of the filing of the application. OCR shall follow WAC 173-152 in the processing of water right applications filed. However, if OCR holds a trust water right, it reserves the right to assign portions thereof to Quad Cities as mitigation water so long as the objectives of RCW 90.90.020 are met.

6. **<u>Future Water Supply Development Partnership:</u>** The Parties agree to partner opportunistically on water supply development projects that meet the objectives of this 2011 Quads MOA. It is anticipated by the Parties that water supply development costs will be project-specific; if Quad Cities elects to receive water under the OCR Program beyond the 6 cfs and 4,336.2 acre-feet of water for the first increment described in Section 2, OCR may recover direct costs for such water supply from the Quad Cities consistent with RCW 90.90. The goal of the Parties is to ensure uninterrupted growth consistent with Permit S4-30976P, and to have a reasonable, non-speculative quantity of water in reserve to bridge the gap between water supply development alternatives.

7. **<u>City of Pasco and City of West Richland Water Right Deficits Resolved:</u>** In the past, Ecology, the City of Pasco, and the City of West Richland have disagreed about commitments to resolve water right deficits (aka "holes") that pre-dated the issuance of Permit S4-30976P and the 2003 Settlement Agreement. By virtue of a water supply project funded by OCR and the associated 2011 Pasco MOU, the City of Pasco agrees all "hole" issues have

been resolved to its satisfaction. The City of West Richland agrees all "hole" issues have been resolved to its satisfaction based on the following:

a. Ecology's processing of numerous change decisions in 2008 providing for greater source flexibility amongst city sources and water rights.
b. Ecology's issuance of new water right permit G4-35203P to the City in 2010 for 1,650 gpm (additive to existing rights) and 2,661 acre-feet (non-additive to existing rights).
c. Ecology and the City's agreement in this MOA regarding pending City applications G4-32304 and G4-32395 as follows:
    i. Ecology and the City agrees the intent of modifying application G4-32304 and G4-32395 to a supplemental designation was to provide an alternate, but non-additive source of water for the Quads permit (S4-30976P).
    ii. If a quantity of water is approved by Ecology for application G4-32304 and G4-32395, then an equal quantity of Permit S4-30976P would be cancelled and a superseding permit issued.
    iii. Ecology agrees it will begin processing application G4-32304 and G4-32395, or will otherwise modify existing Permit G4-35203P[2], to meet the goal of issuing 2,800 gpm and 4,531 acre-feet of water additive to the existing groundwater rights, but with a commensurate reduction of 2,800 gpm and 4,531 acre-feet from Permit S4-30976.

[2] If Permit G4-35203P is modified to accomplish this goal, then the face sheet of the permit will reflect that the 2,661 acre-feet authorized is now additive, so long as 2,661 acre-feet of water from Quads Permit S4-30976P is similarly reduced.

iv. Consistent with RCW 90.03.290, Ecology can only approve applications where water is available, will not impair other rights or the public interest, and is for a beneficial use.

v. West Richland understands that the groundwater being requested is in an area with uncertain recharge and with a history of complaints regarding declining water levels that have necessitated deepening of pump depths. If Ecology processes less than 2,800 gpm and 4,531 acre-feet in new groundwater applications or permit amendments, Ecology and West Richland agree to enter into negotiations for OCR-funding of a feasibility study for a potential aquifer storage and recovery project.

8. **Regulatory Actions Not Constrained**: To the extent this MOU contemplates Ecology taking regulatory action on any application, permit, certificate, or other document, the parties understand that Ecology must make decisions consistent with legal requirements, notwithstanding this MOU. The parties further understand that such decisions are subject to possible appeal by other parties, and that if an appeal alters or reverses a decision by Ecology, Ecology shall be relieved of any obligation to the contrary under this MOU.

9. **MOU Not a Binding Contract**: This MOU is intended only to improve intergovernmental coordination and is not intended to and does not create a legally binding contract or any right or benefit, substantive or procedural, enforceable at law or in equity by any party against another party, its

directors, officers, employees or other persons. This MOU does not constitute an explicit or implicit agreement by the parties to subject the other party to the jurisdiction of any federal or state court over and above any rights or procedures presently available to the parties. This MOU shall not be construed to create any right to judicial review involving the compliance or noncompliance of the parties with the MOU.

10. **No Commitment Except as Authorized**: Nothing in this MOU shall be construed as committing any party to actions for which it lacks authority. All actions and schedules called for by this MOU are subject to and contingent upon the availability and allocation of future appropriations, existing and future limitations on a party's statutory authorities, and state and federal regulatory approvals as needed.

11. **Principle of Construction**: This Agreement has been prepared jointly by the parties following negotiations between them. The parties were represented by legal counsel of their choosing. It shall be construed according to its terms and not for or against any of the parties.

MOU Acceptance By:

Representing the Washington State Department of Ecology:

Date 12/15/11

Derek Sandison, Director
Office of Columbia River

Representing City of Kennewick:

Peter M. Beaudry

Date 12/12/2011

Peter M. Beaudry
Director of Public Works
City of Kennewick

Representing City of Pasco:

Date 12/13/2011

Ahmad Qayoumi
Public Works Director
City of Pasco

Representing City of Richland:

Date 12/9/2011

Peter Rogalsky
Public Works Director
City of Richland

Representing City of West Richland:

Date 12/9/2011

Roscoe C. Slade III
Public Works Director
City of West Richland

Appendix A: Buckley and Byerly Water Rights Summary

Name	Water Right	Consumptive Use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Buckley	4672-A	cfs	0.00	0.00	0.00	1.47	1.47	1.47	1.10	0.00	1.10	0.00	0.00	0.00	
		ac-ft	0.00	0.00	0.00	87.32	90.23	87.32	21.78	0.00	65.34	0.00	0.00	0.00	351.98
Buckley	8416-A	cfs	0.00	0.00	0.00	0.00	0.39	0.39	0.00	0.00	0.39	0.39	0.00	0.00	
		ac-ft	0.00	0.00	0.00	0.00	23.94	23.17	0.00	0.00	23.17	21.62	0.00	0.00	91.89
Buckley	1275-A(A)	cfs	0.00	0.00	0.00	1.39	1.39	1.39	0.00	0.00	1.02	2.13	0.00	0.00	
		ac-ft	0.00	0.00	0.00	49.54	85.32	41.28	0.00	0.00	32.31	126.52	0.00	0.00	334.98
Buckley	3099-A	cfs	0.00	0.00	0.00	0.85	0.85	0.85	0.00	0.00	0.85	0.85	0.85	0.00	
		ac-ft	0.00	0.00	0.00	50.49	52.17	50.49	0.00	0.00	50.49	52.17	13.46	0.00	269.28
Buckley	6417-A	cfs	0.00	0.00	0.00	0.00	0.76	0.76	0.00	0.00	0.76	0.76	0.00	0.00	
		ac-ft	0.00	0.00	0.00	0.00	46.65	45.14	0.00	0.00	24.08	46.65	0.00	0.00	162.52
Buckley	9537-A	cfs	0.00	0.00	0.00	0.00	1.77	1.77	0.00	0.00	1.77	1.77	0.00	0.00	
		ac-ft	0.00	0.00	0.00	0.00	108.64	52.57	0.00	0.00	56.07	108.64	0.00	0.00	325.93
Byerly	5283	cfs	0.356	0.356	0.356	0.303	0.303	0.303	0.231	0.231	0.231	0.356	0.356	0.356	
		ac-ft	21.85	19.74	21.85	17.99	18.59	17.99	14.33	14.19	13.73	21.61	21.15	21.85	224.87
Byerly	3605B	cfs	0.010	0.010	0.010	0.007	0.007	0.007	0.005	0.005	0.005	0.010	0.010	0.010	
		ac-ft	0.62	0.56	0.62	0.41	0.43	0.41	0.30	0.30	0.29	0.61	0.60	0.62	5.78
		Peak Rate (cfs)													**7.00**
		Monthly Total (ac-ft)	22.47	20.30	22.47	205.75	425.96	318.37	36.42	14.49	265.48	377.82	35.21	22.47	**1767.23**

Appendix B: Buckley, Byerly and Lake Roosevelt Water Rights Summary

Name	Consumptive Use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Buckley and Byerly	cfs	0.37	0.37	0.37	4.02	6.94	6.94	1.34	0.24	6.13	6.27	1.22	0.37	6.94
	ac-ft	22.47	20.30	22.47	205.75	425.96	318.37	36.42	14.49	265.48	377.82	35.21	22.47	1767.23
Lake Roosevelt	cfs	0.00	0.00	0.00	13.25	13.25	13.25	13.25	13.25	0.00	0.00	0.00	0.00	13.25
	ac-ft	0.00	0.00	0.00	787.13	813.37	787.13	813.37	813.37	0.00	0.00	0.00	0.00	4014.37
Total	cfs	0.37	0.37	0.37	17.27	20.19	20.19	14.59	13.49	6.13	6.27	1.22	0.37	**20.19**
	ac-ft	22.47	20.30	22.47	992.88	1239.33	1105.50	849.79	827.86	265.48	377.82	35.21	22.47	**5781.60**

Amended Appendix A: Buckley and Byerley Water Rights

Name	Water Right	Consumptive Use	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Total
Buckley	4672-A	Maximum (cfs)				1.73	1.73	1.73	1.30	1.30	1.30				
April 1 – Oct 1* Oct 1 – April 1** (original Season of use)		Continuous (cfs)				0.98	0.65	1.17	1.30	1.30	0.85				
		Acre-feet	0.0	0.0	0.0	32.88	40.24	69.54	79.93	79.93	50.48	0.0	0.0	0.0	**353.0**
Buckley	8416-A	Maximum (cfs)					0.46	0.46	0.46	0.46	0.46	0.46			
No season given*		Continuous (cfs)					0.17	0.30	0.44	0.34	0.22	0.03			
		Acre-feet	0.0	0.0	0.0	0.0	10.60	18.30	27.5	21.37	13.28	1.95	0.0	0.0	**93.0**
Buckley	1275A(A)	Maximum (cfs)				1.73	1.73	1.73	1.30	1.30	1.30				
April 1 – Oct 1*		Continuous (cfs)				0.89	0.64	1.14	1.30	1.29	0.82				
		Acre-feet	0.0	0.0	0.0	29.91	39.34	68.00	79.93	79.40	49.02	0.0	0.0	0.0	**345.6**
Buckley	3099-A	Maximum (cfs)				1.00	1.00	1.00	1.00	1.00	1.00	1.00			
When available*		Continuous (cfs)				0.57	0.50	0.90	1.00	1.00	0.63	0.09			
		Acre-feet	0.0	0.0	0.0	19.28	30.89	53.39	61.50	61.50	38.75	5.69	0.0	0.0	**271.0**
Buckley	6417-A	Maximum (cfs)					0.89	0.89	0.85	0.85	0.85	0.85			
Year around*		Continuous (cfs)					0.28	0.50	0.73	0.57	0.37	0.52			
		Acre-feet	0.0	0.0	0.0	0.0	17.31	29.91	44.97	34.93	21.72	3.16	0.0	0.0	**152**
Buckley	9537-A	Maximum (cfs)				2.60	2.60	2.60	0.0	0.0	0.0				
April 1 – July 1		Continuous (cfs)				1.81	1.81	1.81	0.0	0.0	0.0				

Amended Appendix A: Buckley and Byerley Water Rights

Name	Water Right	Consumptive Use	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Total
Oct 1 – Apr 1***		Acre-feet	0.0	0.0	0.0	107.47	111.05	107.47	0.0	0.0	0.0	0.0	0.0	0.0	**326.0**
Name	**Water Right**	**Consumptive Use**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Byerley	5283	Continuous rate (cfs)	0.356	0.356	0.356	0.303	0.303	0.303	0.231	0.231	0.231	0.356	0.356	0.356	
		Acre-feet	21.85	19.74	21.85	17.99	18.59	17.99	14.33	14.19	13.73	21.61	21.15	21.85	**224.9**
Byerley	3605B	Continuous rate (cfs)	0.010	0.010	0.010	0.007	0.007	0.007	0.005	0.005	0.005	0.010	0.010	0.010	
		Acre-feet	0.62	0.56	0.62	0.41	0.43	0.42	0.30	0.30	0.29	0.61	0.60	0.62	**5.8**
Total Peak Rates (cfs)			**0.37**	**0.37**	**0.37**	**7.37**	**8.72**	**8.72**	**5.15**	**5.15**	**5.15**	**2.68**	**0.37**	**0.37**	
Duration at peak rate (days)**			(31)	(28)	(31)	(14.20)	(15.52)	(21.11)	(30.20)	(28.55)	(18.33)	(6.21)	(30)	(30)	
Total Continuous Pump Rate (cfs)			**0.37**	**0.37**	**0.37**	**4.56**	**4.36**	**6.13**	**5.01**	**4.74**	**3.13**	**0.54**	**0.37**	**0.37**	
Monthly Total (acre-feet)			**22.47**	**20.3**	**22.47**	**207.94**	**268.45**	**365.02**	**308.46**	**291.62**	**187.27**	**33.02**	**21.75**	**21.75**	**1771.3**

*The season-of-use given for each of the Buckley water rights above is the season-of-use on the original water right certificates (Also mentioned in Table 5 of the Quad Cities ROE). However, consumptive use of water on the Buckley property took place during the traditional April to October irrigation season (infra-red photo evidence). Often water is not needed until May. Therefore, the historic pattern of use for the Buckley water rights is represented in the table above not the original water right certificates' seasons-of-use.

**This period of use only applied when water wasn't available to fulfill the right between April 1st and October 1st.

***This water right didn't provide water during the months of July, August and September. The trust water right also excluded these months up to September 15th.

ATTACHMENT D

Memorandum of Agreement for Management of Quad Cities Water Right and Related Program

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August 18, 2005

Memorandum of Agreement for Management of Quad Cities Water Right and Related Program

I. Purpose and Objective

This Memorandum of Agreement (MOA) is for the purpose of managing the area's water resources and Quad Cities water rights required to meet the public water supply needs of the Urban Growth Area and related water service areas. The primary objectives are:

1. To provide for regional management and supply development strategies, joint supply projects, and system interties that ensure that the Urban Growth Area water needs and water rights are planned and developed in a coordinated manner.
2. To define the criteria, development schedule, place of use, water use efficiency objectives, and procedures to be followed by the four Cities in developing the Quad Cities water rights required to meet the Urban Growth Area needs.
3. To manage the withdrawal and return of water resources to the Columbia River and area aquifer consistent with the conditions associated with the Quad Cities water rights and other local plans.

II. Parties to Agreement

This MOA is between the Cities of Kennewick, Pasco, Richland, and West Richland hereafter referred to as the "Cities," and the "Parties" to the MOA.

III. Urban Growth Area – Place of Use

For the purposes of this MOA and to establish in all future urban area water right applications, a place of use of the Quad Cities' water right is generally defined as the Urban Growth Area and adjacent rural service areas, as jointly defined by the four Cities under the provisions of the State Growth Management Act in 1997, and as subsequently amended. The place of use shall include as a minimum the area shown on Figure 1 on the Quad Cities Water Right Permit, or as amended by the Cities State approved Water System Plans.

If the Cities' water resources management and supply development plan utilizes land application or aquifer recharge areas located in rural areas adjacent to the Urban Growth Area, the expanded resource management area shall be considered integral to this Agreement's definition of Place of Use.

IV. Urban Growth Area Demand Projection

For the purposes of this MOA, the projected average day, maximum day, and instantaneous demand for water right purposes shall be based on the current "Regional Water Forecast and

Conservation Plan (RWFCP) for the Cities of Kennewick, Pasco, Rich[redacted]nd prepared to be consistent with the Quad Cities water rights condition.

The RWFCP shall be incorporated by the four Cities into their State-approved Water System Plans and their Comprehensive Plans as the water supply element. The four Cities agree to update the RWFCP at least every six years and to project their water supply needs for a minimum of 5, 10, 20, and 50 years. The Department of Health has established 2009 as the required next update to the individual Water System Plans.

The June 2000 Regional Water Supply Plan projections shall be used until a new RWFCP is approved by the Cities except as modified by the MOA.

V. Water Use and Water Conservation

The Cities agree to jointly develop a regional conservation plan and incorporate in their individual Water System Plans a demand management and water conservation plan that meets the condition of the Quad Cities water right and the criteria established jointly by the Department of Ecology (Ecology) and Department of Health.

The Cities agree to organize their common data collection system in 2004 and begin to collect the data in 2005. The 2005 data through 2007 will be used to update the RWFCP in 2008 for use in the 2009 Water System Plan Update. The State required six-year update cycle will then guide future updates.

VI. System Interties and System Reliability

The Cities will outline a regional supply development and intertie program to optimize use of existing supply systems. Where surface and ground water continuity exists a conjunctive use strategy will be outlined to minimize localized impacts on instream uses. To accomplish maximum system flexibility and reliability, a system of interties between the four Cities will be evaluated and expanded if found to be beneficial for the objectives of this MOA. The Cities will define prior to the next update to their WSP, an intertie program that would enable the Cities to wholesale/transfer supplies between the four systems and the irrigation districts.

VII. Water Right Allocation – Quad Cities Water Right

Each of the Cities currently holds water rights that partially meet their long-term needs.

The Cities agree to allocate the Quad Cities water rights based on updated and projected demands (base allocation), with the balance placed in an unallocated "Quad-Cities Water Reservation Account."

The original projected demands were established in the Regional Water Supply Plan, June 2000. The June, 2000 demand projection shall be considered the base allocation until a revision is accepted by the MOA Water Committee. The June, 2000 base allocation will be revised in the 2008 RWFCP approved by the Cities using the information referenced in Section V and in subsequent RWFCP demand forecasts. Future RWFCPs will establish the six-year and 20-year water demands for each City and will define how much Quad Cities water right is required to meet the City's needs. The first 10 cfs of Quad Cities' water right appropriation has been mitigated by the State, with each City receiving 2.5 cfs of mitigation credit. When additional Quad Cities' water right (greater than 10 cfs) is required, and additional mitigation cost is assigned, the City that requires the mitigated water right is responsible for the mitigation cost.

The demand projections of the Cities will be based on the same methodology and reviewed and approved by the MOA Water Committee.

If the water rights in the Water Reservation Account are fully committed and one of the other Cities' base allocation is not committed, the MOA Water Committee may, by unanimous vote, direct that a portion of the base allocation water right from S4-30976P be reallocated to meet the City's newly documented demand.

The four Cities will jointly manage the urban area water resources and seek additional water rights for the area identified as the place of use for the Quad Cities water right in the future if existing rights are not adequate to meet the Urban Growth Area needs.

VIII. Accumulative Water Rights – Applications and Use

Consistent with the objectives of this MOA, the Parties to this MOA will seek to manage the existing and future municipal and industrial water rights held by the four Cities for the collective use of the Urban Growth Area. The water rights of each City will be held by that City for their use. The accumulative instantaneous and annual quantities for the four Cities for the Urban Growth Area will be used by Ecology to monitor the water use authorized by water right documents in common, prior to the use of the Quad Cities water right that may require mitigation. The Quad Cities water right is held in the name of the four Cities, and therefore, this MOA is the management document to allocate mitigation cost and reallocate use of the Quad Cities water right as use patterns and needs may change. Once a City's demand and supply plan is accepted by the MOA Water Committee and the Water System Plan is approved by the State, the allocation of the initial 2.5 cfs to each of the Quad Cities' water right and any subsequent allocations to a City will continue indefinitely, unless the City has determined for itself that it no longer has a need for the water right.

IX. MOA Water Committee

The public works director of each City or their designee shall represent their City on the MOA Water Committee. The Water Committee shall meet at least quarterly to coordinate the regional water supply program, monitor projections, prepare the RWFCP, and implement this MOA.

The Water Committee shall consider requests for reallocation of water rights held in the Water Reservation Account. The request from any participant City for an additional allocation or reallocation of water shall be based on documented water demands that will meet growth needs, create new jobs, and that are reflective of the economic and growth management strategies incorporated in the City's adopted Comprehensive Plan.

If an unresolved conflict occurs, the parties agree to select an independent party to review and mediate the debate and recommend a non-binding solution. If any recommendation or proposal would change ownership or the planned use of any portion of the Quad Cities water right, such change shall be presented to the City Councils for approval prior to approval by the Water Committee.

The vote of the Water Committee shall be presented to Ecology as a unanimous finding if the request is consistent with this MOA and related State laws.

X. Cost Sharing

The Cities agree to share the cost equally for the preparation of the RWFCP and future updates. The Cities will individually be responsible for collecting and assembling the specified data for the RWFCP. Implementation of the common programs of the RWFCP will be allocated by the MOA Water Committee based on the benefits received by each City, including any joint staffing plan.

The mitigation cost associated with the use of the Quad Cities water right will be allocated annually to the benefiting City after adjusting for the 10 cfs mitigated water right assigned equally to each City.

XI. Application and Changes Processed

The Cities agree to prepare the necessary documents for approval by the State to process all necessary changes and applications in a timely manner in accordance with State law.

XII. Modification and Term of MOA

The MOA will continue unless terminated by mutual agreement by all signators. It is the intent of all parties that if one City wished to have the MOA terminated the remainder of the unassigned water in Permit S4-30976 will be assigned to the Water Reservation Account and will remain with the Cities continuing to participate in the MOA.

City of Kennewick	9/28/2005 Date	City of West Richland	10-11-05 Date
City of Pasco	11-8-05 Date	City of Richland	9/22/05 Date

Table 4.1 from June 2000 Regional Water Plan

This table was prepared and adopted by the Parties as part of the June 2000 Regional Water Plan (Table 4-1). In accordance with the MOA, the parties will update the 2015 and long term demand forecast, the water rights held by each city, and the water rights required by each city from the "Quad Cities Water Right Reserve Account" for 2015. The balance of the Quad Cities water right will be held in the Reserve Account until the MOA water committee reallocates water rights in accordance with the MOA. The updated table is shown as Table F-3.

Table F-1
Regional Demand, Water Rights, Deficiencies, and Water Bank (MGD)

City	Demand (MGD)		Water Rights (MGD)		Peak Day Deficiencies		Proposed Assignment of 178 Qa Rate [3] [5] [6]	
	2015 Avg Day/Pk Day	2045 Avg Day/Pk Day	Qa	Qi	2015[2] MGD/cfs	2045 MGD/cfs	2015 MGD/cfs	2045 MGD/cfs
Kennewick	23.6/46.0	43.8/87.0	14	38	8/12.3	49/75.8	8/12.3	
Pasco	17.3/38.1[1]	38.7/85.1[1]	6.8	23.6	14.5/22.4	61.5/95.1	14.9/23	
Richland	30/58	55/105	29	58	0	47/72.7	23.5/36.4	
West Richland	4.3/9.4	10.3/22.7	2.8	4.3	5.1/7.8	18.4/28.4	5.1/7.8	
Totals	75.2/151.5	147.8/299.8	52.6[4]	123.9	27.6/42.5	175.9/272	51.5/79.5	63.5/98.5

(1) Based on 2.2 peaking factor.

(2) These deficiency figures for the year 2015 represent the initial assignment of water under application S4-30976A for 178 cfs (115 MGD). Some of the pending groundwater rights are not included in this total.

(3) This column assigns the water right quantities (subject to modification, as appropriate, dependent upon future comprehensive planning) remaining (63.5 MGD/99.3 cfs) after 2015 deficiencies and the Richland assignment have been deducted. The remaining water right has then been retained for the Urban Growth Area without designations to a city pending future joint assignment and demonstrated location of new demands requiring additional supply.

(4) The Qa equals 58,919 AF/yr.

(5) A Memorandum of Agreement (MOA) between the four Cities establishes the method of assigning the unallocated amounts and reallocating the year 2015 assignments if the current demand projections shift in location to one of the other Cities.

(6) The Qa available for S4-30976A equals 31,481 mg or 96,619 AF/yr based on pumping at a rate of 178 cfs for an average of 18 hours per day. The peak day related to the water right is 2.2 x 115 MGD = 253 MGD. The peak hour is 3.0 x 115 = 345 MGD.

Table F-2
Domestic Water Summary
Calculation of Net Consumptive Use by Quad Cities

Source of Supply Meter Readings in MG													
Kennewick	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pasco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Richland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
West Richland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Water System Pumpage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peak Day in MG (During Peak Month)													
Kennewick													
Pasco													
Richland													
West Richland													
Non-Revenue Water in MG (Estimated)													
Non-Billable Water - Unmetered Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Accounted for Water in MG (Service Meter Readings + Non-Revenue + Emergency Interties (Exp.) + Wholesale (Exp.))	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unaccounted for Water in MG (Total Pumpage - Total Accounted for + Emergency Interties (Imp.) + Wholesale (Imp.))	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Percent Unaccoutned for Water (Annual) (Total Pumpage - Total Accounted for)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Estimated Population Served (Average Annual)													
Total Served													
City Population Only													
Estimated Number of Connections													
Single-Family Residential Connections													
Multi-Family Residential Connections													
Commercial/Industrial Connections													
Municipal/Government Connections													
Agricultural (Not above classes)													
Total Active Water System Connections													
Return Flows in MG (Estimated)													
Wastewater Treatment Plants	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Septic Systems (Excl. return from exempt wells)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation (excludes water from IDs)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Return Flows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Withdrawals in MG (Pumpage + Wholesale Exported - Return)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Use/All Water Rights	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Use/All-Excluding Quad Water Rights	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Use (Quad Cities Water Rights)	0	0	0	0	0	0	0	0	0	0	0	0	0

Colored cells represent calculated values

Table F-3
Regional Demand, Water Rights, Deficiencies, and Water Bank (MGD)

City	Demand (MGD)		Existing Water Rights (MGD)		Peak Day Deficiencies		Proposed Assignment of 178 Qa Rate [3] [5] [6]	
	2015 Avg Day/Pk Day	2045 Avg Day/Pk Day	Qa	Qi	2015[2] MGD/cfs	2045 MGD/cfs	2015 MGD/cfs	2045 MGD/cfs
Kennewick								
Pasco								
Richland								
West Richland								
Totals								

(to be completed as a part of the 2008 RWFCP)

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