City of Ellensburg

ASR PREFEASIBILITY STUDY

Submitted to:

Ecology Agreement No. WRYBIP-213-EllePW-00022

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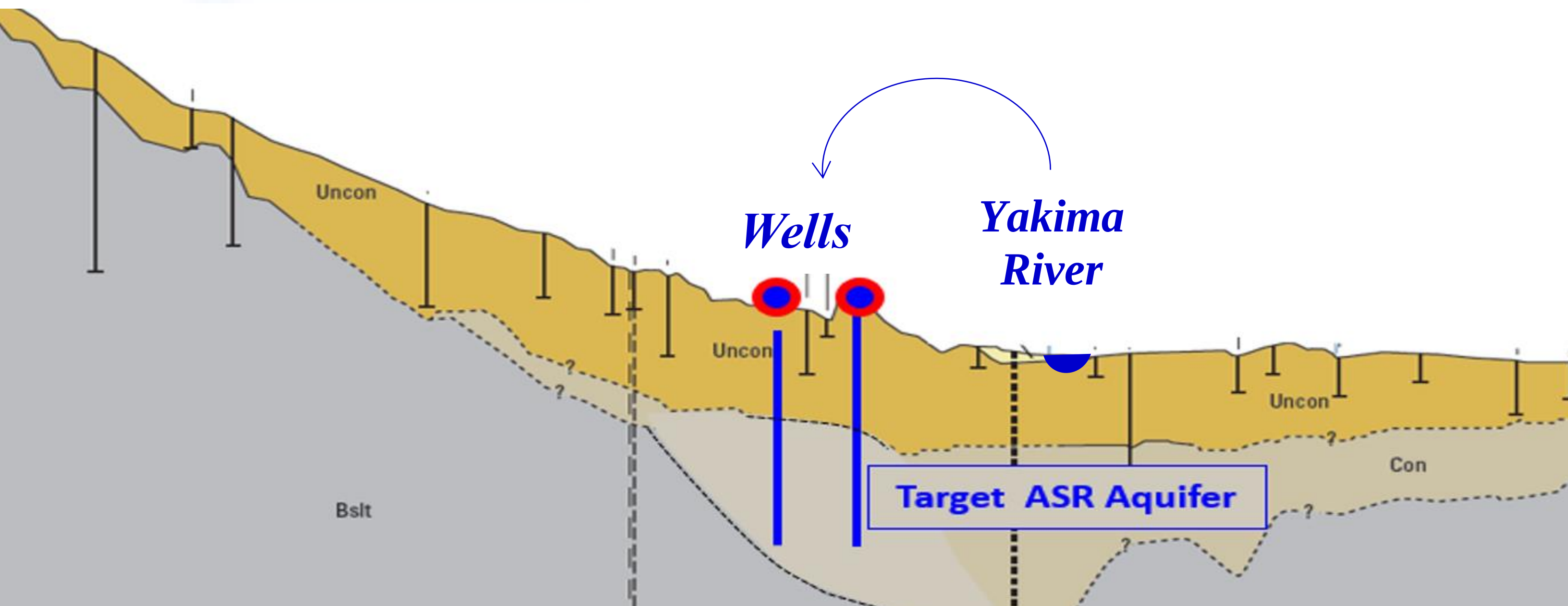
Prepared by:



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L.Hg. expires May 22, 2022

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Cover image from Jones and others (2006) modified with Pitre and Holom (2009a and 2009b).

EXECUTIVE SUMMARY

This study focuses on the City of Ellensburg's proposed concept for Aquifer Storage and Recharge (ASR) in the Kittitas Valley: the recharge of Yakima River water into the Upper Ellensburg Formation via existing City-owned wells. This study includes a compilation and synthesis of readily available information regarding the feasibility of development of an ASR project. Some information has not been accessed due to limitations of time and budget. Our evaluation reveals important considerations and no serious impediments to development of the project. Benefits of the ASR program will secure municipal water supply, provide salmonid aquatic habitat, and increase the Total Water Supply Availability (TWSA) in the Yakima Basin. Coho recommends proceeding with an ASR pilot test to further inform the viability of an ASR program and permitting.

HYDROGEOLOGY / GROUNDWATER STORAGE CAPACITY: The hydrogeology of the Kittitas Valley is favorable for ASR. Original groundwater levels were flowing artesian in parts of the valley. Current groundwater levels are generally 20 to 100 feet below ground surface. Potential static groundwater storage volume ranges between 1,600 and 77,000 acre feet, based on aquifer storage (S) and specific yield (S_y), respectively. Groundwater pumping data indicate a dynamic annual groundwater storage of greater than 60,000 acre-feet/year (afy). The groundwater storage capacity in the Ellensburg Formation of the Kittitas Valley is estimated to be 61,600-137,000 afy.

The low aquifer storage (S), the volume of annual groundwater pumping, and the slowly declining groundwater levels over decades suggest that flow through the aquifer is quick – possibly less than ten years. Impacts, both positive and negative, from ground water pumping and aquifer recharge to deep portions of the aquifer system, are expected to accrue to the Yakima River at the head of the Yakima Canyon near Thrall.

INFRASTRUCTURE RECHARGE CAPACITY: The practical volume of water that can be recharged will be limited by available facilities, and not by aquifer properties, other than the rate of recharge by individual wells. The City of Ellensburg's City Wells facility (a Ranney-type well), in close hydraulic continuity with the Yakima River, is the proposed source of recharge water. It has historically produced about 5,000 gallons per minute (gpm; 11 cubic feet per second [cfs]).

The recharge capacities of individual existing wells are estimated to be in the range of 300-1,000 gallons per minute (gpm) based on depth to groundwater and well yields. Existing wells that are candidates for recharge are the Route 10, Hayward and Illinois Wells because they have production casing surface seals extending 300 to 600 feet below ground surface. Purpose-built wells for ASR may be installed for additional recharge capacity. Anderson and others (2008) assumed a recharge rate of 2,000 gpm per well, through four wells, for half of the year, or 6,000 afy.

RESIDENCE TIME OF RECHARGED WATER: Coho estimates that water recharged to the Ellensburg Formation in the Kittitas Valley will have a storage residence time intermediate between that of a floodplain recharge project with a residence time of weeks to months, and the closed “bathtub” concept commonly associated with recharge to Columbia River Basalt with a residence time of millennia. ASR in the Kittitas Valley is expected to create stored water that can be actively recovered within a few years, thereby contributing to Total Water Supply Available (TWSA), as well as the increased seepage to the Yakima River that will contribute to TWSA and provide thermal refugia in both the summer and winter to salmonids. A groundwater flow model may provide an expanded perspective.

The United States Geological Survey (USGS) modeled groundwater flow across the Yakima Basin, including the Kittitas Valley. The model has not been fully evaluated for its usefulness in the context of an ASR program in Kittitas Valley. The model is complex, focused on the basalts, and may be a valuable tool to evaluate ASR. The model was accessed in this project for pumping data within the Kittitas Valley, courtesy of the Bureau of Reclamation (Reclamation). Data presented in the prefeasibility report supplements and complements the USGS model. The model may be resourced as this project proceeds, with the support of Reclamation. Modeling may be needed to support processing of a groundwater reservoir (ASR) permit, either a refinement of the USGS model, and/or a new model.

WATER QUALITY: No water quality concerns have been identified. City Wells, the source of ASR recharge water, is a permitted drinking water source. Water entering this Ranney-type well undergoes 700 feet of riverbank filtration and is expected to have low total organic carbon concentrations. The City targets a residual chlorine concentration at the City Wells source of 0.25-0.3 milligrams per liter, which is low. Disinfection by-products (DBPs) are non-detect in the City's distribution system. Confirmatory sampling is planned in preparation for an ASR pilot test.

BENEFITS: The identified benefits of an ASR program by the City of Ellensburg are:

- Securing the City of Ellensburg's groundwater drinking water supply.
- Helping to meet YBIP's storage target for municipal supply.
- Providing thermal refugia to salmon at the head of the Yakima Canyon.
- Increasing Total Water Supply Availability (TWSA) at the Parker Gage.
- Possibly providing water for use in markets, such as for drought relief.
- Providing adaptation and resilience to climate change and drought.

ALTERNATIVES: Alternative Managed Aquifer Recharge (MAR) options briefly evaluated included alternate methods of recharge, sources of recharge water, infrastructure, and recharge locations. A new direct surface water diversion is considered difficult to permit. Any direct surface water source, whether new, irrigation canals or an off-channel surface water reservoir (e.g., in the Naneum catchment), may require treatment before recharge. A Surface Aquifer Recharge (SAR) program may have a reduced need for pre-recharge treatment. Seasonal availability of water may be a limitation of irrigation canals and/or an off-channel reservoir.

No viable alternatives to the Ellensburg ASR program have yet been developed. We recommend SAR continue to be evaluated because of the low cost of infiltration facilities.

ASR PILOT TEST RECOMMENDED: We recommend an ASR pilot test using the City Wells as the recharge water source and the Route 10 Well as the recharge well to provide empirical data regarding:

- Proof of concept.
- Water quality, including showing compliance with WAC 173-200A, drinking water criteria, and operational considerations.
- Refinement of the physical parameters of well performance, operations, and aquifer response.

The cost of conducting a pilot test at the Route 10 Well is estimated to be $800,000 (Pitre and Wilhelm, 2021). Half of this cost is attributable to engineering retrofit to connect the source of recharge water (City Wells) to the recharge well. Retrofits for pilot test purposes will also be designed, to the degree feasible, for full-scale implementation of an ASR program. Recharge through the annular space between the pump column and the production casing is considered, as is done in the city of Yakima ASR program. Alternatives will be evaluated in greater detail.

Most of the permitting for pilot testing is in place (i.e., water rights for the recharge and withdrawal of water). A SEPA checklist will be conducted. A pre-application for a new groundwater reservoir water is recommended to ensure common understanding of data to be collected during the pilot test to support a future application.

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1. INTRODUCTION

The City of Ellensburg is considering the development of an Aquifer Storage and Recharge (ASR) project in the Kittitas Valley (Figure 1). This prefeasibility study presents a compilation of readily available information to inform decisions on whether it is worthwhile to further pursue such a project. The ASR program being considered can provide substantive contribution to meet water demand in the Yakima Basin – municipal supply, agricultural irrigation and Total Water Supply Available (TWSA) – and improve habitat conditions for salmonids.

1.1. ASR Program Needs

Requirements for an ASR program are:

1. Appropriate geology.
2. A source of water of acceptable quality to recharge.
3. Infrastructure to deliver and recharge water.
4. A need or benefit.
5. Regulatory compliance.

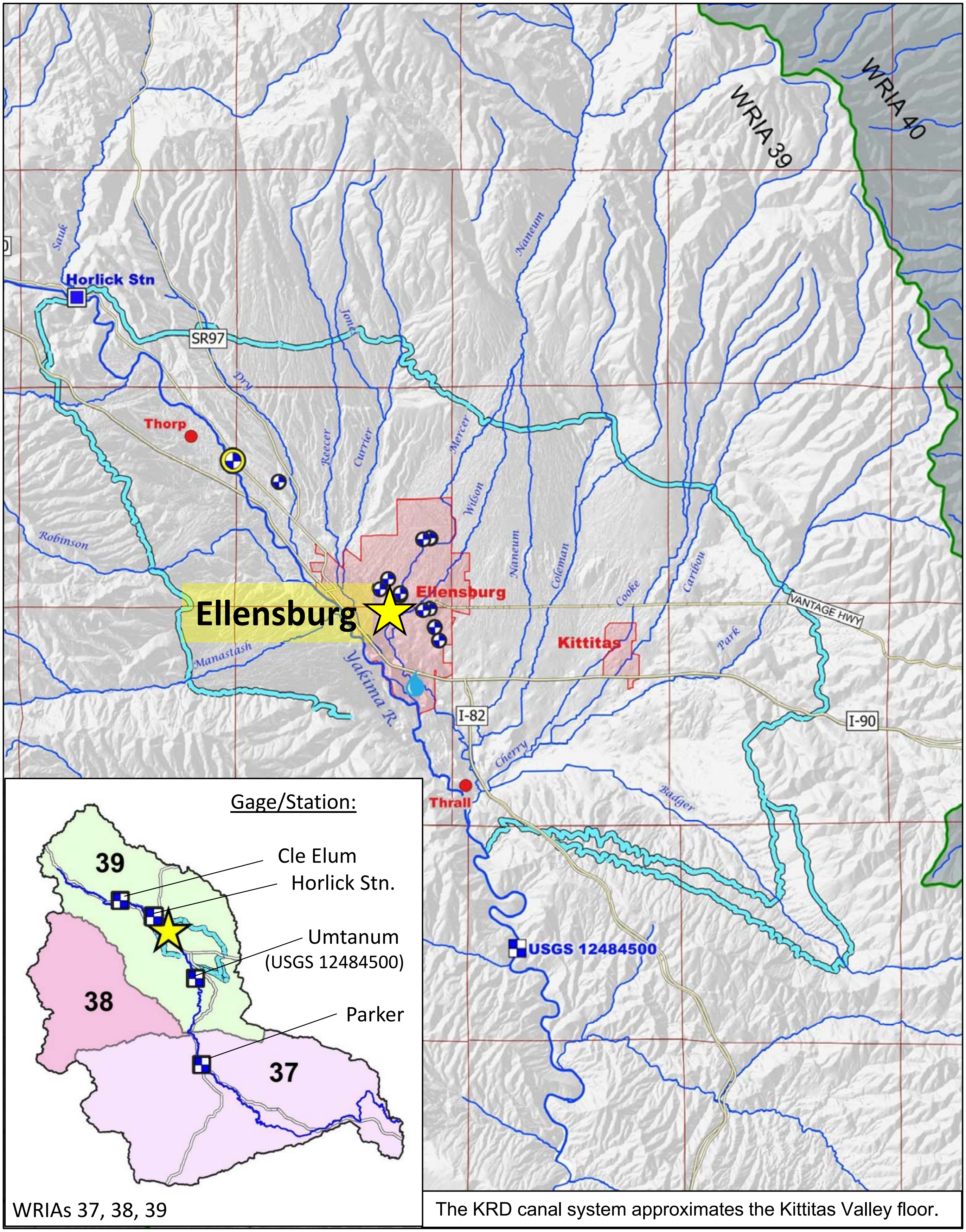
The potential City of Ellensburg ASR program has many of the prerequisites for a viable program, including an aquifer with capacity for additional water, existing available water, and infrastructure to recharge water.

The motivation to implement an ASR program often comes down to a cost/benefit analysis. The principal anticipated benefits of the Ellensburg ASR program are:

- Securing municipal water supply.
- Salmonid habitat thermal refugia.
- Increase in Total Water Supply Availability (TWSA).

The costs are anticipated to include:

- Permitting.
- Retrofit of facilities for ASR function.
- Operation.



The KRD canal system approximates the Kittitas Valley floor.

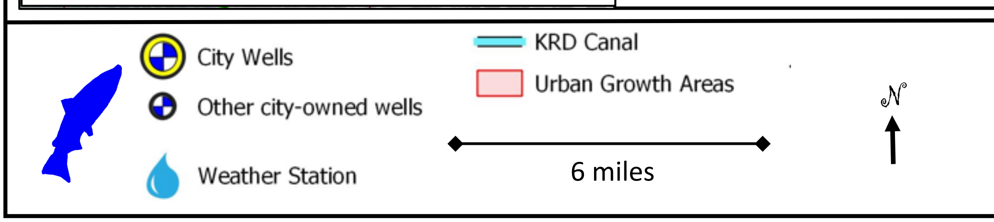


Figure **1**

Location and physiography

City of Ellensburg
ASR Pre-application

1.2. Opportunity & Concept

The City of Ellensburg previously considered ASR in 2001. At that time, insufficient information was available to support a decision to further evaluate this option. Since then, the City has collected data from the installation of four municipal water supply wells (Hayward, Route 10, Airport #3 and Illinois Wells) that has provided information supporting further consideration of an ASR program.

The current concept for the ASR program consists of:

- Using City Wells (Ranney well) as the source of recharge water:
  - This facility is approximately six miles northwest, upstream, of the City.
  - This is a horizontal infiltration gallery in direct hydraulic continuity with the Yakima River.
  - This is an approved drinking water source used by the City for municipal drinking water supply for more than 100 years (since 1913). Water from this source is filtered by 700 feet of aquifer material between the Yakima River and the withdrawal facility, and is designated a groundwater source by the Washington Department of Health (DOH, 2004)
- Delivering water through the City's distribution system to candidate recharge wells. A 24-inch transmission main delivers water from City Wells to the City's service area and is connected to deep production wells.
- Recharging water via:
  - Existing wells retrofitted for ASR.
  - New purpose-built ASR wells.
- Active recovery of recharged water through other wells of the City completed in the recharge formation (Upper Ellensburg Formation), and/or passive recovery by seepage back to the Yakima River.

The city of Yakima's operational ASR program is used as an analogue to that being considered for the City of Ellensburg. Both have similar features:

- Source of recharge water: The city of Yakima has a direct surface water diversion from the Naches River. The City of Ellensburg has a horizontal infiltration gallery in direct hydraulic continuity with the Yakima River.
- Both cities have distribution systems that connect:

  1) A source of surface water to recharge.

  2) Deep wells completed in the Upper Ellensburg Formation through which to recharge and recovery water.

1.3. Previous Work

Studies of groundwater and the potential for Managed Aquifer Recharge (MAR) in the Yakima Basin and the Kittitas Valley have been conducted by:

- Anderson and others (2008): Used the ASR program developed by the city of Yakima as an analogue for the Kittitas Valley and estimated that ASR in the Kittitas Valley could achieve up to 6,000 acre-feet/year (afy) of recharge, and up to 18,000 acre feet (af) in drought year recovery.
- United States Geological Survey (USGS): Conducted an extended study of the Yakima Basin, including the Kittitas Valley, and issued a series of reports culminating in a groundwater flow model of the Yakima Basin. These reports include the following, among others:
    - Estimates of groundwater pumping (Vaccaro and Sumioka, 2006).
    - Groundwater recharge (Vaccaro and Olsen, 2007).
    - Hydrogeological framework (Vaccaro and others, 2009).
    - A groundwater model (Ely and others, 2011)
- Pitre and Austreng (2013): Evaluated Surface Aquifer Recharge (SAR) potential in the East Kittitas Valley.
- United States Bureau of Reclamation (Reclamation; 2018): Updated and used the USGS model to evaluate groundwater recharge scenarios.
- EA Engineering and others (2020): Evaluated possible locations for MAR throughout the Yakima Basin.

1.4. Project Context, Authorization & Scope of Work

Funding for this prefeasibility study is provided by the Washington State legislature to advance the Yakima River Basin Integrated Water Management Plan (YBIP), which works to enhance the water needs of this top agricultural-producing region and important fish-bearing watershed in Washington. Seven elements of the Plan are:

- Fish passage
- Fish habitat enhancement
- Modifying existing irrigation structures and operations
- Surface storage
- Water market-based reallocation (water banks)
- Groundwater storage
- Enhanced water conservation

Responding to years of drought, fish extinctions, and changing climate, the plan takes a holistic approach to the Yakima basin's water needs, integrating water supply projects with fish and habitat enhancement efforts. The seven elements of the Plan include groundwater storage, in recognition of its potential to recharge water when it is available. Storing water in the ground provides the following benefits:

- Restores groundwater.
- Enhances seeps to surface water that provide critical thermal refugia to salmonids.
- Augments surface water and agricultural irrigation water supply (Total Water Supply Available [TWSA]).
- Sustains the source water of drinking water, including municipal water supply.
- May be used in water market-based reallocation (water banks).

Recharged water may be actively recovered through wells when needed and/or allowed to passively seep back to streams to provide habitat and TWSA benefits.

The scope of work of the prefeasibility study is to develop a concept for the City of Ellensburg ASR program, compile existing information, and evaluate the potential water supply benefits to the Yakima Basin Integrated Plan (YBIP). The report presents findings, an ASR concept, and makes a recommendation.

The City of Ellensburg has infrastructure that provides a unique opportunity to implement a groundwater storage project and, with the encouragement of the Groundwater Storage Subcommittee, submitted a proposal for $20,000 to conduct a prefeasibility study of ASR on March 4, 2021. With the endorsement of the Groundwater Storage Subcommittee, Ecology entered into an agreement with the City effective on June 21, 2021 (Agreement No. WRYBIP-213-EllePW-00022).

The City authorized Coho to proceed with conducting the study on June 24, 2021. This work is conducted within the limitations of time and budget. Additional information exists that was not compiled for this report, including information requested from agencies that was not received in time for incorporation.

2. KITTITAS VALLEY SETTING

The Kittitas Valley is located in Water Resources Inventory Area (WRIA) 39 (Upper Yakima) in Central Washington State (Figure 1). This WRIA is one of three WRIAs comprising the Yakima Valley. The valley floor is at ~1,500-2,000 feet above mean sea level (amsl) and is bounded:

- By uplands that lead to the Cascade Mountain Range to the west.
- By rounded basalt ridges to the north and south (up to ~5,500 feet amsl).
- By a low pass (~2,500 feet amsl) to the east opening up to the Columbia Basin.

Vegetation on the ridges above approximately 3,000 feet amsl consists of sparse Ponderosa and lodgepole pines. The natural vegetation on the valley floor is shrub-steppe consisting of grass and sage brush typical of high desert.

2.1. Climate

Average daily high temperatures are 23° F in January and 84° F in July, though excursions below 0° F and above 100° F are common. Precipitation averages 8 inches per year, mostly in the winter, including 21 inches of snow (Figure 2). Several wind power farms have been established around the valley to tap the strong, persistent westerly winds.

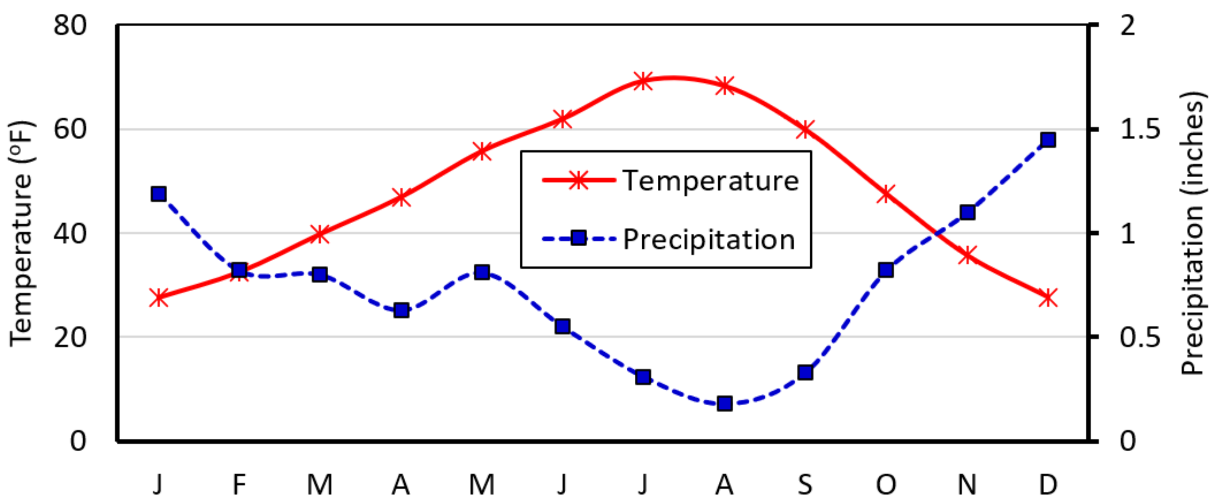


Figure 2: Average temperature and precipitation at Ellensburg.
(1991-2020; https://www.ncei.noaa.gov/access/us-climate-normals/#dataset=normals-monthly&timeframe=30&station=USC00452505)

2.2. Development

The first humans in the valley appeared as long as 9,000 years before present, and possibly earlier. The Kittitas Valley is within the Usual and Accustomed areas for fishing, hunting and gathering of the Confederated Tribes and Bands of the Yakama Nation. European settlers entered the valley in the mid-1800s and established an agricultural industry by the late 1800s – first based on rangeland, and subsequently augmented by agriculture made possible by irrigation canals diverting water from the Yakima River.

Reclamation built a network of reservoirs in the Yakima Basin in the early 1900s to serve a number of irrigation districts, including the Kittitas Reclamation District (KRD). Completion of construction of the KRD irrigation system in 1933 largely shaped the current condition of the valley. The North Branch and South Branch Canals surround the main agricultural cultivated lands of the valley (Figure 1). Hay is the primary crop, though orchards have more recently been installed in response to favorable conditions caused by climate change.

Kittitas County (current population ~40,000) was carved from the northern part of Yakima County and the City of Ellensburg was incorporated in 1883. The population is approximately 21,000, of which about half consists of the student population of Central Washington University.

2.3. Surface Water

Natural streams in the Kittitas Valley are the Yakima River and tributaries, whose hydrographs are strongly influenced by snowpack. Overlain on this natural setting are the operation of reservoirs high in the basin that are operated by Reclamation and dominates the Yakima River hydrograph, and irrigation canal systems throughout the floor of the valley. Local tributaries have relatively low flow rates but provide salmonid refugia (thermal and flow) and habitat.

2.3.1. Yakima River mainstem

The major river of the Kittitas Valley, the Yakima River, flows approximately 20 miles across the valley floor from Thorp in the northwest (Taneum Creek) to Thrall at the head of the Yakima Canyon in the south (Figure 1). The natural hydrograph of the Yakima

River peaked during snowmelt runoff in the spring and decreased to a low in the late summer (Figure 3). This natural hydrograph is altered by the operation of surface water storage reservoirs in the Upper Yakima Basin (Keechelus, Kachess and Cle Elum Reservoirs). Regulation of river flows lowers winter flows and increases summer flows to store winter water and deliver irrigation water during the summer from the upper basin reservoirs to downstream irrigators. Because high flows in the summer are detrimental to the migration of salmon returning to spawn, flows are reduced in early September to aid spawning and incubation of the salmon eggs in the Yakima River (Figure 3).

Seepage runs indicate a gain of streamflow from groundwater on the order of 101 cubic feet per second (cfs) at the head of the Yakima Canyon (Vaccaro, 2011). Local and complex exchanges of groundwater and surface water occur along this reach, and it was identified as a priority reach for salmonid habitat restoration (Snyder and Stanford, 2001).

2.3.2. Tributaries

Numerous tributaries drain the Wenatchee Mountains and Mission Ridge to the north of the valley and enter the left bank (looking downstream) of the Yakima River (Table 1). Among these, Naneum Creek splits into three distributaries as it discharges from the basalt uplands and flows across its alluvial fan. These distributaries then join into Wilson Creek further out on the valley floor.

Taneum, Robinson and Manastash Creeks drain Manastash Ridge from the south and enter the Yakima River's right bank.

Tributaries provide significant salmonid refugia from high flows and/or high temperatures. The conceptual model is that Kittitas Valley tributaries: 1) have cold water seeps/springs at the edge of the sedimentary valley near the contact with underlying basalt; 2) may lose water over alluvial fans; and 3) gain shallow groundwater in their lower reaches before they merge with the Yakima River. There are numerous fish passage blockages on most of the left bank tributaries in the form of irrigation diversions, culverts and other structures. Removal of these blockages and restoration work is on-going by natural resource managers (e.g., the Yakama Nation, the Washington Department of Fish and Wildlife, and others).

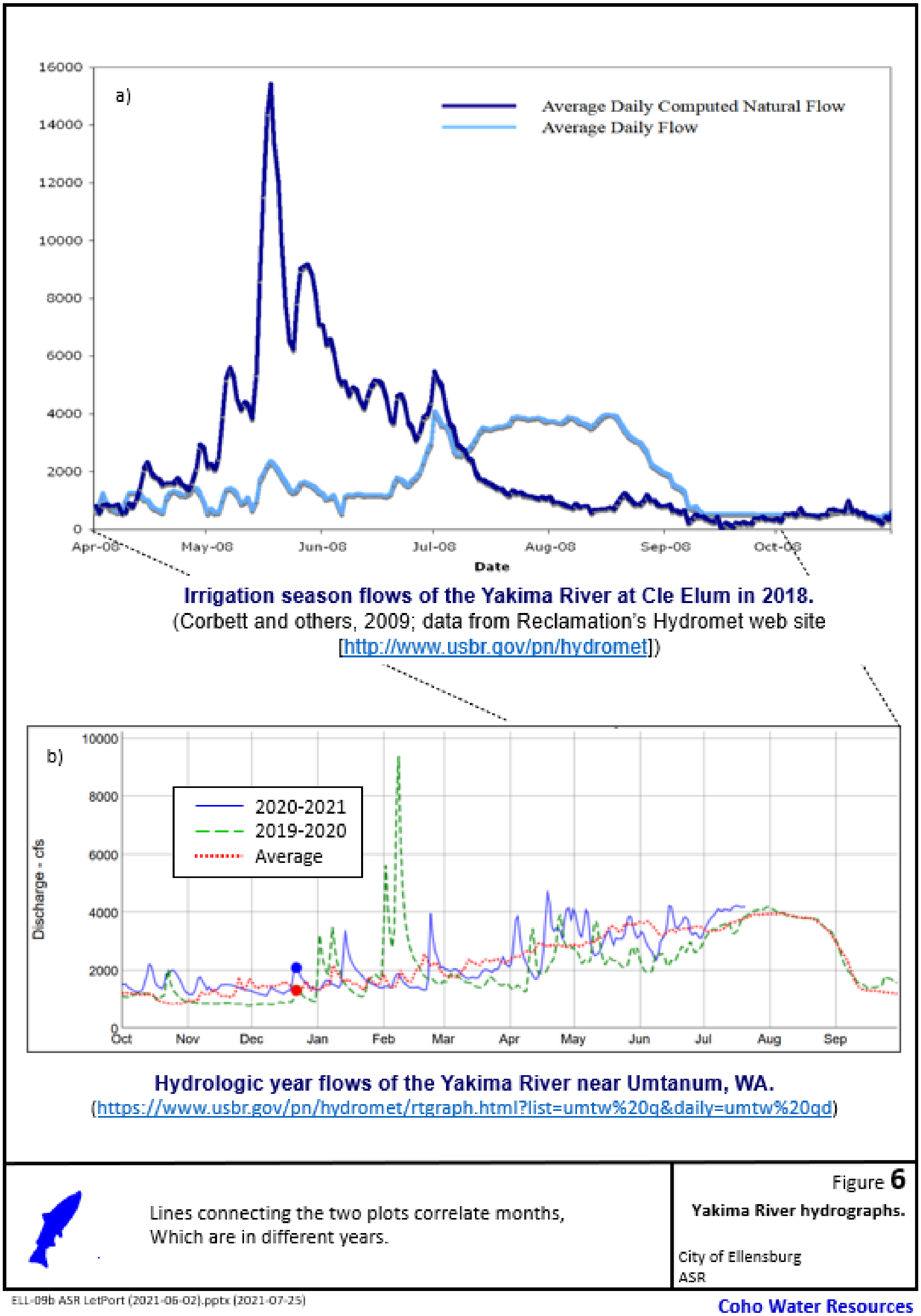


Figure 3: Yakima River hydrographs.

Table 1: Yakima River tributaries in the Kittitas Valley.
(Northwest to southeast; upstream to downstream.)

<table>
<tr><th colspan="3">Left Bank (northeast) Tributaries</th><th rowspan="12">Yakima River</th><th>Right Bank (southwest) Tributaries</th></tr>
<tr><td colspan="3">Dry</td><td>Taneum</td></tr>
<tr><td colspan="2">Reecer</td><td rowspan="2">Reecer</td><td rowspan="2">Robinson</td></tr>
<tr><td colspan="2">Currier</td></tr>
<tr><td rowspan="3">Naneum -> distributaries</td><td>Mercer</td><td rowspan="3">Wilson</td><td rowspan="8">Manastash</td></tr>
<tr><td>Wilson</td></tr>
<tr><td>Naneum</td></tr>
<tr><td colspan="2">Coleman</td><td rowspan="5"></td></tr>
<tr><td colspan="2">Cooke</td></tr>
<tr><td colspan="2">Cherry</td></tr>
<tr><td colspan="2">Park</td></tr>
<tr><td colspan="2">Badger</td></tr>
</table>

2.3.3. Irrigation

The irrigation season for the KRD, which is the largest purveyor of irrigation water in the valley and is representative of all irrigation in the valley, is from April 15 to October 31. Irrigation water is distributed through numerous lateral ditches. Flood irrigation has historically been the dominant method, which has resulted in significant return flows to streams. More efficient irrigation methods are increasingly being used.

2.4. Salmonids

The Yakima Basin supports anadromous, resident native, and introduced species of fish, as well as more than 250 species of wildlife. Historically, the Yakima Basin was one of the major producers of salmon and steelhead in the Columbia River Basin. It is estimated that before large-scale Euro-American immigration and settlement began around 1850, some 500,000 to 900,000 adult salmon and steelhead returned from the ocean to spawn in the Yakima Basin annually, including spring, summer and fall Chinook, coho, sockeye, and steelhead (Northwest Power and Conservation Council, 2021).

Today, native summer Chinook, sockeye, and native coho are extinct in the basin (hatchery-bred coho and sockeye have been introduced). In the late 1990s and early 2000s, spring Chinook returns varied from 645 fish to more than 25,000. Fall Chinook returns averaged 2,000 to 4,000 fish, and coho returns were between 1,000 and 2,000 fish. The Yakama Nation is working to rebuild the salmon and steelhead runs through a large-scale hatchery program that produces juvenile fish for release into the wild in an experiment to rebuild naturally spawning runs. Two fish species in the Yakima basin listed for protection under the Endangered Species Act are bull trout and mid-Columbia steelhead.

3. GEOLOGY & GROUNDWATER

This section presents the geological and hydrogeological setting of the Kittitas Valley within which the Ellensburg ASR program is being evaluated and assesses the groundwater recharge capacity of the target aquifer.

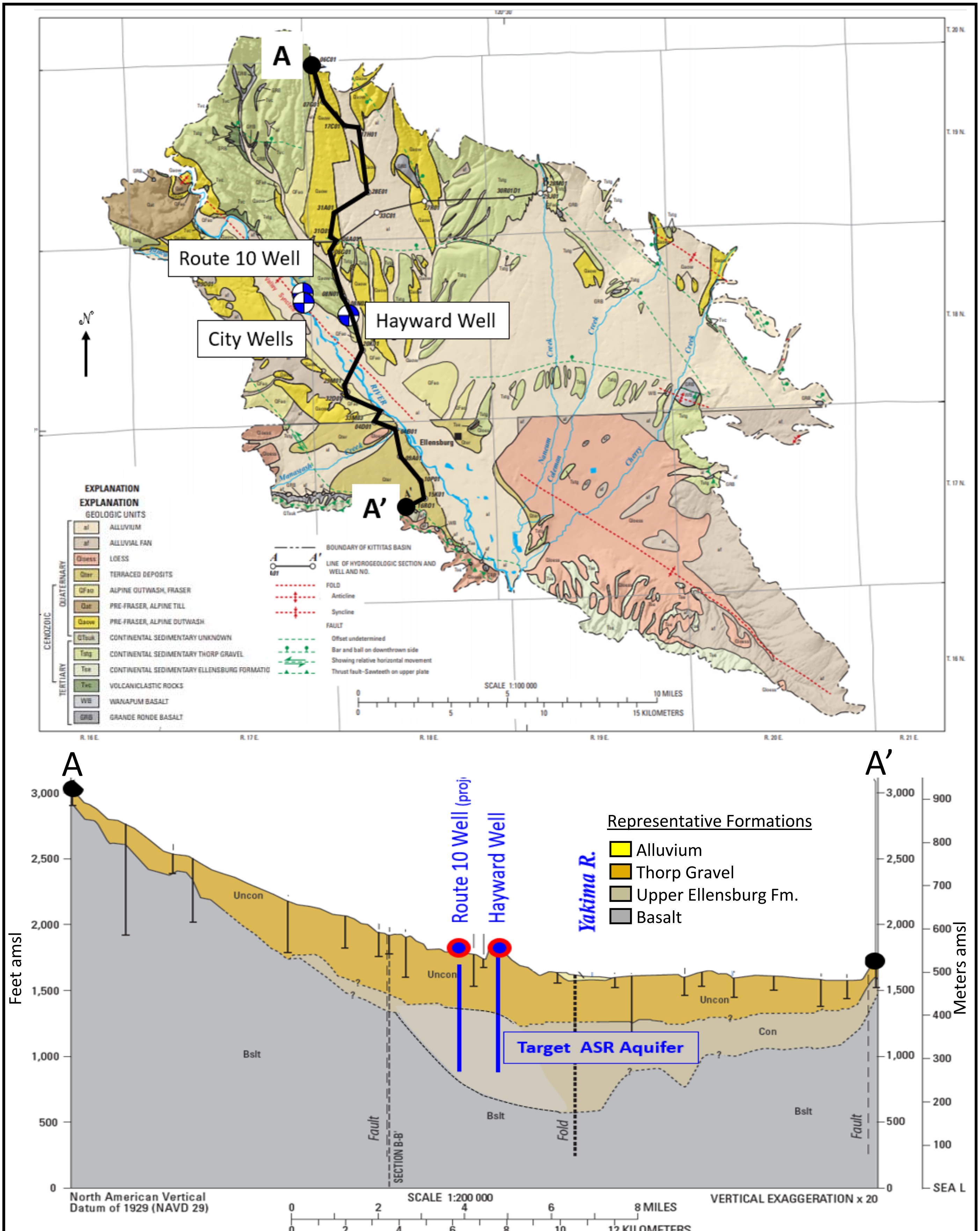
Seminal studies of the geology and hydrogeology of the Kittitas Valley have been conducted by:

1. Kinnison and Sceva (1963): Defined basic hydraulic continuity relationships between groundwater and the Yakima River. Noted losing reaches where the Yakima River enters a structural sedimentary basin and gaining reaches as the Yakima River exits such basins.
2. Waitt (1979): Characterized the Kittitas Valley sedimentary fill (excluding the Ellensburg Formation).
3. Tabor and others (1982): Mapped surficial geology of the valley at 1:100,000 scale.
4. USGS study of the Yakima Basin, including the Kittitas Valley. Includes:
    - Jones and others (2006): Description of the hydrogeologic framework.
    - Vaccaro (2006): Analyzed river-aquifer exchanges.
    - Jones and Vaccaro (2008). Interpreted the thickness of valley fill sediments, including the thickness of the Upper Ellensburg Formation in the Kittitas Valley.
5. Sadowski and others (2020): Mapped in detail the North Ellensburg and southern half of the Reecer Canyon 7.5-minute quadrangles.

3.1. Geology

The surficial geology and a generalized stratigraphic column are shown in Figure 4 and Table 2. The geology of the Kittitas Valley is simplified as three general units, from ground surface to depth:

1. Unconsolidated glacial and alluvial sediments at ground surface.
2. Semi-consolidated sediments that form most of the valley fill (Thorp Gravel and the Upper Ellensburg Formation).
3. Basalt bedrock underlying and ringing the valley (Columbia River Basalts [CRB] and interbedded Lower Ellensburg Formation sediments).



From:
Jones and others (2006),
Modified with Pitre and Holom (2009a and 2009b)

Figure **4**
Geology

City of Ellensburg
ASR Pre-application

Table 2: Generalized stratigraphy of the Kittitas Valley.
(Ma = million years)

<table>
<tr><th>Period (within the Cenozoic Era)</th><th>Epoch</th><th>Age (years before present)</th><th colspan="2">Simplified Geologic Unit</th><th>Structural Events</th></tr>
<tr><td rowspan="2">Quaternary</td><td>Holocene</td><td>0-12,000</td><td rowspan="2">Unconsolidated sediments</td><td>Alluvium</td><td rowspan="3">Yakima Fold Belt</td></tr>
<tr><td>Pleistocene</td><td>0.01-2.6 Ma</td><td>Glacial</td></tr>
<tr><td rowspan="5">Neogene

(includes Upper Tertiary)</td><td>Pliocene</td><td>2.6-5.3 Ma</td><td rowspan="2">Semiconsolidated sediments</td><td>Thorp Gravel</td></tr>
<tr><td rowspan="4">Miocene</td><td>5.3-14.5 Ma</td><td>Upper Ellensburg Formation</td><td rowspan="4"></td></tr>
<tr><td>14.5-15.5 Ma</td><td rowspan="3">Columbia River Basalts</td><td>Wanapum Basalt</td></tr>
<tr><td>~15.5 Ma</td><td>Vantage Member of the Lower Ellensburg Formation</td></tr>
<tr><td>15.5-17 Ma</td><td>Grande Ronde (contains the Coleman Member of the Lower Ellensburg Formation)</td></tr>
</table>

3.1.1. Unconsolidated sediments

Unconsolidated sediments cover most of the Kittitas Valley floor as a thin veneer on the order of 5-20 feet thick. Thicknesses increase in isolated alluvial fans along the edge of the valley and in deposits up to approximately 100 feet thick under and along the Yakima River. These sediments include:

1. Alluvium along streams and in old stream channels, which consist of clean permeable sand and gravel, and fine-grained overbank flood deposits.
2. Landslide deposits on steep slopes from mass wasting.
3. Alluvial fan deposits where streams transition from basalt uplands to the valley floor, found along both sides of the valley.
4. Wind-blown loess (fine-grained, wind-blown). Holocene (less than 12,000 years ago) loess of the Palouse Formation deposited from wind-blown redistribution of fine-grained sand and silt of slack-water deposits from cataclysmic Missoula floods related to continental glaciations (McDonald and Busacca, 1992).
5. Pleistocene outwash glacial deposits (within the last 2M years). The Thorp Prairie delineated by Taneum Creek in western Kittitas Valley marks the furthest

advance of glaciers into the valley. Outwash deposits emanate from this ancestral front across the Kittitas Valley.

6. The vertical profile across these unconsolidated sediments includes centimeter-scale horizontal layers of caliche (cemented by carbonate or silica) and tephra (air-borne deposited volcanic fine ash), which slow infiltration to groundwater.

3.1.2. Semiconsolidated sediments

Semiconsolidated sediments include:

1. Thorp Gravel (~3.7 million years old).
2. Upper Ellensburg Formation (~3.7-6 million years old) – **Target ASR aquifer**.
3. Lower Ellensburg Formation (6-15 million years old).

3.1.2.1. Thorp Gravel

The Thorp Gravel is the oldest of periglacial outwash deposits in the Kittitas Valley. Its distinct ochre-color comes from the oxidation and weathering of iron-rich basalt clasts that it contains derived from adjacent basalt uplands. It is generally poorly sorted and contains layers rich in fines (silt and clay), and cleaner sand and gravel layers. The Thorp Gravel may be several hundred feet thick and caps several upland areas around the valley, such as Hayward Hill and Craigs Hill.

Sadowski and others (2020) provide the following description of the Thorp Gravel:

> Glacio-fluvial accumulation of polymict cobbles and pebbles of andesite, basaltic andesite, conglomerate, sandstone, vein quartz, chalcedony, chert, and metamorphic rock (Cascade-sourced). Imbrications of clasts suggest southward and eastward paleocurrent directions. Weathering rinds on basalt clasts range from 1–20 mm and are commonly 2–5 mm wide. Capping loess is pervasive and silicic caliche is common.

3.1.2.2. Upper Ellensburg Formation – Target ASR Aquifer

The Upper Ellensburg Formation (Teu) is the target formation for recharging water in the Ellensburg ASR program. It is distinct from:

- The overlying Thorp Gravel by color: The Thorp gravel is rusty-colored, while the Upper Ellensburg Formation is cream-colored.
- The Lower Ellensburg Formation in that the Upper Ellensburg Formation unconformably and fully overlies the Columbia River Basalt. The Lower Ellensburg Formation is within and interfingered with basalt flows.

The Upper Ellensburg Formation is one continuous member that ranges in thickness from absent to over 2,000 feet below ground surface (Figure 5; Jones and Vaccaro, 2008).

The Upper Ellensburg Formation is principally formed of andesitic and dacitic volcaniclastics from the Cascade volcanic range deposited as fine-grained airborne ashfall, poorly sorted lahars, fluvially reworked clean sand and gravel, and fluvial overbank fine-grained silty sediments. The mineralogy reflects the components of the source rock, which is dominantly andesite and dacite, with minor amounts of rhyolite and basalt compositions (Table 3). There is a significant amount of volcanic glass and secondary clay alteration minerals.

Cements within the Upper Ellensburg Formation tend to be either ferruginous (FeO) or argillaceous (shaly/clayey). Argillaceous cements are primarily composed of kaolinite and montmorillonite clays. Typically, the sediments become mor cemented lower in the sequence. Carbonate cements may be present in minor amounts. Silicic caliche is common in the older alluvium (Sadowski and others, 2020).

3.1.2.3. Lower Ellensburg Formation

The Lower Ellensburg Formation (Tel) is distinguished from the Upper Ellensburg Formation in that it is comprised of several members within and interfingered with Columbia River Basalt (CRB) flows. The sequence (from top to bottom) of two of the major members of the Lower Ellensburg Formation, and the bounding CRB flows and are:

- Wanapum Basalt (CRB)
  - **Vantage Member of the Lower Ellensburg Formation.**
- Sentinel Member of the Grande Ronde Basalt (CRB)
  - **Coleman Member of the Lower Ellensburg Formation (~16 Ma; Sadowski and others, 2020).**
- Grouse Creek Member of the Grande Ronde Basalt (CRB)

The Lower Ellensburg Formation was deposited during quiescent periods of the CRB flows and is generally fine-grained fluvial and lacustrine deposits. This formation does not factor significantly into the Ellensburg ASR program that is focused on recharge to the Upper Ellensburg Formation, though Sadowski and others (2020) have identified the Coleman Member of the Lower Ellensburg Formation as a potential ASR target aquifer.

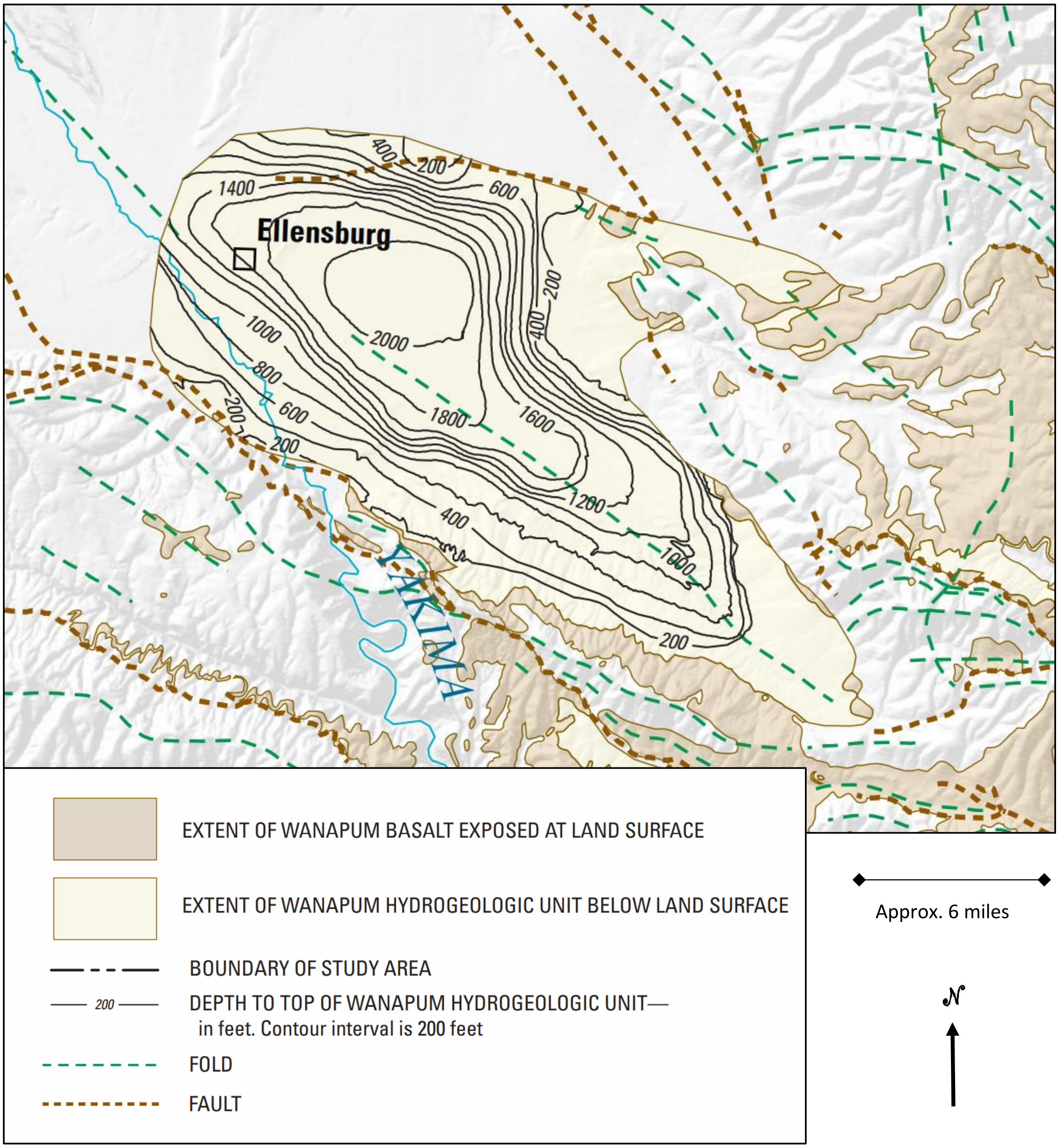


Figure 5: Thickness of the Upper Ellensburg Formation.
As represented by the top of the Wanapum Basalt. Also includes alluvial sediments, the Thorp Gravel and other minor deposits. From Plate 3 of Jones and Vaccaro (2008).

Table 3: Mineralogy of the Upper Ellensburg Formation.

Mineral	Chemical Formula	Source Rock
Major Minerals		
Plagioclase Feldspar	$NaAlSi_3O_8$ to $CaAl_2Si_2O_8$	All
Quartz	SiO_2	
Augite (Pyroxene)	$CaMgSi_2O_6$ to $CaFeSi_2O_6$	
Alkali Feldspar	$NaAlSi_3O_8$ to $KAlSi_3O_8$	Andesite, Dacite, Rhyolite
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	
Hornblende Amphibole	$(Ca,Na)_{2\text{-}3}(Mg, Fe, Al)_5Si_6(Si, Al)_2O_{22}(OH)_2$	
Volcanic glass		
Hypersthene (Pyroxene)	$Mg(Fe)Si0_3$	Basalt
Montmorillonite (as cement)	$(Al,Mg)_8(Si_40_{10})_3(OH)_{10}$*$12H_2O$	In situ clay alteration
Kaolinite (as cement)	$Al_2Si_2O_5(OH)_4$	
Minor Minerals		
Apatite	$Ca_5(PO_4)_3(F, Cl, OH)$	All
Zircon	$ZrSi0_4$	
Chlorite (as an alteration product)	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2$ * $(Mg,Fe)_3(OH)_6$	
Fe-oxides (in pumice and volcanic glasses)	Fe_xO_y	Basalt, Andesite
Olivine	Mg_2SiO_4 to Fe_2SiO_4	Basalt
Minor sulfides (pyrite, chalcopyrite, galena, etc.)	FeS_2, $CuFeS_2$, PbS, etc.	Inclusions in clasts

3.1.3. Columbia River Basalt (CRB)

The CRB underlies the project area, the lower elevations of the Yakima Basin, and most of the Columbia Basin. In the Yakima Basin the CRB consists of three major groups (youngest to oldest):

1. Saddle Mountain
2. Wanapum
3. Grande Ronde

The Saddle Mountain Basalt has not been identified in the Kittitas Valley. The Wanapum and Grande Ronde Basalts consist of multiple tholeiitic flows. The flow tops and bottoms are more rubbly and porous, and host most of the horizontal groundwater flow. The interiors of the flows are more massive with colonnade structure dominated by vertical fractures that provide vertical hydraulic connection between interflow zones.

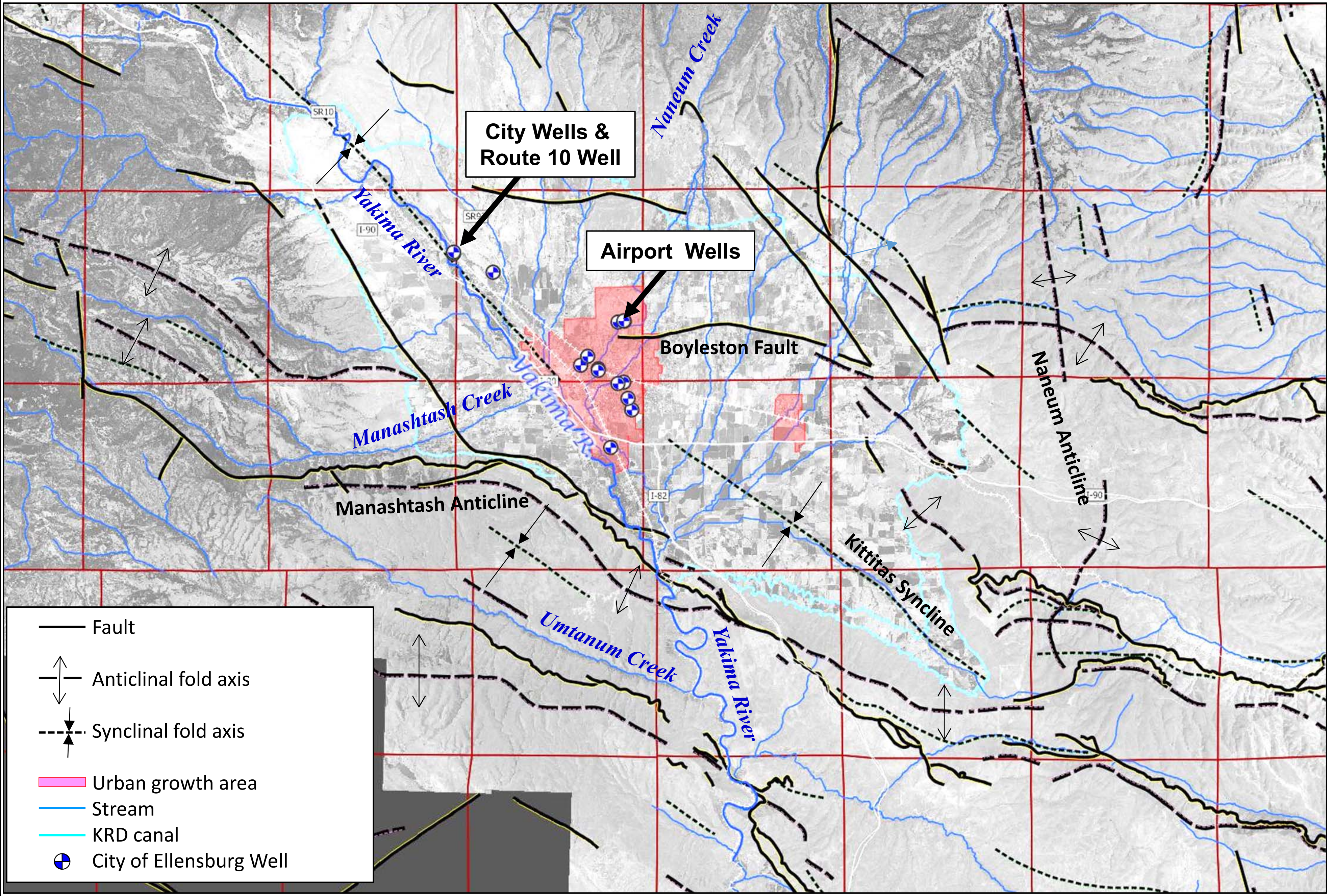
3.1.4. Structural geology

The Yakima Fold Belt is the dominant structure in the project area (Figure 6). The Manastash and Naneum Ridge anticlines together form the doubly-plunging converging Kittitas Syncline – a bowl surrounded by basalt hills, in-filled by the semiconsolidated sediments of the Upper Ellensburg Formation.

The structural deformation formed faults in the basalt and semi-consolidated sediments throughout the valley. Faults are best documented around the edges of the Kittitas Valley. Two variables are recognized to explain the apparent concentration of faults around the edges of the Kittitas Valley:

- Faults associated with folding are commonly concentrated along fold axes, both anticlinal and synclinal.
- Faults are more easily mapped in bedrock outcrops and may be masked within the valley by sedimentary cover.

The structural geology in the Kittitas Valley is not fully understood. This fault system is part of the Yakima Fold belt, is compressive, and forms barriers to groundwater flow. Faults are mapped near the Airport Wells in the north of the City of Ellensburg (Figure 6). Owens (1995) interpreted the presence of folds and faults at depth along the central synclinal axis of the Kittitas Valley. The Boyleston Fault extends from the east to south side of the Airport Wells. Pumping tests of the City’s Airport Wells showed no hydraulic connection between the wells, which are located within several hundred feet of each other. The lack of hydraulic continuity between the wells suggests the presence faults that create barriers to groundwater flow. The presence of faults should be taken into consideration when making groundwater resource decisions, whether those decisions relate to water supply and potential well yield, and/or implementing an ASR program.



Data source: WA DNR 1:100,000 on-line database.
Simplified presentation of the geological structure.

Figure **6**

Kittitas Valley structural geology.

City of Ellensburg
ASR

3.2. Groundwater

The geologic units each play different roles in the hydrogeology of the Kittitas Valley. The unconsolidated sediments near the surface host the water table aquifer and interact most directly with streams (Figure 7). The Thorp Gravel is heterogeneous and variable, which likely imparts a high horizontal-to-vertical anisotropy to the permeability that hinders vertical flow of groundwater. Permeable portions support wells for residential and limited other uses (e.g., 10s to 100s of gallons per minute [gpm]).

The Upper Ellensburg Formation and underlying basalt formations support large capacity production wells in the Kittitas Valley (e.g., 1,000s of gpm). The Upper Ellensburg Formation provides relatively clean permeable zones of aquifer material that are cumulatively several hundred feet thick. Groundwater in the basalts is mostly contained and moves through relatively porous interflow zones and fractures. Discussion in this report focuses on the lower portion of the Upper Ellensburg Formation, which is the target aquifer for Ellensburg ASR project.

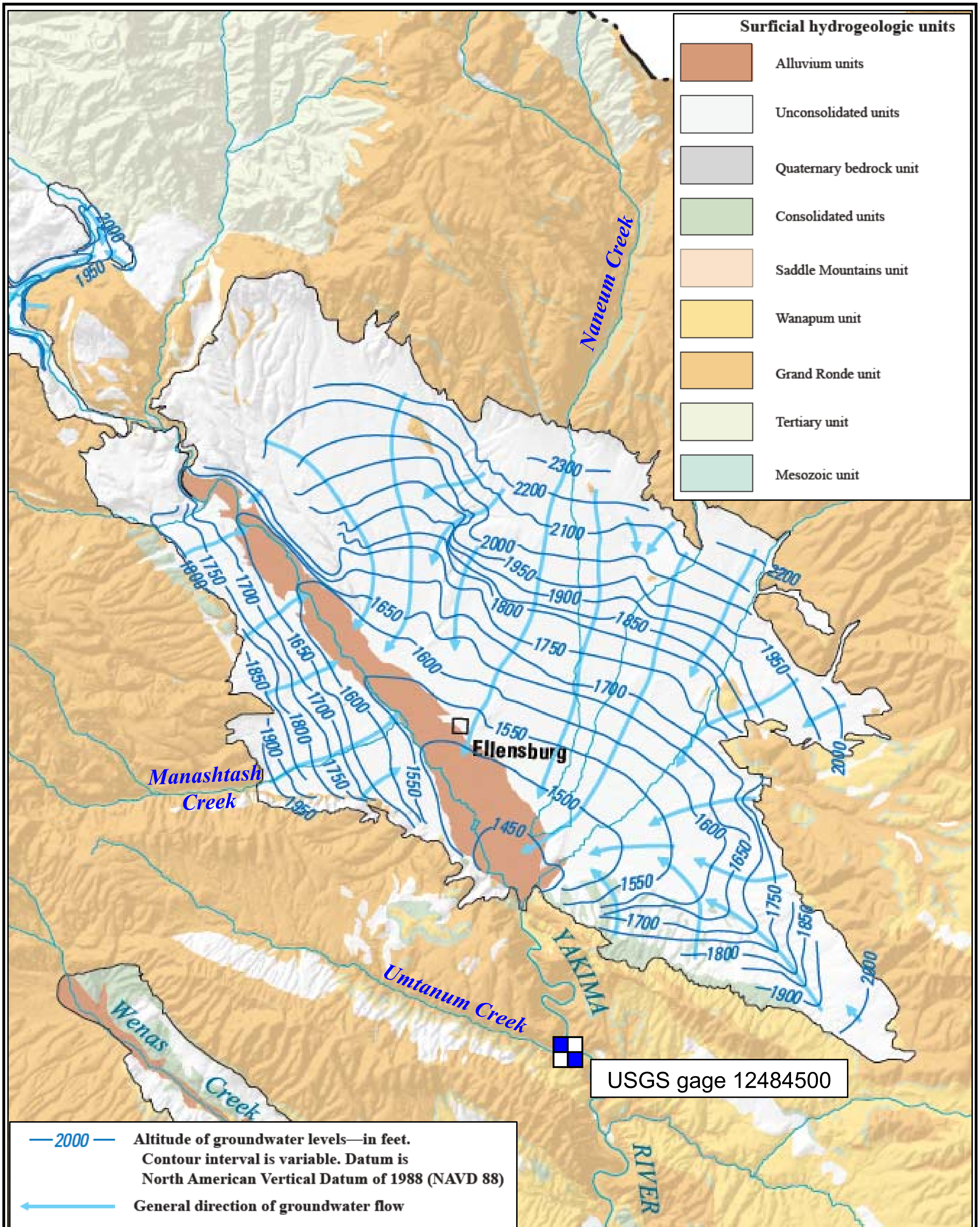
Sadowski and others (2020) also interpreted the presence of a deep member of the Lower Ellensburg on north side of the Kittitas Valley, which has been identified as a candidate to receive ASR recharge water (Coleman Sand Member; >1,000 feet below ground surface; Nazy, 2021).

3.2.1. Groundwater recharge

Groundwater of the Kittitas Valley is supplied by:

- Precipitation.
- Irrigation.
- Losing reaches of streams

Natural recharge over the basalt uplands, estimated at 5 to 20 inches per year (Vaccaro and Olsen, 2007), contributes to deep groundwater flow paths that upwell through the Upper Ellensburg Formation and ultimately discharge to the Yakima River and its tributaries. Annual natural recharge over the valley floor is less than two inches (Vaccaro and Olsen, 2007).



From Plate 3 of Vaccaro and others (2009), showing the generalized altitude of the water table, Spring 2001.

Figure **7**

Kittitas Valley water table.

City of Ellensburg
ASR

Distribution of agricultural irrigation water through main canals and laterals, and application practices result in more than four feet per year of recharge to groundwater in the Kittitas Valley floor (Vaccaro and Olsen, 2007). This recharge is mostly confined to the shallow unconsolidated sediments of the groundwater system and returns quickly to streams with little residence time in the ground (e.g., weeks to months; Pitre and Austreng, 2013). Groundwater levels are close to ground surface year-round as a result of precipitation in the winter, and irrigation in the summer (Pitre and Austreng, 2013).

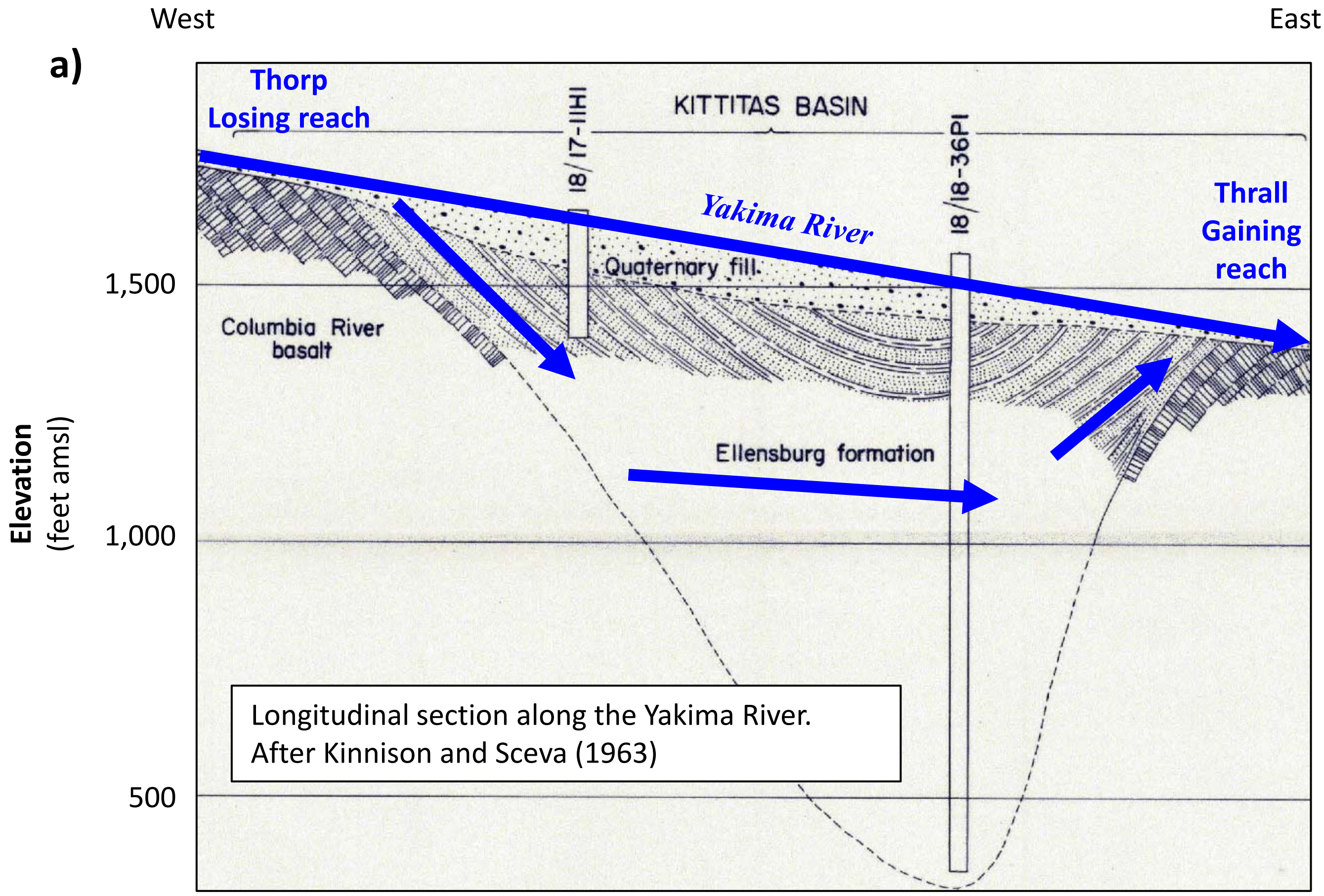
Kinnison and Sceva (1963) describe the interaction between the Yakima River and groundwater through the subbasins of the Yakima Valley (Figure 8). The Yakima River generally loses water as it enters sedimentary subbasins, such as the Kittitas Valley near Thorp, and recharges groundwater. The Yakima River regains upwelling groundwater as the river exits subbasins, such as in the vicinity of Thrall near the head of the Yakima Canyon. Taylor and Gazis (2014) developed a conceptual model of groundwater flow patterns along a cross-section of the Kittitas Valley using geochemical data (Figure 8).

3.2.2. Groundwater pumping

Groundwater is the primary source of drinking water in the Kittitas Valley and is also used to supply irrigation (domestic and agricultural), and other demands. Typical groundwater wells are on the order of 50-100 feet deep, which tap the water table, and greater than 300 feet deep, which tap the Upper Ellensburg Formation.

The USGS modeling study of the Yakima Basin estimated groundwater pumping from 1959-2001 (Vaccaro, and Sumioka, 2006). The Bureau of Reclamation extracted data from that study of groundwater pumping within the footprint of the valley floor, from the upper twelve model layers (Figure 9; Ely and others, 2011). These model layers were selected because they were assumed to encompass the majority of the sedimentary basin fill of the Kittitas Valley. Model layers do not correlate directly with geologic layers, likely include most of the groundwater pumping from the alluvial sediments, Thorp Gravel, and Upper Ellensburg Formation, and may contain some pumping from the basalt. Pumping outside of the footprint of the valley floor, and below layer 12, which may be more likely completed in basalt, is not included in the extracted data.

a)



b)

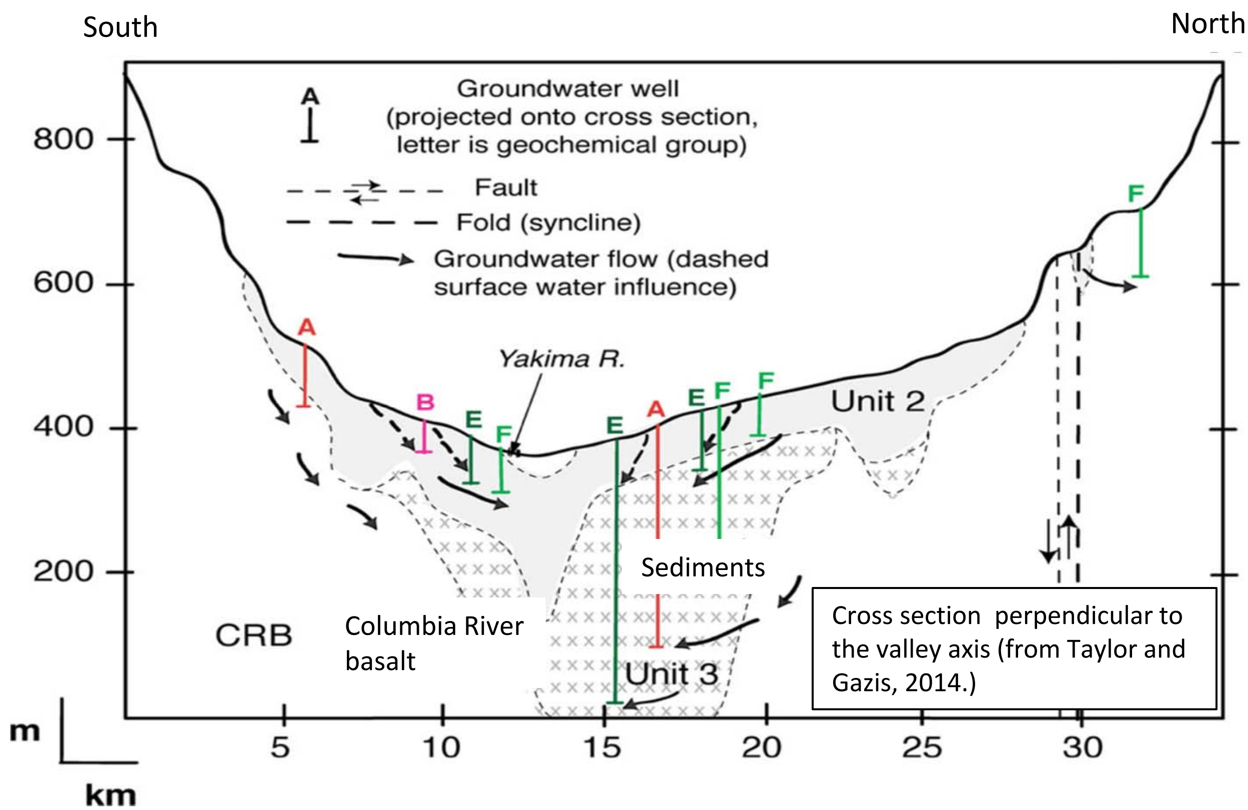


Figure **8**

Conceptual groundwater flow paths

City of Ellensburg
ASR

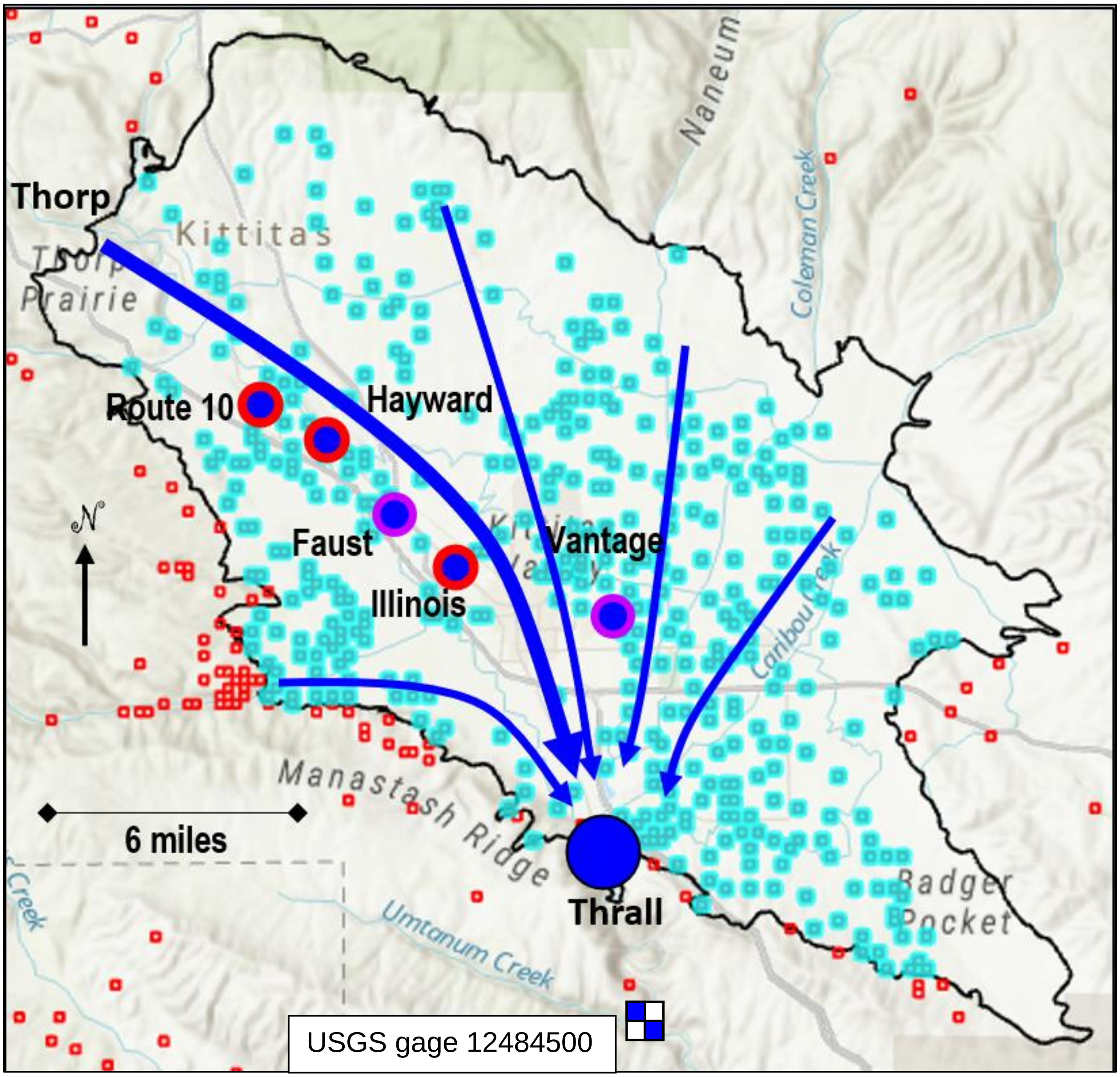


Figure 9: Pumping in the Kittitas Valley & conceptual deep groundwater flow paths.

Blue squares are pumping centers included in the estimate of pumping from the Kittitas Valley; red squares are excluded from the estimate.

Blue lines are conceptual groundwater flow paths.
The large blue dot near Thrall represents a groundwater discharge locus.

Smaller blue dots represent candidate recharge wells
(red rimmed blue dots = existing well; magenta rim = possible future well).

Base map provided courtesy of Wilderotter (2021).

More than 60,000 afy is estimated to be pumped from within the floor the Kittitas Valley (Figure 10). Additional pumping occurs in deeper layers of the model and around the periphery of the valley floor. Of this pumped volume, approximately 4,000 afy or less than 7% of the total groundwater pumping in the Kittitas Valley is pumped by the City, much of which returns through the municipal wastewater treatment plant to the Yakima River. Water use by other than the City is assumed to be largely consumptive for agricultural irrigation, with minor amounts for other uses (e.g., commercial and domestic uses).

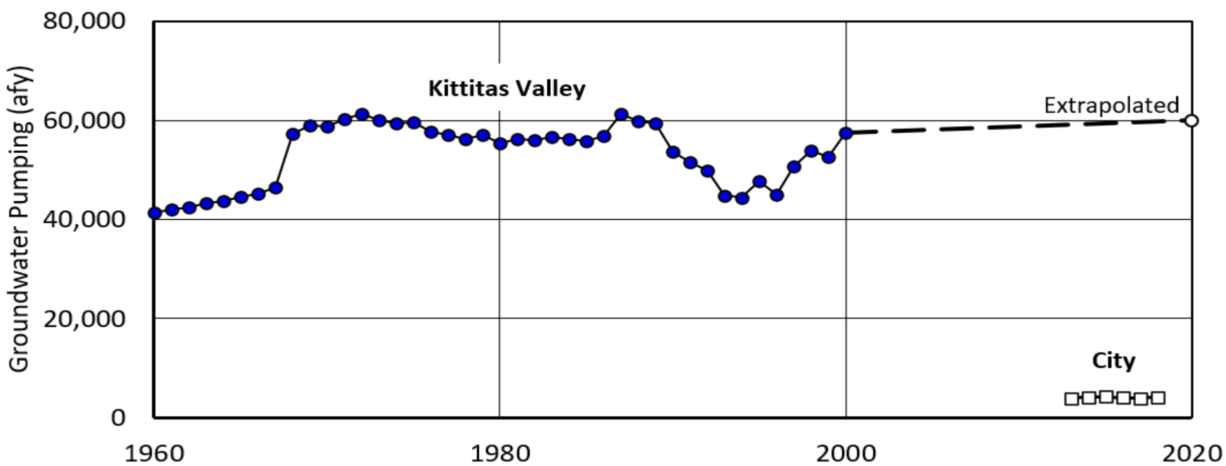
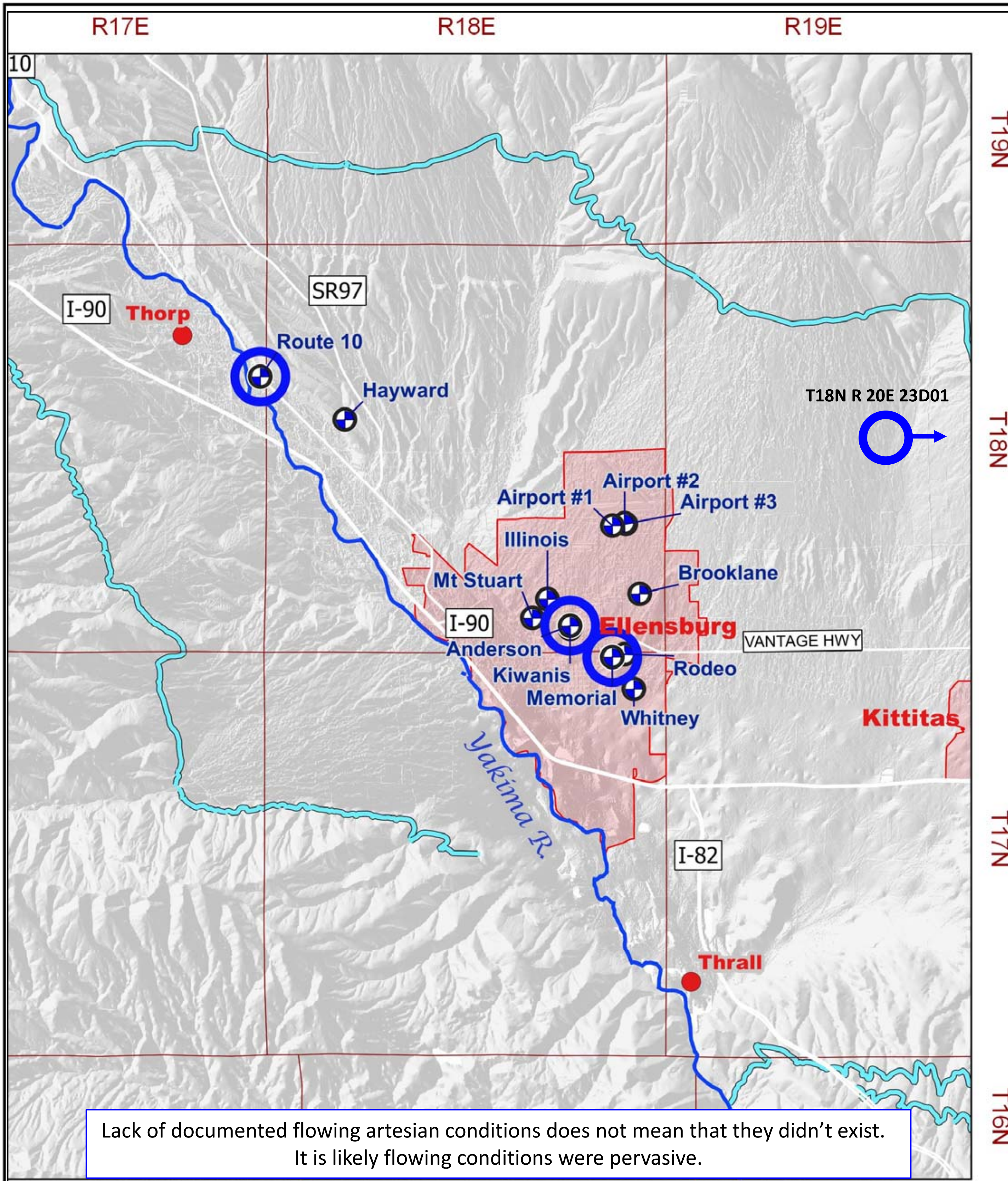


Figure 10: Groundwater pumping in the Kittitas Valley floor.
Kittitas Valley data extracted from Ely and others (2011) by Wilderotter (2021). City data from the Water System Plan (RH2, 2021).

Groundwater pumping in the Yakima Basin upstream of Thrall, most of which occurs in the Kittitas Valley, is estimated to reduce Yakima River flow by approximately 18 cfs (13,000 afy) at the Umtanum Gage (USGS gage 12484500, approximately half a mile upstream of the confluence of Umtanum Creek and the Yakima River; Ely and others, 2011). Impacts from pumping of deeper portions of the aquifer system are interpreted to accrue to the Yakima River at the head of the Yakima Canyon near Thrall (Figure 9).

3.2.3. Groundwater hydrographs

Hydrographs of groundwater levels in City of Ellensburg water supply wells completed in the Upper Ellensburg Formation are shown in Figure 11 and Figure 12. Flowing artesian conditions were the original condition in the floor of the Kittitas Valley (i.e., water flowed from wells without pumping; Figure 11). These conditions persisted in some areas as recently as 2009 (Pitre and Holom, 2009). Depth to groundwater currently ranges from near ground surface to near 200 feet (Figure 12).



Artesian Wells, Past or Present

City-Owned Wells

KRD Canal

Urban Growth Areas

N

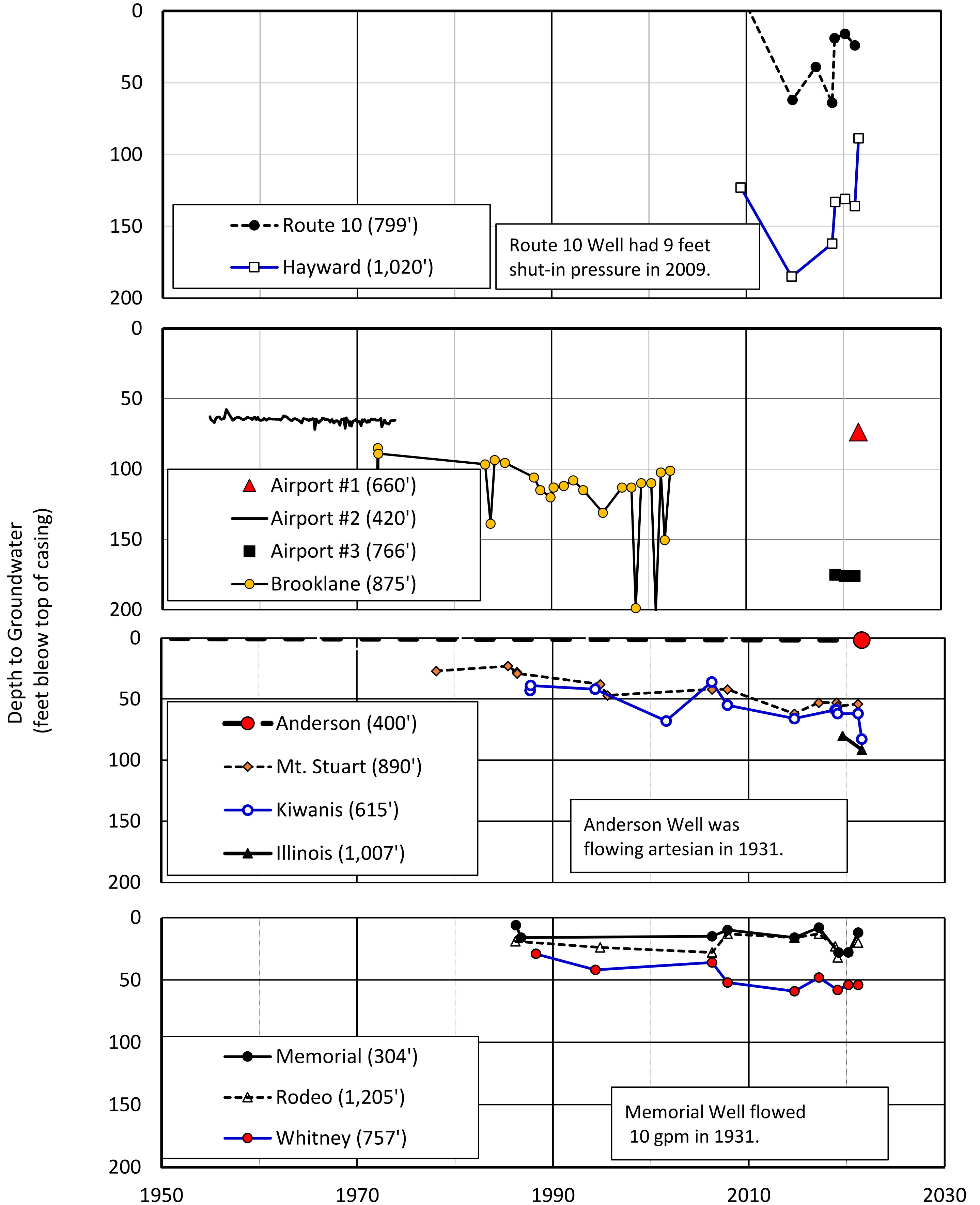
0 1.5 3 4.5 6 mi

Figure **11**
Map key to groundwater level monitoring points.

Ellensburg
ASR Prefeasibility Study

QGISEB_hydro.qgs

Coho Water Resources



Pumping and seasonal fluctuations may have affected some of the data. Bottom of screen intervals given in legends.

Figure 12
Groundwater hydrographs.

City of Ellensburg
ASR

3.2.4. Aquifer properties

Aquifer properties of the Upper Ellensburg Formation in the Kittitas Valley are listed in Table 4:

Table 4: Upper Ellensburg Formation aquifer properties.

Well	Transmissivity (ft^2/d)	Storage	Reference
Airport #1	1,300	-	Pitre (2016)
Airport #3	500	-	Krautkramer and others (2012)
Brooklane	3,800	-	Robinson (1972)
Hayward	1,900	-	Pitre and Holom (2009a)
Illinois	4,000	0.0004	Pitre and Prior (2020)
Kiwanis	3,200	0.0005	Ellis (1987)
Mount Stuart	2,700	-	Krautkramer and Carr (1978)
Mount Stuart	3,700	-	Pitre (2019)
Rodeo	2,700	0.0003	Noble (1986)
Route 10	1,300	0.00025	Pitre and Holom (2009b)
Whitney	2,100	-	Ellis (1988)
Average (excluding Airport Wells)	**2,700** (20,000 gpd/ft)	**0.00035**	

Transmissivity (T) influences the potential rate of recharge through wells. Transmissivity is constant where it is measured at any one well but varies across the aquifer. Values from the Airport wells are excluded from the calculated average because of the influence of faults. The average value of 2,700 feet squared per day (ft^2/d) compares to the average of 4,000 ft^2/d for the city of Yakima's operational ASR wells in the Ahtanum Valley (Golder, 2000).

Aquifer storage (S) indicates how much water can be stored and the change of groundwater levels from pumping and recharge activities. The average value of 0.00035 is half of the average of the city of Yakima's operational ASR wells (0.0007).

Assuming all other variables being constant, the comparative values of T and S suggest the potential of ASR in the Upper Ellensburg Formation in the Kittitas Valley is approximately half that in the Ahtanum Valley.

3.2.5. Groundwater recharge capacity

Lowered water levels in the Upper Ellensburg Formation across the Kittitas Valley represent storage capacity. Estimating the storage recharge capacity of an aquifer system is influenced by static properties intrinsic to the aquifer system (e.g., aquifer storage and specific yield), and dynamic values (e.g., groundwater flow rates and total groundwater pumping in the valley). Several approaches are examined to estimate the recharge capacity of the sediments in the Kittitas Valley to provide context:

- Aquifer properties:
  - Confined aquifer conditions (aquifer storage = 0.00035)
  - Unconfined aquifer conditions (aquifer specific yield = 0.1).
- Total groundwater pumping in the Kittitas Valley.

3.2.5.1. Groundwater storage estimated from aquifer storage (confined aquifer)

Aquifer storage for a confined aquifer considers the compressibility of a saturated part of the aquifer. Expansion and contraction of the aquifer is attributable to:

- Compressibility of mineral and water (insignificant).
- Compressibility of air pockets entrained in the aquifer.
- Changes in ground surface level, flexing of the geological strata.

The available storage capacity for a confined aquifer is estimated using the following parameters:

- S = 0.00035: Average aquifer storage.
- Delta s= 60 feet: Representative groundwater level charge:
  - Original flowing artesian conditions of 1 foot above ground surface.
  - Representative current groundwater levels of 59 feet below ground surface.
- 120 square miles: The area of the Kittitas Valley floor.

- **1,600 af – Hypothetical recharge capacity using aquifer storage** (specific storage * aquifer thickness).

This value provides a lower bound of the range of possible aquifer recharge capacity based on the aquifer storage property. If recharge of 1,600 af resulted in raising aquifer groundwater levels 60 feet, then the corollary of a decline of 60 feet of groundwater levels from pumping 1,600 afy would result. This decline is not observed, and an explanation is proposed in section 3.2.5.3.

The use of a confined aquifer storage value results in a conservatively small storage capacity value. The aquifer storage value is estimated from pumping tests (Table 4), which measure the property near the pumping well and does not account for the full system. Response of the complete system to groundwater recharge in an ASR program is expected to be greater.

Seasonal water level fluctuations indicate a dynamic system, in which potential aquifer storage is not static. There is significant leakage and hydraulic continuity between groundwater and streams, primarily the Yakima River. The static aquifer storage estimate of 1,600 af is conservatively small and is likely much higher.

3.2.5.2. Groundwater storage estimated from specific yield (unconfined aquifer)

Specific yield (Sy) is the drainable volume from aquifer materials, which is the same as the pore volume less the field capacity, the wetness in the material after it has been drained. Specific yield typically ranges from 10% to 30% (0.1-0.3).

The available storage capacity for an unconfined aquifer is estimated using the following parameters:

- S = 0.1: Representative specific yield.
- ∆s= 10 feet: Half of the average depth to groundwater (Pitre and Austreng, 2013).
- 120 square miles: The area of the Kittitas Valley floor.

- **77,000 af – Hypothetical recharge capacity using specific yield** (porosity less residual field capacity).

This value provides an upper bound of the possible recharge capacity of the aquifer based on the aquifer specific yield property. Only half of the average annual depth to groundwater was used in the calculation to produce a conservatively small value for feasibility study purposes, account for seasonal fluctuations, and reduce the potential of ASR operations contributing to flooding.

3.2.5.3. Groundwater storage estimated from groundwater pumping volumes

Annual groundwater pumping in the Kittitas Valley is greater than 60,000 af (Wilderotter, 2021). Therefore, a dynamic recharge storage capacity of greater than 60,000 afy is a reasonable assumption.

The professional judgement of Coho is that the quantitative residence time of recharged water is less than 10 years (as opposed to the residence time of molecules). Groundwater flow modeling is needed to provide a more reliable estimate. An ASR program in the Kittitas Valley will be intermediate between: 1) a floodplain recharge project; and 2) the closed “bathtub” concept commonly associated with recharge to Columbia River Basalt. Floodplain storage may offer habitat benefits, but the residence time is typically on the order of weeks to months and provides limited contribution to the Total Water Supply Available (TWSA). Groundwater recharge to basalt “bathtub” formations offers the prospect of storing water for long periods of time but offers limited immediate habitat value. ASR in the Kittitas Valley is expected to create stored water recoverable within a few years, and seepage to the Yakima River providing thermal refugia in both the summer and winter.

3.2.5.4. Summary of groundwater recharge capacity.

Groundwater aquifer properties indicate a range of potential static groundwater storage volume between 1,600 af and 77,000 af. Groundwater pumping data indicate a dynamic groundwater storage of greater than 60,000 afy. A total groundwater storage capacity of 61,600-137,000 afy is estimated. A groundwater model may refine this estimate.

The accuracy needed to estimate the recharge capacity of an aquifer is only to determine if it will be a limitation on the planned ASR program. Recharge rates will practically be limited by infrastructure, not the aquifer. Anderson and others (2008) assumed an infiltration rate of 6,000 afy through four wells (2,000 gpm per well for half a year; total injection rate of 8,000 gpm [18 cfs]). The capacity of the recharge water source, City Wells, has historically been 5,000 gpm (11 cfs).

3.2.6. SAR as an alternative recharge method

Two methods of groundwater recharge are:

- Aquifer Storage and Recovery (ASR), which is the term adopted by the GWSC to indicate direct injection through wells, with or without active recovery.
- Surface Aquifer Recharge (SAR), where water is spread on the surface to passively infiltrate down into the underlying aquifer system.

The Ellensburg project proposes to use ASR. The Kittitas Valley also contains potential SAR opportunities. Compared to ASR, SAR does not require injection wells, which may reduce infrastructure costs, but requires an appropriate infiltration capacity at surface. Where such conditions exist, infiltration usually occurs via construction of an infiltration gallery/pond.

Alluvial fans where streams such as Naneum Creek disgorge from the basalt uplands onto the valley floor remain conceptual candidates for further evaluation for SAR. Jones and Reecer Creeks appear to have a distributary pattern similar to Naneum Creek and may also have permeable geology at surface conducive to SAR. It is not known whether recharge to these terrains would discharge quickly back to streams and/or provide recharge to deeper portions of the aquifer system. Further evaluation may be warranted.

Sadowski and others (2020) suggested the shallow outcrops of basalt on the north side of the Kittitas Valley may be a candidate for SAR. Practical sources of recharge water would have to be provided (e.g., off-channel storage in the basalt uplands). Alternatively, water could be pumped uphill from irrigation canals.

The Thorp Prairie, where the KRD canal crosses the topographic high flats (elevation ~2,200 feet amsl; elevation of the confluence of Taneum Creek with the Yakima River is ~1,700 feet amsl), was identified as a prospective MAR site (Pitre and Austreng, 2013). The Thorp Prairie is a terminal glacial moraine, whose internal structure is unknown but likely complex. Further investigation should focus on the possible presence of transmissive strata, the feature's storage capacity, and the geotechnical stability in response to the higher groundwater levels that SAR would create. Because there are few, if any, wells on the prairie, an exploratory well in conjunction with a geophysical survey may be the best means of evaluating the potential for MAR.

Investigation of the East Kittitas Valley and a field reconnaissance of the northern part of the valley (i.e., Dry Creek catchment) close to the KRD North Main Branch canal did not indicate favorable conditions for SAR (Pitre and Austreng, 2013). The water table in these areas is close to ground surface year-round, in part due to irrigation practices – standing water in these areas is common. Water recharged to the surface aquifer within the valley floor is assumed to have a short residence time in groundwater (e.g., weeks) and will therefore not contribute substantively to the storage goals of YBIP.

SAR, like ASR, requires a water source and a means of delivering that water to recharge site. Delivering recharge water to these sites may require pumping from nearby irrigation canals (e.g., the North Branch KRD canal).

Insufficient information has been accessed in this study to evaluate recharge to the Columbia River Basalt.

4. INFRASTRUCTURE

The City of Ellensburg provides most of the infrastructure required for an ASR program:

- A source of recharge water ("City Wells" Ranney-type well).
- A delivery system (drinking water distribution system).
- Recharge facilities (wells that can be retrofitted for recharge).

These features are reviewed in this section, as well as possible alternatives to the proposed concept.

4.1. Recharge Water Source

The following sections first discuss the proposed source of recharge water, followed by a consideration of alternative sources.

4.1.1. Proposed water source

The proposed physical source of water is the City Wells facility, a horizonal infiltration gallery, Ranney-type well located approximately six miles northwest of the City. City Wells was constructed in 1913, and last rehabilitated in 2006. The well consists of a 30-inch perforated concrete pipe laid horizontally in shallow gravel approximately 700 feet from the Yakima River. Water produced from City Wells is treated with chlorine and fluoride. The wellhouse contains a 150 horsepower (hp) vertical turbine pump operated with a variable frequency drive (VFD), which slows the pumping rate if the well is drawn down due to an inadequate water supply. It has historically been pumped at 4,851 gpm. It is currently pumped at approximately 1,400 gallons per minute (gpm) when in use and is typically only used during times of peak demand.

This source is in direct hydraulic connection with the Yakima River. The water quality signature may reflect a mix of surface water and upgradient shallow groundwater. Regardless, pumping City Wells is hydraulically pumping water from the Yakima River, whether that be pulling water from the river or intercepting groundwater that would contribute to streamflow.

City Wells is about 700 feet distant from the Yakima River. The aquifer materials through which water from the Yakima River travels to reach City Wells provide significant filtration. Detailed analyses of water quality have shown that water pumped from City Wells, while being considered hydraulically a surface water source, is designated a groundwater source for drinking water purposes (DOH, 2004). Using the City Wells as an effective surface water source provides benefits of a source of recharge water over that of a direct surface water diversion. City Wells, relative to a direct surface water diversion:

- Is not subject to physical hurdles commonly associated with direct surface water diversions such as ice jams and debris.
- Is less susceptible to varying surface water quality, such as turbidity from storm events that may affect recharge well clogging,
- Likely has less Total Organic Carbon (TOC), such as algae, that contributes to the creation of Disinfection By-Products (DBPs; as discussed in Section 5).

4.1.2. Alternative recharge water sources

Alternative recharge water sources considered are:

- A new direct diversion from the Yakima River.
- Delivery from irrigation canals.
- Supply from new off-channel reservoirs.

A new direct surface water diversion from the Yakima River would require an in-channel structure. Permitting of such would be difficult. A direct diversion would likely require treatment to:

- Remove suspended solids that may clog a recharge well.
- Reduce TOC to meet antidegradation of groundwater regulations (WAC 173-200A)
- Meet drinking water standards complying with the federal surface water treatment rule, if the drinking water system of the City of Ellensburg is used to deliver and recharge water.

Use of a direct diversion from the Yakima River would be susceptible to damage or interruption of supply due to debris and ice jams during periods of high turbidity (e.g., winter, and runoff from storm or forest fire events).

If recharge water is delivered through the drinking water system of the City, it will have to be chlorinated. The presence of algae in a direct surface water diversion would raise the total organic carbon in the recharge water, result in higher DBP concentrations, and present a regulatory concern with respect to protection of groundwater quality.

Irrigation canals offer an existing option for the delivery of recharge water to some potential recharge sites. Irrigation canals as an alternative source of ASR recharge water, would likely:

- Require treatment for regulatory and operational considerations (i.e., clogging and compliance with WAC 173-200A). Irrigation canals might be used without treatment for Surface Aquifer Recharge (SAR).
- Be available for recharge only during the operational season of the canals (e.g., not during the winter, when water is more available for MAR).
- Need to be connected by a delivery system to recharge facilities (e.g., infiltration ponds and/or wells).

Irrigation canals present on the northeast side the Yakima River in the Kittitas Valley include:

- North Branch of the KRD.
- Town Ditch of the Ellensburg Water Company.
- Bull Ditch Company.

The KRD canal is the topographically highest and can more readily access areas considered for MAR projects. Sourcing recharge water from irrigation canals would have similar considerations as a direct surface water diversion with respect to treatment (e.g., DBPs). There would no concerns of jams (ice or debris) and less concern of high turbidity, depending on the individual irrigation canal. The KRD canal is diverted at Easton, high in the Yakima Valley, and will have better water quality. The other irrigation canals divert from the Yakima River within the Kittitas Valley, lower in the river system, and may be more susceptible to higher suspended sediment loads and TOC.

Use of irrigation canals would likely be limited to shoulder seasons (Figure 13):

- **April to October:** Operational period. Canals are running with water.
- **April-June:** Shoulder season. Delivery capacity exceeds demand. Capacity may be available for MAR applications.
- **July-August:** Peak demand period. Limited capacity maybe available for MAR applications.
- **September-October:** Shoulder season. Delivery capacity exceeds demand. Capacity may be available for MAR applications.
- **November-March:** Canals not currently being operated.

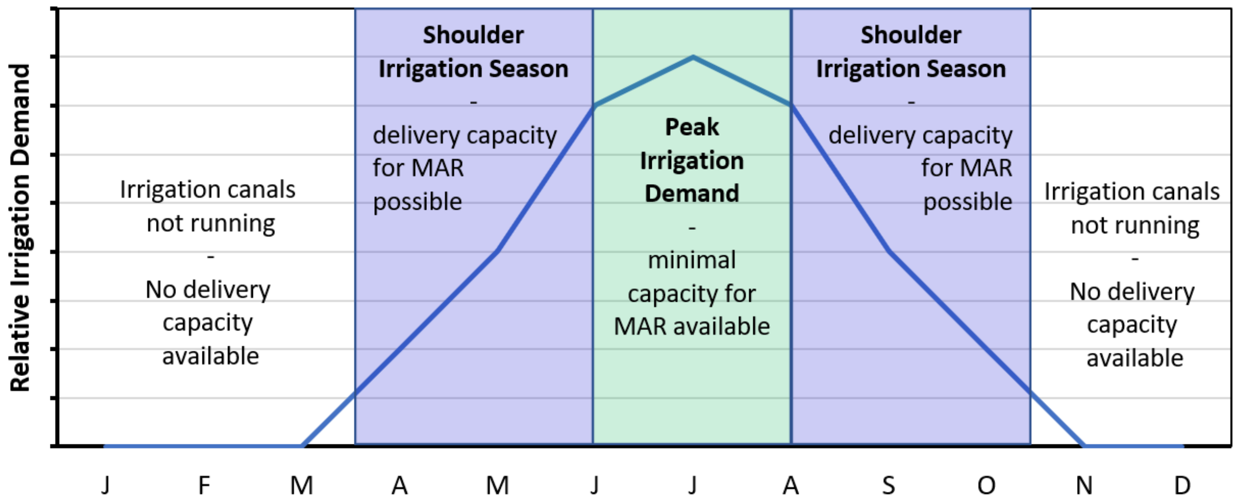


Figure 13: Conceptual availability of irrigation canal delivery capacity for MAR.

Off-channel reservoirs are being considered that could provide a source of surface water storage and/or a source groundwater recharge water, such as in the Naneum Creek catchment (Eberhart, 2021). This reservoir would capture spring freshet runoff and alleviate chronic flooding in the City of Ellensburg. Details, such as the storage volume, timing of availability, ownership, and permitting structure, are not available at this time. This concept warrants further consideration and development.

4.2. Distribution System

Discussion of a delivery or distribution system for MAR purposes considers: 1) the proposed scenario for the City of Ellensburg ASR program; and, 2) alternative scenarios.

4.2.1. Proposed delivery infrastructure

The backbone of the distribution system for delivering ASR recharge water from City Wells to potential recharge wells is a 24-inch transmission main running approximately six miles from the City Wells site to the City's service area. The Route 10 and Hayward Wells also feed into the 24-inch transmission line near its western end. The distribution system connects all of the City's wells. The Route 10 Well is located on the same property parcel as City Wells and is the proposed recharge point for an ASR pilot test. Retrofits such as valving, plumbing, meters, and telemetry components are needed to modify the system for a functional ASR program.

A second candidate recharge well, the Hayward Well, is located approximately a mile to the east on a hill at an approximate elevation of 1,700 feet above mean sea level (amsl; City Wells is at an elevation of approximately 1,600 feet amsl). Further analysis is needed to determine whether the pressure from City Wells will be sufficient to provide recharge water at an appropriate rate to this well (e.g., to maintain full pipe flow, and minimize entrainment of air during recharge).

Hydraulic modeling of the distribution system is needed to better ensure ASR operations can be conducted without compromising the supply of drinking water to the City's customers and fire flow pressures. Varying the rate of recharge can attain a balance between pressure to recharge a well and the corresponding decrease in the distribution system in the neighborhood around a recharge well.

For pilot test purposes, engineering modifications are required to the connection between City Wells and a recharge well, and of the recharge well. Currently it is assumed the Route 10 Well will be used for pilot testing. City Wells and the Route 10 Well are currently connected, and opening valves to allow the flow of recharge water from City Wells and through the wellhead facilities of the Route 10 Well need further engineering evaluation.

If the Route 10 Well is used for pilot testing, City Wells and the Route 10 Well will be isolated from the City's distribution system such that the two wells operate independent from the rest of the distribution system during a pilot test. Analysis is needed to evaluate how the recharge rate will be controlled by dynamic pressure from City Wells and the build-up of head pressure in the Route 10 Well.

Among other items, a scope of work in development for a feasibility study considers:

- Water right and legal diversion capacities associated with the Ranney Well (City Well).
- Hydraulic modeling of the distribution system during ASR recharge operations
- Initial retrofits of a well for pilot testing will serve future ASR operations. Additional retrofits are needed to enable other wells for recharge.

4.2.2. Alternative delivery infrastructure

No existing delivery alternative to that of the City's distribution system is currently recognized. Construction of new delivery systems may cost on the order of $1M/mile in a rural setting. If a new delivery system is constructed independent of the City's drinking water system, treatment to meet drinking water standards may be avoided. Treatment for operational purposes may still be needed (e.g., to prevent recharge well clogging and biofouling).

4.3. Candidate Recharge Wells

Discussion of a recharge wells considers: 1) existing City wells; and, 2) new wells.

4.3.1. Existing candidate recharge wells

The City of Ellensburg has several wells completed in the Upper Ellensburg Formation that may be retrofitted for ASR function. Wells with surface seals greater than 50 feet bgs are considered as candidate recharge wells in order to contain and deliver recharged water under dynamic recharge pressures to the target aquifer (Table 5).

Table 5: Wells with surface seals >50 feet.

Well	Representative Static Water Level (feet bgs)	Assumed Recharge Rate (gpm)	Estimated Specific Capacity (gpm/ft)	Prospective Head Buildup (feet ags)	Prospective Pressure at the Wellhead (psi)	Depth of Surface Seal (feet bgs)
Route 10	30’	500	7	40	18	401
Hayward	100’	800	8	100	0	600
Illinois	90’	2,000	21	95	2.3	400

ags = above ground surface
bgs = below ground surface
ft = feet
gpm = gallons per foot
psi = pounds per square inch

Important variables that should be evaluated in greater detail are:

i. Specific capacity, yields, and recharge capacities.
ii. Build-up of pressure within a well.
iii. Changes in well performance due to biofouling, clogging or other causes.
iv. Retrofit needs.

The cost to enable recharge from City Wells to the Route10 Well is estimated to be on the order of $500,000. Costs to retrofit other wells have not been evaluated.

The proposed method of recharging wells is through the annular space between the production casing and the pump column. This is the same method used by the city of Yakima. This method is feasible when the rate of recharge is high enough to quickly fill the annular space and minimize entrainment of air during recharge. An air release valve is needed on the wellhead. Air entrainment may fill pore spaces in the aquifer material and reduce permeability, which would reduce well recharge and production rates. The reversibility of the effects of injecting entrained air into an aquifer is not known.

Recharge through the annular space of the production casing has worked well for the city of Yakima. Recharging through the annular space between the production casing and the pump column is economical because, engineering-wise, it is simple. Further evaluation of recharge through installed pump columns should be evaluated. Recharging through the pump column may require a flow control valve affixed to the pump, which costs on the order of several $100,000. If a well is specially retrofitted for recharge, including the option to generate electricity may offset costs. Alternatives will be evaluated in the next engineering design phase of this project.

Recharge wells may be used to recover recharged water. Other wells of the City completed in the recharge aquifer can also be used to recover recharged water.

4.3.2. Alternative injection wells

Purpose built wells for ASR operation as part of the City of Ellensburg drinking water system, are estimated to be on the order of four million dollars each ($4M/well). This includes well installation and testing, engineering, pump installation, well house construction, and connection to the distribution system, including meters, valves, and treatment (chlorination and fluoridation).

5. WATER QUALITY

Water quality is relevant to an ASR program in three ways:

A. Regulatory compliance (e.g., antidegradation of groundwater)

B. Drinking water protection

C. Operations (e.g., well clogging)

The recharge water source (City Wells) and the recharge and active recovery points (other drinking water wells of the City of Ellensburg) are all drinking water sources approved by the Washington Department of Health (DOH). The water quality of both recharge water and groundwater are similar to that of the city of Yakima's implemented ASR program. Therefore, water quality considerations with respect to regulatory, drinking water and operations are also expected to be similar.

Sources of water quality data obtained and used in this study include the following:

- City of Ellensburg
- DOH drinking water quality database (Washington DOH, 2021)
- Well installation and testing reports
- Taylor and Gazis (2014)
- National Water Information System (NWIS; USGS, 2021)

These data sources were accessed within the limitations of time and budget. We do not claim to have comprehensively accessed all relevant and available data.

Water quality processes that may occur in an ASR program include:

1. Mineral dissolution and/or precipitation.
2. Redox reactions (e.g., oxidation of sulfide minerals that may release heavy metals).
3. Disinfection by-product (DBP) formation and attenuation.

Well clogging phenomena and temperature dynamics are briefly addressed in the summary of this section.

The major ion chemistry provides an initial indication of compatibility between recharge water and the receiving groundwater. Such data are available for City Wells, the proposed source of recharge water (Taylor and Gazis, 2014). Similar data are not available for the Route 10 Well, the proposed recharge well. However, the same data are available from the Thorp Well and Hayward Well, which also tap the Upper Ellensburg Formation and are located approximately 0.8 miles to the west and 1.4 miles to the east of the Route 10 Well, respectively (NWIS, 2021, and Pitre and Holom, 2009a, respectively; Figure 14;Table 6).

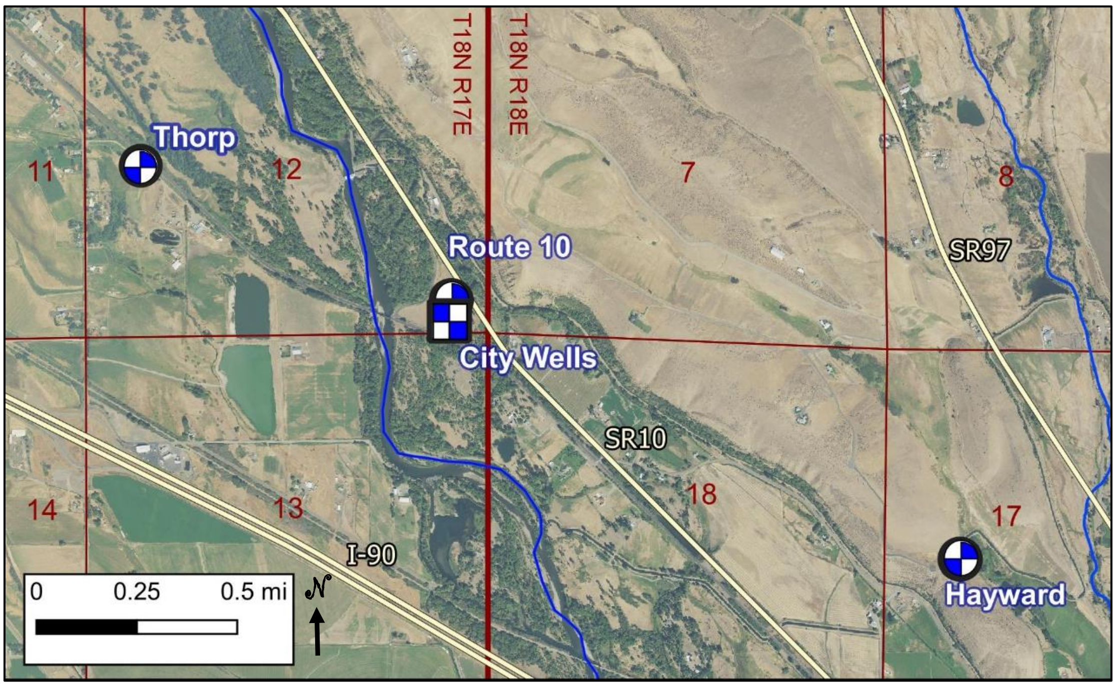


Figure 14: Location of wells used to characterize aquifer receiving waters.
(Thorp and Hayward Wells)

Table 6: Major ion chemistry.
(mg/L)

Source (depth in feet)	Cations				Anions			
	Na	K	Mg	Ca	Cl	HCO3	SO4	NO3
City Wells (23)	3.9	0.3	3.8	9.8	2.6	53	1.7	0.5
Hayward Well (1,007)	14	3.09	5.98	16.7	1.5	66.3	2.46	0.32
Thorp Well (720)	18.9	3.9	7.5	18.2	1.7	128	1.8	0.416

Data from Pitre and Holom (2009), Taylor and Gazis (2014), and USGS (2021).

5.1. Mineral Dissolution & Precipitation Potential

Plots of the major ions in the recharge and receiving waters are similar (Figure 15 and Figure 16). The lower total concentrations in the recharge water indicate that ASR operations may result in dissolution of aquifer material. Increased silica concentration in water recovered in the Yakima ASR program indicated the dissolution of volcanic glass, which is considered benign. During ASR operations by the City of Ellensburg, concentrations of silica in the recharged water may similarly rise to those naturally occurring in groundwater. No precipitation reactions are anticipated because solute concentrations in the recharge water are lower than in the receiving groundwater. No other signs of mineral dissolution were observed in the Yakima program, and no other are expected in the City of Ellensburg ASR program.

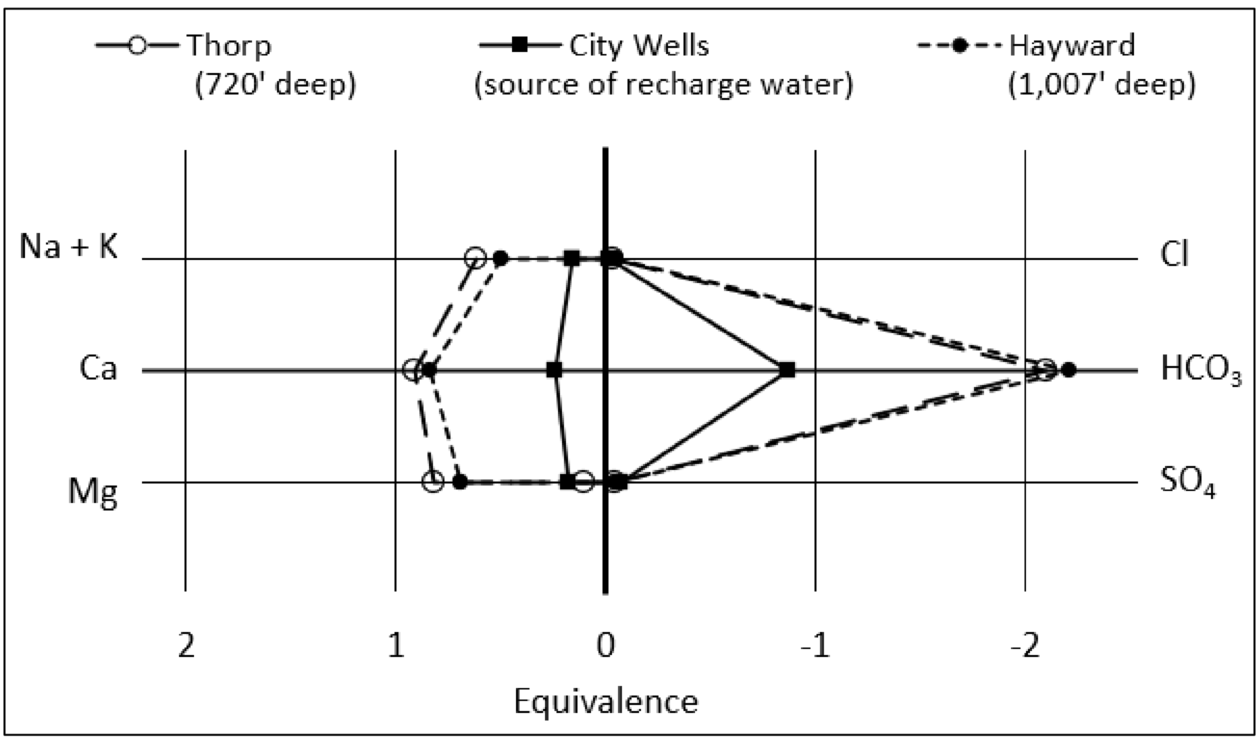
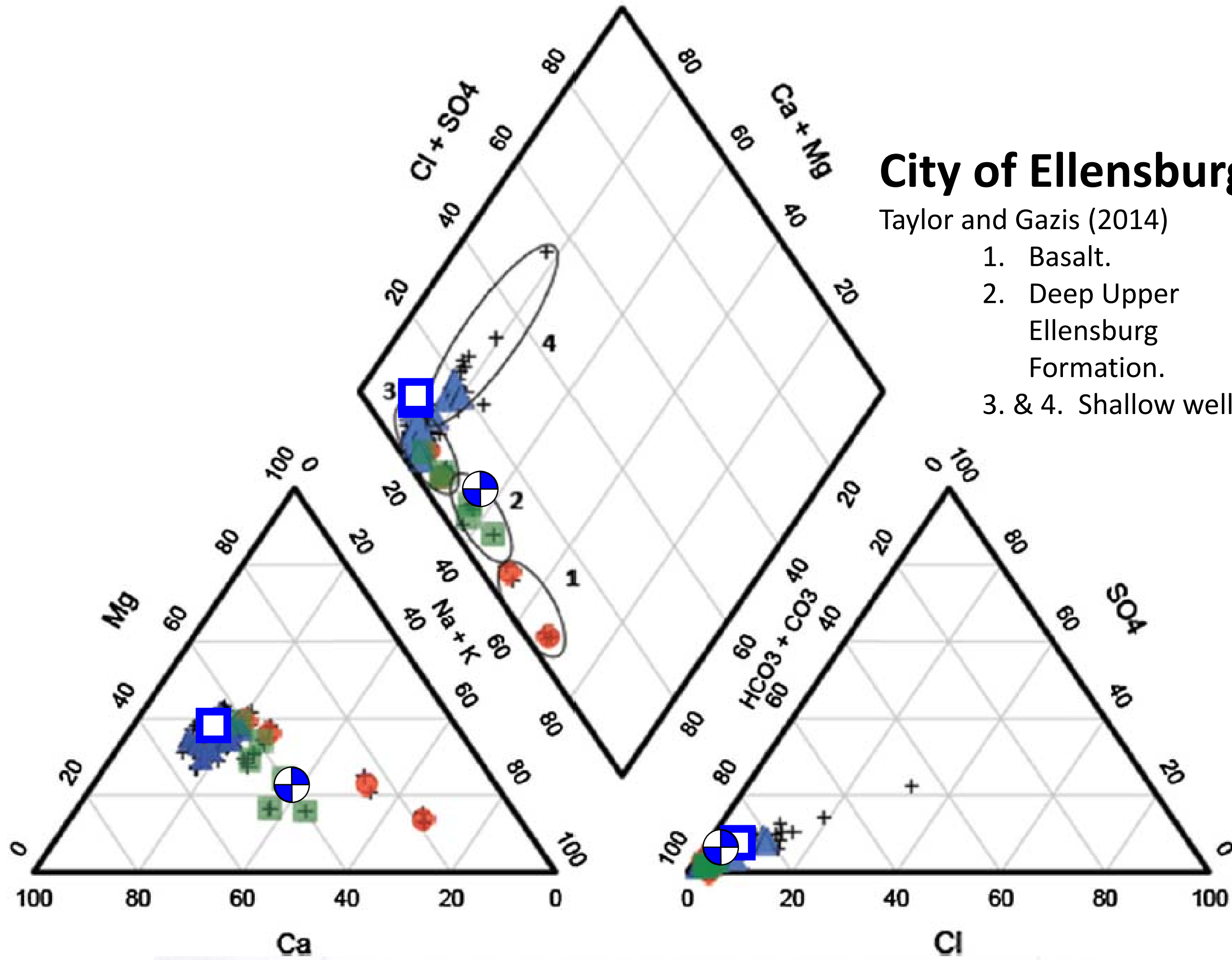


Figure 15: Stiff diagrams.



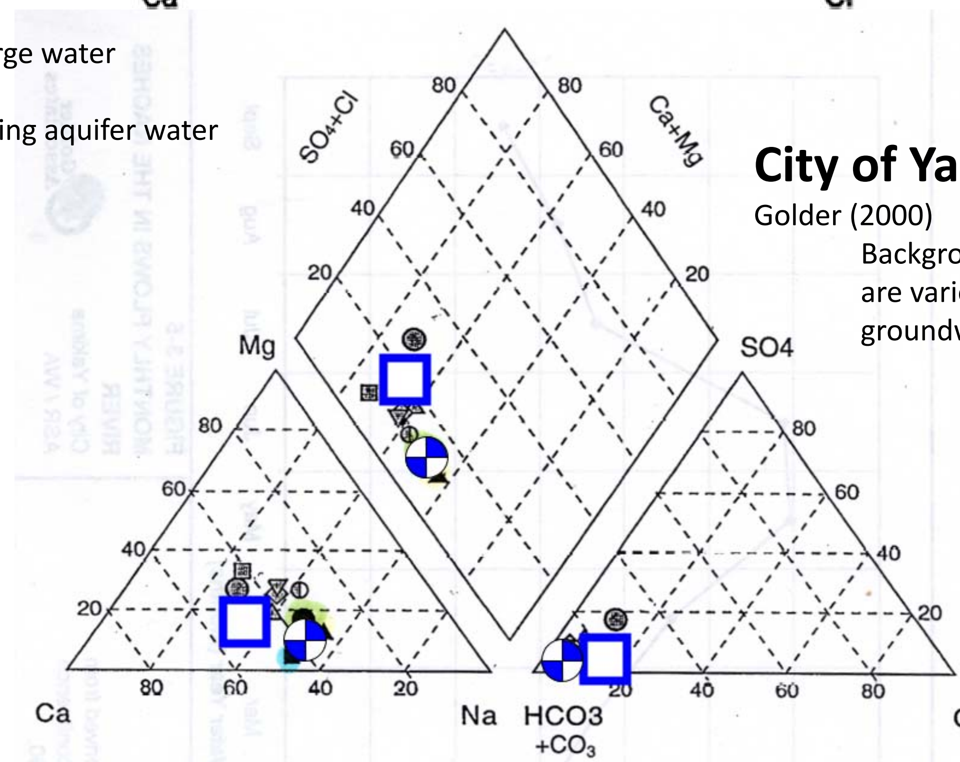
City of Ellensburg

Taylor and Gazis (2014)

1. Basalt.
2. Deep Upper Ellensburg Formation.
3. & 4. Shallow wells.

Recharge water

Receiving aquifer water



City of Yakima

Golder (2000)

Background symbols are various deep groundwater wells.

Plots of water quality of source recharge water and receiving groundwater for the cities of Ellensburg and Yakima are provided to show similarities.

Figure 16
Piper diagrams.

Ellensburg ASR

5.2. Oxidation-Reduction Reaction Potential

Nitrate is present in all waters considered in the Ellensburg ASR program, which indicates pervasive aerobic conditions (Table 6). Therefore, no oxidation-reduction (redox) reactions are expected. Redox reactions are of concern related to the oxidation of sulfide minerals and the potential release of associated heavy metals. While sulfide minerals are present in the aquifer materials, they are locked in clasts and not substantively accessible to recharged water or the water that may be recovered. The presence of aerobic conditions in the deep portions of the portion of the aquifer system being considered in the City of Ellensburg ASR program is consistent with the interpretation of a relatively fast groundwater flow regime. Anaerobic conditions are more likely to develop in a slow-moving groundwater flow system.

5.3. Disinfection By-Products (DBPs)

DBPs are formed by the reaction between:

1. Chlorine that is used to disinfect and reduce pathogens in drinking water.
2. Organic material that may be present in the water being treated.

DBPs include trihalomethanes and haloacetic acids. The health benefits from chlorination of drinking water are considered to be greater than the attendant risk (DOH, 2021). Concentrations of these compounds in public water supplies are regulated under the Safe Drinking Water Act and analyzed regularly in Washington State public water systems. DBPs are non-detect in the City of Ellensburg drinking water system.

Guidelines and targets for residual chlorine (Cl_r) are:

- <5 mg/L: The World Health Organization (WHO).
- <2 mg/L: Washington State Department of Health (DOH).
- 1 mg/L: City of Yakima's ASR program.
- 0.25-0.3: City of Ellensburg for the City Wells drinking water source.

The city of Yakima's ASR program recharges water from the Naches River, which is used as a benchmark for the City of Ellensburg. The Naches River is subject to elevated total organic carbon (TOC) due to turbidity, entrained organic debris, and algae. The City of Ellensburg's source of recharge water is the City Wells facility, which taps the Yakima River but is located approximately 700 feet from the river. Water withdrawn from City

Wells is filtered by the intervening alluvial aquifer material and is expected to contain a lower concentration of TOC than the Naches River. With lower TOC and Cl_r, lower DBP concentrations are expected. Concentrations of DBPs in the city of Yakima's ASR program meet regulatory requirements, as is expected of the City of Ellensburg's ASR program. Concentrations of DBPs in the City of Ellensburg drinking water system are non-detect where sampled in the distribution system.

Additional sampling of City Wells is needed to more directly evaluate the potential of DBP formation during recharge. Most of the City of Ellensburg's drinking water sources draw water from deep within the Upper Ellensburg Formation. City Wells is an anomaly as a source for the City of Ellensburg because it is in direct hydraulic continuity with the Yakima River. Water in the general distribution system, where DBP sampling is conducted, mostly represents water withdrawn from deep wells with low TOC.

5.4. Water Quality Summary

In this initial analysis water quality data from the city of Yakima ASR program are used as a proxy for the proposed City of Ellensburg ASR program. The source of recharge water is similar, as is the receiving aquifer (i.e., the Upper Ellensburg Formation).

In the proposed Ellensburg ASR program increases in silica relative to the recharged water are expected as a result of dissolution of volcanic glass. Silica is not a regulated drinking water parameter or a health concern, and its concentration does not bear on regulatory or operational considerations.

The proposed recharge water and receiving groundwater consistently contain nitrate, which indicates compatible and consistent aerobic redox conditions. No redox reactions are expected that may release heavy metals by the oxidation of sulfide minerals.

DBPs are of regulatory concern for ASR projects. The proposed source of recharge water and all candidate recharge points are DOH-approved drinking water sources of the City of Ellensburg, and concentrations of DBPs must meet drinking water quality standards. The water is chlorinated for disinfection for pathogens and fluoridated for dental health. DBPs have not been detected in the City of Ellensburg's distribution system.

Temperature of the recharged water will be moderated (Table 7). Groundwater temperature is relatively constant within one well, while the surface water temperature varies seasonally.

Table 7: Yakima River and groundwater temperatures.

	Yakima River @ Horlick (near Thorp; Reclamation, 2021)		**City of Ellensburg Groundwater**	
	^oF	^oC	^oF	^oC
Maximum	75	24	64	18
Minimum	32	0	54	12

Well clogging potential from physical (e.g., total suspended sediment [TSS]) and/or biofouling have not been evaluated because there is not enough data available. Given a clean source of recharge, as is anticipated from City Wells, a cause of physical clogging is distribution system scale. This is anticipated to be minimal for pilot testing purposes because: 1) the distance between the recharge source (City Wells) and the recharge well (Route 10 Well) is approximately 300 feet; 2) the water mains will be mostly newly installed on which there will have been minimal time for scale to form; and, 3) newly installed pipe may consist of polyvinyl chloride (PVC) plastic, which creates negligible scale.

Well clogging from biofouling and/or physical clogging is best evaluated in a pilot test with appropriate monitoring.

6. BENEFITS

The information provided in the preceding sections is integrated to define potential benefits from the ASR program in the Upper Ellensburg Formation in the Kittitas Valley. Benefits provide the motivation to implement an ASR program. Benefits from the Ellensburg ASR program are:

- Securing municipal water supply.
- Aquatic habitat improvements.
- Increasing TWSA.

The estimated 1,600 af of storage available in the aquifer resulting from decreased groundwater levels represents only the static available storage in the confined portion of the aquifer system. Groundwater in the Upper Ellensburg Formation of the Kittitas Valley appears to be in close hydraulic continuity with the Yakima River such that pumping water into or out of the aquifer will impact the Yakima River after a relatively short lag time (e.g., several years). Hence, the capacity of the aquifer to receive recharge water is estimated at greater than 10,000 afy.

Implementing an ASR program in the near future will have long-lasting benefits for the City and the Yakima Valley. However, it will provide immediate benefits primarily to aquatic habitat and TWSA. These benefits meet some of the goals of the Groundwater Storage Subcommittee of the Yakima Basin Integrated Plan (YBIP).

6.1. Benefits to Municipal Water Supply

The ASR program involves operation by the City of Ellensburg because all the infrastructure is wholly owned by the City. The benefit to the City is to secure municipal water supply. The future holds several unknowns, such as drought and climate change, that may affect the reliability of groundwater for municipal supply. Previous City leaders worked to best secure water supply for the city. The current leadership group wishes to continue this legacy and considers an ASR program worth pursuing.

The City of Ellensburg is one of the fastest growing communities in Washington State. The City has identified an ASR program as a tool to secure future municipal water supply. The City has installed on average one municipal supply well every three years in the last

12 years. The need for additional wells is driven in part by diminishing yield from existing wells, and in part by growing demand. The City is considering the installation of two additional wells in the near future. New wells could be designed for ASR purposes and increase the installed ASR recharge capacity. Cost for new wells may be reduced by cost-sharing if used conjunctively for municipal purposes and an ASR program.

The installation of additional wells will likely be permitted under existing water rights. The purpose of the proposed ASR program is not to obtain additional water rights, but rather to develop a water resource management tool. The City recognizes that working with YBIP stakeholders to best utilize this tool will provide benefits to multiple needs, including those that align with City municipal water delivery responsibilities.

6.2. Benefits to Aquatic Habitat

Salmonids include sockeye, coho, Chinook, bull trout, and steelhead, some of which are listed under the Endangered Species Act (ESA; Table 8). Benefit from ASR operations in the Kittitas Valley to salmonid habitat will be primarily temperature-based. Quantitative flow benefits from recharge to groundwater and subsequent seepage to streams will occur but are not anticipated to be significant with regard to aquatic habitat. Instead, seepage of recharged water back to streams will benefit aquatic habitat by providing concentrated localized discharges that will moderate temperature to provide thermal refugia, under both the hot summer and freezing winter conditions.

The upper limit of guidelines for healthy salmon survival based on the corresponding soluble concentration of oxygen salmon need for salmon to breath is 18 ^{o}C (64 ^{o}F; Figure 17). Temperatures above 25 ^{o}C (77 ^{o}F) approach lethal limits for salmonids. Peak activity periods of salmonids in which there is thermal stress are:

- High temperature stress (>18 ^{o}C; July through September):
  - **July-August:** Sockeye in-migration.
  - **September:**
    - Summer/Fall Chinook in-migration.
    - Spring Chinook spawning.
    - Bull trout spawning (ESA threatened).
- Freezing risk (December thru February):
  - **December:** Coho spawning.

Table 8: Salmonid periodicity use in the Upper Yakima Basin (WRIA 39).

(Scott and others, 2006)

Fish Species	Life Stage	J	F	M	A	M	J	J	A	S	O	N	D
Yakima River Summer/Fall Chinook	Adult In-Migration												
	Spawning												
	Rearing												
	Juvenile Out-Migration												
Upper Yakima River Spring Chinook American River Spring Chinook Naches River Spring Chinook	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Upper Yakima Summer Steelhead Naches Summer Steelhead (ESA Threatened)	Adult (spawners & kelts) Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Yakima Sockeye (Not ESA listed)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Yakima Coho (ESA Not Warranted)	Adult In-Migration												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Out-Migration												
Yakima River Core Area Bull Trout (ESA Threatened)	Adult Migrations												
	Spawning												
	Egg Incubation & Fry Emergence												
	Rearing												
	Juvenile Migrations												

= No use.
= Some activity or use occurring.
= Peak activity.

Heat stress risk
Freezing risk

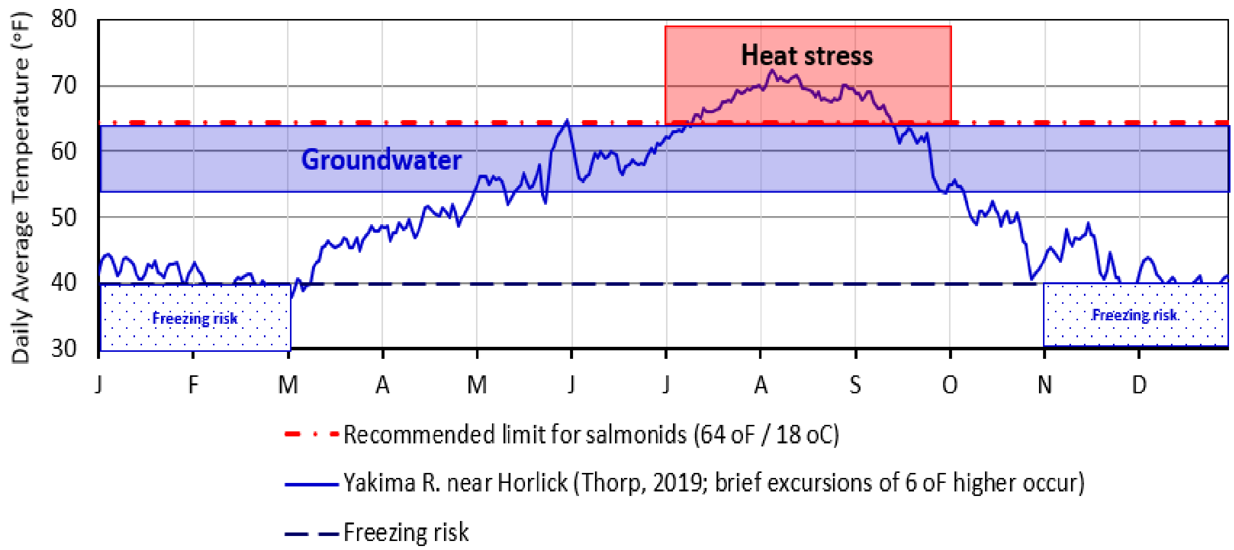


Figure 17: Yakima River and groundwater temperatures in 2019.
Yakima River temperature near Horlick (Thorp; Reclamation, 2021).

Many other salmonid life stages are present in these thermal stress periods, such as year-round rearing and migrations.

Groundwater seeps provide critical refugia to fish species by moderating surface water temperature in both the summer and winter. Groundwater temperature in the deeper part of the Upper Ellensburg Formation ranges between 54-64 degrees Fahrenheit (^{o}F; 12-18 degrees Celsius [^{o}C]).

Summer surface water temperatures in tributaries are strongly influenced by irrigation return flows, which reflect ambient air temperature that often exceeds 100 degrees Fahrenheit (^{o}F; 38 ^{o}C). Groundwater seeps in the summer provide relatively cold thermal refugia, and oxygen that is more soluble in cold water, during migration, spawning, incubation and rearing.

Winter conditions often result in freezing of the river surface, and groundwater seeps provide relatively warm thermal refugia. Congregation of salmon at groundwater seeps has been observed during the winter when portions of the Yakima River were frozen over (Nicolai, 2021). The value of groundwater seeps in providing thermal refugia in both the summer and winter is confirmed by Kohr (2021).

The conceptual hydrogeologic model of the Kittitas Valley proposes that recharged water in an ASR program not actively recovered by pumping will discharge primarily at the head of Yakima Canyon. In this area increased groundwater seepage from ASR operations will provide thermal refugia to improve salmonid habitat in both summer and winter.

6.3. Benefits to Total Water Supply Availability (TWSA)

Water recharged by the Ellensburg ASR program will replenish groundwater storage and subsequently discharge to the head of the Yakima Canyon (Figure 9). Annual groundwater pumping in the Kittitas Valley is estimated to be greater than 60,000 af (Wilderotter, 2021; Figure 10). This withdrawal likely results in a similar reduction of groundwater discharge to surface water. An ASR program will partially offset these impacts and contribute to TWSA (Sections 3.2.2 and 7.2).

7. RECOMMENDATION

It is recommended that an ASR pilot test be conducted. This prefeasibility study finds that an ASR program by the City of Ellensburg is viable and will provide benefits to the City, the public, salmonid habitat, and other aquatic habitat and will increase Total Water Supply Availability (TWSA) in the Yakima Basin. This project is the most developed and most likely to succeed of identified options in Kittitas Valley, based on our comparison of: **1)** alternative methods of recharge (Section 3.4); **2)** sources of water (Section 4.1); and **3)** delivery and recharge infrastructure (Sections 4.2 and 4.3). This proposal also has the advantage of having a well-established entity (City of Ellensburg) willing to manage the project. The motivation of the City is to secure municipal water supply into the future.

Coho recommends an ASR pilot test be conducted for the following reasons:

- Provide empirical evidence of the viability of an ASR program.
- Familiarize the City with ASR operations as they consider undertaking this program.
- Provide water quality data for All Known And Reasonable Treatment (AKART) analysis and the protection of groundwater quality.
- Inform the permitting process (e.g., a groundwater reservoir [ASR] permit).

7.1. ASR Pilot Test

A scope of work was presented to the Groundwater Storage Subcommittee August 6, 2021 (Wilhelm and Pitre, 2021). A revised scope is presented with this draft report of the prefeasibility report that provides more clarity with respect to phasing. The first phase covers preparatory work, including a significant portion of required permitting, and engineering design of retrofit needs to allow an ASR pilot test to be conducted recharging water from City Wells to the Route 10 Well.

Most permits are in place to conduct an ASR pilot test. The City holds a municipal water right for the source of water to be recharged, groundwater recharge is a valid municipal purpose of use, and the City holds a groundwater right for the withdrawal of recharged water. The City is seeking a new ASR water right for groundwater storage under existing water rights.

A pre-application meeting of the City with Ecology should be conducted to determine additional permitting processes for a pilot test, which may include:

- Developing an ASR Plan (e.g., pumping and monitoring schedule). A well-developed plan is anticipated to be presented to Ecology for consideration as part of a preapplication meeting for an ASR application. Processing the application is anticipated to occur after completion of a pilot test.
- Coordinating with Ecology and DOH.
- Preparing a Quality Assurance Project Plan (QAPP).
- Evaluating whether the National and/or State Environmental Policy Acts (NEPA/SEPA) need to be addressed.
- Compliance with AKART is necessary for full implementation of an ASR program. Recharge during an ASR pilot test will be hydraulically controlled and permitted by DOH as part of the operation of a drinking water source. The City will work closely with the Office of Columbia River and the Water Quality Section of Ecology to ensure full regulatory compliance.
- Registering the recharge well for the ASR pilot test with the Underground Injection Control (UIC) program promulgated by the federal Environmental Protection Agency and implemented by Ecology.

This prefeasibility report contains information supporting an ASR application (Table 9).

7.2. Future Buildout

Pending positive results from a pilot test, implementation of a fully permitted and operational program will depend on the following programmatic variables:

- Permitting.
- Operation using appropriate existing wells, including needed retrofits.
- Construction of ASR purpose-built wells to expand recharge capacity beyond appropriate existing wells.
- Allocation of benefits, costs, and financing.
- Funding.

Technical variables may require:

- Running the hydraulic model of the City's distribution system to ensure reliable delivery of water to customers, and maintenance of system pressures for fire-fighting flows.
- Using a groundwater model to inform ASR permitting parameters. The model of Ely and other (2011) may be used, operated by Reclamation. Alternatively, a simplified and focused groundwater model may be developed by consultants.

Costs may include:

- Purpose-built ASR wells may cost on the order of $4M each.
- Operations.
- On-going monitoring and reporting requirements.

The City of Ellensburg is inclined to implement and manage an ASR program into the future and partnering with other beneficiaries of the ASR program.

Table 9: Documentation required for an ASR application.

Section	Required information	Regulatory Reference(s) & If covered in this Report
7.1	Maps showing: i. The proposed aquifer storage reservoir project ii. Source diversion and/or withdrawal locations iii. Any associated points of diversion or withdrawal iv. Any associated place(s) of use v. Estimated area where water will be stored within the storage aquifer vi. Well monitoring network locations vii. Nearby hazards	WAC 173-157-120 through -170 **i. thru v.: Covered in this report.** vi. & vii. To be prepared in the next project phase.
7.2	If platted property, a complete copy of the plat map.	n/a
7.3	A conceptual model of the hydrogeological setting, prepared by a hydrogeologist licensed in the state of Washington.	WAC 173-157-120 **Covered in this report.**
7.4	An operational plan of the proposed project, prepared by an engineer or a geologist licensed in the state of Washington.	WAC 173-157-130 To be prepared in the next project phase.
7.5	A description of the legal framework of the proposed project.	WAC 173-157-140 To be prepared in the next project phase.
7.6	An environmental assessment and analysis for the proposed project. A copy of SEPA Threshold Determination, if applicable.	WAC 173-157-150 To be prepared in the next project phase. A checklist and Determination of Non-Significance (DNS) are anticipated.
7.7	A mitigation plan for the proposed project, if required. The mitigation plan must be reviewed and approved or prepared by an appropriately experienced engineer licensed in the state of	WAC 173-157-160 To be prepared in the next project phase.
7.8	A monitoring plan for the proposed project.	WAC 173-157-170 To be prepared in the next project phase.
7.9	Provide a timeline for your project.	To be prepared in the next project phase.

ACKNOWLEDGEMENTS

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