GSI Water Solutions, Inc.

TECHNICAL MEMORANDUM

Initial Feasibility Evaluation of ASR, City of Silverton, Oregon

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1. Introduction

This technical memorandum summarizes the results of GSI Water Solution's (GSI) preliminary evaluation of the feasibility of developing an Aquifer Storage and Recovery (ASR) system for the City of Silverton (City). This evaluation was completed in collaboration with Keller Associates, Inc. (KA). The City is identifying and exploring alternatives for developing resilient, sustainable, and cost-effective water sources to help meet the demands of its customers. Currently, the City meets existing water demands via surface water diversions from Abiqua Creek and Silver Creek. ASR has been identified as a potential alternative for future consideration as a supplemental supply source for meeting future peak demands and/or in the event that its surface supply sources are interrupted.

ASR is a technique for storing water in a suitable aquifer involving injecting treated drinking water through a well into the storage aquifer, and later recovering the water for its intended purpose using the same well. Water is usually stored during periods of when diversion and/or treatment capacity exceeds demands, commonly during the winter and spring months. The stored water can later be recovered and used during higher water demand periods, or for emergency use when the primary supply source has been interrupted. ASR is technically not a new source, but provides a way to better align existing source capacity with demands, reducing the size of or delaying expansion of its source and treatment infrastructure. ASR also is a tool to increase supply resiliency with reduced snowpack storage and less reliable stream flows because of climate change. ASR does not however serve the same function as an above-ground reservoir to regulate operational flows and provide fire or peak hour flows.

The purpose of this study is to evaluate whether ASR is a viable alternative to include in future water system master planning efforts by the City. The objective of the study is to complete a preliminary desk-top evaluation of ASR potential within the defined Study Area. The Study Area (**Figure 1-1**) includes areas within ¼-mile radius of the City's Urban Growth Boundary (UGB) and Highway 214 between Silverton and Mount Angel. The specific objectives of the study are to:

- Confirm the availability of a treated ASR source water supply and estimate potential rates and volumes of water available for storage
- Identify and evaluate potential candidate ASR storage aquifers in the Columbia River Basalt Group (CRBG) based on data from existing wells,

- Estimate potential injection/recovery rates and storage volumes.
- Identify potential fatal flaws to ASR development in the Study Area.
- Identify favorable areas for siting an ASR system based on hydrogeologic, water infrastructure and land ownership and use.
- Outline a roadmap for developing an ASR system, including uncertainties, risks and costs

2. Existing Water System and Proposed ASR System Criteria

2.1 Water Supply Needs

Historical and future water demand projections from the 2021 Water Master Plan (WMP) are presented in Table 2-1. Three different scenarios of future demands were developed. The WMP uses Scenario 2 demands in determining the adequacy of source, storage, treatment, and distribution system capacities for the water system. Scenario 2 (from the WMP) is described as residential per capita demands lower by 3% over the next 10 years and then remain constant. Commercial demand in 2021 is reduced with the closing of the BrucePac processing facility, but grows at a rate of 2.5% a year after that. **Table 2-1** below summarizes existing and future system demands for the WMP Scenario 2.

Table 2-1. WMP Future System Demands[1]

Year	2020	2030	2035	2040	2055
Population	**10,701**	**12,310**	**13,076**	**13,759**	**15,631**
Scenario 2 Average Annual Demand	1.41	1.46	1.59	1.72	2.17
Scenario 2 Average Summer Demand	2.05	2.18	2.37	2.56	3.18
Scenario 2 Average Winter Demand	1.04	1.05	1.15	1.25	1.58
Scenario 2 Peak Day Demand	3.08	3.27	3.56	3.84	4.77

Note

[1] Values are daily demands in million gallons (mg)

The City derives its water supply from intakes on two surface sources: Abiqua Creek and Silver Creek. Water diverted from these sources is conveyed to and treated at the Water Treatment Plant (WTP). The City can use both intakes, or one based on the time of the year and creek conditions. A transmission line break for one or both intake pipelines would cause a critical failure point to the existing system. Additionally, the surface source capacity may become deficient due to natural disasters. For example, fires spreading ash into the creeks or a spill into the creek upstream of the intakes. Currently, the intake at Abiqua Creek reportedly suffers from sediment build-up and blinding due to leaves during the fall season. Additionally, the intake is at risk of plugging with leaves during power outages, because the cleaning mechanism used to clear the screens does not have an emergency backup power supply.

Potential benefits to the City of an ASR system include: (1) supplementing system capacity to meet peak summer demands; and (2) providing redundancy at a different location than the WTP. As a redundant source, the ASR system would protect the City against supply interruptions caused by natural disasters that effect the intakes and WTP, or in the event of an algae bloom in Silver Creek Reservoir. An ASR system also potentially could provide a supplemental or backup source of wholesale supply to Mount Angel with an intertie.

2.2 Source Water Availability

The City derives its water supply from two surface sources: Abiqua Creek and Silver Creek. Water from Abiqua Creek is conveyed by gravity directly to the WTP. The City's Abiqua water right was established in 1916 (the oldest on the creek) and is for 10.0 cfs (or 6.5 MGD). The City has a current development limitation ("greenlight water") of 7.0 cfs (or 4.5 MGD) for this water right. The Silver Creek water right established in 1911 is for 5 cfs (or 3.2 MGD) and has no development limitations. The current measured pump capacity of the Silver Creek intake is 2.3 MGD with both pumps running. The City has a water right to use 14 cfs (9.0 MGD) of the water stored in the Silverton Reservoir. The 14 cfs can be released from the reservoir and diverted from the current intake on Silver Creek but the total annual volume that can be diverted is limited to 1,300 acre-feet (AF) per year, of which only 200 AF per year is greenlit. The total capacity of water rights is 15 cfs (or 9.7 MGD)..

2.3 Water System Information

The source water is comprised of two creeks (Abiqua and Silver Creek) that are fed from two different watersheds. This configuration makes the City's water supply less vulnerable to an event within one of the watersheds that would significantly alter the water quality being delivered to the treatment facility. While this provides some level of protection to the City, it also creates a unique challenge to the operation of the plants. The water sources, while similar, also have unique characteristics that change the treatment approach within the WTP. The City's primary and preferred source is Abiqua Creek, a perennial stream with good water quality. If flow in Abiqua Creek is low or has high turbidities, the City switches to water from Silver Creek.

Silverton has two treatment facilities at the WTP site, Plant 1 and Plant 2. Silverton's two plants operate independent of each other. Plant 1 was constructed in 1957 with upgrades in 1962 and 1972, and programmable logic control (PLC) upgrades in 1994. Plant 1 is only operated in the summer and has a capacity of 1.5 MGD. Plant 2 was constructed in 1982 and has a treatment capacity of 2.5 MGD. The treatment capabilities of both plants have been reduced due to age of the facilities and operator experience.

There are six pressure zones in the City's water system. Placement of an ASR well in different areas of the water distribution system will have varying impacts. Placing the ASR well in the High Level Zone or Edison Booster Zone will allow for redundancy at the highest hydraulic grade line, although require pumping to fill the above ground reservoir. Alternately, adding the ASR system to a low zone will require less energy. Potential future infrastructure needs for an ASR may include but are not limited to a new booster station, a stormwater detention pond, and larger pipes for the backbone of the system.

2.4 Water Availability

This section summarizes the capacity and limitations of the different elements of the City's water system, including water rights, intakes, the WTP and distribution system.

The City holds a combined Abiqua Creek and Silver Creek water right capacity of 15 cfs, as explained in section 2.2. Additionally, 14 cfs can be diverted from the Silver Creek Reservoir to the Silver Creek intake with an existing authorized development limitation of 200 AF per year. The full annual volume of the water right for the Silver Creek Reservoir is 1,300 AF per year.

The Abiqua Creek intake includes a gravity transmission line with a capacity of 6.5 MGD. The Silver Creek intake has an existing capacity limitation of 2.3 MGD, although the City will be replacing it with a 4.1 MGD intake structure in 2022. Combined, the City has sufficient intake capability as well. The City historically runs one intake at a time. This means the potential production limitation is 2.3 MGD, and the future production limitation is 4.1 MGD after the intake project is completed.

The existing treatment plant has a design seasonal capacity of 4.0 MGD in the summer and 2.5 MGD during the other seasons. With backwashing, the effective seasonal treatment capacities are 3.8 MGD and 2.3 MGD. The 2.3 MGD winter effective treatment capacity will limit existing ASR well recharge capabilities. The treatment capacity currently is the bottleneck for existing and future growth. A new treatment plant is currently under design and will provide a treatment capacity of 4.0 MGD year round.

Demands were determined from Scenario 2 of the water master plan, as explained in section 2.1. In theory, the ASR well would recharge in the winter and extract in the summer and/or peak day events. Because of the seasonal scenarios, average winter day is evaluated when recharging the well, and peak day is used when extracting from the well. The existing winter average day demand and peak day demands are 1.0 MGD and 3.1 MGD, respectively. The future winter average day demand and peak day demands are 1.6 MGD and 4.8 MGD, respectively. **Table 2-2** and **Table 2-3** summarize the existing and future volumes and rates of water available for an ASR well.

Table 2-2. Existing Water Balance

Scenario	Summer		Fall - Winter - Spring	
	gpm	MGD	gpm	MGD
Abiqua and Silver Creek - Water Rights (15 cfs)	6,732	9.7	6,732	9.7
Silver Creek Reservoir Water Right - Greenlight Water	124	0.2	124	0.2
Abiqua Creek Intake Capacity - Existing	4,514	6.5	4,514	6.5
Silver Creek Intake Capacity - Existing	1,597	2.3	1,597	2.3
Treatment Capability - Design Treatment Capacity	2,778	4.0	1,736	2.5
Treatment Capability - Effective Treatment Capacity	2,639	3.8	1,615	2.3
Average Day Demand (ADD) – Existing	1,424	2.1	722	1.0
Peak Day Demand (PDD) – Existing[1]	2,139	3.1		
Water Availability for ASR Storage (Effective WTP Capacity – ADD)			**893**	**1.3**

Note

[1] Peak Day Demand is not specified by season in the 2021 Silverton Water Master Plan and assumed to occur during the summer.

Table 2-3. Future Water Balance

Scenario	Summer		Winter	
	gpm	MGD	gpm	MGD
Abiqua and Silver Creek - Water Rights (15 cfs)	6,732	9.7	6,732	9.7
Silver Creek Reservoir - Full Water Right	804	1.2	804	1.2
Abiqua Creek Intake Capacity - Future	4,514	6.5	4,514	6.5
Silver Creek Intake Capacity (2040 flows) - Future	2,826	4.1	2,826	4.1
Treatment Capability - After Improvements	2,778	4.0	2,778	4.0
Average Day Demand - 2055	2222	3.2	1,097	1.6
Peak Day Demand – 2055[1]	3,313	4.8		
Water Availability for ASR Storage (WTP Capacity – ADD Winter 2055)			**1,681**	**2.4**

Note

[1] Peak Day Demand is not specified by season in the 2021 Silverton Water Master Plan and assumed to occur during the summer.

As explained above, the existing Silver Creek intake has a production limitation of 2.3 MGD, although a new intake is set to be built in 2022 that will raise this to 4.1 MGD. Additionally, the Abiqua Creek intake has a capacity of 6.5 MGD. This means the existing treatment limitation of 2.5 MGD in the winter, and effective treatment capacity of 2.3 MGD after backwash will determine the amount of surplus water for ASR. With an existing winter average demand of 1.0 MGD, approximately 1.3 MGD is currently available for recharging in the winter. The existing peak day demand of 3.1 MGD, which most likely occurs in the summer, is less than the effective summer treatment capacity of 3.8 MGD.

In the future, the upgraded design WTP capacity will be 4.0 MGD. The 2055 peak day demand is 4.8 MGD which is 0.8 MGD more than production capacity. The 2055 Winter Average day is 1.6 MGD, leaving approximately 2.4 MGD available for ASR recharge. Thus, if an ASR system is developed, the City can use a portion of this available winter time WTP capacity for recharge and storage to meet the 0.8 MGD WTP capacity shortfall during summer peak demand periods.

3. Hydrogeologic Feasibility

3.1 Geologic Conditions

This section summarizes the general hydrogeologic framework of the Silverton area and potential ASR storage aquifer targets. **Figure 3-1** presents a map of the general geology in the Silverton area and outlines the City's UGB. The predominant geologic units of the area, from youngest to oldest, include alluvial deposits, basalt lava flows of the Columbia River Basalt Group (CRBG), and older marine sediments:

- **Alluvium:** The uppermost hydrogeologic unit in this area consists of alluvial deposits comprised of unconsolidated silt, clay, sand and gravel. This unit is relatively thin in areas of the City where it is exposed at surface and may be up to 250 feet thick in the northwest portions of the Study Area. The alluvium generally consists of an uppermost finer-grained silt unit and underlying coarser-grained Willamette Aquifer. Although the Willamette Aquifer typically has moderate to high permeability with more favorable well yields compared to the overlying silt unit, the aquifer is unconfined to semi-confined and has been shown to be in hydraulic connection with surface waters, rendering it generally less suitable for consideration as an ASR storage aquifer.

- **Columbia River Basalt Group:** The Columbia River Basalt Group (CRBG) hosts an aquifer system that within multiple layered sequences of flood basalts. Work by the USGS (Conlon, et. al., 2005) indicates that CRBG in the Study Area ranges in thickness between 100 and 600 feet. The thickest portion of CRBG (500 feet or greater) is defined by a trough located west-northwest of the City that extends in a northeasterly direction from the Salem area. The CRBG thins out east-southeast of the City.

  Groundwater within the CRBG aquifer system is hosted within thin permeable zones of fractured or rubbly material comprising the top of one flow and the base of the overlying flow. These zones are commonly referred to as “interflow zones” and may be highly transmissive, yielding 250 to >1,000 gpm (reported at various CRBG wells throughout the Willamette Valley). The interflow zones are separated by the dense, low permeability interiors of each basalt flow that inhibit the vertical movement of groundwater, and act as confining layers. The high yield of CRBG interflow zones, limited recharge and intrinsic storage characteristics (thin and confined) renders the CRBG aquifer system highly susceptible to depletion from overdraft (e.g., the Victor Point Groundwater Restricted Area (GRA) located in Silverton). Some of these same characteristics also often contribute to making the CRBG aquifer system highly suitable as an ASR storage aquifer. Approximately three-quarters of the 20+ operational ASR systems in Oregon and Washington are hosted by CRBG aquifers.

- **Marine Sediments (Older Rocks)**: This hydrogeologic unit consists of older consolidated siltstone, sandstone, and claystone that were deposited in ancient marine environments. The marine sediments represent the floor/basement unit of the Willamette Valley and underlie the CRBG in the immediate vicinity of the City and Study Area, with thicknesses estimated to be over 1,000 feet. Small exposures (outcrops) are present in the topographic higher areas to the east and southeast of the City. Groundwater within this unit is commonly saline and well yields are relatively low (<20 gpm). The marine sediments are generally not suitable for ASR because of poor yields.

A conceptual diagram of these hydrogeologic units in the central Willamette Valley is presented on Figure 2B.

3.2 Local Geologic Structures

Geologic structures, such as faults and folds, can act as barriers to groundwater movement, affecting well yields and storage volumes. In some cases, faults and folds can compartmentalize geologic units, limiting natural recharge to and discharge from aquifers. Structures have been found to affect the CRBG aquifer system in a number of ways including:

- Forming barriers to the lateral and vertical movement of groundwater; a series of faults can create hydrologically isolated areas.
- Providing a vertical pathway for hydraulic connection between otherwise confined CRBG aquifers.
- Exposing interflow zones and creating local opportunities for aquifer recharge and/or discharge.

Faults located along Silver Creek and in the southern Silverton area (USGS, 1999) could have potential impact on the occurrence and movement of groundwater through the underlying CRBG aquifers. In general, these structural faults appear to compartmentalize aquifer units and likely may limit the potential of loss of stored water during ASR. Additional evidence of aquifer compartmentalization is suggested by groundwater level declines that preceded declaration of the Victor Point GRA. Faulting appears to be less prominent in the northern and western portions of the City and Study Area, providing a larger area for storage in the CRBG aquifer system.

3.3 Hydrogeologic Conditions

The feasibility of implementing an ASR program for the City would be determined by local hydrogeologic conditions, engineering infrastructure, and source water considerations, which would ascertain the costs and benefits of the program. This section focuses on hydrogeologic considerations. General criteria used as guidelines for evaluating the hydrogeologic feasibility of ASR include the following:

- A productive aquifer capable of yielding target injection and recovery rates to reasonably efficient well, and sufficient storage volume to maintain recovery rates for the duration of critical demand periods. Well yields and injection rates are determined by the productivity of the aquifer and the efficiency of the well, and also are related to the static groundwater level in the well. Target yields for an ASR system have not been defined for the City. We are assuming for the purposes of this analysis that the desired minimum recovery capacity of 1 MGD recovery capacity (694 gpm) to meet the future projected 2055 peak day demand shortfall in WTP capacity of 0.8 MGD.
- The target aquifer is confined and has sufficient available space to store the desired volume of injected water, as determined by the boundaries of the aquifer and depth to groundwater (available "headroom").
- Other high-capacity wells that could capture stored water are not present.
- The aquifer, source water, and native groundwater are geochemically compatible such that chemical interactions will not result in clogging of the aquifer or adversely affect water quality.

The following sections summarize our analysis of these hydrogeologic feasibility criteria in the Silverton area.

3.3.1 Potential Storage Aquifers

Review of the hydrogeologic characteristics of geologic units in the Silverton area indicates that the CRBG is most suitable for hosting an ASR system, and the remainder of this study focuses on the CRBG as a potential ASR storage aquifer. The CRBG is commonly used to host ASR systems in Oregon because it is confined, contains productive storage zones and the native groundwater and host rock are typically geochemically compatible with the injection source water. The CRBG underlies the entire Silverton area, and thicker and deeper sequences of these basalt flows and interflows generally present greater potential for the presence of suitably productive aquifers for an ASR system.

3.3.2 Well Yield

Aquifer productivity within CRBG aquifers underlying the Silverton area appears to be favorable for ASR development as there are several wells with relatively high well yields and specific capacities that are similar to other successful ASR systems in the Willamette Valley. GSI focused its research within the Study Area on deeper basalt wells (greater than 200 feet bgs and generally drilled for irrigation purposes) with relatively high reported yields (greater than 100 gpm). Reported well yields from deeper CRBG-supply wells (greater than 200 feet bgs) in the Silverton area generally range from 100 to 1,800 gpm. **Figure 3-1** presents a spatial distribution of the wells that meet these criteria, including OWRD well code, well depth (in feet), and yield (in gpm). It is unknown how many of the wells shown on **Figure 3-1** have reported capacities that represent the full yield potential of CRBG water bearing-zones in this area, because drillers generally will only drill to a depth where the target yield is achieved, and many of the wells not shown on **Figure 3-1** are drilled for domestic supply, needing only 5 to 20 gpm of capacity.

Well yields generally increase with depth within the Study Area. Overall, the north, west, and southwest portions of Silverton and the Study Area appear to have wells with relatively high yields in thicker sections of CRBG. Conversely, areas in the southern and eastern portions of Silverton have thinner sections of CRBG; basalt wells in the Victor Point GRA were relatively deep but have relatively low yields (~5 - 20 gpm).

SC is another measurement of aquifer productivity that integrates the performance of a well and yield of the aquifer. The higher the specific capacity, the more productive the well and, generally, the higher aquifer transmissivity. Although specific capacity will vary with pumping rate, available drawdown, duration of pumping and well construction, it is still a useful estimate for the comparison of wells that yield water from the same aquifer and a reasonable approximation for the aquifer response anticipated for the recharge and recovery for ASR. Specific capacities for CRBG wells in the Silverton area vary considerably, but generally have been found to be between 4 and 12 gallons per minute of yield per foot of drawdown in the well (gpm/ft). The reported specific capacities for some higher capacity wells in the vicinity of Silverton include:

- The City of Mount Angel's three supply wells are open to between 160 ft and 460 ft of the same units of the CRBG aquifer system that are present in Silverton. The wells reported yields of 600 to 1,200 gpm and specific capacities ranging between 4 and 10 gpm/ft.
- The 24-hour specific capacity of the City of Stayton ASR test well was 49 gpm/ft at a pumping rate of approximately 500 gpm.
- Woody (2007) reported a specific capacity of 51 gpm/ft for the irrigation well in the Mount Angel area.

These values fall within range of specific capacities of municipal ASR wells in CRBG aquifers located in the Willamette Valley, which commonly range between 3 gpm/ft and 30 gpm/ft, with well yields range from 450 gpm to over 2,000 gpm.

3.3.3 Hydraulic Properties

Aquifer properties including transmissivity, storativity, and aquifer boundary conditions are also important characteristics for assessing the feasibility of ASR at a particular location and can be helpful to determine potential injection and recovery rates. Transmissivity is a measure of the productivity of an aquifer and is a function of its hydraulic conductivity and thickness. Storativity is a measure of the storage characteristics of an aquifer. CRBG aquifers typically have high transmissivities and low storativities. The implication of these characteristics is that the CRBG aquifers are often capable of accepting and yielding water at high rates, but are subject to relatively greater water level changes in response to the injection or pumping than many sedimentary aquifers.

Aquifer test data presented in Table 2 of *Ground-Water Hydrology of the Willamette Basin, Oregon* (Conlon, et. al., 2005) for wells completed in the CRBG in the Central Willamette area indicate a range of observed values for transmissivity between 14,500 to 32,000 ft^2/day. Hydraulic parameters for the CRBG aquifer system derived from pumping tests of wells in the vicinity of Silverton include:

1. Mount Angel Well 6 (located approximately 4 miles north of Silverton) has a reported range of transmissivity values from 18,000 to 23,000 ft^2/day.
2. The near-field (early time) transmissivity in the City of Stayton ASR test well is greater than 13,000 ft^2/day.
3. An irrigation well in the Mount Angel area was reported to have a transmissivity of 18,000 ft^2/day (Woody, 2007).

These values for transmissivity fall within the ranges observed at successful ASR systems utilizing the CRBG aquifer system elsewhere in the Willamette Valley.

Storativity values can vary between 0.00001 and 0.01 in the CRBG, and usually fall between 0.0001 and 0.001.

3.3.4 Water Levels

Depth to groundwater within the target aquifer is another criterion for assessing the feasibility of ASR. The depth to groundwater determines how much "headroom," or draw up is available for ASR recharge, and how much drawdown above the aquifer is available for recovery pumping. Injection headroom and available drawdown, together with the well performance and aquifer parameters, determine achievable long-term injection and recovery rates. While the preference is to inject without water levels exceeding ground surface, it is possible to design wellhead systems to inject under pressure, though with greater capital and operational costs.

Hydrographs for basalt wells in the Study Area with available long-term water level datasets from OWRD's Groundwater Information System Mapping Tool were reviewed for this study. Water levels in a majority of the basalt wells reviewed were observed to be at or near their historical lows and generally exhibit declining trends overall. Measurements from March 2020 reveal that depth to groundwater in CRBG wells within the Study Area varies from 34 ft to 210 ft below ground surface (bgs), corresponding to elevations of between 102 feet above mean sea level (msl) to 111 feet msl. Based on the available land and water surface elevation data, water levels below ground surface are anticipated to be shallower (i.e. less available headroom) in the north, northwest and west portions of the City and the Study Area. Water levels are anticipated to significantly deeper (more available head room) in the southern and eastern portions of the City, especially where there are topographic highs. Available drawdown in many of the wells with deep water levels (more headroom) may not have sufficient available drawdown to sustain desired yields. There are several deep basalt wells within the Victor Point GRA that have deep water levels and poor well yields, indicating limited recovery potential for ASR.

3.3.5 Groundwater Quality

Understanding water quality dynamics is essential to evaluating the technical feasibility of an ASR program. Only two different public-use basalt wells (MARI 19809 and MARI 56164) were located in the general Study Area; water quality data for these wells were available on the Oregon Public Health's Drinking Water Data Online website. Water quality data for the Mount Angel wells were also reviewed for this study. These wells are relatively proximal to the City (within 4 miles) and are constructed into CRBG aquifers. Below is a summary of the general groundwater quality characteristics for basalt wells in the region based on review of those available data sources.

The groundwater character of the local CRBG aquifers systems in the region appear to be predominant a mixed sodium- to calcium-bicarbonate (Na-HCO_3 to Ca-HCO_3) type, suggesting the water is somewhat evolved geochemically. Groundwater in the CRBG evolves from a calcium-bicarbonate type to a sodium bicarbonate-type along its flow path. Arsenic was also detected in two of the Mount Angel wells, but at concentration below current EPA Maximum Contaminant Levels (MCLs) for drinking water. There were also few detections for radiological constituents such as gross alpha, radium, and uranium in a few wells, but all detections were below their respective MCLs for drinking water. Overall, groundwater pumped from the Mount Angel wells is not chlorinated, does not require treatment, and meets all State and Federal drinking water requirements (MSA, 2010). There are no other known groundwater quality issues from basalt wells within and/or near the study area. Additional native basalt groundwater and ASR injection source water quality data should be collected and evaluated for geochemical compatibility as part of a next, proof-of-concept phase of a feasibility study.

3.3.6 Local ASR Systems

Municipalities throughout Washington and Oregon have been using ASR to store excess treated drinking water in CRBG-hosted aquifers since the mid- to late-1990s as a means to help optimize their water right portfolios, manage their water supply resources and provide drought resiliency. Eight ASR systems hosted in CRBG aquifers are currently operational in the Willamette Valley, and at least seven other CRBG-hosted systems are operating in eastern Oregon and Washington. Consequently, much is known about characterizing ASR feasibility, storage characteristics, geochemical compatibility, and well operations of these CRBG-hosted systems. Existing CRBG ASR systems that are proximal to Silverton include the City of Salem, and Fessler Nursery. In addition, areas near Silverton have been determined to have suitable storage aquifers, including the Mt Angel area (Woody, 2007), and recently, Stayton. Information regarding the ASR systems and evaluations in the general area is summarized below:

- City of Salem ASR: The City of Salem began pilot-testing their ASR system in 1997 using treated surface water from the North Santiam River as the ASR supply source. Salem currently operates four ASR wells completed in the CRBG aquifer system, and to date has successfully stored more than 1,900 acre-feet (620 million gallons, MG) annually for subsequent recovery and beneficial use. Salem is currently considering adding additional ASR wells and expanding their ASR program.
- Fessler Nursery: Fessler nursery operates a small-scale ASR system that utilizes the CRBG aquifer system to store water for irrigation purposes, the fourth such system used for irrigation in Oregon. Fessler Nursery is located approximately 6 miles north of Silverton.
- City of Mount Angel: Mt Angel, located approximately 4 miles to the north of Silverton, was identified as an area with favorable characteristics for ASR in a statewide evaluation of ASR Feasibility based on suitable aquifer storage for ASR and with 75% of optimal ASR parameters based on a study by Woody (2007).
- City of Stayton: As indicated earlier, Stayton is conducting an ASR feasibility study and initial findings indicate the presence of a suitable storage aquifer in the CRBG. The feasibility study will be completed in Spring 2022.

3.4 ASR Development Areas

Hydrogeologically, the most favorable areas for ASR development within the Study Area appear to be in the northern and western portions of the UGB, and along alignment of Highway 214 (**Figure 3-3**). Although CRBG aquifers underlie the entire City and Study Area, thicker sections of the CRBG, which are likely to encounter more suitable storage zones, are located in the north and west portions of the City and Study Area, and away from the upland areas to the east and south of the City, where the CRBG thins out.

Mapped geologic structures likely compartmentalize areas in the uplands south and east of Silverton, potentially constraining storage volumes and injection/recovery rates excessively. The Victor Point GRA is an area with relatively low well yields and historically declining water levels. The northern and western portions of the City and the Study Area appear to have higher well yields and are located outside the geologically compartmentalized areas to the south and east.

3.5 Potential Injection and Recovery Rates

3.5.1 Injection Rates

Injection rates depend on a variety of factors including aquifer characteristics and boundaries and well performance. In the absence of injection testing data, the injection capacity of a well can be estimated using available pumping specific capacity data. As discussed in Section 3.3.2, pumping specific capacity values from CRBG wells in the Study Area generally ranged from 4 to 12 gpm/ft. Potential injection rates are calculated according to the equation:

$$Q_{inj} = SC_{inj} * s_{inj}$$

Where

Q_{inj} = Injection rate (gpm)
Sc_{inj} = Injection specific capacity (gpm/ft)
s_{inj} = Injection head room or available draw up (ft)

The values used for injection specific capacity and headroom for this evaluation are based on the following assumptions:

Injection Specific Capacity: A pumping specific capacity value of 8 gpm/ft was used as basis to estimate potential injection rates for an ASR well in the Silverton area. This value is considered to be conservative as there is data for nearby wells to suggest specific capacity from deeper CRBG aquifers could be higher. In our experience and for these purposes, the injection specific capacity is conservatively assumed to be between 50% and 75% of the specific capacity of pumping, or approximately 4 to 6 gpm/ft.

Injection Headroom: Considering potential well interference, and average depths to water available head room or draw up in an ASR well is estimated to range between 75 and 125 ft during the wet season when injection would likely be conducted. Assuming that the injection water level in the well would be kept below the ground surface, and applying a safety factor of 15 feet, the total available draw up is 60 to 110 feet.

Using these assumptions, potential injection rates range between 300 gpm (0.4 MGD) and 694 gpm (1 MGD) using the average of specific capacities in the area. The estimated injection rates based on the higher end of the typical range of pumping specific capacities (12 gpm/ft) would be 450 gpm to greater than 1,000 gpm. Significantly higher rates could be achieved if the ASR system was designed to inject under pressure (injection head above land surface). ASR systems that inject under pressure are commonly designed for maximum pressures of 100 pounds per square inch (psi) and operated at pressures of approximately 50 psi, or an approximate elevation head of 115 feet above ground surface.

Final achievable injection rates would be determined with a test well drilling and testing program, as part of the next phase of the feasibility study. For comparison purposes, the injection rates for municipal systems using CRBG aquifers for ASR in the Willamette Valley range from 350 gpm to 1,400 gpm.

3.5.2 Recovery Rates

Using the hydrogeologic data collected from this evaluation, as well as other operational assumptions for ASR, potential recovery rates can be estimated for a new ASR well. For this recovery rate estimate, we have assumed the following aquifer and pumping parameters:

a. Ground surface elevation = 200 to 250 feet above mean sea level, amsl
b. Static water level elevation = 100 to 115 feet amsl
c. Depth to CRBG = 200 feet bgs
d. Top of CRBG elevation = 0 to 50 feet amsl
e. Depth to storage zone = 400 feet (200 feet into the CRBG)
f. Storage zone elevation = -200 to -150 feet amsl
g. Assumed minimum pump submergence = 40 feet (net positive suction head + 15 feet safety factor)
h. Maximum drawdown (elevation) = -160 to -110 feet amsl
i. Available drawdown (feet) = 210 to 275 feet

Based on the above parameters, if we assume a pumping specific capacity in the range of 6 to 8 gpm/ft, then estimated recovery rates theoretically could be on the order of 1.8 to 3.5 MGD (1,250 to 2,000 gpm). These estimated recovery rates do not account for potentially unknown aquifer boundaries that might be identified as part of a test well drilling program in the next phase of the feasibility study. None of the wells located near Silverton report pumping rates this high, but several report capacities in excess of the assumed target recovery rate of 1 MGD, and recovery rates in Salem ASR wells are within the lower end of the estimated range.

3.5.3 Potential Storage Volumes

Potential storage volumes were estimated based on the estimated range of injection rates and assuming a 5-month injection period consisting of 140 days of active injection. The remaining 10 days in the period are assumed to accommodate periodic backflushing events and for system maintenance. The estimated storage volumes over this time period based on the injection rates that assume injection is conducted under gravity-flow only range from 61 to 133 MG. Assuming an allowable recovery of 95 percent, this range of storage volumes would accommodate between 57 and 126 days of pumping at a target recovery rate of 1 MGD. We have reason to believe that the lower end of this storage volume may be highly conservative; however, the achievable recovery/injection rates and storage volumes remain uncertain until a test well or full-scale ASR well is completed.

4. Potential ASR Sites

Several properties located throughout the City were evaluated for potential well siting. Considerations included redundant offsite emergency water source, higher probability of reaching thicker CRBG layer, distribution network impacts, public vs private property, environmental permitting/land use impacts, and cost. Extracted water will need to be routed to stormwater infrastructure or to an authorized outfall, approximately 1,000 gpm for 30 minutes during each startup, or pump-to-waste process.

Potential properties were narrowed down to four sites (Figure 4-1): Silverton High School, New Reservoir site, Industrial Parcels, and the Senior Center Park. The Silverton High School, located in Northwest Silverton is connected to the treatment plant through 1.7 miles of pipeline. The site is zoned as public/semi-public and is in the low level zone. The New Reservoir site is in Southwest Silverton and is connected through 2.2 miles of pipeline. The Water Master Plan calls for a new reservoir to be built on this site. The site is zoned as public/semi-public and is in the Edison Booster Zone. The Industrial site located in Northeast Silverton and is connected through 0.9 miles of pipeline. The site is zoned as public/semi-public and is in the low level Zone. The Senior Center Park site is in the western side of Silverton and is connected through 1.3 miles of pipeline. The site is zoned as public/semi-public and is in the Anderson PRV Zone. The Selection Matrix scoring each site is summarized below in Table 4-1. The scores range from 1 to 5 with 5 being the best.

Table 4-1. Selection Matrix

	Redundant Offsite Emergency Water Source	Hydro-geologic ASR Suitability	Distribution Network Impacts	Public vs Private Property	Environ-mental Permitting / Land Use Impacts	Cost	Totals
Weighting	**15%**	**30%**	**15%**	**5%**	**5%**	**30%**	
High School	2	4	3	3	5	2	**3.0**
New Reservoir Location (Victor Pointe)	5	2	1	5	5	1	**2.3**
Industrial Parcels (Eska Way)	2	4	5	1	2	4	**3.6**
Senior Center Park	2	4	3	3	3	3	**3.2**

4.1 Planning-level cost estimates

AACE level 5 cost estimates were developed for the top two scored sites. **Table 4-2** and **Table 4-3** provide cost estimates for the Industrial Parcels and the Community Center Park sites, respectively. Actual construction costs may differ from the estimates presented, depending on specific design requirements and economic climate when a project is bid. An AACE Class 5 estimate is normally expected to be within -50 and +100 percent of the actual construction cost. As a result, the final costs will vary from the estimate presented in this document. The range of accuracy for a Class 5 cost estimate is broad, but these are typical accuracy levels for planning work.

The costs are based on experience with similar water distribution improvement and master planning projects. The cost estimates provide costs for well drilling and other well development costs (i.e permitting, testing). The total estimated probable project costs include contractor markups and 30% contingencies. Overall project costs include total construction costs, costs for engineering design, construction management services, inspection, as well as administrative costs.

Table 4-2. Industrial Parcels Cost Estimate

General Line Item	Est. Qty	Unit	Unit Price	Amount
Final Feasibility Study/Proof-of-Concept	1	LS	$400,000	$400,000
Contingency and Allowances	1	LS	30%	$120,000
Final Feasibility Subtotal				**$520,000**
10-inch DI Pipe - Excavation, Backfill, Fittings	1,700	LF	$280	$480,000
Full Lane Pavement Repair	200	LF	$100	$20,000
Traffic Control	200	LF	$15	$3,000
New Well – Drilling, Construction, and Testing	1	LS	$750,000	$750,000
New Well - Structural, Mechanical, Electrical, Site Work	1	LS	$1,745,000	$1,745,000
Pump-to-Waste and Stormwater Detention Pond	1	LS	$100,000	$100,000
Mobilization	1	LS	10%	$310,000
Contingency and Allowances	1	LS	30%	$929,000
Construction Subtotal (rounded)				**$4,337,000**
Engineering and CMS	1	LS	25%	$1,085,000
Legal and Admin	1	LS	5%	$217,000
Land Acquisition	1	LS	$100,000	$100,000
Permitting – ASR Well	1	LS	$65,000	$65,000
Permitting – Site Development	1	LS	$200,000	$200,000
Total Project Cost (rounded)				**$6,524,000**

Notes

The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Keller Associates and/or GSI has no control over variances in the cost of labor, materials, equipment, services provided by others, contractor's methods of determining prices, competitive bidding or market conditions, practices or bidding strategies. Keller Associates and/or GSI cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented herein.

Table 4-3. Senior Center Cost Estimates

General Line Item	Est. Qty	Unit	Unit Price	Amount
Final Feasibility/Proof-of-Concept	1	LS	$400,000	$400,000
Contingency and Allowances	1	LS	30%	$120,000
Final Feasibility Subtotal				**$ 520,000**
10-inch DI Pipe - Excavation, Backfill, Fittings	4,300	LF	$280	$1,204,000
Full Lane Pavement Repair	3,800	LF	$100	$380,000
Traffic Control	3,800	LF	$15	$57,000
New Well – Drilling, Construction, and Testing	1	LS	$750,000	$750,000
New Well - Structural, Mechanical, Electrical, Site Work	1	LS	$1,745,000	$1,745,000
Pump-to-Waste and Stormwater Detention Pond	1	LS	$100,000	$100,000
Mobilization	1	LS	10%	$424,000
Contingency and Allowances	1	LS	30%	$1,398,000
Construction Subtotal (rounded)				**$6,058,000**
Engineering and CMS	1	LS	25%	$1,514,000
Legal and Admin	1	LS	5%	$302,900
Permitting – ASR Well	1	LS	$65,000	$65,000
Permitting – Site Development	1	LS	$30,000	$30,000
Total Project Cost (rounded)				**$8,490,400**

Notes

The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Keller Associates and/or GSI has no control over variances in the cost of labor, materials, equipment, services provided by others, contractor's methods of determining prices, competitive bidding or market conditions, practices or bidding strategies. Keller Associates and/or GSI cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented herein.

5. Conclusions

The findings from this preliminary evaluation of hydrogeologic and technical feasibility indicate that development of ASR appears feasible in the Silverton area utilizing a storage aquifer in the CRBG. The CRBG aquifers underlying the City and defined Study Area support highly productive wells with specific capacities ranging between 4 and 12 gpm/ft, or possibly higher, based on recent aquifer testing results of nearby wells. Groundwater levels in this highly productive aquifer will allow target rates of recharge and recovery, and a large capacity for ASR storage with minimal potential for creative excessive groundwater level changes in other wells. Aquifer characteristics in the CBRG in the northern and western portions of the City are most favorable for ASR.

Potential injection rates for a new ASR well could be on the order of 300 (0.4 MGD) to 694 gpm (1 MGD), or significantly greater if the future system is designed to inject under pressure. Achievable recovery rates are estimated to meet or exceed the assumed target demands for recovery of 1 MGD assuming a suitable aquifer is identified at the selected location for an ASR system.

Based on existing water availability, surface water rights, and water system capacities, there appears to be capacity to support a new ASR system in the Silverton area. Based on existing infrastructure and water system capacities, approximately 1.3 MGD is currently available for recharge source water in the low demand month. Recovery from an ASR well could also be used to meet future system peak demand shortcomings during summer peak demand periods.

6. Next Steps

An ASR system would be adaptable to the City's existing infrastructure, including existing water sources. An ASR system would provide the City a redundant source of water and would increase the overall system resiliency combined with the City's existing surface water supply sources. Infrastructure requirements would include a new ASR well, connectivity to the sanitary sewer conveyance for pump to waste, conveyance piping from the water treatment plant to the well, as well as direct connectivity to the City's distribution system. Should the City decide to explore the feasibility of developing an ASR system as a redundant source, the next steps typically includes the following:

1. Final feasibility Study/Proof-of-Concept

This step involves a field investigation to verify findings from this initial feasibility evaluation and develop final system design parameters and costs that include:

- Drill an exploratory borehole on one or more select sites
- Conduct hydraulic testing to evaluate storage aquifer parameters including design storage volume, and injection and recovery rates
- Collect samples of native groundwater and complete an equilibrium geochemical compatibility modeling to evaluate potential reactions between source water, native groundwater, and the aquifer matrix.
- Develop preliminary system design
- Refine initial evaluation cost estimates to site and construct an ASR well
- Make go/no-go decision
- Apply for water supply development grant funding

2. System Construction and Permitting

- Apply for an ASR limited license and other permits
- Design, drill and complete a full-scale ASR well
- Complete design and construction of ASR wellhead, controls, electrical, distribution, and disinfection improvements
- Complete short-duration shakedown and cycle testing to verify system performance

Complete full-scale injection, storage, and recovery testing, including delivering recovered water to customers

3. Apply for ASR Permit

- Obtain permanent ASR system when full system is developed and tested

The ASR permitting process is relatively straight forward and familiar to the regulatory agencies involved, including OWRD, Oregon Department of Environmental Quality (ODEQ) and OHA-DWP. ASR operational pilot testing is authorized under the ASR Limited License issues by OWRD. A Class V underground injection control (UIC) permit from ODEQ and new source plan review approval from OHA-DWP are required for construction of an ASR Well. Based on GSI's experience in permitting and operating several CRBG-hosted systems in the Willamette Valley, significant permitting hurdles for an ASR system in Silverton are not anticipated. OWRD is likely to look favorably on development of an ASR system in the CRBG within the Silverton area.

7. References

Conlon, T.D., Wozniak, K.C., Woodcock, D., Herrera, N.B., Fisher, B.J., Morgan, D.S., Lee, K.K., and Hinkle, S.R., 2005, Ground-water hydrology of the Willamette Basin, Oregon, Scientific Investigations Report 2005-5168: U. S. Geological Survey, Reston, VA.

MSA, 2010. Water System Master Plan & Water Management and Conservation Plan, City of Mount Angel, Oregon. Murray, Smith & Associates, Inc, August 2010.

Tolan, T.L. and Beeson, M.H., 1999, Geologic Map of the Stayton NE 7.5 Minute Quadrangle, Northwest Oregon: U. S. Geological Survey and Oregon Department of Geology and Mineral Industries.

Tolan, T.L. and Beeson, M.H., 1999, Geologic Map of the Silverton and Scott Mills 7.5 Minute Quadrangle, Northwest Oregon: U. S. Geological Survey and Oregon Department of Geology and Mineral Industries.

Woody, Jen. A Preliminary Assessment of Hydrogeologic Suitability for Aquifer Storage and Recovery (ASR) in Oregon. Thesis prepared by Jen Woody for Oregon State University. November 20, 2007.

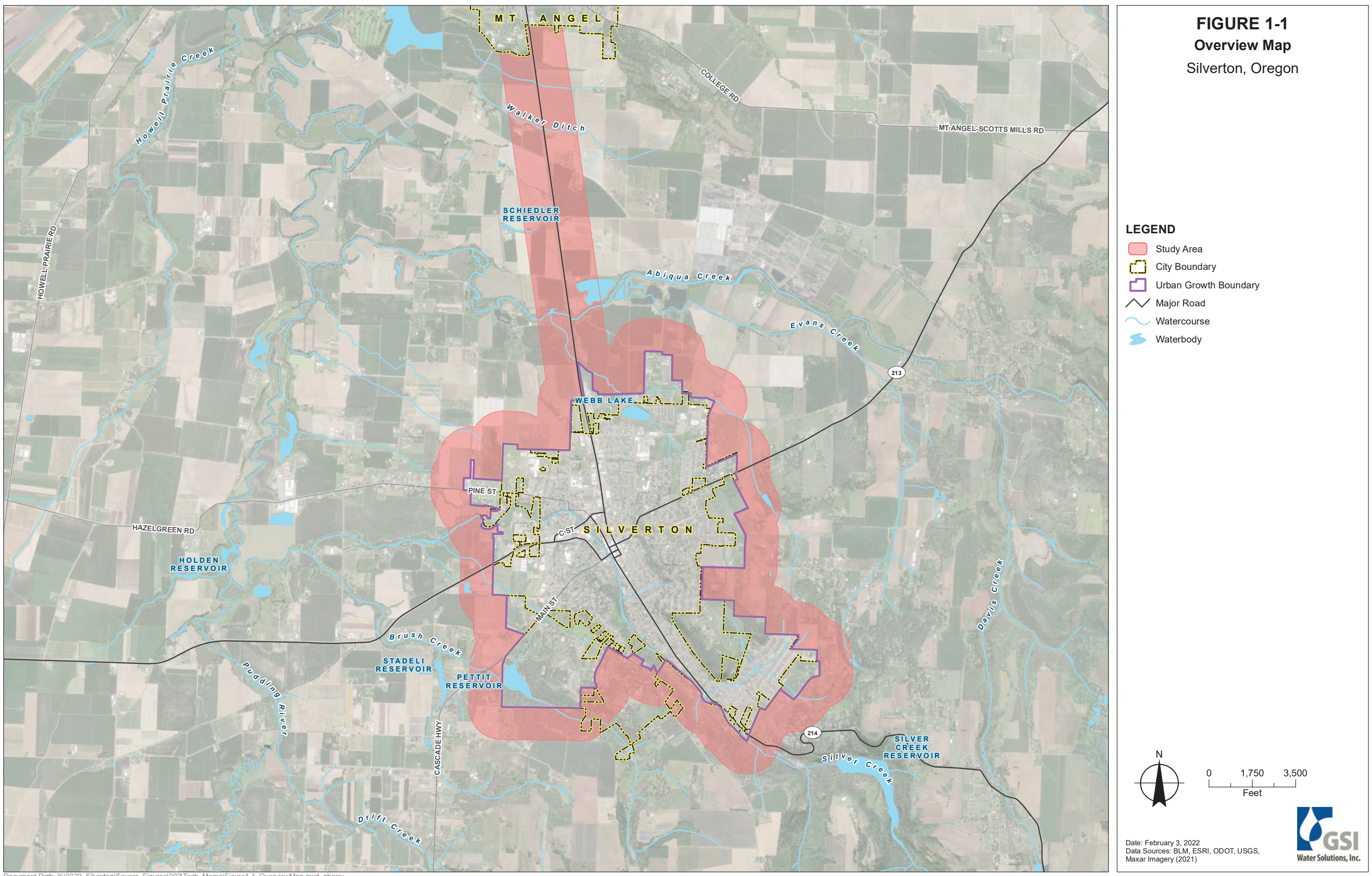
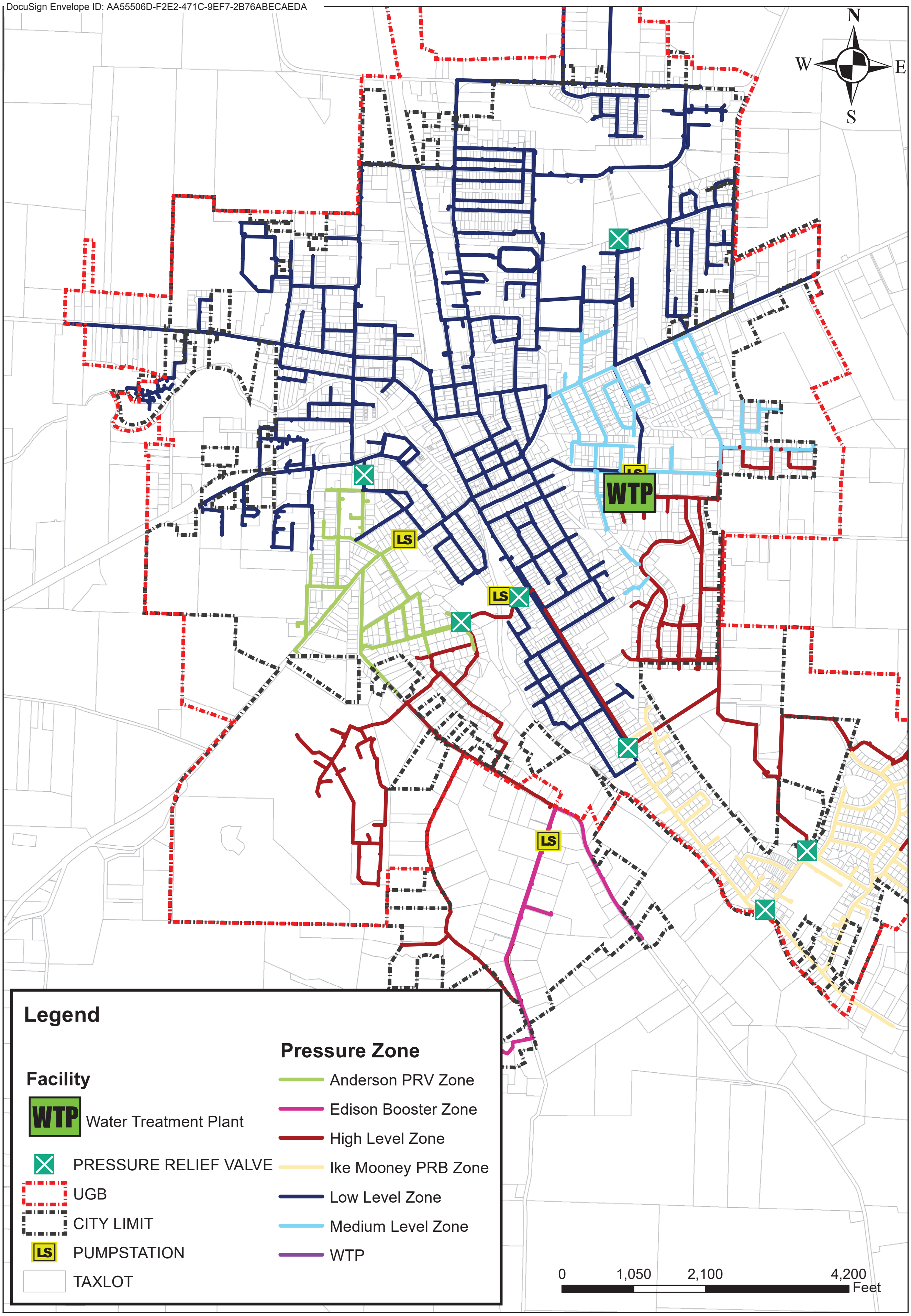


FIGURE 1-1
Overview Map
Silverton, Oregon



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Pressure Zones

Initial Feasibility Evaluation of ASR

CITY OF SILVERTON · EST 1854 · OREGON'S GARDEN CITY

Figure 2-1

City of Silverton, OR

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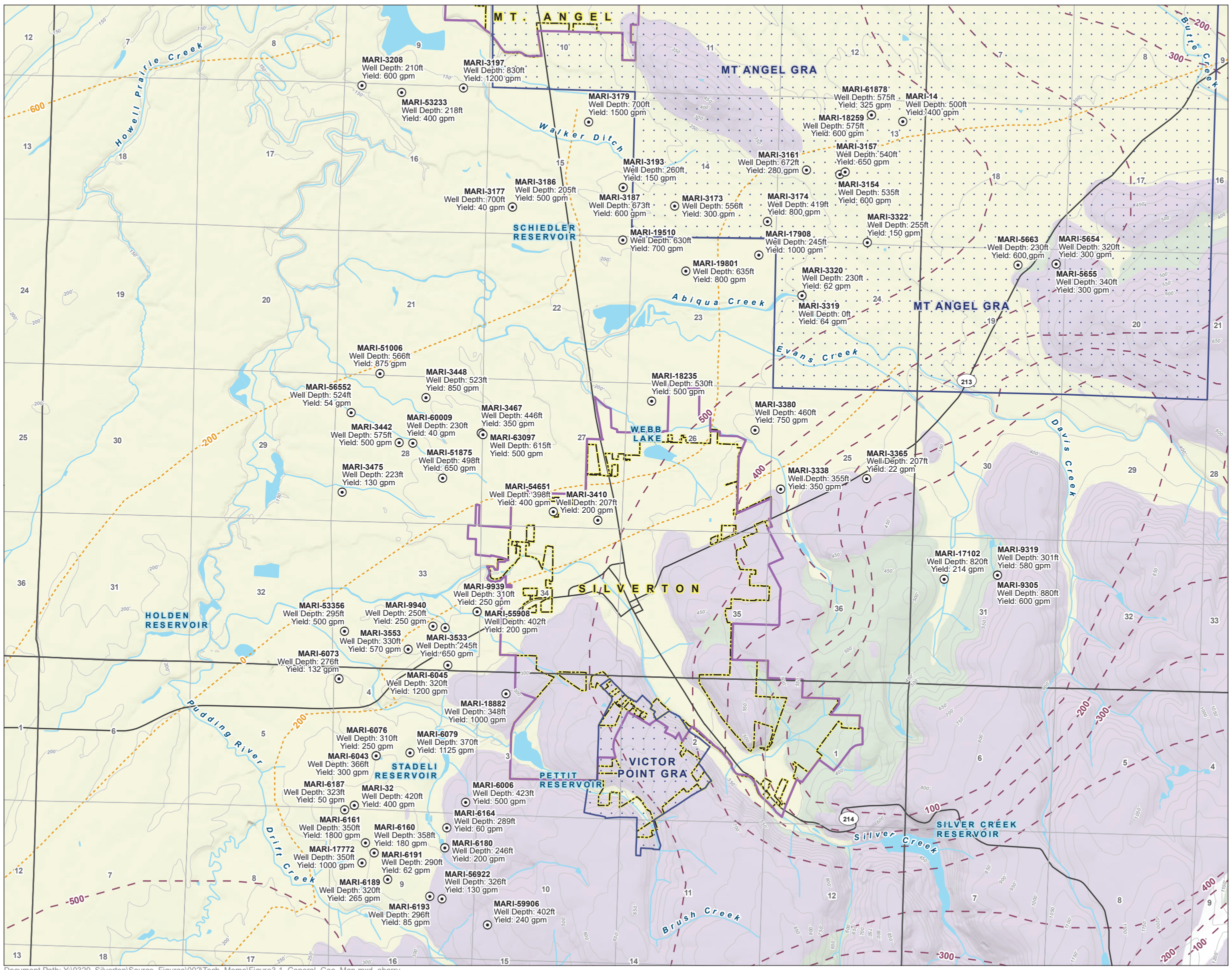

FIGURE 3-1

General Geology Map

Silverton, Oregon

LEGEND

- Irrigation Well (depth > 200ft)
- Approximate Thickness in feet of Columbia River Basalt Group[1]
- Altitude in feet of the Top of Columbia River Basalt Group[1]
- Surface Contour (feet)
- Groundwater Restrictive Area (GRA)

Generalized Geology

- Alluvium
- Columbia River Basalt Group
- Older Rocks

All Other Features

- Major Road
- City Boundary
- Urban Growth Boundary
- Watercourse
- Waterbody

NOTES

gpm: gallons per minute

[1]Isopach and contour lines adapted from a 2005 USGS-OWRD report, Figure 9 and 10.

N

0 1,750 3,500
Feet

Date: February 3, 2022
Data Sources: BLM, ESRI, ODOT, USGS, DOGAMI

GSI Water Solutions, Inc.

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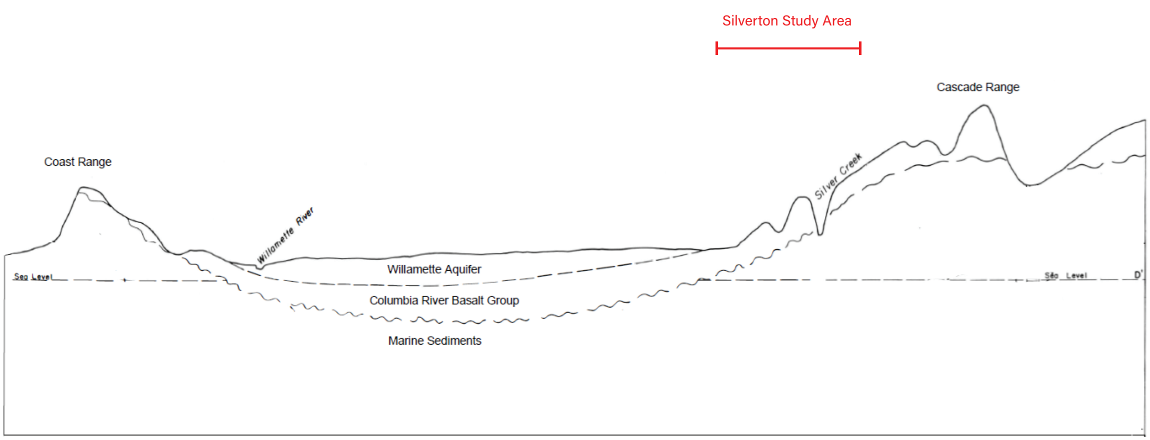

FIGURE 3-2

Conceptual Diagram of Major Hydrogeologic Units in the Central Willamette Valley

Silverton, Oregon

GSI Water Solutions, Inc.

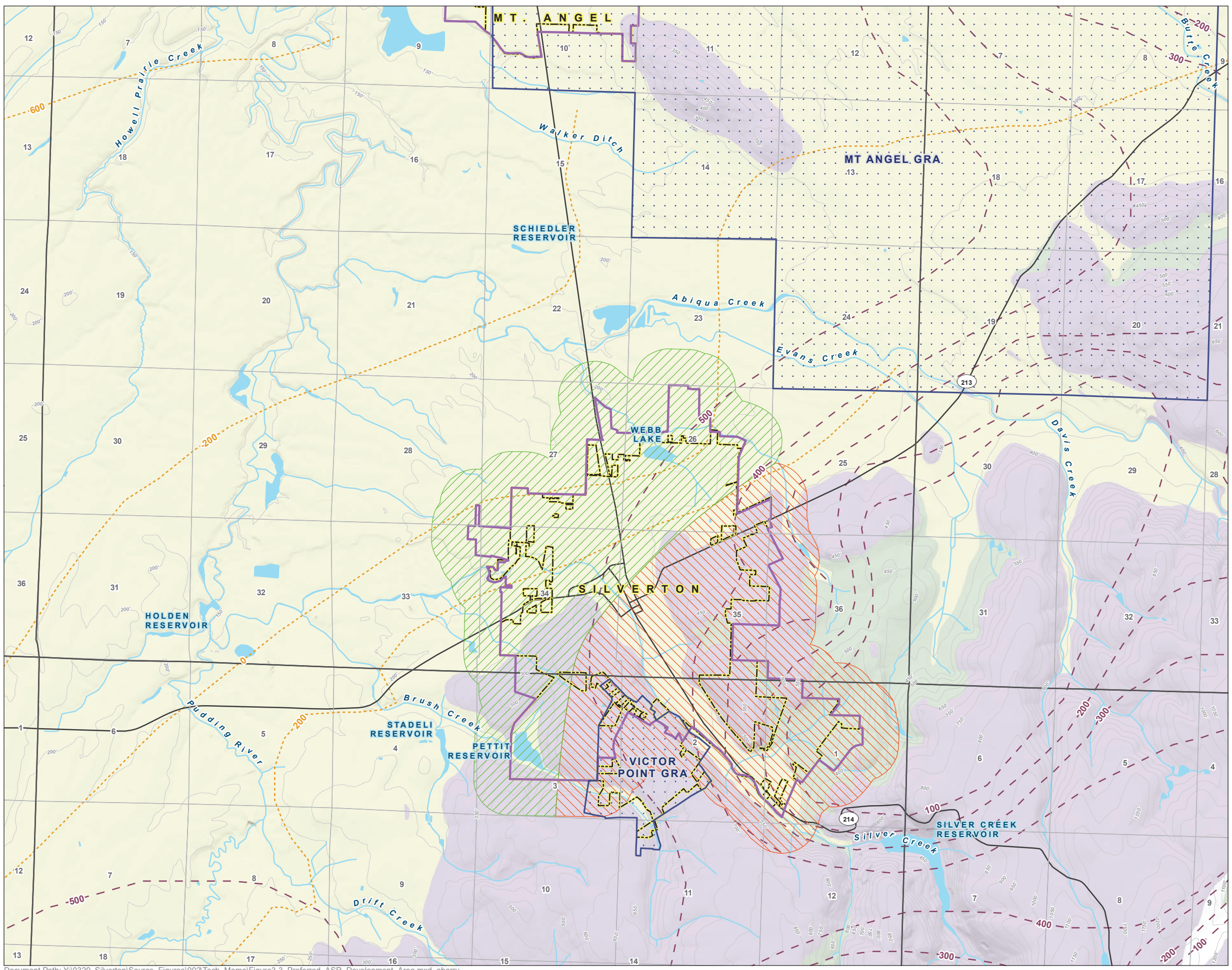

FIGURE 3-3
Preferred ASR Development Area
Silverton, Oregon

LEGEND
- Approximate Thickness in feet of Columbia River Basalt Group[1]
- Altitude in feet of the Top of Columbia River Basalt Group[1]
- Surface Contour (feet)
- Groundwater Restrictive Area (GRA)

ASR Development Area
- More Favorable ASR
- Less Favorable ASR

Generalized Geology
- Alluvium
- Columbia River Basalt Group
- Older Rocks

All Other Features
- Major Road
- City Boundary
- Urban Growth Boundary
- Watercourse
- Waterbody

NOTE
[1]Isopach and contour lines adapted from a 2005 USGS-OWRD report, Figure 9 and 10.

N

0 1,750 3,500
Feet

Date: February 3, 2022
Data Sources: BLM, ESRI, ODOT, USGS, DOGAMI

GSI Water Solutions, Inc.

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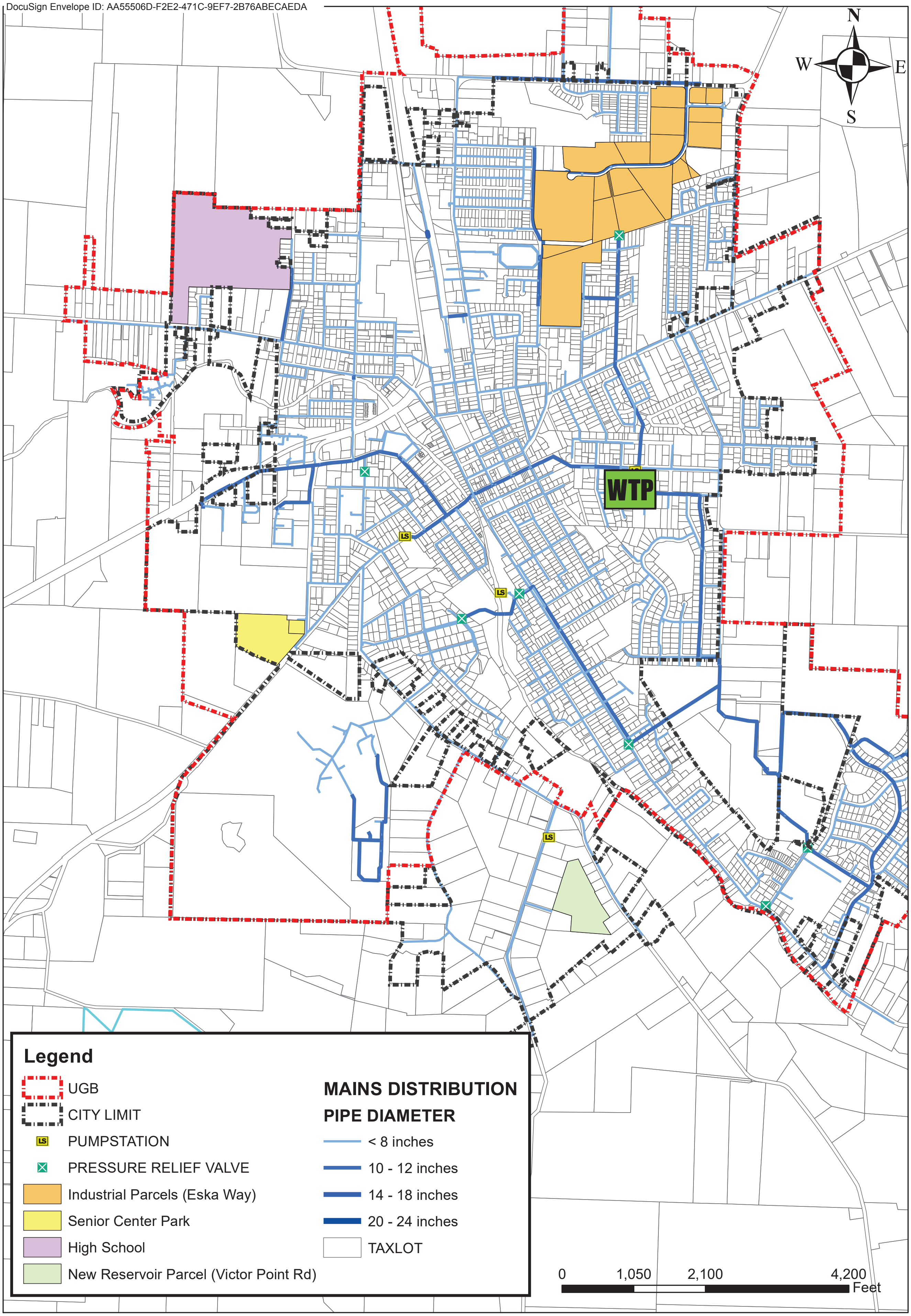

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Potential ASR Sites

Initial Feasibility Evaluation of ASR

Figure 4-1

City of Silverton, OR