BANKS-GREEN MOUNTAIN AQUIFER STORAGE AND RECOVERY FEASIBILITY STUDY

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Prepared for:
City of Banks
13680 NW Main Street
Banks, Oregon 97106

CwM-H2O
Complete Water Management

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13680 NW Main Street
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This document has been prepared by CwM-H2O LLC. The material and data in this technical report was prepared under the supervision and direction of the undersigned.

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EXECUTIVE SUMMARY

CwM-H2O (CwM) prepared this study for the City of Banks (City) to evaluate the feasibility of an aquifer storage and recovery (ASR) system to meet the projected long-term (2050) water supply demands of the City and provide an ecological benefit that would allow for the Green Mountain Springs to flow freely during the peak summer months. The City of Banks is located approximately 26 miles west of Portland in the eastern foothills of the Oregon Coast Range. The City currently provides water to approximately 1,775 residents within City limits and 305 residents outside the City. The City currently obtains water through diversion and treatment of surface water from the Green Mountain Springs located north of the City, and through Well 1 and Well 2 that appropriate groundwater from water bearing zones of the Columbia River Basalt Group (CRBG) underlying the City.

With respect to the City's projected long-term (2050) water supply balance, it is estimated that an average annual water supply deficit of 17.2 million gallons (MG) will exist by 2050. To aid the City in meeting this projected water supply deficit, the feasibility of an ASR system has been evaluated. Generally, an ASR system involves the procurement of water from a water source during periods of excess (winter/spring), then injecting and storing that water in a suitable underground aquifer for future recovery and use during periods of peak water supply demand (summer).

Results of the ASR feasibility evaluation show that ASR is feasible for the City in terms of aquifer storage capacity (45.1 MGY), recovery of stored water (75.2 to 116.6 MGY), existing infrastructure compatibility, and permitting. However, the feasibility of operating an ASR system is ultimately limited by the City's existing source water supplies, as the Green Mountain Springs surface water supply does not have the winter flow volume necessary to meet the City's winter demands and support an ASR system.

The City's projected 2050 average annual water supply deficit (17.2 MG) precludes using the City's existing water source water supplies (Green Mountain Springs certified water rights) as source water for an ASR system. Before the City can consider using ASR as a water management tool, a new water supply must be developed.

The recommended option for increasing the capacity of the City's water supply and implementing ASR is estimated to cost approximately $9.2 million dollars, and can be constructed in the following three phases:

Phase I – New Source Water Development

Phase I consists of adding the Quail Valley Well to the Well 2 water right, expanding the pumping capacity from Well 2 and Quail Valley to 448 gpm. Phase I components and cost estimates include the following:

- Hydrogeologic Study, Pilot Testing, Limited License and Water Rights Transfer - $ 90,000
- Redevelop Quail Valley Well and Pipeline - $1,502,000

Phase I Cost - $1,592,000

Phase II – ASR Implementation

Phase II consists of constructing a WTP to appropriate available surface water from the West Fork Dairy Creek during periods of excess to aid in meeting the City's water supply demands and provide source water for ASR. Phase II also consists of reconfiguring Well 2 for use in an ASR system. Phase II components and cost estimates include the following:

- Reconfigure Well 2 for ASR operations - $310,000
- West Dairy Creek Water Treatment Plant - $4,440,000

Phase II Cost -$4,750,000

Phase III – ASR Expansion

Phase III consists of groundwater exploration and development of a new deep basalt well southwest of the City to expand the capacity of the ASR system to meet summer time demands and provide a redundant water supply. Phase III components and cost estimates include the following:

- Southwest Well 3 - $2,895,200

The total cost estimate for the three phases of new source water development and implementation of ASR is approximately $9,237,200.

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1 INTRODUCTION

1.1 Overview

CwM H2O (CwM) has prepared this feasibility study for the City of Banks (City) to evaluate the potential for implementing an aquifer storage and recovery (ASR) system to meet the projected long-term (2050) water supply demands of the City.

The City of Banks is located approximately 26 miles west of Portland in the eastern foothills of the Oregon Coast Range and currently provides water to approximately 1,775 residents within and outside City limits. The City currently obtains water through diversion and treatment of surface water from the Green Mountain Springs located north of the City, and through appropriation of groundwater from water bearing zones of the Columbia River Basalt Group (CRBG) underlying the City, as shown on Figure 1.

To aid the City in meeting its projected long-term (2050) water supply deficit (Section 2.2), the feasibility of an ASR system has been evaluated. Generally, an ASR system involves the procurement of water from a water source during periods of excess (winter/spring), then injecting and storing that water in a suitable underground aquifer for future recovery and use during periods of peak water supply demand (summer).

ASR systems have been successfully designed and operated to meet a wide range of objectives at sites with varying physical and hydrological conditions and features. The permitting and capital investment associated with ASR systems is generally less costly than constructing above ground storage infrastructure, making ASR an affordable and effective water management tool (Woody, 2007). The number of active ASR projects in Oregon has increased form zero in 1995 to ten in 2008 (KJC, 2011).

1.2 Feasibility Study Scope and Organization

This feasibility study evaluates a range of specific ASR system components and scenarios to assess the overall applicability of an ASR system to meet the water supply goals of the City of Banks. The intent of this feasibility study is to provide a technical tool to aid in planning of the City's long-term water supply, including consideration of its future water supply infrastructure and water rights. The objectives of this feasibility study are to:

- Project the City's long-term (2050) water supply demands;
- Develop hydrologic conceptual site models for potential ASR study areas;
- Evaluate the feasibility of storing and recovering source water in local underground aquifers;
- Evaluate the quantity of source water currently or potentially available for ASR utilization;
- Evaluate the capacity of the City's existing infrastructure to effectively operate an ASR system;
- Estimate the costs of modifying existing infrastructure or constructing new infrastructure to effectively operate an ASR system; and
- Evaluate the overall applicability and feasibility of ASR for the City of Banks to meet its projected long-term water supply demand, identify data gaps or uncertainties, and provide recommendations.

To address these objectives, this feasibility study is organized into the following sections:

- **Section 1. Introduction:** This section presents the objectives, scope, and organization of the feasibility study.
- **Section 2. Banks Water Supply System:** This section describes the City's existing water rights and water supply system, and projects the City's 2050 water demands.
- **Section 3. Conceptual Site Model:** This section presents the conceptual site models for potential ASR study areas including their physical, hydrologic, and hydrogeologic settings.
- **Section 4. ASR Feasibility Evaluation:** This section identifies, describes, and evaluates existing infrastructure and source water supplies of the City for utilization in an ASR system, and evaluates the following ASR components; aquifer storage capacity, stored water recovery, existing source water supplies, and existing infrastructure compatibility.
- **Section 5. Identification of New Source Water Supplies:** This section identifies and preliminarily characterizes new source water supplies to help the City meet its projected 2050 water supply demands and provides cost estimates for developing each identified source water supply.
- **Section 6. Recommendations for ASR Implementation:** This section summarizes the results of the ASR feasibility evaluation section and provides recommends for implementing an ASR system.
- **Section 7. Conclusions**: This section summarizes results of the report and provides recommendations to the City.
- **Section 8. Identified Data Gaps and Study Limitations:** This section identifies and discusses any existing data gaps.

2 BANKS WATER SYSTEM

This section presents a review of the City's existing water supply system. This review includes the City's water rights, supply sources, water supply infrastructure, and water user demands. Consideration of these elements will frame the requirements of ASR and allow an evaluation of the added benefit of an ASR system. This evaluation is based on the 5-year average of water use reported to OWRD from 2013-2017.

2.1 Existing Water System

This section reviews the City's current water supply system, including its water rights, water supply infrastructure, and water supply sources. A conceptual depiction of the City's water supply is illustrated on Figure 2, showing the surface water and groundwater sources

2.1.1 WATER RIGHTS

The City of Banks diverts surface water from the Green Mountain Springs, the West Spring and East Spring, under two certified surface water rights (5353 and 83138) and appropriates groundwater from two production wells, Well 1 and Well 2, under groundwater permits (G-7593 and G-16312). The locations of these water sources are shown on Figure 1. The City has water rights totaling approximately 2.27 cubic feet per second (cfs) or 1,018.8 gallons per minute (gpm), with approximately 269 gpm based on the water rights associated with the Green Mountain Springs and 749.5 gpm based on the groundwater rights associated with the City's production wells. The City's water rights have no maximum duty restriction. Furthermore, the City's water sources do not contain listed species, are not water quality limited, and do not occur in critical groundwater areas. A summary of these water rights including priority dates, water right numbers and statuses, Banks water system naming conventions, and authorized appropriation/diversion rates are tabulated on Table 1.

2.1.2 WATER SUPPLY AND INFRASTRUCTURE

The City of Banks has historically utilized diverted surface water from the Green Mountain Springs as their primary water source. The springs were first developed as the City's water supply source in 1924 and are located in the hills approximately 4 miles north of the City of Banks, as shown on Figure 1. Today, the springs still make up 82% of the City's annual water use. The Green Mountain Springs are composed of two spring groups, referred to as the West Spring and the East Spring. A brief description of each spring is provided below:

- West Spring: The primary spring water source for the City with an average diversion of approximately 58.3 million gallons per year (MGY)[1], the point of diversion is located at approximately 900 feet above mean sea level (ft amsl).
- East Spring: Produces less spring water than the West Spring at approximately 8.3 MGY[1], the East Spring consists of two individual points of diversion located at approximately 760 ft amsl. More water is available from the East Spring, but the cost of treatment limits the amount diverted for use by the City.

The flow from each spring is captured behind concrete impoundment and diversion structures built a few hundred feet below the spring outlets. Captured spring water is then conveyed to the City's water treatment plant (WTP), a slow sand filtration plant consisting of two basins and a 0.07 MG chlorine contact chamber, before being transmitted south approximately 3.2 miles via the Sellers Road Pipeline to the City's two primary

[1] Average spring diversion data based on most recent 5-year period (2013-2017) from OWRD Water Use Reporting

reservoirs referred to as the Carsten Reservoirs, which have a cumulative storage capacity of 1.5 MG. From the Carsten Reservoirs, the chlorinated water is distributed to customers.

Spring flows are at a maximum in late winter and early spring, then taper to minimum flows in the summer. Spring flow reductions during the summer coupled with turbidity events more than the WTP's treatment capacity can result in water diversions being significantly less than their allocated water rights. Review of diversion data provided by the City shows that approximately 59% of the West Spring and 19% of the East Spring's possible water rights have been used on an annual basis over the past five years. Analysis of the spring diversion data and estimated total yield of the springs is provided in Appendix A.

Due to limited summer spring flows and high turbidity events, the City installed a production well (Well 1) in 1979 located in the City of Banks. Another production well (Well 2) was drilled in 2005 approximately within 67 feet from Well 1, as seen on Figure 1. Well 2 was brought online beginning in the 2012-2013 water year. Both well motors, piping and valves, chlorination equipment, and control systems are in a secure facility on the south side of NW Banks Road. The well pumps are controlled automatically by the City's telemetry system, which signals the pumps to start and stop as determined by water levels of the Carsten Reservoirs. Water appropriated from the production wells is chlorinated via injection of chlorine gas from 150-pound cylinders into the conveyance piping between the wells and the Carsten Reservoirs. A brief description of each production well is provided below, with as-built diagrams of the production wells being depicted on Figure 3:

- Well 1: With a completed depth of 450 feet below ground surface (ft bgs), Well 1 appropriates water from the Banks ASR study area CRBG aquifer a peak rate of approximately 230 gpm, coming online every sixth pumping cycle, with cycles being dictated by water level changes in the Carsten Reservoirs. The pump of Well 1 is set at 277 ft bgs, approximately 50 feet below protective steel casing. The individual maximum four-month production rate of Well 1 has been estimated to be 190 gpm (Golder, 2008).
- Well 2: With a completed depth of 669 ft bgs, Well 2 is the primary groundwater production well of the City, and currently appropriates water from the Banks ASR study area CRBG aquifer at a peak rate of approximately 290 gpm. Well 2 comes online every pumping cycle, with cycles being dictated by water level changes in the Carsten Reservoirs. The pump of Well 2 is set at 283 ft bgs, within the confines of the well's protective steel casing. The individual maximum four-month production rate of Well 2 has been estimated to be 300 gpm (Golder, 2008), however this maximum production rate is limited by the capacity of the pump to 290 gpm.

Utilizing spring diversion and well appropriation data (OWRD), the reported maximum four-month pumping rates of the production wells (Golder, 2008), and analyses of total spring yields (Appendix A), a monthly water supply summary for the City was created and is tabulated on Table 2. Table 2 shows that the City's average annual use by the City is approximately 113.6 MGY for the most recent 5-year period (2013-2017).

The total capacity of the City's existing water supply was calculated to be approximately 139.8 MGY based on natural system constraints (i.e. drawdown/spring yield) water right limitations, infrastructure limitations, and factor of safety considerations, as described below:

- The total available volume of the aquifer supplying water to the production wells was estimated to be 71.2 MGY, which is based on the total volume appropriated during 2012 that resulted in significant drawdown at the production wells and curtailment of water supply to customers by the City.

- CwM used a hydrologic analysis (Appendix A) to estimate the live flow of the West Spring plus the 5-year average diversions for the East Spring to define the total available surface water of the springs. The result is the total available yield of 113.8 MGY. Based on limitations of the WTP (treatment capacity of 184 gpm) the City is limited to a total surface water supply of 93.3 MGY. A 15% safety factor was applied to the City's total water supply to account for reductions in operating efficiency such as mechanical breakdowns, power outages, etc.

Therefore, the City's 5-year average annual demand of 113.6 MGY represents 81% of the 139.8 MGY total annual water supply capacity of the City.

Using the total annual water supply capacity of 139.8 MG, a monthly water supply capacity scheme was developed to mirror the monthly demand. Monthly surface water diversion schemes were developed utilizing existing diversion data (East Spring), or potentially available live flow based on the hydrologic analyses of Appendix A (West Spring). Monthly pumping volumes for the production wells were calibrated manually to meet changes in demand while ensuring that the total volume pumped did not exceed the annual aquifer capacity (71.2 MG) and that the maximum pumping rate did not exceed infrastructure capacity (290 gpm, Well 2). The resulting monthly water supply capacity summary can be seen on Table 2, City of Banks Water Supply Summary.

2.2 2050 Water Demand

The City of Banks provides water to residential, commercial, industrial, and irrigation customers within and outside City limits. The City of Banks water system service area includes the area within the incorporated City limits and other contiguous or neighboring areas that the City Council may choose to serve. A small service area west of the City's urban growth boundary and a series of connections along the treated water transmission line running from the City's WTP to the main distribution area are the only served areas that lie outside the City limits. A moratorium on creating new connections outside the City limits is currently in force.

2.2.1 HISTORICAL WATER DEMANDS

To assess the future demands of the water supply system, the historical water usage and population were evaluated. Reported use from each of the City's supply sources (springs/wells) for the period 2013 to 2017 was obtained from the OWRD Water Use Reporting System for evaluation. Historical population estimates were referenced from the 2017 Oregon Population Research Center (Proehl, 2017). The customers served outside the Banks service area were assumed to have remained static at 305 because of a moratorium on connections outside City limits (Golder, 2010). A summary of the 2013 through 2017 service area population and water usage estimates for the Banks Water System is provided in Table 3.

The per-capita water demand for the reported period of 2013- 2017 fluctuated considerably, likely a result of leaks during this time period that were detected and fixed by 2017. The average per-capita demand for the period 2013- 2017 was approximately 141.6 gallons per capita per day (gpcpd). This demand is in the upper range of national averages, which are approximately 100-150 gpcpd.

2.2.2 2050 WATER DEMANDS

Projection of water supply demands for the City are based on estimations of per-capita water usage and future population. Population projections for the period 2018-2050 were derived through utilization of population projections provided by the Oregon Population Research Center (Proehl, 2017). Using these population projections, a service population of 3,412 is projected for 2050, as tabulated on Table 4.

Projection of per-capita water usage for the period 2018-2050 was derived assuming; conveyance losses have been reduced from approximately 30% to 10% due to the replacement of the Sellers Road Pipeline, and a continuation of the water service moratorium and Water Use Curtailment Plan (City Ordinance 50.23). Assuming conservation measures are implemented effectively, the per-capita water usage is projected to decrease from approximately 141.6 gpcpd to 125.9 gpcpd (Golder, 2010). The water requirement projections calculated in this report assume that the reduced per-capita water use rates are achieved and maintained throughout the duration of projection period (2018-2050).

The resulting water demands of the City for the period 2018-2050 are tabulated on Table 4. By 2050, an average annual demand of 157 MG is projected.

2.3 2050 Water Demands and Available Water Supply Comparison

The following sections compare the 2050 projected demands of the City to various water supply scenarios, being:

1. **Existing Water Supply:** The total capacity of the City's existing water supply (139.8 MGY);
2. **Emergency or Ecological Water Supply Scenarios:** A reduced capacity of the City's existing water supply, assuming one or more water supply sources have been lost to emergency scenario (i.e.. fires, landslides) or an ecological scenario such as a voluntary contribution to instream flows of surface waters.

2.3.1 EXISTING WATER SUPPLY

As previously discussed in Section 2.1, the capacity of the City's existing water supply is approximately 139.8 MGY (Table 2). The projected water supply demands of the City for 2050 include an average annual demand of 157 MG, resulting in an average annual water supply deficit of 17.2 MG. A comparison of average annual supply vs average annual demand for the period 2018-2050 is presented on Table 4. Figure 5 shows that an average annual water supply deficit exists beginning approximately in 2029. The comparison of the City's existing water supply and projected demands are also illustrated on both an annual and monthly basis (Figures 5 and 6) and shows that average supply seasonal demand occurs from May to August.

2.3.2 EMERGENCY OR ECOLOGICAL WATER SUPPLY SCENARIOS

This section compares the projected demands of the City to water supplies of the City, assuming that one or more water supply sources have been lost to emergency scenarios such as fires, landslides, or other failures. Water supply sources that are not redundant and are susceptible to natural hazards such as landslides, fires, or other failures have the potential to be lost for a period of time, reducing the total available water supply of the City. The Green Mountain Springs were identified as susceptible to emergency scenarios due to their physical location and absence of a redundant water source of equal capacity. This loss of water supply from the springs also equates to a voluntary contribution to provide instream ecological flows to downstream surface waters such as the West Fork of Dairy Creek. The impact of the loss of the Green Mountain Springs on the ability to meet the City's demands was briefly evaluated in the following three emergency scenarios:

1. **Loss of East Spring:** Should water supplies of the East Spring be lost due to an emergency or ecological scenario, the City's existing water supply would be reduced to 131.5 MGY, a loss of 8.3 MGY (6% loss) (Table 5). With a loss of the East Spring, the average annual demand would exceed supply by 2025 (Figure 7).

2. Loss of West Spring: Should water supplies of the West Spring be lost due to an emergency or ecological scenario, the City's existing water supply would be reduced to 79.4 MGY, a loss of 60.3 MGY (43% loss) (Table 5). With a loss of the West Spring, the average annual demand would exceed supply for the entire period of 2018-2050 (Figure 7).
3. Loss of Both Springs: Should water supplies of both springs be lost due to an emergency or ecological scenario, the City's existing water supply would be reduced to 71.2 MGY, a loss of 68.6 MGY (49% loss) (Table 5). With a loss of both springs, the average annual demand would exceed supply for the entire period of 2018-2050 (Figure 7).

The impacts of each of the three evaluated emergency or ecological scenarios is tabulated on Table 5. The impacts of each emergency scenario are also depicted visually on an annual and monthly basis on Figures 7 and 8. Should a loss of a water supply source result in a water supply deficit, an ASR system could be considered to meet deficiencies during emergency scenarios or other periods when high demand results in a water supply deficit.

2.3.3 SUMMARY OF SUPPLY AND DEMAND ANALYSIS

In this section CwM has estimated the volume of annual supply that would have to be replaced by another source of water, either a new source or a storage source such as ASR or surface impoundment.

The volume of annual supply that would have to be replaced by another source is calculated to be 41.6 MGY, being calculated as follows; the maximum volume of water lost from the Green Mountain Springs over a three-month period in an emergency or ecological scenario (24.4 MG) plus the projected 2050 average annual water supply deficit (17.2 MG).

For the volume of water lost in an emergency or ecological scenario, the largest volume of water lost over a three-month period was selected because it was assumed that lost water sources can be repaired and restored within three months. Evaluation of hydrologic model data (Appendix A) and historic spring diversions / water rights (OWRD) indicate that the three-month period resulting in the largest volume of spring yield available for utilization by the City is from March to May, with a total volume of 24.4 MG.

Based on this estimate, the target volume for an ASR program that can meet this demand is 41.6 MGY. In the chapters that follow, CwM will evaluate both the capacity of ASR storage options and whether the Green Mountain Springs or another new source is required to implement ASR.

3 CONCEPTUAL HYDROGEOLOGIC MODEL

This section presents a conceptual hydrologic model for two areas applicable to ASR development. The first area is the Sellers Road study area which is assessed for its potential to contribute source water for ASR operations. The second area evaluated is the Banks ASR study area, which is assessed on a hydrogeologic basis for use as an ASR system.

3.1 Regional Area

This section presents the conceptual hydrologic model of the northwest corner of the Tualatin Valley which includes the City of Banks and the surrounding area. This section provides geographic information relevant to both source water areas (Banks and Sellers Road study areas).

3.1.1 PHYSICAL SETTING

The City of Banks is in the northwest corner of the Tualatin Valley. The Tualatin Valley consists of broad valley plains and the lower slopes of the Oregon Coast Range with altitudes ranging from 100 to 1,800 feet above mean sea level (ft amsl) (USGS, 1965). The Tualatin Valley generally comprises an area approximately 30 miles long by 10 miles wide, and includes numerous tributaries and watersheds associated with the Tualatin and Willamette Rivers. The valley has an average elevation of approximately 200 ft, with hill slopes rising gently from the valley floor.

3.1.2 CLIMATE

The broad climate classification of the Pacific Northwest corridor between the coastal ranges to the Cascade ranges falls under the Mediterranean climate (Koppen classification system; Peel *et al* 2007) characterized by dry summers and cool, rainy winters. Given the amount of rain that falls in the northwest portion of the Tualatin Valley, the regional area of Banks could also fall under an Oceanic climate, which typically receives more than 35 inches of rain per year.

Climate data from the Hillsboro Airport[2] indicate minimum and maximum temperatures of 33 degrees Fahrenheit (°F) and 53°F in the winter, and 45°F to 82°F in summer months. Analysis of rainfall data from the nearby Buxton-Mountaindale rain gage[3] indicates mean annual rainfall of more than 50 inches with a maximum average rainfall of 8.8 inches occurring in December. Mean annual potential evapotranspiration (PET)[4] is estimated at 32.5 inches, with a maximum PET value of 6 inches in July.

3.1.3 GEOLOGY AND HYDROGEOLOGY

The Tualatin Valley consists of broad valley plains of alluvial material bounded by uplifted marine and volcanic material of the Tualatin Mountains to the east, the Chehalem Mountains to the south, and the lowlands of the Oregon Coast Range to the west. Structurally, the Tualatin Basin is a saucer-shaped syncline, with units dipping gently towards the center of the basin (USGS, 1965). The bowl-shaped structure of the Tualatin Valley is largely the result of displacement mechanisms such as faulting, which also significantly impacts groundwater resources of the region. Development of groundwater for municipal supply within the Tualatin Valley primarily

[2] Portland Hillsboro Airport Weather Station, KHIO, Station ID USW00094261

[3] Buxton, Oregon, Station ID USC00351222

[4] Potential Evapotranspiration is the total possible amount of water from the lands surface transformed to water vapor. This includes evaporation from standing water and soil moisture to transpiration, or expiration, of water from the leaves of plants (Dingman 2002).

occurs in interflow zones of the Columbia River Basalt Group (CRBG), and within shallow alluvial aquifers to a lesser extent.

The geology of the regional area has been mapped and described in multiple studies and reports, including; a geological professional survey paper prepared by the United States Geological Survey (USGS) (USGS, 1965), local mapping produced by the Oregon Department of Geology and Mineral Industries (DOGAMI) (DOGAMI, 1998), and a Source Water Assessment Report (SWAR) prepared by the Oregon Department of Human Services (ODHS) (ODHS, 1998). Review of these sources show three general geologic units in the Banks area. These identified units are generally described below, with more detailed descriptions specific to each study area being found in subsequent sections:

- Unconsolidated Sediments (Qal/Qs): Sand, gravel, and silt deposits along channels and floodplains. Thicknesses increase towards the center and low-lying portions of the Tualatin Basin. In the area local to Banks, alluvial units reach maximum thicknesses of approximately 500 feet (USGS, 1965). Groundwater yields are characterized as low to moderate, except along perennial water bodies which provide a near-constant recharge (USGS, 1965).
- Columbia River Basalt Group (Tcr): Layered basalt flows of the Columbia River Basalt Group (CRBG) of the middle to upper Miocene. Composed of dark gray to black jointed interbeds with weathered peripherals and tuffaceous sedimentary interbeds. In most of the upland areas of the Tualatin Valley, the top 20 to 200 feet of basalt is weathered to residual lateritic soil, forming distinctive "red land" soils (USGS, 1965). In the area local to Banks, the CRBG unit reaches a maximum thickness of approximately 550 feet. Groundwater yields are characterized as moderate to large within the porous interflow zones (USGS, 1965).
- Marine Sedimentary Rocks (Tm): Massive and thick bedded marine sandstone, siltstone, shale, and claystone of multiple formations dating to the lower Miocene to Eocene epochs. Maximum thicknesses for this unit are generally approximated to be 1,200 feet in the area local to Banks, however, actual thickness of this unit is unknown as the deepest borings in the area terminate within the unit. Groundwater yields are characterized as low as this unit is largely devoid of water due to its low porosity and conductivity (USGS, 1965).

3.2 Banks ASR Study Area

This section presents the conceptual site model of the Banks ASR study area. The Banks ASR study area encompasses the following components of the City's water supply system: the City of Banks (primary service area), the City's production wells (Well 1 and Well 2), and the Carsten Reservoirs. The location of the Banks ASR study area is depicted on Figure 1.

3.2.1 PHYSICAL SETTING

The Banks ASR study area is located at the base of the foothills of the Oregon Coast Range in the northwest corner of the Tualatin Valley, and compromises an area of approximately 12 square miles. The Banks ASR study area is generally bounded by the following features; to the west by the West Fork Dairy Creek, to the south by Oregon Route 6, to the east by NW Aerts Road, and to the north by U.S. Route 26. Elevations in the Banks ASR study area range from 200 ft amsl in the southwest portion of the study area to 550 ft amsl in the northwest portion of the study area.

3.2.2 HYDROLOGY

Within the vicinity of the City of Banks, numerous perennial streams drain the coastal range mountains to the north, including the West Fork Dairy Creek to the west, Banks Creek, Bausch Creek, Bledsoe Creek, and East Fork Dairy Creek to the east (USGS, 2016). Banks Creek is a small, four-mile long creek that drains from the top of the hill north of Banks into the West Fork Dairy Creek due south of Banks.

The West and East Forks of Dairy Creek converge approximately 3.5 miles southeast of Banks and become Dairy Creek. At the West and East Fork confluence, the total drainage area of the catchment is 144 square miles, with 80 square miles comprising the west fork and 64 square miles comprising the east fork.

Stream flows peak in the winter months and abate during the summer and early fall. Low flows during the summer months range from 15-20 cubic feet per second (cfs), with a five-year return period, (USGS, 2017a). The West Fork Dairy Creek at Banks has an estimated two-year flood flow of 1,760 cfs.

3.2.3 GEOLOGY

Available well logs from the Banks ASR study area were evaluated to refine the geologic and hydrogeologic conceptual model for the study area. A total of 90 well logs within the Banks ASR study area were acquired from the Oregon Water Resources Department (OWRD) and examined, and are provided as Appendix B. Using the available data and professional interpretation of the observed geologic landforms and features, the following refined geologic and hydrogeologic conceptual model for the Banks ASR study area is presented.

At the northern and western boundaries of the study area, faulting has uplifted and deformed geologic units, with uplifted basalt flows of the CRBG being exposed at topographic highpoints. These uplifted units dip south and east towards the center of the Tualatin Valley at angles ranging from 4 to 10 degrees. At lower elevations such as those in the City of Banks, alluvial material overlays the CRBG at the surface, with alluvial thicknesses increasing towards the center of the Tualatin Valley. Surficial geology and well log locations within the Banks ASR study area are shown on Figure 9.

Utilizing available well logs and published information, generalized geologic cross sections were created for the study area, and show approximate unit locations, thicknesses, and contact points. These cross sections are labeled as A-A' and B-B' and are conceptually depicted on Figures 10 and 11. Cross section A-A' runs west to east, while cross section B-B' runs northeast to southwest. Both cross sections approximately intersect the north portion of the City at Northwest Banks Road where the City's production wells are located. The youngest and uppermost geologic units within the study area consist of alluvial material, which is generally located along streams, rivers, and topographic low-lands. Alluvial material within the study area reaches a maximum thickness of approximately 425 feet in the south and east of the study area. Well logs within the study area show that uplifted CRBG material has been considerably weathered to reddish brown fines of thicknesses up to 200 feet. The CRBG unit has a maximum thickness of approximately 750 feet in the upper portion of the study area, with thicknesses decreasing towards the east. Marine sediments underlie the CRBG unit at an unknown minimum thickness as wells and borings in the area do not penetrate through the marine sediment unit.

3.2.4 HYDROGEOLOGY

Groundwater within the Banks ASR study area primarily occurs within the permeable interflow zones of the CRBG basalt flows, generally flowing from the northwest to the southeast, toward the center of the Tualatin Valley, as depicted on Figure 12. Recharge of the interflow zones of the Banks ASR study area CRBG aquifer primarily occurs via precipitation onto outcrops of exposed CRBG material and structural faults. Outcrops of

exposed CRBG material are located at elevated reaches of the northern portion of the Banks ASR study area. Surface water bodies such as creeks and streams also contribute to recharge to a lesser degree, as vertical conductivity of basalt flows is minimal. Based on OWRD well logs, the cumulative thickness of water bearing zones at Well 2 is approximately 66 ft as depicted on Figure 3. The cumulative thickness of water bearing zones for the entire study area is approximately 150 ft, based on well log records. The water bearing zones in the Banks area are considered semi-confined to confined, as vertical conductivity between water bearing zones is minimal due to basalt flows having dense interior structures that prohibit flow (USGS, 1965).

The most recent static water level elevation (1/2018) at the production wells is approximately 183 ft amsl, or approximately 52 ft bgs at the location of the production wells, as shown on Figure 13. A 72-hour pump test conducted for Well 2 in 2005 determined the pumping transmissivity of the CRBG aquifer in the Banks ASR study area to be approximately 956 feet squared per day (ft^2/day), giving a hydraulic conductivity of 1.6×10^{-4} feet per second (ft/s) (Golder, 2008).

In January 2018, a geophysical survey at the City of Banks' Well 2 was performed by Pacific Surveys LLC to refine the understanding of the geologic setting, hydrogeologic productivity, and existing condition of the well. The geophysical survey included the performance of video, dynamic/static spinner log, and caliper surveys. Results of the Well 2 geophysical survey are included as Appendix C. The geophysical survey confirmed the existence of two productive water bearing zones within the CRBG at Well 2, as depicted on Figure 3. The upper water bearing zone accounted for 40% of the well's total production while the lower water bearing zone accounted for 60% of the well's total production. Additionally, the exchange of water between the two water bearing zones was observed, with water from the lower water bearing zone moving upwards and mixing with the upper water bearing zone.

The two water bearing zones appear to have similar historic water levels that are within a few feet of each other and change in hydraulic grade relative to one another depending on the year of measurement. It is apparent from the record, Figure 13, that sometimes Well 1 has a higher water level than Well 2 and sometimes that relationship is reversed. The gradient changes are likely due to changes in pumping routine between Well 1 and Well 2, and perhaps other pumping wells in the area, which suggest that the water bearing zones are not confined from one another.

To assess the relative interconnected nature of the basalt water bearing zones and evaluate the relative differences in water levels of the basalt water bearing zones in the Banks ASR study area, CwM completed a statistical analysis of the static water levels. The results of the analysis indicate that the static water levels as a group exhibit a relatively consistent potentiometric surface[5], as seen on Figure 14. The potentiometric surface is generally sloped from the north and west to the south and east, which is in line with the estimated flow direction.

Figure 14 shows the potentiometric surface of the basalt water bearing zones relative to the ground surface elevation and the top of the basalt elevation viewed from true north to south. The potentiometric surface shown in Figure 14 was derived from annual static water level measurements taken at eight wells in the Banks area that penetrate different depths and water bearing zones. These water level measurements are typically

[5] A potentiometric surface is the elevation to which groundwater in a confined aquifer would rise if exposed to atmospheric pressure (such as in a well). The potentiometric surface should not be confused with groundwater table which is the elevation of groundwater of the unconfined aquifer in the area.

associated with water level reporting from water users or from observation wells. The potentiometric surface estimated based on a linear regression of the water levels in the wells and indicates 2.4 percent gradient with a coefficient of determination of 0.89.

These results also suggest that the two water bearing zones are sufficiently interconnected to act as a single aquifer with multiple basalt water bearing zones.

3.3 Sellers Road Study Area

This section presents the conceptual hydrologic model of the Sellers Road study area and includes an assessment of surface water and groundwater sources. The Sellers Road study area encompasses the following components of the City's water supply system: the Green Mountain springs (West and East Spring) and Green Mountain WTP. The location of the Sellers Road study area is depicted on Figure 1.

3.3.1 PHYSICAL SETTING

The Sellers Road study area is located within the foothills of the Oregon Coast approximately 3.5 miles north of the City of Banks. The Sellers Road study area consists of the Green Mountain Springs, their associated recharge area, and the adjacent local area totaling an area of approximately 10 square miles. The Sellers Road study area is generally bounded to the west by Rock Creek, to the south by U.S. Route 26, to the east by the East Fork Dairy Creek, and to the north by Murtaugh Creek. Elevations in the Sellers Road study area range from 200 ft amsl in the southern portion of the study area to 1,350 ft amsl in the northern portion of the study area.

3.3.2 HYDROLOGY

Hydrology of the Sellers Road study area is critical to understanding the nature of the Green Mountain Springs water supply. The Green Mountain Springs are part of larger catchments that drain to the West Fork Dairy Creek. The flows of these catchments include the springs that feed the City's water rights in the area.

Historically, the West and East Spring catchments have not been gaged. To further characterize hydrology of the Sellers Road study area, CwM installed a stream gage at the West Spring impoundment in 2017. The East Spring was not instrumented due to the inability to securely install gages and transducers. The West Spring impoundment was constructed with an overflow weir which allows for flow estimates to be made based on the height of the water behind the weir. Recording of the flow from the West Spring impoundment began in March 2017 and ran through May 2017.

Using data collected between March to May of 2017, a hydrologic model was developed for the West Spring to estimate a multi-year record of spring yield. The hydrologic model consisted of calibrating the three months of gaged data of the West Spring watershed to a watershed with a more robust dataset (East Fork Dairy Creek) and developing a regression relationship to estimate yields of the West Spring.

The West Spring hydrologic model was projected for the period 10/1/2002 to 9/30/2016, or 14 years. Model results indicate that the mean annual water yield from the West Spring is approximately 105 million gallons (mg) with a minimum annual yield of 100 MG and a maximum annual yield of 116 MG. The monthly variation in spring yield is from an average of 6.2 MG in September to an average of 11.4 MG in January. Table 6 presents median monthly catchment yields. Details of the hydrologic model development are included in Appendix A.

3.3.3 GEOLOGY

Available well logs from the Sellers Road study area were evaluated to refine the geologic and hydrogeologic conceptual model for the study area. A total of 165 well logs within the Sellers Road study area were acquired from OWRD and examined. These well logs are provided as Appendix B. These well logs along with published literature of the local hydrogeology form the basis of a refined geologic and hydrogeologic conceptual site model for the Sellers Road study area, presented in the following paragraphs.

Within the Sellers Road study area, faulting has uplifted and deformed geologic units, with uplifted basalt flows of the CRBG being exposed at topographic highpoints which are underlain by marine sediments. These uplifted units dip south towards the West Fork Dairy Creek at angles ranging from approximately 7 to 10 degrees. Surficial geology and well log locations within the Sellers Road study area are shown on Figure 15.

CwM developed generalized geologic cross sections for the study area that show approximate unit locations, thicknesses, and contact points. These conceptual cross sections are labeled as A-A' and B-B', and are presented on Figures 16 and 17, respectively. Cross section A-A' runs southwest to northeast, while cross section B-B' runs south to north. Well logs within the study area show that uplifted CRBG material has been considerably weathered to reddish brown fines of thicknesses up to 200 feet in the upper portions of the study area. In total, the CRBG unit has a maximum thickness of approximately 680 feet in the upper portions of the study area before being pinched out by underlying marine sediments at a suspected normal fault line running northwest to southeast. As previously noted, thickness of the marine sediments is unknown, but they are approximated to be at least 1,000 to 1,200 feet thick (USGS, 1965).

3.3.4 HYDROGEOLOGY

The Green Mountain Springs are characterized as contact springs, which occur when a permeable water bearing unit such as the CRBG overlies a less permeable unit such as the marine sediments and the contact between these units intersects the ground surface. The CRBG unit is considered the primary water bearing unit of the study area, with water existing in interflow zones between subsequent basalt flows. Utilizing water bearing zone information from local well logs, a cumulative water bearing zone thickness of 30 feet was approximated for the CRBG unit. Like the water bearing zones of the Banks ASR study area CRBG, the water bearing zones of the Sellers Road study area CRBG are considered semi-confined to confined, as vertical conductivity above water bearing zones is minimal due to basalt flows having dense interior structures that are prohibitive of flow (USGS, 1965). The hydraulic conductivity of the CRBG's water bearing zones is similar to that of the Banks ASR study area, at 1.6×10^{-4} ft/s, based on historical pump tests and material thicknesses (Golder, 2008).

The contact point between the CRBG and marine sediment units creates a no-flow boundary for water infiltrating the CRBG. The no-flow boundary forces the groundwater to surface at the contact between the geologic units, resulting in the Green Mountain Springs. The contact point between the CRBG and marine sediment units occurs approximately halfway up the slope of the study area at an elevation of approximately 900 ft amsl, as seen on Figure 17. The recharge area of the springs is at elevations at or higher than the elevations of the springs. The generalized recharge area of the springs is presented on Figure 15, and measures approximately two square miles in area.

4 AQUIFER STORAGE AND RECOVERY FEASIBILITY EVALUATION

As discussed in Section 2.3, the volume of annual supply that would have to be replaced by another source such as ASR is calculated to be 41.6 MGY, being calculated as follows; the maximum volume of water lost from the Green Mountain Springs over a three-month period in an emergency or ecological scenario (24.4 MG) plus the projected 2050 average annual water supply deficit (17.2 MG).

ASR has been identified as a potentially feasible alternative to meet the City's water supply deficits. Generally, an ASR system involves the procurement of water from a surface water source during periods of abundant water availability (winter/spring season), then injecting and storing the surface water in a suitable underground aquifer for future recovery and use during periods of peak water supply demand (summer).

This section identifies and evaluates the components of the City's existing infrastructure and source water supplies for utilization in an ASR system to replace 41.6 MGY. Each identified ASR system component is evaluated individually to address the benefits, risk, and overall feasibility associated with each system component. The ASR system components evaluated in this feasibility study include the following:

- Aquifer Storage
- Stored Water Recovery
- Existing Source Water Supplies
- Existing Infrastructure Compatibility
- ASR Permitting

4.1 Feasibility Evaluation Criteria

Each of the above ASR system components is evaluated by criteria specific to each component, with each component criteria being rated on the following general scale:

- High ASR Feasibility: ASR system component has a high potential feasibility of aiding the City of Banks in meeting its 2050 water supply demands through inclusion in an ASR system. ASR system component is likely beneficial to the City of Banks water supply system, service population, existing water right holders, and environment.
- Low ASR Feasibility: ASR system component has a low potential feasibility of aiding the City of Banks in meeting its 2050 water supply demands through inclusion in an ASR system. ASR system component is not likely beneficial to the City of Banks water supply system, service population, existing water right holders, and environment.

The specific rating criteria and rational for each of the ASR system components is detailed on Table 7. For ASR system components that include multiple alternatives or scenarios, a comparison between alternatives is provided separately to aid in the evaluation and selection of an alternative.

4.2 Aquifer Storage

The first component in evaluating the feasibility of an ASR system is the storage of injected water. Injected water is stored underground in a suitable aquifer until recovery at a future time. A suitable aquifer for ASR storage should have sufficient capacity to store water without losing it to leakage, and a moderate to high transmissivity for future recovery of stored water. With respect to the City of Banks 2050 water supply demands, the target storage volume for an ASR program is 41.6 MGY. The criteria to evaluate aquifer storage are presented below, and are also tabulated in Table 7:

- Aquifer Storage capacity
  - **Low ASR Feasibility**: Storage capacity <75% of 41.6 MGY (41.6 MGY = emergency scenario lost volume [24.4 MG] + 2050 average water supply deficit [17.2 MG]).
  - **High ASR Feasibility**: Storage capacity >75% of 41.6 MGY (41.6 MGY = emergency scenario lost volume [24.4 MG] + 2050 average water supply deficit [17.2 MG]).
- Potential Negative Impacts
  - **Low ASR Feasibility**: Surface seepages projected to occur at >5% of wells within the same local aquifer system (CRBG).
  - **High ASR Feasibility**: Surface seepages projected to occur at <5% of wells within the same local aquifer system (CRBG).
- Aquifer Sustainability
  - **Low ASR Feasibility**: Aquifer replenishment (10% of stored volume left unrecovered) <2 MGY.
  - **High ASR Feasibility**: Aquifer replenishment (10% of stored volume left unrecovered) >2 MGY.

4.2.1 AQUIFER STORAGE CAPACITY

In Oregon, the CRBG and other basalt formations are often targeted for ASR storage due to their confined nature, high storage space resulting from over-pumping, and relatively geochemically inert nature (Woody, 2007).

The target storage aquifer for an ASR system for the City is the CRBG aquifer within the Banks ASR study area, located on Figure 1. This aquifer was identified as a potentially suitable storage aquifer due to a history of high capacity from production wells, proximity existing infrastructure such as the City's production wells (Well 1, #2) and reservoirs (Carsten Reservoirs), proximity to most of the City's service area, and preliminary assessment of aquifer properties.

The primary criteria by which an aquifer is evaluated for ASR storage utilization is by its aquifer thickness, hydraulic conductivity, and available injection head (i.e.. the height between ground surface and static water level). Transmissivity is important in ASR storage as it quantifies the ease with which water can move through the geologic formation (for injection or recovery), and accounts for the thickness of the formation. For example, a low material transmission rate (hydraulic conductivity) can be compensated for by a large aquifer thickness, resulting in an overall transmissivity suitable for ASR operation. A minimum aquifer thickness of 25 ft is generally recommended for ASR storage (Woody, 2007). Should Well 2 be exclusively utilized for ASR, the cumulative thickness of water bearing zones is approximately 66 ft as depicted on Figure 3, as determined by the January 2018 geophysical survey of the well.

Transmissivity values preferred for ASR storage are generally greater than 5,000 square feet per day (ft^2/day) (Woody, 2007). A 72-hour pump test conducted for Well 2 in 2005 determined the pumping transmissivity of the CRBG aquifer in the Banks ASR study area to be approximately 956 ft^2/day (Golder, 2008). While this transmissivity is below the recommended criteria of 5,000 ft^2/day, multiple municipal ASR projects in the state of Oregon have had success with ASR system operation despite having low transmissivities similar to that of the Banks ASR study area CRBG aquifer, including the Tigard ASR (T = 900 ft^2/day), Baker City ASR (T = 980 ft^2/day), Dallas ASR (T = 1,300 ft^2/day), and the Sunrise Water Authority (T = 1,400 ft^2/day) (Woody, 2007).

The final criteria for ASR storage evaluation is an aquifer's available head for injection of source water. Available head dictates the rate and volume of water that can be stored before the static water level rises to the surface, preventing further injection unless additional pressurization is applied to the well. The most

recent static water level elevation (2018) at the production wells is approximately 183 ft amsl, or approximately 52 ft bgs at the location of the production wells, as shown on Figure 13. Subsequently, water storage is limited to a water level rise of 52 ft at the production wells, to prevent surfacing of groundwater unless pressurized injection is applied to the well head.

To project the maximum injection rate and storage volume for a period of 180 days assuming no well head pressurization, an inverse Cooper-Jacob straight line method was modified to determine water level rise and mounding due to injection for one scenario, being:

- Injection Via Well 2: This scenario evaluates the potential storage capacity and impacts of injection assuming that Well 2 is utilized for injection at a continuous injection rate for 180 days and is limited to 52 ft of water level rise at the well.

The resulting maximum injection rate for the 180-day period based on 52 ft of available head at Well 2 was found to be approximately 175 gpm, with a total annual storage volume of 45.1 MG. The injection and storage assessment for Well 2 is included as Appendix D of this report.

For the modeled storage scenario, the annual storage volume exceeds the target ASR volume (41.6 MG) by 3.5 MG. Subsequently, ASR storage for the Banks ASR study area CRBG aquifer is given a High ASR Feasibility rating.

4.2.2 AQUIFER STORAGE POTENTIAL NEGATIVE IMPACTS

Currently, groundwater from the CRBG aquifer in the Banks ASR study area is withdrawn and utilized by a multitude of water right holders for a variety of beneficial uses. The continuous appropriation of groundwater can result in aquifer drawdown and residual lowering of the static water level. The storage component of ASR typically results in ecologically beneficial impacts to groundwater budgets, as a percentage of stored water (up to 10% as part of ASR Limited Licenses) is reserved for aquifer recovery. However, should source water be stored in and recovered from the CRBG aquifer within the Banks ASR study area, the following negative impact could potentially be incurred:

Surface Seepages At Other Wells: The mechanisms for storing and recovering water underground can potentially result in local impacts such as uncontrolled surface seepages. If source water is injected for storage at a rate and volume exceeding the aquifer's storage and transmission capacity, water will mound at the point of injection and raise the static water level. Surface seepages will occur if the static water level is raised above the surface elevation for the wells that access the same semi-confined aquifer as the injection well. Wells that tap other aquifers such as shallow alluvial aquifers would likely not demonstrate impacts because they do not have a hydraulic connection to the basalt aquifers that the City's production wells access.

Results

Using a modified Cooper-Jacobs method, a mounding analysis was conducted to quantify the impacts resulting from storing water at the rate and volume specified in Section 4.2.1, or approximately 175 gpm for a total of 45.1 MG over six months at Well 2. The details and results of these mounding analyses are provided in Appendix D. Static water level rises for the storage scenario were estimated for each well within the Banks ASR study area CRBG aquifer and are discussed below as well as being conceptually depicted on Figure 18. Assuming an injection rate of 175 gpm for six months, surface seepages were projected to occur at the following well(s):

- **WASH_7665:** Located approximately 4,000 feet southeast of the production wells, the static water level reported on the well log at the time of construction is 8 ft bgs. The water level in the well was projected to rise by 9.5 feet, exceeding the 8 feet available below the surface by 1.5 feet. It should be noted that the well log for this well indicates a well depth of 335 and that the well does not penetrate a water bearing basalt layer. However, nearby wells in the area contact basalt layers beginning at approximately 250 ft bgs.

  While the mounding analysis predicts surface seepage to occur at WASH_7665, the head available for injection at this well is based on the water level measured at the time of construction (1974). Historic groundwater levels suggest that the continuous appropriation and utilization of groundwater in the Banks ASR study area may have lowered the static water level ten feet or more, as illustrated on Figure 13. It is likely that the existing static water level at WASH_7665 is lower than the level measured at the time of construction. Therefore, the estimated water level rise at these locations will likely not result in surface seepages but should be monitored.

Surface seepage impacts within the Banks ASR study area are not likely to occur considering the projected water level rises (Figure 18) and existing water levels from the Well 2 storage analysis. Subsequently, potential negative impacts from ASR storage activities are considered minimal and given a **High ASR Feasibility** rating.

4.2.3 AQUIFER SUSTAINABILITY

As previously stated, groundwater from the CRBG aquifer in the Banks ASR study area is withdrawn and utilized by a multitude of water right holders for various beneficial uses. However, should source water be stored in and recovered from the CRBG aquifer within the Banks ASR study area, sustainability of the CRBG aquifer would be enhanced as follows:

- **Banks ASR study area CRBG Aquifer Replenishment:** As outlined in Oregon ASR statues (OAR 690-350-0010 through 690-350-0030) 10% of stored water would not be recovered to aid in mitigation of the local aquifer. Analyzing historical drawdown levels and pumping rates from the City's production wells and accounting for other local groundwater appropriators, the pre-development volume of all water bearing zones was determined to be approximately 1,450 MG larger than its current (2017) volume. Should ASR be implemented and 10% of stored water remain unrecovered to aid in aquifer mitigation, this could result in a mitigative addition of 4.51 MGY to the Banks ASR study area CRBG aquifer, based on the Well 2 storage analysis.

The 10% of stored water reserved for aquifer recovery is projected to contribute either 4.51 MGY towards aquifer mitigation and recovery based on the Well 2 storage analysis. Subsequently, the potential sustainability of operating an ASR system in the Banks ASR study area is given a **High ASR Feasibility** rating.

4.3 Stored Water Recovery

As source water is injected underground for storage, it flows away from the point of injection as it is displaced by the injection of additional source water. Source water will continue to flow away from the point of injection until recovery activities are commenced. The percentage of stored water that is recovered via pumping is termed recoverability. While an understanding of recoverability provides insight to the dynamics of an ASR system and aquifer, a low recoverability does not determine the success of an ASR system, as non-storage water (i.e.. native groundwater) can be recovered for utilization to meet water supply demands. Ultimately, the total volume of water appropriated (storage or non-storage) for utilization to meet water supply demands

is the primary criteria by which ASR recovery activities is evaluated. This section evaluates the recovery of a conceptualized ASR system within the Banks ASR study area by the following criteria (presented on Table 7):

- Volume of Water Recovered
    - **Low ASR Feasibility:** Volume of water recovered <100% of 69.9 MGY (69.9 MGY = emergency or ecological scenario volume [24.4 MG] + 2050 average annual water supply deficit [17.2 MG] + volume of groundwater water currently appropriated from May through October [28.3 MG]).
    - **High ASR Feasibility:** Volume of water recovered >100% of 69.9 MGY (69.9 MGY = emergency or ecological scenario volume [24.4 MG] + 2050 average annual water supply deficit [17.2 MG] + volume of groundwater water currently appropriated from May through October [28.3 MG]).

Within the Banks ASR study area, groundwater generally flows southeast towards the center of the Tualatin Valley. This flow gradient is illustrated on Figure 12, which utilizes static water levels from well logs identified within basalt units in the Banks ASR study area to generate groundwater contours within the basalt aquifer. To quantify the potential recoverability of an ASR system within the Banks ASR study area, a conceptual ASR system was developed for two recovery scenarios, which included the following system components and assumptions:

1. **Recovery Via Well 2:** This scenario evaluates the potential recoverability via utilization of Well 2. Under this scenario, injection would occur at Well 2 for six months at a constant rate of 175 gpm (Section 4.2.1). Recovery would then commence at Well 2 at a rate of 290 gpm for six months.

2. **Recovery Via Well 2 and Additional Recovery Well:** This scenario evaluates the potential recoverability of an ASR system assuming that recovery occurs via Well 2 and at an additional downgradient recovery well. Recovery occurring at the Quail Valley Well was modeled for this scenario, however, a new recovery well could also be installed as an alternative to utilizing the Quail Valley Well. Under this scenario, injection would occur at Well 2 for six months at a constant rate of 175 gpm (Section 4.2.1). Recovery would then commence at Well 2 and the additional downgradient recovery well at rates of 225 gpm for both wells for a period of six months.

All recovery scenarios assumed that injected source water flows downgradient from the injection well (Well 2) at a velocity dependent upon the transmissivity (956 ft^2/day) and available water bearing zone thickness of Well 2 (66 ft), for a saturated hydraulic conductivity of 1.6×10^{-4} ft/sec.

Results

A capture zone analysis was conducted for the three conceptualized recovery scenarios using the method presented by Grubb *et al* (1993) for confined aquifers. These conceptualized ASR recovery scenarios did not take into consideration influences from factors such as pumping from other wells, seasonal hydraulic gradient variability, or groundwater flow barriers/preferential pathways. Results of the conceptualized ASR scenarios are presented on Table 8 on Figure 19, and include the following volumes and percent of recovered water:

1. **Recovery Via Well 2:** The recoverability of this scenario was calculated to be 43% (Table 8, Figure 19). The total volume of water appropriated to meet the target ASR volume and water supply demands of the City (69.9 MG) would be 75.2 MG. Subsequently, the recovery component of this

conceptualized ASR system is given a **High ASR Feasibility rating**, as the volume of water appropriated exceeds the target ASR volume and water supply demands of the City (69.9 MG).

2. **Recovery Via Well 2 and Additional Recovery Well:** The recoverability of this scenario was calculated to be 74% (Table 8, Figure 19). The total volume of water appropriated to meet the target ASR volume and water supply demands of the City (69.9 MG) would be 116.6 MG. Subsequently, the recovery component of this conceptualized ASR system is given a **High ASR Feasibility rating**, as the volume of water appropriated exceeds the target ASR volume and water supply demands of the City (69.9 MG). To evaluate pumping interference between Well 2 and the Quail Valley Well, the Theiss equation (Driscoll, 1980) was used to project the drawdown of each well using the most recent (1/2018) water level data from Well 2. The resulting pumping interference and drawdown is presented on Figure 20, which shows that while some interference exists (overlap of projected drawdown), the drawdown at experienced at each well will not reach levels endangering pumps or necessitating curtailment.

Results of the ASR aquifer recovery feasibility evaluation are presented on Table 8 and Figure 19. In general, the following notes regarding ASR recovery should be considered in designing and operating a full-scale ASR system:

- ASR recoverability decreases with an increase in storage duration;
- ASR recoverability increases with an increase in recovery rate; and
- Should recoverability be found to be unacceptably low, recovery wells could be installed downgradient of the existing production wells (Well 1, Well 2) to expand the ASR system's cumulative capture zone and improve recoverability. Existing downgradient wells such as the Quail Valley Well could be retrofitted for ASR recovery utilization.

4.4 ASR Source Water

The third component to an ASR system is the source water supply, which should provide water to meet the goals for ASR underground storage. A suitable source water supply is one that reliably provides a sufficient quantity of water with minimal adverse impacts to other users or the environment. Additionally, the source water supply should be geochemically compatible with the groundwater of the storage location to minimize geochemical reactions between two different waters and the aquifer matrix itself. These reactions can result in degradation of water quality including mineral precipitations and subsequent well clogging. What follows is simply an evaluation of the quantity and quality of the City's existing source water supplies. Criteria to evaluate identified source water is described below and is also presented on Table 7:

- <u>Available Quantity</u>
    - **Low ASR Feasibility:** Source water quantity available to water supply system <100% of 41.6 MGY (41.6 MGY = emergency scenario lost volume [24.4 MG] + 2050 average water supply deficit [17.2 MG]).
    - **High ASR Feasibility:** Source water quantity available to water supply system >100% of 41.6 MGY (41.6 MGY = emergency scenario lost volume [24.4 MG] + 2050 average water supply deficit [17.2 MG]).
- <u>Geochemical Compatibility</u>
    - **Low ASR Feasibility:** Likely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely required.

- High ASR Feasibility: Unlikely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely not required.

- Potential Negative Impacts
  - Low ASR Feasibility: Likely occurrence of negative impacts to existing water right holders, local environment, or population.
  - High ASR Feasibility: Unlikely occurrence of negative impacts to existing water right holders, local environment, or population.

Identified source water supplies include those from existing sources (existing water rights of the City).

4.4.1 EXISTING WATER RIGHTS – GREEN MOUNTAIN SPRINGS WATER SUPPLY

The City has two certificated water rights (5353 and 83138) to divert water from two spring sources at Green Mountain. The annual water rights for these two springs totals approximately 141.5 MG (Table 9). The water is treated in a slow sand filter WTP before being transmitted to reservoirs near the City. The potential for surface waters from these existing sources to be used to meet the target ASR volume of 41.6 MGY is evaluated in this section.

Currently Available Quantity

CwM conducted a water availability assessment of the existing surface water rights and available spring yields for the Green Mountain Springs which is included as Appendix A of this report. This assessment included an analysis of historical water diversions by the City, field data collection, hydrologic modeling of the spring catchments and runoff to estimate spring yields, and flow availability determination as outlined by the Oregon Water Resources Department's "Percent of Flow" Approach (OWRD, 2014).

The City has certified surface water rights for the two springs (5353 and 83138), however, full diversion and utilization of their surface water rights is only achieved in periods of high spring yield such as the winter and early spring. Examination of the most recent five years of diversion data (2013-2017) from the West and East Spring indicated mean monthly diversions of 4.9 and 0.7 million gallons of water from the West and East Spring respectively, and mean annual diversions of 58.3 and 8.3 million gallons respectively. On an average annual basis, this volume represents approximately 59% and 19% of the volume authorized by their certificated water rights from the West and East Spring. Evaluation of the monthly and seasonal diversion data indicates the highest diversion rates are from March to July for the West Spring, and from January to June for the East Spring. Table 9 and Figure 21 highlight the apparent difference in the City's water rights and what is available for use. The reasons for the unfulfilled water yields are due to three main factors:

1. Dry Season Low-Flows: Diversions from the West Spring have been limited during summer months to a little as 4.7 million gallons (110 gpm); and
2. High Turbidity Events: Water yields from the East Spring are significantly lower than its water right allows because wet season flows, particularly during storm events, have high sediment concentrations which the WTP cannot filter effectively. Additionally, decreasing yields during the dry season limit the overall production of the East Spring. Therefore, the East Spring is currently diverting as much water as currently feasible throughout the year at 8.3 MGY.
3. Treatment Capacity of the WTP: The current treatment capacity of the WTP (184 gpm) is a limitation to spring diversions, and results in an average annual volume of 7.3 million gallons of water left unutilized by the City. The treatment capacity of the WTP limits available spring diversions for eight months (November through June).

Because the East Spring yield is considered maximized due to turbidity events, any additional water available for use by the City must come from flows from the West Spring. The hydrologic model developed for the West Spring (Appendix A) shows that on average, the City should be able to meet their full water right for the West Spring (188.5 gpm) between November and June, however, the current treatment capacity of the WTP (184 gpm) is a limitation to spring diversions, and results in an average annual volume of 7.3 MG of water left unutilized by the City. Therefore, the total average annual yield of the springs is approximately 93.3 MG, which is approximately 26.7 MG more than the City's current annual diversions. The average monthly spring yields and limiting factors (WTP capacity) are presented on Table 9 and Figure 21.

Therefore, the potential for existing water supplies to meet the target ASR volume of 41.6 MGY is given a Low ASR Feasibility rating. While the volume currently available for ASR utilization is below the target ASR volume of 41.6 MGY, this source water supply is retained for further analysis as water rights and infrastructure already exist to utilize available spring water.

Water Quality Compatibility

Source water for ASR is stored in an underground aquifer until recovery at a future time. Mixing between source water and native groundwater of the storage aquifer can potentially result in mineral precipitations or other reactions that could clog the injection well/storage aquifer or degrade water quality. To evaluate the potential occurrence of such reactions between source water from the Green Mountain Springs and target storage aquifer (Banks ASR study area CRBG aquifer), CwM conducted a geochemical evaluation which included field and laboratory analysis of both water systems and modeling of potential ASR mixing scenarios.

On August 30, 2017, CwM collected a total of three water samples to characterize water qualities of the source water and target storage aquifer systems. One sample were taken from the effluent of the Green Mountain Springs WTP, while two samples were taken from each of the two production wells in the Banks ASR study area (Well 1 and #2).

Field measurements and analytical results for each water system are discussed briefly below, with associated field sheets and lab reports being included as Appendix E of this report:

- Green Mountain Springs: Field measurements and analytical results of water from the Green Mountain WTP effluent are tabulated on Table 10 and are depicted on Figures 22 and 23 as stiff diagrams and piper plots[6]. Water from the Green Mountain WTP effluent has a high quality, with a near neutral pH of 6.8, a low hardness of 36.8 milligrams per liter (mg/L), and concentrations of metals and inorganics being below primary and secondary MCLs. Additionally, the water from the Green Mountain WTP effluent was found to have a moderate buffering capacity, with an alkalinity of 73 MG/L.
- Banks ASR study area CRBG Groundwater: Field measurements and analytical results of water from Well 1 and Well 2 are tabulated on Table 10 and are depicted on Figures 22 and 23 as stiff diagrams and piper plots. Water from the Banks ASR study area CRBG groundwater was found to have a moderate to high quality, with a near neutral pH (6.9 Well 1 and Well 2), a moderate hardness (82 MG/L Well 1, 71.6 MG/L Well 2). Concentrations of metals and inorganics were found to be below primary and secondary MCLs, except for iron at Well 1. Iron was detected at a concentration of 0.315

[6] Stiff diagrams and piper plots function to illustrate general water quality. Continual monitoring and graphing of water quality data allows variations in water qualities to be visually identified as stiff diagram shapes change or piper plotted points move.

MG/L, which is higher than the secondary MCL of 0.3 MG/L. Iron was not detected above the laboratory method detection limit from the sample collected from Well 2. It is likely that elevated iron concentrations of Well 1 are the result of groundwater interaction with material of the CRBG, which typically has a ferrous oxide composition of 11-15% by weight (Camp, 1982). The resulting iron exceedance at Well 1 could also be the result of iron bacteria growths due to the infrequent utilization of Well 1 in comparison to Well 2. The groundwater from the Banks ASR study area CRBG groundwater was found to have a moderate to high buffering capacity, with alkalinities of 96 and 110 MG/L, for Well 1 and Well 2, respectively. In comparison to water from the Green Mountain WTP effluent, groundwater from the Banks ASR study area CRBG groundwater generally has higher concentrations of major ions, as illustrated on the stiff diagrams of Figure 22.

Mixing Model Analysis

The United States Geological Survey's mixing model PHREEQC Version 3.3.12 (USGS, 2017b) was utilized to evaluate the mixing characteristics associated with ASR storage, including potential mineral precipitations and reactions. PHREEQC is a water mixing modeling program that is widely accepted among the regulatory and scientific community.

Using PHREEQC, the potential for mineral precipitation was evaluated using the saturation index (SI). For any mineral, an SI less than zero denotes sub-saturation, indicating a propensity for the mineral to dissolve. Alternatively, an SI greater than zero denotes supersaturation, indicating a propensity for the mineral to precipitate. Mineral stabilities were evaluated for a range of minerals under various mixing scenarios involving varying proportions of source water and native groundwater, including; 10%, 25%, 50%, 75%, and 90% native groundwater of the Banks ASR study area mixed with remaining available proportions of source water from the Green Mountain Springs.

The resulting saturation indices for selected minerals for each mixing scenario are tabulated in Appendix F. In general, mineral precipitations were not projected to occur, with the exception of some iron and silica-based species.

The positive saturation indices of iron and silica species is likely the result of groundwater interaction with iron and silica rich material of the CRBG, which typically has a ferrous oxide composition of 11-15% by weight and silicon dioxide composition of 50-60% by weight (Camp, 1982).

While the positive saturation indices of iron and silica-based species indicates supersaturated conditions and the possible occurrence of mineral precipitation, it is likely that mineral precipitation will not occur as precipitation reaction kinetics would likely be on the order of decades, and evidence of iron speciated precipitation has not occurred (i.e.. water staining, water system clogging). Subsequently, the water quality compatibility of water sourced from the Green Mountain Springs is given a High ASR Feasibility rating.

Potential Negative Impacts

Excess water from the springs is not currently diverted for treatment and consumption. This excess water flows downstream past the spring impoundments until converging with other downgradient water bodies. Should this excess water from the springs be utilized for ASR purposes, the following impacts could potentially be incurred:

- Reduction in Downstream Surface Water Quantity and Quality: Currently, the 26.7 million gallons not utilized by the City flow past the WTP, feeding downstream water bodies such as the West Fork Dairy Creek. Use of this water for ASR purposes would reduce downstream flows.

Any reduction in downstream surface water quantity due to the fulfillment of the City's existing water rights would have a minor impact to downstream water bodies. Additionally, this non-diverted water is part of the City's existing water rights which they are entitled to beneficially use. Subsequently, potential impacts from using the Green Mountain Springs as a source water supply for ASR are minimal and rated as High ASR Feasibility.

4.4.2 WATER RIGHT TRANSFER - TRANSFER OF EAST AND WEST SPRING WATER RIGHTS TO GROUNDWATER

The City has two certificated water rights to divert water from two spring sources at Green Mountain. The annual water rights for these two springs totals approximately 141.5 MG, as shown on Table 9. Due to limitations of the WTP and periods of low spring flow, actual diversion and treatment is less than the total certified water rights at approximately 47% (66.5 MGY, Table 9). To potentially maximize these certified water rights, the City could transfer these water rights from a surface water source to a groundwater source as outlined in OAR 690-380-2130 and preserve their priority dates. Transfer of the City's certified surface water rights to groundwater could provide ecological benefit to downstream flows of the West Fork Dairy Creek, as spring flows would no longer be diverted for municipal use. This section includes an evaluation of the quantity of water available and environmental impacts associated with developing this source water supply for use as ASR source water.

Currently Available Quantity

To determine the available quantity of groundwater for use to meet the City's water supply demands, a detailed hydrogeologic assessment was conducted for the Sellers Road study area. The assessment included an analysis of local well logs and water rights, creation of hydrogeologic cross sections, evaluation of aquifer recharge and other properties, and modeling of groundwater pumping using the groundwater modeling program HYDRUS 2D (HYDRUS 2D, 2014).

The target aquifer for groundwater production in the Sellers Road study area is the CRBG unit. To quantify the area of recharge and extent of these water bearing zones, mapped CRBG material at elevations above the East Spring was delineated (Figure 15). Local well logs were utilized in conjunction with geologic reports to create hydrogeologic cross sections of the study area, as shown on Figures 16 and 17. Published aquifer properties of the CRBG, such as transmissivity, saturated conductivity, and interflow thicknesses, were based on CRBG properties outlined in Section 3.3.4. These data were compiled and utilized to create a generalized 2D plan-view groundwater model using the 2D finite element program HYDRUS 2D. To account for aquifer recharge of the model, recharge rates were estimated by calibrating the model to spring flows until flow was approximately equivalent to the average spring flows of the surface water assessment discussed in Section 3.3.4. To quantify the maximum volume of available water for pumping, constant pumping was simulated from a single well (*Pumping Well*, Figure 24) north of the springs until the water level had fallen below the depth of the pump, or approximately a drawdown of 125-150 feet at the pumping well.

Results

Results of the groundwater pumping model indicate that pumping at a rate of 212 gpm for a period of six months will result in drawdown of approximately 150 feet at the pumping well resulting in an exhaustion of groundwater resources available for pumping. The pumping rate of 212 gpm was selected to estimate the

maximum volume of water that could be appropriated from the aquifer over a six-month period before being limited by drawdown at the pump. The pump would then be turned off to allow the aquifer to recharge. Before subsequent pumping could be initiated, the aquifer would need to recharge for approximately 6 months, at which point water levels would rebound to a level acceptable for pumping. Under this theoretical aquifer pumping and recovery schedule, pumping could occur for six months of every year.

Based on the modeled pumping scenario, the total volume of water available for use would be approximately 54.8 MGY which is 38.5 MG less than the existing capacity of the springs water supply of 93.3 MGY (Table 11). Additionally, the projected drawdown at the pumping well (150 feet) would likely prevent permitting acceptance from OWRD. As a result of pumping, the flows of the West and East Spring were projected to decrease by approximately 35% and 46%. While spring flows were projected to be reduced, the total volume of water that would flow downstream to the West Fork of Dairy Creek would increase by 52.5 MGY, as spring flows would no longer be diverted for municipal use.

The potential for Green Mountain groundwater supplies from transferring the surface water rights of the East and West Springs to meet the target ASR volume of 41.6 MGY is given a Low ASR Feasibility rating, and removed from consideration due to the reduction of the total water supply available to the City (-38.5 MGY) and for the permitting challenges (drawdown of 150 feet) and potential injury to existing groundwater rights.

4.4.3 WATER RIGHT TRANSFER - TRANSFER OF EAST SPRING WATER RIGHT TO GROUNDWATER

While both Green Mountain Springs divert less than their total certified water rights, the East Spring fails to utilize its water right the most, diverting only 19% of its total water right compared to the 59% utilization of the West Spring. To potentially maximize the East Spring's certified water right while preserving the surface water right utilization of the West Spring, the City could transfer the East Spring water right from a surface water source to a groundwater source as outlined in OAR 690-380-2130 and preserve its priority dates.

Currently Available Quantity

CwM determined the available quantity of groundwater for utilization by performing a hydrogeologic assessment and groundwater modeling exercise for the Sellers Road study area (Section 4.4.2). To quantify the maximum volume of available water for pumping, constant pumping was simulated from a single well (*Pumping Well*, Figure 25) north of the springs until the water level had fallen below the depth of the pump, or approximately a drawdown of 125-150 feet at the pumping well.

Results

Results of the groundwater pumping model indicate that pumping at a rate of 80 gpm for a period of 18 months will result in drawdown of approximately 150 feet at the pumping well. The pumping rate of 80 gpm was selected to estimate the maximum volume of water that could be appropriated from the aquifer within the authorized rate of the East Spring's water right (80.8 gpm) before being limited by drawdown at the pump. Before subsequent pumping could be initiated, the aquifer would need to recharge for approximately 6 months, at which point water levels would rebound to a level acceptable for pumping. Under this theoretical aquifer pumping and recovery schedule, pumping could cyclically occur for an entire year in the first year, and for six months in the second year, with the last six months of year two being reserved for aquifer recovery/rebound.

Based on the modeled pumping scenario, the total volume of groundwater available for use from transferring the water right of the East Spring to a groundwater source would be approximately 41.8 MG in the first year, and 20.9 MG in the second year, or an average of 31.4 MG per year for the entire two-year pumping cycle.

The volume of water available for use from diversions of the West Spring would be reduced due to the pumping of groundwater at the new Sellers Road well, with annual diversions being reduced by approximately 23% (-21.3 MGY). The total volume of water that would flow downstream to the West Fork of Dairy Creek would decrease by 19.2 MGY, as 98% of the reduced spring flows of the West Spring would be diverted for municipal use under the City's existing water right.

The cumulative impact on the City's water supply would be a net gain of 20.5 MG at the end of the first year of pumping and a net loss of 0.4 MG at the conclusion of the second year of pumping, or on average, a net gain of 10.1 MGY for the full two-year pumping cycle. The projected drawdown at the pumping well (150 feet) would likely prevent permitting acceptance from OWRD. Therefore, the potential for the East Spring groundwater plus West Spring diversions to meet the target ASR volume of 41.6 MGY is given a Low ASR Feasibility rating and removed from further consideration at this time due to the variable impact to the City's water supply volume (-0.4 MG loss to 20.5 MG gain per year) and for the environmental impacts and permitting challenges (drawdown of 150 feet).

4.5 Existing Infrastructure Compatibility

Infrastructure to effectively operate an ASR system generally includes; a conveyance system to transmit source water to the storage location, injection/production wells for storage and recovery, and a treatment system to treat source/recovered water. This section evaluates the capacity of the City's existing infrastructure to effectively operate an ASR system at the approximate rates and volumes previously described. The existing infrastructure components evaluated for ASR compatibility include:

- Green Mountain Water Treatment Plant
- City of Banks Water Conveyance System
- Injection / Extraction Wells (Well 1, Well 2, Quail Valley Well)

4.5.1 WATER TREATMENT SYSTEMS

As specified in OAR 690-350-0010(6)(a)-(c), the injection of source water for ASR is required to comply with drinking water standards, treatment requirements, and performance standards established by the state Health Department or maximum measurable levels established by the Environmental Quality Commission, whichever are more stringent. Therefore, the City's existing treatment systems are evaluated for potential utilization in a compliant ASR system. The criteria for evaluating the City's existing treatment systems is presented on Table 7, and is also described below:

- Water Treatment Systems
    - Low ASR Feasibility: Likely that replacements or upgrades to the existing treatment systems of the City will be required for ASR utilization.
    - High ASR Feasibility: Unlikely that replacements or upgrades to the existing treatment systems of the City will be required for ASR utilization

4.5.1.1 Green Mountain Water Treatment Plant

Should water for ASR be sourced from the Green Mountain Springs, water conveyed to the Banks ASR study area for storage would first be treated by the Green Mountain WTP. Therefore, the treatment capacity of the WTP could potentially limit the rate of storage for ASR.

The Green Mountain WTP consists of a two slow sand filters measuring 55 by 30 feet and 6 to 12 feet deep. According to the City of Banks Engineer (Kennedy/Jenks, *pers. comm* 2018), the individual basin average

treatment rate is approximately 60 gpm, for a cumulative average treatment rate of 120 gpm. According to the City of Banks Public Works Supervisor (Tom Tuski, *pers. comm* 2017) the individual basin maximum treatment rate observed is approximately 92 gpm. Therefore, the maximum effective treatment capacity of both basins is 184 gpm, which is 68% of the combined water rights of the West Spring (188.5 gpm) and East Spring (80.8 gpm).

Based on the Sellers Road water availability assessment (Appendix A), the treatment capacity of the WTP limits the City from utilizing available water for eight months (November through June). During this eight-month period, the combined yields of the West and East Springs exceed the treatment capacity of the WTP by an average of 21.1 gpm, resulting in an unutilized annual volume of 7.3 million gallons. Therefore, the existing capacity of the WTP is given a **Low ASR Feasibility** rating.

4.5.2 CONVEYANCE SYSTEM

Should water for ASR be sourced from the Sellers Road study area, water would be conveyed approximately 3.2 miles before passing through the Carsten Reservoirs and being injected via Well 2. Therefore, the conveyance effectiveness of the pipeline to the Banks ASR study area could potentially limit the rate of storage for ASR. The criteria for evaluating the City's conveyance systems is presented on Table 7, and is also described below:

- Conveyance System
    - **Low ASR Feasibility:** Projected conveyance system losses are greater than 20%.
    - **High ASR Feasibility:** Projected conveyance system losses are less than 20%.

Currently, it is estimated that the conveyance pipe between the WTP and the Carsten Reservoirs loses approximately 25-30% of the water coming from the WTP (KJC, 2011). Generally new, well-managed water systems can reduce losses to 10% or less, whereas older systems typically demonstrate losses of 20% or more (AWWA, 2005). The Sellers Road pipeline is being replaced in 2019. Losses of the new pipeline losses are projected to be 10-15%, resulting in annual savings of approximately 6.1 MG. Subsequently, the capacity of the City's water conveyance system for efficient ASR operation is given a **High ASR Feasibility** rating.

4.5.3 INJECTION / EXTRACTION WELLS

Three existing wells have been identified as potentially suitable for conversion to ASR operation: Well 1, Well 2, and the Quail Valley Well, as shown on Figure 1. As previously discussed, Well 1 and Well 2 are owned and operated by the City to meet water supply demands. The Quail Valley Well is owned by the Quail Valley Golf Course within the City of Banks UGB. The construction, location, and hydrogeologic setting of potential ASR injection/extraction wells are integral in the operation of an efficient ASR system. The criteria used for evaluating the City's well systems are presented on Table 7, and is also described below:

- Injection / Extraction Wells
    - **Low ASR Feasibility:** Well is not open to the target aquifer (CRBG aquifer), it is unlikely that the well size will accommodate ASR equipment as currently constructed, and/or construction of a conveyance system to connect the well to the City's water supply system is required.
    - **High ASR Feasibility:** Well is open to the target aquifer (CRBG aquifer), it is likely that the well size will accommodate ASR equipment as currently constructed, and/or construction of a conveyance system to connect the well to the City's water supply system is not required

Some wellhead modifications would be required regardless of which well is selected for ASR utilization, as operation of ASR wells is generally more complex than groundwater production wells. Keeping in mind these evaluation criteria and considerations for ASR wells, the ASR modification potential of each of the three identified wells is detailed below:

- **Well 1:** Installed in 1979 to supplement water supply during the summer months, Well 1 has a total depth of 450 ft bgs, an 8-inch diameter, and is sealed with steel casing to 210 ft bgs as illustrated on Figure 3. Additionally, the current pump intake setting for Well 1 is approximately 277 ft bgs, with a peak pumping capacity of 230 gpm. A technical memorandum summarizing pump test analysis by Golder (2008) at Well 1 indicated a specific capacity of 1.0 at 260 gpm for a four-month period (Golder, 2008). Specific capacity of an aquifer is defined as the quantity that a well can produce per unit of drawdown. According to well logs, Well 1 is open to approximately 130 ft of upper CRBG water bearing zones and does not penetrate to the depth of the deeper more productive zones found in Well 2 and the Quail Valley Well. Well 1 has the smallest diameter of the three identified wells which presents challenges for retrofitting the pump and motor system for ASR. The narrow diameter and limited penetration of water bearing zones at Well 1 are the basis for giving the well a **Low ASR Feasibility** rating.
- **Well 2:** Installed in 2005 as an additional water supply source, Well 2 has a total depth of 669 ft bgs, a 12-inch diameter, and is sealed with steel casing to 300 ft bgs as illustrated on Figure 3. Additionally, the pump intake setting for Well 2 is approximately 283 ft bgs, with a peak long-term pumping capacity of 290 gpm. A tech memo analyzing pump tests conducted at Well 2 indicates a specific capacity of 1.4 at 395 gpm for a four-month period, and a transmissivity of 956 ft^2/day (Golder, 2008). Results of the 2018 Well 2 geophysical survey indicate that Well 2 is open to 66 ft of CRBG water bearing zones. The diameter of Well 2 (12-inches) can accommodate ASR retrofitting, however, the diameter of Well 2 is considered narrow compared to the preferred 16 to 24-inch diameter of an ideal ASR well. Well 2 is currently connected to pump directly to the Carsten Reservoirs. This infrastructure would allow for direct injection of treated water to the well with some modifications to the wellhead being required for ASR utilization. Due to its existing connection to the City's distribution system and moderate diameter the capacity of Well 2 for ASR compatibility is given a **High ASR Feasibility** rating.
- **Quail Valley Well:** Installed in 1996 as an irrigation water supply source for the Quail Valley Golf Course, the Quail Valley Well has a total depth of 640 ft bgs, a ten-inch diameter and is sealed with steel casing to 310 ft bgs as illustrated on Figure 3. Currently, appropriated groundwater from the Quail Valley Well is stored in ponds of the golf course, which are then utilized for golf course irrigation when the Tualatin Valley Irrigation District cannot supply irrigation water to Quail Valley. Utilization of the Quail Valley Well for ASR would require a Memorandum of Understanding (MOU) between the City and Quail Valley Golf Course in addition to the reconstruction of the wellhead and controls and construction of a water supply pipeline from the Quail Valley Well to the City's pipeline between Well 2 and the Carsten Reservoirs.

  A long-term pump test has not been conducted on the Quail Valley Well, existing data indicates favorable hydraulic conditions for ASR operation, as evidenced by the thickness of water bearing zones (240 ft) and flow rates of these water bearing zones (>180 gpm). However, this water bearing zone thickness is based on drilling well logs and should be considered an approximation. The small diameter of the Quail Valley Well (10-inches) would be a challenge to accommodate injection tubing and

submersible pumps for ASR operation. Additionally, the Quail Valley Well is not currently connected to the City's production wells or water supply system. Conveyance piping between the Quail Valley Well and the City's production wells could present additional high capital costs, considering the distance between these wells (4,000 ft). However, due to the proximity to the City's distribution system and the moderate diameter of the well, the existing construction and capacity of the Quail Valley Well for ASR compatibility is given a **High ASR Feasibility** rating.

Criteria specific results of the ASR existing infrastructure compatibility feasibility evaluation are presented on Table 12.

4.6 ASR Permitting

Federal, state, and local programs participate in regulating ASR wells, which are identified as Class V injection wells. On a federal level, regulation of these wells is guided by the Underground Injection Control (UIC) program authorized by Part C of the Safe Drinking Water Act (SDWA). Oregon is a primacy state for UIC Class V wells (ASR wells), and the UIC program is administered by the Oregon Department of Environmental Quality (ODEQ). However, the Oregon Administrative Rules (OAR) contain special provisions administered by the Water Resources Department addressing ASR and artificial ground water recharge (OAR 690 Division 350). OAR requires a limited license for ASR testing before a permanent ASR permit may be obtained (690-350-0010(2) OAR). The injection of source water for ASR is required to comply with drinking water standards, treatment requirements, and performance standards established by the state Health Department or maximum measurable levels established by the Environmental Quality Commission, whichever are more stringent. No license or permit may establish concentration limits for water to be injected for ASR in excess of standards established by the Health Department or the Environmental Quality Commission (690-350-0010(6)(a)-(c) OAR). Use of artificially recharged waters requires a secondary ground water permit specifying the maximum diversion rate and volume of withdrawals and allowable uses of stored recharged water (690-350-0130 OAR). This secondary groundwater permit is called an ASR Limited License.

4.7 Summary of ASR Feasibility Evaluation

Results of the ASR feasibility evaluation show that ASR is feasible for the City in terms of aquifer storage capacity (45.1 MGY), recovery of stored water (75.2 to 116.6 MGY), existing infrastructure compatibility, and permitting. However, the feasibility of operating an ASR system is ultimately limited by the City's existing source water supplies, as no existing source water supplies were found to have water available for use in an ASR system.

The City's projected 2050 average annual water supply deficit (17.2 MG) precludes using the City's existing water source water supplies (Green Mountain Springs certified water rights) as source water for an ASR system. Before the City can consider using ASR as a water management tool, a new source water supply must be developed. Developing a new source water supply will increase the total capacity of the City's water supply, likely reducing the City's reliance on its existing surface water supplies and in turn potentially allowing those surface water supplies to be utilized for ASR source water or to enhance downstream ecological surface water flows.

5 IDENTIFICATION OF NEW SOURCE WATER SUPPLIES

This section identifies new source water supplies to aid in meeting the City's target ASR volume of 41.6 MGY. Adding new source water supplies will increase the total capacity of the City's water supply, likely reducing the City's reliance on existing surface water supplies and in turn potentially allowing those surface water supplies to be utilized for ASR source water or to enhance downstream ecological surface water flows.

Potential source water supplies include the following alternatives:

- New groundwater rights;
- New surface water rights; and/or
- Procurement of water from regional providers.

In the following sections, each identified potential new source supply is evaluated based on quantity/quality of available water, including an estimation of implementation costs.

5.1 New Water Right – Available Surface Water West Fork Dairy Creek

To meet the City's target ASR volume of 41.6 MGY, the City could divert available surface water from the West Fork Dairy Creek, specifically during winter months when flows in the creek are relatively high and consumptive uses for water rights, such as irrigation are relatively low. The West Fork Dairy Creek flows from the north into the northwest portion of the Banks ASR study area before turning southwest away from the City. Given this proximity of Dairy Creek to Banks, surface water from Dairy Creek could potentially be appropriated when it is available and used for ASR. Such a diversion would require the construction of a new water treatment plant as well as infrastructure to convey water to the City's distribution system. This section summarizes the quantity available, water quality compatibility, and potential impacts of using available surface water of the West Fork Dairy Creek to meet the target ASR volume of 41.6 MGY.

Currently Available Quantity

Using the OWRD Water Availability Reporting System for the West Fork Dairy Creek, the availability of water was assessed for diversion (Cooper, 2002). The water availability was assessed on a month-to-month basis assuming some months water would not be available due to low flows within the watershed or the need to provide minimum flow rates for downstream watersheds.

The OWRD Water Availability Reporting System summarizes the water availability within the entire watershed as well as demands further downstream. For the West Fork Dairy Creek, the downstream watersheds include Dairy Creek (past the confluence with East Fork Dairy Creek), the Tualatin River, and the Willamette River. If any one of the watersheds should not have available flows including downstream watershed, the upstream watersheds are considered limited for availability as well.

Factors that affect the availability of water within a given watershed include the amount of flow in the creek, the surface water and storage water rights within the watershed, and the instream flow requirements. The instream flow requirements are flows that are not diverted out but kept within the creek for public use, such as fish and wildlife habitat, recreation, and water quality benefits.

For the West Fork Dairy Creek, the Water Availability Analysis showed that water was available within the creek during the months of December through April. The availability analysis was conducted assuming a dry year

with high water right demands (80 percent exceedance) per the OWRD guidance (Cooper, 2002). Table 13 shows the availability of water in West Fork Dairy Creek. There is no water availability in the West Fork from the months of May to November. From December through April, there is at least 500 MG per month available, with as much as 1,600 MG available for storage during the month of February. The total annual volume of water available for storage is 5,400 MGY. This source water could be used as ASR source water or to meet water supply demands of the City.

Water Quality Compatibility

The geochemical composition and quality of the Dairy Creek water is not known at this time as the City has not collected water quality data for Dairy Creek at the location where water would likely be extracted. Additionally, while public databases of surface water quality have some data associated with sites in and around Banks, much of the data is more than 50 years old and does not encompass a suite of parameters sufficient to conduct a water quality compatibility assessment. While no data was found regarding the geochemical composition and quality of the West Fork Dairy Creek, treatment to drinking water criteria will be required prior to utilization/storage, and geochemical compatibility is likely to be favorable.

Potential Negative Impacts

Currently, surface water of the West Fork Dairy Creek is utilized by downstream users. Should available surface water be utilized by the City to meet its long-term water supply demands, the following negative impacts could potentially be incurred:

- Injury to Downstream Surface Water Users: Diversion of water from the West Fork Dairy Creek could result in injury to downstream senior water rights holders, particularly in dry years or in the months of April and December. Nevertheless, during the 80th percentile year of exceedance (dry year), the Water Availability Analysis showed that more than 500 MG of water were available during the months of April and December for a total volume of 5,400 MGY.

- Infrastructure Construction: Construction of necessary infrastructure such as a surface intake and treatment plant, and pipeline to the distribution system could potentially result in impacts to the local environment, landowners, and businesses. However, the extent of construction related impacts are considered minimal and similar to typical road or municipal construction related impacts.

Further information and field testing should be gathered to more fully quantify and understand potential impacts associated with available surface water appropriate from the West Fork Dairy Creek. However, given the abundance of water available during certain winter months and the comparatively low volume of water the City would seek to appropriate, the cumulative potential impacts from utilizing West Fork Dairy Creek as a source water supply for ASR are considered minimal.

5.2 New Water Right - Groundwater Southwest of Banks

To meet the City's target ASR volume of 41.6 MGY, the feasibility of groundwater development in the southwest portion of the Banks ASR study area could be explored to develop an additional sustainable basalt well groundwater supply. This would require a new water right to appropriate groundwater and construction of new infrastructure (i.e.. well/wellhead, pump, pipeline).

Currently Available Quantity

In comparison to the area adjacent to the City's production wells, the southwest portion of the Banks ASR study area (Figure 1) is poorly characterized at the target aquifer depth (500-1,000 feet) in terms of

hydrogeology and potential groundwater production, as little data was found from the well installations. However, the hydrogeologic properties and characteristics of the Banks ASR study area discussed in Section 3.2, including strata thicknesses, saturated hydraulic conductivities, water bearing zone thicknesses, and transmissivities are likely applicable to the southwest portion of the Banks ASR study area. It is also likely that groundwater production for this area would be similar to that of the City's production at Well 2, resulting in an aquifer capacity of 71.2 MGY. This results in an additional sustainable annual supply of 60.5 MGY to the City's existing water supply after applying a 15% safety factor. While the new volume of water from this alternative would not be used as ASR source water it could the increase in the City's water supply capacity to reduce the City's reliance on surface water supplies (Green Mountain Springs).

Potential Negative Impacts

Currently, groundwater southwest of Banks is pumped at low rates and quantities by local users primarily for domestic and irrigation use. Should groundwater from the southwest portion of the Banks ASR study area be pumped and used to meet the City's water supply demands, the following negative impacts could potentially occur:

- Injury to Local Groundwater Users: Pumping of groundwater in the southwest portion of the Banks ASR study area would likely drawdown the local watertable. Such drawdown could impact local groundwater users, potentially limiting the quantity of groundwater available to them.

- Infrastructure Construction: Construction of necessary infrastructure such as an extraction well system, pump station, and pipeline to the distribution system could potentially result in impacts to the local environment, landowners, and businesses. However, the extent of construction related impacts are considered minimal and similar to typical construction related impacts.

Further information and field testing should be gathered to more fully quantify and understand potential impacts associated with groundwater development to increase the capacity of the City's existing water supply. However, based on our preliminary conceptual understanding of the Banks ASR study area groundwater resources, the cumulative potential impacts are considerable and would likely present permitting challenges.

5.3 Regional Water Providers

To meet the target ASR volume of 41.6 MGY, the City could consider sourcing water from regional water providers, such as the Joint Water Commission (JWC). The JWC is the primary drinking water supplier in Washington County, and is comprised of four agencies from the cities of Hillsboro, Forest Grove, Beaverton, and the Tualatin Valley Water District (TVWD). Currently, all water supplied from the JWC is called for under one of the members supply projections (*Meeting with JWC Manager Kevin Hanway, 10/31/2017*).

Preliminary discussion with JWC staff indicated water would likely be available to meet the City's target ASR volume of 41.6 MGY. However, to obtain supply from the JWC, the City would have to pay the incremental cost of replacing the water from another source (system development charge or SDC) or enter a long-term contract for water as a wholesale customer to the JWC. The long-term contract could fail to be renewed if one of the other members decided to utilize the share of water needed by the City of Banks. Because the JWC does seek wholesale customers and has available long-term capacity, the potential for procuring water from a regional provider is considered favorable.

Water quality compatibility and potential negative impacts associated with this source water scenario are not known at this time as multiple water sources of the JWC could supply water to the City of Banks, and a

determination of water quality compatibility and potential negative impacts is dependent on the selection of water source by the JWC. However, the widespread use of treated surface waters in Oregon as a source of storage water for basalt aquifers has been found to be compatible in every evaluation to date and similar compatibility is anticipated for water sourced from the JWC.

5.4 ASR Implementation & New Source Water Supply Costs

This section evaluates planning level cost estimates associated with the modification of existing infrastructure or the construction of new infrastructure to operate an ASR system or develop a new source water supply. System permitting, design, installation, development, and conveyance system costs are estimated at a planning level and discussed for each of the following scenarios.

5.4.1 ASR IMPLEMENTATION – MODIFICATION OF WELL 2

As identified in Sections 4.2 through 4.4, existing infrastructure would likely be utilized in operation of an ASR system. Specifically, Well 2 was identified as an ideal candidate for ASR modification and utilization based on its existing construction, hydrogeologic setting, and proximity and interconnection with the City's water supply system. As previously discussed in Section 3.2.5, OWRD may determine that the upper and lower water bearing zones of Well 2 are separate aquifers that are commingling. This scenario evaluates the potential cost of modification assuming that both water bearing zones (upper and lower) are available for ASR utilization. Modification of Well 2 for ASR utilization under this scenario would likely be straightforward, and potentially only require modifications to its wellhead.

Project Components

- Design and Consulting; and
- ASR Wellhead Modifications.

Estimated Cost

- $310,000

5.4.2 ASR IMPLEMENTATION – MODIFICATION OF QUAIL VALLEY WELL

In Section 4.5, the Quail Valley Well was identified as a candidate for ASR modification and utilization based on its existing construction and hydrogeologic setting. Modification of the Quail Valley Well could include; wellhead reconstruction and equipment upgrades, and conveyance/intertying with the City's water supply system.

Project Components

- Hydrogeologic Study and Well Testing;
- Wellhead Redesign and Construction;
- Conveyance Pipeline (8-inch, 5,000 ft); and
- Land.

Estimated Cost

- $1,502,000

5.4.3 NEW WATER SUPPLY – AVAILABLE SURFACE WATER WEST FORK DAIRY CREEK

As identified in Section 5.1, a new surface water right could potentially be acquired to appropriate available surface water from the West Fork Dairy Creek during periods of excess to aid in meeting the City's target ASR volume of 41.6 MGY. This would require construction of a WTP to to capture and treat surface water and a

conveyance pipeline to the City's water supply system. For the WTP, a treatment capacity of 250 gpm was assumed to meet the target ASR volume of 41.6 MGY over a 5-month period (period of available flow of West Fork Dairy Creek).

Project Components

To capture and treat available surface water from the West Fork Dairy Creek at the design capacity required by the City (250 gpm) with a surface intake system and water treatment plant would need to be constructed. The design of such an appropriation system is considered preliminary.

- Design and Permitting;
- WTP (250 gpm);
- Conveyance Pipeline (12-inch, 5,000 ft); and
- Land.

Estimated Cost

- $4,440,000

5.4.4 NEW WATER SUPPLY – WELL 3 SOUTHWEST OF BANKS

As identified in Section 5.2, a new water right could potentially be acquired in the southwest portion of the Banks ASR study area to aid in meeting the City's target ASR volume. This would require construction of new infrastructure to appropriate groundwater and convey the extracted groundwater to the City's water supply system.

Project Components

Considering the hydrogeologic conceptual site model for the southwest portion of the Banks ASR study area and typical basalt production well construction considerations, the following components are accounted for in the estimated cost of a new water supply well. The conceptual well design is presented on Figure 27:

- Purchase of Land;
- Total depth of approximately 1,000 feet based on the projected depth of the CRBG unit in the southwest portion of the Banks ASR study area (Figure 11). A refined determination of total depth would be a function of observed water bearing zone depths and productivity following the completion of further hydrogeological exploration;
- Steel casing completed to a depth approximately 50 feet past the interface of the CRBG unit, with a diameter of 16 to 20-inches to accommodate necessary equipment (pumps, transducers, etc.);
- Submersible pump capable of sustaining required flowrates (300-500 gpm), and a transducer and flow meter synchronized with a data logger to accurately measure changes in water levels and flow rates. Additionally, telemetric controls to allow pumping adjustments to be made remotely; and
- Conveyance pipeline (12-inch, 8,000 ft).

Estimated Cost

- $2,895,200

5.4.5 NEW SOURCE WATER SUPPLY - REGIONAL WATER PROVIDER

The City attended a preliminary planning meeting with the JWC to assess the potential cost of developing an interconnection with the JWC as a wholesale customer. Their estimate includes a system development charge (SDC) prorate by JWC that would be required for initial interconnection.

Project Components

- Conveyance pipeline (12-inch, 40,000 ft)
- JWC SDC (2,000 – ¾ connections at $3,500 each)

Estimated Cost

- $14,776,000

6 RECOMMENDATIONS FOR ASR IMPLEMENTATION

This section presents a plan for water system and ASR development based on the finding of this ASR Feasibility Study. This plan includes development of new drinking water sources and a phased approach to ASR.

Three new source water supplies were identified to aid in meeting the City's target ASR volume of 41.6 MGY. Adding new source water supplies will increase the total capacity of the City's water supply, reducing the City's reliance on surface water supplies (Green Mountain Springs) and potentially allowing those surface water supplies to be utilized for ASR source water or to enhance downstream ecological surface water flows.

Based on CwM's evaluation of future annual water supply deficits and the path to developing and ASR, the City of Banks must first develop available source water to help meet the projected water supply demands (2050 average annual deficit of 17.2 MGY), then evaluate excess winter/wet season water supplies that could be made available for ASR. CwM recommends the following water development scenarios that lead to a robust ASR system:

6.1 Phase I – New Source Water Development

Quail Valley Well, ASR Pilot Testing Plan, and Limited License Application: A Pilot Testing program is required as part of the application process for an ASR Limited License. Assuming the City reaches an agreement to acquire the Quail Valley Well, CwM recommends that the Quail Valley Well be the focus of the Pilot Test. This will allow the City to proceed with the redevelopment of the Quail Valley Well and interconnect the well to the City's water system, while preparing it for ASR, and starting the ASR Pilot Testing Program required by the ASR Limited License without disruption of the current water supply regime. The Quail Valley well will also be added to the Well 2 water right, expanding the pumping capacity from Well 2 and Quail Valley to 448 gpm.

Redevelop Well 2 for ASR: Assuming the Pilot Test is successful at the Quail Valley Well, proceed to redevelop the wellhead at Well 2 and begin pre-design of water treatment plant.

6.2 Phase II – ASR Implementation

Develop a WTP at the West Fork of Dairy Creek: Develop a WTP at the West Fork of Dairy Creek to divert winter water supply will provide a redundant supply for emergency or ecological enhancement scenarios. The WTP will divert most of its water supply during the winter months for ASR operations at Quail Valley Well and the ASR modified Well 2. This will allow the West Fork of Dairy Creek WTP to meet the target ASR volume of 41.6 MGY (which accounts for the projected 2050 average annual water supply deficit of 17.2 MG) by utilizing winter water diversions that will be stored in and recovered from Well 2 and the Quail Valley Well.

Consolidation of the Green Mountain Springs water rights down stream to this location could also allow the city to ultimately retire the existing water treatment and spring collection facility in the Seller's Road study area. This would allow the Green Mountain Spring summer flow to stay in-stream until it reached the location of the new WTP on West Dairy Creek, providing an ecological benefit to the upper reaches of West Dairy Creek. The legal feasibility of such a water right transfer has not been evaluated in this study.

6.3 Phase III – ASR Expansion

Develop Southwest Well 3: Exploration and development of a deep basalt well southwest of the City would significantly expand the capability of the ASR system to meet summer time demands and provide redundant capacity. Under an ASR Limited License this well could be developed for ASR operations without a new water right. The City may choose to seek a new water right, but new groundwater rights in the basalt aquifers have become more difficult to obtain and developing a new water right is uncertain. Implementation of Well 3 as an ASR expansion will also reduce the cost of the construction estimate because the pipeline would run to the new WTP and not the full distance to the City's existing infrastructure. However, the original cost estimate is used here as a place holder.

6.4 ASR Implementation and New Source Water Supply Cost Estimate

Based on the planning level cost estimates presented in Section 5 the cost estimate for the recommend scenario is presented in three phases.

Phase I – New Source Water Development

- Hydrogeologic Study, Pilot Testing, Limited License and Water Rights Transfer - $ 90,000
- Redevelop Quail Valley Well and Pipeline - $1,502,000

Phase I Cost - $1,592,000

Phase II – ASR Implementation

- Reconfigure Well 2 for ASR operations - $310,000
- West Dairy Creek Water Treatment Plant - $4,440,000

Phase II Cost -$4,750,000

Phase III – ASR Expansion

- South West Well 3 - $2,895,200

The total cost estimate for new source water and implementation of ASR is approximately $9,237,200.

7 CONCLUSIONS

CwM prepared this feasibility study for the City of Banks to evaluate the potential feasibility of an ASR system to meet the projected 2050 water supply demands of the City. A conceptual model for hydrogeology and applicable environmental conditions was developed for the Sellers Road and Banks ASR study areas using available data and professional experience. The conceptual models for each study area were utilized to identify, develop, and evaluate multiple ASR system component scenarios.

Results of the ASR feasibility evaluation show that ASR is feasible for the City in terms of aquifer storage capacity (45.1 MGY), recovery of stored water (75.2 to 116.6 MGY), existing infrastructure compatibility, and permitting. However, the feasibility of operating an ASR system is ultimately limited by the City's existing source water supplies, as no existing source water supplies were found to have water available for use in an ASR system.

The City's projected 2050 average annual water supply deficit (17.2 MG) precludes using the City's existing water source water supplies (Green Mountain Springs certified water rights) as source water for an ASR system. Before the City can consider using ASR as a water management tool, a new source water supply must be developed.

The recommended option for increasing the City's water supply and implementing ASR is estimated to cost approximately $9.2 million dollars and can be constructed in three phases with increased water supply capacity brought on-line in Phase I for a cost of $1,592,000.

The option to connect with a regional water provider was also evaluated based on information from the JWC. Construction and SDC costs for that project were estimated to be approximately $14.8 million dollars.

8 IDENTIFIED DATA GAPS AND STUDY LIMITATIONS

In the process of conducting this ASR Feasibility Study for the City of Banks, instances arose in which the available and existing data was insufficient or incomplete. CwM made all reasonable efforts to address these data gaps and has fully addressed the agreed scope of work. Nevertheless, in the interest of the scope and schedule of the project, not all gaps in information could be addressed at this time. The following data gaps and study limitations were identified during evaluation of ASR feasibility for the City:

8.1.1 AQUIFER STORAGE

Data gaps and limitations were identified during evaluation of aquifer storage, as discussed below:

- Modeling of surface seepage impacts is primarily based on outdated water level measurements. It is likely that modeled surface seepage occurrences are conservative projections as current static water levels are lower than those at the time of construction.
- Aquifer thickness based on water bearing thicknesses of Well 2 only.

8.1.2 STORED WATER RECOVERY

Data gaps and limitations were identified during evaluation of aquifer recovery, as discussed below:

- Seasonal hydraulic gradient variability, influence of pumping from local wells, and groundwater flow barriers/preferential pathways not accounted for in modeling of recoverability.
- Aquifer thickness based on water bearing thicknesses of Well 2 only.

8.1.3 ASR SOURCE WATER

Data gaps and limitations were identified during evaluation of source water supplies, as discussed below:

- There is a moderate to high degree of uncertainty regarding the hydrogeologic characterization of the Sellers Road study area. Modeled yields from transferring surface water rights to groundwater should be considered order-of-magnitude estimates based on the preliminary hydrogeologic conceptual model created from the limited available data.

8.1.4 EXISTING INFRASTRUCTURE ASR COMPATIBILITY

Data gaps and limitations were identified during evaluation of existing infrastructure compatibility, as discussed below:

- Utilizing the Quail Valley Well for recovery or other ASR functions would require a Memorandum of Understanding (MOU) between the City and Quail Valley Golf Course, potentially altering the feasibility of using the Quail Valley Well.

8.1.5 NEW SOURCE WATER SUPPLIES

Data gaps and limitations were identified during evaluation of new source water supplies, as discussed below:

- The hydrogeologic characterization of the southwest portion of the Banks ASR study area is similarly limited and has a high degree of uncertainty. Estimated yields from developing a new groundwater source water supply in this area should be considered order-of-magnitude estimates founded on data from the production wells in the northern portion of the Banks ASR study area. Additionally, the water

quality and associated compatibility of groundwater from this area is not known; hence it was assumed the water quality is equivalent to that of the groundwater quality of the production wells.

- Water quality of the West Fork Dairy Creek is very limited and insufficient to form a basis of water quality compatibility assessment.
- The feasibility of procuring water from a regional provider for ASR development requires further discussion with regional providers (JWC) to refine water availability, water source selection, water quality compatibility, and conveyance system design.
- Compatibility of water treatment systems for ASR utilization determined based on existing water quality data. Lack of water quality data from source water scenarios (surface water from West Fork Dairy Creek or a regional provider) may alter feasibility and compatibility of water treatment systems.

8.1.6 ASR SYSTEM COSTS

Data gaps and limitations were identified during the estimation of ASR system costs, as discussed below:

- Estimated costs associated with construction of water supply options will need to be refined during engineering predesign. All estimates of cost are planning level estimate and may range from 20% less to 50% more depending on design choices selected during the engineering predesign.

9 REFERENCES

AWWA, 2005. Water Conservation Planning Programs – a Planning Manual, First Edition. American Water Works Association Research Foundation. 2005.

AWWA, 2008. Design, Operation, and Maintenance for Sustainable Underground Storage Facilities. American Water Works Association Research Foundation. 2008.

Camp, V.E., 1982. Columbia River Basalt in Idaho; Physical and Chemical Characteristics, Flow Disribution, and Tectonic Implications. Idaho Bureau of Mines and Geology Bulletin 26. Page 55-75. 1982.

Cooper, R.M., 2002. Determining Surface Water Availability in Oregon. State of Oregon Water Resources Department. Open File Report SW 02-002. Salem, Oregon. June 2002.

Dingman, S.L. 2002. Physical Hydrology, Second Edition. Prentice Hall. 2002.

DOGAMI, 1998. Geologic Map of the Northern Willamette Valley, Clackamas, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill Counties, Oregon. Oregon Department of Geology and Mineral Industries. 1998.

Gannett, M.W. and Caldwell, R.R. 1998. Geologic Framework of the Willamette Lowland Aquifer System, Oregon and Washington. US Department of the Interior & US Geologic Survey

Golder, 2008. Analysis of Existing Pumping Test Data From City of Banks Production Wells. Golder Associates Inc. February 2008.

Golder, 2001. City of Tigard ASR Geochemical Evaluation. Memorandum included in Phase I – ASR Feasibility Report prepared for the City of Tigard. Golder Associates Inc. 2001.

Golder, 2010. City of Banks Water Management and Conservation Plan. Golder Associates Inc. and Kennedy/Jenks Consultants. October 2010.

Grubb, Stuart, Yang, Jeffrey, 199. Analytical Solutions for Determination of Non-Steady-State and Steady-State Capture Zones. Blackwell Publishing Ltd. 1993.

HYDRUS, 2014. HYDRUS 2D Version 2.04. PC-Progress. September 2014.

KJC, 2011. City of Banks Water System Master Plan Amended November 2011. Kennedy/Jenks Consultants. November 2011.

OWRD 2014. A Proposed "Percent of Flow" Approach for Water Storage Projects in Oregon. Senate Bill 839 Science Subgroup Report. February 1, 2014.

Peel, M. C., Finlayson, B. L., and McMahon, T. A. 2007. Updated world map of the Köppen–Geiger climate classification. Hydrologic Earth Systems Sciences. 11: 1633–1644.

Proehl, Risa S., 2017. Certificate of Population Enumerations and Estimates of Oregon Counties and Incorporated Cities: Annexations and Revised Populations Supplement 1. Portland State University Population Research Center. June 6, 2017.

USGS, 1965. Geology and Groundwater of the Tualatin Valley Oregon, Geological Survey Water-Supply Paper 1697. United States Department of the Interior, United States Geological Survey. 1965.

USGS, 2017a. USGS StreamStats, version 3. United States Department of the Interior, United States Geological Survey. Accessed October 2, 2017.

USGS, 2017b. PHREEQC (Version 3.3.12) – A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. United States Department of the Interior, United States Geological Survey. May 10, 2017.

WHO, 2003. Contaminants in Drinking Water: Background document for development of WHO Guidelines for Drinking Water Quality, 2nd Edition Volume 2. World Health Organization. 2003.

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

FIGURES

FIGURES

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Figure 27 Southwest Banks ASR study area New Well Conceptual Design

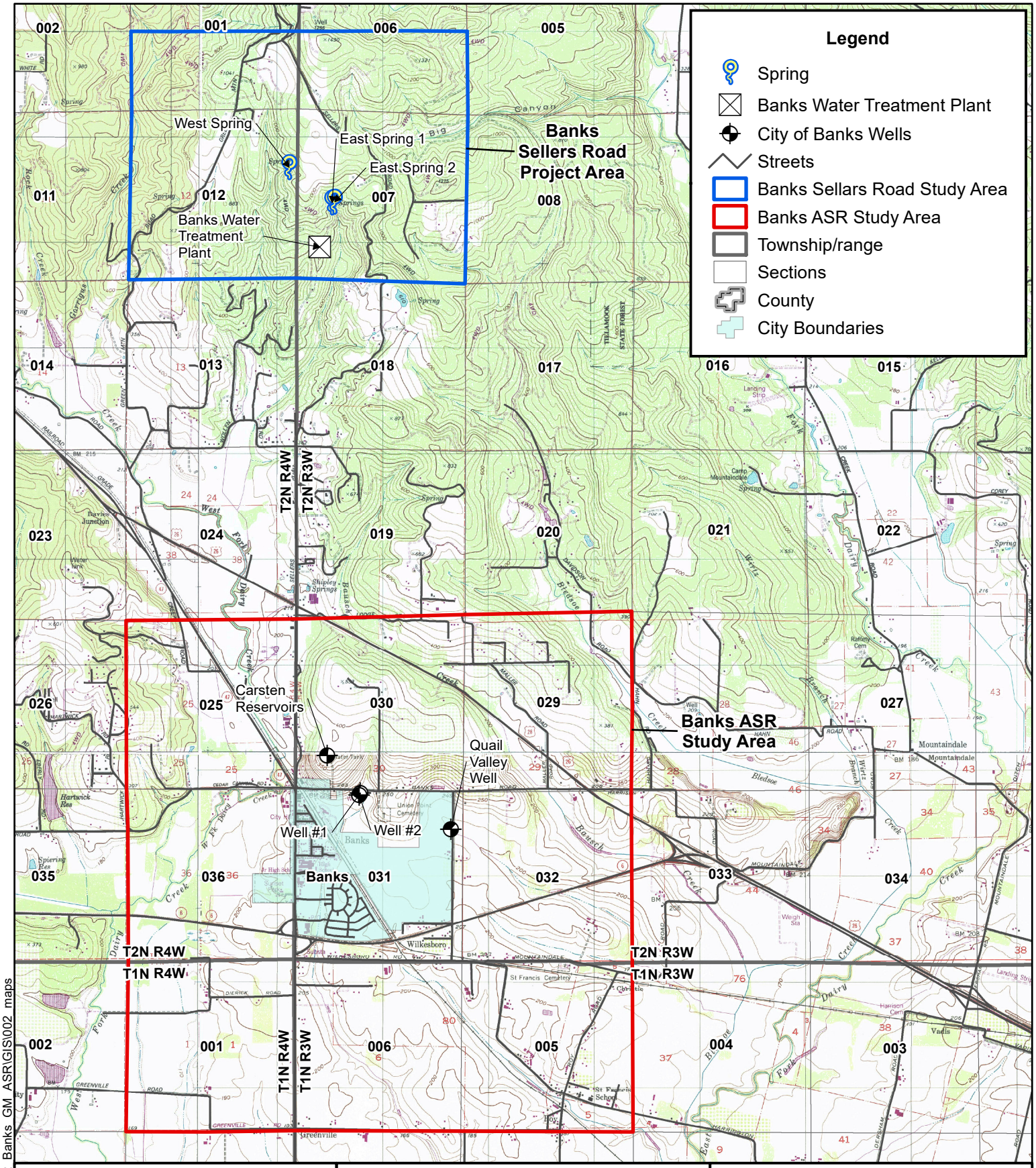

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FIGURE 1
Sellars Road and Banks Green Mountain ASR Green Mountain Study Area

No.	Date	By	Revisions
1	10/18/17	RMS	DRAFT

N

2,000 0 2,000 4,000 ft

1 inch = 4,000 ft

Proj #: 1501002; Banks Green Mountain ASR
City of Banks
13680 NW Main Street
Banks, OR 97106

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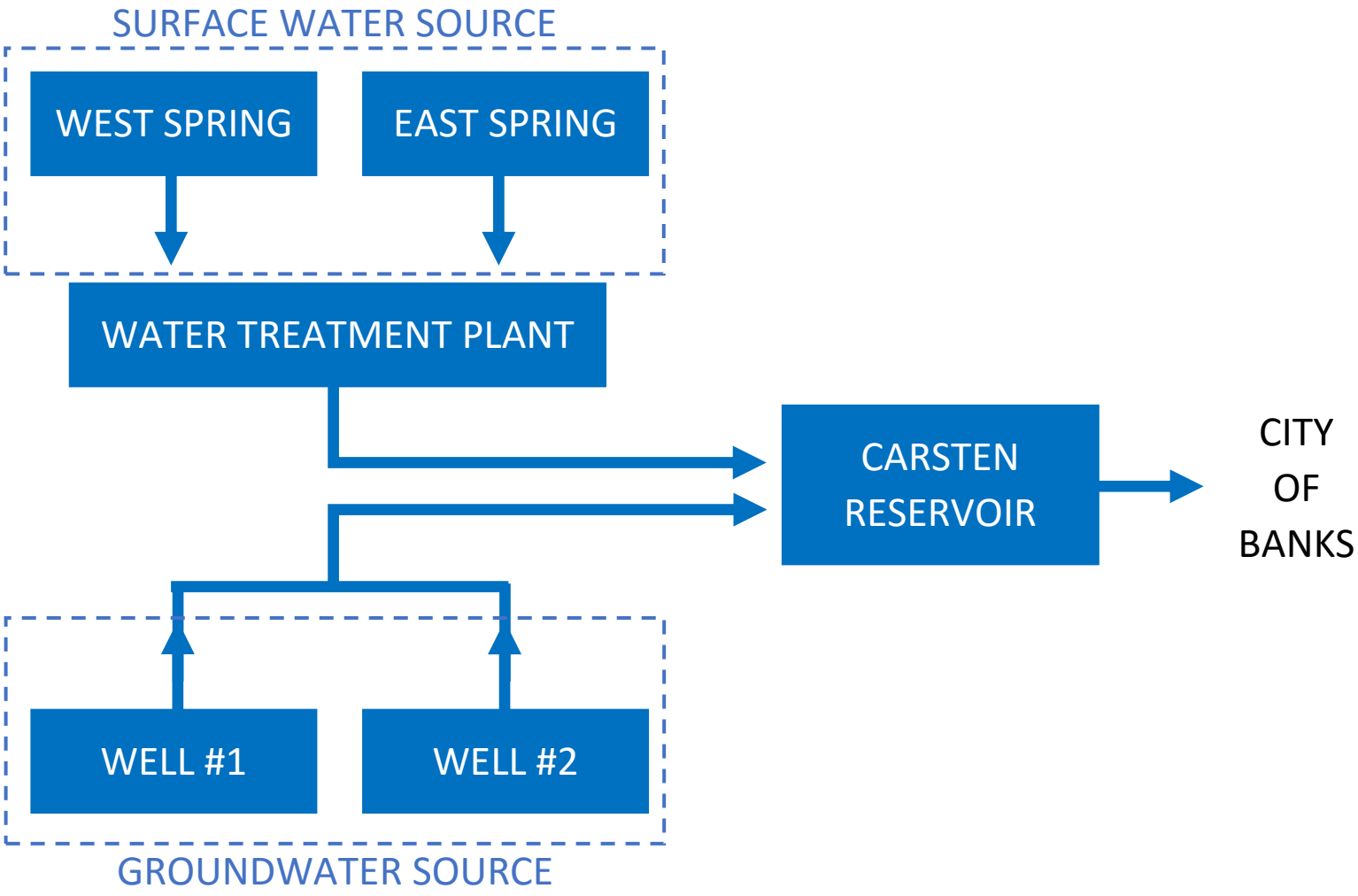
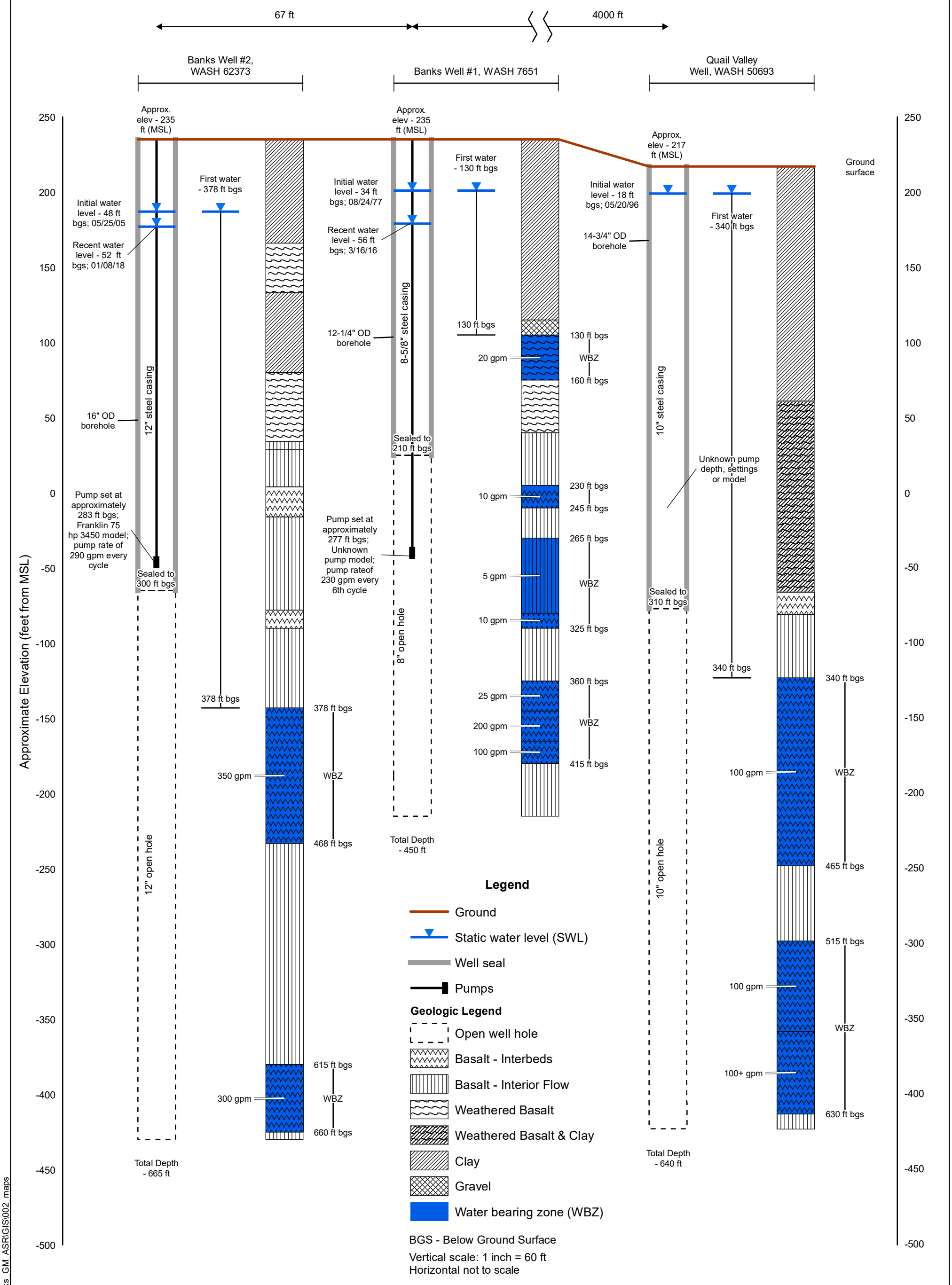
Figure 2. Conceptual Depiction of Banks Water System





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Geologic interpretation based on drillers logs.
No geochemistry of basalt available at the time of the study.

No.	Date	By	Revisions
1	11/01/17	RMS	DRAFT

FIGURE 3
Banks Production Wells As-Built Profiles and Geology

Proj#: 1501002
Banks Green Mountain ASR Project
City of Banks
13680 NW Main Street
Banks, OR 97106

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Figure 4. Green Mountain Springs Water Availability Summary

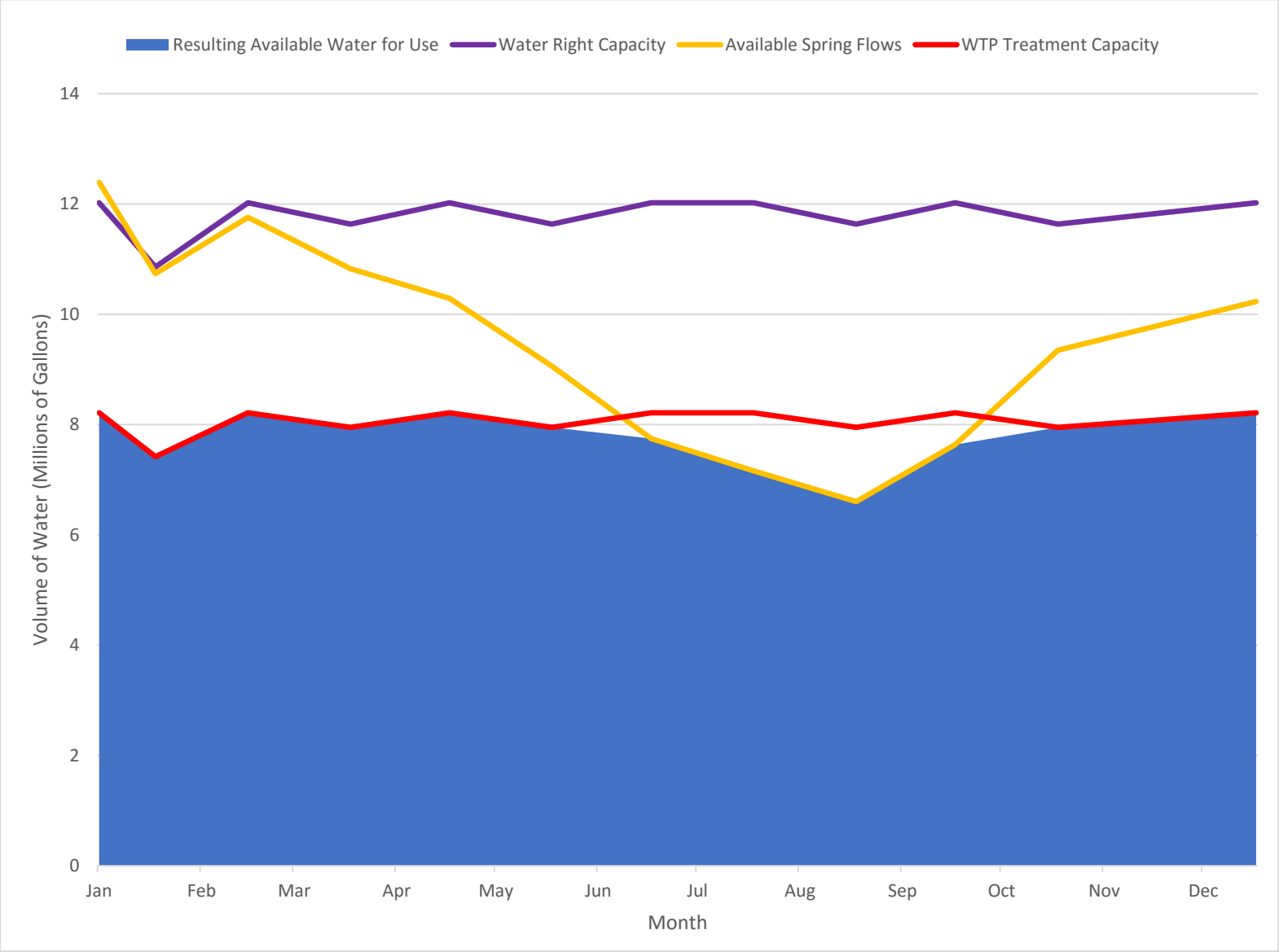


Figure 5. Banks Annual Existing Water Supply vs. Projected Demand

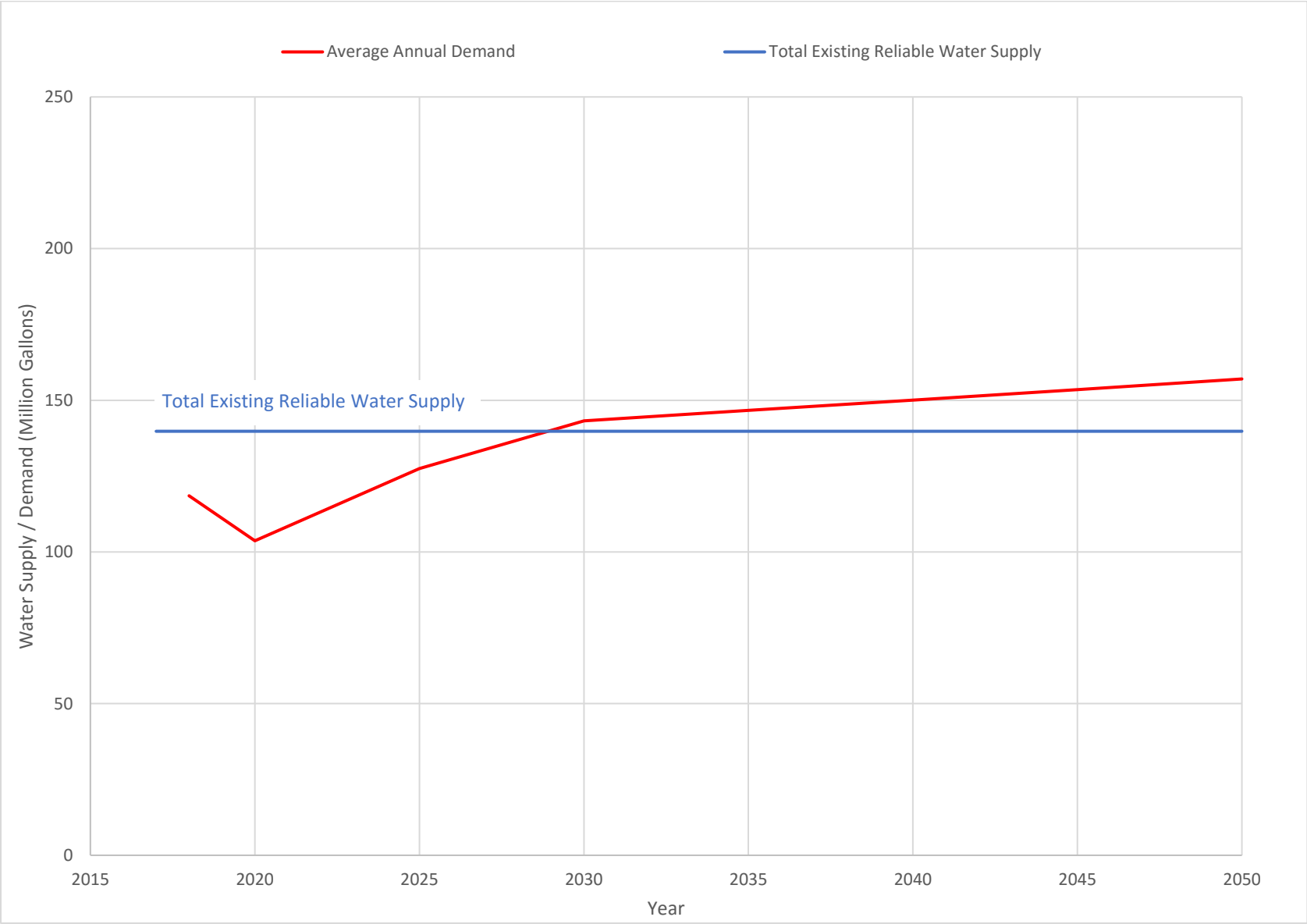


Figure 7. Banks Annual Existing Water Supply vs. Projected Demand – Emergency Scenarios

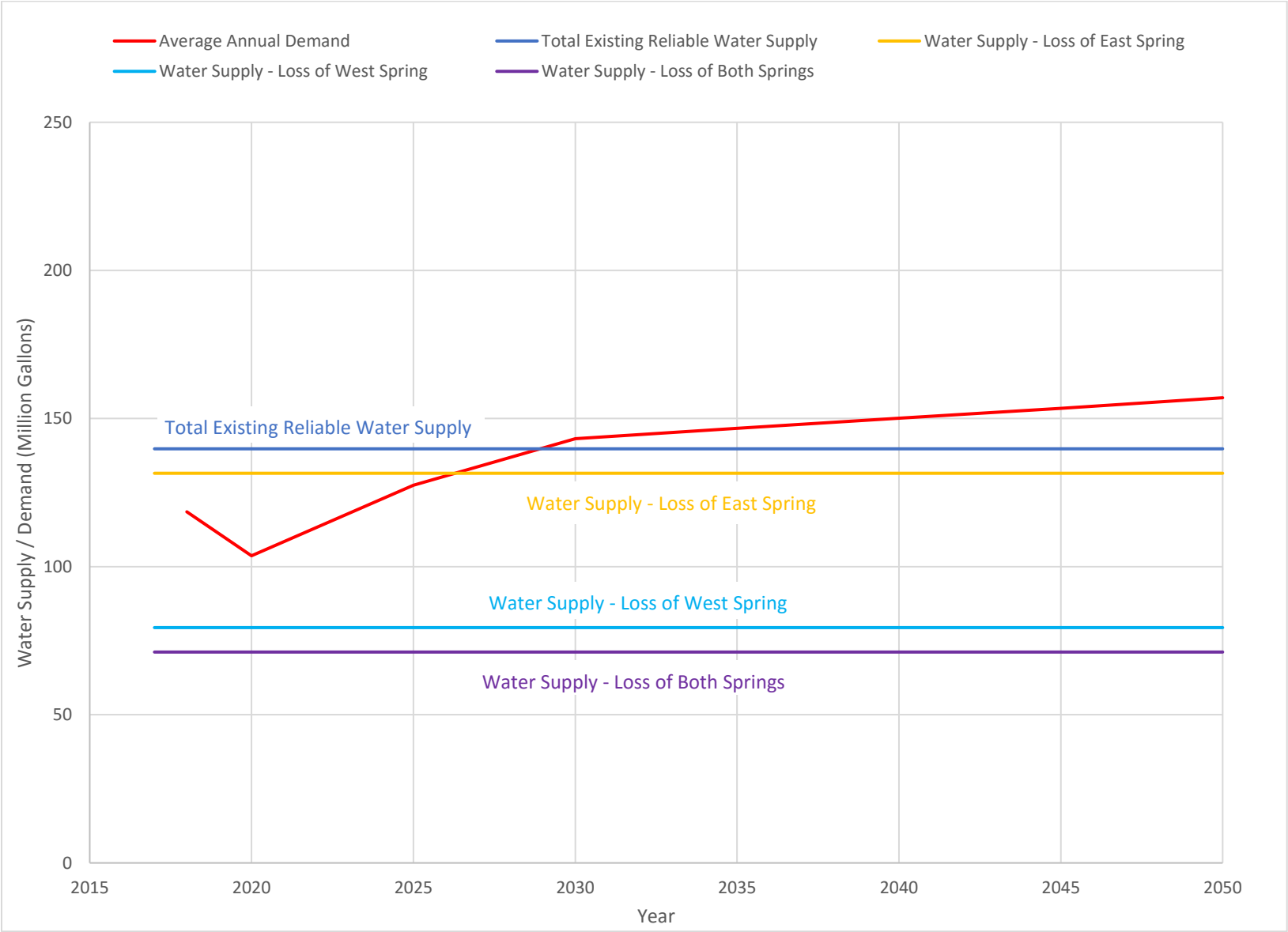


Figure 8. Banks Monthly Existing Water Supply vs. Projected Demand – Emergency Scenarios

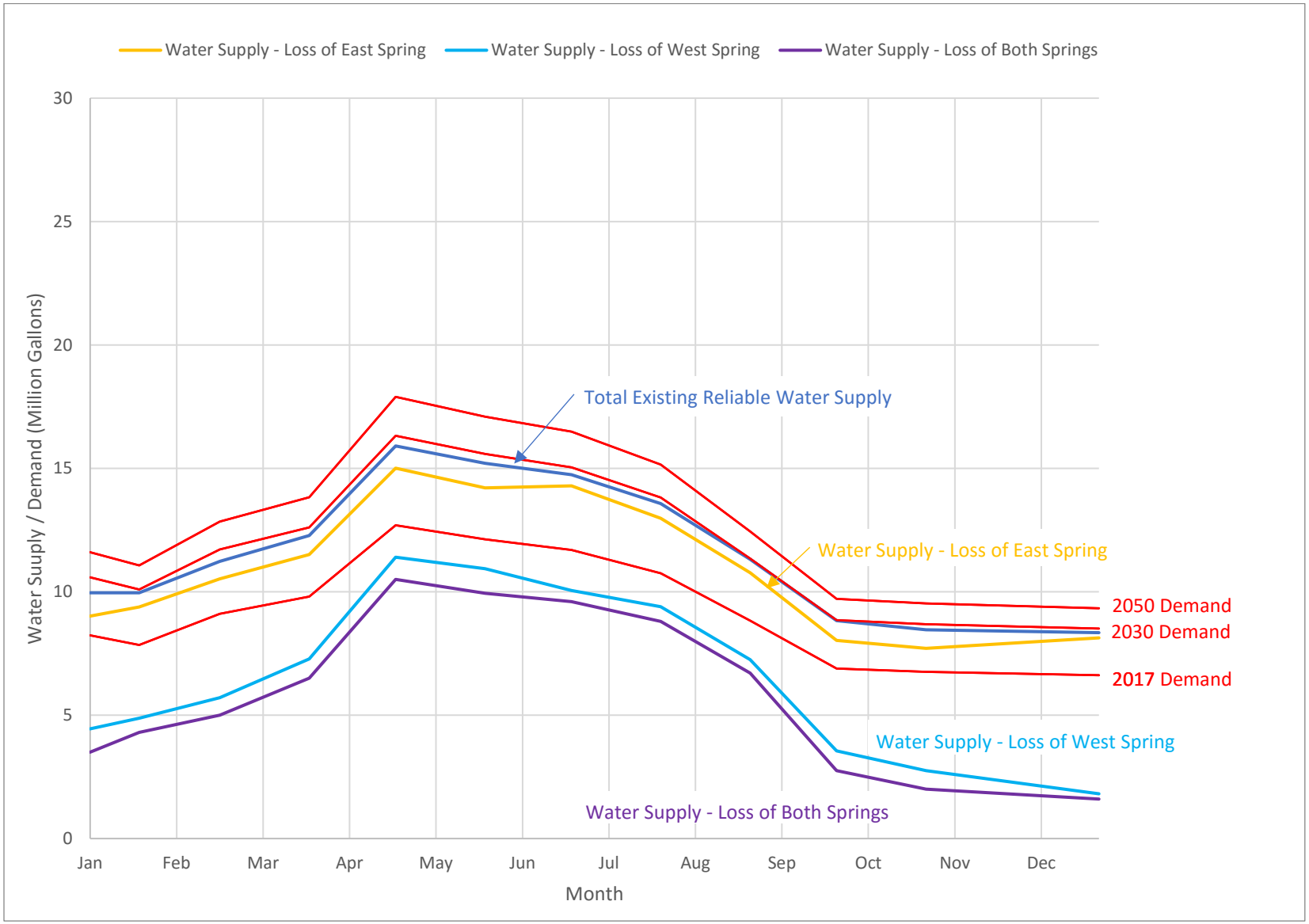
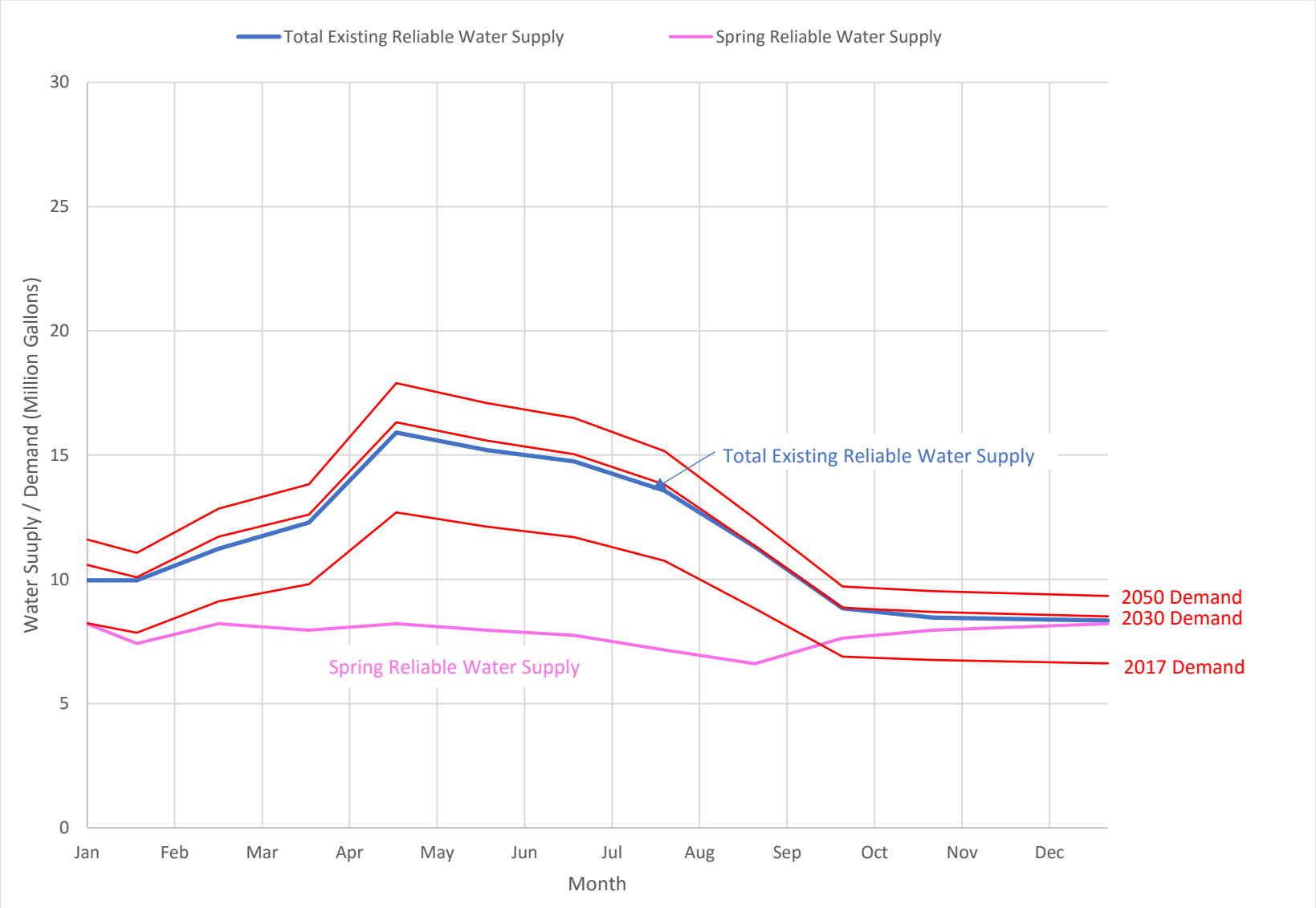


Figure 6. Banks Monthly Existing Water Supply vs. Projected Demand



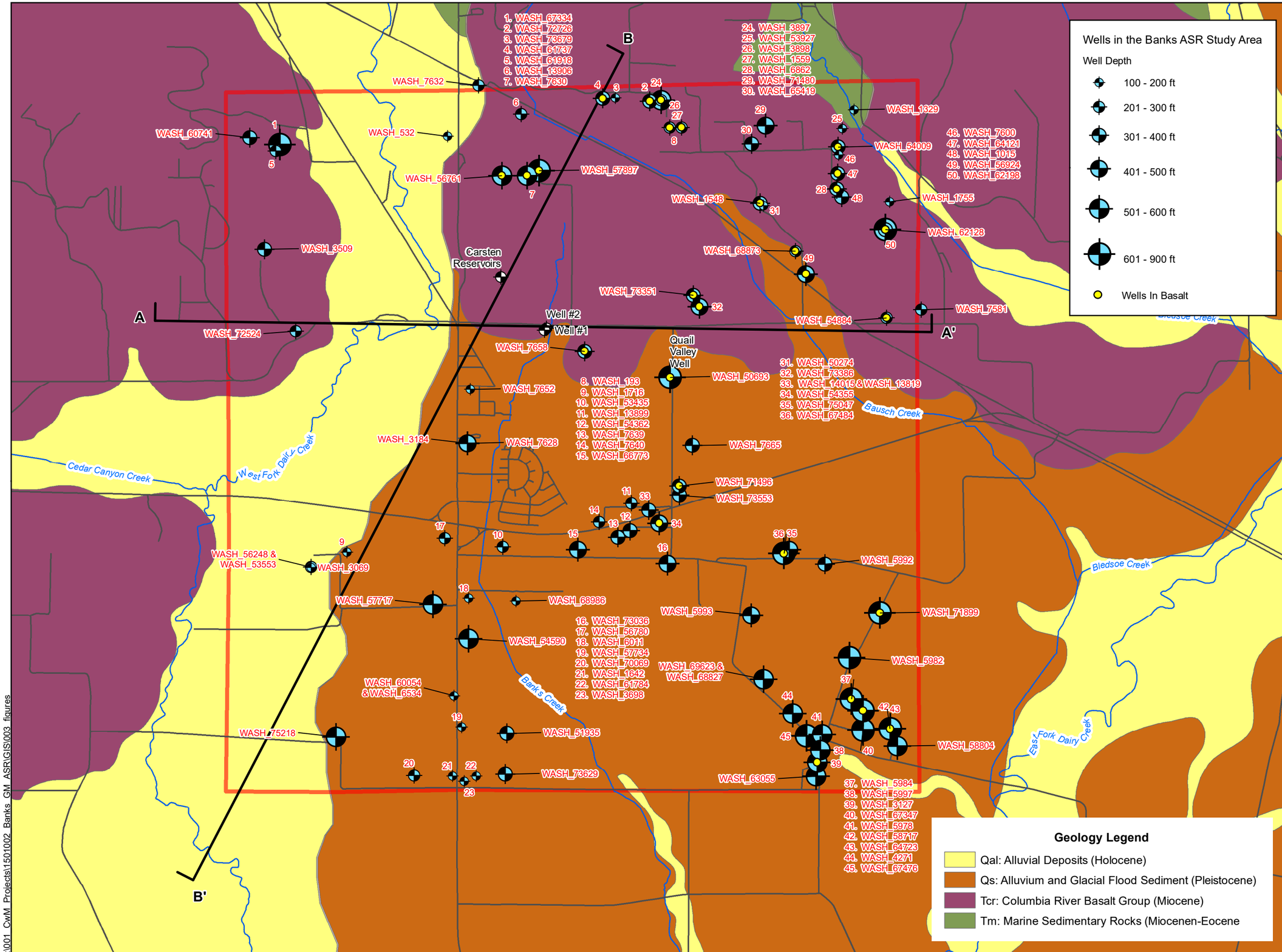
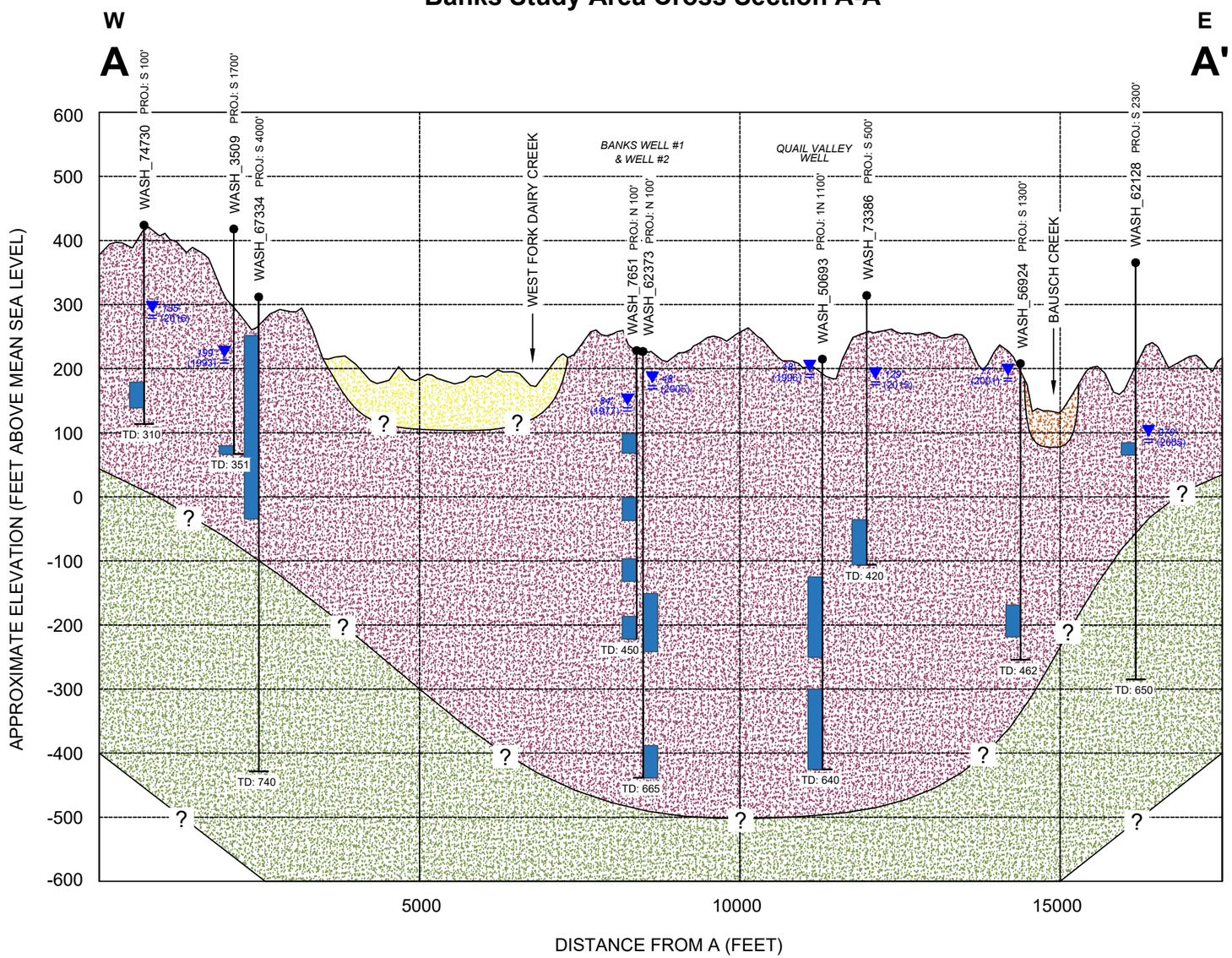


FIGURE 9
Banks ASR Study Area
Surficial Geology

Proj #: 1501002; Banks
Green Mountain ASR
City of Banks
13680 NW Main Street
Banks, OR 97106

Generalized Geologic Cross Section
Banks Study Area Cross Section A-A'



Geology Legend

- Qal: Alluvial Deposits (Holocene)
- Qs: Alluvial Deposits (Pleistocene)
- Tcr: Columbia River Basalt Group (Miocene)
- Tm: Marine Sedimentary Rocks (Miocene-Eocene)
- – ? – Contact Point Between Lithologic Units Approximated

Well Legend

- PROJ: S 120' — Distance and Direction Projected From Cross Section Transect Line
- Top of Well
- 65.0 — Static Groundwater Level at Time of Completion (Feet Below Ground Surface)
- TD=75' — Total Well Depth (Feet Below Ground Surface)

Stamp

This map is not intended to provide legal dimensions or property ownership lines.

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

0 100 Vertical Scale

0 1000 Horizontal Scale

Figure 10
Banks Study Area Cross Section A-A'

Project #: 1501002
Banks Green Mountain ASR

City of Banks
13680 NW Main St.
Banks, OR 97106

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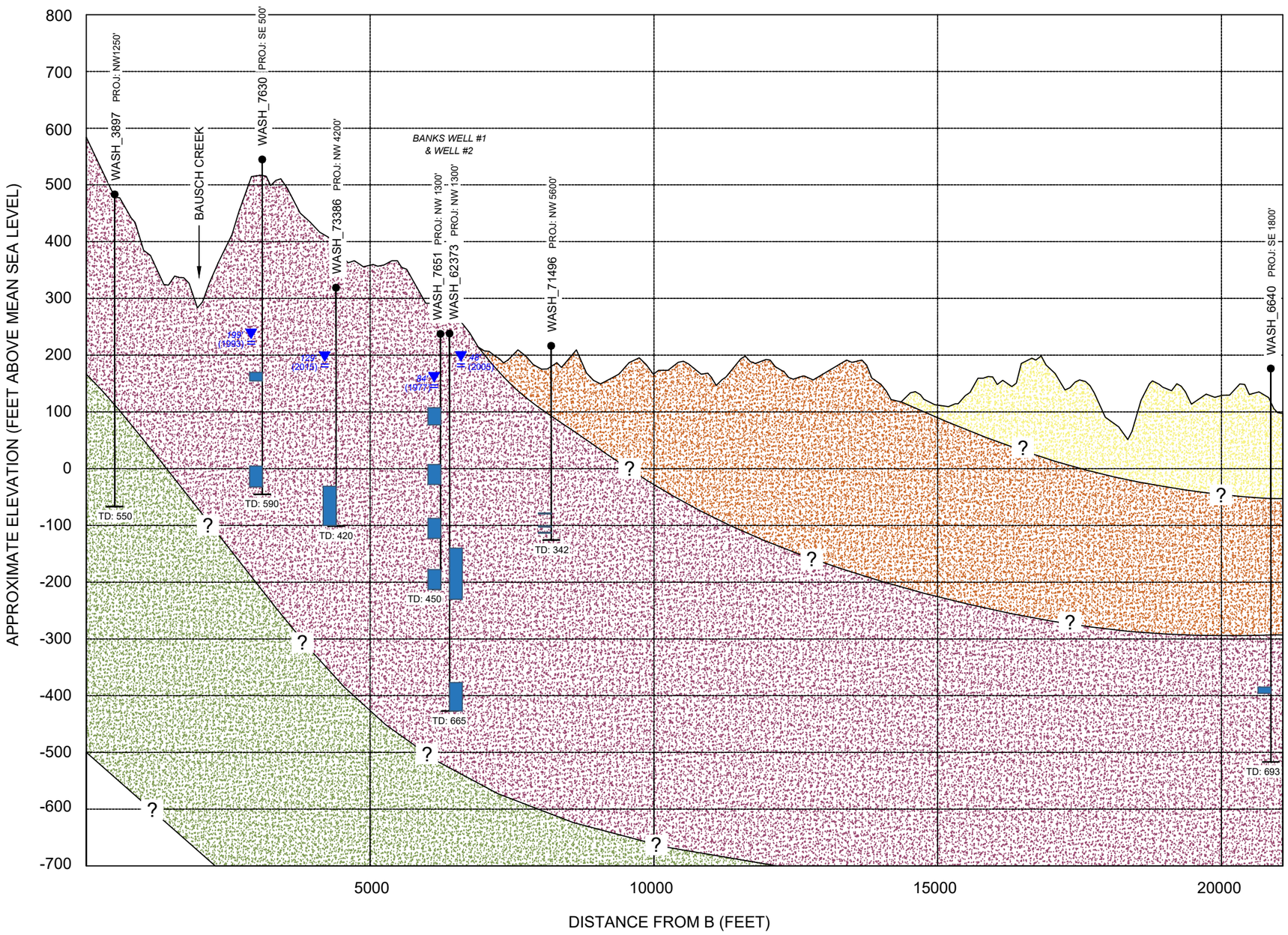
Generalized Geologic Cross Section
Banks Study Area Cross Section B-B'



Geology Legend

- Qal: Alluvial Deposits (Holocene)
- Qs: Alluvial Deposits (Pleistocene)
- Tcr: Columbia River Basalt Group (Miocene)
- Tm: Marine Sedimentary Rocks (Miocene-Eocene)
- - ? - Contact Point Between Lithologic Units Approximated

Well Legend

- PROJ: S 120' — Distance and Direction Projected From Cross Section Transect Line
- Top of Well
- 65.0 — Static Groundwater Level at Time of Completion (Feet Below Ground Surface)
- TD=75' — Total Well Depth (Feet Below Ground Surface)

Stamp

This map is not intended to provide legal dimensions or property ownership lines.

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

0 — 100 Vertical Scale

0 — 1000 Horizontal Scale

Figure 11
Banks Study Area Cross Section B-B'

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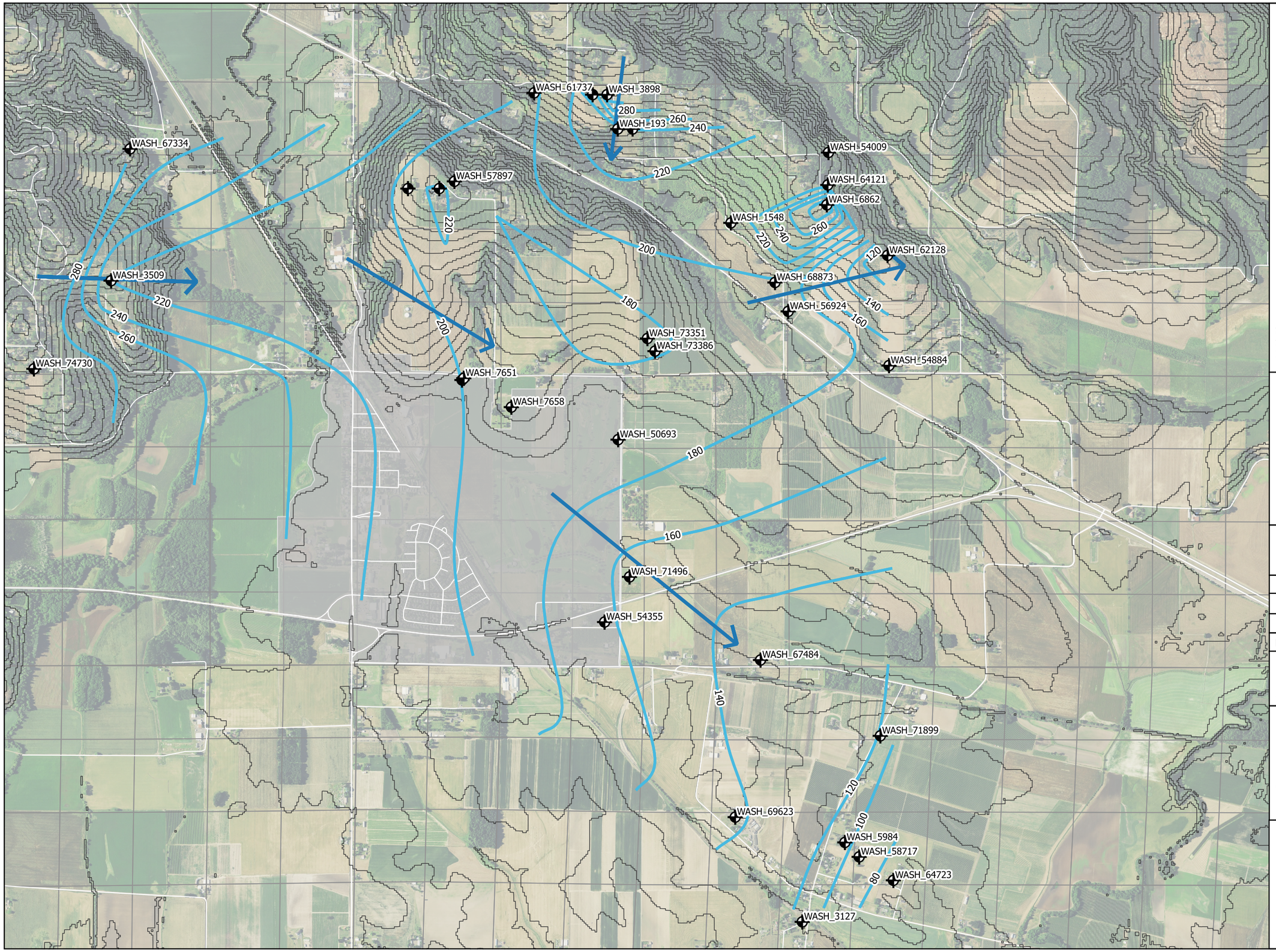
Portland, Oregon 97214
(503) 945-1326



Legend

- Approximate Groundwater Contour (20 feet)
- Approximate Groundwater Flow Direction (CRBG Basalt Aquifer)
- Basalt Well Location
- City of Banks UGB

Note: Groundwater contours generated from water levels at time of construction from any wells penetrating water bearing zones of the Columbia River Basalt Group

No.	Date	By	Revisions
1	9/16/2017	RMD	DRAFT

N

0 800 ft

FIGURE 12
Banks Study Area Groundwater Gradients

Proj #: 1501002
Banks Green Mountain ASR

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Banks, OR 97106

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Figure 13. City of Banks Production Wells Static Water Level Elevations 1977-2018

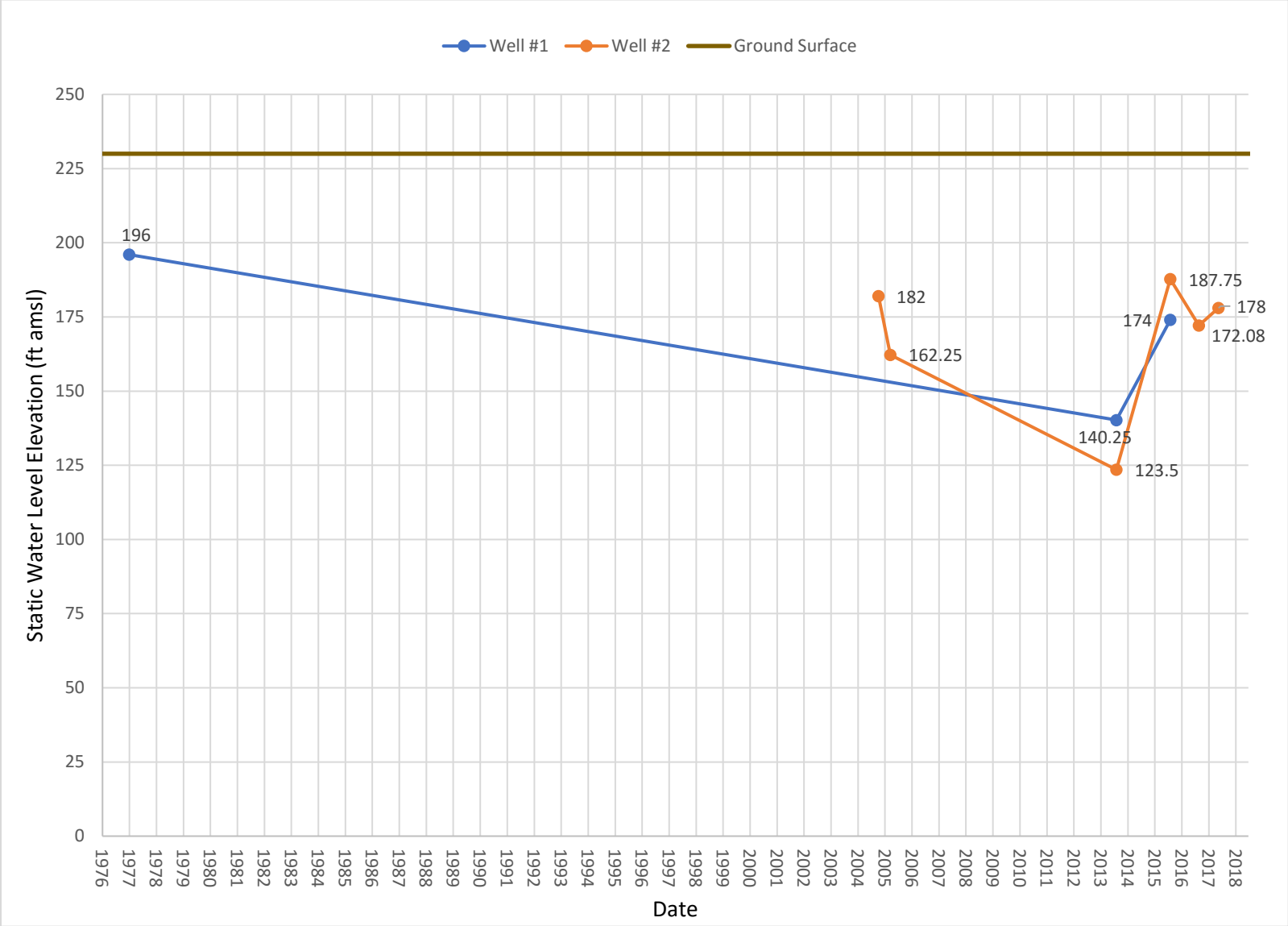
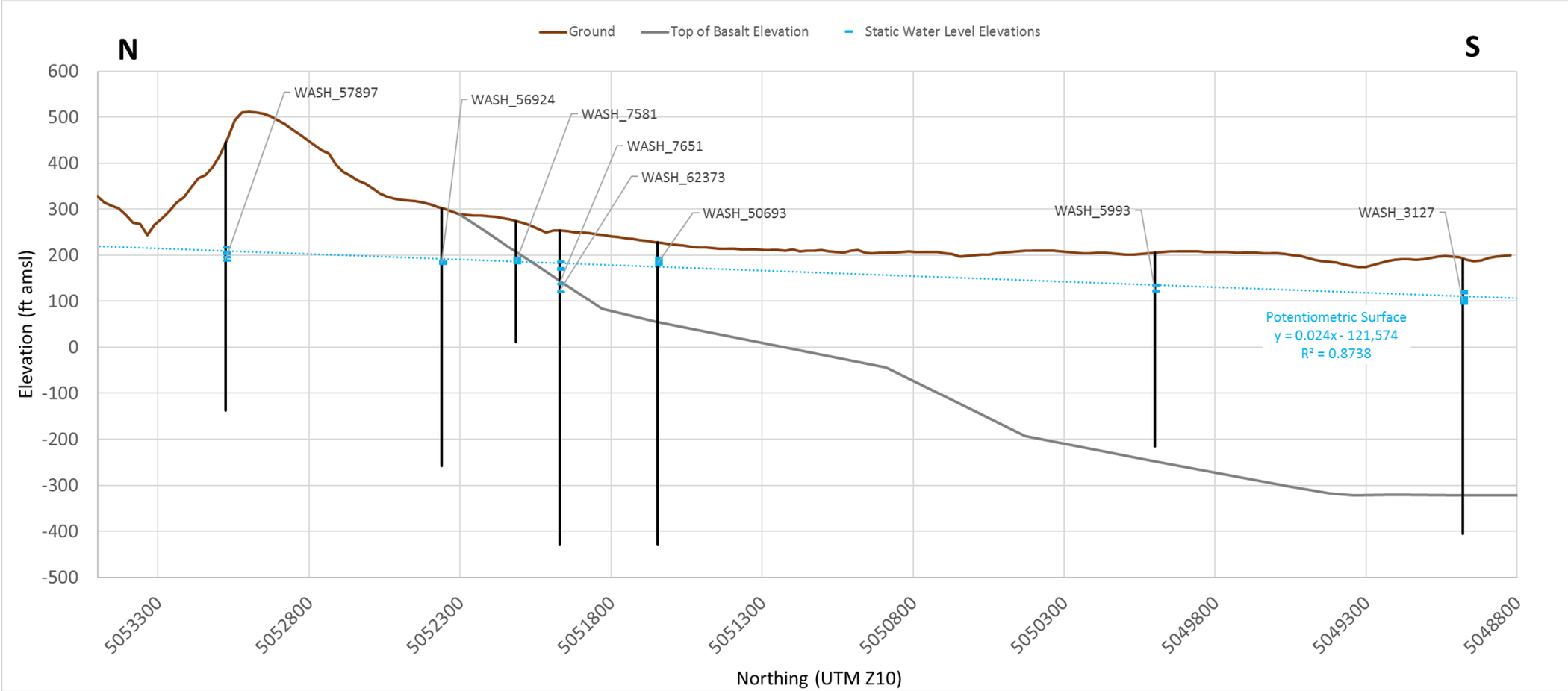
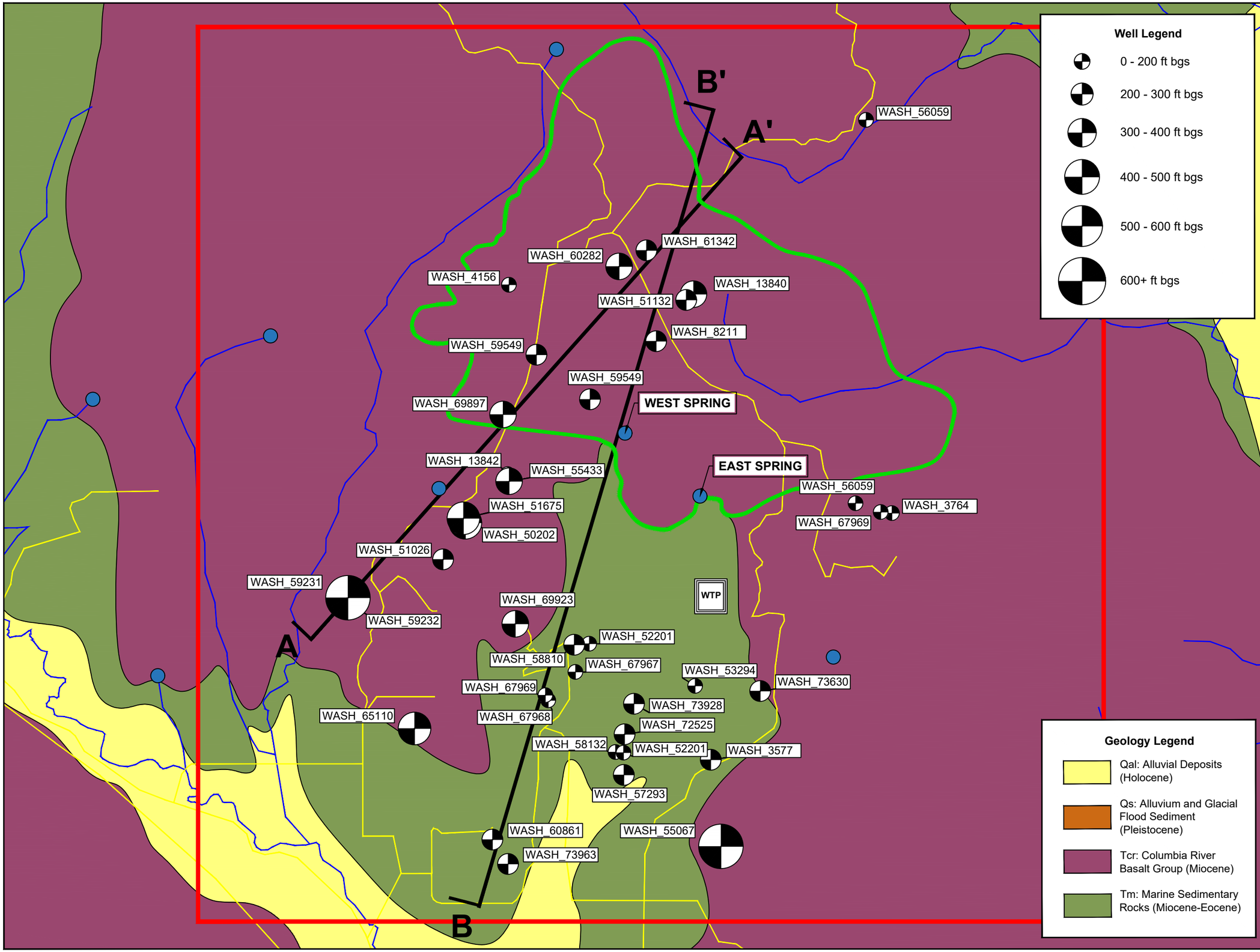


Figure 14. Banks ASR Study Area Static Water Levels and Potentiometric Surface





Well Legend

- 0 - 200 ft bgs
- 200 - 300 ft bgs
- 300 - 400 ft bgs
- 400 - 500 ft bgs
- 500 - 600 ft bgs
- 600+ ft bgs

Legend

- Boring / Well Location
- Sellers Road GM ASR Study Area
- Approximate East and West Spring Recharge Area
- Banks Water Treatment Plant
- Spring
- Road
- Streams / Creeks
- Cross Section Transect Line

Geology Legend

- Qal: Alluvial Deposits (Holocene)
- Qs: Alluvium and Glacial Flood Sediment (Pleistocene)
- Tcr: Columbia River Basalt Group (Miocene)
- Tm: Marine Sedimentary Rocks (Miocene-Eocene)

This map is not intended to provide legal dimensions or property ownership lines.

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

N

0 1800'

GRAPHIC SCALE

Figure 15
Sellers Road Study Area Surficial Geology

Project #: 1501002
Banks Green Mountain ASR

City of Banks
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Banks, OR 97106

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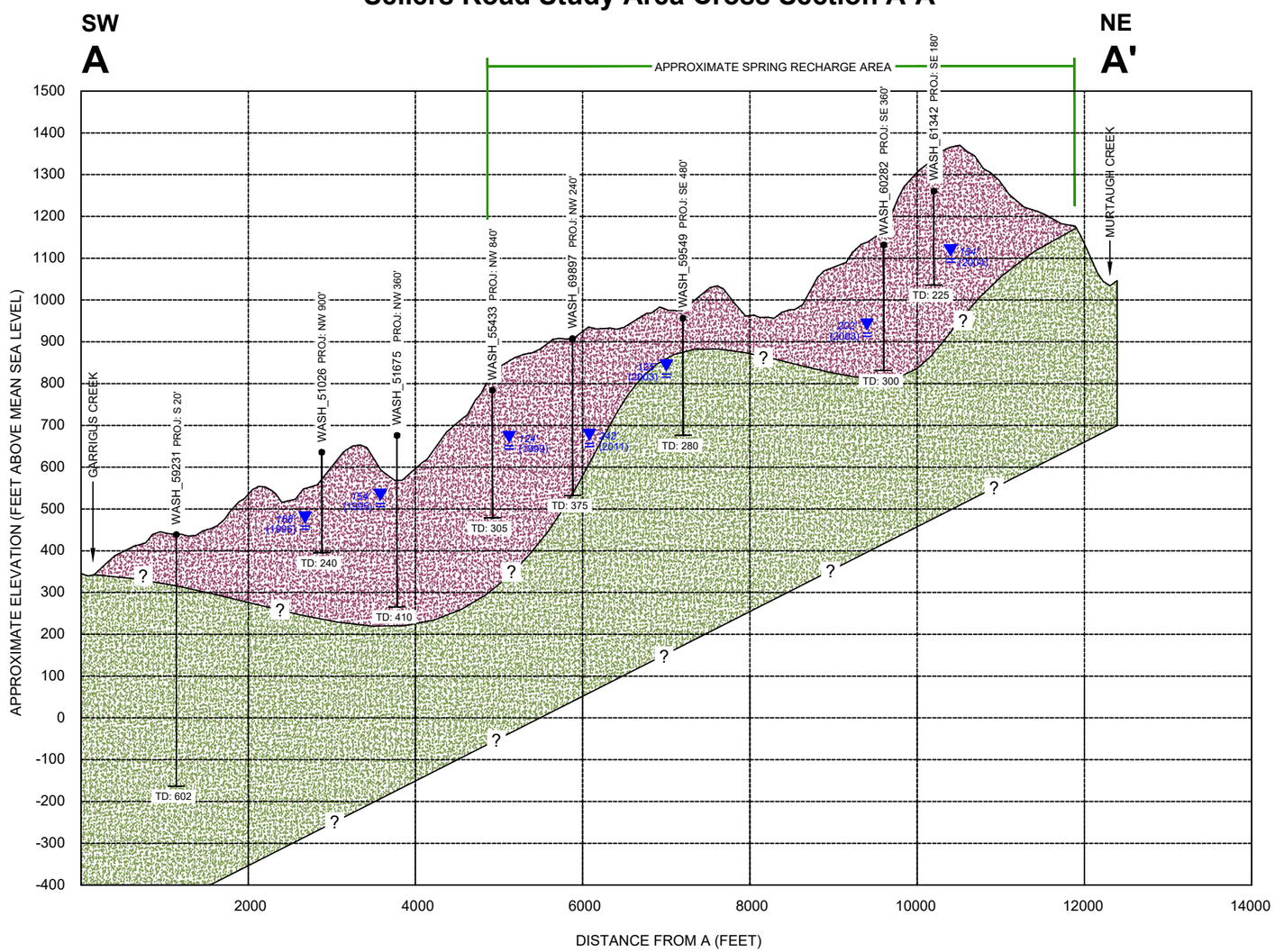
Generalized Geologic Cross Section
Sellers Road Study Area Cross Section A-A'



Well Legend

PROJ: S 120' — Distance and Direction Projected From Cross Section Transect Line

Top of Well

65.0 — Static Groundwater Level at Time of Construction (Feet Below Ground Surface)

TD=75' — Total Well Depth (Feet Below Ground Surface)

Geology Legend

Tcr: Columbia River Basalt Group (Miocene)

Tm: Marine Sedimentary Rocks (Miocene-Eocene)

- ? - Contact Point Between Lithologic Units Approximated

Stamp

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

Vertical Scale: 0 – 100

Horizontal Scale: 0 – 1000

Figure 16
Sellers Road Study Area Cross Section A-A'

Project #: 1501002
Banks Green Mountain ASR

City of Banks
13680 NW Main St.
Banks, OR 97106

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Complete Water Management

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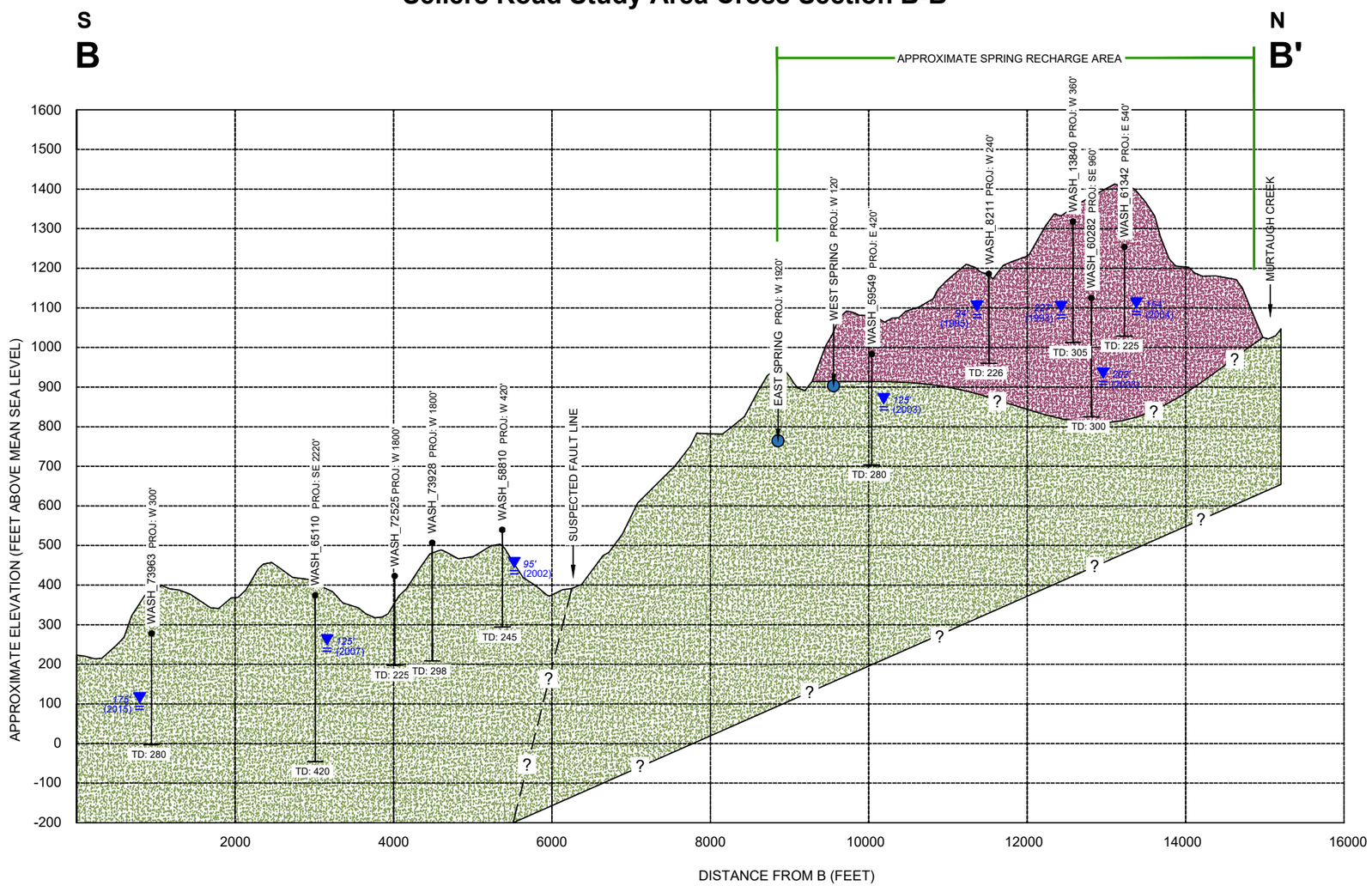
Generalized Geologic Cross Section
Sellers Road Study Area Cross Section B-B'



Well Legend

PROJ: S 120' — Distance and Direction Projected From Cross Section Transect Line

Top of Well

65.0 — Static Groundwater Level at Time of Construction (Feet Below Ground Surface)

TD=75' — Total Well Depth (Feet Below Ground Surface)

Stamp

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

0 100 Vertical Scale

0 1000 Horizontal Scale

Figure 17
Sellers Road Study Area Cross Section B-B'

Project #: 1501002
Banks Green Mountain ASR

City of Banks
13680 NW Main St.
Banks, OR 97106

Geology Legend

Tcr: Columbia River Basalt Group (Miocene)

Tm: Marine Sedimentary Rocks (Miocene-Eocene)

- ? - Contact Point Between Lithologic Units Approximated

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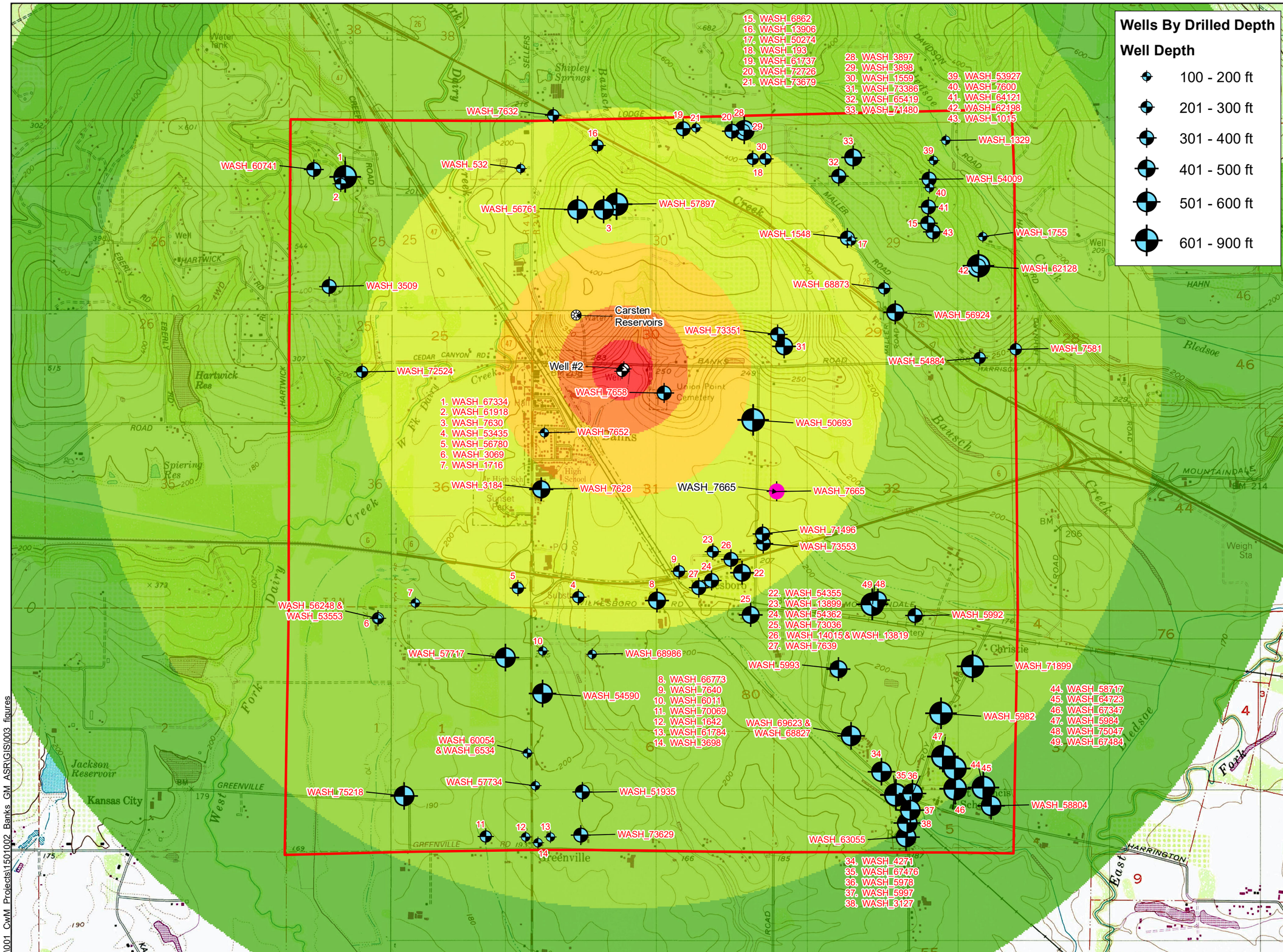
Wells By Drilled Depth
Well Depth
100 - 200 ft
201 - 300 ft
301 - 400 ft
401 - 500 ft
501 - 600 ft
601 - 900 ft
Legend
Potentially Impacted Wells
Carsten Reservoirs
Well
Banks Study Area
Projected Mounding
0 - 4 ft
4 - 8 ft
8 - 12 ft
12 - 16 ft
16 - 20 ft
> 20 ft
Carsten Reservoirs
Well #2
1. WASH_67334
2. WASH_61918
3. WASH_7630
4. WASH_53435
5. WASH_56780
6. WASH_3069
7. WASH_1716
8. WASH_66773
9. WASH_7640
10. WASH_6011
11. WASH_70069
12. WASH_1642
13. WASH_61784
14. WASH_3698
15. WASH_6862
16. WASH_13906
17. WASH_50274
18. WASH_193
19. WASH_61737
20. WASH_72726
21. WASH_73679
22. WASH_54355
23. WASH_13899
24. WASH_54362
25. WASH_73036
26. WASH_14015 & WASH_13819
27. WASH_7639
28. WASH_3897
29. WASH_3898
30. WASH_1559
31. WASH_73386
32. WASH_65419
33. WASH_71480
34. WASH_4271
35. WASH_67476
36. WASH_5978
37. WASH_5997
38. WASH_3127
39. WASH_53927
40. WASH_57600
41. WASH_64121
42. WASH_62198
43. WASH_1015
44. WASH_58717
45. WASH_64723
46. WASH_67347
47. WASH_5984
48. WASH_75047
49. WASH_67484
WASH_7632
WASH_60741
WASH_532
WASH_56761
WASH_57897
WASH_1548
WASH_3509
WASH_72524
WASH_7658
WASH_7652
WASH_3184
WASH_7628
WASH_7665
WASH_7665
WASH_50693
WASH_73351
WASH_68873
WASH_56924
WASH_54884
WASH_7581
WASH_62128
WASH_1755
WASH_54009
WASH_1329
WASH_71496
WASH_73553
WASH_5992
WASH_56248 &
WASH_53553
WASH_57717
WASH_68986
WASH_54590
WASH_5993
WASH_71899
WASH_69623 &
WASH_68827
WASH_5982
WASH_60054
& WASH_6534
WASH_75218
WASH_57734
WASH_51935
WASH_73629
WASH_63055
WASH_58804
Hartwick Res
Spiering Res
Jackson Reservoir
Kansas City
Greenville
Shipley Springs
Union Point Cemetery
Sunset Park
Christie
Bausch Creek
Bledsoe Creek
West Fork Dairy Creek
Notes:
Projected mounding impacts assuming six-month constant injection rate of 175 gpm at Well #2
This map is not intended to provide legal dimensions or property ownership lines.
1 | 10/26/17 | RMS | DRAFT
No. Date By Revisions
N
1,000 0 1,000 2,000 ft
1 inch = 2,000 ft
FIGURE 18
Projected ASR Storage Mounding Impacts
Proj #: 1501002; Banks
Green Mountain ASR
City of Banks
13680 NW Main Street
Banks, OR 97106
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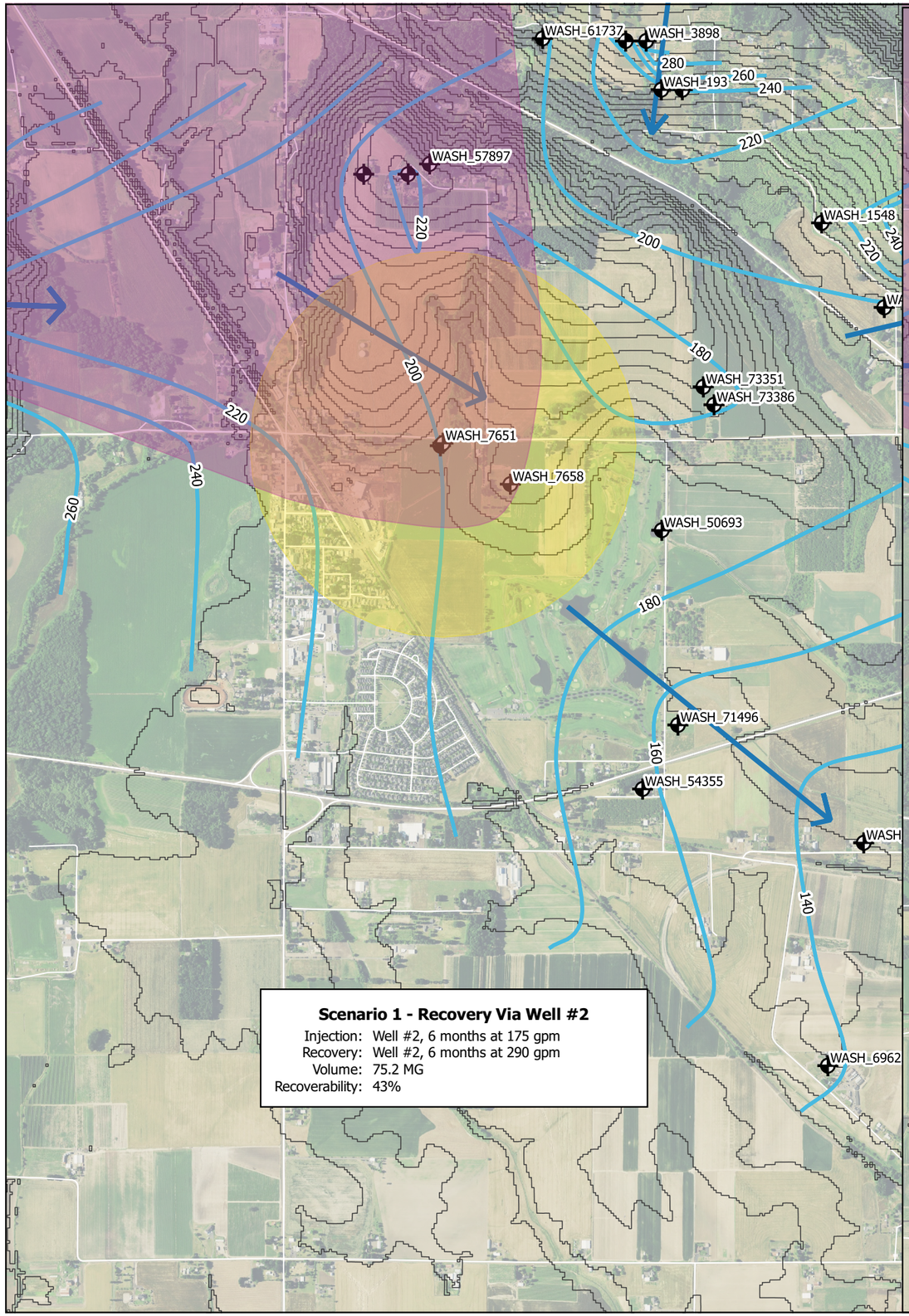
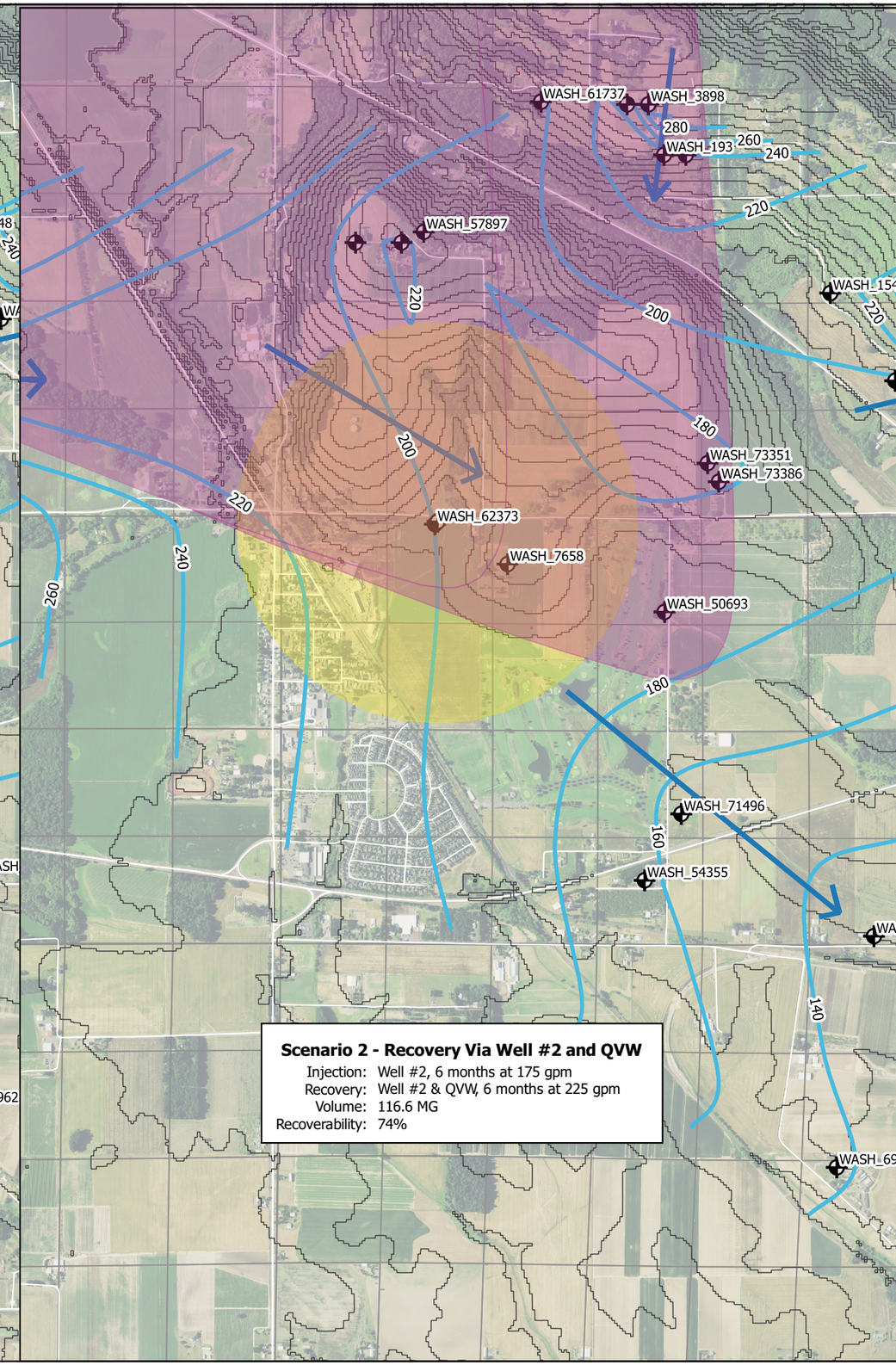
Portland, Oregon 97214
(503) 954-1326
C:\001_CwM_Projects\1501002_Banks_GM_ASR\GIS\003_figures



Scenario 1 - Recovery Via Well #2

Injection: Well #2, 6 months at 175 gpm
Recovery: Well #2, 6 months at 290 gpm
Volume: 75.2 MG
Recoverability: 43%



Scenario 2 - Recovery Via Well #2 and QVW

Injection: Well #2, 6 months at 175 gpm
Recovery: Well #2 & QVW, 6 months at 225 gpm
Volume: 116.6 MG
Recoverability: 74%

Legend

- Approximate Groundwater Contour (20 feet)
- Basalt Well Location
- Approximate ASR Storage Travel Distance (6 Months)
- Approximate ASR Recovery Capture Zone (6 Months)

Note: Groundwater contours generated from water levels at time of construction from any wells penetrating water bearing zones of the Columbia River Basalt Group

No.	Date	By	Revisions
1	9/16/2017	RMD	DRAFT

N

0 800 ft

FIGURE 19
Conceptual Recovery of Stored Water

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Banks Green Mountain ASR

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Banks, OR 97106

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Figure 20. Projected Pumping Interference – Well #2 and Quail Valley Well

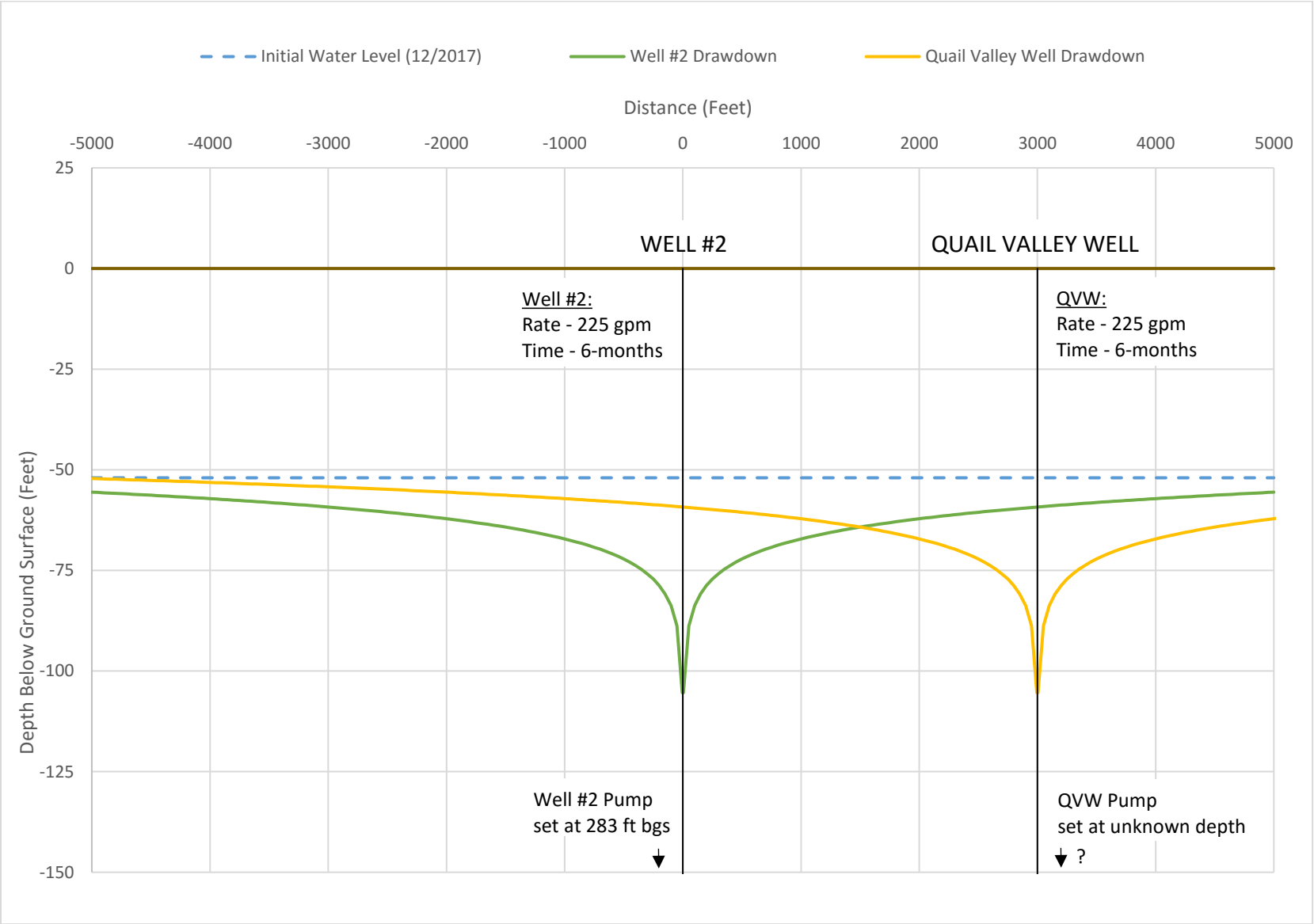
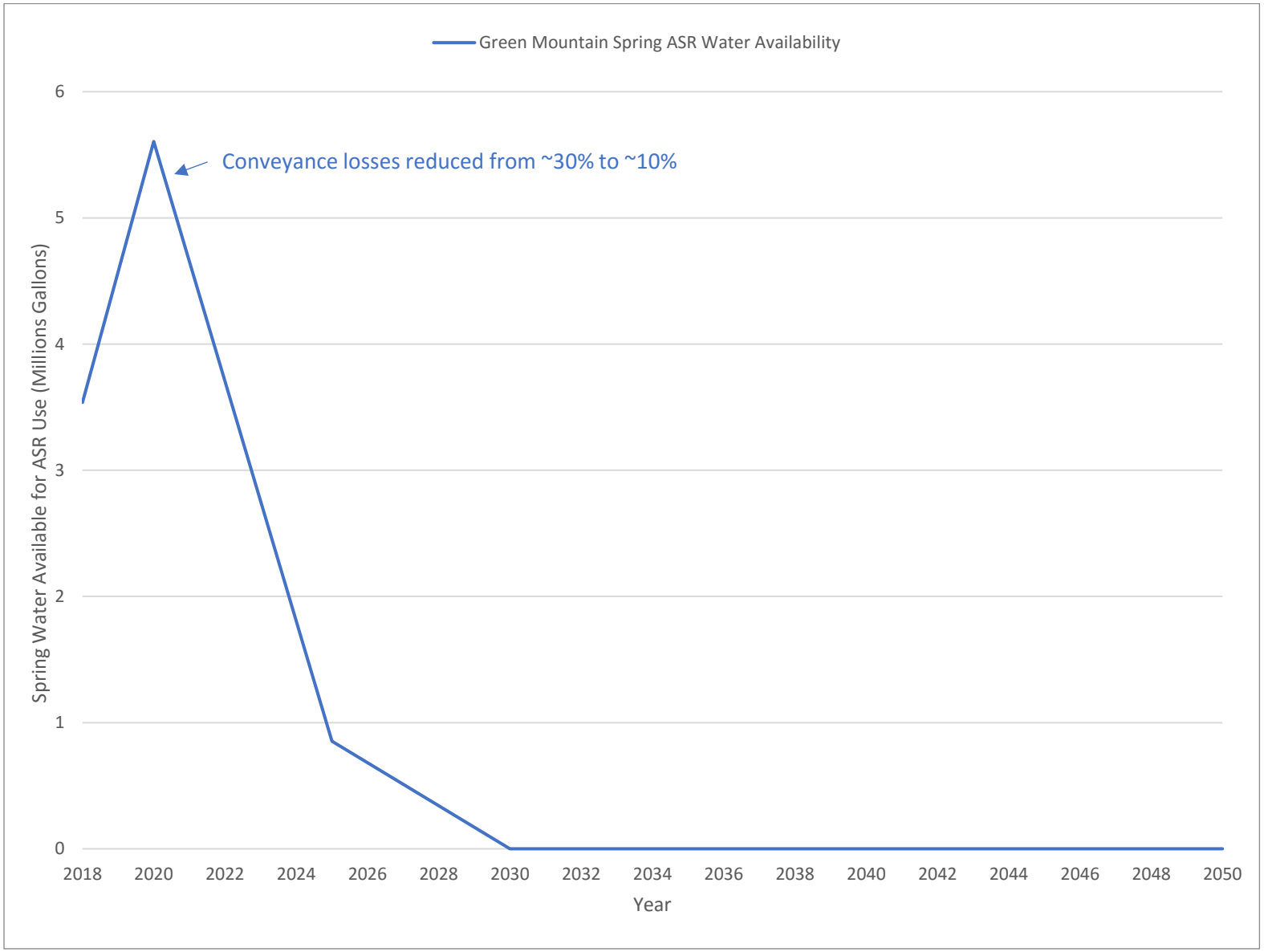


Figure 21. Green Mountain Springs ASR Water Availability



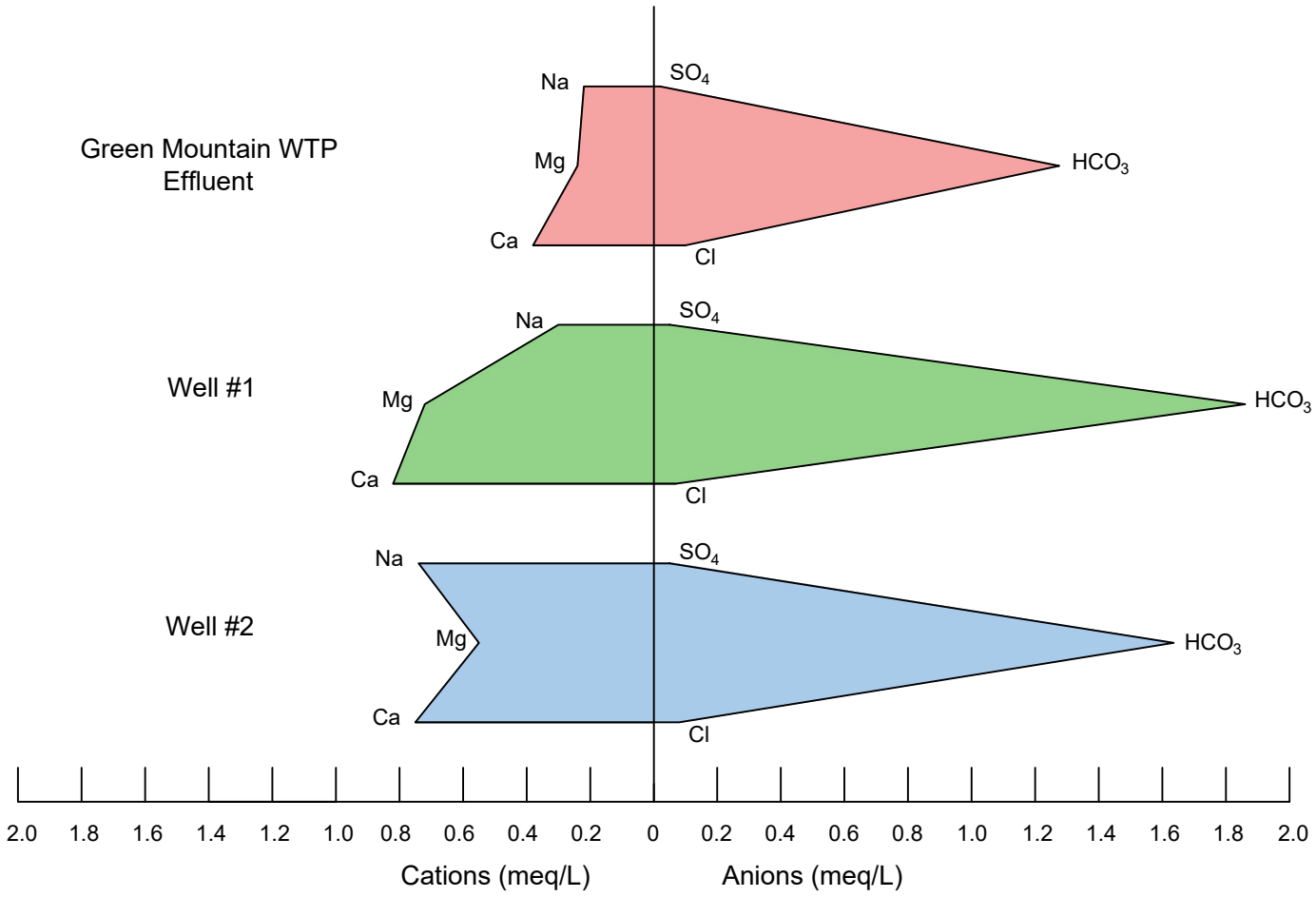


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Figure 22
Water Quality Stiff Diagrams

No.	Date	By	Revisions
1	9/25/2017	RMD	DRAFT

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City of Banks
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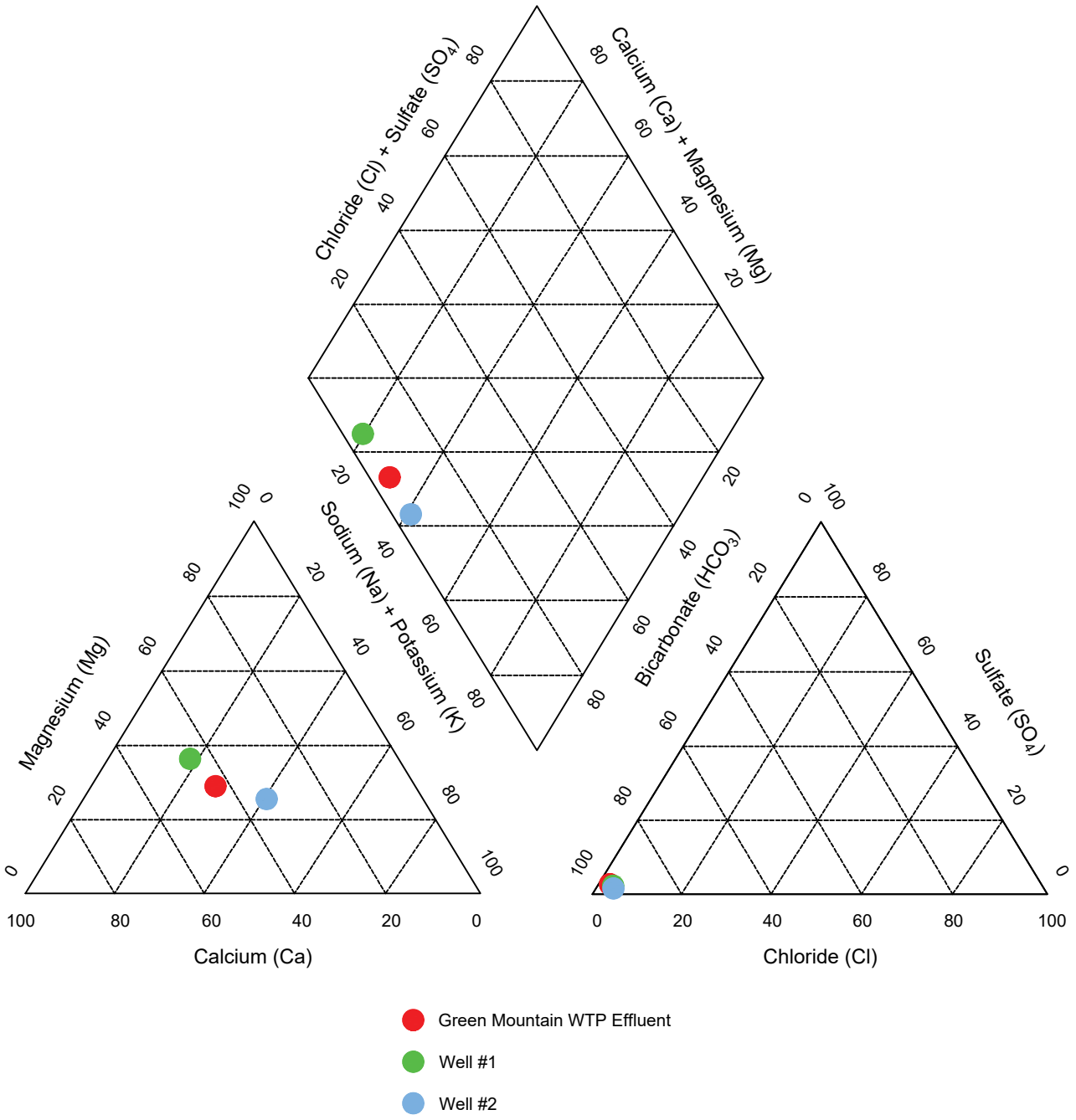

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Figure 23
Water Quality Piper Plots

No.	Date	By	Revisions
1	9/25/2017	RMD	DRAFT

Project #: 1501002
Banks Green Mountain ASR

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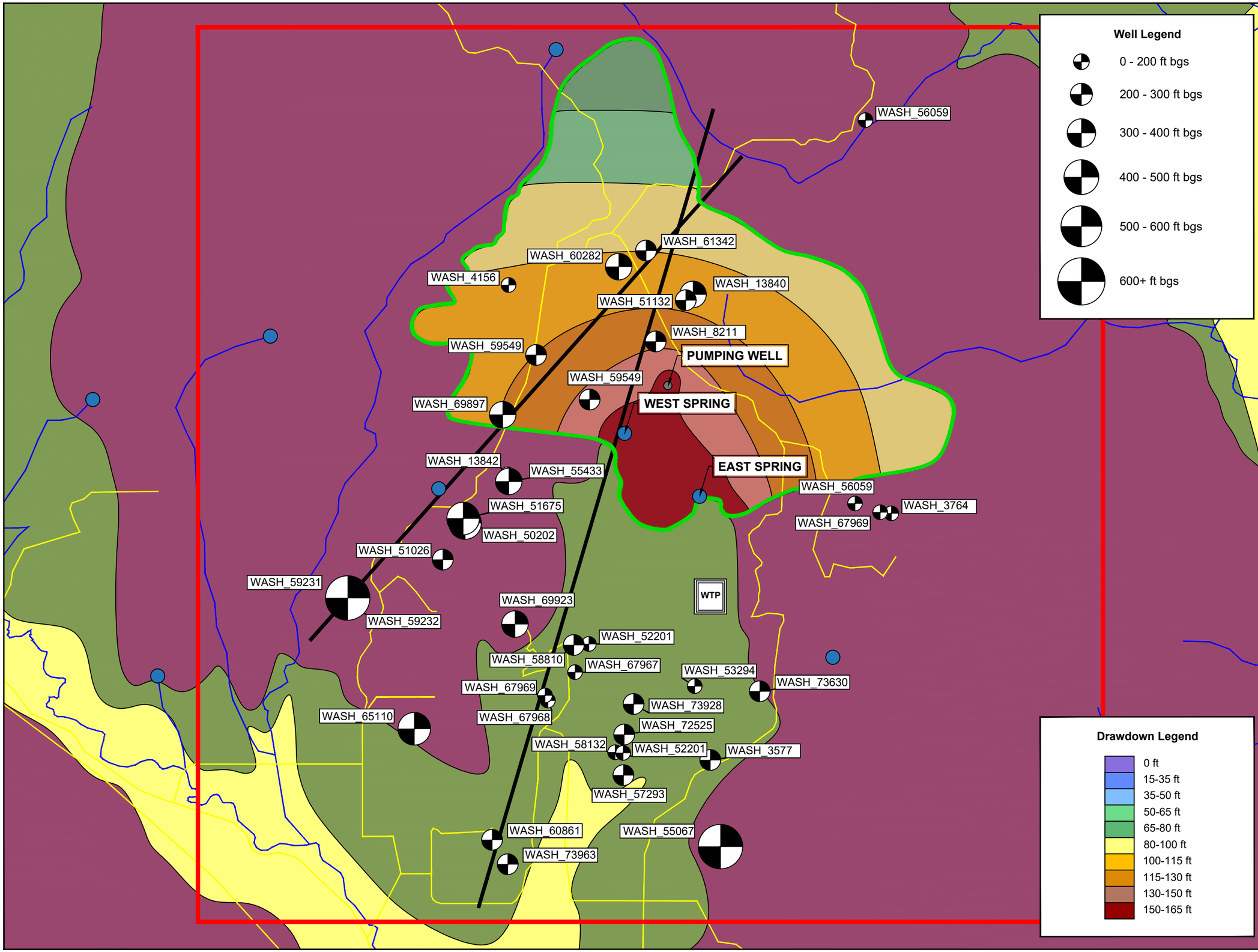
Banks, OR 97106



Legend

- Boring / Well Location
- Sellers Road GM ASR Study Area
- Approximate East and West Spring Recharge Area
- Banks Water Treatment Plant
- Spring
- Road
- Streams / Creeks

TRANSFER OF EAST AND WEST SPRING WATER RIGHTS

Pumping Rate:	212 gpm
Pumping Duration:	6-months
Volume Pumped:	54.8 MGY
Spring Flow Reduction:	35% W, 46% E

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

N

0 1800'

GRAPHIC SCALE

Figure 24
Projected Drawdown Following Completion of Groundwater Pumping - Transfer of East and West Spring Water Rights

Project #: 1501002
Banks Green Mountain ASR

City of Banks
13680 NW Main St.
Banks, OR 97106

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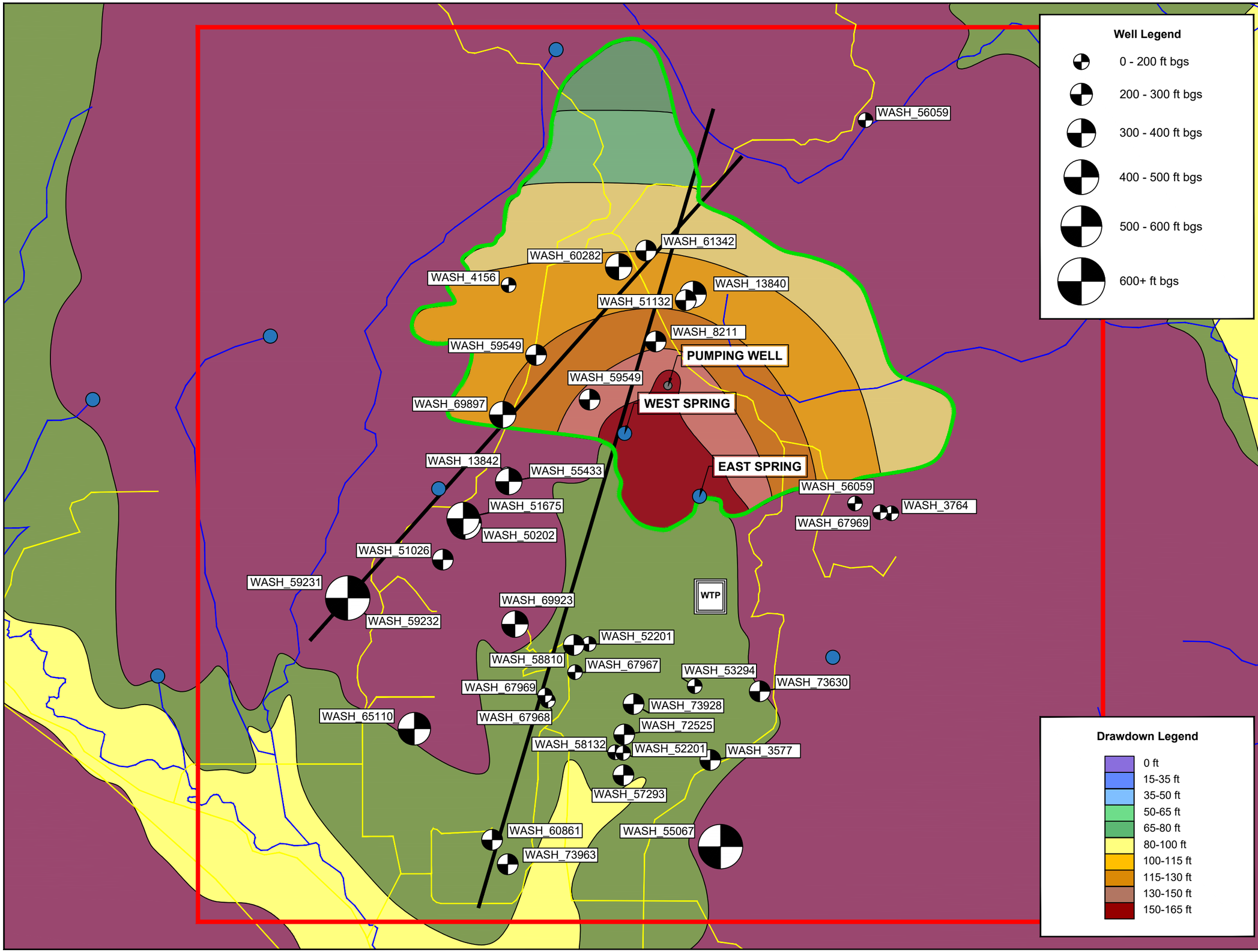

Legend

- Boring / Well Location
- Sellers Road GM ASR Study Area
- Approximate East and West Spring Recharge Area
- Banks Water Treatment Plant
- Spring
- Road
- Streams / Creeks

TRANSFER OF EAST SPRING WATER RIGHT

Pumping Rate:	80 gpm
Pumping Duration:	18-months
Volume Pumped:	62.7 MG
Spring Flow Reduction:	23% W

No.	Date	By	Revisions
1	8/7/2017	RMD	DRAFT

N

0 1800'

GRAPHIC SCALE

Figure 25
Projected Drawdown Following Completion of Groundwater Pumping - Transfer of East Spring Water Rights

Project #: 1501002
Banks Green Mountain ASR

City of Banks
13680 NW Main St.
Banks, OR 97106

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Complete Water Management

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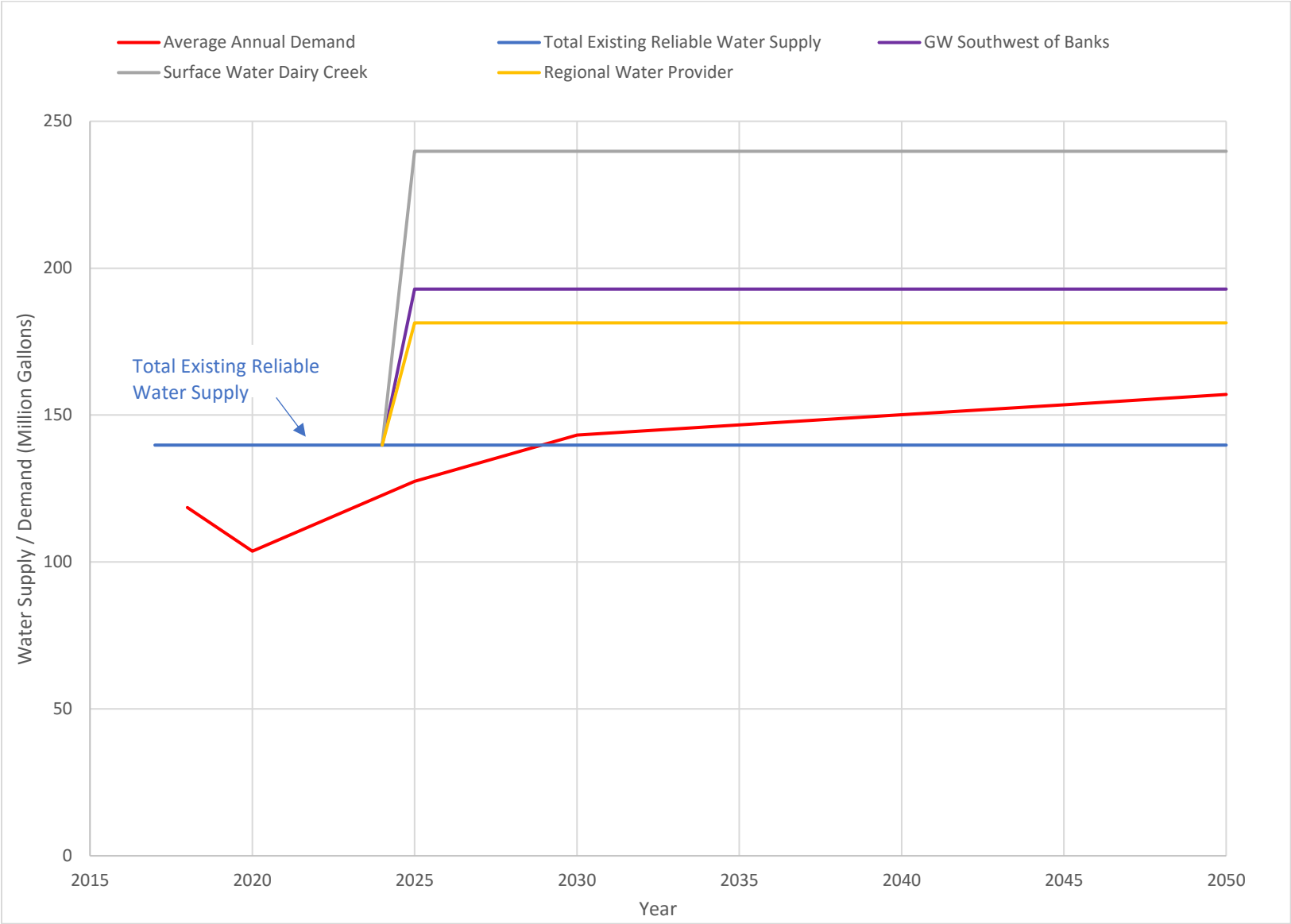
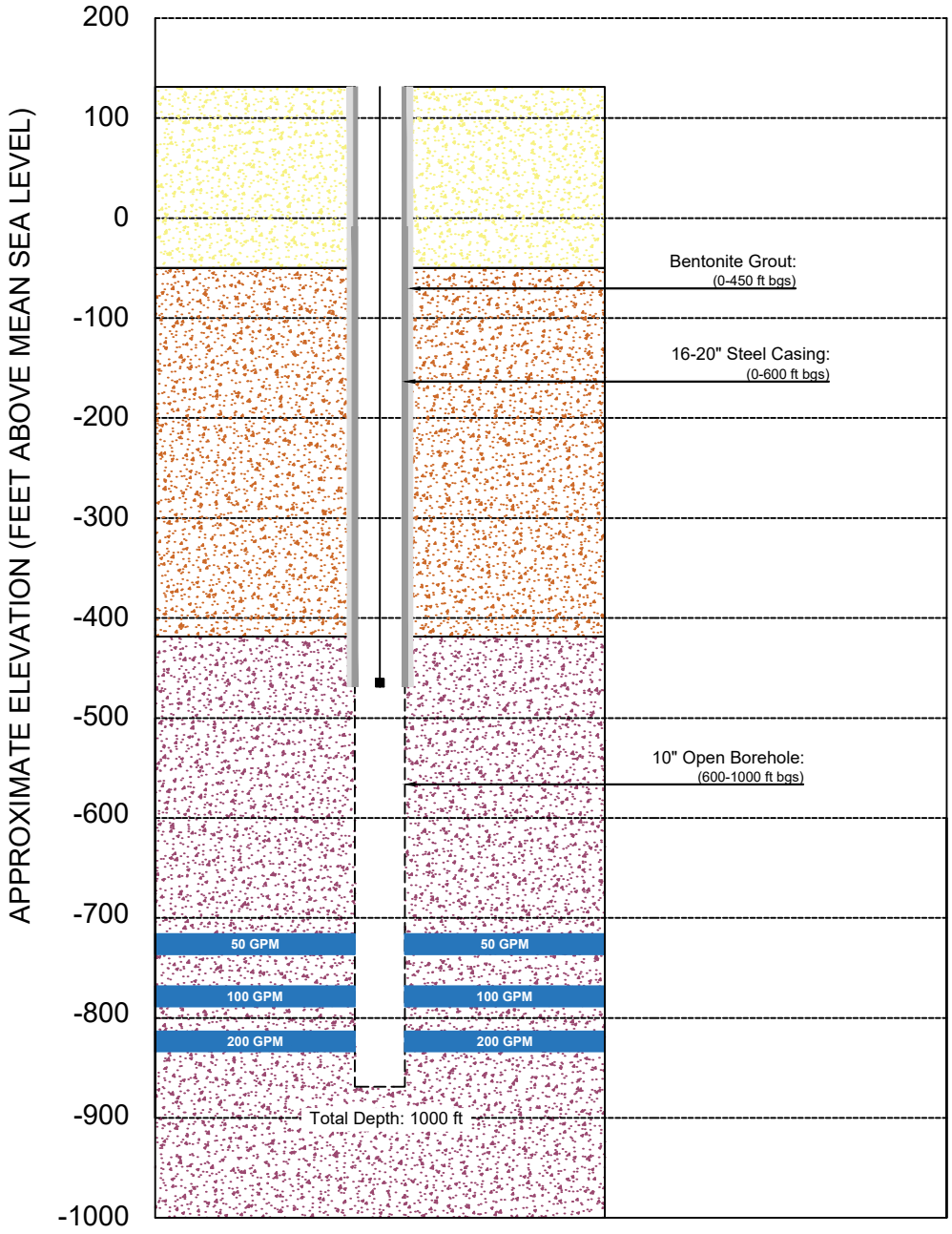
Figure 26. New Source Water Supply Alternatives vs. Projected Demand



COST ESTIMATION CONCEPTUAL DESIGN



LITHOLOGY LEGEND:

- (Qal): Alluvium (Holocene)
- (Qs): Alluvium (Pleistocene)
- (Tcr): Columbia River Basalt Group (Miocene)
- Water Bearing Zone

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Figure 27
ASR/Production Well #3 Conceptual Design

No.	Date	By	Revisions
1	8/3/2017	RMD	DRAFT

Project #: 1501002
Banks Green Mountain ASR

City of Banks
13680 NW Main St.
Banks, OR 97106

TABLES

TABLES

Table 1	City of Banks Water Rights Summary
Table 2	City of Banks Existing Water Supply Summary
Table 3	City of Banks Service Population and Water Usage 2013-2017
Table 4	City of Banks Projected Demands and Water Supply Balance
Table 5	City of Banks Emergency / Ecological Water Supply Scenarios
Table 6	West Spring Median Monthly Catchment Yield
Table 7	ASR Feasibility Evaluation Criteria
Table 8	Recovery of Stored Water Summary
Table 9	Green Mountain Springs Water Rights and 5-Year Average Diversions
Table 10	Water Quality Field Measurements and Analytical Results
Table 11	Existing Source Water Supply Evaluation Summary
Table 12	ASR Existing Infrastructure Compatibility Evaluation Summary
Table 13	West Fork Dairy Creek Water Availability Analysis
Table 14	New Source Water Supply Summary
Table 15	Planning Level Cost Estimate for ASR Implementation and New Source Water Supplies

CwM

Table 1. City of Banks Water Rights Summary

ASR Study Area	Current Naming Convention	Previous Alias	Application Number	Permit Number	Certificate Number	Transfer Number	Priority Date	Authorized Use (cfs)	Authorized Use (gpm)	Use	Source
Sellers Road	West Spring	-	S-9207	S-6516	5353	-	10/3/1923	0.42	188.5	Municipal	Spring
	East Spring	-	S-65611	S-48173	83138	-	8/25/1983	0.18	80.8	Municipal	Spring
Banks	Well 1	BehrmanWell	G-8476	G-7593	-	T-10055	9/29/1977	0.67	300.7	Municipal	Groundwater Well
	Well 2	-	G-15887	G-16312	-	-	12/5/2002	1.00	448.8	Municipal	Groundwater Well

Notes:

cfs = cubic feet per second
gpm = gallons per minute

CwM

Table 2. City of Banks Existing Water Supply Summary

EXISTING WATER SUPPLY AND WATER RIGHTS																						
Month	Production Wells							Springs											Total Demand Based on 5-Year Average Use (MG)	Total Supply		
	Available Aquifer Production		5-Year Average Use			Authorized by Water Right		Available Flow			5-Year Average Use			Authorized by Water Right								
	Available Rate[1] (gpm)	**Total Available Volume[1] (MG)**	Well #1[2] (MG)	Well #2[2] (MG)	**Total Volume (MG)**	Authorized Rate (gpm)	**Total Authorized Volume (MG)**	Available Live Flow West Spring[3] (MG)	Available Flow East Spring[4] (MG)	**Total Available Volume (MG)**	West Spring Diversions[5] (MG)	East Spring Diversions[5] (MG)	**Total Diversions (MG)**	West Spring Rate (gpm)	East Spring Rate (gpm)	West Spring Volume (MG)	East Spring Volume (MG)	**Total Authorized Volume (MG)**		Total Spring Supply Based on Authorized and Available Live Flow[6] (MG)	Total Spring Supply Based on WTP Limitations[7] (MG)	**Total Water Supply Based on 15% Safety Factor[8] (MG)**
January	78.4	**3.5**	0.3	2.9	**3.2**	749.5	**33.5**	11.5	0.9	**12.4**	4.4	0.9	**5.4**	188.5	80.8	8.4	3.6	**12.0**	8.5	9.4	8.2	**10.0**
February	106.6	**4.3**	0.3	2.3	**2.6**	749.5	**30.2**	10.2	0.6	**10.7**	4.9	0.6	**5.5**	188.5	80.8	7.6	3.3	**10.9**	8.1	8.2	7.4	**10.0**
March	112.0	**5.0**	0.2	2.3	**2.5**	749.5	**33.5**	11.1	0.7	**11.8**	5.6	0.7	**6.3**	188.5	80.8	8.4	3.6	**12.0**	8.8	9.1	8.2	**11.2**
April	150.5	**6.5**	0.1	2.2	**2.3**	749.5	**32.4**	10.1	0.8	**10.8**	5.5	0.8	**6.3**	188.5	80.8	8.1	3.5	**11.6**	8.6	8.9	7.9	**12.3**
May	225.0	**10.5**	0.6	4.4	**5.0**	749.5	**33.5**	9.4	0.9	**10.3**	5.4	0.9	**6.3**	188.5	80.8	8.4	3.6	**12.0**	11.3	9.3	8.2	**15.9**
June	230.0	**9.9**	0.3	3.0	**3.3**	749.5	**32.4**	8.1	1.0	**9.1**	5.2	1.0	**6.2**	188.5	80.8	8.1	3.5	**11.6**	9.5	9.1	7.9	**15.2**
July	215.0	**9.6**	0.5	5.6	**6.1**	749.5	**33.5**	7.3	0.5	**7.7**	5.7	0.5	**6.1**	188.5	80.8	8.4	3.6	**12.0**	12.2	7.7	7.7	**14.7**
August	205.0	**8.8**	0.2	5.6	**5.8**	749.5	**33.5**	6.6	0.6	**7.2**	5.3	0.6	**5.9**	188.5	80.8	8.4	3.6	**12.0**	11.7	7.2	7.2	**13.6**
September	155.1	**6.7**	0.4	3.9	**4.2**	749.5	**32.4**	6.1	0.5	**6.6**	4.3	0.5	**4.9**	188.5	80.8	8.1	3.5	**11.6**	9.1	6.6	6.6	**11.3**
October	61.6	**2.8**	0.5	3.3	**3.9**	749.5	**33.5**	6.8	0.8	**7.6**	4.1	0.8	**4.9**	188.5	80.8	8.4	3.6	**12.0**	8.8	7.6	7.6	**8.8**
November	46.3	**2.0**	0.4	3.5	**3.9**	749.5	**32.4**	8.6	0.8	**9.4**	3.8	0.8	**4.6**	188.5	80.8	8.1	3.5	**11.6**	8.5	8.9	7.9	**8.5**
December	35.8	**1.6**	0.3	3.4	**3.7**	749.5	**33.5**	10.0	0.2	**10.2**	4.1	0.2	**4.3**	188.5	80.8	8.4	3.6	**12.0**	8.0	8.6	8.2	**8.3**
TOTAL ANNUAL (MG)		**71.2**	4.2	42.4	**46.6**		**393.9**	105.5	8.3	**113.8**	58.3	8.3	**66.5**			99.1	42.5	**141.5**	113.1	100.6	93.3	**139.8**
WATER RIGHT UTILIZATION		18%			12%					80%			47%			59%	19%	78%	21%	71%	66%	**26%**

Notes:

1 - Available aquifer production for wells based on maximum pumping year data [OWRD, 2012], monthly rate manually calibrated to match projected demands

2 - Current use for production wells based on OWRD Water Use Reporting 5-Year average (2013-2017)

3 - Available live flow for West Spring based median monthly yield (Table 2) of Appendix C Sellers Road Hydrologic Analysis

4 - Available live flow for East Spring based on OWRD Water Use Reporting 5-Year average (2013-2017) under assumption that yield is currently maximized due to treatment capacity of WTP (ie. turbidity issues)

5 - Current use/diversions for springs based on OWRD Water Use Reporting 5-Year average (2013-2017)

6 - Total spring supply based on authorized and available live flow determined by taking the limiting variable quantity (ie. water right limited or live flow limited) for a given month

7 - Total spring supply based on WTP limitations determined by taking the limiting variable quantity between the WTP capacity (ie. WTP treatment capacity [184 gpm x # days in month]) or total spring supply based on authorized and available live flow (Note 5)

8 - Total water supply = (total spring supply based on WTP limitations + available aquifer production) x Safety Factor of 15%, to account for mechanical breakdowns, climate variability, etc.

Definitions:

Available - Existing quantity of water based on natural system constraints (ie. aquifer recharge); Determined via field methods (pump tests) or theoretical models (hydrologic models)

Authorized - Quantity of water that the City is permitted to appropriate/divert for utilization by water rights

Current Use - Average quantity of water appropriated/diverted by the City for the most recent full 5-year period (2013-2017)

Table 3. City of Banks Service Population and Water Use 2013-2017

Year	Total Service Population[1]	Average Day Demand (gpcpd)	Average Annual Demand (MG)	Source
2013	2,080	142.0	107.8	Proehl, 2017
2014	2,080	172.5	130.9	Proehl, 2017
2015	2,080	116.6	116.6	Proehl, 2017
2016	2,080	130.4	99.0	Proehl, 2017
2017	2,080	146.7	111.3	Proehl, 2017
Average	2,080	141.6	113.1	-

Notes:

[1] Total Service Population = Estimated City Population (Proehl, 2017) + Outside Service Area Population [305] (Golder, 2010)
gpm = gallons per minute
gpcpd = gallons per capita per day

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Table 4. City of Banks Projected Demands and Water Supply Balance

Year	Total Service Population[1]	Projected Water Demands		Existing Water Supply (MGY)	Water Supply Balance (MGY)
		Per Capita Use[2] (gpcpd)	Average Annual Demand (MG)		
2018	2,208	146.7	118.5	139.8	21.3
2020	2,257	125.9	103.7	139.8	36.1
2025	2,769	125.9	127.5	139.8	12.3
2030	3,111	125.9	143.2	139.8	-3.1
2035	3,187	125.9	146.7	139.8	-6.9
2040	3,261	125.9	150.1	139.8	-10.3
2045	3,335	125.9	153.5	139.8	-13.7
2050	3,412	125.9	157.0	139.8	-17.2

Notes:

[1] Total service population estimated by Oregon Population Research Center for the period 2018-2050 (Proehl, 2017)
[2] Average per-capita demand assuming conveyance losses reduced from 30% to 10%
gpm = gallons per minute
gpcpd = gallons per capita per day
MGY = million gallons per year

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Table 5. City of Banks - Emergency and Ecological Water Supply Scenarios

Month	Total Existing Water Supply	Scenario 1. Loss of East Spring	Scenario 2. Loss of West Spring	Scenario 3. Loss of Both Springs
January	10.0	9.0	4.4	3.5
February	10.0	9.4	4.9	4.3
March	11.2	10.5	5.7	5.0
April	12.3	11.5	7.3	6.5
May	15.9	15.0	11.4	10.5
June	15.2	14.2	10.9	9.9
July	14.7	14.3	10.1	9.6
August	13.6	13.0	9.4	8.8
September	11.3	10.8	7.2	6.7
October	8.8	8.0	3.5	2.8
November	8.5	7.7	2.8	2.0
December	8.3	8.1	1.8	1.6
Total Annual	139.8	131.5	79.4	71.2
% Reduction	-	**6%**	**43%**	**49%**

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Table 6. West Spring Median Monthly Catchment Yields

Month	Total Water Yield[1] (MG)
January	11.45
February	10.16
March	11.05
April	10.05
May	9.39
June	8.06
July	7.29
August	6.57
September	6.06
October	6.84
November	8.60
December	10.02
TOTAL ANNUAL	105.54

Notes:

[1] Median monthly catchment yields determined by modeling data from 2003-2016 as described in Appendix A
MG = million gallon

Table 7. ASR Feasibility Evaluation Criteria

ASR System Component		ASR Feasibility	
ASR System Component	Sub-Category	Low	High
Aquifer Storage	Storage capacity	- Aquifer storage volume of <75% of 41.6 MGY *(41.6 MGY = 2050 average annual water supply deficit + 3-month emergency/ecological scenario volume)*	- Aquifer storage volume of >75% of 41.6 MGY *(41.6 MGY = 2050 average annual water supply deficit + 3-month emergency/ecological scenario volume)*
	Potential Negative Impacts	- Surface seepages projected to occur at > 5% of wells within the same local aquifer system (CRBG)	- Surface seepages projected to occur at < 5% of wells within the same local aquifer system (CRBG)
	Aquifer Sustainability	- Aquifer replenishment (10% of stored volume left unrecovered) <2 MGY	- Aquifer replenishment (10% of stored volume left unrecovered) >2 MGY
Stored Water Recovery	Volume of Water Recovered	- Volume of water pumped <100% of 69.9 MGY *(69.9 MGY = 2050 average annual water supply deficit + 3-month emergency/ecological scenario volume + volume currently appropriated for 6-month period)*	- Volume of water pumped >100% of 69.9 MGY *(69.9 MGY = 2050 average annual water supply deficit + 3-month emergency/ecological scenario volume + volume currently appropriated for 6-month period)*
ASR Source Water	Available Quantity	- Available quantity of water <100% of 41.6 MGY *(41.6 MGY = 2050 average annual water supply deficit + 3-month emergency scenario volume)*	- Available quantity of water >100% of 41.6 MGY *(41.6 MGY = 2050 average annual water supply deficit + 3-month emergency scenario volume)*
	Water Quality Compatibility	- Likely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely required.	- Unlikely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely not required.
	Potential Negative Impacts	- Likely occurrence of negative impacts to existing water right holders (ie. drawdown, spring flow reduction); and/or - Likely occurrence of negative impacts to the local environment or population lasting for more than 5 years, as a result of ASR system construction/installation	- Unlikely occurrence of negative impacts to existing water right holders (ie. drawdown, spring flow reduction); and/or - Unlikely occurrence of negative impacts to the local environment or population lasting for more than 5 years, as a result of ASR system construction/installation
Existing Infrastructure Compatibility	Water Treatment Systems	- Likely that replacements or upgrades to the existing treatment systems of the City will be required for ASR utilization	- Unlikely that replacements or upgrades to the existing treatment systems of the City will be required for ASR utilization
	Conveyance System	- Projected conveyance system losses > 20%	- Projected conveyance system losses < 10%
	Injection / Extraction Wells	- Well closed to target aquifer; - Unlikely that well size will accommodate ASR equipment as currently constructed; and/or - Construction of conveyance system required to connect well to the City's water supply system	- Well open to target aquifer; - Likely that well size will accommodate ASR equipment as currently constructed; and/or - Construction of conveyance system not required to connect well to the City's water supply system

Table 8. ASR Aquifer Recovery Evaluation Summary

Recovery Scenario	Recovered Volume
Recovery Via Well 2	**High ASR Feasibility** - Total pumped volume of 75.2 MGY - Recoverability of 43%
Recovery Via Well 2 and Additional Recovery Well	**High ASR Feasibility** - Total pumped volume of 116.6 MGY - Recoverability of 74%

Table 9. Green Mountain Springs Water Rights and 5-Year Average Diversions

Water Use	West Spring (MG)	East Spring (MG)	Total (MG)
Annual Water Right	99.1	42.5	141.5
Mean Annual Use (2013-2017)	58.3	8.3	66.5
Unused Water Remaining From Water Right	40.8	34.2	75.0

Table 10. Water Quality Field Measurements and Analytical Results

Result Category	Constituent	Method	Units	Primary MCL[1]	Secondary MCL[1]	Sample Location		
						Well 1	Well 2	Green Mountain WTP Effluent
Field Measurements	Temperature	Hach HQ411D Meter	°C	-	-	13.9	15.3	14.3
	pH	Hach HQ411D Meter	pH	-	6.5-8.5	7.42	7.43	7.64
Analytical Metals	Calcium	SM3111D	mg/L	-	-	16.3	15	7.54
	Copper	SM3111B	mg/L	1.3	-	ND<0.05	ND<0.05	ND<0.05
	Iron	SM3111B	mg/L	-	0.3	0.315	ND<0.05	0.137
	Magnesium	SM 3111B	mg/L	-	-	8.64	6.62	2.92
	Manganese	SM3111B	mg/L	-	0.05	ND<0.025	ND<0.025	ND<0.025
	Potassium	SM 3111B	mg/L	-	-	2.5	3.8	1.3
	Silica	EPA 370.1	mg/L	-	-	48	48	30
	Sodium	SM3111B	mg/L	-	20	6.9	17	5
	Zinc	SM 3111B	mg/L	-	5	ND<0.2	ND<0.02	ND<0.02
Analytical Inorganics	Total Alkalinity ($CaCO_3$)	EPA 310.1	mg/L	-	-	96	110	73
	Bicarbonate	SM4500-CO2D	mg/L	-	-	96	110	73
	Chloride	EPA 300.0	mg/L	-	250	2.3	2.9	3.5
	Color	SM2120-B	CU	-	15	ND<5	ND<5	ND<5
	Specific Conductance	EPA 120.1	uS/cm	-	-	189.5	216	94.7
	Hardness	EPA 130.2	mg/L	-	250	82.0	71.6	36.8
	Nitrate (as N)	EPA 300.0	mg/L	10	-	ND<0.1	ND<0.1	0.142
	Nitrite (as N)	EPA 300.0	mg/L	1	-	ND<0.01	ND<0.01	ND<0.01
	pH	EPA 150.1	pH	-	6.5-8.5	6.9	6.9	6.8
	Sulfate	EPA 300.0	mg/L	-	250	2.3	2.2	ND<1
	Total Solids	SM 2540-B	mg/L	500	-	110	140	70
	Turbidity	EPA180.1	NTU	5	-	4.4	0.1	1.4
	Total Volatile Solids	SM 2540-E	mg/L	-	-	10	20	10

Notes:

Indicates MCL exceedance

[1] MCLs from Oregon Drinking Water Service (ODWS) published maximum contaminated limits (MCLs), or United States Environmental Protection Agency (USEPA) in lieu of ODWS limits. Primary MCLs enforceable, secondary MCLs not enforceable.

CU = Color Units

mg/L = Milligrams per liter

ND< = Analyte was not detected above the method reporting limit. Method reporting limit used in lieu of detection

NTU = Nephelometric turbidity units

uS/cm = microseimens per centimeter

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Table 11. Existing Source Water Supply Evaluation Summary

Water Supply Category	Water Supply Scenario	Available Quantity[1]	Water Quality Compatibility	Potential Negative Impacts
Existing Source Water Supplies	Existing Water Rights Green Mountain Springs Surface Water Rights	**Low ASR Feasibility** - Available volume of 26.7 MGY above current diversions for use by the City	**High ASR Feasibility** - Unlikely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely not required	**High ASR Feasibility** - Unlikely potential injury to downstream water right holders (i.e., creek flow reduction)
	Water Right Transfer Transfer of East and West Spring Water Rights to Groundwater	**Low ASR Feasibility** - Available volume of 54.8 MGY represents a decrease of 38.5 MGY from the City's existing water supply	**High ASR Feasibility** - Unlikely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely not required	**Low ASR Feasibility** - Injury to existing water right holders (i.e., drawdown) - Reduction in Spring flows (flow reductions of 35% and 46% to East and West Springs) - Construction of infrastructure likely impacting local environment
	Water Right Transfer Transfer of East Spring Water Right to Groundwater	**High ASR Feasibility** - Average annual increase of 10.1 MGY to the City's existing water supply	**High ASR Feasibility** - Unlikely occurrence of mineral precipitations or degradation of water quality. Additional pre-storage treatment likely not required	**Low ASR Feasibility** - Injury to existing water right holders (i.e., drawdown) - Reduction in Spring Flows (flow reductions of 50% and 23% to East and West Springs) - Construction of infrastructure likely impacting local environment

Notes:

[1] Available quantity for ASR utilization is limited by aquifer storage capacity of the Banks ASR study area CRBG aquifer. The six-month maximum storage capacity for the Banks ASR study area CRBG aquifer is approximately 45.1 MG.

MGY = million gallons per year

NA = Not analyzed; analysis outside the scope of the ASR feasibility study and requires separate evaluation

Table 12. ASR Existing Infrastructure Compatibility Evaluation Summary

Infrastructure Category	Infrastructure Component	Existing ASR Compatibility
Water Treatment Systems	Green Mountain WTP	**Low ASR Feasibility** - Existing configuration of WTP does not have capacity to treat peak fluxes from springs, limiting annual diversion by 7.3 MG
Conveyance System	Sellers Road Pipeline	**High ASR Feasibility** - New pipe conveyance losses projected to be 10%
Injection / Extraction Wells	Well 1	**Low ASR Feasibility** - Well open to target aquifer - Well diameter of 8 inches likely insufficient for ASR equipment
	Well 2	**High ASR Feasibility** - Well open to target aquifer - Well diameter of 12 inches likely sufficient for ASR equipment - Well connected to existing distribution system
	Quail Valley Well	**High ASR Feasibility** - Well open to target aquifer - Well diameter of 10 inches not likely sufficient for ASR equipment - Construction of conveyance system spanning approximately 3,000 ft required to intertie well with the City's water supply system

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Table 13. West Fork Dairy Creek Water Availability Analysis

Month	Mean Monthly Stream Flow (cfs)	Water Rights Diversions (cfs)	Instream Flow Requirement (cfs)	Net Stream Flow Available (cfs)	Net Water Available (MG)
Jan	80.4	2.1	17.7	60.3	1208
Feb	108.2	2.6	17.7	88.1	1594
Mar	90.4	1.9	17.7	70.9	1421
Apr	52.5	1.6	17.7	33.2	644
May	21.2	5.0	17.7	0.0	Not Available
Jun	10.2	6.1	5.9	0.0	Not Available
Jul	3.2	8.5	1.8	0.0	Not Available
Aug	2.4	7.3	1.2	0.0	Not Available
Sep	2.5	4.0	1.2	0.0	Not Available
Oct	3.4	0.5	5.9	0.0	Not Available
Nov	3.1	0.5	17.7	0.0	Not Available
Dec	46.5	2.1	17.7	26.7	534

Notes:

Indicates surface water not available.

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Table 14. ASR Source Water Supply Evaluation Summary

Water Supply Category	Water Supply Scenario	Available Quantity	ASR Water Quality Compatibility	Potential Negative Impacts
New Source Water Supply	New Water Right Groundwater Southwest of Banks	- Additional 71.2 MGY potentially available, assuming sustainable groundwater development rates similar to that of the City's existing production wells	NA, Groundwater Source	- Injury to existing water right holders (i.e., drawdown) - Construction of infrastructure likely impacting local environment
	New Water Right Available Surface Water West Fork Dairy Creek	- Additional 5,400 using OWRD Water Availability Reporting System	- Water quality compatibility of West Fork Dairy Creek surface water not known due to lack of data. It is likely that high turbidity, pesticide, and pathogen concentrations typical of surface waters in agricultural regions will require additional pre-storage treatment.	- Unlikely potential injury to downstream water right holders considering the quantity of available water - Construction of infrastructure and surface water diversions likely impacting local environment
	Regional Water Provider	- Regional providers (JWC) have preliminarily indicated availability at the approximate quantity of the City's target ASR volume (41.6 MGY). Further discussion with regional providers required to refine evaluation.	- Likely compatible, further evaluation needed	- Potential negative impacts associated with sourcing water from a regional provider not known at this time

Notes:

MGY = million gallons per year

NA = Not analyzed; analysis outside the scope of the ASR feasibility study and requires separate evaluation, or lack of current data prevents analysis and rating.

Table 15. Planning Level Cost Estimate for ASR Implementation and New Source Water Supplies

Infrastructure Category	Description	Item	Estimated Cost
ASR Implementation	Modification of Well 2	Design and Consulting	$60,000
		ASR Wellhead Modification	$250,000
		TOTAL COST	**$310,000**
	Modification of Quail Valley Well	Hydrogeologic Study and Well Testing *(KJC, 2009)*	$90,000
		Wellhead Design and Construction *(KJC, 2009)*	$640,000
		Conveyance Pipeline *(8-inch, 5,000 ft)*	$672,000
		Land	$100,000
		TOTAL COST	**$1,502,000**
New Source Water Supply	Available Surface Water West Fork Dairy Creek	Design and Permitting	$300,000
		Water Treatment Plant and Diversion Structure *(250 gpm)*	$3,200,000
		Conveyance Pipeline *(12-inch, 5,000 ft)*	$840,000
		Land	$100,000
		TOTAL COST	**$4,440,000**
	New Well Southwest Banks ASR study area	New Production Well *(1,000 ft deep, 16-inch, design, testing)*	$600,000
		Building, Wellhead, Controls *(KJC, 2009)*	$640,000
		Conveyance Pipeline *(12-inch, 8,000 ft)*	$1,555,200
		Land	$100,000
		TOTAL COST	**$2,895,200**
	Regional Water Provider	Conveyance Pipeline *(12-inch, 40,000 ft)*	$7,776,000
		JWC SDC *(2000 – ¾ connections @ $3,500)*	$7,000,000
		TOTAL COST	**$14,776,000**