Final Report

Comprehensive Well Assessment and Action Plan

City of Troutdale, Oregon 2015

Prepared for

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Glossary of Acronyms

ATP – adenosine triphosphate

bgs – below ground surface

C-date – completion date

Cells/ml – cells per milliliter

cfs – cubic feet per second

COBU – Claim of beneficial use

DSFC – Downhole suction control flow

EPA – Environmental Protection Agency

ft/gpm – feet per gallon per minute

ft/sec – feet per second

ft^2/day – feet squared per day

gpm – gallons per minute

gpm/ft of dd – gallons per minute per foot of drawdown

GSI – GSI Groundwater Solutions Inc.

Hz – hertz

IRB – iron related bacteria

LSI – Langalier saturation index

MCL – maximum contaminant limit

MDD- maximum daily demand

MG – million gallons

MGD –million gallons per day

mg/L – milligrams per liter

µg/L - micrograms per liter

MULT – Multnomah

mV – millivolts

OAR- Oregon Administrative Rule

OHA – Oregon Health Authority

OWRD – Oregon Water Resources Department

ORP – oxidation reduction potential or “redox”

pH – measure of acidity or alkalinity

PMOP – preventative maintenance and operations plan

ppb- parts per billion

ppm – parts per million

SDWA – Safe Drinking Water Act

SGA – Sand and Gravel Aquifer

SLYM – slime forming bacteria

SMCL – Secondary Maximum Concentration Limit

SRB – Sulfate reducing bacteria

STPP- sodium triphosphate

SS – stainless steel

SU – standard units

TDH – total dynamic head

TDS – total dissolved solids

TOC – total organic carbon

TON – Threshold Odor Number

TSA – Troutdale Sandstone Aquifer

WSE – Water System Engineering

WMP – Water Master Plan

Executive Summary

GSI Water Solutions, Inc. (GSI) provided an evaluation and summary of the City's municipal water supply wells, municipal source water rights, and water quality as part of its Water Master Plan (WMP) update to assess current and future demands (Black and Veatch, 2012). Observations during that WMP update identified several actions to assist the City with protecting and fully utilizing their groundwater assets and recommended the City evaluate options for improving well yield and water quality. The long-term goal of the City is to develop and maintain sufficient source capacity of good quality water to reliably meet current and future anticipated demands. The City selected the project team of GSI Water Solutions, Inc. and Keller Associates to perform the 2015 comprehensive assessment and develop an action plan identifying short term and long term actions for the City to fully develop, manage and protect its groundwater assets.

The 2015 comprehensive well assessment included evaluation of the City's seven groundwater supply wells using current and historic well performance evaluation, bacterial and water quality assessments and evaluating pump and motor performance. The City has six wells (Well 3, Well 4, Well 5, Well 6 and Well 7) completed in the Sand and Gravel Aquifer (SGA) of the lower Troutdale Formation. Well 2 is completed in the shallower Troutdale Sandstone Aquifer (TSA). Water treatment options were evaluated to address water quality issues observed in the City's wells which includes:

- Presence of manganese in Wells 3, 4, 6, 7 and 8 at concentrations that approach or exceed the Secondary Maximum Contaminant Level (SMCL) of 0.05 milligrams per liter (mg/L).
- Elevated concentrations of total dissolved solids (TDS) are present in Well 4.
    - TDS concentrations are greater than 300 mg/L, which is not typical of the SGA
    - Carbonate minerals/scale observed on distribution system and plumbing fixtures in areas serviced by Well 4.
- Arsenic has historically been present at concentrations below but near the maximum contaminant level (MCL) of 0.010 mg/L at Well 7.
- Hydrogen sulfide is present in all SGA wells except Well 5.

To better understand the impacts of water quality on City customers, the project team assisted the City with customer outreach surveys to provide feedback on water quality within the City's service areas.

The status of the City's water rights was also evaluated as part of the comprehensive assessment. The City has a vested interest in fully developing unused capacity on existing water rights permits to retain those water rights into the future, while also utilizing the well field in a sustainable manner to ensure long-term viability of the groundwater supply.

Well Assessment

The comprehensive assessment of the City's wells expanded upon the preliminary findings from the WMP update that identified wells with significant well yield and performance declines. The City has attempted to redevelop and rehabilitate several of its wells with either limited or short lived improvements in well performance. Well declines can be the result of several processes including:

1. Normal pump and motor wear which leads to performance deterioration overtime.
2. Changes in distribution system operation and head as the system is developed and modified.
3. Changes in aquifer conditions, such as water levels, water quality, or nearby pumping by other groundwater wells (i.e., well interference).
4. Physical plugging of the well screen and filter pack resulting from poor well construction and/or improper well design, inadequate well development, bridging of aquifer material in pore spaces, or structural damage to the well screen or casing.
5. Chemical precipitation or encrustation of the well screen, filter pack, and/or near well aquifer matrix because of water quality conditions.
6. Biological fouling of the well screen, filter pack, and/or near well aquifer matrix.

In order to better understand the potential cause(s) of the well declines GSI performed the following assessment actions at individual wells:

- Historical review of well performance and water quality
- Current well performance assessment using step rate pumping tests.
- Bacterial and water quality assessment.
- Pump and motor performance evaluation.

This approach resulted in the following key observations:

- Well 2 does not appear to have any outstanding issues; however, access to measure water levels during operation should be improved and the well should be monitored as part of a preventative maintenance program.
- Well 3 appears to have a shallow groundwater influence based on lower pH values and the presence of nitrate. Additionally, the well appears to produce sand at higher pumping rates which is indicative of a well construction or design issue. Iron oxidizing bacteria are present at levels of concern, which would suggest biofouling is also a clogging mechanism resulting in the observed well performance declines. Specific capacity was observed to be 2.02 gallons per minute per foot of drawdown (gpm/ft of dd) at the operational pumping rate of 202 gpm. The aggressive water chemistry observed might suggest a well integrity issue (similar to Well 4 which was reconstructed in 2008) related to its relatively shallow surface seal. Alternatively, the observed sand production in the well may have resulted in caving of formation material, which could allow downward vertical flow along the well casing from shallower zones.

- Well 4 water quality has improved slightly with the 2015 TDS values much less than historical values of 550 mg/L; however, the potential to form scale and mineral deposits within the distribution system is still a concern. Slime forming bacteria were present in the casing sample at levels that are of concern and anaerobic and sulfate-reducing bacteria were also observed. The bacterial population does not appear to have affected well performance which has been relatively consistent at approximately 12 gpm/ft of dd since 2006.
- Well 5 well performance and yield do not appear to have changed substantially. Water quality is good overall with slightly elevated manganese concentrations observed in 2014. The well is limited to an instantaneous production rate of 1394 gpm based on the City's water rights associated with Well 5. The observed specific capacity during 2015 step rate testing was 65.02 gpm/ft of dd at a maximum rate of 1736 gpm. The well specific capacity does not appear to have decreased substantially since installation in 2007.
- Well 6 specific capacity in 2015 is 8.3 gpm/ft at the operational yield of 475 gpm, an improvement from the 2011 specific capacity (Black &Veatch, 2011). Water quality and bacterial assessment suggests that a shallow groundwater source may be affecting Well 6. Well 6 had iron related bacteria populations identified in 2006; however, the 2015 results indicate lower levels of bacterial activity at Well 6 since last tested in 2006. Well 6 performance is likely affected by interference from City Well 8 and potentially other SGA groundwater users.
- Well 7 currently has a specific capacity of 12.0 gpm/ft of dd at the operational target rate of 488 gpm. Sand production at higher pumping rates has been a problem that has persisted since the well was originally constructed. Modifications were made to the well in 1993 to try to arrest filter pack settlement due to the sanding condition and improve access to the screened intervals. Aesthetic water quality was poor at the start of pumping but improved after continued pumping during 2015 testing. Chlorine was observed in the untreated groundwater during testing conducted during two separate events on April 14, 2015 and August 14, 2015. The concentration of chlorine diminished over time but was still present even with continued pumping during both events. The observation of chlorine in the discharge in the initial samples and after continued pumping is enigmatic, has no obvious source and would not be anticipated to be naturally present or persist given the chlorine demand in the aquifer based on the observed organic carbon concentrations. Arsenic was observed at concentrations well below the observed historical values and the current MCL. The presence of nitrate and a lower pH observed at Well 7 suggests a shallow groundwater source potentially related to the multiple screen intervals in the SGA or well integrity issues due to its relatively shallow surface seal and a corrosive groundwater condition in the well. Lastly, anecdotal evidence suggests that downward vertical flow has been observed in Well 7 since it was constructed, which may contribute to the extreme bacterial populations observed in 2015. Given the differences in water quality and well design between Well 7 and Well 8, the mixing of aerobic and anaerobic groundwaters between the shallow and deeper screened intervals within Well 7 is likely promoting biofouling in the well and appears to influence water quality at Well 8 when Well 8 is in operation.

- Well 8 has a specific capacity of 6.7 gpm/ft of dd at the operational target rate of 509 gpm. With the exception of elevated manganese, water quality was overall good. Bacterial populations consisting primarily of slime forming bacteria were present at concentrations of concern in Well 8, in both the casing and the aquifer sample. On this basis the well performance loss is likely due to biofouling; however, physical clogging of particulates accumulating within the filter pack cannot be eliminated. Performance of Well 8 is likely affected by well interference from City Well 6, Well 7 (when operated) and potentially other SGA groundwater users.

One recommendation from the 2015 review is the implementation of a Preventative Maintenance and Operations Plan (PMOP) for all City wells to monitor well performance, water quality, bacterial populations and pump and motor performance on a periodic basis. Implementation will allow identification of changes that may affect well performance and/or water quality.

Water Treatment Options Analysis

Iron, manganese, TDS, hydrogen sulfide, and arsenic were all reviewed specifically to quantify the concerns expressed by the City. Based on that review for wells 2, 3, 4, 5, 6, 7, and 8, we recommend that a distribution system operations management approach will be the best solution to address water quality concerns rather than more costly treatment methods. Specific system operational changes include the following:

- Enhanced pump-to-waste protocols to prevent introduction of poor quality water, accumulated hydrogen sulfide, biofilm, and sediment into the distribution system.

- Structured unidirectional flushing program performed periodically to remove any accumulated biofilm and sediment in the distribution system.

- Blending of high TDS water from Well 4 with lower TDS water in the distribution system.

Implementation of these system changes will improve water quality delivered to City customers by eliminating introduction and accumulation of hydrogen sulfide, biofilm, metals and sediment within the distribution system.

Action Plan

On the basis of observations from the 2015 testing program, water rights transactions and both short term and long term action plans were developed for the City to protect and develop its groundwater assets.

Water Rights Transactions

1. The City should submit a Water Management Conservation Plan (WMCP) to the OWRD to meet the requirements outlined in the final orders of the Extension of Time applications for Permit G-6881, Permit G-9866 and Permit G-9867.

2. Develop a COBU to document the City's historic use of water under T-3119 so that the water right may be certificated. The water use data needed to support the COBU must be from before the completion dates (C-date) of October 1, 1993.

3. Develop additional groundwater supply at Well 2 through a new TSA water right application.

4. The C-dates for Permits G-6881, G-8655, G-9867, G-9866, and G-13565 are all October 1, 2017. Prepare extension of time applications for each permit (5 total) requesting additional time to develop the water use authorized under the permits. The driving need for the time extension is to refurbish and/or replace wells.

5. Prepare a transfer application for the certificate resulting from the certification of T-3119 to add one or more existing or planned wells to replace the single well listed on this water right (Drinker Well).

6. Prepare permit amendment application for Permits G-6881, G-8655, G-9867, G-9866, and G-13565 to change and/or add well(s) to the permits sufficient to allow the City to appropriate the full rate authorized under the permits based on observed operational rates and allow flexible allocation for a future well(s).

Short Term Actions (2015 to 2017)

1. Adjust pump-to-waste operations to diminish sediment, hydrogen sulfide and biofilm introduction into the distribution system when bringing wells online. The extended pump- to-waste period will be long enough to remove 2 to 5 borehole volumes. The pump-to-waste cycle duration will vary from well to well based on construction, well yield and observation of water quality improvements.

2. Consider reducing operational pumping rates of wells and implementing longer run cycles for filling reservoirs or rotation of well operation, if possible. The reduced operational pumping rates will be adjusted to maintain a sufficient water column above the pump intake to minimize introduction of oxygen into the standing water column in the well. The modification to the rate and pumping duration will vary from well to well , system demand and distribution system operation to fill reservoirs.

3. Periodically perform a structured unidirectional flushing program to remove accumulated biofilm, sediment and mineral precipitates from the distribution system.

4. Modify Well 2 to allow access for monitoring well performance and evaluate if additional capacity exists.

5. Perform well video surveys at Wells 3, 6, 7 and 8. Recommendations for future redevelopment, reconstruction or maintenance activities will depend on observations of the condition of the wells. For planning purposes we recommend the City plan for at least 2 well redevelopment efforts at Well 6 and either Well 3 or Well 8.

6. Implement the Preventative Maintenance and Operations Plan (PMOP) annual maintenance monitoring program at all City Wells to identify well maintenance, water quality and well redevelopment.

Long Term Action Plans (2015 to 2020)

1. Develop additional groundwater supply at the proposed Well 9 location for redundancy and long term projected demand.

2. Evaluate other potential well locations within the City's service areas should other Well 3 or Well 7 need to be replaced. Based on the available information of current conditions at Well 3 and Well 7, we do not recommend further well redevelopment or investment in maintaining these wells as groundwater assets for long-term use. Unless well video surveys (or other downhole evaluations) provide supplemental information suggesting that the wells can be modified and/or redeveloped, we recommend the City consider abandoning these wells in the future and transferring the authorized water right permitted rate(s) to a new or replacement well.

3. Replace Well 3 and Well 7 with a new water supply well to meet the City's projected future demands. This will require additional water right transactions to maximize the City's water rights associated with Well 3 and Well 7. Proposed Well 9 may be capable of replacing one or both of these well locations depending on encountered aquifer conditions; however, additional new well(s) may be required.

4. Revise and continue to implement the PMOP based on observations of well redevelopment effectiveness, identify well maintenance and water quality improvement needs.

Section 1

Introduction

GSI Water Solutions, Inc. (GSI) provided an evaluation and summary of the City's municipal water supply wells and municipal source water rights during the facility inventory in 2011 as part of its Water Master Plan (WMP) update (Black and Veatch, 2012) to assess current and future demands on the groundwater supply. Based on observations during the 2011 facility assessments, the City's wells are limited in production capacity by both water rights and long term well performance declines and need to be addressed to meet future demands. On this basis, the City pursued a comprehensive well assessment to identify the cause(s) for the diminished well performance and yield exhibited by the City's water supply wells.

Groundwater Supply

The City has seven groundwater supply wells (2, 3, 4, 5, 6, 7 and 8) that can be used to meet current customer water demands (Figure 1). Most of the City's original water supply wells (2, 3, 4, and 6) were installed between 1978 and 1981; Well 7 was installed in 1991; Well 8 and Well 5 were subsequently added to the system in 1993 and 2007, respectively. The City currently only operates wells 2, 3, 4, 5, 6 and 8 regularly. Well 7 is tested periodically to ensure the pump and well are operational when needed. The City's updated WMP suggests the wells have a combined yield of approximately 5.15 million gallons per day (MGD), with a theoretical maximum of 7.4 MGD.

All but one of the City groundwater wells (Well 2) are interpreted to be completed in the Sand and Gravel Aquifer (SGA) unit (Hartford and McFarland, 1989) of the lower Troutdale Formation in the Portland Basin. The SGA is the major aquifer used by other nearby municipalities in the Portland Basin, including the City of Portland. The SGA consists of varying proportions of loose to moderately cemented sand and gravel, interfingered with finer-grained sediments which represent alluvial deposits from the ancestral Columbia River and rivers draining the Cascade Range in Oregon. City Well 2 is completed in the Troutdale Sandstone Aquifer (TSA) which is encountered at shallower depths and separated from the SGA by low permeability clay and silt sediments of the Confining Unit 2 (Hartford and McFarland, 1989). Water well reports and well construction information for the City's wells are included in Appendix A.

Water Rights

The long-term goal of the City is to develop and maintain sufficient source capacity of good quality water to reliably meet current and future anticipated demands. In doing so, the City also has a vested interest in fully developing unused capacity on existing water rights permits to retain the water rights into the future, while utilizing the well field in a sustainable manner to ensure long-term viability of the groundwater supply.

The City currently holds seven water rights for municipal use with a cumulative total water right capacity of 5,606 gallons per minute (gpm) [12.49 cubic feet per second (cfs) or 8.07 MGD]. Of the City's seven existing water rights, one is a water right certificate, five are water use permits, and one is a water right transfer. Four of the City's water rights are associated with a single City water supply well, with the remaining three water rights being associated with two or more other water supply wells. A matrix of the City's water rights and water supply wells is provided in Table 1 to provide a means of illustrating the allocation of the City's well production capacity (based on the City reported 2015 pumping rate for its water supply wells) among its current water rights.

Key observations from Table 1 include the following:

- The City's current water rights authorize a total cumulative rate of 5,606 gpm (12.49 cfs) for municipal use by the City.
- 3,714 gpm (8.27 cfs) of the City's current well production capacity is being utilized under the City's water rights.
- The City has 1,892 gpm (4.22 cfs) of water right capacity that is not being currently used by an existing City water supply well.
- The City has 1,232 gpm (2.75 cfs) of well production capacity without allocated water rights: 41 gpm at Well 2, 676 gpm at Well 5, and 515 gpm at Well 7.

The City has the opportunity to complete the development of its water rights through water right transfers, the improvement of well performance of its existing wells, and through well replacement and/or addition of new wells. This comprehensive well assessment will evaluate these different options to assess which are the most cost beneficial to fully utilize their existing water rights.

In June 2015 the Oregon Water Resources Department (OWRD) notified the City that it is requiring the submittal of an updated Water Management and Conservation Plan (WMCP) to minimize potential problems related to certification of its water use Permits and to allow the City to gain authorization to appropriate groundwater at a greater rate than the "Development Limitations" specified in the conditions for the applications for Extension of Time that were approved for Permits G-6881, Permit G-9866 and G- 9867 in 2008. Previously, the City was required to submit the WMCP update by October 1, 2015; however, during the Permit Extension of Time process the OWRD conditioned the approval with a submittal date of May 23, 2011 and "Development Limitations" based on Oregon Admistrative Rule (OAR) 690-09 and OAR 690-33 (Table 1).

Prior to pursuing any additional water right transactions, the City must submit an updated WMCP to the OWRD as required under Oregon Administrative Rule (OAR) 690 -86. The updated WMCP is intended to be a long term planning tool to identify needs, management and conservation tools and to help secure OWRD authorization for increased diversion under the extended Permits.

Well Performance and Well Yield Declines

During the 2011 facility inventory, City wells 3, 4, 6, 7 and 8 were observed to have substantial declines in well yield and well performance since they were originally constructed (Table 2). Several of the City's wells have been rehabilitated one or more times. Comparison of current operational well performance to initial well performance results indicated specific capacity declines of 40 to 60 percent. The performance declines are reflected by well yield declines of up to 450 gpm for individual wells.

Typically, the loss of well performance and yield can result from one or more of several major causes related to well construction, water quality, aquifer properties or operational conditions including:

1. Pump and motor wear and deterioration overtime.
2. Changes in distribution system operation and total dynamic head (TDH) as the system is developed and modified.
3. Changes in aquifer conditions, such as water levels, water quality, or nearby pumping by other groundwater wells (i.e., well interference).
4. Physical plugging of the well screen and filter pack resulting from poor well construction and/or improper well design, inadequate well development, bridging of aquifer material in pore spaces, or structural damage to the well screen or casing.
5. Chemical precipitation or encrustation of the well screen, filter pack, and/or near well aquifer matrix because of water quality conditions.
6. Biological fouling of the well screen, filter pack, and/or near well aquifer matrix by iron related bacteria (IRB), slime-forming (SLYM), or sulfate-reducing bacteria (SRB).

The influence of one or more of these conditions can significantly affect the well performance and in some instances, if not diagnosed early, can affect the longevity of a water supply wells operating life cycle. In the absence of changes in the pumping system or distribution system and well interference, the loss of well performance and yield is primarily a result of clogging of the well screen and/or filter pack. Conditions 4, 5 and 6 listed above will result in clogging and limit flow into the well during pumping. Preliminary review of the available information during the facility inventory indicated that several of the City wells may be experiencing declines in well performance due to one or more of these conditions.

Water Quality

In addition to decreasing well performance and yields, the City has experienced aesthetically-objectionable water quality in several of the SGA wells. Well 7 has historically had arsenic concentrations that approaches the primary drinking water Maximum Contaminant Limits (MCL) established by the Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) and adopted by the Oregon Health Authority (OHA). Several wells approach or exceed the Secondary Maximum Contaminant Limits (SMCL) for drinking water criteria for manganese, sodium and total dissolved solids (TDS). Additionally, hydrogen sulfide is present in groundwater resulting in taste and odor (i.e. rotten egg odor) issues with aesthetic water quality.

Specific water quality issues observed in the City's wells include:

- Manganese is present in wells 3, 4, 6, 7 and 8 at concentrations that approach or exceed the SMCL of 0.05 milligrams per liter (mg/L).
- Elevated concentrations of total dissolved solids (TDS) are present in Well 4.
  - TDS concentrations are greater than 300 mg/L, not typical of the SGA
  - Carbonate minerals/scale observed on distribution system and plumbing fixtures in areas serviced by Well 4.
- Arsenic has historically been present at concentrations near the MCL of 0.010 mg/L at Well 7.
- Hydrogen sulfide is present in all SGA wells except Well 5.

The generally poorer SGA water quality in Troutdale water supply wells relative to wells operated by municipalities west of the City may be attributable to local and regional geologic structures present in the area in the vicinity east of Troutdale. The geologic faults and structures may serve as potential conduits for deeper, more mineralized waters to intrude into the overlying Troutdale Formation. Additionally, because the SGA is relatively thin on the east side of Troutdale, pumping induced upward vertical gradients may enhance upwelling of more mineralized higher TDS waters from the underlying basalt aquifers (Black and Veatch, 2012).

Goals and Objectives for 2015 Study

The 2012 Water Master Plan Update recommended that the City perform a comprehensive well assessment to investigate each of the City's wells performance histories, local aquifer conditions and water quality to define specific actions for the City to further develop it's groundwater source and mitigate any further well performance declines and water quality issues. The specific goals and objectives of this study include:

- Review of the 2012 Water Master Plan for the City, Water Quality Reports and any available supporting documentation regarding well construction, water quality, water rights and local and regional hydrogeology.
- Conduct a comprehensive sampling and testing program at each of the City's wells.
- Identify mechanisms that contribute to well performance decline and water quality issues at individual wells.
- Provide prioritized actions to arrest or recover well yields and water quality.
- Provide specific scoping and planning level costs where possible with the available information collected as part of the comprehensive assessment.
- Provide planning level scoping and cost estimates for other actions that may require further evaluation outside of the scope of the comprehensive well assessment.

Report Organization

The Comprehensive Well Assessment and Action Plan is organized as follows:

Section 1 – Introduction
Section 2 – Assessment Approach
Section 3 - Water Supply Well Assessments
Section 4 - Customer Survey Results
Section 5 – Water Quality Treatment Options
Section 6 – Action Plan Alternatives Analysis
Section 7 – Action Plan

Tables and Figures are included at the end of the report. Electronic copies of Appendices A-G are included on a data CD attached to the end of the report.

Section 2

Assessment Approach

This section summarizes the methodology and approach for the evaluation of the individual well performance, the bacterial assessment and water quality, pump and motor performance and observations and the general condition of each of the City's wells.

Assessment Approach and Methodology

Each water supply well was evaluated to determine the condition of well including:

- Well performance.
- Bacterial assessment and water quality profile.
- Pump and motor performance.

Evaluating a water supply well using these diagnostic tools in concert can help to identify the cause of well performance decrease and whether to redevelop, rehabilitate, reconstruct or replace a well. Additionally, the comprehensive evaluation also provides baseline information for any future well performance or water quality related issues at the City's well; however, other diagnostic tools requiring removal of the pump and motor such as well video surveys, flow profiling or geophysical surveys may also be required to determine the causes of well performance decline. Brief descriptions of each of the diagnostic approaches utilized for the 2015 assessment are described below.

Well Performance

The City has maintained documentation of the well yields and long term well performance of its wells since they were constructed. Well performance can be estimated from the specific capacity of the well. The specific capacity of a well is estimated by dividing the well yield (in gpm) by the total drawdown in the well (in feet of drawdown) at the observed pumping rate. Several factors affect the observed specific capacity of a well including:

- Aquifer properties
- Pumping rate and duration of pumping
- Well screen and filter pack design
- Well drilling method and well development
- Aquifer or hydrologic boundaries, if present
- Other groundwater wells (i.e. well interference)

Using both long term specific capacity trends and step rate pumping test analysis can provide clues to the individual contributions of these factors to the total drawdown at a pumping well. The City typically operates their wells at a "sustainable" pumping rate determined by the current well performance for a period of hours or the long term specific capacity. The long term specific capacity of the wells were evaluated during the 2011 facility inventory and have not changed substantially based on s comparison of City operational pumping rates reported in 2015.

Evaluating specific capacity at multiple (typically increasing) pumping rates (commonly referred to as a step rate pumping test) is useful in tracking trends in well performance. The value of a step rate pumping test is that it allows evaluation of the contributions of various frictional losses that contribute to the total drawdown in a well over a range of pumping rates. The total drawdown within the well casing during pumping is generally greater than the drawdown immediately outside the well in the aquifer due to both laminar and turbulent frictional losses within the aquifer and as water enters the well (Figure 2).

Aquifer losses are largely dependent on the formation and the aquifer properties (i.e. transmissivity and storage coefficient), but are also dependent on the duration of pumping and well construction. The turbulent well loss contribution to the total drawdown is a combination of turbulent losses near the well bore, screen and within the well as water enters the well. On that basis, the turbulent well losses would be most affected by the reduced permeability in the screen, filter pack and formation near the well by well clogging. The turbulent well losses and aquifer losses are related to the total drawdown by the following empirical equation:

$s_w = BQ + CQ^P$ (i.e. the Hantush- Biershenk equation)

Where:

s_w = total well drawdown [feet]
Q = flow rate at the observed drawdown [gpm]
B = the aquifer loss due to laminar flow to the well [feet/gpm]
C = the turbulent flow loss in the well, also referred to as the “well loss” [ft/gpm]
P = constant turbulent flow exponent with a general value of 2, but ranging from 1 to 3 (Kawecki, 1995)

A Hantush- Biershenk analysis was performed to evaluate the contribution of turbulent well losses and aquifer losses to the total observed drawdown of the well (Krusemann and de Ridder, 1991; Kawecki, 1995). Assuming a constant of 2 for the turbulent flow exponent (P), the above equation can be simplified so that aquifer losses and the turbulent well losses can be estimated on a linear plot of step rate pumping test data where we plot specific drawdown (s/Q) versus the flow rate (Q) for each well (see Appendix B). The determination of B and C also using the Hantush-Biershenck plot allows the following:

- Prediction of drawdown at an extrapolated target pumping rates.
- Estimation of the percent of total head loss due to laminar flow (Driscoll, 1986)

These estimates are particularly useful when evaluating operational changes due to well performance decline.

The values of B and C can also be estimated using a residual statistical solution of the step rate pumping test observations with the Dougherty and Babu (1984) solution of the Theis (1935) equation in the aquifer test analysis software AQTESOLV PRO. Estimated values for B and C using the Hantush-Biershenk method or the residual statistical solution should be in general agreement; however, one of the underlying assumptions to the Hantush-Biershenk analysis is that each pumping step reaches steady-state conditions and this isn't always achievable in the field. An advantage of the residual statistical solution is that it accounts for transient conditions and also allows estimation of the additional parameters of transmissivity and the well bore skin value (S_w).

The well bore skin value typically ranges from -5 to 20 (Kawecki, 1995). A negative S_w estimate suggests that the permeability near the well is enhanced relative to the aquifer formation, and the well is properly designed and properly developed. In the case of a positive skin factor the drawdown within the well is greater than outside the well. A positive S_w is a result of the drawdown within the well is greater than outside the well due to a lower permeability in a damaged skin zone. This typically is the result of many factors including mud infiltration into the aquifer formation during drilling, bridging of screen openings by coarse particles; mineral precipitation, improper screen and filterpack design causing the well to experience clogging or poor well development.

The interpretation of the step rate testing analyses using the Hantush-Biershenk method and Theis method combined with the review of the long term specific capacity trends in the City Wells will allow evaluation of contributions to total drawdown due to linear well and aquifer losses and turbulent well losses; however, pumping by other SGA users and the City's SGA wells is reflected in the variability in the specific capacity in the City's historic operational data for several wells (Well 6, Well 7 and Well 8 in particular).

Bacterial Assessment and Water Quality Profile

Bacteria are present in soil, surface water, groundwater and the biosphere. In the most general sense, bacteria of concern in water supplies can be divided into those that are pathogenic (or capable of making a person ill) and those that are non-pathogenic. The pathogenic bacteria of concern in drinking water are Coliform bacteria because they are indicative of sanitary conditions and their presence may suggest that other pathogens may be present including disease-causing bacteria, viruses, or protozoa and many multicellular parasites. Sodium hypochlorite introduced into the distribution system at a sufficient concentration and allowed the required duration of contact time will effectively eliminate pathogens and maintain sanitary conditions in source water. The City regularly tests for the presence of coliform bacteria and also maintains sufficient chlorine residual within the distribution system to meet sanitary standards.

Non-pathogenic bacteria are problematic due to their ability to grow and mature within the environment of a water supply well and/or distribution system. Under the right conditions, non-pathogenic bacteria populations can proliferate and result in biological fouling of the well screen, filter pack, and/or near well aquifer matrix and microbial induced corrosion in the well. These bacteria are typically iron related bacteria (IRB), slime-forming (SLYM), or sulfate-reducing bacteria (SRB). These bacteria can accumulate biological depositions of iron and manganese, produce excessive slime (or biofilm) and release hydrogen sulfide as a by-product of anaerobic respiration of sulfate. While not a threat to human health, their presence generally results in color, taste, staining and odor issues with source water quality, clogging and/or corrosion of an affected well and scale, slime buildup and corrosion within the distribution system. The presence of nutrients such as iron, manganese, sulfate, phosphate or nitrate can support bacterial populations under aerobic or anaerobic conditions, which results in bacterial plugging of the well screen, filter pack and formation. Identification of the bacteria population and nutrient sources can help identify the causes of well performance losses and poor water quality.

In addition to bacterial populations, water quality variability can also cause clogging of the well screen and/or the well bore in a water supply well. Groundwater with chemistry prone to chemical precipitation typically has higher concentrations of TDS, carbonate, iron and manganese. As groundwater enters the oxidizing environment in a pumping well precipitation of in precipitation of carbonate scale, ferrihydroxide and oxide minerals on the well, screen, filterpack and within the distribution system Additionally, mixing of waters within the well from different water bearing zones that have subtle differences in water quality or an oversaturated condition with respect to carbonate can also cause the precipitation of minerals to occur.

Water quality sampling results can be used to evaluate groundwater quality at each well to determine whether favorable conditions were present for chemical precipitation and biological populations of the wells. At each well a "casing" sample and an "aquifer" sample were collected in unpreserved 1 liter sterile polyethylene bottles to evaluate bacterial populations and water quality in the vicinity of the wellbore, and further away from the well, within the aquifer. During sample collection water quality parameters of temperature, specific conductance, oxidation–reduction potential (ORP), pH, and dissolved oxygen were observed and recorded using a YSI 556 multi-parameter water quality meter. Trends in water quality parameters can be diagnostic of well construction issues or bacterial populations

The dominant bacterial species and identifiable bacterial population were evaluated using both microscopic analysis and quantitative methods (i.e. adenosine triphosphate (ATP) fluorescence) to estimate the total relative bacterial populations. The water quality samples were characterized for selected nutrients, metals and typical ions (i.e. carbonate, sulfate, chloride, etc.) to evaluate the potential for precipitation of minerals and corrosiveness of the groundwater. Additionally, to evaluate the historical occurrence of arsenic at Well 7, time-series sampling of the arsenic species arsenite (+3) and arsenate (+5) were collected to evaluate potential sources of historically elevated concentrations of arsenic relative to other SGA wells.

The bacterial assessment and water quality samples were submitted to Water Systems Engineering (WSE) in Ottawa, Kansas to evaluate the potential for bacteriological and/or chemical precipitation as causes of clogging. The arsenic speciation samples were submitted to ALS analytical labs in Kelso, Washington. The field parameter observations, WSE reports for bacterial assessments, WSE water quality and ALS water quality results are included as Appendix D at the end of this report.

Pump and Motor Performance

Deterioration of pump and motor performance can result in the loss of well yields. Periodic evaluation of the pump and motor condition can be performed by observing the discharge rate and total dynamic head (TDH) within the design curve of the pump. Deviations from the design curve for the installed pump and motor can provide indications of potential mechanical (i.e. bowl, shaft or bearing wear) or electrical wear in the pumping system. The pump and motor evaluation was performed during the step rate pumping tests to evaluate system performance over the range of the design curve for the pump.

The following data were collected: Voltage, amperage, pumping water level, pump discharge rate, and system pressure/back pressure; however, because a suitable wattmeter or power factor meter was not available the power factor was assumed to be 90 percent, which is a typical for a 100 horsepower motor at full load. Additionally, wells with variable frequency drives installed were manually overridden to operate a frequency of 60 Hertz (Hz) to remove ambiguity and limit the additional calculations required to account for the affinity laws if the pump frequency was varied during system testing. Pump and motor field forms, system as-builts and design curves are compiled in Appendix D.

The observed data were used to calculate the water horsepower, input kilowatts, and pump efficiency. Overall efficiency or "wire-to-water" efficiency of the pumping system was evaluated. The typical efficiency of a new pump is 75 to 85 percent at its design point (i.e. TDH and flow) and a full load efficiency electric motor is typically 85 to 96 percent efficient. For a 100 Hp pump the following overall efficiency ranges are:

- Excellent – greater than 66 percent
- Good – 66 to 63 percent
- Fair – 63 to 57 percent
- Low – below 57 percent

Due to well performance issues the City is operating several of its pumps well below the design flow rate (i.e. at higher TDH and lower pumping rates) resulting in low overall estimated efficiencies.

SECTION 3

Water Supply Well Assessments

This section presents individual well assessment results for the City's water supply wells. The comprehensive assessments are presented for individual wells as follows:

- Well Construction
- Well Performance
- Bacterial Assessment
- Water Quality
- Well Video Survey Observations (where available)

A comparison of historic and current well performance is provided in Table 4. Summaries of the bacterial assessment results and water quality results are shown in Table 5 and 6, respectively. A summary of the step rate pumping test observations and estimated parameters for each well is presented in Table 7.

Well 2 Assessment

The City's oldest water supply well still in use is Well 2 (MULT 1430), which is located adjacent to Reservoir 2. Well 2 was originally installed in 1976, with a reported yield of 550 gpm. Well 2 is completed in the TSA, the shallow portion of the Troutdale Aquifer.

Well Construction

In addition to being the only well not completed in the deeper SGA aquifer, Well 2 is also the only City well that was constructed with a natural formation pack screen design (i.e. no engineered filter or gravel pack). The well was constructed using telescoping steel casing with 12-inch casing driven to 280 feet below ground surface (bgs) and 10–inch casing driven within the 12-inch casing to a depth of 448 feet bgs. The well has a 2-inch annular seal (i.e. 16-inch borehole) to 45 feet bgs and the 10-inch casing was driven into a clay layer. No grout seal was installed between the 10-inch and 12-inch casing and the well does not meet current OWRD standards for well construction.

The well is screened from 450 to 480 feet bgs in a sand and gravel unit. The screen interval consists of 6 feet of 0.020 slot 10-inch telescopic stainless steel (SS) screen and 24 feet of 10-inch telescopic SS screen. The screen design capacity is 860 gpm at recommended design threshold of entrance velocity of 0.1 feet per second (ft/sec) (Driscoll, 1986).

Well Performance

Well 2 is currently capable of producing approximately 494 gpm. The original specific capacity of the well was reported to be 7 gpm/ft of dd. The current specific capacity could not be evaluated as the access port to measure water levels is currently blocked by a water level sounder; however, the well yield has remained consistent since it was last evaluated during the facility inventory in 2011.

Water Quality

City staff report that the well has not had any problems since installation, and has excellent water quality in comparison to other wells operated by the City. The well has low total dissolved solids (TDS), a low alkalinity and low dissolved and total metals concentrations relative to other City wells (Table 5). Well 2 pH is greater than 8.0 SU, which is more similar to SGA wells and nitrate historically has been non-detect, suggesting anaerobic conditions are present in the TSA near the well. The low concentrations of dissolved oxygen (< 1 mg/L) observed during the step rate testing support this conclusion (Figure C-1).

Bacterial Assessment

The bacterial assessment results for Well 2 indicated the lowest bacterial population and biological indicators observed at the City wells tested in 2015 (Table 6). At this time the well does not appear to be prone to or affected by biofouling or well clogging.

Historic Well Video Survey

Downhole video surveys at Well 2 were not reviewed as part of this study.

Well 3 Assessment

Well 3 (MULT 1429) is an SGA well located to the east of Reynolds High School, on the east side of SW 257th Avenue, in a below ground vault. After installation in 1978, Well 3 had a reported yield of 500 gpm with a specific capacity of 5 gpm/ft of dd. This specific capacity was observed to increase during subsequent testing in 1991 and 1993 (E & E Services, 1993), but has since decreased significantly. Filter pack and/or formation material has been observed in the distribution system during routine flushing near the well.

Well 3 was rehabilitated and redeveloped in 2008, by the City with minor improvement in well yield and/or performance. Redevelopment included using mechanical surging and swabbing in combination with use of the dispersing agent sodium triphosphate (STPP). The dispersing agent was recommended to mobilize fine silts which were suspected to be the cause of the decrease in well performance. The well was superchlorinated using 200 parts per million sodium hypochlorite solution (Steve Schnieder, pers comm., 2011).
Since bringing Well 5 online, the City has reduced the operation of Well 3 due to its diminished performance and water quality issues.

Well Construction

Well 3 has a 2-inch surface annular seal to a depth of 60 feet bgs. Below 60 feet the well has 12-inch casing to 508 feet bgs. The 12-inch casing was driven to a total depth of 615 before the shoe being cut off and the casing pulled back to 508 feet. The annular seal for Well 3 does not meet current well construction standards that require a grout seal be installed in wells completed in unconsolidated aquifers with significant clay beds (OAR 690-210-140). The construction standards require a 2-inch grout seal be installed a minimum of 5 feet into a clay bed that separates the shallower aquifer from a deeper aquifer (i.e. theTSA is separated from the SGA).

The well has 30 feet of 8-inch pipe size 60 slot SS screen installed from 510 to 545 feet bgs with a 5 foot blank from 530 to 535 feet bgs. The resulting design capacity of the well is approximately 1200 gpm at 0.1 ft/s

Well Performance

The 2011 specific capacity was approximately 2 gpm/ft of dd and the estimated maximum potential yield of the well was reported to be 285 gpm (Table 2). The reported yield of 285 gpm for Well 3 was observed to be at the limits of performance of the well, and pumping levels are close to the net positive suction head of the pump.

During testing in 2015, Well 3 was tested at a maximum rate of 222 gpm with 97 feet of drawdown which results in a specific capacity of 0.69 gpm/ft of dd, approximately 14% of the original specific capacity of 5 gpm/ft of dd. The aquifer losses and turbulent well losses were observed to be relatively high (Table 4); however, because the well appears to be developing during pumping, the estimated linear, turbulent well loss coefficients and well loss due to laminar flow are likely inaccurate (Figure B-1). The aquifer transmissivity estimated from the step rate pumping test is the lowest of all of the City's SGA wells (Figure B-2).

Water Quality

Well 3 has historically had elevated concentrations of manganese and dissolved hydrogen sulfide gas. During 2014 and 2015, Well 3 was observed to have relatively low TDS and alkalinity and was undersaturated based on its Langaleir saturation index, suggesting a low potential for forming scale but a slightly corrosive groundwater (Table 5). The following other observations were made for the water quality at Well 3:

- Well 3 was observed to have relatively low pH (less than 7 SU)
- Nitrate (as Nitrogen) present at concentrations above 2.5 mg/L.
- Total organic carbon (TOC) in the casing sample was 2 mg/L while it was not detected in the aquifer sample.
- Both the casing and aquifer sample had re-suspended iron (organically derived iron) present.
- Manganese was 0.0012 mg/L, well below the SMCL of 0.05 mg/L
- Sodium was also well below the SMCL of 20 mg/L, ranging from 5.12 to 4.84 mg/L.
- Langalier saturation index (LSI) results ranged from -0.94 to -1.1 suggesting it's under-saturated with respect to calcium carbonate and is corrosive.

Consistent with the presence of nitrate, the water quality parameter trends observed during step rate pumping at Well 3 indicated dissolved oxygen greater than 6 mg/L, a pH of less than 7 SU, and an oxidizing ORP (Figure C-2). These conditions are not typical of the deeper SGA and suggest the potential influence of shallow groundwater at Well 3. Combined with the differences in sodium, nitrate and manganese it would appear that Well 3 may be receiving shallower groundwater due to a well construction or well integrity issue.

Bacterial Assessment

Bacteria assessment of Well 3 suggests a moderate bacterial population comprised predominately of iron/manganese oxidizing bacteria *Gallionella* and *Leptothrix* were present in the casing sample. The ATP counts were above 100,000 cells per milliliter (cells/ml) in the casing sample, but less than 30,000 cells/ml in the aquifer sample (Table 6).

Historic Well Video Survey

Downhole video surveys at Well 3 were not reviewed as part of this study.

Well 4 Assessment

Installed in 1980, Well 4 (MULT 1340/93369) is located behind the City Public Works building. The well reportedly had an original yield of 900 gpm and a specific capacity of 11 gpm/ft of dd. GSI completed flow profiling and depth discrete water quality profiling of Well 4 in December 2006 to evaluate whether the quality of water produced from the well could be improved by modifying the screened intervals of the well (GSI, 2008a). Subsequent to that study Well 4 was reconstructed.

Well Construction

Well 4 was originally constructed with a 12-inch diameter casing to 494 feet bgs, with the screened interval consisting of 6–inch pipe size 30 slot continuous wire-wrapped SS screen from 493 to 563 feet bgs. The 2-inch cement grout annular surface seal was installed to a depth of 38 feet bgs. Based on the screen design the well has a maximum capacity of approximately 970 gpm at a screen entrance velocity of 0.1 ft/sec.

In 2006 a video survey of Well 4 revealed extensive corrosion of the 12-inch production casing below the static water level, including a hole at an approximate depth of 150 feet. The presence of the hole in the casing and lack of a seal below an approximate depth of 64 feet required repair or abandonment of the well to comply with Oregon Water Resources Department (OWRD) well construction standards.

The well was repaired by perforating the 12-inch casing, installing a10-inch diameter mild steel casing (0.25-inch wall thickness) liner between +1 foot and 438 feet bgs, and installing a grout seal between the 10-inch and 12-inch casings to bring the well up to the OWRD standards.

Well Performance

The yield of Well 4 has decreased by approximately 300 gpm from when the well was first operated, primarily due to the reduction in the diameter of the well after the repair, requiring installation of a lower capacity pump. The specific capacity of the well was reported to gradually increase to 17 gpm/ft of dd by 1992 and has been consistently close to 12 gpm/ft of dd since 2006.

During 2015 testing the specific capacity was observed to be between 12.16 and 12.9 gpm/ft of dd. The linear and turbulent well losses were estimated to be relatively low and the total head loss appears to be predominately due to laminar flow (Figure B-3). The aquifer transmissivity estimated from the step rate pumping test was 7,500 ft^2/day and suggests that the SGA aquifer is highly transmissive in this area.

Water Quality

Historically, water quality at Well 4 meets all primary drinking water standards; however, manganese and TDS are above the secondary drinking water standards (Table 5). The TDS concentration in Well 4 has historically exceeded 550 mg/L, resulting in mineral precipitation on plumbing fixtures in the area of the City it serves. The concentration of chloride also has been historically elevated in Well 4, but does not exceed secondary standards. Additionally, hydrogen sulfide gas is present at Well 4.

Water quality sampling results performed in 2014 and 2015 indicate the following:

- Well 4 TDS concentrations were observed to be in the range of 219 to 312 mg/L nearly half of historic concentrations observed at the well.
- Sodium values have also decreased from 150 mg/L in 2005 to 50 mg/L or less in 2014/2015 sampling.
- Chloride is well below the MCL of 250 mg/L with concentrations ranging from 17.8 to 37.2 mg/L.
- A positive LSI was observed (0.56 to 0.14) indicating the potential for deposition of carbonate and/or metal oxide scale.

Water quality trends at Well 4 during the step rate pumping test suggest generally anaerobic (dissolved oxygen < 1 mg/L) and reducing (ORP < 0 millivolts [mV]) while the pH that was slightly alkaline (greater than 8 SU) (Figure C-3). It appears that water quality has improved slightly at Well 4 since it has been reconstructed; however, it still has relatively higher TDS and the potential for forming scale or mineral deposits within the distribution system is greater relative to other City wells.

Bacterial Assessment

Well 4 bacterial assessment sampling observed relatively moderate bacterial activity based on the visual microscopic evaluation and ATP counts (Table 6). The casing bacterial populations were 219,000 cells/ml and the aquifer sample was 59,000 cells/ml. The bacteria identified to be present were *Pseudoxanthomas* and *Acidovorax*. Anaeorobic growth was 10% of the total microbial population in each sample, which is likely the source of the odor observed at startup of the well.

Historical Well Video Review

The most recent well video surveys available for Well 4 were reviewed as part of the 2006 well reconstruction project (GSI, 2008). Given that the video surveys were run prior to reconstruction and after reconstruction was completed, they do not provide useful diagnostics or insight into the well's current performance.

Well 5 Assessment

Well 5 (MULT 90881), installed in 2007, is the City's highest yielding well and is capable of producing 2,000 gpm, but currently is operated at a maximum rate of 1,324 gpm because of water rights limitations. The well had a 48-hour specific capacity of approximately 50.1 gpm/ft of dd (48.78 gpm/ft of dd was estimated from the water well report of drawdown at a pumping rate of 2,000 gpm when first installed).

Well Construction

Well 5 is the City's deepest well and is completed in the SGA (Table 1). The well has 16-inch steel casing installed to a depth of 525 feet bgs with a 2-inch cement annular seal installed to the same depth. Well 5 is screened in the SGA across multiple zones consisting of medium to fine black sands. The well has completed with 89 feet of 12-inch pipe size 40 slot continuous wire-wrapped SS screen with an estimated transmitting capacity of 3600 gpm at an entrance velocity of 0.1 ft/sec.

Well Performance

The observed specific capacity of Well 5 ranges from 79.69 to 65.02 gpm/ft of drawdown at pumping rates of up to 1,736 gpm based on step rate testing in 2015. A specific capacity of approximately 90 gpm/ft of drawdown was observed at the current operational target rate of 1,400 gpm during the step-rate pumping test of Well 5 after completion of the well (GSI, 2008b). The transmissivity of the SGA estimated for Well 5 is the highest amongst the City's wells (Table 4).

Water Quality

Well 5 water quality during the 2014 and 2015 sampling event was generally acceptable and does not appear to have any issues not previously identified during the facility inventory. The following observations were made.

- The LSI was observed to be slightly positive oversaturated.
- Nitrate was not-detected.
- Odor was also not-detected in 2014 or 2015.
- pH was slightly alkaline at 8.01 to 8.02 SU.
- Manganese was present at a concentration of 0.0568 mg/L, which is slightly above the SMCL of 0.05 milligrams per liter (mg/L).
- Sodium was observed at 23.2 mg/L, also slightly exceeding theSMCL of 20 mg/L.

No substantial trends in water quality were noted during testing and overall water quality was consistent with those anticipated in the SGA (Table 5). During the 2015 step rate pumping test at Well 5 water quality conditions were observed to be generally anaerobic (dissolved oxygen < 2 mg/L), slightly oxidizing (ORP ~ 100 mV) with a slightly alkaline pH near 8 SU(Figure C-4). The presence of hydrogen sulfide noted during drilling of the well has not observed during subsequent operation of Well 5 or during 2015 testing.

Bacterial Assessment

The biological activity in Well 5 was the lowest observed in the City's SGA wells (Table 6). Very little biological activity was observed during the microscopic and quantitative analysis. ATP counts were well below the level of concern of 100,000 cells/ml.

Historic Well Video Review

The most recent video for Well 5 was performed in 2012 when pump maintenance was performed. The well screen and filter pack were relatively clear of any debris or biofilm. Minor debris that was dislodged during the pump removal and/or by the camera assembly was visible in the water column. The visual observations during the video survey in 2012 support the WSE sample analysis of a low level of biological activity at Well 5.

Well 6

Well 6 (MULT 67091) is located in Sweetbriar Park and was installed in 1981. Well 6 had an original reported yield of 900 gpm with a specific capacity of 14 gpm/ft of drawdown. During re-testing of the well in 1992 the specific capacity was observed to have decreased to 8 gpm/ft of drawdown. Performance of the well had been observed to continue to diminish and the specific capacity was estimated to be 6.6 gpm/ft of drawdown at 476 gpm in 2011 (Black &Veatch, 2011).

Well Construction

Well 6 has a telescopic seal, with a 2-inch annular seal from ground surface to 100 feet and a 1-inch annular seal from 100 to 195 feet bgs (Table 1). The well appears to be sealed into a cemented gravel of the TSA rather than a well-defined confining sediment layer (i.e. clay or silt). Below the annular seal, driven 12-inch steel casing is present to 420 feet. Well 6 does not meet current OWRD construction standards due to the lack of an annular seal installed 10 feet below the top of a confining unit that hydraulically separates the shallower TSA from the deeper SGA.

The screen section consists of 75 feet of 6-inch pipe size 30 slot continuous wire-wrapped SS screen (Table 1). The estimated transmitting capacity of the screen at an entrance velocity of 0.1 ft/sec is approximately 1600 gpm.

Well Performance

The specific capacity and yield of Well 6 were reported to have declined as early as 1988. After chemical rehabilitation in 1988, the pumping rate was reduced to 600 gpm to maintain lower screen entrance velocities and uphole velocities during pumping. Specific capacity quickly diminished after the rehabilitation and well redevelopment using mechanical techniques and jetting was recommended in the 1993 water master plan document (E & E Services, 1993). The well was last documented to be redeveloped in 2008 using mechanical surging and swabbing in combination with sodium triphosphate (STPP), a dispersing agent. The dispersing agent was recommended to mobilize fine silts which were suspected to be the cause of the decrease in well performance. The well was then superchlorinated using a 200 parts per million (ppm) sodium hypochlorite solution (Steve Schnieder, per comm. 2011).

Testing of the well in 2015 suggests that well performance is better than previously estimated (Table 3). The well was observed to have an estimated specific capacity ranging from 8.79 gpm/ft of drawdown at 123 gpm to 8.32 gpm/ft of drawdown at 499 gpm. Performance of Well 6 was observed to be 6.6 gpm/ft of drawdown at 476 gpm during the facility inventory in 2011. Review of historic specific capacity data collected by the City suggests year to year fluctuation of both increases and decreases in specific capacity, particularly after the installation of Wells 7 and 8 (Appendix B). This is consistent with observations during the Well 8 pumping test results that observed approximately 3.5 feet of drawdown at Well 6. Well interference from the City's wells (and other SGA users) may be responsible for the observed year to year variation in specific capacity at Well 6.

Water Quality

Water quality at Well 6 is observed to have an elevated manganese concentration and hydrogen sulfide odor, which is generally consistent with the City's other SGA wells. Water quality results from 2014 and 2015 sampling are tabulated in Table 6 and summarized below:

- pH was slightly alkaline at 7.9 to 8.08 SU based on the lab results.
- Manganese was 0.0491 mg/L, slightly less than the secondary standard.
- The threshold odor number (TON) was 6.73 SU above the SMCL of 3.0 SU, likely due to hydrogen sulfide.
- LSI ranged from -0.12 to -0.3.
- Nitrate was detected (0.3 mg/L) in the 2015 casing sample, but not detected in the aquifer sample or the 2014 sample.
- Sodium ranged from 25.5 to 27.4 mg/L.
- Dissolved oxygen was less than 1 mg/L and strongly reducing conditions (less than -100 mV) were observed during step rate testing (Appendix C).

The groundwater at Well 6 appears to be slightly corrosive and is undersaturated with respect to carbonate, which likely would limit scale formation within the well and distribution system. On the basis of customer complaints and the TON of 6.73 SU in 2014, hydrogen sulfide odor is persistent at Well 6. The field parameter monitoring suggests anaerobic (dissolved oxygen < 1 mg/L) and reducing (ORP < -150 mV) conditions with an alkaline pH (pH > 8 SU) groundwater at Well 6 (Figure C-5). The operation of the submersible pump and motor resulted in minor shifts in the temperature of the discharge during the step rate pumping test.

Bacterial Assessment

Prior to the current bacterial assessment testing in 2015, GSI collected and submitted a water quality sample to Water System Engineering of Ottawa, Kansas in 2006 for bacterial assessment. Microscopic evaluation of the 2006 samples showed a moderate population of the iron and manganese oxidizing bacteria *Crenothrix*. This bacterium is often of concern due to its active digestion of available iron and manganese in a well. In addition to corrosive tendencies, this bacterium secretes an iron or manganese rich, gelatinous stalk. The stalk that is produced can actively bridge and clog screen openings as well as pump intakes. Furthermore, the bacteria can migrate beyond the well setting, affecting distribution lines and water treatment procedures.

In 2015, Well 6 was observed to have relatively low bacterial activity overall; however, several bacteria and protozoa were identified in the casing sample, which had an ATP count of 217,000 cells/ml (Table 7). Anaerobic growth represented 10 percent of the total microbial growth, which likely attributes to the odor observed at Well 6. The presence of the protozoa in the sample would suggest surface water influences; however, some protozoa do occur in biofouled wells. On the basis of the 2015 results it would appear that the 2008 chemical treatment and superchlorination have effectively controlled the bacteria population at Well 6.

Historic Well Video Review

GSI reviewed three historical videos for Well 6 performed between 1988 and 2004. Review of the historic videos suggests that Well 6 has experienced biofouling since installed. Well video surveys suggest that the well has experienced plugging due to iron- oxide deposition on the well screen. Iron oxide deposition was significant enough to limit visibility of the filter pack sections of the well screen.

Well 7

The City installed Well 7 (MULT 1444) in 1981 in the Sandee Palisades residential area. The original reported well yield and specific capacity were 1,000 gpm and 18.6 gpm/ft of drawdown respectively. The well was not put into service until 1990, but once in service quickly began to experience well performance issues and required redevelopment. The well is currently capable of producing 518 gpm with a specific capacity of 9.8 gpm/ft of drawdown; however, the City does not operate Well 7 regularly and only exercises the well to ensure that it is operational in case it is needed as a back-up supply.

Well Construction

Well 7 was poorly designed and constructed based on a review of the original water well report and observations during subsequent in-well work. The annular seal at Well 7 is reported to consist of cement grout from ground surface to 20 feet bgs; which meets the minimum requirements for an annular surface seal for OWRD, but does not meet current requirements for sealing off aquifers with significant clay beds because the seal does not extend down into a confining clay bed below the TSA and above the SGA.

Based on the OWRD water well report, Well 7 is constructed with 30 feet of 100 slot stainless steel screen with a gravel pack consisting of ¼- inch to ¾- inch pea gravel and screened over two intervals from 360 to 385 feet (cemented gravel) and 465 to 475 feet (clay and gravels); however, during subsequent in well work the actual screen intervals was noted to begin at 358 to 384 feet and the lower interval(s) was from 465 to 475 feet bgs, 480 to 490 feet bgs and from 495 to 525 feet bgs. This is consistent with the as-built information reported by Robinson and Noble (1981). The well screen has an estimated transmitting capacity of 1200 gpm at 0.1 ft/sec.

During initial step rate testing after construction, Well 7 was observed to produce substantial amounts of green sand at the start of pumping with sand production increasing as the well was pumped at higher rates; most likely due to the aggressive screen slot size and filter pack design. The sanding condition has persisted and the City currently pumps to waste at the start of pumping to prevent introduction of sand particulate, sediment and turbid water into the distribution system.

Well Performance

The current specific capacity of the well was observed to range from 10.69 to 18.88 over pumping rates ranging from 151 to 588 gpm (Figure B-9). During initial testing in 1980, Well 7 was originally observed to have specific capacity ranging from 15.4 to 30.7 at pumping rates ranging from 470 to 1000 gpm. After rehabilitation in 1993, the well had a specific capacity of 17 gpm/ft of dd at 700 gpm (Robinson and Nobles, 1993) The current well performance is generally consistent with the long duration specific capacity estimate of 9.8 gpm/ft of dd at 550 gpm observed during the 2011 facilities inventory (Black and Veatch, 2011), but has decreased substantially since originally constructed.

During 2006, the City performed dynamic flow profiling of Well 7 to evaluate if well reconstruction could address the arsenic occurrence. The dynamic flow profiling was performed at a target pumping rate of 600 gpm and over the interval from 360 feet bgs to 525 feet bgs. Approximately 21 percent of the total production was observed in the upper screen interval while 66 percent was observed in the interval from 465 to 490 feet bgs. The remaining 13 percent was from 500 to 509 feet bgs.

Water Quality

Water quality at Well 7 differs from other SGA wells (including nearby Well 8) based on the historical presence of elevated concentrations of arsenic which approach the EPA MCL, the presence of nitrate and a lower more neutral pH (less than 7.5 SU). Water quality results observed during 2015 at Well 7 are presented in Table 5. Results from 2014 and 2015 can be summarized as follows:

- pH ranged from 7.13 to 7.24 SU.
- Well 7 groundwater is slightly undersaturated (LSI of -0.7 to -1) and mildly corrosive.
- Chlorine was observed to be present at 4.85 mg/L and at 0.11 mg/L in 2015 samples.
- Chlorine was re-tested and observed at concentrations of 5.93 mg/L to 0.10 mg/L
- Nitrate (as nitrogen) was present at concentrations 0.5 mg/L to 2.5 mg/L in 2015.
- Manganese was 0.4 mg/L in the 2015 casing sample and 0.0187 mg/L during 2014 City water quality sampling.
- Odor was not detected in 2014 sampling.
- Arsenic (total) was 0.7 to 0.8 μg/L, well below the MCL of 10 μg/L.
- Sodium is present at concentration below the MCL, ranging from 13.1 to 14.0 mg/L.

Visual observations during sampling suggest aesthetically poor water quality at system startup that improved during pumping. Water quality trends during step rate pumping were observed to be slightly aerobic (dissolved oxygen > 2 mg/L), oxidizing (+200 mV) and a pH of 7.2 SU (Figure C-6). ORP appears to decrease with each change in pumping rate. Similar to other wells, minor shifts in temperature are observed during the step rate pumping test related to the operation of the submersible motor. The 2014 and 2015 general water quality would support that the water quality is generally good at Well 7; however, the low pH and elevated dissolved oxygen trends suggest a shallower aquifer source rather than the SGA. Additionally, the sodium concentrations in Well 7 are relatively low for an SGA well and are comparable to Well 2 (a TSA well) and Well 3.

Due to its reactivity in nature, chlorine does not occur naturally in groundwater at the concentrations observed at Well 7. The City performed confirmation sampling of the WSE results on August 14, 2015. The confirmation sampling included 4 samples taken at approximately 1 hour intervals. Similar to the previous results, the residual chlorine concentration was highest in the casing sample and decreased with continued pumping (Table 5).Subsequent conversations with the WSE laboratory and City staff have not identified a likely source for the presence of chlorine such as sampling artifacts/error, laboratory error, a faulty check valve or a leaking pump lubrication line; however, colorimetric methods that use N,N Diethyl-1,4 Phenylenediamine Sulfate (DPD) indicator (such as standard method 4500 CI-G) are prone to interference from oxidized manganese, copper and turbidity. Oxidized manganese is the most common and its interference results in a "false positive" or elevated chlorine results due to its reactivity with chlorine.

Natural sources for chlorine could include certain bacteria that produce organochlorines during decomposition of plant matter or volcanic gasses which contain hydrogen chloride. Alternative anthropogenic sources could include leaking chlorinated swimming pool(s) or an open-loop heat pump system; however, in both instances the chlorine demand within the shallow subsurface would rapidly consume the highly reactive chlorine by converting it to chloride salts or other organochlorines. Available information does not provide a clear source for the observed elevated chlorine concentrations present in Well 7. Given the biological and chemical reactivity of chlorine in aqueous solutions and the high manganese concentrations observed at Well 7, we suspect that the residual chlorine results are "false positives" due to interference in the colorimetric analysis.

Arsenic Occurrence Evaluation

Two potential sources for the arsenic in Well 7 had been proposed previously: (1) the presence of sediments derived from hydrothermally altered volcanic rocks of the western Cascades and geochemical conditions conducive to dissolution and mobilization of arsenic; or (2) bioaccumulation by iron-related bacteria observed to be present at Well 7. However, based on the other water quality observations in 2015 a third potential source for arsenic may be possible. The presence of nitrate, elevated dissolved oxygen and a lower pH value suggest that a shallower water bearing zone may be contributing to the water quality observed at Well 7 and this might be the source of arsenic.

To evaluate the first two working hypotheses, GSI performed time series sampling at Well 7. Sampling was performed to collect arsenic samples at system start up and after pumping 5, 10, 15 and 45 times the standing borehole volume. If groundwater is the arsenic source a more constant result would be anticipated, whereas if arsenic mobilization were more related to biofilm then decreasing trends with continued pumping would be anticipated. The total arsenic concentrations were observed to be between 0.83 μg/L to 0.584 μg/L and consisted primarily of arsenic (V), or arsenate the oxidized form of arsenic. Arsenic speciation results are summarized in Table 7.

The time series sampling approach was designed to evaluate arsenic mobility as redox and/or pH conditions changed with extended pumping (see Figure C-6). Arsenic (+V) is strongly adsorbed by ferrihydrite and oxyhydroxides like those that are deposited by iron-related bacteria. The tendency for strong adsorption makes arsenic (+V) easier to treat than arsenite, the redox state that has a greater acute toxicity. Fluctuations in pH and Eh can mobilize metals and adsorbed arsenic resulting in its sporadic occurrence in water supply wells.

Given the high levels of bacteria observed in the casing sample, arsenic would have been expected to be higher in the earlier time series samples and less in subsequent samples if it were the source, but arsenic concentrations did not vary substantially in the 10, 15 and 45 borehole volumes during testing, which might suggest an aquifer source. However, arsenic is not typically present at concentrations of concern in the SGA in Troutdale and surrounding areas and therefore hypothesis No. 1 still seems unlikely. Given the presence of nitrate observed at Well 7, the presence of arsenic may be associated with agricultural land use practices with arsenic based pesticides and herbicides that have infiltrated shallow groundwater hydraulically upgradient from Well 7.

Arsenic concentrations in Well 7 have been steadily decreasing since 2006; however, based on the available data it is uncertain if the decrease in arsenic concentrations is due to decreased operation of Well 7 since 2006 or a change in groundwater conditions near Well 7.

Bacterial Assessment

The loss of well capacity may be related to iron bacteria *Crenothrix* populations that were observed in the water supply system near Well 7 (E & E Services, 1993). Subsequent video surveys observed a depleted gravel pack and scale encrustation on the lower screen interval below 464 feet. The well was recommended to be cleaned, disinfected and the gravel pack replenished. Available information indicates that the well was superchlorinated in an attempt to control the bacterial population (E & E services, 1993).

The 2015 bacterial assessment strongly suggests that biofouling is the primary well clogging mechanism (Table 6). Microscopic and quantitative analysis indicate moderate to extremely high bacteria populations at Well 7, particularly in the casing sample. The ATP result for the casing sample was extremely high at 14.7 million cells/ml and the aquifer sample was above the threshold value of concern of 100,000 cells/ml. Both the casing and aquifer sample were observed to have iron and manganese oxidizing bacteria present. *Crenothrix* and *Leptothrix* were the primary iron related bacteria and are typically found together in heavily biofouled wells. Aerobic bacteria *Bacilli specie* and nitrate bacteria *Cupriavidus nectar* were also identified.

As noted previously, both the aquifer and casing samples had detectable concentrations of chlorine, which if present did not affect the mature and well established bacterial population within Well 7. Given the biological and chemical reactivity of chlorine in aqueous solutions, we suspect that the chlorine is a false positive due to interference in the colorimetric anlaysis.

Historic Well Video Review

The City provided two well videos of Well 7. The well videos were of generally poor quality; however, during video surveying of Well 6, the narrative by the operator from Well Scan (or Robinson and Noble) had commentary about observed "down hole" flow at Well 7. This narrative would be consistent with observations that only the lower interval was encrusted during the initial well redevelopment in 1993.

Based on the encountered geology, the two water bearing zones appear to be separated by significant clay to sandy clay layer(s) within the SGA. Downhole flow under static conditions has been observed in other wells completed in the SGA (GSI, 2014). The downhole flow may be promoting well clogging and/or biofouling by introducing water that has slightly different geochemistry, higher dissolved oxygen concentrations and/or nutrients into the lower portion of Well 7; however, given the differences in water quality of Well 7 and Well 8 (see next section) there may be another cause such as a well integrity issue (similar to those observed at Well 1B and Well 4 where the casing had corroded) allowing the introduction of shallower groundwater into the well.

Well 8 Assessment

Well 8 (MULT 4372) was installed in 1994 and is co-located with Well 7 at Sandee Palisades Park. Well 8 was originally tested at a yield of 1,200 gpm and a specific capacity of 17.6 gpm/ft of drawdown. Well 8 has experienced diminished well performance since installation and has undergone multiple rehabilitations with the most recent occurring in 2008. Similar to Well 3 and Well 6, the last redevelopment performed consisted of mechanical redevelopment assisted by a STPP dispersing agent followed by superchlorination of the well. Well 8 does not share the same high arsenic occurrence with neighboring Well 7, located several hundred feet away.

Well Construction

Well 8 has a bentonite annular seal from ground surface to 94 feet bgs, below 94 feet the well was reportedly sealed with slough and/or "squeeze" from the formations. Like wells 3 and 6 it does not meet current OWRD requirements due to the lack of an annular seal below the TSA. The well is screened over six intervals from 410 feet bgs to 533 feet bgs with 10-inch pipe size 40 slot stainless steel wire wrapped screen with an 8 x 12 gradation sand filter pack (Table 1). The screen has a design capacity of 2650 gpm at an entrance velocity of 0.1 ft/sec.

It should be noted that Well 8 does not share the shallower screen interval at Well 7 and has a much more conservative well screen and filter pack design over the lower interval of the well.

Well Performance

When originally tested in 1994, Well 8 had a 24 hour specific capacity of 17.9 gpm/ft of dd. The specific capacity ranged from 6.39 ft/dd to 6.98 ft/dd during the 2015 short duration step rate pumping test (Table 3). During the facility inventory in 2011, the operational specific capacity of Well 8 was observed to vary between 4.9 to 6.5 gpm/ft of drawdown at 471 gpm, which is approximately 30 to 40 percent of the original well performance. The minor variability in well performance observed during longer operational cycles is likely due to the influence of other groundwater wells including the City's Wells 6 and Well 7

Water Quality

Similar to as the City's other wells, Well 8 has had hydrogen sulfide and manganese affect its aesthetic water quality; however, Well 8 does not share the low pH, presence of arsenic or nitrate concentrations observed at nearby Well 7, located approximately 100 feet away. Key observations of Well 8 water quality from 2014 and 2015 sampling include the following:

- pH is slightly alkaline, ranging from 7.90 to 8.02 SU.
- LSI ranged from -0.4 to +.04 and was observed to change subtly with continued pumping.
- Manganese was 0.0443 mg/L, slightly less than the secondary standard of 0.05 mg/L.
- TON was 1.41 SU in 2014, well below the SMCL of 3.0 SU.

Water quality results for Well 8 are summarized in Table 5. Water quality trends suggest anaerobic (less than 2 mg/L) conditions, slightly reducing conditions (less than 0 mV) and an alkaline pH of 8.0 SU (Figure C-7). Due to the submersible pump motor, temperature increased slightly with increases in pumping rate. Additionally, ORP was observed to decrease with increases in pumping rate during 2015; however, during the final step it was observed to decrease while pH shifted slightly lower and dissolved oxygen increased slightly. These trends may reflect the influence on Well 8 water quality of Well 7 located only 100 feet away.

Bacterial Assessment

Well 8 was observed to have relatively low visible bacterial activity, but moderately high ATP counts in both the casing (693,000 cell/ml) and aquifer (206,000 cells/ml) sample. Iron or manganese oxidizing bacteria were not observed; however anaerobic growth was 10 percent. The major bacterial populations identified during microscopic analysis consisted of *Acidovorx temperans* and *Acinetobacter lwoffii.*

Relative to nearby Well 7, Well 8 well performance is not as affected by biofouling from a well performance perspective, but the moderate bacterial population may contribute to the observed hydrogen sulfide odor (TON 1.41 in 2014).

Historic Well Video Review

Well videos performed in 2001 (2) and 2004 were reviewed to evaluate the condition of Well 8. The well videos were performed prior to well redevelopment/cleaning in 2001. The well videos did not indicate any damage to the well screen or liner. In general, the condition of the screens was good with some plugging concentrated in the upper screens on "pre-cleaning" video. Tuberculation and/or pitting were noticeable in the upper portion of the casing, likely the result of bacterial and/or the hydrogen sulfide present in the well.

Well Assessment Summary

A summary of the individual well assessments is provided in Table 8. A brief summary of the conclusions derived from our assessment of the status of the City's groundwater supply wells are as follows:

- Well 2 does not appear to have any outstanding issues; however, access to measure water levels during operation should be improved and the well should be monitored as part of a preventative maintenance program.

- Well 3 appears to have a shallow groundwater influence based on its lower pH values and the presence of nitrate. Additionally, the well appears to produce sand at higher pumping rates which may indicate a well construction issue. Bacterial populations were at levels of concern and iron oxidizing bacteria were identified which would suggest biofouling as the primary clogging mechanism for well performance declines. Specific capacity was observed to be 2.02 gpm/ft of dd at the operational pumping rate of 202 gpm/ft of dd. The aggressive (or corrosive) water chemistry observed might suggest a well integrity issue related to its relatively shallow surface seal and corrosion or damage to the casing (similar to Well 4). Alternatively, the observed sand production in the well may have resulted in caving of native formation material along the casing allowing downward vertical flow from shallower zones. Options for well redevelopment or replacement of Well 3 may be limited due to the small property size and the location of the vault.
- Well 4 water quality has improved slightly over time with observed TDS values much less than historical reported values of up to 550 mg/L; however, the potential to form scale and mineral deposits within the distribution system is still a concern. Slime forming bacteria were present in the casing sample at levels of concern and anaerobic bacteria were observed. The bacterial population does not appear to have affected well performance which has been relatively consistent at approximately 12 gpm/ft of dd since 2006.
- Well 5 performance and yield do not appear to have changed substantially. Specific capacity does not appear to have changed substantially since installation in 2007. Overall water quality is good with slightly elevated manganese concentrations observed in 2014. The well is limited to a production rate of 1324 gpm based on the City's water rights assigned to Well 5.
- Well 6 specific capacity is 8.3 gpm/ft in 2015 at the operational yield of 475 gpm, an improvement from 2011 specific capacity reported in B &V (2011). Water quality and bacterial assessment suggests that a shallow groundwater source may be affecting Well 6. Well 6 previously had iron related bacteria populations; however, the 2015 results indicate lower levels of bacterial activity at Well 6. Well 6 is likely affected by well interference from the operation of City Well 8 and potentially other SGA groundwater users.
- Well 7 was observed to have a specific capacity of 12.0 gpm/ft of dd at the operational target rate of 488 gpm. Sand production at higher pumping rates has been a problem that has persisted since the well was originally constructed. Modifications were made to

the well in 1993 to try to arrest filter pack settlement due to the sanding issue and improve access to the screen area. Aesthetic water quality was poor at the start of pumping but improved after continued pumping. The observation of chlorine in the aquifer even with continued pumping is enigmatic, has no obvious source and would not be anticipated to persist given the chlorine demand based on organic carbon concentrations observed in the well and/or aquifer. Arsenic was observed at concentrations well below the historical values and the MCL. The presence of nitrate and the lower pH observed at Well 7 suggest a shallow groundwater source potentially related to the multiple screen intervals in the SGA or well integrity issues due to its relatively shallow surface seal and a corrosive groundwater condition in the well. Lastly, anecdotal evidence suggests that downward vertical flow has been observed in Well 7 since it was constructed, which may contribute to the extreme bacterial populations observed in 2015. Given the differences in water quality and well design between Well 7 and Well 8, the mixing of aerobic and anaerobic groundwaters between the shallow and deeper screened intervals within the Well 7 is likely promoting biofouling in the well.

- Well 8 has a specific capacity of 6.7 gpm/ft of dd at the operational target rate of 509 gpm during 2015 testing. With the exception of elevated manganese water quality was overall good. Bacterial populations consisting primarily of slime forming bacteria were present at concentrations of concern in Well 8 in both the casing and the aquifer sample. On this basis the well performance loss is likely due to biofouling; however, physical clogging of particulate accumulating within the filter pack cannot be eliminated based on observations of the well specific capacity improving during pumping (i.e. development).

SECTION 4

Customer Survey Results

As part of the comprehensive well assessment the City requested assistance with completing a customer survey program. The survey program incorporated a web based approach using the City's website portal and social media accounts (i.e. Facebook) to reach out to the larger customer base and also included phone interview of selected customers representing different water uses such as industrial, food service and commercial. Brief descriptions of the web based and customer outreach survey results are provided below for each program. The full results are included in Appendix E.

Web Survey Results

The City developed a web based questionnaire that was designed to illicit feedback regarding several aspects of the customers experience with City drinking water but focused primarily on water quality. The questionnaire was advertised on the City's monthly water bills sent to its water customers. The questionnaire hosted on the Survey Monkey website and made available to customers in early May through the City's web portal.

The respondents to the web survey were residential customers. Of those respondents seventy five percent (75%) rated their water quality as better than average and eighty three (83%) rated their service as better than average. The most typical complaints were related to odor (rotten eggs or earthy/musty smell), hard water (i.e. staining and scale) and color or cloudiness related to iron and manganese content.

Commericial Customer Outreach Survey Results

City staff provided a preliminary list of commercial customers to contact to interview regarding the quality of the City's water and it's suitability for industrial, commercial, manufacturing and food service uses. The initial list of commercial customers included the following:

- Toyo Tanso.
- Diebold Lumber.
- Tube Specialties.
- Ristorante Di Pompello, a restaurant.
- Travel Centers of America (several commercial water uses).
- Albertson's (with Starbucks Coffee).
- Skyland Pub.
- Cherry Park Market Center Dental office.
- McMenamin's Edgefield Lodge (several commercial water uses).
- One of the adult care facilities on 257th and Cherry Park Road.
- A motel in the Northern part of the City.
- A school within the City (Reynolds High School).

- A fast food customer in the southern part of the City.

The targeted outreach interview included an extended list of the questions included in the web-based survey. Of the customers and/or categories listed above, the City received responses from 12 customers. Diebold Lumber and McMenamins declined to participate in the survey. The responses are summarized in Table 9.

Customer Survey Summary

In general, the residential and commercial customers found water quality to be acceptable (Figure 4); however, taste, staining and odor issues were noted and in some cases treated using a point of use filter or water softener. Specifically, most of the odor complaints appear to be related to the Well 6, 7 and 8 service area (Figure 5) and are predominately hydrogen sulfide (i.e. “rotten egg” smell) and earthy/musty odors (Figure 6).

SECTION 5

Water Quality Treatment Options

This section describes the treatment options for water constituents that can cause aesthetic issues and/or are regulated as risks to human health based on chronic exposure under the Safe Drinking Water Act (SDWA).

Treatment

Based on the 2014 and 2015 water quality results, customer survey results, and interviews conducted with the City's Water Department Staff, it was anticipated that treatment of the City's source water might be needed to address water quality concerns at several of the individual wells. The water quality concerns faced by the City of Troutdale have included both primary (arsenic) and secondary contaminants (iron, manganese, odor and TDS), as identified in the drinking water standards established by the USEPA under the SDWA.

The primary standards are legally enforceable standards that apply to public water systems, and are intended to protect public health by setting guidelines for chronic exposure of water users to contaminants in drinking water. The secondary drinking water standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water quality. A summary of the national primary and secondary drinking water regulations (current as of 2015) is provided in Appendix F of this report for reference.

The secondary contaminants identified through interviews with City staff are iron, manganese, and TDS. Arsenic, a primary contaminant, and hydrogen sulfide, an unregulated contaminant, were also identified as water quality concerns. These contaminants have been problematic to the City for a number of years and as described previously, one of this study's goals was to address these concerns.

The process used by our team to evaluate the identified water quality concerns and evaluate the treatment options was as follows:

- Conduct project meetings with City staff to discuss the concerns
- Review available historical water quality data for all wells (2, 3, 4, 5, 6, 7, & 8)
- Conduct water quality sampling at each well to identify changes in water quality with continued pumping (Table 5)
- Review the typical operation and maintenance of the City wells and distribution system

A discussion of recommendations for the treatment or mitigation and management of these contaminants within Troutdale's water supply is described by contaminant below.

Iron and Manganese

Iron and manganese are naturally occurring and are present in minerals within the SGA and can affect drinking water systems. Secondary standards have been established for iron and manganese for aesthetic reasons and due to their staining potential. The SMCL for iron is 0.3 mg/L; the SMCL for manganese has been set at 0.05 mg/L. Iron and manganese are discussed together because of their similar behavior and the treatment methods.

Iron in a drinking water system can come from natural deposits in the ground, from the steel casings of a drinking water well, or from cast iron, ductile iron, or steel distribution system piping. Iron concentrations in the source water and distributions can also be related to the presence of iron-related bacteria populations in the well or distributions system. Iron causes red or brown staining on plumbing fixtures that accumulates over time.

Manganese in a drinking water system comes only from dissolution of naturally occurring manganese minerals within the source aquifer, for the City wells this is the SGA. Manganese causes black (sometimes described as dark brown) staining on plumbing fixtures that accumulates over time. Although not commonplace in SGA wells in the Portland area, elevated concentrations of manganese have been encountered in some areas, particularly in the vicinity of Troutdale, Fairview, Wood Village and Blue Lake Park; however, occurrences of manganese in the SGA are not well understood.

The alternatives available for the treatment of iron and manganese involve either chemical precipitation or adsorption of the contaminants. For the City of Troutdale, it would be desirable to accomplish this through a pressurized system since the water supply consists of wells that are pumped. Options include greensand filtration with a pressure filter, use of a proprietary adsorption media, or membrane filtration. All of these options have significant costs associated with them for capital construction and operation and maintenance.

Treatment utilizing any of the three methods discussed has a cost range of $1 to $2 million per well location where the treatment is required. The capital cost and the range would vary based on the type of treatment selected, the well production rate, the level of contamination being removed, space available to construct and house the treatment facility, and the methods available for disposing of the resulting waste material. In addition to the capital cost, the operation and maintenance cost for any of these systems is significant; they require increased licensure of the City's operation staff, expanded laboratory sampling requirements, higher power consumption, and chemical purchase and usage.

Total Dissolved Solids (TDS)

TDS includes any minerals, salts, metals, cations, or anions dissolved in water. TDS are comprised of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) plus small amounts of organic matter that are dissolved in the water. It is common for ground water to contain measurable TDS which can sometimes be significant. TDS causes the build-up of what may be commonly referred to as hard water deposits or scaling on plumbing fixtures and within a municipality's water system. Because of the aesthetic concerns with high levels of TDS, the established secondary drinking water criteria is 500 mg/L.

The treatment for TDS varies based on the specific chemical composition of a water source's TDS (i.e. hardness vs. salts). If the TDS is predominantly hardness-based (primarily calcium and magnesium), softening techniques are used to reduce the concentrations. Softening techniques may include lime softening, if the treatment is accomplished on a large scale at a single source, or adsorption. The use of adsorption-type water softeners is typically not used on a large scale at a single source due to the high sodium concentrations resulting from the process. (As with household water softeners, salt (sodium chloride) is used to regenerate the media. After regeneration, the media then releases sodium into the water which can cause concerns for people with high blood pressure.) Potassium chloride is an alternative, but it is significantly more expensive, and is not employed on large scale due to its cost.

If softening is required to remove hardness types of TDS, it is typically accomplished by homeowners with individual water softeners. The capital expense and operation and maintenance of the system is borne by the homeowner.

Hydrogen Sulfide

Hydrogen sulfide is an unregulated aesthetic concern that can cause the perception of a "rotten egg" or mineral odor in drinking water. Hydrogen sulfide can be detected by the nose at levels less than 1 mg/L; there is not an established drinking water criteria for hydrogen sulfide because it does not pose a health threat at the concentrations that are typically found in drinking water. Hydrogen sulfide is naturally occurring in some ground water sources, and is highly volatile and easily removed. It is typically associated with thermal or warm water sources, and is the byproduct of sulfate-reducing bacteria that can live within thermal aquifers.

The treatment for hydrogen sulfide on a large scale is accomplished via air stripping, which uses either forced airflow or a tower to remove the hydrogen sulfide. The simplest and most common form of removal is through an air stripping tower. The water is pumped to the top of a tower (typically 10 to 20 feet high) and cascades through a media source while air is forced upward through the media. The interaction of the air with the cascading water strips the hydrogen sulfide out of the water and releases it to the atmosphere. The water from the tower drains into a small tank, from which it is typically chlorinated and then pumped into the distribution system. The costs for these systems are in the general range of $600,000 to $1.0 million, depending on water flow rate and the contaminant concentration.

Arsenic

Arsenic is a primary drinking water contaminant with an MCL of 10 micrograms per liter (μg/L) or parts per billion (ppb). The most common source of arsenic in a drinking water system is the erosion/dissolution of natural occurring arsenic minerals. Arsenic can also come from surface contaminant sources, such as pesticides applied to agricultural areas that are washed through the soil into the deeper ground water aquifers. It has been observed only at City Well 7 at concentrations of concern.

Treatment of water that contains elevated arsenic concentrations include adsorption to media (either a proprietary media or activated alumina), or filtration through membranes. If the arsenic is in the dissolved form, oxidation may be required to convert it to a form that can be removed by adsorption or filtration. Some small water systems have used point-of-use treatment systems that are installed at each connection within the distribution system. This method would not be manageable or feasible for the City due to the number of connections.

Arsenic treatment at a well head requires the addition of a treatment unit that is sized to remove sufficient arsenic to produce water with arsenic levels below the MCL. The treatment technique is similar to that for iron and manganese, and the costs for construction ($1.0 to $2.0 million) and operation and maintenance are also similar to those for iron and manganese treatment. Arsenic does have the added complexity of disposing of the regeneration or backwash stream produced by the treatment process. Because the backwash contains concentrations of arsenic, it cannot be discharged to the environment without additional treatment. Many communities dispose of this waste stream through their wastewater system, which requires consideration of how the bio-solids at the wastewater treatment plant are handled. Since this may involve additional cost, a detailed preliminary study should be completed for arsenic treatment.

Blending Options

Blending of water sources to reduce the concentration of contaminants may also be a consideration. Blending requires dedicated piping to combine several water sources before delivery to the public. In addition, operational interlocks are required to prevent the contaminated water source from operating without the blending water source. This option can become costly if the City's water sources are not close together. The costs for this alternative are predominately capital costs that address the construction of blending pipelines and the necessary telemetry to inter-tie the operation of the two sources. Some additional operation and maintenance costs may be associated with this alternative but they are typically not significantly more than normal operations. Depending on the pipeline lengths, this alternative can range from the tens of thousands of dollars to well into the millions.

System Management

GSI and Keller Associates reviewed the City of Troutdale's water quality variability with continued pumping (Table 5). Based on the results observed in the 2015 sampling and sampling conducted by the City in 2014, system management may be a viable alternative to treatment for the City. This alternative would establish operational protocols for each of the seven wells, as well as the distribution system.

The operational protocols would include an extended pump-to-waste operation before a well is pumped into the system. The pump-to-waste period would be determined for an individual well based on the standing water volume of the well and observation of water quality parameters such as turbidity, pH and ORP. Extending the pump-to-waste interval will be especially important when a well has been off-line for a period of time. Another protocol would involve periodic operation of each well to avoid leaving a well dormant for significant periods of time, since leaving a well dormant allows the standing water column in the well to stagnate which may promote or worsen the water quality within a well.

A structured unidirectional system flushing program performed on an annual basis could also reduce the incidences of dirty or cloudy water as well as taste and odor complaints. In our review of the 2015 water sampling results, we identified that City wells have significant differences in their chemistry (as demonstrated by the Langelier Saturation Index and hardness). Each water distribution system (and/or service zone) develops its own natural biofilms based on the source water it receives and are sensitive to changes in water chemistry.

The City operates seven wells (using Well 7 sparingly), turning various wells on and off based on seasonal demand fluctuations and the water needs of the community. Since the wells have differing water chemistry, this process can cause subtle changes in the water chemistry within the distribution system. These subtle changes in water chemistry and system operation has been observed to cause biofilm sloughing which may be reported by customers as dirty, cloudy, or rusty water. These incidents can be managed by a structured unidirectional system flushing program and extended pump-to waste cycles as dormant sources are brought on line to meet seasonal demand.

SECTION 6

Action Plan Alternatives Analysis

This section presents a summary of the comprehensive well assessment and the action plan alternatives for enhancing existing well capacity, developing new well capacity, improving system water quality and protecting the City's groundwater assets.

Enhance Operational Capacity of Existing Wells

The operational capacity of existing wells can be increased in several ways. First, the City can complete several water rights transactions to allow pumping of wells 2 and 5 to their full physical capacity and, if feasible bring Well 7 back on line as an operational well. Second, Wells 2, 5, 7 and 8 may allow for higher pumping rates based on the available drawdown remaining at current operational pumping rates, particularly in Well 8. Lastly, the performance and capacities of Wells 3, 6, 7 and 8 have declined significantly over time, and capacity may be regained by implementing a structured rehabilitation program or in the case of Well 3 and Well 7 replacement of the well. Brief descriptions of each of these alternatives are provided below.

Water Rights Transactions:

The City has 1,892 gpm of unutilized water right capacity available to meet future needs (Table 2). The City should complete water rights transactions to align unutilized water right capacity with well production capacity, including that of both current and planned production wells. The specific details for water rights transactions were provided in the 2011 facilities inventory (Black and Veatch, 2012) and are summarized as follows:

- Make modifications to Well 2 to enable an assessment of well performance.
- Develop a Certificate of Beneficial Use (COBU) to document the City's historic use of water under T-3119 so that the water right may be certificated.
- Once a certificate is obtained for T-3119, submit a transfer application adding one or more of the City's current water supply wells as additional points of appropriation. At a minimum, we recommend that Well 5 be added as an additional point of appropriation as Well 5 has additional well production capacity beyond the water right capacity currently allocated to it and because Well 5 is the well associated with the sister permit, Permit G-6881 (i.e., in combination, T-3119 and Permit G-6881 would provide a year-round rate of 700 gpm for Well 5).
- Submit a permit amendment application for Permit G-9867 to reallocate the authorized rate of the permit among the wells currently associated with the permit (Wells 5, 6, 7, and 8). This reallocation of the permit rate would allow the City to maximize the production capacity of Well 5 and Well 7 (or a replacement well).

- Submit a permit amendment application for Permits G-8655 and G-11761 to add planned Well 9 as an additional point of appropriation to utilize the additional water right capacity under these water rights that is not being currently utilized by the City.

Additionally, the City's water use permits have a completion date of October 2017. The City will need to file for an extension of time to demonstrate completeness of the construction and full beneficial use of the water. Depending on the City's preferred strategy for replacing Well 7on Permit G-9867 and for the addition of Well 9 to Permit G-8655 and G-11761, the City will need to apply for the extension of time prior to performing the related water right transfers.

Additional Well Capacity

Well 2, Well 5, Well 7 and Well 8 appear to have additional capacity based on 2015 testing. Well 2 yield and performance suggests that it has additional capacity that could be developed. Modifications to Well 2 will need to be made to ascertain the additional capacity available. Well 8 has been observed to have 40 feet of additional available drawdown at the operational rate of 696 gpm during testing in 2015. The water right appropriation authorized rate for Well 8 is 1001 gpm. Based on the current specific capacity of Well 8 the City could pump the well up to 950 gpm (assuming 20 feet of water column above the intake). Well 5 has a current water authorized rate of 1324 gpm, but could be pumped at rates up to 2000 gpm.

Well 7 appears to have additional pumping capacity up to 800 gpm based on its observed specific capacity and available drawdown; however, it has been observed to produce sand at higher pumping rates. Limiting sand production could be accomplished with a downhole suction flow control (DSFC) screen installed below the pump. The DSFC screen limits mobilization of sand by utilizing a smaller diameter screen with a finer slot size (i.e. a well within a well) that better distributes flow through the well's screen interval and/or limits flow from certain sections of the well screen interval; however, additional frictional losses associated with more screen intervals installed in the well will occur and the additional production capacity a DSFC screen would provide is not certain. Lastly, the DSFC screen would likely be subject to the biofouling that persists at Well 7 and plugging of the DSFC screen would likely offset any improvements in well yield.

Increased pumping rates are not recommended at this time for Well 3, 4, and 6.

Alternatives for Well Performance Improvement

City Wells 3, 6, 7 and 8 all have experienced declines in well performance; however, GSI would only recommend that 6 and 8 be considered for further evaluation and redevelopment. Redevelopment at Well 6 and 8 would consist of a mechanical redevelopment and chemical treatment, if required. The costs associated with well redevelopment are well specific and may depend on observations during well video surveys, but based on similar projects in the SGA the estimated cost would be from $30,000 to $50,000 dollars for mechanical redevelopment and $80,000 to $120,000 dollars with chemical treatment. It is not recommended to perform chemical treatment without attempting mechanical redevelopment first. An outline of the recommended scope of work for mechanical redevelopment and chemical treatment are included in the updated Preventative Maintenance and Operations Plan (Appendix F).

Based on the potential additional production capacity, there is not a substantial difference in the cost per gallon for well rehabilitation of Well 3, 6, 7 and 8; however, if well reconstruction or other alternatives are required at Well 3 and 7 they will have substantially higher costs per gallon than Well 6 and Well 8. Further evaluation for Well 3 and Well 7 is described below.

Further Evaluation of Well 3

Prior to making a recommendation for well rehabilitation, further evaluation is required at well 3 to determine whether the observed water quality is related to a well integrity issue and whether sand production can be arrested or mitigated. Additional evaluation includes performing a well video survey to assess the condition of the well casing and screen in each of these wells. If an obvious condition cannot be identified the City may want to consider performing a static flow profile of the well using a dye tracing method or similarly sensitive method. Removal of the pump and motor during the video survey will allow the City to modify access tubes to the well in the event that flow profiling (or other tools) is required to perform further evaluation of borehole conditions.

Further Evaluation of Well 7

Well 7 could continue to be utilized with adjustments to the pump-to-waste program and if water right transactions allowing usage with Well 5 are completed. A similar approach to evaluate Well 7 could also be performed; however, there are several conditions that will limit the ability to redevelop/rehabilitate the Well 7 including:

- Overly aggressive filter pack and screen design, resulting in sand production limiting redevelopment methods
- Potential downward flow from shallower water bearing zones to deeper water bearing zones will persist without reconstruction.
- Potential well integrity issues related to the annular seal will persist without reconstruction.
- Extreme biological fouling relative to other wells as a result of water quality.
- Presence of arsenic historically.
- Apparent influence of Well 7 on Well 8 water quality during 2015 pumping.

As noted above a DSFC screen could reduce sand production in Well 7. If the evaluation determines a well integrity issue that could be resolved by the installation of a liner (similar to Well 4), reconstruction of Well 7 would likely be problematic. Due to the original construction, any installed liner insert will reduce the size of the pump that could be installed, further reducing production well capacity. On this basis, reconstruction and /or modification of Well 7 is not cost beneficial and would not likely substantially increase overall system capacity. If the City wishes to increase system capacity, GSI would recommend the City consider replacement of Well 7 and/or decommissioning of the existing well once well integrity problems are confirmed.

Groundwater System Expansion

The City has 1,892 gpm of unutilized water right capacity available to meet future needs (Table 2). A strategy needs to be implemented to protect and fully utilize this water right capacity. Adding a well would serve to help develop this unutilized water right capacity and increase the total supply capacity. The City has previously identified a future well location (Well 9) at the Strebin Road Reservoir site as part of future expansion of the water supply system. The City should consider a review of the location and OWRD records to make sure that conditions have not changed or identify additional information that may have become available (i.e. new nearby wells) since the original exploratory study in 2009.

Completion of a new production well at this (or another location) would accomplish a number of beneficial objectives, including:

- Capture unutilized water right capacity, as recommended above.
- Increase the City's firm source capacity to be able to meet the year 2030 MDD.
- Replace capacity that cannot be restored in deteriorating wells.
- Replace capacity from wells that produce lower quality water, such as wells 4 and 7.

We recommend that the City plan to construct a new well and replace one (or more) wells. Implementing the recommendations for enhancing the capacity of the existing wells should provide ample time for the City to develop the necessary funds for the new well (Well 9) and a replacement well. Estimates for installation and testing of a new SGA well range from approximately $450,000 to $600,000 based on 2015 cost estimates. Additional costs for the installation of the well house, pump, motor, controls and distribution housing are conservatively estimated to be $900,000 to $1,100,000, not including design cost.

While the potential exists for the City to fully utilize its water rights with the addition of a new Well 9, it may also want to consider replacing Well 3 and/or Well 7. The current Well 3 location has limited opportunity to site a new well due to site size limitations and interpreted poor hydrogeologic conditions. An alternative location within the service area may need to be identified; however, the Well 7 facility has sufficient options to site a replacement well near the existing well facility, which would allow the City to utilize the existing pumphouse, distribution system and controls already in place and minimize development costs.

This could be done using a pitless adaptor (or offset) well installation from the existing pumphouse. Besides potential cost savings, the Well 7 location has the advantage of an understanding of the hydrogeology, whereas the Well 9 would be an exploratory location and its production capacity is unknown (GSI, 2008). A properly drilled, designed and constructed well to replace Well 7 would likely be able to perform similar or better than the original well, limit sand production and also limit the influence of shallow groundwater. This would improve water quality particularly with respect to the arsenic, which is typically not present in the deeper SGA water supply wells in the Portland Basin. Water rights transactions would be required to increase the flexibility in using the replacement well for Well 7 in conjunction with Well 5.

Water Quality Management Alternatives

After evaluating the water quality results for the City of Troutdale (which included both 2014 and 2015 sampling reports for wells 2, 3, 4, 5, 6, 7, and 8), we believe that a distribution system management approach will be the best solution to address water quality concerns. Per the original scope for this study, our team reviewed treatment options presented in Section 5 of this report.

However, based on the review of recent water quality data, we conclude that treatment would likely be a costly and unwarranted approach for the City. This conclusion is supported by the responses to the customer surveys that were conducted. While some of the responses may appear to be clustered when you consider the system with the City's operation of their wells in each service zone, the reports of poor water quality seem to be more global in nature. The water quality concerns are more related to SGA groundwater quality and distribution system maintenance than to a single source or well specific concern. This agrees with the well sampling results.

Iron, manganese, TDS, hydrogen sulfide, and arsenic were all reviewed specifically to quantify the concerns expressed by the City. In our review of the water quality results, we did find elevated levels for some of these constituents; however, we also found evidence that these levels can likely be managed through system operations rather than treatment. Though the iron levels reported in Wells 4, 6, and 7 are all above the SMCL for the casing (first draw) samples, the total iron level in the aquifer samples is below the SMCL in all but one well. Iron (resuspended) levels above the SMCL in the aquifer sample for Well 4 and Well 7 are likely due to the release of trapped particulate iron that has been deposited by iron-fixing bacteria during long periods of well inactivity. This suggests that consistent pumping of the wells and the use of a pump-to-waste protocol will likely mitigate iron concerns without the installation of treatment.

A pump-to-waste cycle should be established for Wells 4, 6, and 7. These should include a seasonal first start-up protocol, which will likely be manually initiated by the operations staff and monitored to ensure the iron level has reduced before the well is placed in an automatic mode. The second protocol that should be considered is the amount of time the well should pump-to-waste automatically when it is called for in the normal operation of the system. Pumping to waste should continue until the water quality parameters of turbidity, specific conductance, ORP and pH stabilize and are indicative of low concentrations of biofilm, accumulated solids and sediment, and improved water quality. Stabilization times of these parameters will be well specific and additional monitoring of iron and manganese concentrations should be performed at some of the City wells.

The manganese levels reported in Wells 6 and 7 are also above the SMCL for the casing samples. However, the aquifer samples are zero and non-detect respectively. As with the recommendation for iron, the best solution for the mitigation of the elevated manganese concentrations is likely a consistent seasonal (manual) and normal operation (automatic) pump-to-waste protocol. This protocol should also be established as described above for iron. Testing should be completed to determine the optimum pump-to-waste timing, to ensure that excess amounts of accumulated iron and manganese are not pumped into the system. A field test kit that utilizes a colorimetric method to measure the manganese concentration in the water should be used. The water should be tested on 5 minute increments to determine the optimum pump to waste time for normal operation. Less frequent monitoring intervals could be used for wells that are seasonally operated or remain idle for long periods of time.

Treatment of the elevated TDS in Well 4 (312 mg/L reported in 2014) is an option the City should consider. The reported level is well below the SMCL of 500 mg/L for TDS. As described in Section 5, TDS is typically addressed through the installation of private residential water softeners. An alternative to water softening could be blending. This approach would require the construction of transmission piping and the operational inter-tying of two wells. Reviewing the TDS in the remaining wells, it appears that a blending strategy would be successful in reducing the TDS of the water being delivered to customers from Well 4 to a level in the mid-200's. The costs of constructing a blending pipeline and increasing the operational complexity of the well should be considered. A blending pipeline will be specific to the route selected and the length and diameter of the pipeline. Costs for this alternative can range from $50 to $120 per foot depending on pipeline diameter, length, and the surface repairs necessary after installation of the pipe.

For hydrogen sulfide, we recommend further study to verify that the reported hydrogen sulfide odor is coming from a ground water source, rather than as the result of poor water quality within the distribution system. This would require evaluation of water quality within the distribution system to determine if sulfate reducing bacteria (or other biofilm consortiums) are present within the distribution system and measurement of hydrogen sulfide at each well head and within other areas of the distribution system. Treatment options for hydrogen sulfide are dependent on the concentrations that the hydrogen sulfide is present in the groundwater well(s) or within the distribution system. At lower concentrations aeration/air stripping (less than 2 mg/L), filtration (up to 10 mg/L) and chlorination (up to 75 mg/L). Air stripping systems can be expensive because it requires re-pumping after aeration and filtration systems require continuous operation, maintenance and replacement/regeneration of filter media. The most cost effective treatment for hydrogen sulfide at low levels typically is chlorination, which is the current disinfection method the City utilizes at its individual water supply wells.

If the City determines the hydrogen sulfide persistence can be attributed to higher hydrogen sulfide concentrations in a single well (such as Well 6), testing should be conducted to determine if dosing or an adjustment in dose of chlorine solution has an effect on the hydrogen sulfide. This can be conducted on a bench scale with sodium hypochlorite before a decision is made to treat. It is also recommended that distribution system maintenance be performed in the areas that are reporting the hydrogen sulfide odor. The testing results at Wells 3, 6 sand 7 did identify low levels of sulfate, which can be a source of hydrogen sulfide if sulfate-reducing bacteria are present within the distribution system. A pump-to-waste protocol could also be beneficial to remove any hydrogen sulfide that may have accumulated in a well source while idle.

Arsenic was the final contaminant of concern included in this evaluation. The 2014 and 2015 water quality sampling results indicated that the City has two wells that contain low levels of arsenic: Well 3 at 0.3 ppb and Well 7 at 0.497 ppb to 0.83 ppb. The observed concentrations are well below the 10 ppb MCL for arsenic. From the sample information that has been reviewed for this report to establish current conditions, we do not believe any treatment is necessary for arsenic in the City of Troutdale's wells. The City should continue to monitor arsenic concentrations as required by OHA as part of their routine drinking water quality sampling.

The conclusion of the treatment options analysis that was completed for the City of Troutdale's drinking water wells indicates that implementing some management approaches will likely have a significant impact on water quality. Three approaches are outlined below:

1. A more robust pump-to-waste program should be established for each of the City's seven wells. This program should develop pump-to-waste times for each well for two scenarios.

    - The first scenario is the seasonal start-up protocol when the well is being added to the system after a period of inactivity. This should be a manual process. The pump-to-waste period should be significant enough to ensure that the concentrations of iron, manganese, and hydrogen sulfide as applicable to each individual well, are acceptable before the water is introduced to the distribution system. This will be unique for each well and is determined through field trials.

    - The second scenario is pump start-up to meet system demands after the well has been placed into service. For this situation, the pump-to-waste scenario should be automated, and will be significantly shorter than the seasonal start-up protocol. The well should be pumped to waste long enough to remove any minor contaminant build-up that may have occurred since its last start.

2. A second recommended water quality management approach is a bi-annual unidirectional distribution system flushing program. A unidirectional flushing program can have a significant impact on the City's current water quality concerns, and will help control dirty or cloudy water complaints due to re-suspended iron and bio-film buildup.

    - The flushing program should start at the well head and work its way outward to the interface of the next well within the service zone or distribution system tie-in.

    - The length of time the system should be flushed at each point should be calculated to ensure the flushing is accomplishing its intended purpose. Hydrant exercise typically does not constitute a long enough period of time for a beneficial flush to occur. Flushing times at each location may reach 10, 20, or 30 minutes, depending on the length and diameter of the pipeline being flushed.

    - As the flushing is occurring, the pipeline should be isolated so the water is forced from the source through the flushing point. If water comes from side branches, the water velocity will be too slow to accomplish an effective flush.

- A preliminary flushing program can be confirmed by a hydraulic model, if one exists, before it is implemented in the distribution system.

- Once the system has been thoroughly flushed, maintenance flushing can be accomplished at shorter durations to maintain the distribution system.

We recommend that the City flush starting from the wells to remove iron and manganese sediments that are precipitated within the distribution system due to oxidation reactions after disinfection with the chlorination solution. We recommend that wells be used a minimum of 3 weeks every three months. This is a good starting point and should be adjusted based on long term observations to optimize the water quality.

3. The final recommendation is operating the wells at lower flow rates more frequently to meet water demands, rather than allowing them to be inactive for long periods during low demand. The benefits of longer pumping at lower flow rates includes consistent water movement through each well, reduced stress on the aquifer, and limiting the introduction of oxygen. This approach will help prevent the buildup of contaminants such as iron and manganese, and may help to reduce the hydrogen sulfide concerns.

   It should be noted that reductions in flow rates can lead to deposition of sediments and particulate within the distribution system. However, a high velocity flushing protocol as described above, which the operations staff has indicated they currently employ, would remove any deposition within the distribution system.

   Any flowrate reductions would be to allow supply to more closely meet demand during low demand times. Lowered or reduced pumping rates would likely require the coordination of the well control system, and would be the most beneficial if wells are operated on VFDs like Wells 3, 5 and 6. If VFDs are not installed, another way to accomplish this would be to rotate the wells on an established schedule, with each well being used as a lead well at least once per month. The changes in supply well operations will have to be reviewed with the City operations staff to determine the challenges that exist in accomplishing this change in source water supply operational schedule.

The water quality of the City's wells is good overall and does not warrant additional cost that would be required by treatment. Adjustments to operating the wells and distribution system should provide cost-effective improvements to City drinking water quality, but may require additional City resources to implement (i.e. the unidirectional flushing program).

SECTION 7

Action Plan

The action plan for the City includes both short term actions and longer term planning level actions to protect the City's groundwater assets, improve system water quality and provide additional capacity. Water right transaction and associated planning level costs estimates for preparation and submission to OWRD are provided below. The recommended short term and long term actions are also presented below; estimated costs and required resources for each well maintenance action and well replacement action are included in Table 10. Appendix G has specific and general scope of work documents for well maintenance actions identified in Table 10.

Water Rights Transactions and Planning Level Costs

1. The City should submit the updated WMCP to the OWRD to meet the requirements of the outlined in the final orders of the Extension of Time applications for Permit G-6881, Permit G-9866 and Permit G-9867. Costs to update the WMCP are dependent on changes to the WMCP approved by OWRD in 2005 and on availability of records to support the required information to complete the update but generally are $10,000 to $25,000 dollars; OWRD fee $ 1,800 dollars.

2. Develop a COBU to document the City's historic use of water under T-3119 so that the water right may be certificated. The water use data needed to support the COBU must be from before the completion dates (C-date) of October 1, 1993. Planning level cost estimate: COBU preparation $3,000; OWRD fee $0; optional (but recommended) expedited review by OWRD $1,000 dollars.

3. Develop additional groundwater supply at Well 2 through a new TSA water right application. Application preparation: $1500 dollars; OWRD fees $1650.

4. The C-dates for Permits G-6881, G-8655, G-9867, G-9866, and G-13565 are all October 1, 2017. Prepare extension of time applications for each permit (5 total) requesting additional time to develop the water use authorized under the permits. The driving need for the time extension is to refurbish and/or replace wells. Planning level cost estimate: Application preparation $10,000; OWRD fees $2,875 dollars.

5. Prepare a transfer application for the certificate resulting from the certification of T-3119 to add one or more existing or planned wells to replace the single well listed on this water right (Drinker Well). Planning level cost estimate: Application preparation $3,000 dollars; OWRD fee $1,350 dollars.

6. Prepare permit amendment application for Permits G-6881, G-8655, G-9867, G-9866, and G-13565 to change and/or add well(s) to the permits sufficient to allow the City to appropriate the full rate authorized under the permits based on observed

operational rates and allow flexible allocation for a future well(s). Planning level cost estimate: Application preparation $10,000 dollars; OWRD fee $6,500 dollars.

Short Term Actions (2015 to 2018)

1. Adjust pump-to-waste operations to diminish sediment, hydrogen sulfide and biofilm introduction into the distribution system when bringing wells online. The costs to perform this include City staff time and water quality parameter monitoring equipment and/or analytical lab costs.
2. Consider reducing operational pumping rates of wells and implementing longer run cycles for filling reservoirs, if possible. This may require some trial and error adjustment by City staff, but no other associated costs are anticipated.
3. Periodically perform a structured unidirectional flushing program to remove accumulated biofilm, sediment and mineral precipitates from the distribution system. Costs to perform this consist of City staff time and analytical laboratory fees (optional testing for bacterial populations and/or scale analysis).
4. Modify Well 2 to allow access and evaluate if additional capacity exists (see Table 10 for planning level costs).
5. Perform well video surveys at Wells 3, 6, 7 and 8. Recommendations for future redevelopment, reconstruction or maintenance activities will depend on observations of the condition of the wells. For planning purposes we recommend the City plan for at least 2 well redevelopment efforts at Well 6 and either Well 3 or Well 8 (see Table 10 for planning level costs).
6. If the City elects to perform Well 8 redevelopment it should also consider decommissioning Well 7 (depending on well integrity evaluation results) at the same time since 2015 observations suggest that nutrient and dissolved oxygen migration from Well 7 influences Well 8 during pumping and may promote biofouling at Well 8 (see Table 10 for planning level costs).
7. Implement the Preventative Maintenance and Operations Plan (PMOP) annual maintenance monitoring program at all City Wells to identify well maintenance, water quality and well redevelopment (Appendix F).

Long Term Action Plans (2015 to 2020)

1. Develop additional groundwater supply at the proposed Well 9 location for redundancy and long term projected demand (see Table 10 for planning level costs). As part of this action the City should revisit the Well 9 siting study to evaluate whether groundwater conditions have changed and/or additional groundwater wells that might provide additional information on local hydrogeology have been installed since the original study. Costs to review and/or update of the siting study are approximately $7500 dollars.

2. Evaluate other potential well locations within the City's service areas should other Well 3 or Well 7 need to be replaced. This could be done in conjunction with the re-evaluation of the preferred location for Well 9 recommended above.

3. Periodically revise and continue to implement the PMOP based on observations of well redevelopment effectiveness, identified well maintenance and water quality improvement needs at City water supply wells or within the distribution system (Appendix F). Costs to revise the PMOP will be dependent on identified needs, well and pumping system modifications and future expansion of the City's water supply; however, planning level costs for annual review of well performance testing, pump and motor performance and water quality testing performed by City staff are approximately $5,000 dollars.

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Tables

Table 1. Well Construction and Pump Installation Summary

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

Well Construction Information, Historical Yield and Specific Capacity 2015

Well Name (OWRD Well ID)	Year Constructed	Aquifer	Depth Drilled (ft bgs)	Seal Depth (ft bgs)	Well Casing Diameter (inches/Type)	Screen Interval (ft bgs) Slot Size in Parentheses	Filter pack Interval(s) (feet bgs)	Screen Diameter (inches/Type)	Static Water Level during Installation (feet bgs)	Original Yield gpm/MGD [1]	Original Specific Capacity [2] (gpm/ft of dd)	Reported Specific Capacity 1993 [1] (gpm/ft of dd)	Reported Yield 1993[2] (gpm/ft of dd)	Operationa;l Yield 2010- 2015 (gpm)[3]	Reported Specific Capacity 2015 near Operational Rate (gpm/ft of dd)	% of Original Specific Capacity
Well 2 (MULT 1430)	1976	TSA	485	65	10 PS	450 to 456 (20 slot) 456 to 480 (35 slot)	None	10 T	280	550/0.79	7	7	490	490	NA	--
Well 3 (MULT 1429)	1979	SGA	615	60	12 PS	510 to 530 (60 slot) 535 to 545 (60 slot)	481 to 550 No. 6 Monterey Sand	8 PS	288	600/0.865	5	7.5	390	150	2.4	48.0%
Well 4 (MULT 1340/93369)	1980/2008	SGA	573	98.2(ben. Chips) 438(Cement)	12 PS	470 to 572 (30 slot)	No. 8 Sand 469 to 571	6 PS	118	900/1.297	11.2	15.5	700	650	12.3	109.8%
Well 5 (MULT 90881)	2007	SGA	697	525	16 PS	515 to 561 (40 slot) 575 to 581 (40 slot) 636 to 673 (40 slot)	CSS 10 X 20 491 to 679	12 PS	304.5	2000/2.88	90 [4]	NA	NA	890	81.4	90.4%
Well 6 (MULT 67091)	1981	SGA	545	195	12 PS	467 to 477 (30 slot) 482 to 492 (30 slot) 497 to 507 (30 slot) 512 to 522 (30 slot) 527 to 532 (30 slot)	Sand Aqua No. 8 381 to 544	6 PS	205.4	900/1.297	14	8	500	490	8.3	59.3%
Well 7 (MULT 1444)	1980	SGA	575	20	12 PS	360 to 385 (100 slot) 465 to 475(100 slot)	3/4 to 7/8 inch washed 320 to 538	6 T	174	1000/1.44	18.6	16	550	515	10.7	57.5%
Well 8 (MULT 4372)	1994	SGA	548	50 (ben.); and from 50 to 94 and 94 to 378 (ben. Slough/squeeze? See well log)	12 PS	410 to 415 (40 slot) 435 to 450 (40 slot) 454 to 474 (40 slot) 485 to 495 (40 slot) 505 to 515 (40 slot)	8 X 12 378 to 548	10 PS	185	1200/1.73	17.6	NA	790	570	6.6	37.5%

Pump Installation Information and 2010-2011 Testing Summary

Well Name	Pump type	Pump Model/Stages	Motor Horsepower	Pump Design Flow Rate	Pump Target TDH	Pump Intake Set Depth (feet bgs)	Date Tested	Transducer Set Depth	Water Above Transducer (feet)	Static Water Level (ft bgs)	Transducer Reading (feet of water above transducer)	Tested Pumping Rate 2010-2011(gpm)	Drawdown (feet)	Specific Capacity	Maximum Capacity in 2011[3]	Water Right Permitted Rate (gpm)
Well 2	VLS	Peerless 9LA 17 stage	100	500	561	452.03	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]		NA [1]	7	500	449
Well 3	SUB	Goulds 9WAC 4 stage	100	500	580	451	7/10/2010	440	150.0	290.01	10	285	140	2.0	285	285
Well 4	SUB	Goulds 8RJHC 4 stage	75	600	363	322	4/5/2010	320	88	232	67	567	21	27.0	600	600
Well 5	VLS/VFD	Fairbanks Morse 12S.3+ 9 stage	350	2000	520	438	6/13/2011	430	143.6	286.43	107	1403	36.6	38.4	2000	1370
Well 6	SUB	Goulds 9WAC 4 stage	100	400	579	360	6/10/2011	352	144	208	72	476	72	6.6	400	400
Well 7	SUB	Floway 10DKH 12 stages	125	720	470	290.58	7/28/2010	270	75	195	22	518	53	9.8	538	538
Well 8	SUB	Goulds 12CHC 8 stage	200	1200	515	336	6/10/2011	321	142.12	178.88	64	471	78.1	6.0	735	735

Notes:

ft bgs = feet below ground surface
gpm = gallons per minute
MGD = million gallons per day
cfs = cubic feet second
TSA = Troutdale Sandstone Aquifer
SGA = Troutdale Sand and Gravel Aquifer

gpm/ft of dd = gallons per minute per foot of drawdown
SUB = submersible
VLS = vertical line shaft
VFD = variable frequencey drive
slot size = 30 slot = 0.030 inches
CSS = Colorado Silica Sand

PS = pipe size
T = telescopic

[1] Well Yield from OWRD Well logs and E & E (1993)

[2] 1993 Yield and specific capacity estimates from E & E (1993)

[3] Well capacity based on 4-hour pumping tests conducted in 2011.

[4] Theoretical Maximum Capacity: If a well had greater than 20 feet of available drawdown during the testing, the well capacity from the 2010/2011 testing was adjusted using the well's specific capacity to either the maximum flow rate conincident with 20 feet of pump submergence or the design flow rate of the well pump to generate a theoretical maximum capacity.

[4] Estimated Well 5 specific capacity based on short duration step rate pumping test at 1400 gpm

Table 2. Allocation of Water Right Capacity on Existing Water Rights

City of Troudale Comprehesive Well Assessment and Action Plan, 2015

Water Right ►	T-3119 ~~Cert. 34708~~ Per. G-2320 App. G-2512	T-9484 Per. G-6881 App. G-6627	50525 Per. G-7035 App. G-7589	Per. G-8655 App. G-9291	T-10208 T-7453 Per. G-9867 App. G-9714	T-10341 Per. G-9866 App. G-9583	Per. G-11761 App. G-13565	Total Water Right Rate
Water Right Appropriation Rate Authorized (cfs)	0.81	0.75 | 1.56	1	1.1	4.4	2.2	2.23	12.49 cfs
Water Right Development Limitation Condition Rate (cfs) [1]	0.81	***0.33***	1	1.1	***0.834***	***0.492***	2.23	***7.22*** cfs
Water Right Appropriation Rate Authorized (gpm)	**364**	**337 | 700** [2] **700**	**449**	**494**	**1,975**	**987**	**1,001**	**5,606 gpm**
Priority Date	*12/26/1962*	*8/19/1974*	*11/2/1976*	*6/26/1979*	*5/1/1980 (50%)* *12/16/1981 (50%)*	*7/17/1981 (50%)* *9/20/1982 (50%)*	*11/26/1993*	
Completion Date	*10/1/1993*	*10/1/2017*	*n/a*	*10/1/2017*	*10/1/2017*	*10/1/2017*	*10/1/2017*	

Well Name	Source	Well Capacity (gpm) [3]	Water Right Use Allocated by Well (gpm)							Well Capacity Allocated (gpm) [4]	Well Capacity Remaining (gpm)
			T-3119	T-9484	50525	Per. G-8655	T-10208	T-10341	Per. G-11761		
Drinker Well	**SGA**	**0**	**0**	**0**	n/a	n/a	n/a	n/a	n/a	0	0
Well 2	**TSA**	**490**	n/a	n/a	**449**	n/a	n/a	n/a	n/a	449	41
Well 3	**SGA**	**150**	n/a	n/a	n/a	**150**	n/a	n/a	n/a	150	0
Well 4	**SGA**	**650**	n/a	n/a	n/a	n/a	n/a	**650**	n/a	650	0
Well 5	**SGA**	**890** (4)	n/a	**337**	n/a	n/a	**553**	n/a	n/a	890	676
Well 6	**SGA**	**490**	n/a	n/a	n/a	n/a	**490**	n/a	n/a	490	0
Well 7 (5)	**SGA**	**515**	n/a	n/a	n/a	n/a	**515**	n/a	n/a	0	515
Well 8 (6)	**SGA**	**570**	n/a	n/a	n/a	n/a	**0**	n/a	**570**	570	0
Well 9	**not drilled**	**0**	n/a	n/a	n/a	n/a	n/a	**0**	n/a	0	0
Water Right Appropriation Rate Allocated (gpm)			0	337	449	150	1558	650	570		
Water Right Appropriation Rate Remaining (gpm)			364	0	0	344	417	337	431		

Notes:

[1] Water right "Development Limitation" were imparted as part of the conditional approval of the Extension of Time for Permit G-69867, G-9866 and G-6881. Authorized rates less than water right appropriation shown in bold italics.

[2] Rate of use reduced during irrigation season: 337 gpm during irrigation season, 700 gpm during non-irrigation season

[3] Well capacity based on operational rates provided by City in March 2015.

[4] Well 5 can be operated at a much higher instantaneous rate than current operation; however Well 5 is limited to 987 gpm cfs on T-10208 (shared with Well 7) and 337 gpm under T-9484 [1324 gpm total]

[5] Well 7 is not currently operated. Allocation of well capacity based on 2015 reported pumping rate. See note #2 above.

[6] Well 8 is allocated up to 987 gpm (2.2 cfs) and can utilize any remaining water right allocation not used by Well 5, 6 and 7 under permit amendment T-10208.

Table 3. Well Construction and Pump Installation Summary

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

Well Construction Information, Historical Yield and Specific Capacity												
Well Name (OWRD Well ID)	Year Constructed	Static Water Level during Installation (feet bgs)	Original Yield gpm/MGD (1)	Original Specific Capacity (2) (gpm/ft of dd)	Transducer Set Depth (ft brp)	Yield 2010- 2011 (gpm)	Reported Specific Capacity 2010-2011 (gpm/ft of dd)	% of Original Specific Capacity	Reported Specific Capacity 2015 (gpm/ft of dd)	2015 Operational Pumping Rate (gpm)	Maximum Pumping Rate during Step Rate Testing 2015(3)	Water Right Permitted Rate (gpm)
Well 2 (MULT 1430)	1976	280	550/0.79	7	NA (1)	NA	NA	--	No apparent decline in yield or performance	490	500	449
Well 3 (MULT 1429)	1979	288	600/0.865	5	440	285	2	40.0%	2015: 2.02 gpm/ft @ 202 gpm Origiinal: 5 gpm/ft @ 600 gpm	150	222	494
Well 4 (MULT 1340/93369)	1980/2008	118	900/1.297	11.2	320	567	27	241.1%	2015: 11.6 gpm/ft @611 gpm 1993: 15.5 gpm/ft @ 900 gpm	650	647	987
Well 5 (MULT 90881)	2007	304.5	2000/2.88	90 (4)	430	1403	53.9	59.9%	2015: 69 gpm/ft @ 1485 gpm 2007: 72 gpm/ft @1400 gpm	890	1736	1,975/337
Well 6 (MULT 67091)	1981	205.4	900/1.297	14	352	476	6.6	47.1%	2015: 8.2 gpom/ft @ 493 gpm Original: 14 gpm/ft @ 900 gpm Well Interference	490	499	1975
Well 7 (MULT 1444)	1980	174	1000/1.44	18.6	270	518	9.8	52.7%	2015: 10 gpm/ft @ 551 gpm Original: 18.6 gpm/ft @ 1000 gpm Well Interference	515	588	1975
Well 8 (MULT 4372)	1994	185	1200/1.73	17.6	321	471	6.5	36.9%	2015: 6.8 gpm/ft @ 518 gpm Original: 17.6 gpm/ft @ 1200 Apparent decrease since 2011: 3 gpm/ft (9.8 @ 518)	570	696	1,001/1,975

Notes:

ft bgs = feet below ground surface

gpm/ft of dd = gallons per minute per foot of drawdown

gpm = gallons per minute

MGD = million gallons per day

[1] Well Yield from OWRD Well logs and E & E (1993)

[2] 1993 Yield and specific capacity estimates from E & E (1993)

[3]Well capacity based on maximum tested rate during step rate pumping tests conducted in 2015.

Well 2: 490gpm
Well 3: 150gpm @ current speed setting, will require significant throttling at full speed
Well 4: 650gpm
Well 5: 890gpm @ current speed setting
Well 6: 490gpm @ Hz
Well 7: 515gpm and throttled to unknown pump head
Well 8: 570gpm but is throttled to 140psi pump head

Table 4. Aquifer and Turbulent Well Loss Estimates

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

		Hantush-Beirshenk Solution		Theis Solution			General Guidance for Well Loss Coefficient[2]						
Well	**Slope on Hantush-Beirshenk Plot[1]**	**B day/ft^2**	**C day^2/ft^5**	**B day/ft^2**	**C day^2/ft^5**	**Skin Factor S_w**	**new Well C < 6.7E-10**	**Mild Deterioration 6.7E-10 < C < 1.3E-9**	**Well Beyond Rehabilitation C > 1.3E-9**	**Original Transmissivity Estimate [3] (ft^2/day)**	**2015 Transmissivity Estimate (ft^2/day)**	**Well Loss due to Laminar Flow (L_p) as % of Total Head Loss**	**Notes [4]**
Well 3	Negative	2.65E-03	-1.12E-09	7.19E-04	4.17E-10	10.0	X			1,340	1,200	102.0%	Well appears to be developing
Well 4	Positive	3.69E-04	4.51 E-10	3.53E-04	2.53E-10	10.9	X			3,041	7,500	86.8%	--
Well 5	Positive	4.51E-05	1.01E-10	2.95E-05	2.92E-11	-4.5	X			15,410	11,000	56.2%	--
Well 5 - 2007	Positive	1.39E-05	3.89E-10	1.59E-05	7.10E-11	-5.0				15,410	9,700	--	--
Well 6	Positive	5.79E-04	5.53E-10	3.45E-04	6.20E-10	0.4	X	X?		3,832	2,400	52.2%	--
Well 7	Positive	2.14E-04	2.48E- 9	1.63E-04	2.37E-09	-0.9			X	4,154	4,900	43.3%	--
Well 8	Negative	7.86E-04	-4.53E-11	4.72E-04	4.82E-12	10.0	X			5,896	4,000	100.8%	Well appears to be developing

Notes:

[1] A negative slope on the Hantush-Beirshenk plot indicates that the well is developing.

[2] General guidance numbers from Walton (1970). These numbers are for general guidance and well specific information should be used, particularly in the case of Well 3 and Well 8 where the C value may not be representative.

[3] Original transmissivity estimated using the wells original specific capacity using the method of Driscoll (1986) for Wells 3, 4, 6, and 7. Well 5 and Well 8 were calculated values were from the orignal well construction reports

[4] Development of a well is the improvement of well performance by removal of fine grained particles, sediment or biofilm in the well screen, filterpack or aquifer sediments that may be limiting groundwater flow to the well. In older wells, this typically results from higher intake velocities at higher pumping rates. Typically well performance decreases as the pumping rate and duration increases.

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Table 5. Summary of City of Troutdale Inorganic Well Assessment

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

		Well 2		Well 3		Well 4		Well 5		Well 6		Well 6		Well 7 [1]		Well 8	
		3/17/2015		3/25/2015		3/17/2015		3/17/2015		11/20/2006		3/25/2015		3/17/2015		3/25/2015	
Analyte	Units	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer
2015 Water System Engineering Results																	
pH Value	mg/L	8.06	8.22	***6.99***	***6.96***	8.17	8.17	8.01	8.01	***7.2***	***7.5***	7.85	7.9	***7.15***	***7.13***	7.9	8.02
Phenolphthalein Alkalinity	mg/L	4	4	ND	ND	ND	ND	ND	ND	0	0	ND	ND	ND	ND	ND	ND
Total Alkalinity	mg/L	112	112	88	92	160	160	112	116	112	108	124	128	124	104	136	140
Hydroxide Alkalinity	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0	0	ND	ND	ND	ND	ND	ND
Carbonate Alkalinity	mg/L	8	8	ND	ND	ND	ND	ND	ND	0	0	ND	ND	ND	ND	ND	ND
Bicarbonate Alkalinity	mg/L	104	104	88	92	160	160	112	116	112	108	124	128	124	104	136	140
Total Dissolved Solids	mg/L	158	138	158	150	221	219	170	200	171	165	143	208	158	104	186	184
Conductivity	µm or µS/cm	220	191	220	209	307	304	236	278	238	229	199	209	220	161	258	255
Oxidative Reduction Potential	mV	197.6	191.7	212.9	208.5	202.9	209.1	205	199.7	147	112	181.1	166	206	224	201.1	199.7
Langelier Saturation Index	SU	0.014	0.18	***-0.94***	***-1.1***	0.56	0.14	0.03	0.08	***-1.57***	***-1.28***	-0.12	-0.19	***-0.7***	***-0.8***	-0.09	0.04
Total Hardness	mg/L	72	80	80	88	104	80	72	72	32	28	56	56	88	80	40	44
Carbonate Hardness	mg/L	72	80	80	88	104	80	72	72	32	28	56	56	88	80	40	44
Non Carbonate Hardness	mg/L	0	0	0	0	ND	ND	0	0	0	0	0	0	0	0	0	0
Calcium	mg/L	48	44	56	44	68	52	40	44	20	20	36	28	48	48	32	32
Magnesium	mg/L	24	36	24	44	36	28	40	28	12	8	20	28	40	32	8	12
Sodium (as Na)	mg/L	18.6	17.1	***5.12***	***4.84***	35	36.2	23.2	28.5	45.8	44.1	25.5	27.4	***13.1***	***14***	39	39.9
Potassium (as K)	mg/L	2.1	2.2	2	2	3.5	3.5	3.1	3.5	2.7	2.3	2.8	2.8	1.4	1.8	2.8	3.1
Phosphate (as PO_4)	mg/L	0.28	0.23	0.6	0.4	0.32	0.48	0.69	0.36	0.7	0.7	0.75	0.77	0.76	0.46	0.7	0.69
Chlorides (as Cl)	mg/L	8	8.4	9.6	12	37.2	25.6	18	26	10.4	11.6	11.2	12	12.8	12.8	11.2	12.8
Nitrate (Nitrogen)	mg/L	ND	ND	***2.6***	***3.1***	ND	ND	ND	ND	***0.8***	***ND***	***0.3***	***ND***	***0.5***	***2.5***	ND	ND
Chlorine (as Cl)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0	0	ND	ND	***4.85***	***0.11***	ND	ND
Dissolved Iron (as Fe^{2+})	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0	0	ND	ND	ND	ND	ND	ND
Suspemded Iron (as Fe^{3+})	mg/L	ND	ND	0.09	ND	0.68	0.15	0.06	ND	0.1	0.1	0.3	ND	0.63	ND	0.02	ND
Iron Total (as Fe)	mg/L	ND	ND	0.09	0.09	0.68	0.15	0.06	ND	0.1	0.1	0.3	ND	0.63	ND	0.02	ND
Iron (resuspended)	mg/L	ND	ND	0.7	0.04	0.78	0.38	0.16	ND	0.2	0.2	0.07	0.3	19.7	0.03	0.08	0.06
Copper (as Cu)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0	0	ND	ND	ND	ND	ND	ND
Manganese (as Mn)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	0.1	0	ND	ND	0.4	ND	ND	ND
Sulfate (as SO_4)	mg/L	ND	ND	4	4	ND	ND	ND	ND	0.5	0.7	ND	ND	3	3	ND	ND
Silica (as SiO_2)	mg/L	18	20.1	46	42.3	31.8	36.5	37.6	38.2	32.6	32.5	36.5	32.2	38.9	41.8	35.6	34.6
Tannin/Lignin	mg/L	ND	ND	ND	ND	0.1	0.1	ND	ND	0.1	0.1	ND	ND	0.3	0.1	ND	ND
Total Organic Carbon (C)	mg/L	0.9	1.3	2	0	1.4	3.2	0.2	1.3	1.1	0.4	1.9	0	1.9	1.5	1.1	1.3
2014 Water Quality Results (July and October 2014)																	
		7/14	10/15	7/14	10/15	7/14	10/15	7/14	10/15	7/14	10/15	7/14	10/15	7/14	10/15	7/14	10/15
pH	SU	--	8.42	--	7.87	--	7.97	--	8.02	--	--	--	8.08	--	7.24	--	7.95
Total Dissolved Solids	mg/L	--	104	--	136	--	312	--	188	--	--	--	148	--	164	--	184
Langelier Saturation Index	SU	--	0.2	--	-0.4	--	0	--	-0.1	--	--	--	-0.3	--	-1	--	-0.4
Sodium (as Na)	mg/L	17.8	--	17.2	--	50.3	--	26.3	--	--	--	27.9	--	16.7	--	38.7	--
Nitrate (Nitrogen)	mg/L	ND	--	0.131	--	ND	--	ND	--	--	--	ND	--	1.3	--	ND	--
Arsenic (total)	mg/L	ND	--	0.0036	--	ND	--	ND	--	--	--	ND	--	0.000788	--	ND	--
Managanese (total)	mg/L	--	0.0343	--	0.0012	--	**0.0606**	--	**0.0568**	--	--	--	0.0491	--	0.0187	--	0.0443
Odor	(TON)	--	1.19	--	1.41	--	1.19	--	ND	--	--	--	6.73	--	ND	--	1.41

Notes:

Italicized results are not typical results in the SGA aquifer water quality

Bold Values exceed SMCL for Manganese

mg/L = milligrams per liter

SU = Standard units

mV = millivolts

µS/cm = microSiemen per centimeter

TON - Threshold Odor Number

ND = Not Detected

NA = Not Analyzed

Casing = Sample collected after standing water in pump column evacuated

Aquifer = Sample collected prior to competing aquifer pumping test, typically 3 to 4 hours

[1] **Well 7 was resampled for Chlorine on August 14, 2015 to evaluate its presence using time series sampling**

Initial Result =	5.93	mg/L
10 minutes =	0.511	mg/L
34 minutes =	0.144	mg/L
77 minutes =	0.100	mg/L
77 minutes =	0.099	mg/L (Duplicate)

These results are consistent with those observed during original testing. Fulll analytical lab report is in Appendix C.

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Table 6. Summary of Bacterial Results for ASR Well No. 1

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

Biological Analysis	Well 2 3/17/2015		Well 3 3/25/2015		Well 4 3/17/2015		Well 5 3/17/2015	
	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer
Plate Count (colonies/ml)	2	0	42	2	12	42	22	1
Anaerobic Growth	<10%	<10%	10%	10%	10%	10%	10%	10%
Sulfate Reducing Bacteria	Negative	Negative	Negative	Negative	Negative	Positive	Negative	Negative
Fe/Mn Oxidizing Bacteria	Negative	Negative	Positive	Negative	Negative	Negative	Negative	Negative
ATP (cells per ml) Initial	56,000	12,000	138,000	27,000	217,000	59,000	32,000	6,000
ATP (cells per mL) 24 Hour	13,000	6,000	152,000	21,000	710,000	577,000	42,000	32,000
Bacterial Identification	*Acidovorax delafieldii;*	*No ID Possible*	*Acidovorax delafieldii, ; Gallionella; Leptothrix*	*Acidovorax delafieldii*	*Pseudoxanthomonas mexicana*	*Acidovorax delafieldii; Staphylococcus epidermidis*	*Acidovorax delafieldii;*	*No ID Possible*
Microscopic Analysis								
Biological Activity	Very Low	None	*Low*	*Very Low*	*Low*	*Moderate*	Very Low	Very Low
Iron Oxide	--	--	*Minor*	*Very Low*	*lLow*	*Heavy*	Low	Trace
Crystalline Debris	--	--	*Minor*	*Trace*	*Trace*	*Trace*	*Moderate*	--
Iron Oxide Biomass	--	--	*Trace*	--	*Low*	*Low*	*Trace*	--
Bacterial Identification	*No Sheathed or Stalked Bacteria*	--	*Gallionella; Leptothrix*	--	*No Sheathed or Stalked Bacteria*	--	--	--

Notes:

M = million

F = filtered

Biological Analysis	Well 6 11/20/2006		Well 6 3/25/2015		Well 7 3/17/2015		Well 8 3/25/2015	
	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer	Casing	Aquifer
Plate Count (colonies/ml)	`1	No Growth	46	1	>1,500	1	6	0
Anaerobic Growth	<10%	<10%	10%	<10%	10%	10%	10%	10%
Sulfate Reducing Bacteria	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Fe/Mn Oxidizing Bacteria	Negative	Negative	Negative	Negative	Positive	Positive	Negative	Negative
ATP (cells per ml) Initial	5.0 M	<1000	271,000	11,000	14.9 M	127,000	693,000	206,000
ATP (cells per mL) 24 Hour	Not Reported	Not Reported	1.7 M	86,000	14.5 M	102,000	493,000	375,000
Bacterial Identification	*Crenothrix*	*No ID*	*Acidovorax delafieldii; Microbacterium maritypicum; Gordonia namibiensis*	*Psuedomomas fuscovagineae*	*Acidovorax delafieldii, Cupriviavidus necator, Leptothrix*	*Bacillus specie. Leptothrix, Crenothrix*	*Acidovorax temperans; Acinoetobacter lwofii*	*No ID Possible*
Microscopic Analysis								
Biological Activity	*Trace*	*Mone*	*Very Low*	*Very Low*	*Moderate*	*Low*	*Very Low*	*Very Low*
Iron Oxide	*Minor*	*Minor*	*Trace*	--	*Moderate*	*Moderate*	*Trace*	--
Crystalline Debris	*Large*	*None*	--	--		*Moderate*	--	--
Iron Oxide Biomass	.--	--	*Trace*	--	*Heavy*	*Low*	--	--
Bacterial Identification	*Crenothrix*	--	--	--	*Leptothrix and Protozoa*	*Leptothrix Crenothrix*	--	--

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Table 7. Welll 7 Arsenic Speciation

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

Sample No.	Approximate Number of Borehole Volumes	Volume Pumped (gals)	Total Inorganic Arsenic (μg/L)	Arsenic (III) (μg/L)	Arsenic (V) (μg/L)	Comments
Well 7-1	--	800	0.83	ND	0.83	Sample very turbid
Well 7-2	5	7100	0.537	0.04	0.497	--
Well 7-3	15	19700	0.582	0.054	0.528	--
Well 7-4	45	58300	0.584	0.013	0.584	--

Notes:

Arsenic (III) = arsenite

Arsenic (V) = arsenate

μg/L = micrograms per liter = parts per billion

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Table 8. Summary of Comprehesive Well Assessment Finding and Potential Actions

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

Well	Well Performance [1]	Allocated Water Right (gpm)	Additional Water Right Rate [2,3,4,5] (gpm)	Water Quality	Bacterial Assessment	Well Construction	Clogging Mechanism	Other	Recommended Well Maintenance Action
2	No apparent decline in yield or performance; tested at 499 gpm	449	-50	Good	Normal	TSA Well	None	--	Pull pump and motor to remove transducer and/or replace sounding tube
3	2015: 2.1 gpm/ft @ 222 gpm Origiinal: 5 gpm/ft @ 600 gpm	494	344	pH, Nitrate suggest shallower aquifer	Moderate Population Iron Related Bacteria	Well Seal Integrity Questionable/Sanding Issue	Physical plugging/Minor Biofouling	Did not respond to redevelopment	Perform well video; depending on observations consider mechanical redevelopment and chemical treatment. May also consider decommissioning/replacing well in future.
4	2015: 11.6 gpm/ft @611 gpm 1993: 15.5 gpm/ft @ 900 gpm	987	337	Elevated TDS, manganese, silica, hydrogen sulfide	Slight Bacterial Population	Reconstructed 2006	None/Minor Physical Plugging	--	None; consider water quality blending to address elevated TDS/manganese
5	2015: 69 gpm/ft @ 1485 gpm 2007: 72 gpm/ft @1400 gpm	1324	0	Elevated manganese	Normal	No issues	None/Minor Physical Plugging	Boundary Condition?	Perform well video when pump/motor serviced; depending on observations consider mechanical redevelopment and chemical treatment.
6	2015: 8.2 gpm/ft @ 493 gpm Original: 14 gpm/ft @ 900 gpm Well Interference	987	497	Elevated manganese, hydrogen sulfide/odor	Moderate Population Iron Related Bacteria; protozoa detected	Well Seal Integrity Questionable	Physical plugging/Minor Biofouling	Well Interference with 7 and 8 (other SGA Wells); Responded to redevelopment	Perform well video; depending on observations consider mechanical redevelement and chemical treatment.
7	2015: 10 gpm/ft @ 551 gpm Original: 18.6 gpm/ft @ 1000 gpm Well Interference	538	--	Elevated manganese and arsenic (not observed in 2015), nitrate, low pH, sodium, dissolved oxygen suggest shallower groundwater source. Chlorine Present?	Mature Well Established Population of Iron Related Bacteria	Well Seal Integrity Questionable/ Sanding Issue	Biofouling/Physical plugging	Well Interference with 6 and 8 (other SGA Wells); Did not respond to redevelopment	Perform well video; depending on observations consider mechanical redevelopment and chemical treatment. May also consider decommissioning/replacing well in future.
8	2015: 6.8 gpm/ft @ 518 gpm Original: 17.6 gpm/ft @ 1200 Apparent decrease since 2011: 3 gpm/ft (9.8 @ 518) Well Interference	1001	483	Elevated manganese and hydrogen sulfide/odor dissolved oxygen	Moderate Population Iron Related Bacteria; protozoa detected	No issues	Physical plugging/Minor Biofouling	Well Interference with 6 and 7 (and other SGA Wells?)	Perform well video; perform mechanical redevelopment and depending on observations consider chemical treatment.

Notes:

[1] Well perf ormance based on historical reported values and 2015 observations during step rate testing.

[2] Well capacity based on operational rates provided by City in March 2015.

[3] Well 5 can be operated at a much higher instantaneous rate than current operation; however Well 5 is limited to 987 gpm cfs on T-10208 (shared with Well 7) and 337 gpm under T-9484 [1324 gpm total]

[4] Well 7 is not currently operated. Allocation of well capacity based on 2015 reported pumping rate. See note #2 above.

[5] Well 8 is allocated up to 987 gpm (2.2 cfs) and can utilize any remaining water right allocation not used by Well 5, 6 and 7 under permit amendment T-10208.

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Table 9. Summary of Customer Outreach Survey

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

	Skyland Pub 3175 S Troutdale Rd	**Comfort Inn** 1000 NW Graham	**Cherry Park Dental** 2513 SW Cherry Park Rd	**Tube Specialties** 1459 NW Sundial Rd	**Starbucks- Albertsons** 25691 Southeast Stark	**Cherry Park Plaza** 1323 SW Cherry Park Rd	**Burger King** 25135 SE Stark	**Travel Centers of America** 790 NW Frontage Rd	**Albertsons** 25691 Southeast Stark	**Toyo Tanso** 2575 NW Graham Cir	**Reynolds School District** For all schools in district	**Ristorante Di Pompello** 177 E. Historic Columbia River Hwy
Drinking Water Source	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale	City of Troutdale
Do you drink from tap?	Yes, no filter	Bottled water	Bottled water	Yes	With filter for drinks	With filter	With filter	Yes	With filter	With filter	With filter	With filter
Water use (business, outdoor, food service, manufacturing)	Indoor business and food service	Indoor, outdoor and food service	Indoor business	Indoor business, Outdoor irrigation, industrial processes	Indoor business, food service	Indoor business, outdoor, food service and manufacturing	Indoor business, outdoor and food service	Indoor business, outdoor and food service	Indoor business and food service	Manufacturing/ industrial processes	Indoor business	Indoor business, outdoor, food service
Rate Quality of drinking water - 1 (poor) to 5 (excellent)	4	2	3	5	5	1	4	4	4	3	3	5
Rate water service you receive from City - 1 (poor) to 5 (excellent)	4	4	3	5	5	5	5	5	5	4	3	5
Any characteristics with City water (cloudiness, odor, taste, sediment, hard water, soft water, stains, etc) Explain	None	Bad taste- avoided City water for years. Hard water. Stains on fixtures, dishware and laundry	Odor-earthy, musty, happens several times a month	None	None	Bad taste-Mineral and metallic taste every day. Hard water and leaves stains on fixtures	Cloudiness- brown when it rains	Hard water, Stains on fixtures	None	Bad taste, mineral randomly	Cloudiness- red/orange/brown, rarely. Bad taste- mineral taste, daily. Sediment. Hard water. Scale left on fixtures	None
Does water quality vary	Consistent	Consistent-bad	Varies randomly	Consistent	Consistent	Consistently bad	Varies randomly	Consistent	Consistent	Varies randomly	Varies randomly	Varies randomly
Equipment to improve water quality	None	No	no	no	Yes, triple purifier	Filter	Filter	Water softening system	Filter	Filter	yes, filter	Yes, filter
Water Pressure	Good	Good	Good	Good	Good	Good	Good	Good	Water pressure varies throughout the day	Good	Good	Good
Notes	--	Lifespan of linens is significantly shortened by hard water yellowing	--	--	--	Please fix the bad taste	--	--	--	--	--	--

Table 10. Summary of Potential Well Maintenance Actions and Planning Level Cost Estimates

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

Well	Asset Management Priority	Associated Water Right(s)	2015 Operational Rate (gpm)	Allocated Water Right(s) Rate (gpm)	Additional Water Right Rate Available (gpm)	Well Performance	Recommended Well Maintenance Action	Estimated Cost to Perform Well Maintenance Actions	Additional Comments
2	**Mod**	Cert. 50525	490	449	-41	No apparent decline in yield or performance; tested at 499 gpm	Pull pump and motor to remove transducer and/or replace sounding tube	$15000 - pull pump and motor, video and install sounding tube	--
3	**High**	Per G-8655	150	494	344	2015: 2.3 gpm/ft @ 222 gpm Origiinal: 5 gpm/ft @ 600 gpm	Perform well video; depending on observations consider mechanical redevelopment and chemical treatment (otpional).	$50,000 (mechanical only) $80,000 to $100,000 (redevelopment with chemical treatment) $50,000 (well decommissioning)	Reportedly produces sand: May need reconstruction or alternatives to mitigate sand production; Well seal concern
4	**Low**	T-10341 (Per G-9866)	650	987	337	2015: 11.6 gpm/ft @ 611 gpm 1993: 15.5 gpm/ft @ 900 gpm	None; consider water quality blending to address elevated TDS/manganese	--	Water quality shows slight improvement in 2014/2015
5	**Low**	T-9484/Per G-6881 T-10208 (Per G9867)	890	1324	434	2015: 69 gpm/ft @ 1485 gpm 2007: 72 gpm/ft @ 1400 gpm	Perform well video when pump/motor serviced; depending on observations consider mechanical redevelopment in the future.	$15,000 - pull pump and motor/video $50,000 (mechanical redevelopment only)	Well capacity is water right limited; Evalaute impacts of higher pumping rates (i.e. well interference)
6	**High**	T-9484 T-10208 (Per G9867)	490	987	497	2015: 8.2 gpom/ft @ 493 gpm Original: 14 gpm/ft @ 900 gpm Well Interference	Perform well video; depending on observations consider mechanical redevelopment and chemical treatment (optional).	$50,000 (mechanical redevelopment only) $80,000 to $100,000 (redevelopment with chemical treatment)	Bacterial population reduced after last well rehabilitation; Well performance improved
7	**Low/Mod**	T-9484 T-10208 (Per G9867)	515	987	472	2015: 10 gpm/ft @ 551 gpm Original: 18.6 gpm/ft @ 1000 gpm Well Interference	Perform well video; depending on observations consider mechanical redevelopment and chemical treatment. Consider decommissioning/replacing Well 7 in future.	$50,000 (mechanical redevelopment only) $80,000 to $100,000 (redevelopment with chemical treatment) $50,000 (well decommissioning)	Well produces sand; Water quality suggests shallow groundwater source; anomolous chlorine concentrations; Influences water quality at Well 8
8	**High**	T-9484 T-10208 /(Per G9867) (Per G-11761)	570	1001	431	2015: 6.8 gpm/ft @ 518 gpm Original: 17.6 gpm/ft @ 1200 Apparent decrease since 2011: 3 gpm/ft (9.8 @ 518 gpm)	Perform well video; perform mechanical redevelopment and depending on observations consider chemical treatment (optional).	$50,000 (mechanical redevelopment only) $80,000 to $100,000 (redevelopment with chemical treatment)	Well 7 appears to influence nutrient and dissolved oxygen
New Well 9	**Mod**	T-10341 (Per G-9866)	NA	NA	NA	TBD	Drill, Construct and Test New Well (similar to Well 5). Design, Build and Construct Wellhouse.	$500,000 (Well Only) $1,600,000 (Well and Wellhouse)	--
Replacement Well for Well 3 or 7	**Mod**	See Above	NA	NA	NA	TBD	Drill, Construct and Test New Well (similar to Well 5). Design, Build and Construct Wellhouse.	$500,000 (Well Only) $1,600,000 (Well and Wellhouse)	If well video survey identify concern then replacement may be recommended

Notes:

See Table 2 for complete water rights allocations.

Wells 5, 6, 7 and 8 share 1,975 gpm (4.4. cfs). Well 5 and 7 share 987 gpm (2.2 cfs). Well 6 has 2.2 cfs. Well 8 has the remainder of the water right rate of 4.4. cfs not used by 6 and 7 and not to exceed the existing water right.

Well 5 also is a point of appropriation on T-9484 (337 gpm/700 gpm) and T-3119. (364 gpm). T-3119 needs to be certificated to allow use.

Costs for chemical rehabilitation will be dependent on well construction, degree of biofouling and amount of chemical treatment needed. Refined costs can be developed after well video surveys.

Costs for well maintenance based on recent projects of similar scope in 2015.

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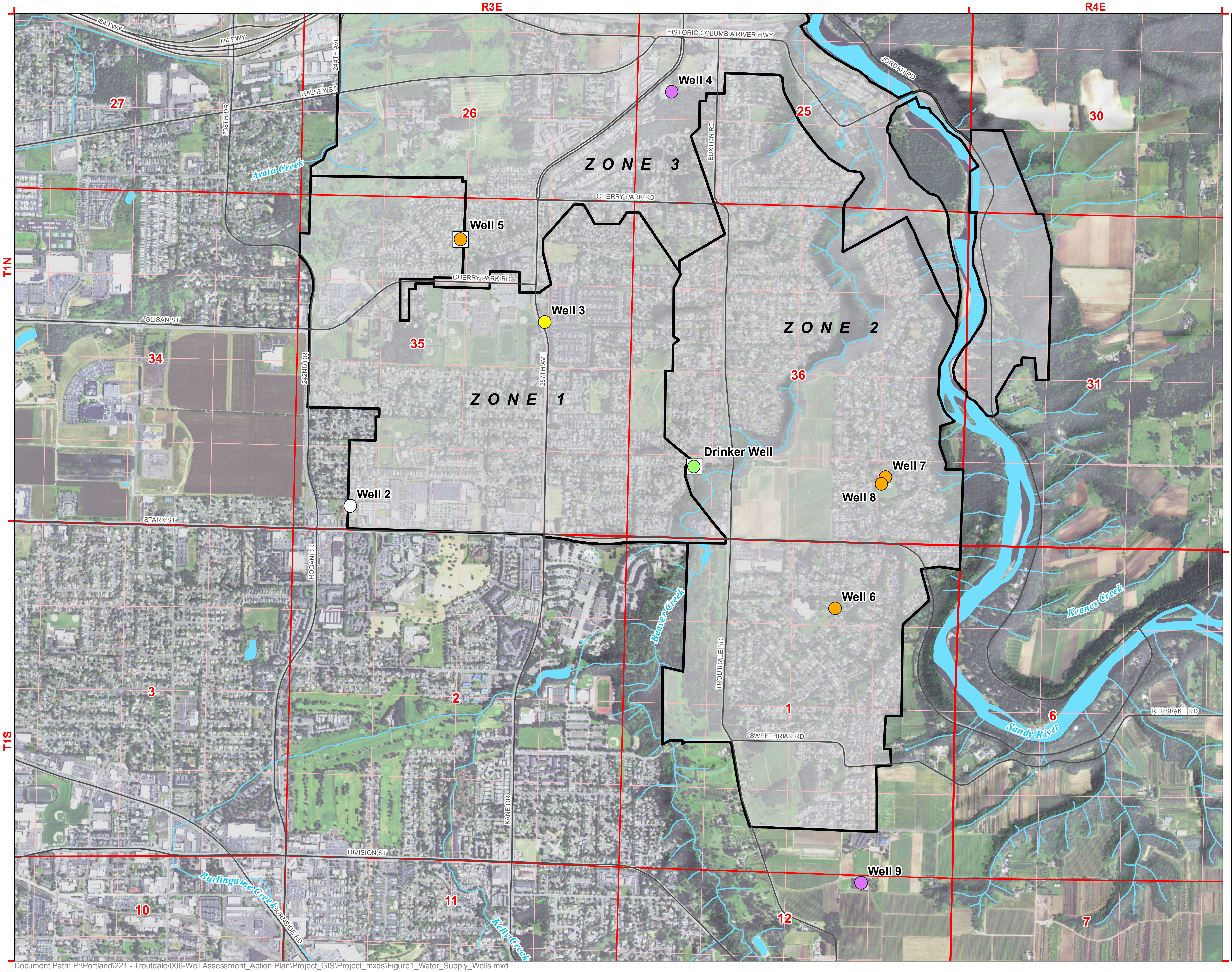
Figures

FIGURE 1

Existing and Proposed Water Supply Wells

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015



LEGEND

Well Locations by Water Right

- Certificate 50525
- Transfer T-3119
- Permit G-9867
- Permit G-9866
- Permit G-8655
- Permit 6881

All Other Data

- Major Roads
- Watercourses
- Waterbodies
- Water Source Zones

N

0 750 1,500 2,250

Feet

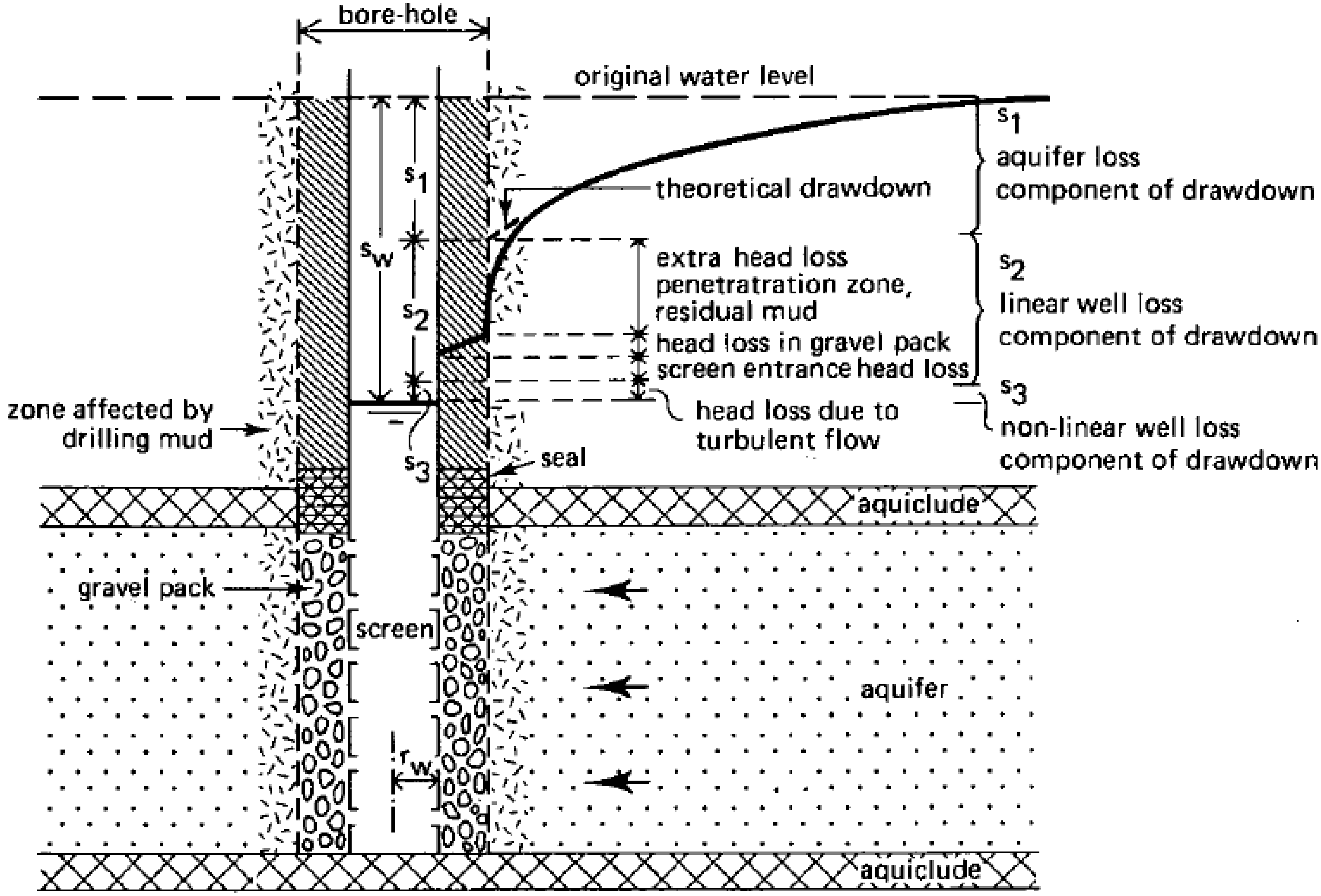
MAP NOTES:

Date: June 30, 2015

Data Sources: OWRD, METRO RLIS

GSI Water Solutions, Inc.

Document Path: P:\Portland\221 - Troutdale\006-Well Assessment_Action Plan\Project_GIS\Project_mxds\Figure1_Water_Supply_Wells.mxd



Notes:

1. S_1 and S_2 are components of the Term B and relate linearly to pumping rate
2. S_3 is the turbulent losses term "C" and varies to the square of the pumping rate. This relationship is the same as that for pipe flow.
3. Sw represents the total drawdown in the well.

Figure 2. Components of Total Drawdown in a Well

GSI Water Solutions, Inc.

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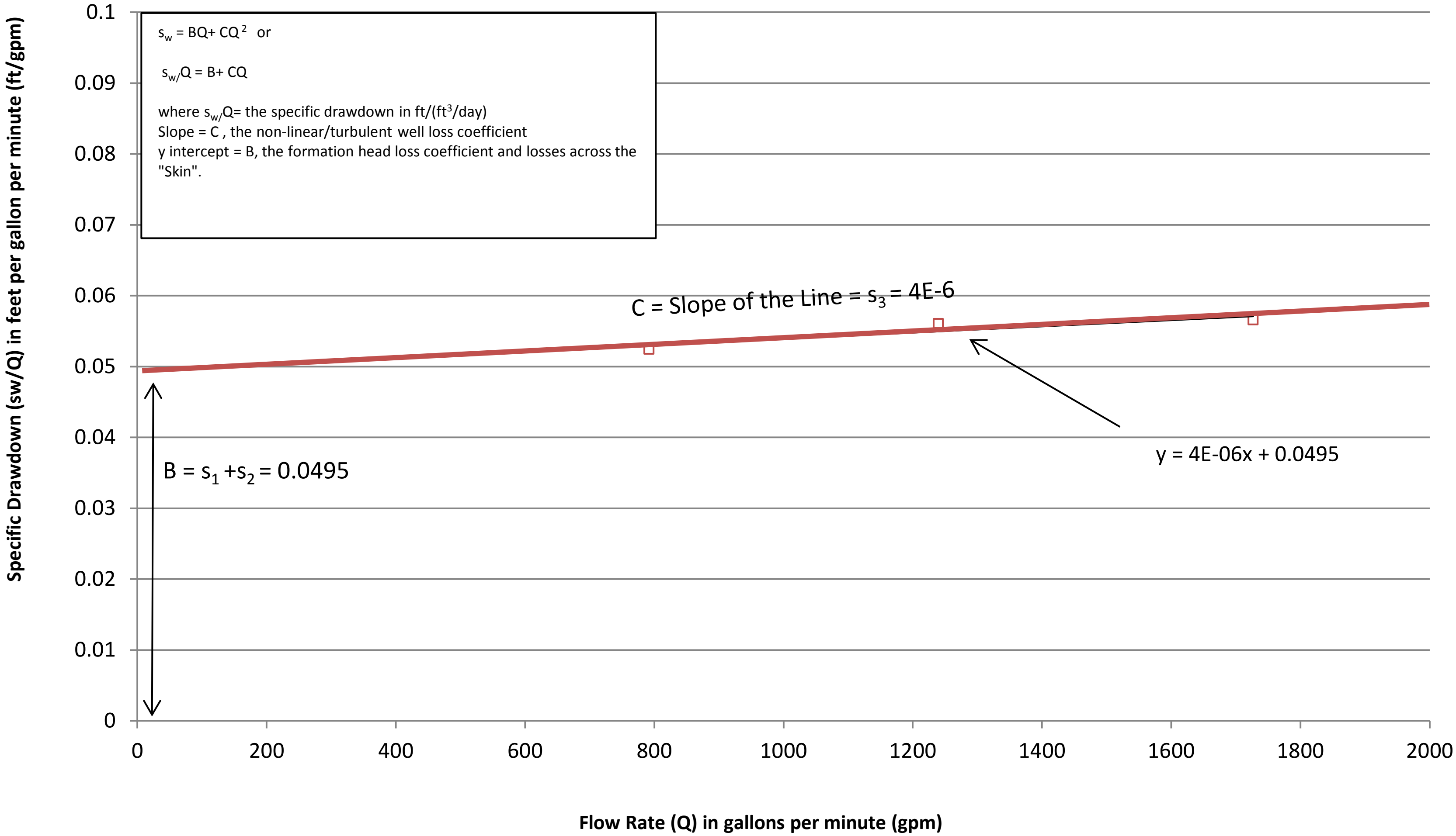

Figure 3. Example of Hantush Biershenk Plot

City of Troutdale Comprehensive Well Assessment and Action Plan, 2015

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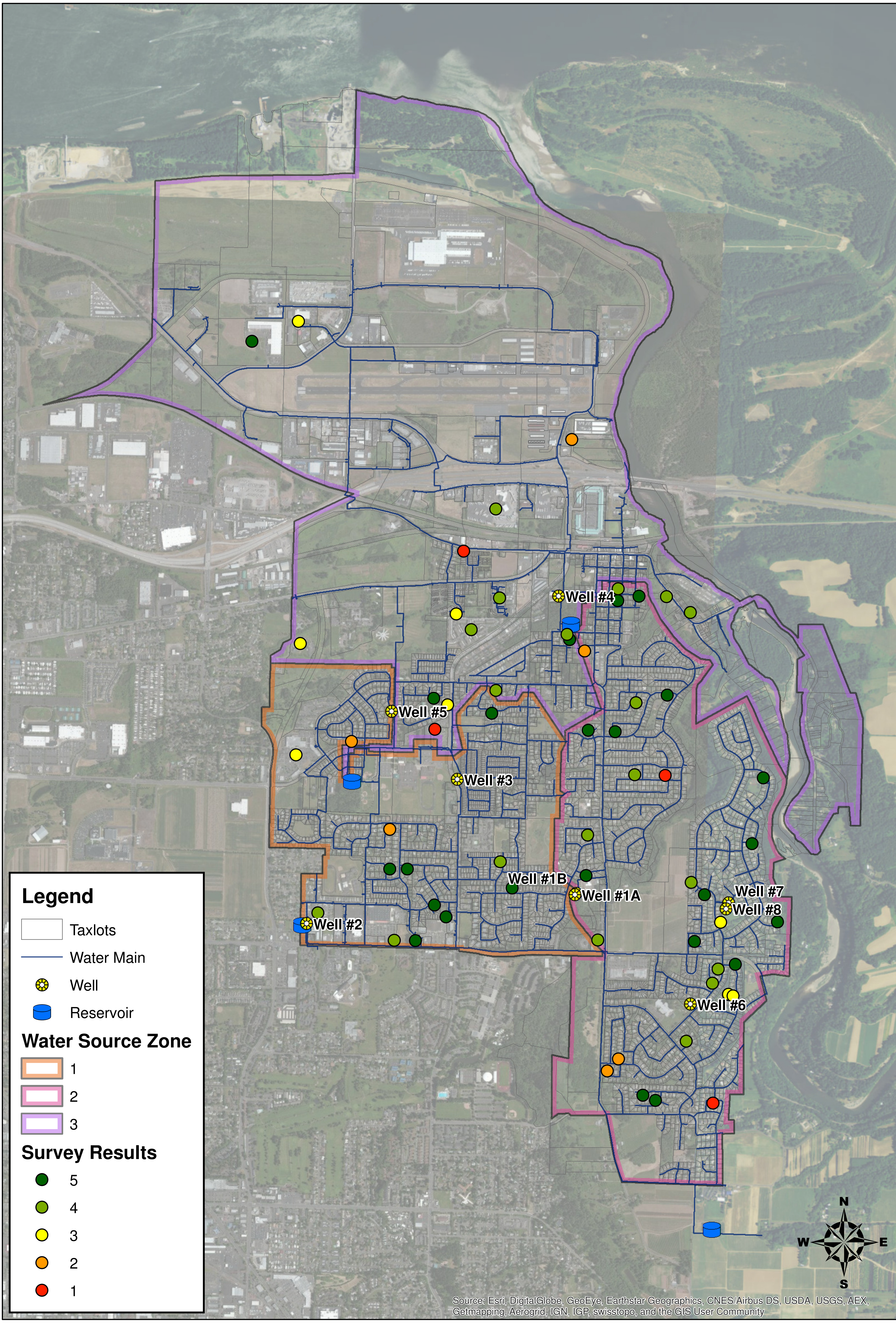

Figure:	Title:	Project:	Prepared for:
4	Water User Survey Results: Water Quality Rating	Well Assessment	City of Troutdale, OR

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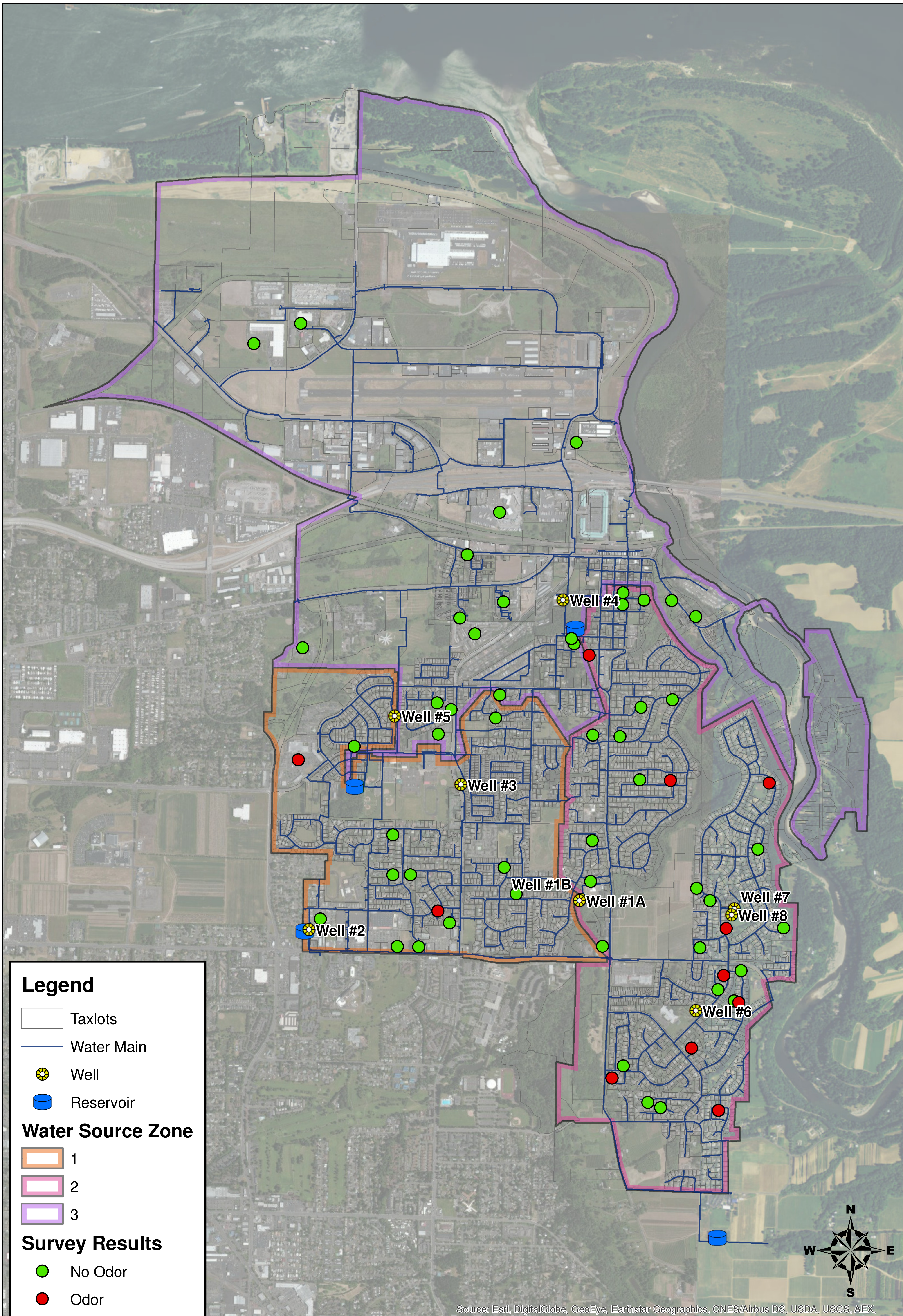

Figure:	Title:	Project:	Prepared for:
5	Water User Survey Results: Odor	Well Assessment	City of Troutdale, OR

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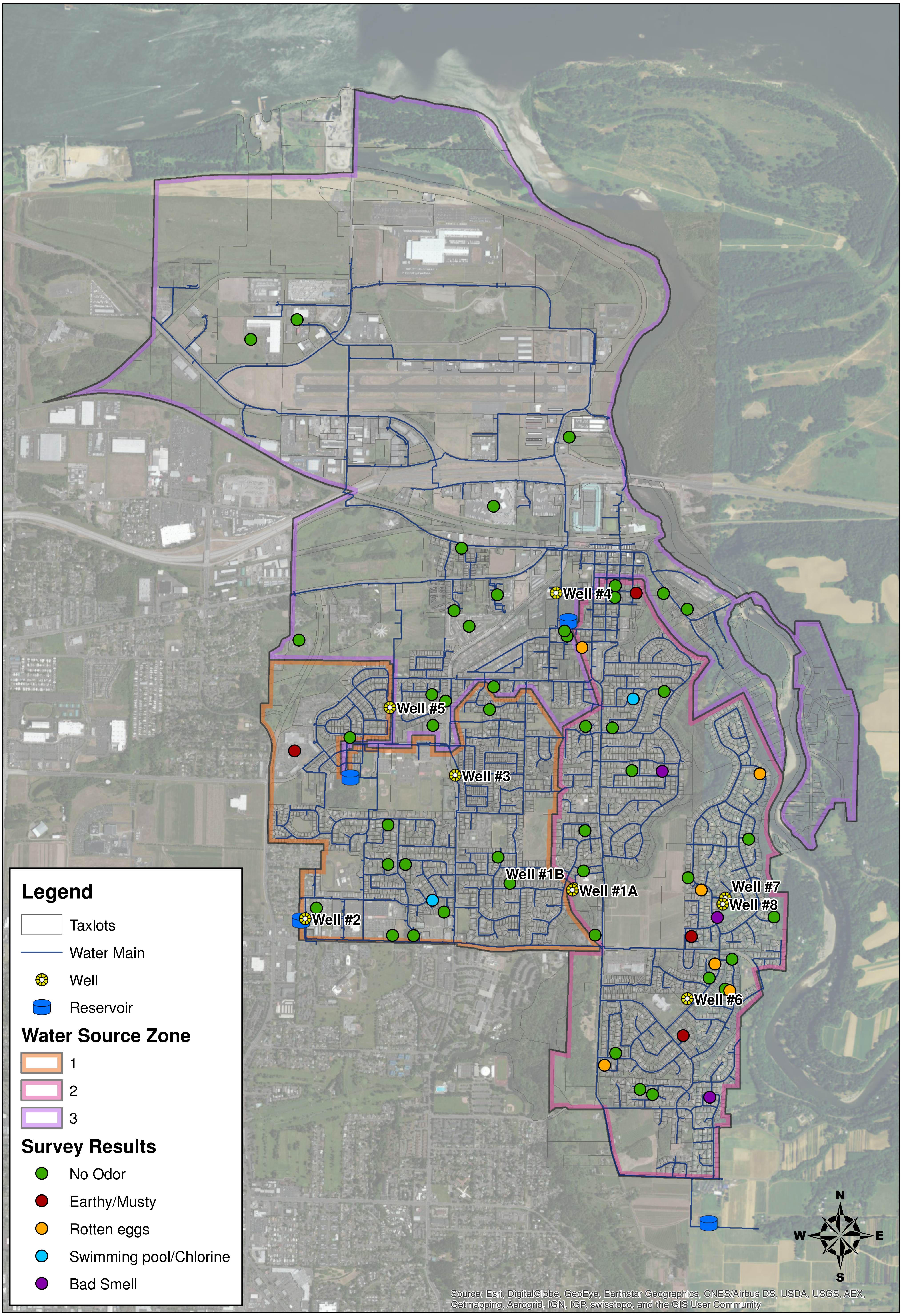

Figure:	Title:	Project:	Prepared for:
6	Water User Survey Results: Odor Description	Well Assessment	City of Troutdale, OR

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Appendices A-G Included on Enclosed Data CD