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TECHNICAL MEMORANDUM

DATE: May 28, 2008

PROJECT: 07-0848.406

TO: Mr. Dennis Wright, P.E., Engineering Director
City of West Linn

FROM: Chris H. Uber, P.E.
Brian M. Ginter, P.E.
Murray, Smith & Associates, Inc.

RE: Technical Memorandum #5: City of West Linn - Water System Master Plan
Task 6 Deliverable: Perform Supply Evaluation

DRAFT

Revised 5/28/08

Purpose

The purpose of this memorandum is to document the evaluation of the City of West Linn's (West Linn) water supply sources as an element of the current work preparing a new Water System Master Plan. This memorandum constitutes the technical memorandum deliverable of Task 6 – Perform Supply Evaluation.

Existing Water Supply

The City's primary water supply source is from the South Fork Water Board (SFWB). The SFWB was established under Oregon Revised Statutes (ORS) 190 by agreement between the

Cities of West Linn and Oregon City for the purposes of supplying water to the two cities. The SFWB owns and operates water supply facilities consisting of a river intake on the Clackamas River, which includes a raw water pumping station, a water treatment plant located in the Park Place area of Oregon City and a finished water pumping station, and raw and finished water transmission pipelines. The City owns a transmission main crossing the Willamette River to supply the City.

Technical Memorandum No. 1, "Comprehensive System Inventory and Summary of Existing Conditions" contains a detailed discussion of the existing water rights, intake, transmission, treatment and pumping facilities supplying the City. Figure 1 illustrates the location of the major facilities supplying the City.

Water Demand Projections

The average daily demand (ADD) and maximum day demand (MDD) projections presented in Table 1 under current and saturation development, or build-out, conditions are based on City demand projections presented in Technical Memorandum No. 2, "Determination of Future Water Needs" and other SFWB demands as presented in the South Fork Water Board Water Master Plan Update (February 2004), herein referred to as the SFWB WMPU. Demand projections are presented in units of million gallons per day (mgd).

Table 1
Water Demand Projection Summary

Water Provider	Year and Demand Projection (mgd)									
	2008 (Current)		2010		2015		2020		Saturation Development	
	ADD	MDD	ADD	MDD	ADD	MDD	ADD	MDD	ADD	MDD
Oregon City	5.0	10.4	5.3	11.1	6.1	12.8	6.9	14.4	7.8	15.0
Clackamas River Water – South	2.0	4.9	2.0	4.9	2.0	4.9	2.0	4.9	2.0	4.9
West Linn	3.5	8.1	3.6	8.3	3.7	8.6	3.9	8.9	4.3	10.0
Total	**10.5**	**23.4**	**10.9**	**24.3**	**11.8**	**26.3**	**12.8**	**28.2**	**14.1**	**29.9**

Supply Capacity Analysis

An analysis of the components of the City's water supply sources is presented below in Table 2. Table 2 identifies each of the components of the supply system, the capacity criteria used to evaluate the component and the actual and required capacity of the component. The criteria presented in Table 2 are based on the criteria presented in the SFWB WMPU. These criteria were evaluated and are considered appropriate for the current analysis relative to the

City's supply needs. A discussion of the current capacity, required capacity and planned system improvements for each component of the City's supply from the SFWB follows.

Table 2
Supply Capacity Analysis Summary

Supply System Component	Capacity Criteria	Current Capacity [3] (mgd)	Total Required Capacity (West Linn Capacity Need)	
			Current (mgd)	Build-out (mgd)
River Intake	MDD	53.0	23.4 (8.1)	29.9 (10.0)
Raw Water Pump Station	MDD (Firm Capacity)	30.0	23.4 (8.1)	29.9 (10.0)
Raw Water Transmission	MDD	22.0	23.4 (8.1)	29.9 (10.0)
Water Treatment Plant	MDD	22.0	23.4 (8.1)	29.9 (10.0)
Finished Water Transmission – SFWB WTP to DSPS	MDD	21.9	21.8 (8.1)	26.7 (10.0)
Finished Water Pump Station	MDD (Firm Capacity)	17.6	18.5 (8.1)	22.6 (10.0)
Finished Water Transmission – West Linn	MDD	~10.0	8.1 (8.1)	10.0 (10.0)

Notes: 1. WTP – Water Treatment Plant; DSPS – Division Street Pump Station
2. See the SFWB Water Master Plan Update for detailed breakdown of required component capacities to supply other SFWB customers.
3. Capacities listed are firm capacity for all pump stations.

Clackamas River Intake

The existing SFWB Clackamas River Intake, constructed in 1996, has a rated capacity of approximately 53 mgd. The required capacity of the intake to supply build-out demand conditions for the entire SFWB service area, including the City, is approximately 28.7 mgd. The existing river intake has adequate capacity to supply the City's water supply needs through the 20-year planning horizon and through build-out of the current water service boundary. The City's ultimate supply need is approximately 10 mgd.

Raw Water Pump Station

The existing SFWB raw water pump station (RWPS), constructed in 1996 in the same structure with the river intake, has a current firm capacity of approximately 30 mgd with the addition of a fifth pump (10.65 mgd), 800 horsepower (hp) motor and variable frequency drive (VFD) in 2005. The required capacity of the pump station to supply the current projected MDD (year 2008) conditions for all SFWB customers is approximately 23.4 mgd and the projected future build-out capacity required is approximately 28.7 mgd. The existing

RWPS has adequate capacity to supply the City’s water supply needs through the 20-year planning horizon and through build-out of the current water service boundary. The City’s ultimate supply need is approximately 10 mgd.

Raw Water Transmission

The existing raw water transmission main from the RWPS at the Clackamas River intake to the SFWB Water Treatment Plant (WTP) consists of approximately 600 linear feet of 42-inch diameter steel main from the existing intake (constructed in 1996) to the abandoned SFWB intake. From this location, the raw water transmission main is a 27-inch diameter concrete-cylinder pipe constructed in 1954, extending approximately 1,800 linear feet from the end of the new 42-inch diameter main to the WTP. The current capacity of the transmission main, based on the capacity of the 27-inch diameter section, is approximately 22 mgd. The required capacity of the transmission main to supply the current projected MDD (year 2008) conditions for all SFWB customers is approximately 23.4 mgd and the projected future build-out capacity required is approximately 28.7 mgd.

Construction of a new 48-inch diameter raw water transmission main to replace the aging 27-inch diameter main, as recommended in the 2004 SFWB Water Master Plan Update, is included in the SFWB Capital Improvement Plan (CIP). With the completion of this improvement, the raw water transmission main capacity will be adequate to supply the City’s water supply needs through the 20-year planning horizon and through build-out of the current water service boundary. The City’s ultimate supply need is approximately 10 mgd.

Water Treatment Plant

The existing SFWB WTP has a nominal capacity of 22 mgd, with the completion of current improvements underway at the WTP, including the construction of a new 2 mg clearwell. The required capacity of the WTP to supply the current projected MDD (year 2008) conditions for all SFWB customers is approximately 23.4 mgd and the projected future build-out capacity required is approximately 28.7 mgd. This build-out capacity requirement includes 10 mgd for the City.

The SFWB Water Master Plan Update included recommendations to complete WTP upgrades by the year 2010 to increase the capacity of the WTP to 30 mgd. These improvements include:

- Sedimentation basin upgrades: Installation of plate settlers and sludge removal system.
- Filter upgrades: Construction of two new filter beds.

With the completion of these improvements, the WTP capacity will be adequate to supply the City’s water supply needs through the 20-year planning horizon and through build-out of the current water service boundary.

Finished Water Transmission (SFWB)

The finished water transmission main from the SFWB WTP to the Division Street Pump Station (DSPS), which provides finished water pumping to Oregon City and the City, is a one and a half mile 30-inch diameter concrete-cylinder pipe constructed in 1958. The nominal capacity of this transmission main, dictated by the suction pressure requirements of the DSPS, is approximately 21.9 mgd. The required capacity of the transmission main to supply the current projected MDD (year 2008) conditions for customers served by the transmission main is approximately 21.8 mgd and the projected future build-out capacity required is approximately 26.7 mgd, of which approximately 10.0 mgd is the City's demand.

The SFWB Water Master Plan Update includes recommendations to complete transmission main upgrades, extending an existing 42-inch diameter transmission main from the WTP to Oregon City's Hunter Avenue Pump Station an additional 4,500 feet to Redland Road to replace segments of the existing 30-inch diameter main and provide expanded suction supply capacity to the DSPS. This improvement will expand the capacity of the finished water transmission main to greater than 30 mgd. With the completion of this improvement, the finished water transmission main capacity to the DSPS will be adequate to supply the City's water supply needs through the 20-year planning horizon and through build-out of the current water service boundary.

Finished Water Pump Station

The DSPS, located in Oregon City near the intersection of 17th Street and Division Street, provides finished water pumping to supply the Oregon City Mountainview Reservoir and the City. Currently, the station is controlled by the level in the Mountainview Reservoir which can backfeed supply to the City when the pump station is not operating. The firm capacity of the DSPS is 17.6 mgd. Supply to the City is through a pressure control station, consisting of two parallel hydraulically actuated 14-inch diameter ball valves, connected to the City's 24-inch diameter transmission main. The required capacity of the DSPS to supply the current projected MDD (year 2008) conditions is approximately 18.5 mgd and the projected future build-out capacity required is approximately 22.6 mgd of which 10 mgd is the City's demand.

The SFWB Master Plan Update includes recommendations to upgrade the DSPS to a firm capacity of approximately 24 mgd by installing one additional pump, motor and VFD by 2010. With the completion of this improvement, the firm capacity of the DSPS will be adequate to supply the City's water supply needs through the 20-year planning horizon and through build-out of the current water service boundary.

Finished Water Transmission Main (West Linn)

The City's 24-inch diameter steel transmission main extends from the DSPS through Oregon City and across the Willamette River as a suspended overcrossing on the I-205 Bridge. The transmission main connects to the City's distribution system in the Bolton pressure zone.

Previous analyses have identified the capacity of this transmission main is 13 mgd. Flow testing conducted by City staff in August 2002, in coordination with the SFWB and the City of Lake Oswego, indicated that the current capacity of the transmission system is limited to approximately 7.5 mgd under normal conditions and approximately 9.6 mgd when supplying water to Lake Oswego through the emergency intertie.

As part of this supply analysis, an assessment of the March 5, 2008 flow testing performed by City staff and previous analysis of the capacity of the transmission main was completed. In addition, the computerized model of the City's distribution and transmission system as used to determine the actual capacity of the transmission main and to determine what limited the flow available during the testing in 2002. A summary of the key findings of this assessment are presented below:

- The nominal capacity of the 24-inch diameter transmission main is approximately 9.5 mgd, assuming a maximum velocity of approximately 5 feet per second (fps).
- Current flow limitations in the transmission main observed during the 2002 flow testing are attributed to flow restrictions at the existing partially open reservoir altitude valves, especially the Bolton Reservoir altitude valve. Operation of this type of globe-style valve requires adequate differential head across the valve, which is not available this close to the reservoir. The City has recently removed this altitude valve (and has already relocated the Willamette Reservoir altitude valve to a lower elevation near Willamette Falls Drive) and relocated the altitude function to the 14-inch diameter ball valves located near the DSPS.
- The SFWB Master Plan recommendations include installation of a new electronically actuated control valve at the beginning of the 24-inch diameter transmission main near the DSPS to isolate supply to the City from Oregon City's Mountainview Reservoir, and to allow operation of the DSPS to supply the City based on the level of the Bolton Reservoir. Since this time, isolation valves have been installed on the transmission main and a new VFD installed at the DSPS, resulting in the removal of this project from the SFWB CIP list.
- An analysis using the water system hydraulic model confirmed that the capacity of the transmission main is a minimum of 9.5 mgd based on velocity criteria of 5 fps. If velocities greater than 5 fps can be achieved for short durations, the transmission main has adequate capacity to transmit the build-out MDD of 10 mgd which results in a flow velocity of 5.6. It is acceptable for the transmission main to operate at higher velocities for short durations. Based on the results of flow testing completed in March 2008 and hydraulic analysis using the City's water system hydraulic model, the existing transmission is capable of delivering flows at velocities greater than 5 fps

Based on the findings presented above, and given current and future planned improvements, the capacity of the transmission main is adequate to meet current, 8.1 mgd, and future demand conditions up to the build-out of the current Urban Growth Boundary MDD of 10 mgd. Further discussion of the reliability and redundancy of this transmission main are presented below.

Supply Redundancy Evaluation

The key elements of the City's supply source with the greatest vulnerability to complete loss of service are the SFWB's raw water transmission main and the City's finished water transmission main, especially the Willamette River crossing. Of these two facilities, the finished water transmission main has the greatest vulnerability because of the risk and exposure of the I-205 bridge crossing. Currently planned upgrades to the most vulnerable segments of the raw water transmission main, discussed above, greatly reduce the vulnerability of the raw water transmission system. Key pumping facilities are designed with backup power sources, including emergency generators, and are also designed to meet future demand conditions with the largest pump out of service. The WTP treatment includes parallel elements within each component of the treatment process and on-site clearwell storage to limit supply disruption in the event that one element of the treatment process must be taken out of service.

The City's emergency intertie with the City of Lake Oswego provides a reliable backup supply, albeit with limited capacity, to the City in the event of a supply disruption. A discussion of opportunities to reduce the vulnerability of the City's transmission system from SFWB and the overall vulnerability associated with the single supply from the Clackamas River is presented below.

Finished Water Transmission Main (Willamette River Crossing)

Given that the existing 24-inch diameter transmission main has adequate capacity to meet the long-term transmission needs of the City, it is not recommended that the City pursue development of a new river crossing at this time. However, should the age and vulnerability of the transmission main, or the status of the existing I-205 Bridge ultimately require the City to consider replacement of the transmission main crossing of the Willamette River a conceptual level evaluation of river crossing alternatives was completed to guide future analysis. Opportunities for development of a second bridge crossing are fairly limited and expose the new transmission main to the same vulnerabilities as the existing transmission main. A future transmission main crossing of the Willamette River should be a hardened river undercrossing, and include flexible piping connections and isolation valves on either side of the river. This type of crossing is consistent with the current planning of other regional water suppliers addressing similar river crossing issues, such as the City of Newberg and the City of Portland.

As discussed in TM #4 – "Task 2 Deliverable: Evaluate and Establish Water Storage Requirements", the most cost effective approach to addressing the vulnerability of the City's transmission system may be to develop reliable emergency supply sources in cooperation with neighboring and regional water providers. Should the City be unable to achieve the goal of securing reliable emergency supplies, consideration of a parallel river crossing should be re-evaluated. A preliminary engineering study to evaluate and establish a recommended alignment, configuration and project cost for a proposed Willamette River crossing will be included in the CIP with a preliminary budget of $75,000. It is recommended that the City proceed with this analysis within the next five years to establish budget, right-of-way acquisition and permitting needs associated with a new crossing should one ultimately be needed.

Aquifer Storage and Recovery

As part of this supply analysis, an evaluation of the potential for development of aquifer storage and recovery (ASR) as a backup or peaking supply was completed. ASR is the underground storage of treated drinking water that is injected into a suitable aquifer and subsequently recovered from the same well or wells, generally requiring no retreatment other than disinfection. ASR is a water supply management tool for water providers whose peak use water demands either approach or exceed supply capacities, while non-peak supply capacities are typically in excess of non-peak demands. A technical memorandum documenting this analysis is included in the Appendix.

The objectives of this evaluation were (1) to identify potential fatal flaws to implementing an ASR program within the City, and using the Kenthorpe Well in particular, and (2) to identify the next steps and potential risks if the City decides to further pursue an ASR program.

This preliminary feasibility evaluation focuses on hydrogeologic considerations. General criteria used as guidelines for evaluating the hydrogeologic feasibility of ASR for the City include the following:

1. To be considered productive, an aquifer should have well yields of at least 700 gallons per minute (gpm) or approximately 1 million gallons per day (mgd), and sufficient storage volume to maintain these well yields during the critical peak demand periods (commonly 50 to 100 million gallons per well site). Well yields and injection rates are determined by the productivity of the aquifer and the efficiency of the well, and also are related to the groundwater level in the well.
2. A suitable target aquifer is confined and has sufficient available space to store the desired volume of injected water, as determined by the boundaries of the aquifer and depth to groundwater (available “headroom”).
3. Other high-capacity wells that could capture stored water are not present.
4. To be considered suitable, the selected aquifer, source water, and native groundwater are geochemically compatible such that chemical interactions will not result in clogging of the aquifer or adversely affect water quality.

The two primary water-bearing geologic units in the City area include the Waverly Heights formation and the Columbia River Basalt Group (CRBG). Existing wells completed in the Waverly Heights formation typically have low yields in the City area, ranging from 8 to 50 gpm and have insufficient transmissivity for ASR. Well log information shows that the thickness of the CRBG section in the City is highly variable, ranging from less than 100 feet to more than 600 feet in the highlands in the western portion of the City. Well data for wells deeper than 300 feet were not available for the southern and eastern portions of the City, particularly the Willamette, Horton, Robinwood, and Bolton areas. However, geologic mapping suggests that the CRBG section on the east side of the City, in the Bolton and Robinwood neighborhoods, could be as thick as 1,500 feet because of the filling of a structural low. Mapping also indicates that the CRBG section is relatively thin, less than 200 feet in the Willamette area.

Based on the limited data available for this evaluation, it appears that the northern Rosemont area and the eastern portion of the City, between the highlands and the Willamette River, have the highest potential for relatively thick basalt sections. The CRBG thickness in the northern Rosemont area and between the crest of the highlands and Highway 43 exceeds 600 feet. Although not verified by deep well data, the Bolton and Robinwood areas between Highway 43 and the river potentially are underlain by more than 1,000 feet of CRBG section and therefore may have the highest potential for productive aquifer conditions. In addition, an area between the southern Rosemont and Willamette areas also has a relatively thick CRBG section. This area also has a great deal of faulting, which could limit the extent of productive interflow zones.

Overall, a preliminary evaluation of the hydrogeologic feasibility of implementing ASR in the City indicates that ASR may not be feasible for the Willamette and southern Rosemont areas. Although limited available information did not identify fatal flaws for other portions of the City, evaluating ASR feasibility in these other locations would require conducting an exploratory drilling and testing program to evaluate and verify aquifer characteristics. Potential locations with the highest opportunity for success have been identified on Figure 1. Estimated costs for an exploratory well program likely would range from $225,000 to $275,000 for a single well site, depending on the ultimate depth of the exploratory well. The primary risk associated with an exploratory well program would be that the program would indicate that suitable hydrogeologic conditions are not present near the exploratory well after the invested effort. Further, verification of ASR feasibility at one location may not be sufficient to show that ASR is feasible at other locations with sufficient certainty, requiring additional drilling and testing at those other locations. If no fatal flaws are found, overall program costs to develop a 6 mgd ASR program for the City is approximately $8 to $9 million.

Supply Source Analysis Recommendations

As discussed above, proposed SFWB system improvements as recommended in the SFWB Water Master Plan Update are required to meet long-term water supply needs for the City. The City should include these projects in the current water system CIP to track the ultimate timing relative to the City's water supply needs as well as to provide adequate budgeting to fund these projects. The City's estimated cost share of these projects will be included in the CIP.

As previously discussed in Technical Memorandum #4, development of reliable, redundant supply facilities to reduce the City's dependence on distribution system storage is recommended as a high priority improvement. The City is currently engaging the Cities of Lake Oswego, Tigard and others to develop intertie facilities to allow for the delivery of reliable supply from other major regional water supply sources besides the Clackamas River to the City of West Linn. Development of the intertie and emergency supply agreements could result in significant capital improvement cost savings relative to other alternatives, including development of additional distribution system storage, construction of a parallel Willamette River crossing transmission main or exploration and development of ASR. Figure 2 presents a decision tree outlining a proposed process for development of reliable, redundant supply facilities that minimizing risk and capital costs.

Summary

This technical memorandum presents an evaluation of the City's existing supply source, including the intake, raw water pumping, raw water transmission, treatment, finished water pumping and finished water transmission. This memorandum documents a review of the current SFWB Water Master Plan Update, an assessment of conceptual level alternatives for a future transmission main Willamette River crossing and an evaluation for the potential development of ASR facilities in the City.

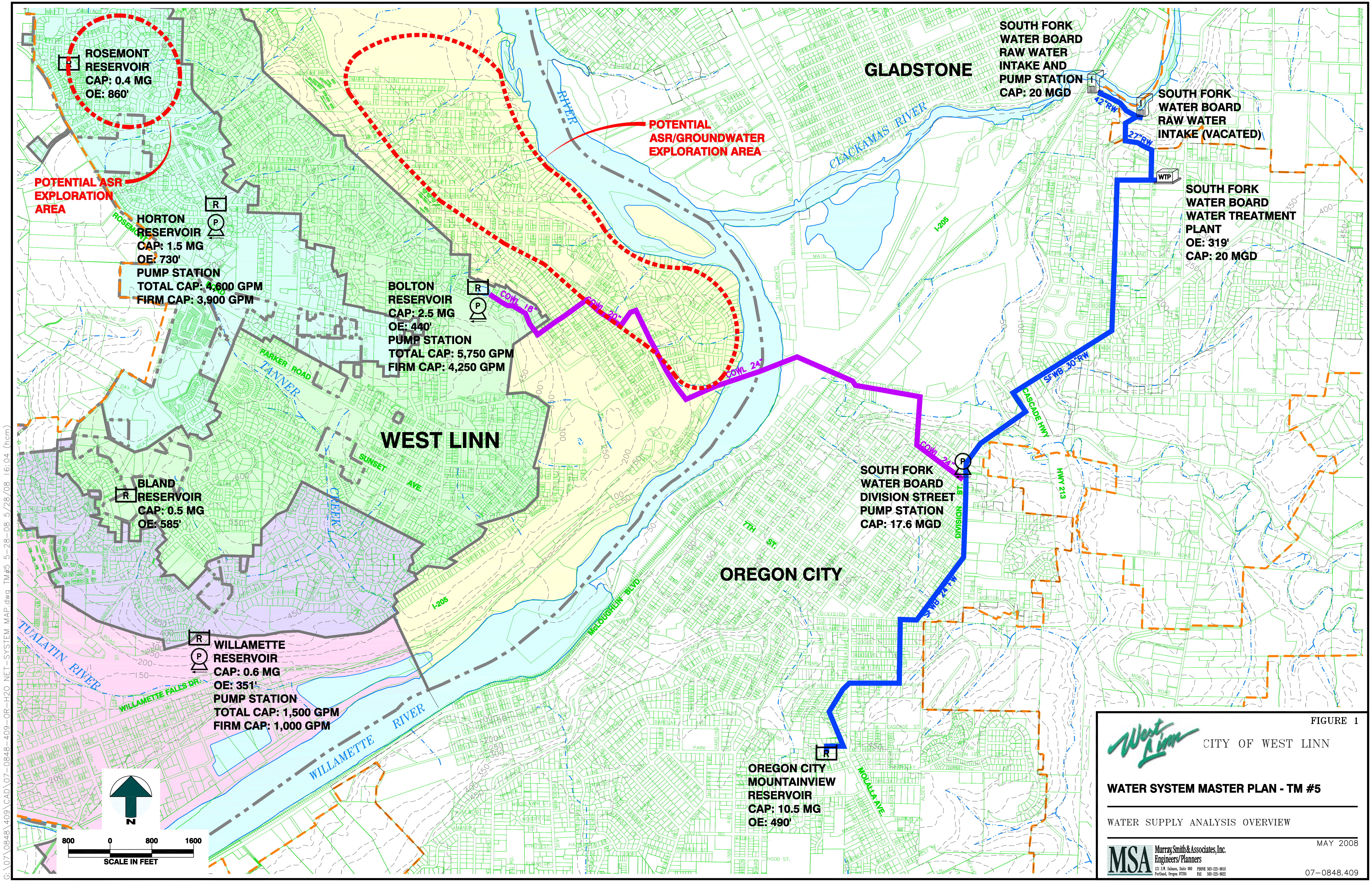

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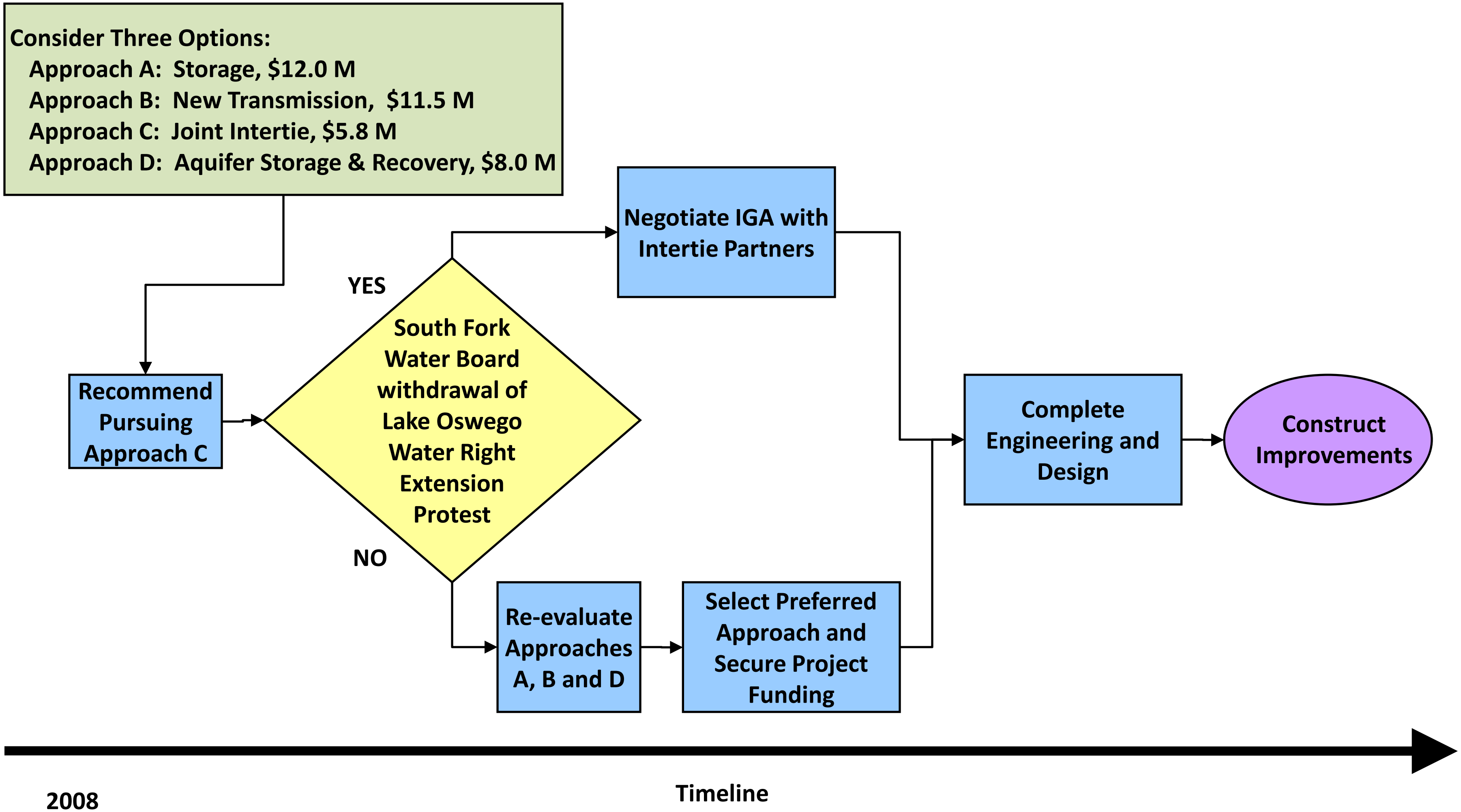
Figure 2 – Supply Approach Decision Tree



APPENDIX

List of Abbreviations

ADD	Average Daily Demand
ASR	Aquifer Storage and Recovery
CIP	Capital Improvement Plan
CRBG	Columbia River Basalt Group
DSPS	Division Street Pump Station
FPS	Feet per Second
GPM	Gallons per Minute
HP	Horsepower
MDD	Maximum Day Demand
MGD	Million Gallons per Day
ORS	Oregon Revised Statutes
RWPS	Raw Water Pump Station
SFWB	South Fork Water Board
VFD	Variable Frequency Drive
WMPU	Water Master Plan Update
WTP	Water Treatment Plant

DRAFT Technical Memorandum

To: Brian Ginter, PE – Murray, Smith & Associates, Inc.

From: Walter Burt, RG – GSI Water Solutions, Inc.
Robyn Cook, GIT – GSI Water Solutions, Inc.

Date: January 22, 2008

Re: **Preliminary ASR Feasibility Evaluation, City of West Linn, Oregon**

Introduction

This technical memorandum (TM) summarizes GSI Water Solutions, Inc.'s (GSI), preliminary feasibility evaluation of implementing an aquifer storage and recovery (ASR) program for the City of West Linn (City). The purpose of this work was to evaluate, as part of an update of the City's water master plan, whether ASR could be a viable alternative for the City to consider as part of its long-range water supply strategy. The objectives of this evaluation were (1) to identify potential fatal flaws to implementing an ASR program within the City, and using the Kenthorpe Well in particular, and (2) to identify the next steps and potential risks if the City decides to further pursue an ASR program.

This evaluation used existing and readily available information. The following primary sources of information were used:

- Well reports from the Oregon Water Resources Department (OWRD)

- Published U.S. Geological Survey (USGS), Oregon Department of Geology and Mineral Industries (DOGAMI), and unpublished geologic mapping and interpretations from Terry Tolan (pers. comm., 2007).

For those areas where fatal flaws to ASR development were not identified in this evaluation, key uncertainties and a cost estimate for taking the next step in determining ASR feasibility are summarized.

Definition of ASR

ASR is the underground storage of treated drinking water that is injected into a suitable aquifer and subsequently recovered from the same well or wells, generally requiring no retreatment other than disinfection. ASR is a water supply management tool for water providers whose peak use water demands either approach or exceed supply capacities, while non-peak supply capacities are typically in excess of non-peak demands. Several municipalities and water districts in the Portland metropolitan area have implemented ASR programs, including the Cities of Beaverton, Tigard, and Tualatin, and the Tualatin Valley Water District. Each of these entities currently has ASR wells, completed in the Columbia River Basalt Group (CRBG) aquifers, which is the target ASR storage zone for the City of West Linn (see Figure 1).

Criteria for ASR Feasibility

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

1. A productive aquifer with well yields of at least 700 gallons per minute (gpm) or approximately 1 million gallons per day (mgd), and sufficient storage volume to maintain these well yields during the critical peak demand periods (commonly 50 to 100 million gallons per well site). Well yields and injection rates are determined by the productivity of the aquifer and the efficiency of the well, and also are related to the groundwater level in the well.
2. The target aquifer is confined and has sufficient available space to store the desired volume of injected water, as determined by the boundaries of the aquifer and depth to groundwater (available "headroom").
3. Other high-capacity wells that could capture stored water are not present.
4. The aquifer, source water, and native groundwater are geochemically compatible such that chemical interactions will not result in clogging of the aquifer or adversely affect water quality.

The remainder of this TM describes the hydrogeologic setting in the West Linn area and evaluates existing information relative to these hydrogeologic criteria.

Hydrogeologic ASR Feasibility Criteria Evaluation

Hydrogeologic Setting

The two primary water-bearing geologic units in the West Linn area include the Waverly Heights formation and the CRBG (see Figure 2). The Waverly Heights formation is Eocene in age (roughly 40 to 60 million years ago [mya]) and underlies the CRBG. The most significant characteristic of the Waverly Heights basalt formation relative to this evaluation is that it is highly weathered and altered, with the pore spaces commonly filled with secondary minerals. The primary relevant effect is a significant decrease in the permeability and transmissivity of otherwise productive zones. (Transmissivity is a measure of how easily water is transmitted in an aquifer.) Consequently, wells completed in the Waverly Heights formation typically have low yields in the West Linn area, ranging from 8 to 50 gpm. Thus, the Waverly Heights formation is insufficiently transmissive for ASR, and the remainder of this evaluation focuses on the CRBG.

The CRBG consists of a series of tabular basalt sheet lava flows that originated from eastern Washington, Oregon, and western Idaho between 17 and 6 mya, and underlie a large area in the Willamette and Tualatin valleys. The thickness of the CRBG depends on the amount of paleotopography in the area when the CRBG flows were emplaced, as well as the degree of uplift and erosion since emplacement. Near the City of Tualatin, the CRBG section is approximately 1,070 feet thick and consists of 13 separate flows. However, well log information shows that the thickness of the CRBG section in West Linn is highly variable, ranging from less than 100 feet to more than 600 feet in the highlands in the western portion of the City. Deep (more than 300 feet deep) well data were not available for the southern and eastern portions of West Linn, particularly the Willamette, Horton, Robinwood, and Bolton areas. However, geologic mapping suggests that the CRBG section on the east side of West Linn, in the Bolton and Robinwood neighborhoods, could be as thick as 1,500 feet because of the filling of a structural low. Mapping also indicates that the CRBG section is relatively thin (less than 200 feet) in the Willamette area. The variability in CRBG thickness is the result of vertical offset of the CRBG by faulting and removal by erosion (Figure 2). Figure 3 is a schematic depiction of the spatial distribution of estimated CRBG thicknesses in the City. Areas shown in dark blue and green have a greater estimated CRBG thickness, whereas yellow and reddish shades denote thinner CRBG sections.

Groundwater in the CRBG is predominantly derived from interflow zones, which represent the contact between the top and bottom of individual basalt flows. Certain interflow zones are porous and rubbly, and thus can transmit water easily, whereas others are less so because of the presence of soils representing weathering horizons or lack of flow emplacement features that create connected pore space for groundwater to move. The interiors of the basalt flows typically are dense and hydraulically separate the interflow zones, except possibly in certain places where disrupted by structural features, such as geologic faults.

Suitability of CRBG Aquifer for ASR in West Linn

Aquifer Productivity

Transmissivity and specific capacity are commonly used as measures of potential aquifer productivity for ASR feasibility. Transmissivity for basalt aquifers in the Tualatin Valley ranges from several thousand gallons per day per foot (gpd/ft) to several hundred thousand gpd/ft. Transmissivity values in CRBG aquifers where ASR currently is being implemented are 15,000 to 150,000 gpd/ft. Transmissivity is determined from controlled pumping tests of wells, and also can be estimated from specific capacity data for wells. Pumping test data for wells in the West Linn area were not available for this evaluation.

Specific capacity of a well, measured in gallons per minute per foot (gpm/ft) of drawdown, is an indication of both the overall productivity of the aquifer and the efficiency of the well. Specific capacity is derived from the pumping rate and pumping water level in the well. In the Tualatin Valley, specific capacities of viable ASR wells range from 7 to 30 gpm/ft.

We reviewed available pumping data for wells completed in the CRBG in the West Linn area. The pumping rates ranged from 1 to 100 gpm, not including the Kenthorpe Well, which was reported to pump 200 gpm (Figure 4). In most cases, the pumping water level was not reported for these wells; consequently, specific capacities and the overall productivity of the CRBG aquifer in the West Linn area could not be confirmed. However, we noted that several wells were drilled through the CRBG and into the Waverly Heights formation in certain areas, suggesting that the available CRBG section is relatively unproductive at these locations.

The quantity and characteristics of basalt interflow zones generally determine the overall productivity of the CRBG aquifer at a given location. Thus, thicker CRBG sections, with generally a greater number of interflows, will increase the potential for the aquifer to be sufficiently productive to host an ASR system. Because data directly describing aquifer productivity were unavailable or inconclusive, we used the thickness of the CRBG section as an alternate method to indirectly assess locations where aquifer productivity potential may be higher than others. CRBG thickness was interpreted from well logs, where available, and geologic mapping.

As discussed in the previous section, the thickness of the CRBG is highly variable because of extensive faulting, which has uplifted the underlying Waverly Heights formation and reduced the CRBG thickness. The schematic cross section in Figure 2 illustrates the faulted and compartmentalized nature of the CRBG in West Linn. Figure 3 is a schematic depiction of the spatial distribution of estimated CRBG thicknesses in the City. Areas shown in dark blue and green have a greater estimated CRBG thickness, whereas yellow and reddish shades denote thinner CRBG sections.

The thickness of the CRBG section in West Linn ranges from less than 100 feet in the southern and central portions of the City, to 600 feet or more in the northern and eastern portions of the City (Figure 3). The CRBG is particularly thin in the western highlands, southern Rosemont, and Willamette areas. Based on the limited data available for this evaluation, it appears that the northern Rosemont area and the eastern portion of the City, between the highlands and the Willamette River, have the highest potential for relatively thick basalt sections. The CRBG thickness in the northern Rosemont area and between the crest of the highlands and Highway 43 exceeds 600 feet. Although not verified by deep well data, the Bolton and Robinwood areas between Highway 43 and the river potentially are underlain by more than 1,000 feet of CRBG section and therefore have the highest potential for productive aquifer conditions. In addition, an area between the southern Rosemont and Willamette areas also has a relatively thick CRBG section. However, this area also has a great deal of faulting, which could limit the extent of productive interflow zones.

Storage Volume

The volume of available aquifer storage is controlled by the extent and thickness of the aquifer, and the available “headroom,” or depth to the groundwater table in an area. While a bounded aquifer can be desirable for ASR, the storage capacity of the aquifer may be inadequate where the extent of the aquifer is overly limited. As discussed above, the CRBG is highly faulted in West Linn, potentially compartmentalizing the aquifer. In particular, faults in the southern portion of West Linn are relatively closely spaced and may highly compartmentalize or limit storage in the aquifer. The aquifer in the northern and eastern portions of the City also may be compartmentalized, but the extent of possible compartments appears greater, allowing for greater storage and thus potentially more suitable for ASR.

Static groundwater levels from well logs were reviewed to evaluate potential storage "headroom" in the aquifer. The depth to water in most of the basalt wells in the highlands in West Linn is several hundred feet below ground surface, which should be sufficient for ASR operations, if the aquifer productivity is adequate. The depth to water in the aquifers in the lowlands, toward the Willamette River, are expected to be significantly less than in the highlands. While a shallow depth to water is desirable for pumping because of reduced lift requirements, a shallow depth to water presents problems for ASR operations because it reduces the available hydraulic head to inject at optimal rates without high wellhead pressures. Consequently, the lower elevation areas with higher groundwater levels require a higher aquifer transmissivity to accept the desired flow rates without unacceptably high injection levels at the ASR well.

Capture of Stored Water

No municipal or industrial high-capacity (>200 gpm) wells were identified in the West Linn area for this evaluation. Although there are several domestic wells in the area, it does not appear that any would capture large quantities of water stored in the CRBG. Roughly half of the domestic wells analyzed in this evaluation are open to the Waverly Heights formation and do not draw water from the CRBG.

Geochemical Compatibility

Groundwater quality and source water quality data were not available for an evaluation of geochemical compatibility. Other CRBG ASR systems in the Portland metropolitan area have not experienced significant geochemical compatibility issues that have affected the feasibility of ASR. Water quality issues have been encountered at some facilities, including relatively high radon concentrations in native groundwater, as well as taste and odor issues. However, these issues have been satisfactorily managed to produce good quality water, allowing development of the ASR systems.

Kenthorpe Well Evaluation

The City owns a former Robinwood Water District supply well, now called the Kenthorpe Well. The Kenthorpe Well is located on Kenthorpe Avenue in northeast West Linn (Figure 1). Based on the OWRD well report, the well is 8 inches in diameter, approximately 278 feet deep, had a static water level of 137 ft bgs at the time of drilling, and was pumped at a rate of 200 gpm with 62 feet of drawdown for a specific capacity of 3.2 gpm/ft. Although a geologic log is not available as part of the OWRD well report, the location of the well relative to the understanding of the geology in the area indicates that the well likely is completed in the upper portion of the CRBG aquifer. No other information regarding the well construction, capacity, pumping history, or water quality was available for review when this TM was being prepared.

The City conducted a site visit to assess the accessibility of the Kenthorpe Well for this evaluation. The well was not accessible because a concrete slab covers the location of the well. Consequently, the condition of the well could not be determined for this TM.

Based on available information, the Kenthorpe Well is not suitable for ASR pilot testing because of capacity limitations, the size of the well, and the lack of accessibility. However, the well penetrates only the upper portion of the CRBG section, and the CRBG near the Kenthorpe Well is potentially 1,000 feet or more thick. Thus, the CRBG in the area of the Kenthorpe Well has a potential to have suitable production and storage characteristics for groundwater supply or ASR development. Completion of an exploratory test well and aquifer testing would be necessary to verify the groundwater supply or ASR potential in this area.

Conclusions

A preliminary evaluation of the hydrogeologic feasibility of implementing ASR in the City indicates that ASR is not feasible for the Willamette and southern Rosemont areas. Although limited available information did not identify fatal flaws for other portions of the City; evaluating ASR feasibility in these other locations would require conducting an exploratory drilling and testing program to evaluate and verify aquifer characteristics. The outcome of drilling and testing in each area is uncertain given the current level of understanding. Specific conclusions from the preliminary ASR evaluation include the following:

- The limited thickness of the CRBG aquifer and extensive faulting in the southern Rosemont and Willamette neighborhood indicate that hydrogeologic conditions are not favorable for ASR in these areas.

- Available hydrogeologic data are insufficient to conclusively identify potential fatal flaws and evaluate ASR feasibility potential in other areas of the City primarily because deep well data to verify the thickness of the CRBG or desirable aquifer characteristics are not available.

- Geologic mapping information indicates that certain areas of the City have a higher potential for hydrogeologic conditions favorable for ASR, primarily based on potentially greater CRBG thicknesses. These areas include the northern Rosemont, Robinwood, Horton, and Bolton neighborhoods. The portion of these neighborhoods near the base of the ridge along Highway 43 likely holds the most promise because of the combination of potentially thick CRBG section and available “headroom” (lower groundwater levels). The northwestern Rosemont and Horton neighborhoods may have somewhat less favorable conditions for ASR because the CRBG section likely is thinner, and the aquifer may be more compartmentalized by faulting.

- The Kenthorpe Well could not be directly evaluated for ASR suitability because it is no longer accessible. However, available information about the well indicates that the as-built construction of the well is not suitable, and the portion of the CRBG aquifer penetrated by the well is not sufficiently productive for ASR.

- The key hydrogeologic uncertainties remain the location and extent of a suitable aquifer in the CRBG.

- Resolving the uncertainties with regard to hydrogeologic characteristics and determining the overall feasibility of an ASR program will require an exploratory test well drilling program.

Next Steps

Should the City elect to further pursue evaluating the feasibility of ASR, the next step would be to drill and test an exploratory well for each specific site or area the City would like to evaluate. An exploratory program would entail the following sequence of work:

1. Well Siting Evaluation. A siting evaluation to choose the exploratory well location(s) would use the following criteria: hydrogeology, land ownership, water demand, and infrastructure (conveyance and storage) to choose a well site or sites.

2. Exploratory Well Drilling and Testing. An exploratory well would be drilled to the base of the CRBG section at the chosen site(s). The base of the CRBG may range from 600 to 1,500 ft/bgs, depending on the location. The exploratory well would be pumped for an extended period of time (e.g., 5 days) and water levels in the well and other nearby wells would be monitored to evaluate the long-term production and storage potential of the aquifer.

3. Geochemical Compatibility Evaluation. Samples of native groundwater and injection source water would be collected and analyzed for geochemical parameters to evaluate potential geochemical reactions that either could clog the aquifer or adversely affect water quality.

4. ASR Feasibility Report and Program Plan. The results of the exploratory program would be summarized in an ASR feasibility report. If the exploratory well project indicates that ASR is feasible, the report also would lay out a phased ASR program plan, including permitting, infrastructure improvements, ASR well drilling and testing, pilot testing, and expansion options. The plan also would provide planning level cost estimates for the ASR program.

Estimated costs for the outlined exploratory well program likely would range from $200,000 to $250,000 for a single well site, depending on the ultimate depth of the exploratory well. Additional exploratory wells to evaluate other areas within the City would cost between $130,000 and $160,000 per site. The primary risk associated with an exploratory well program would be that the program would indicate that suitable hydrogeologic conditions are not present near the exploratory well after the invested effort. Further, verification of ASR feasibility at one location may not be sufficient to show that ASR is feasible at other locations with sufficient certainty, requiring additional drilling and testing at those other locations.

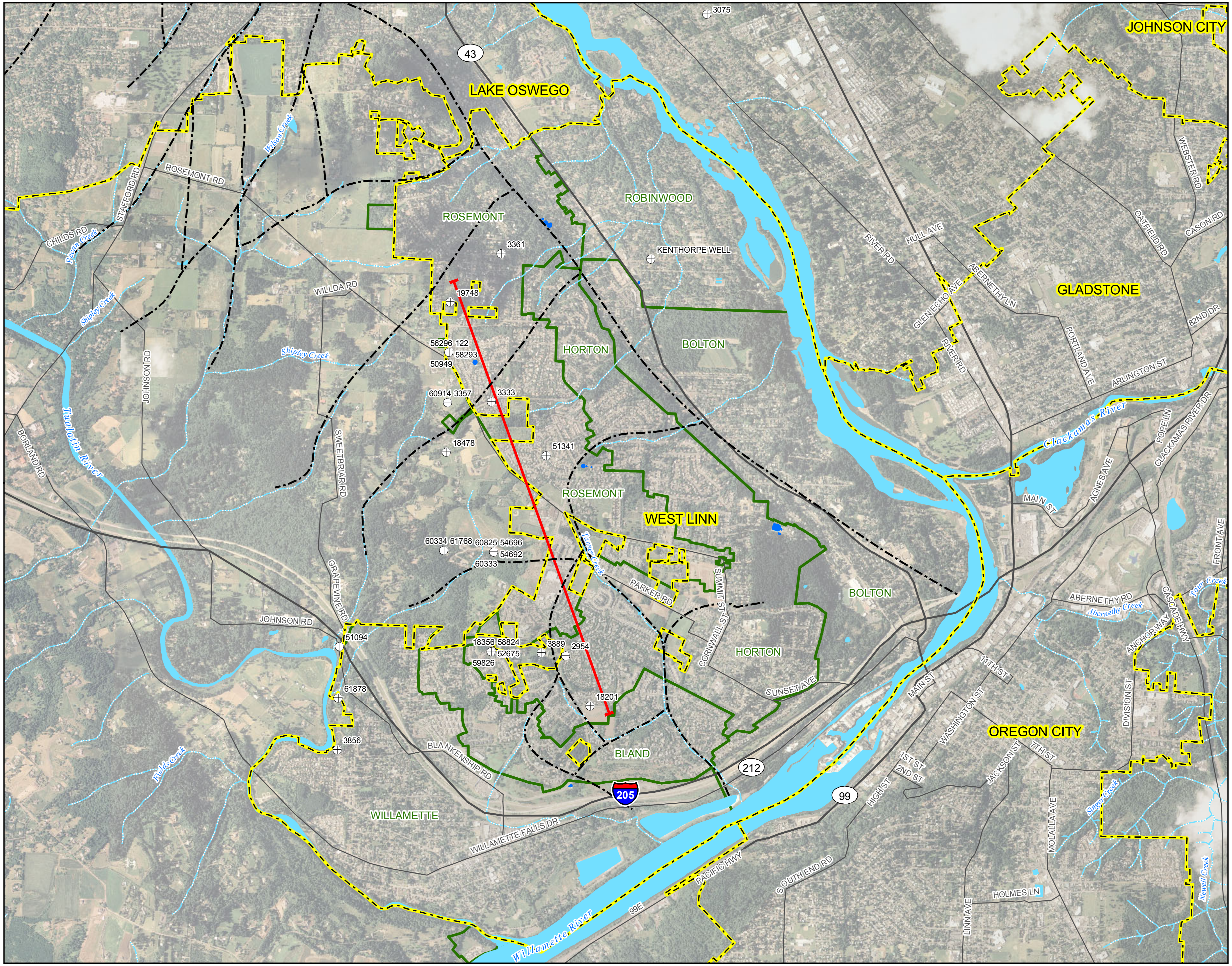


FIGURE 1

Location Map

City of West Linn

LEGEND

- Existing Wells
- Faults
- Geologic Cross Section
- City Pressure Zones
- City Boundaries
- Watercourses
- Waterbodies
- Reservoirs
- Freeways and Highways
- Major Roads

N

Scale

1:30,000

0 1250 2500 3750 5000

Feet

MAP NOTES:
Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: December 20, 2007
Data Sources: Murray, Smith, and Associates, OWRD, Oregon Geospatial Data Clearinghouse

GSI Water Solutions, Inc.

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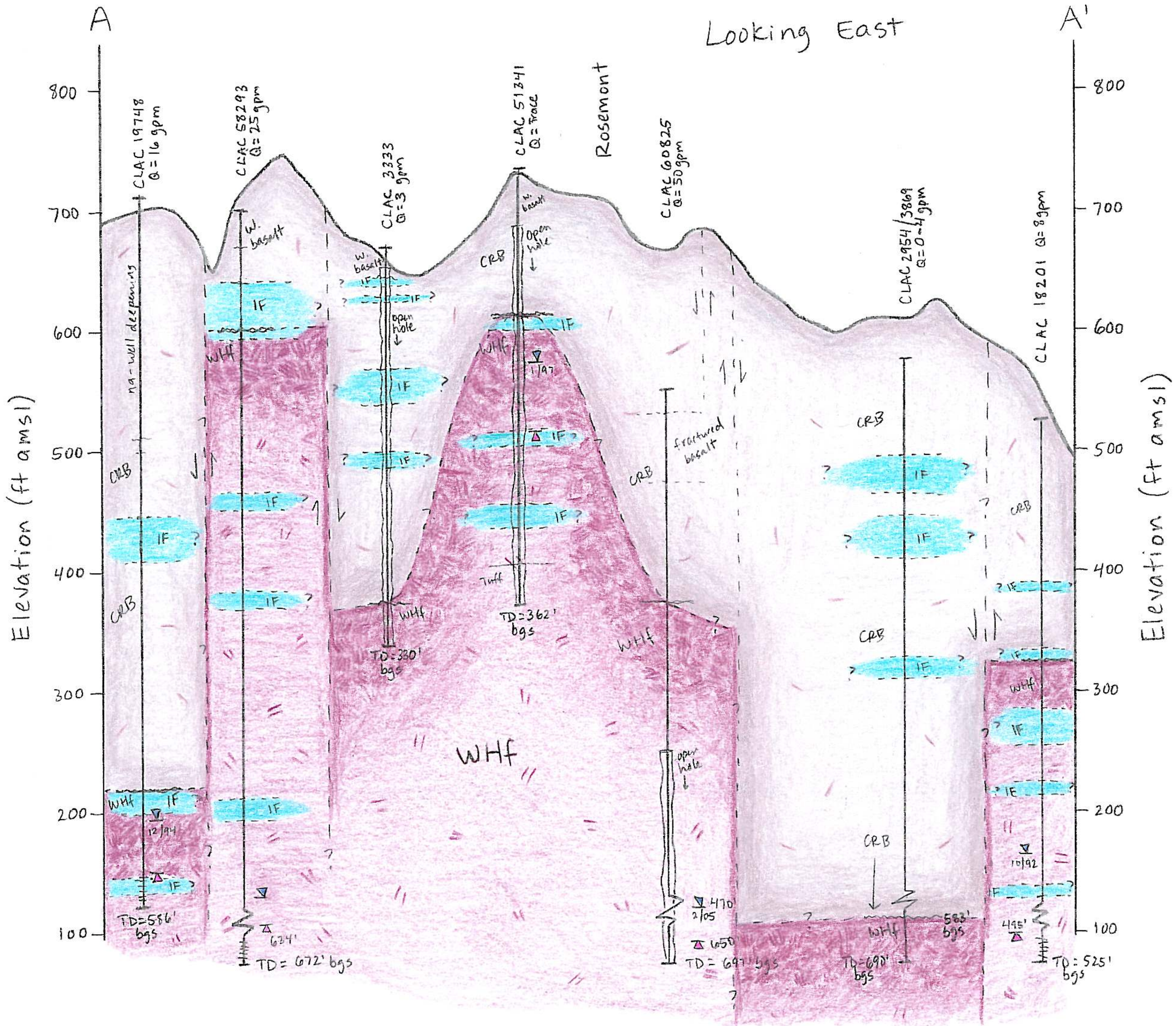

LEGEND

Well

screened interval

open hole

CLAC2954 Well ID

10/92 Static water level (and date)

Depth of first water

IF Interflow

BGS Below ground surface

CRB Columbia River Basalt

WHf Waverly Heights (basalt)

Figure 2
Schematic Hydrogeologic Cross Section
City of West Linn

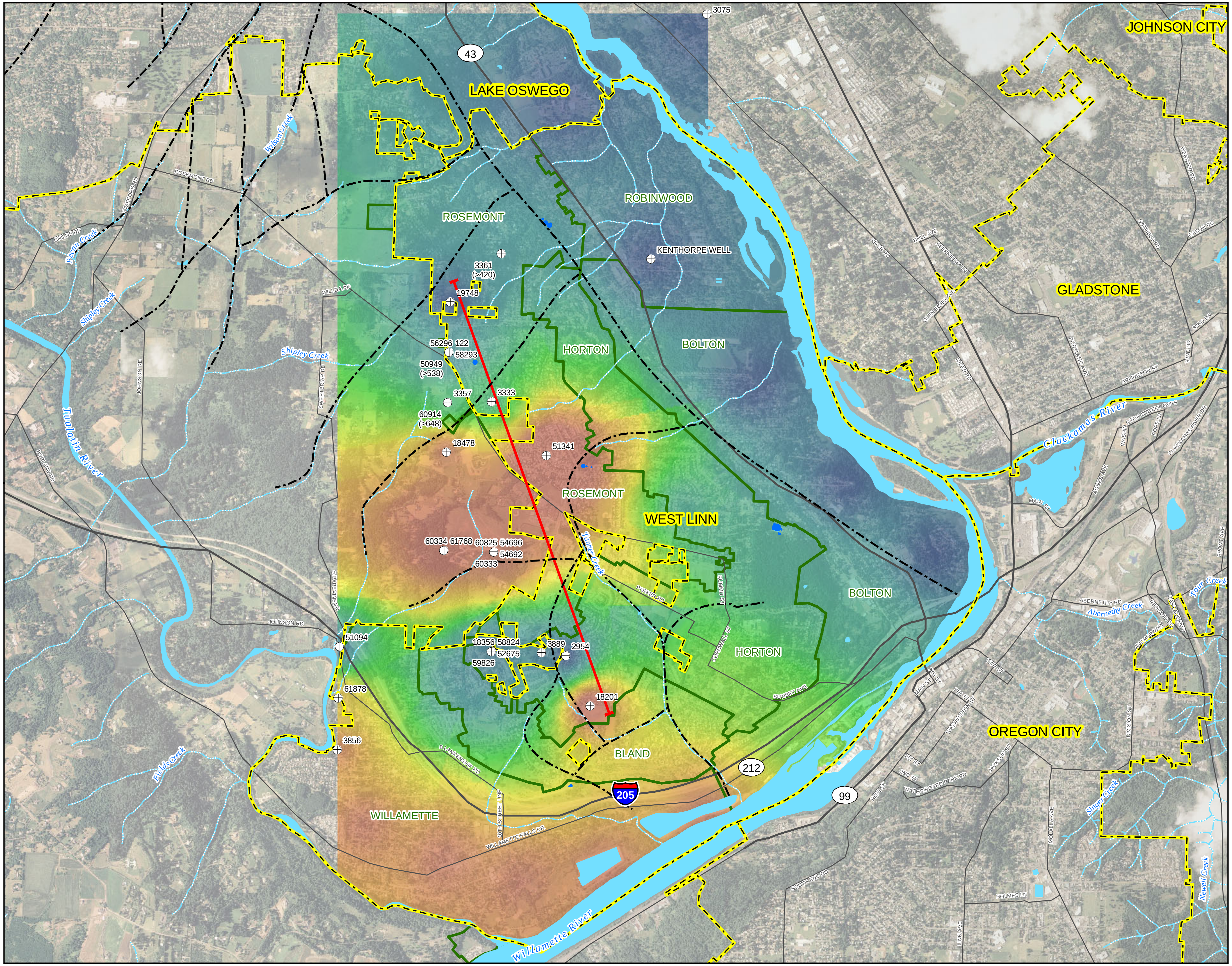

FIGURE 3

Estimated Thickness of CRBG

City of West Linn

LEGEND

Thickness of CRBG

- >580 feet
- 124 feet
- Existing Wells
- Faults
- Geologic Cross Section
- City Pressure Zones
- City Boundaries
- Watercourses
- Waterbodies
- Reservoirs
- Freeways and Highways
- Major Roads

NOTE: The interpreted thickness of the CRBG is based on well logs, published and unpublished mapping of the West Linn, Lake Oswego Quadrangles by the USGS, DOGAMI, and Terry Tolan (GSI).

N

Scale

1:30,000

0 1250 2500 3750 5000

Feet

MAP NOTES:
Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: January 16, 2008
Data Sources: Murray, Smith, and Associates, OWRD, Oregon Geospatial Data Clearinghouse

GSI Water Solutions, Inc.

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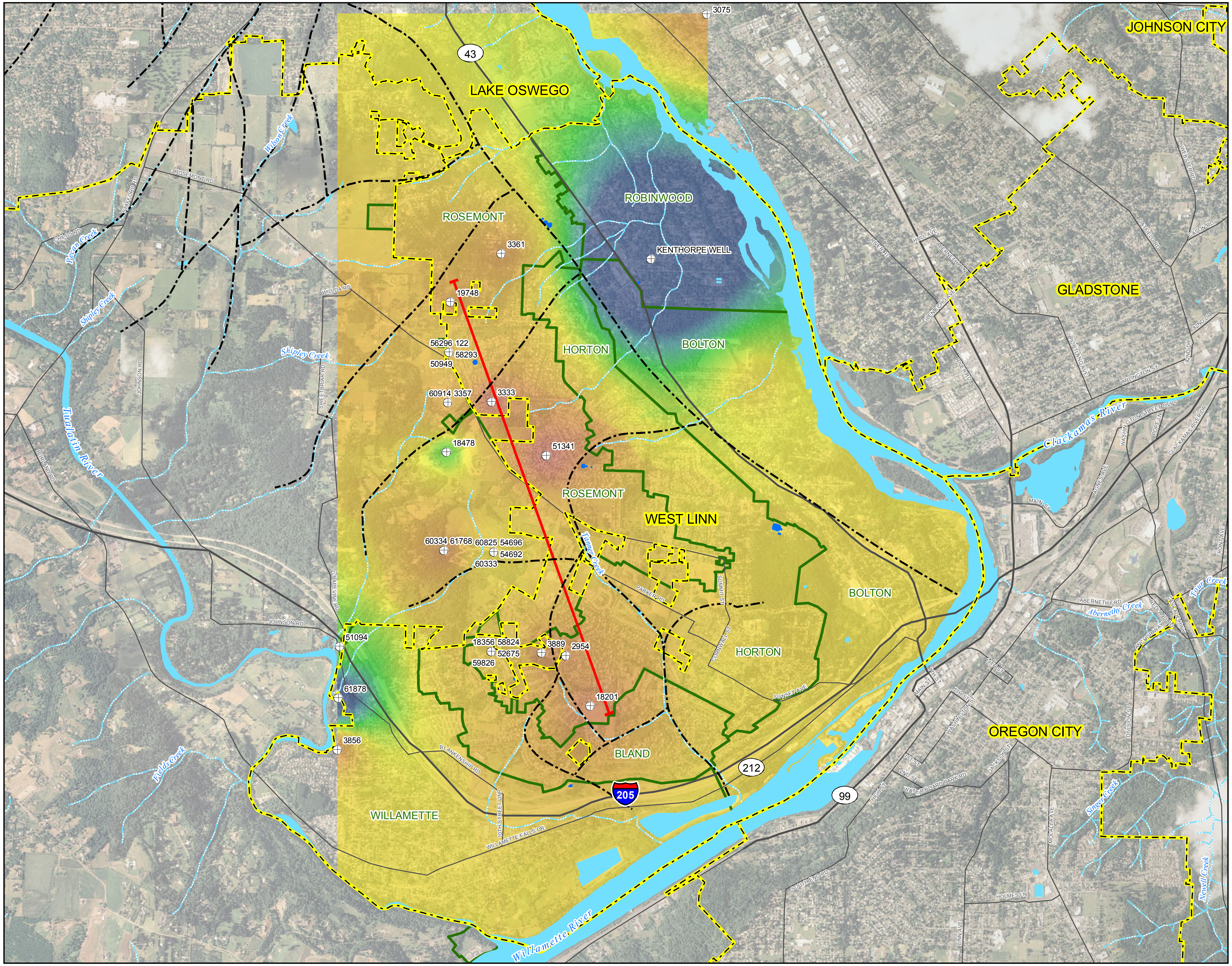

FIGURE 4

Well Yield

City of West Linn

LEGEND

Discharge (gallons per minute)

- 200 gpm
- 1 gpm
- Existing Wells
- Faults
- Geologic Cross Section
- City Pressure Zones
- City Boundaries
- Watercourses
- Waterbodies
- Reservoirs
- Freeways and Highways
- Major Roads

N

Scale
1:30,000

0 1250 2500 3750 5000
Feet

MAP NOTES:
Projection: Oregon State Plane North Zone
Datum: North American Datum of 1983
Date: January 14, 2008
Data Sources: Murray, Smith, and Associates, OWRD, Oregon Geospatial Data Clearinghouse

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