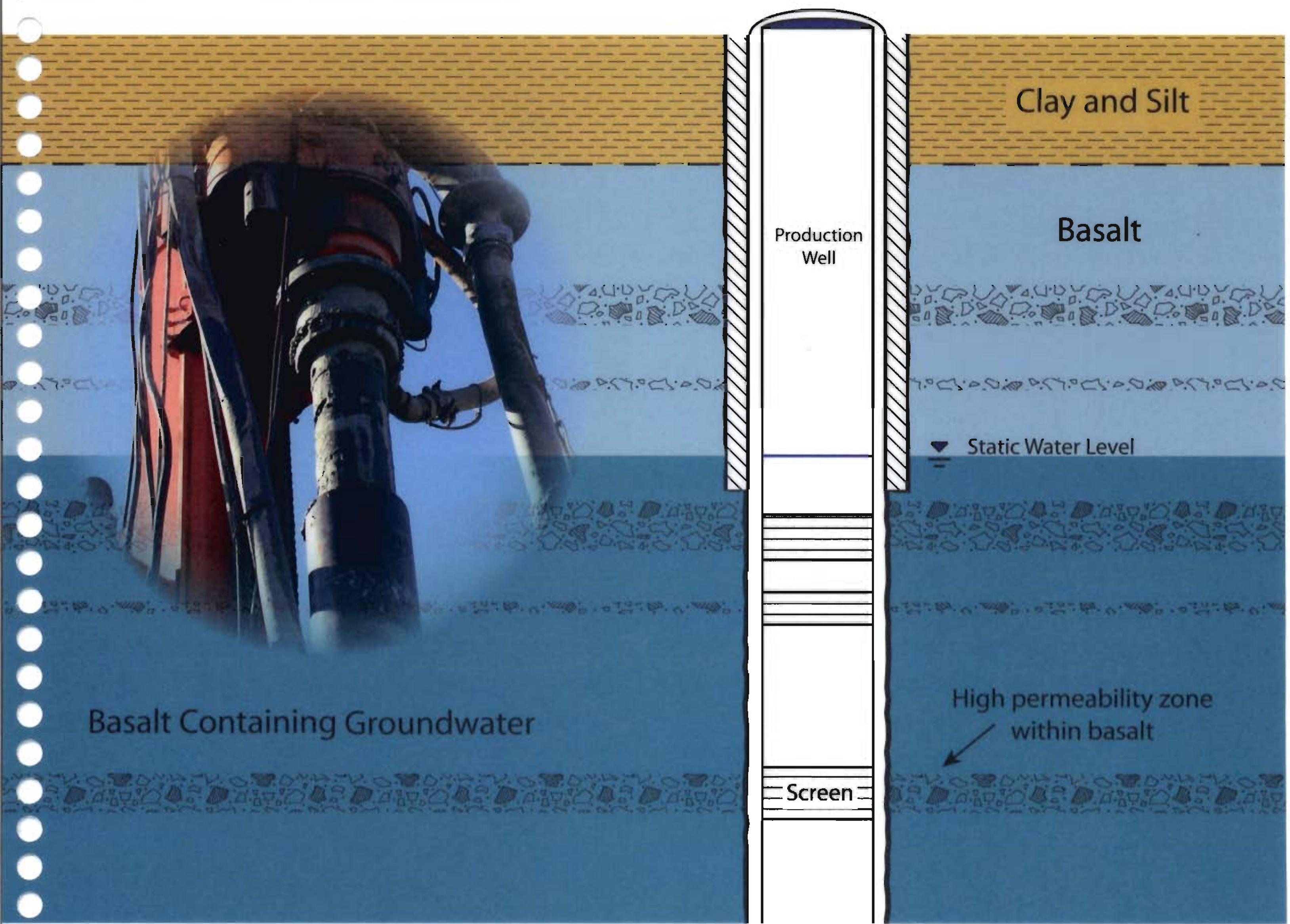
City of Tigard- Year 6 (December 2006 to November 2007) ASR Pilot Test Results

Prepared for Oregon Water Resources Department

TIGARD

Drinking Water Injected to Storage

Water Recovered During High Demand



Prepared by

GSI Water Solutions, Inc.
55 SW Yamhill Street, Suite 400
Portland, OR 97204
503-239-8799
www.gsiwatersolutions.com

GSI
Water Solutions, Inc.

TECHNICAL MEMORANDUM

City of Tigard - Year 6 ASR Pilot Test Results

PREPARED FOR: John Goodrich - City of Tigard
Aaron Beattie - City of Tigard
Robert Murchison, PE - City of Tigard
Brian D. Rager, PE - City of Tigard

PREPARED BY: Larry Eaton, RG - GSI Water Solutions, Inc.
Ted Ressler, RG, CWRE - GSI Water Solutions, Inc.

CC Donn Miller, RG - Oregon Water Resources Department
Mark Norton, RG - Oregon Water Resources Department
Dennis Nelson, RG - Oregon Health Department
Rodney Weick, RG - Oregon Department of Environmental Quality

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REGISTERED OREGON THEODORE R. RESSLER G2060 GEOLOGIST

Introduction

This technical memorandum presents the results of the sixth year of aquifer storage and recovery (ASR) pilot testing conducted by the City of Tigard (City). The purpose of the ASR pilot testing is to confirm ASR feasibility for the basalt (host) aquifer and to develop operational criteria for a full-scale ASR system for the City. Previous reports have outlined in more detail the City's ASR program, as well as results from previous years of ASR pilot testing. The reader is referred to a list of reports at the end of this technical memorandum that provides additional reference material for this project.

The City receives the source water used for ASR primarily from the City of Portland Water Bureau (PWB) with lesser amounts from the Joint Water Commission (JWC) and the City of Lake Oswego. The source water is stored in the basalt aquifer beneath the City during the winter and spring months (December through June) when demands are low. This stored water is then recovered during the summer and fall months (July through October) to augment system capacity during peak demand periods or during an emergency condition.

ASR pilot testing for the City is being conducted under ASR Limited License #005, issued by the Oregon Water Resource Department (OWRD). The limited license permits recovery of 95 percent of the stored water; however, because the City has water rights at ASR 1 and ASR 2, the City has the option to use native groundwater after the ASR account has been depleted. The City has received a 5-year extension of Limited License #005 as of February 20, 2007. The renewed Limited License expires on February 20, 2011.

55 SW Yamhill Street, Suite 400 Portland, OR 97204 P: 503.239.8799 F: 503.239.8940 info@gsiwatersolutions.com www.gsiwatersolutions.com

Executive Summary

ASR pilot testing during Year 6 took place from December 2006 through November 2007 and involved operational activities using both of the City's operational ASR wells, ASR 1 and ASR 2 (Figure 1). A total of 181 million gallons (MG) of treated drinking water was injected into the basalt aquifer from December 18, 2006 to April 3, 2007. An additional 25 MG of stored water was remaining in the aquifer at ASR 2 as carryover from the previous ASR cycle (only 95 percent of the carryover can be withdrawn per condition No. 11 of Limited License #005). Of the 206 MG of water banked for Year 6, a total of 68 MG of water was recovered from April 16 to September 26, 2007, with full allowed recovery of stored water at ASR 1 (i.e., 95% of stored volume) and partial recovery at ASR 2. Approximately 128 MG of stored water was left in the aquifer as carryover at ASR 2. The City continued to pump native groundwater from ASR 1 after full allowed recovery of the stored ASR volume (i.e., 95% of stored volume) at this well. Specifically, the City appropriated approximately 98 MG of native groundwater from ASR 1 under the City's water rights.

No long-term decline in the static water level of the regional basalt aquifer has been observed in response to ASR activities and the difference between pre- and post-injection water levels has steadily increased as larger volumes of water have been injected. This indicates that the aquifer is responding positively to ASR with no detectible losses of stored water. The ambient aquifer water level measured prior to the start of each successive ASR cycle has steadily increased since the start of ASR pilot testing. Analysis of historical aquifer water levels, native groundwater production by the City, and precipitation trends, indicates that this year-to-year rise in aquifer water level correlates with trends in precipitation and volume of native groundwater pumped from the basalt aquifer. The historical volume of native groundwater production from the basalt aquifer has been influenced by a number of factors, including year-to-year precipitation, a moratorium on additional groundwater rights as established by the Cooper-Bull Mountain Critical Groundwater Area in 1974, a decline in use of domestic water wells as the area has been urbanized, and most recently the use of ASR by the City that has reduced the yearly volume of native groundwater pumped from the aquifer by the City. Although the City has recently increased the native groundwater production (57 MG in 2006 and 98 MG in 2007), the water level of the aquifer has continued to increase, rising a total of 32 feet since the start of ASR operations in 2002.

Concentrations of water quality parameters in water samples collected during Year 6 operations were compliant with all applicable drinking water standards and ASR injection standards. Water chemistry trends during Year 6 continue to indicate a mixing trend from injection of source water through recovery of the stored water. Interestingly, the water chemistry of source water samples collected during Year 6 also indicated the relative blend of groundwater and surface water in the source water used for injection (i.e., groundwater from Portland Water Bureau's Columbia South Shore Well Field and surface water from Bull Run). No adverse chemical reactions that potentially could clog the well or aquifer have been identified in the water chemistry data.

The City has been testing the feasibility of ASR since 2002. To date, results have been favorable and ASR has played a very important role in helping the City meet peak demand periods during the summer. The City intends to move forward with further ASR testing that will include adding additional ASR wells. For example, the City intends to develop ASR 3,

located on Bull Mountain West of ASR 2, in 2009. Overall, the dynamic response of the aquifer system at ASR 1 has shown that up to 120 MG of water can be injected without a loss of stored water at the Canterbury Lane facility. However, because of rising water levels observed in the Tigard High School well and the Titan Avenue well, no future increases in ASR injection volume are planned for ASR 1 and no additional wells are planned for the Canterbury Lane facility at this time. The City intends to abandon the Titan Avenue well and to convert the Tigard High School well into a pressure sealed piezometer to serve as a dedicated monitoring point. Future ASR expansion will focus on Bull Mountain where ASR pilot testing at ASR 2 and most recently aquifer test results for ASR 3 have shown that the basalt aquifer below Bull Mountain is favorable for ASR and capable of hosting multiple ASR wells. The dynamic response of the aquifer at ASR 2 has shown that up to 160 MG of water can be injected without a loss of stored water. In addition, injection at ASR 2 resulted in much less water level drawup at the Tigard High School well, due in part to a greater separation distance and some amount of hydraulic separation between Bull Mountain and Little Bull Mountain.

Year 5 ASR Pilot Testing and ASR Account Balance

Table 1 summarizes the City's ASR pilot testing during Year 6 (December 2006 to November 2007). Table 2 provides a summary of ASR pilot testing since the onset of testing in 2002.

Table 1
Year 6 ASR Pilot Testing

	ASR 1	ASR 2
Injection:	January 4 to January 31, 2007	December 18, 2006 to April 3, 2007
Storage:	January 31 to April 16, 2007	April 3 to May 30, 2007
Recovery:	April 16 to September 26, 2007	May 30 to September 24, 2007

Well	ASR Volume Stored[2]		ASR Volume Recovered	Native Groundwater	Total Recovery	ASR Account Carryover	
	Carryover	*2007*				*Used*	*Remaining*[3]
ASR 1	0 MG	20 MG	19 MG	98 MG	117 MG	0 MG	0 MG
ASR 2	25 MG	161 MG	49 MG	0 MG	49 MG	0 MG	128 MG
Totals	**25 MG**	**181 MG**	**68 MG**	**98 MG**	**166 MG**	**0 MG**	**128 MG**

Notes:
[1] MG = million gallons.
[2] Only 95 percent of this amount can be recovered per condition No. 11 of Limited License # 005.
[3] Recoverable volume of ASR account carryover is subject to condition No. 11 of Limited License #005: only 95 percent of stored water shall be recovered.

Table 2
ASR Pilot Testing Summary (2002 to 2006)

Year	Well *(ASR Cycle)*	ASR Volume Stored[2]	ASR Volume Recovered	Native Groundwater Recovered[3]	Total Recovery	ASR Account Carry Over[2]
2002	ASR 1 *(Cycle 1)*	97 MG	92.1 MG	3.45 MG	95.6 MG	0 MG
2003	ASR 1 *(Cycle 2)*	117 MG	101 MG	0 MG	101 MG	10.15 MG
2004	ASR 1 *(Cycle 3)*	143 MG	145 MG	0 MG	145 MG	0.49 MG
2005	ASR 1 *(Cycle 4)*	116.6 MG	110.8 MG	0 MG	111 MG	0.44 MG
2006	ASR 1 *(Cycle 5)*	73 MG	69.7 MG	57 MG	126.7 MG	0 MG
	ASR 2 *(Cycle 1)*	97.6 MG	67.7 MG	0 MG	67.7 MG	25 MG
2007	ASR 1 *(Cycle 6)*	20 MG	19 MG	98 MG	117 MG	0 MG
	ASR 2 *(Cycle 2)*	161 MG	49 MG	0 MG	49 MG	128 MG

Notes:
[1] MG = million gallons.
[2] Subject to condition No. 11 of Limited License #005, where 95 percent of the stored water can be recovered.
[3] 95 percent of the stored ASR water was recovered; however, the City continued to pump native groundwater using ASR 1 under its existing water rights.

Water Level Monitoring

To monitor the dynamic response of the aquifer to ASR operation, a network of observation wells was established in the preliminary phase of the project and routinely monitored during the ASR pilot testing program. Wells monitored during Year 6 of the ASR pilot testing are listed below, along with the method and frequency of monitoring. Figure 1 shows the location of the monitoring wells relative to the City's ASR wells.

- **ASR 1** – transducer (1 hour readings)
- **ASR 2** – transducer (1 hour readings)
- **Well 1** – transducer (1 hour readings)
- **Well 2** – manual (monthly)
- **Well 3** – transducer (1 hour readings)
- **Well 4** – transducer (1 hour readings)
- **Well 5** – manual (monthly)
- **Tigard High School** – transducer (1 hour readings)
- **Highway 99 Trailer Park** – manual (monthly)

ASR Pilot Testing Discussion

The City has been testing the feasibility of ASR in the basalt aquifer beneath the City since 2002. The first four years of pilot testing were carried out using only ASR 1. The City's second ASR well, ASR 2, was brought on-line in March 2006. Both ASR 1 and ASR 2 were used by the City during Year 6 (2007) of ASR pilot testing.

Aquifer Water Level Response to Year 6 ASR Operations

Table 3 summarizes the water level response in the City's ASR wells during Year 6 of ASR pilot testing.

Table 3
Water Level Response at the City's ASR Wells - Year 6 ASR Pilot Testing

ASR Well	Average Injection/ Recovery Rate (gpm)	Pre-Injection SWL (ft msl)	Maximum Drawup during Injection[1] (ft)	Pre-Recovery SWL (ft msl)	Maximum Drawdown during Recovery[2] (ft)	Post-Recovery SWL (ft msl)
ASR 1 GS @ 396.25 ft msl Pump Intake @ -73.35 ft msl	Inj. @ 589 Rec. @ 799	179.0	74.7 *(253.7 ft msl)*	199.8	86.7 *(113.1 ft msl)*	182.1
ASR 2 GS @ 470 ft msl Pump Intake @ -80 ft msl	Inj. @ 1245 Rec. @ 1315	169	235 *(404 ft msl)*	186	245 *(-59 ft msl)*	173

<u>Notes:</u>
[1] Maximum drawup measured relative to pre-injection static water level.
[2] Maximum drawdown measured relative to pre-recovery static water level.
[3] Abbreviations: ground surface (GS), gallons per minute (gpm), feet (ft), mean sea level (msl), and static water level (SWL)

ASR 1

Figure 2 presents a hydrograph of ASR 1. Key observations regarding ASR operation at ASR 1 during Year 6 include:

- The periodic drops in drawup at ASR 1 during injection resulted from scheduled redevelopment (backflushing) of the well.
- There was a short injection period at ASR 1 because of an overall higher aquifer level at the start of injection and the relatively strong influence of the injection mound at ASR 1 on the water levels at the topographically lower Tigard High School Well.
- After injection at ASR 1 ended, the water level in ASR 1 declined to 190.5 feet msl, a head buildup of approximately 11.5 feet above the pre-injection static water level; <u>however</u>, as observed during Year 5, the water level in ASR 1began to slowly increase in response to continued injection at ASR 2 reaching a maximum elevation of 199.8 ft msl prior to the start of recovery. As such, part of the 11.5 feet of head build up at ASR 1 is due to injection at ASR 2.
- ASR 1 was not pumped continuously during recovery, resulting in periodic rebounds in the water level in the well.

- After recovery stopped at ASR 1, the water level in the well quickly recovered approximately 55 feet from 125 to 177 feet msl, and then slowly continued to rise until November 26, 2007 when the next year of ASR operations (Year 7) began.
- Overall the pre-injection static water level in ASR 1 has shown a steady upward trend since the beginning of ASR operations, most likely due to regional recharge to the basalt aquifer (described further in subsequent section "Long-Term Aquifer Response to ASR Operations").

ASR 2

Figure 3 presents a hydrograph of ASR 2. Key observations at ASR 2 during the past year include:

- The periodic drops in drawup at ASR 2 during injection resulted from scheduled redevelopment (backflushing) of the well.
- After injection at ASR 2 ended, the water level in ASR 2 declined slowly to 186 feet msl prior to the start of recovery, a head buildup of approximately 20 feet above the pre-injection static water level. No response to ASR 1 injection was discernable during the storage period of ASR 2 because ASR 1 injection ended prior to the end of injection at ASR 2.
- ASR 2 was not pumped continuously during recovery, resulting in periodic rebounds in the water level in the well.
- After recovery stopped at ASR 2, the water level in the well quickly recovered approximately 223 feet from -51 to 172 feet msl and remained at approximately that level until the next year of ASR operations (Year 7) began.

Observation Wells

Table 4 summarizes the aquifer water level response to ASR activities during Year 6 testing as observed in the network of observation wells. Hydrographs for each of the observation wells are provided on Figure 4. The water levels in all observation wells, with the exception of Well 2 and the Trailer Park well, show a similar response to ASR during the past year of ASR pilot testing: a gradual rise in water levels during the recharge period followed by a gradual decrease in water levels during the recovery period. The water level in Well 2 gradually increased during the recharge period, but sharply declined during the summer months due to native groundwater production at Well 2 under the City's groundwater rights. The water level response at the Trailer Park well (WASH 11789) is dissimilar to that of the other observations wells. First, the elevation of the water level at this well is very different, approximately 40 feet lower in elevation. Second, the trend in the water level does not correlate with the injection and recovery phases of the City's ASR operations. The Trailer Park well is located on the opposite side of a fault to the south of Bull Mountain, which appears to offset and compartmentalize the basalt aquifer at his location from the primary basalt aquifer hosting the City's ASR operations. This offset in the basalt aquifer results in a different static water level and lack of or muted response to the City's ASR operations at the Trailer Park well. Continued monitoring of this portion of the basalt aquifer could prove useful for establishing the extent of the 'bubble' developed by the City's ASR operations.

Table 4
Water Level Response to ASR in the Observation Wells - Year 6 ASR Pilot Testing

Well	Distance from ASR Wells		Pre-Injection SWL	Drawup at End of Injection [1] (feet)		Post-Recovery SWL	Comments
	ASR 1	ASR 2	(feet msl)	ASR 1 (20 MG) 1-31-07	ASR 2 (161 MG) 4-3-07	(feet msl)	
Well 1	135 ft SW	5,200 ft E	173.2	18.0	23.5	178.8	Closest well to ASR 1, reflects water level change in aquifer near ASR 1.
Well 2	4,300 ft W-NW	1,560 ft NE	160.5	NA	18	165.5	Similar response to Well 4, but lower magnitude. Completed shallower in the basalt than other wells.
Well 3	9,000 ft NW	5,200 ft NW	178.1	5	15	179.3	Lag in water level response to ASR injection and recovery. Large residual head buildup. Similar response to Well 5.
Well 4	4,950 ft W-SW	975 ft SE	169.6	15.4	29.3	173.8	Strong response to ASR 2, reflects water level change in aquifer near ASR 2.
Well 5	12,130 ft SW	7,140 ft SW	172.8	1.6	9.1	174	Farthest from ASR 1 and 2, and least amount of head rise. Similar response to Well 3
Tigard High School	5,500 ft SE	10,070 ft SE	167.5	1.5	23	172.7	Significant response to ASR 1, given distance from ASR 1. Limited response to ASR 2.
Hwy 99 Trailer Park	6,560 ft SW	5,490 ft S	129.5	1.7	4.5	136.5	Water level elevation does not correspond with other observation wells. Possibly completed in separate basalt block.

Notes:

[1] The rise (drawup) in water level during injection is measured relative to the pre-injection static water level.
[1] NA - Not Available

ASR Well Performance

Specific capacity is defined as the rate of discharge per change in water level in the well or mathematically expressed as discharge divided by drawup (i.e., the increase in water level since the start of injection) or drawdown (i.e., the decrease in water level since the start of recovery). Specific capacity not only reflects the transmitting capacity of the aquifer but also incorporates the efficiency of the completed well. To help assess the performance of an ASR well, we track the specific capacity of the ASR wells over time.

ASR 1

Specific capacity at the beginning of injection was approximately 12 gpm/ft and gradually reduced to 8 gpm/ft toward the end of injection (Figure 5). This reduction is a typical response to continued injection related to aquifer characteristics and matches previous cycle test data for ASR 1. As previously mentioned, the injection period at ASR during Cycle 6 was relatively short compared to previous cycle tests. The important feature to look for in Figure 5 is a major change in slope that is not coincident with a change in injection rate, which would indicate a change in well performance (i.e., clogging event, aquifer boundary, etc.). The specific capacity of ASR 1 was noticeably higher than during previous cycles even though injection was completed at a similar rate of injection. We are currently evaluating why ASR 1 is currently performing better (less drawup per gallon injected) than previous cycles.

Specific capacity during recovery ranged from 13 to 11 gpm/ft (Figure 6). The sharp rises in specific capacity are associated with stopping and starting of the pump in ASR 1. The overall slow decline in specific capacity following start-up of the pump is a typical response to continued production. As with injection specific capacity, the important feature to look for in Figure 6 is a major change in slope that is not coincident with a change in injection rate, which would indicate a change in well performance (i.e., clogging event, aquifer boundary, etc.). The recovery specific capacity during Cycle 6 is also noticeably higher compared to previous cycles.

The exact cause of these increases in specific capacity during injection and recovery is not certain at this time; however, because the water level response of Well 1 (located 135 feet from ASR 1) did not change (compared to previous cycles), the change in ASR 1 has to be due to some change at the well and not a change in the aquifer. We are currently evaluating whether recent modifications made to the wellhead configuration at ASR 1 may have resulted in these changes. Additional observations and data collected during subsequent test cycles will assist in further evaluation of the change in specific capacity.

ASR 2

Specific capacity at the beginning of injection was approximately 10 gpm/ft and gradually reduced to 6 gpm/ft toward the end of injection (Figure 7). This reduction is a typical response to continued injection and is related to aquifer characteristics. The sharp rises in specific capacity are associated with redevelopment (backflushing) cycles used to control and reduce the gradual loss of specific capacity during injection. There were no dramatic changes in the specific capacity trend observed during Cycle 2.

The [short-term] specific capacity during recovery was approximately 7 to 8 gpm/ft, depending on the production rate (Figure 8). The repetitive sharp peaks in specific capacity are associated with stopping and starting of the pump in ASR 2. Due to the frequent stops in recovery (i.e., short pumping cycles), the longer-term stabilized specific capacity of the well is difficult to assess. However, the available data do suggest that there has been a decline in specific capacity since Cycle 1 recovery: ASR 2 has a specific capacity of approximately 8 gpm/ft @ 1700 gpm during Cycle 1 compared to a specific capacity of 7 gpm/ft @ 1600 gpm during Cycle 2. An evaluation of this possible decline in specific capacity at ASR 2 is currently underway.

Long-Term Aquifer Response to ASR Operations

The long-term effects of the ASR pilot testing are assessed by evaluating the changes in aquifer water levels since the start of ASR operations.

ASR Wells

A summary of the observed aquifer response to injection at ASR 1 and ASR 2 since the start of ASR pilot testing is provided below in Table 5 and Table 6. The water level drawup as measured in both the ASR well and the closest observation well are summarized in the tables because the water level drawup during injection as measured in the ASR wells does not truly reflect the water level in the aquifer (outside of the well borehole) because of well inefficiency that amplifies the drawup in the ASR well (by as much as 75-80% based on Well 1 data). For example, the drawup typically observed at Well 1 during injection at ASR 1 is 20 to 40 feet whereas the drawup as measured in ASR 1 ranges from 110 to 175 feet. The 90 to 135 feet of additional drawup at ASR 1 is due to well inefficiencies (e.g. well hydraulics). Well 1 and Well 4 provide the best available estimates of the drawup in the aquifer during injection in the vicinity of ASR 1 and ASR 2, respectively.

Table 5
ASR 1 – ASR Injection and Water Level Drawup

Year	ASR Cycle	Average Injection Rate (gpm)	Injection Volume (MG)	Injection Period (days)	ASR 1 Water Level Drawup (ft)[1]	Well 1 Water Level Drawup (ft)
2002	1	730	97	92	173.4	28.7
2003	2	760	117	76	162.3	32.2
2004	3	600[2]	143	157	143.8	35
2005	4	600	117	134	129.7	32.7
2006	5	622	73	97	108.2	22.6
2007	6	589	20	27	74.7	18[3]

Notes:
[1] The water level drawup reported here represents the highest level reached in the well during injection and not the stabilized water level after the end of injection.
[2] Injection rate was initially at 760 gpm for approximately 17 days after which the rate was reduced to 600 gpm.
[3] Drawup at the end of ASR 1 injection. Injection continued at ASR 2 further increasing the drawup at Well 1.

Table 6
ASR 2 – ASR Injection and Water Level Drawup

Year	ASR Cycle	Average Injection Rate (gpm)	Injection Volume (MG)	Injection Period (days)	ASR 2 Water Level Drawup (ft)[1]	Well 4 Water Level Drawup (ft)
2006	1	1216	98	70	179	28
2007	2	1245	161	106	235	29.3

Notes:
[1] The water level drawup reported here represents the highest level reached in the well during injection and not the stabilized water level after the end of injection.

As shown in Table 5 and Figure 9, the magnitude of water level drawup in the aquifer (as measured at Well 1) is reflective of the injection volume: a larger injection volume results in a larger water level drawup. In addition, approximately the same volume of ASR water was injected (117 MG) during Cycle 4 as was injected during Cycle 2; and in both instances, the aquifer experienced approximately the same amount of water level drawup. This is encouraging as it shows that the aquifer response to ASR injection is not changing with time. With only two years of operational data from ASR 2, a similar trend analysis cannot be completed at this time.

Observation Wells

Water level data collected from the network of observation wells has shown that the water level of the aquifer has steadily increased since the start of ASR operations in 2002 (Figure 4). A detailed hydrograph of Well 1 is shown in Figure 10 which clearly shows the increasing trend in aquifer water level. A best-fit line to the relative pre-injection static water levels before each ASR cycle indicates a steady upward trend in water level:

- Cycle 1 - 141.4 feet msl (Golder, 2003)
- Cycle 2 – 150.1 feet msl
- Cycle 3 – 152.9 feet msl
- Cycle 4 - 156.2 feet msl
- Cycle 5 – 169.6 feet msl
- Cycle 6 – 173.2 feet msl

Although the City has recently increased the native groundwater production (Table 2), the water level of the aquifer has continued to increase by as much as 32 feet since 2003. Analysis of historical aquifer water levels, native groundwater production by the City, and precipitation trends, indicates that the year-to-year rise in aquifer water level correlates with trends in precipitation and volume of native groundwater pumped from the basalt aquifer (Figure 11). The historical volume of native groundwater production from the basalt aquifer has been influenced by a number of factors, including year-to-year precipitation, a moratorium on additional groundwater rights as established by the Cooper-Bull Mountain Critical Groundwater Area in 1974, a decline in use of domestic water wells as the area has been urbanized, and most recently the use of ASR by the City that has reduced the yearly volume of native groundwater pumped from the aquifer by the City. During the past 10 years, the area has experienced average amounts of precipitation and the City has used smaller and smaller amounts of native groundwater (due to ASR); and during this time, the aquifer water level has steadily increased. It appears that the over 30-foot rise in the regional aquifer water level is due to less native groundwater pumping. The aquifer water level is now near historic groundwater levels.

Water Quality Monitoring

Water quality monitoring was continued during Year 6 (2007) to demonstrate that the injected and recovered water quality meets potable standards, to assess potential chemical reactions that could result in clogging of the injection well, to assess whether ASR storage degrades native groundwater quality, and to comply with ASR limited license requirements. The complete list of analyses included in the water quality program and the results from ASR 1 and ASR 2 are presented in Tables 7 and 8, respectively.

Safe Drinking Water Act Compliance

Samples of receiving water (i.e., baseline groundwater), source water, and recovery water collected at ASR 1 and ASR 2 met the regulatory standards established for ASR operations [OAR 690-350-0010(6)]. A summary of water quality testing results is provided below.

- Volatile organic compounds (with the exception of disinfection by-products) were not detected at concentrations above the laboratory reporting limits in water quality samples collected ruing the Cycle 6 program.
- Disinfection by-products were detected sporadically in the source water and recovery water samples; however, all detected concentrations were below regulatory screening criteria.
- Synthetic organic compounds, with the exception of Di-(2-Ethylhexyl)phthalate and BHC-gamma (Lindane), were not detected at concentrations above the laboratory reporting limits in water quality samples collected during the Cycle 6 program. Di-(2-Ethylhexyl)phthalate was detected in the initial source water sample ASR2-C2SW1 (Table 8). The detection of Di-(2-Ethylhexyl)phthalate was attributed to sample collection contamination resulting from the tubing used to collect this sample (vinyl tubing instead of teflon); follow-up sampling of the source water was non-detect for Di-(2-Ethylhexyl)phthalate. Very low concentrations of BHC-gamma (Lindane) were detected in the initial source water samples ASR1-C6SW1 and ASR2-C2SW1 (Tables 7 and 8) at concentrations just above the laboratory method detection limit (but far below 50% of the MCL). The source of the BHC-gamma (Lindane) detections is uncertain; however, because of the extremely low detections (less than 20%of the MCL) resampling of the source water for this parameter was not completed.
- Other regulated parameters, such as metals and radionuclides, were detected at concentrations below their respective regulatory screening criteria in water quality samples collected during the Cycle 6 program.
- All general water chemistry and aesthetic parameters (e.g., odor, color) were very good.

Water Chemistry Trends during ASR Operation

General water chemistry of the receiving, source, and recovery water was monitored throughout Year 6 testing for the purpose of identifying potential reactions that may be occurring during ASR operation.

In general, the water chemistry data collected from ASR 1 and ASR 2 during Year 6 testing indicate a mixing trend from injection of source water through recovery of the stored water and production of native groundwater. Schematic illustrations of the water chemistry changes during Year 6 testing at ASR 1 and ASR 2 are shown using Stiff diagrams in Figures 12 and 13. A Stiff diagram is a graphical means of displaying the concentration of select chemical constituents in a water sample; the concentration of major cations are shown to the left and the concentration of major anions are shown to the right. The source water samples generally have low concentrations of anions and cations compared to the groundwater, as shown by the very 'skinny' Stiff diagrams of the source water to the 'fat' stiff diagrams of the groundwater. However, note that the chemical signature of the initial source water sample appears very similar to the native groundwater compared to the subsequent source water samples or the initial recovery sample. From November 7-20, 2006, Portland Water Bureau (PWB) was unable to use their Bull Run surface water source because of turbidity problems; instead, PWB used their secondary water supply source, which is groundwater from their Columbia South Shore Well Field. This explains why the initial source water samples collected at ASR 1 and ASR 2 on 11/13/2008 had more of a groundwater signature. Subsequent source water samples were collected when PWB was primarily using Bull Run for supply (Figure 13).

The final recovery sample at ASR 1 (ASR1-C6R2) was collected after recovery of all stored water PLUS an additional 98 MG of native groundwater. As such, the water chemistry signature of this sample (Figure 12) is nearly identical to the baseline groundwater sample (ASR1-C6GW). At ASR 2 however, the final recovery sample (ASR2-C2R2) was collected after recovering only 49 of the 161 MG of stored water (Figure 13); accordingly, the signature of the recovered water still resembled that of the stored source water versus the native groundwater.

Radon

Radon has been detected historically during ASR operation in baseline groundwater and in recovery water at concentrations ranging from 162 to 404 picocuries per liter (pCi/L). Radon concentrations detected during Year 6 were generally within the historical range at concentrations of 339 to 472 pCi/L. The source of the radon, based on more detailed work at Beaverton, most likely is from the underlying marine sediments. As previously mentioned in the preceding section, Radon was also detected in the initial source water samples (ASR1-C6SW1 and ASR2-C2SW1) during the past year. The detection of radon in the source water was likely due to PWB's use of their Columbia South Shore Well Field during November 2006 when turbidity problems prohibited their use of surface water from Bull Run.

There has been no change to or implementation of the U.S. Environmental Protection Agency's (EPA) public health standards for radon in drinking water. Under EPA's proposed standards, two options are provided to states and community water systems for reducing radon health risks in both drinking water and indoor air quality. Under the first option, states can choose to develop enhanced state programs addressing radon in indoor air in conjunction with individual water systems meeting a drinking water standard of 4,000 pCi/L. Under the second option, individual water systems in a state would either reduce radon in their system's drinking water to 300 pCi/L or develop individual indoor air radon programs and reduce radon levels in drinking water to 4,000 pCi/L.

Year 7 (2008) Pilot Testing Monitoring and Operational Plan

The anticipated target injection volume for Year 7 (2008) pilot testing is 280 MG; consisting of approximately 30 MG stored at ASR 1, 130 MG stored at ASR 2, and additional 120 MG[1] storage remaining in the ASR account at ASR 2 from Year 6 (2007).

The City intends to maintain the same monitoring network that was used during the past year of ASR pilot testing, which includes the following (see Figure 1):

- **ASR 1** – transducer (1 hour readings)
- **ASR 2** – manual (monthly); transducer (1 hour readings) when well is operational
- **Well 1** – transducer (1 hour readings)
- **Well 2** –manual (monthly)
- **Well 3** – transducer (1 hour readings)
- **Well 4** – transducer (1 hour readings)
- **Well 5** –manual (monthly)
- **Tigard High School** – transducer (1 hour readings)
- **Hwy 99 Trailer Park** – manual (monthly)

Ongoing water level monitoring at this network of wells will assist in the evaluation of the dynamic response of the regional aquifer to ASR activities and will assist the City in directing future ASR development on Bull Mountain. With future expansion of the ASR system (described in the next section), the City may continue to expand and or modify the monitoring network and would work with OWRD in regard to any changes to their ASR monitoring plan.

Water quality sampling will continue during Year 7 (2008) testing; the planned sampling frequency and analytical testing program is provided in Attachment A.

Next Steps

Under Limited License #005, the City's tentative ASR plans from year 2008 through 2010 include:

- Continue to use ASR 1 and ASR 2 to store and retrieve treated drinking water.
- Continue to implement the same ASR pilot testing methodology used during previous years of testing:
  - ASR wells will be redeveloped (backflushed) on a 3- to 4-week rotation during injection to control head buildup in the well and mitigate potential for clogging at the well by removing particulate matter that may have been injected with the source water.
  - Continue to track specific capacity the ASR wells to assess well performance, evaluate aquifer response, and assess any residual clogging at the well.
  - Continue water quality sampling and monitoring during ASR operation that closely match that of previous years and complies with the limited license.

[1] 128 MG of storage at ASR 2 remained in the account after Year 6 (2007); however, per Condition No. 11 of Limited License #005, only 95 percent (120 MG) of this volume may be recovered in the subsequent cycle.

  - Pump native groundwater from the ASR wells under the City's existing water rights once the stored ASR volume is depleted.

- Because of a continuing upward trend in the water level of the ASR host aquifer, despite post-ASR recovery native groundwater pumping, the City intends to request a meeting with the Department to discuss (1) relief of Condition No. 11 of Limited License #005 that requires leaving a residual 5% amount in the aquifer, and (2) possibility of additional native groundwater production under the limited license beyond the City's existing water rights.

- Build out of the City's third ASR well, ASR 3 (see Figure 14), with an anticipated operational data of 2009.

- Prepare a work plan addendum for ASR 3.

- Begin using three ASR wells (ASR 1, ASR 2, and ASR 3) in year 2009 for storing and recovering treated drinking water. The combined storage volume is expected to be 400 MG or more (a modification to Limited License #005 will be needed to allow storage in excess of 400 MG).

- Explore additional sites within the Bull Mountain area that possibly could host ASR wells ASR 4 and ASR 5 (see Figure 14). A modification to Limited License #005 will be needed if additional ASR wells are included in the program.

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Table 7
ASR1 Cycle 6 Water Quality Data
City of Tigard

Category	Analyte	Regulatory Standard	Regulatory Criteria	Units	Baseline ASR1-C6GW 11/13/06	Injection ASR1-C6SW1 11/13/06	Recovered ASR1-C6R1 04/16/07	Recovered ASR1-C6R2 05/30/07
Disinfection by-Products	Chlorine	4	MCL	mg/L	0.1	1.7	0.1 U	NT
	Bromodichloromethane	None	None	mg/L	0.0007	0.001	0.0012	NT
	Bromoform (Tribromomethane)	None	None	mg/L	0.002 U	0.002 U	0.002 U	NT
	Chlorodibromomethane	None	None	mg/L	0.002 U	0.002 U	0.002 U	NT
	Chloroform (Trichloromethane)	None	None	mg/L	0.0144	0.0058	0.025	NT
	Total Trihalomethanes	0.08	MCL	mg/L	0.0151	0.0068	0.0262	NT
	Dibromoacetic Acid	None	None	mg/L	0.007 U	0.007 U	0.007 U	NT
	Dichloroacetic Acid	None	None	mg/L	0.007 U	0.007 U	0.007 U	NT
	Monobromoacetic Acid	None	None	mg/L	0.007 U	0.007 U	0.007 U	NT
	Monochloroacetic Acid	None	None	mg/L	0.007 U	0.007 U	0.007 U	NT
	Trichloroacetic Acid	None	None	mg/L	0.007 U	0.0022	0.0025	NT
	Total Haloacetic Acids	0.06	MCL	mg/L	0.007 U	0.002	0.0025	NT
Field Parameters	Dissolved Oxygen	None	None	mg/L	0.9	0.3	5.8	10.53
	ORP	None	None	mV	111	216	-33	NT
	pH	6 - 8.5 standard units	SMCL	pH	6.55	7.67	7.34	6.61
	Specific Conductance	None	None	us/cm	157	220	52	153
	Temperature	None	None	degC	10.6	14.2	8.45	10.25
Geochemical	Bicarbonate	None	None	mg/L	61	102	17	59
	Calcium	None	None	mg/L	13.3	18.5	4.4	12.1
	Carbonate	None	None	mg/L	2 U	2 U	2 U	2 U
	Chloride	250	SMCL, MML	mg/L	3	4	3	4
	Hardness (as CaCO3)	250	SMCL	mg/L	66	90	20	56
	Magnesium	None	None	mg/L	6.44	8.57	1.78	5.72
	Nitrate as N	10	MCL, MML	mg/L	2.6	0.6	0.8	1.3
	Nitrate+Nitrite	None	None	mg/L	2.6	0.6	0.8	1.3
	Nitrite as N	1	MCL	mg/L	0.01 U	0.01 U	0.01 U	0.01 U
	Potassium	None	None	mg/L	1.8	2.6	0.6	1.7
	Silica	None	None	mg/L	38.5	37.7	21.9	40.6
	Sodium	20	MCLG	mg/L	6.6	13.3	4.1	6
	Sulfate	250	SMCL, MML	mg/L	2.46	3.93	1 U	2.89
	Total Alkalinity	None	None	mg/L	61	103	17	59
	Total Dissolved Solids	500	SMCL, MML	mg/L	130	158	55	118
	Total Organic Carbon	None	None	mg/L	0.5 U	0.5 U	1.3	2.05
	Total Suspended Solids	None	None	mg/L	2 U	2	2 U	2 U
Metals	Aluminum	0.05	SMCL	mg/L	NT	0.05 U	0.05 U	NT
	Antimony	0.006	MCL	mg/L	NT	0.001 U	0.001 U	NT
	Arsenic	0.01	MCL	mg/L	NT	0.003 U	0.003 U	NT
	Barium	1	MML	mg/L	NT	0.05 U	0.02 U	NT
	Beryllium	0.004	MCL	mg/L	NT	0.001 U	0.0005 U	NT
	Cadmium	0.005	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Chromium	0.05	MML	mg/L	NT	0.01 U	0.02 U	NT
	Copper	1	MCL	mg/L	NT	0.05 U	0.02 U	NT
	Iron, Dissolved	0.3	SMCL, MML	mg/L	NT	0.05 U	0.05 U	NT
	Iron, Total	None	None	mg/L	NT	0.05 U	0.05 U	NT
	Lead	0.015	Action Level	mg/L	NT	0.002 U	0.002 U	NT
	Manganese, Dissolved	0.05	SMCL, MML	mg/L	NT	0.02 U	0.02 U	NT
	Manganese, Total	None	None	mg/L	NT	0.03	0.02 U	NT
	Mercury	0.002	MCL, MML	mg/L	NT	0.0002 U	0.0002 U	NT
	Nickel	None	None	mg/L	NT	0.02 U	0.02 U	NT
	Selenium	0.01	MML	mg/L	NT	0.005 U	0.005 U	NT
	Silver	0.05	MML	mg/L	NT	0.02 U	0.05 U	NT
	Thallium	0.002	MCL	mg/L	NT	0.001 U	0.0008 U	NT
	Zinc	5	SMCL, MML	mg/L	NT	0.02 U	0.01 U	NT

Table 7
ASR1 Cycle 6 Water Quality Data
City of Tigard

Category	Analyte	Regulatory Standard	Regulatory Criteria	Units	Baseline	Injection	Recovered	
					ASR1-C6GW 11/13/06	ASR1-C6SW1 11/13/06	ASR1-C6R1 04/16/07	ASR1-C6R2 05/30/07
Miscellaneous	Color	15 standard units	SMCL, MML	cu	5 U	5	5 U	NT
	Corrosivity	Noncorrosive	SMCL	mg/L	-0.89	-0.25	-2.5	-1.95
	Cyanide	0.2	MCL, MML	mg/L	0.02 U	0.02 U	0.02 U	NT
	Fluoride	2	MML, SMCL	mg/L	0.5 U	0.5 U	0.5 U	0.5 U
	Methylene Blue Active Substance	0.5	SMCL, MML	mg/L	0.05 U	0.05 U	0.05 U	NT
	Odor	3 threshold #s	SMCL, MML	ton	1	1 U	1	NT
Radionuclides	Gross Alpha	15	MCL, MML	pCi/L	NT	3 U	1 U	NT
	Gross Beta	50	MML	pCi/L	NT	2.1 +/- 1.4	2.1 +/- 1.4	NT
	Radium, 226/228	5	MCL, MML	pCi/L	NT	1 U	1 U	NT
	Radon	None	None	pCi/L	472	243	344	NT
	Uranium	0.03	MCL	mg/L	NT	0.001 U	0.001 U	NT
Synthetic Organic Compounds	2,4,5-TP	0.01	MML	mg/L	NT	0.0004 U	0.0004 U	NT
	2,4-D	0.07	MCL	mg/L	NT	0.0002 U	0.0002 U	NT
	3-Hydroxycarbofuran	None	None	mg/L	NT	0.004 U	0.004 U	NT
	Alachlor (Lasso)	0.002	MCL	mg/L	NT	0.0004 U	0.0004 U	NT
	Aldicarb	None	None	mg/L	NT	0.002 U	0.002 U	NT
	Aldicarb Sulfone	None	None	mg/L	NT	0.001 U	0.001 U	NT
	Aldicarb Sulfoxide	None	None	mg/L	NT	0.003 U	0.003 U	NT
	Aldrin	None	None	mg/L	NT	0.0001 U	0.0001 U	NT
	Atrazine	0.003	MCL	mg/L	NT	0.0002 U	0.0002 U	NT
	Benzo (a) pyrene	0.0002	MCL	mg/L	NT	0.00004 U	0.00004 U	NT
	BHC-gamma (Lindane)	0.0002	MCL, MML	mg/L	NT	0.00004	0.00002 U	NT
	Butachlor	None	None	mg/L	NT	0.0001 U	0.0001 U	NT
	Carbaryl	None	None	mg/L	NT	0.004 U	0.004 U	NT
	Carbofuran	0.04	None	mg/L	NT	0.001 U	0.001 U	NT
	Chlordane	0.002	MCL	mg/L	NT	0.0004 U	0.00004 U	NT
	Dalapon	0.2	MCL	mg/L	NT	0.002 U	0.002 U	NT
	Di-(2-Ethylhexyl)adipate	0.4	MCL	mg/L	NT	0.001 U	0.001 U	NT
	Di-(2-Ethylhexyl)phthalate	0.006	MCL	mg/L	NT	0.001 U	0.001 U	NT
	Dibromochloropropane (DBCP)	0.0002	MCL	mg/L	NT	0.00002 U	0.00002 U	NT
	Dicamba	None	None	mg/L	NT	0.0005 U	0.0005 U	NT
	Dieldrin	None	None	mg/L	NT	0.0001 U	0.0001 U	NT
	Dinoseb	0.007	MCL	mg/L	NT	0.0004 U	0.0004 U	NT
	Diquat	0.02	MCL	mg/L	NT	0.0004 U	0.0004 U	NT
	Endothall	0.1	MCL	mg/L	NT	0.01 U	0.01 U	NT
	Endrin	0.0002	MML	mg/L	NT	0.00002 U	0.00002 U	NT
	Ethylene Dibromide (EDB)	5.00E-05	MCL	mg/L	NT	0.00001 U	0.00001 U	NT
	Glyphosate	0.7	MCL	mg/L	NT	0.01 U	0.01 U	NT
	Heptachlor	0.0004	MCL	mg/L	NT	0.00004 U	0.00004 U	NT
	Heptachlor Epoxide	0.0002	MCL	mg/L	NT	0.00002 U	0.00002 U	NT
	Hexachlorobenzene	0.001	MCL	mg/L	NT	0.0001 U	0.0001 U	NT
	Hexachlorocyclopentadiene	0.05	MCL	mg/L	NT	0.0002 U	0.0002 U	NT
	Methomyl	None	None	mg/L	NT	0.004 U	0.004 U	NT
	Methoxychlor	0.04	MCL	mg/L	NT	0.0002 U	0.0002 U	NT
	Metolachlor	None	None	mg/L	NT	0.0002 U	0.0002 U	NT
	Metribuzin	None	None	mg/L	NT	0.0001 U	0.0001 U	NT
	Pentachlorophenol	0.001	MCL	mg/L	NT	0.00008 U	0.00008 U	NT
	Picloram	0.5	MCL	mg/L	NT	0.0002 U	0.0002 U	NT
	Polychlorinated Biphenyls (PCBs)	0.0005	MCL	mg/L	NT	0.0002 U	0.0002 U	NT
	Propachlor	None	None	mg/L	NT	0.0001 U	0.0001 U	NT
	Simazine	0.004	MCL	mg/L	NT	0.0001 U	0.0001 U	NT
	Toxaphene	0.003	MCL	mg/L	NT	0.0001 U	0.0001 U	NT
	Vydate	0.2	MCL	mg/L	NT	0.002 U	0.002 U	NT

Table 7
ASR1 Cycle 6 Water Quality Data
City of Tigard

Category	Analyte	Regulatory Standard	Regulatory Criteria	Units	Baseline	Injection	Recovered	
					ASR1-C6GW 11/13/06	ASR1-C6SW1 11/13/06	ASR1-C6R1 04/16/07	ASR1-C6R2 05/30/07
Volatile Organic Compounds	1,1,1-Trichloroethane	0.2	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	1,1,2-Trichloroethane	0.005	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	1,1-Dichloroethene	0.007	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	1,2,4-Trichlorobenzene	0.07	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	1,2-Dichloroethane	0.005	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	1,2-Dichloroethene (Cis)	0.07	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	1,2-Dichloropropane	0.005	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	Benzene	0.005	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Carbon Tetrachloride	0.005	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	Dichloromethane	0.005	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Ethylbenzene	0.7	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Monochlorobenzene	0.1	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	O-Dichlorobenzene	0.6	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	P-Dichlorobenzene	0.075	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	Styrene	0.1	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Tetrachloroethylene	0.005	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	Toluene	1	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Trans-1,2-Dichloroethene	0.1	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Trichloroethene	0.005	MCL	mg/L	NT	0.0005 U	0.0005 U	NT
	Vinyl Chloride	0.002	MCL, MML	mg/L	NT	0.0005 U	0.0005 U	NT
	Xylenes, Total	10	MCL	mg/L	NT	0.0015 U	0.0015 U	NT

Notes:
NT - analyte not tested.
U = Analyte not detected at indicated detection lmit.

Table 8
ASR2 Cycle 2 Water Quality Data
City of Tigard

					Baseline Groundwater	Injection Period			Recovered Water	
Category	**Analyte**	**Regulatory Standard**	**Regulatory Criteria**	**Units**	**ASR2-C2GW 11/13/2006**	**ASR2-C2SW1 11/13/2006**	**ASR2-C2SW2 7/29/2007**	**ASR2-C2SW3 3/26/2007**	**ASR2-C2R1 5/30/2007**	**ASR2-C2R2 9/24/2007**
Disinfection by-Products	Chlorine	4	MCL	mg/L	0.1	1.1	NT	1.6	0.1 U	NT
	Bromodichloromethane	None	None	mg/L	0.0006	0.0013	NT	0.002 U	0.002 U	NT
	Bromoform (Tribromomethane)	None	None	mg/L	0.002 U	0.002 U	NT	0.002 U	0.002 U	NT
	Chlorodibromomethane	None	None	mg/L	0.002 U	0.002 U	NT	0.002 U	0.002 U	NT
	Chloroform (Trichloromethane)	None	None	mg/L	0.0146	0.011	NT	0.0241	0.0235	NT
	Total Trihalomethanes	0.08	MCL	mg/L	0.0152	0.0123	NT	0.0241	0.0235	NT
	Dibromoacetic Acid	None	None	mg/L	0.007 U	0.007 U	NT	0.007 U	0.007 U	NT
	Dichloroacetic Acid	None	None	mg/L	0.007 U	0.007 U	NT	0.0179	0.007 U	NT
	Monobromoacetic Acid	None	None	mg/L	0.007 U	0.007 U	NT	0.007 U	0.007 U	NT
	Monochloroacetic Acid	None	None	mg/L	0.007 U	0.007 U	NT	0.007 U	0.007 U	NT
	Trichloroacetic Acid	None	None	mg/L	0.007 U	0.0047	NT	0.0127	0.0058	NT
	Total Haloacetic Acids	0.06	MCL	mg/L	0.007 U	0.0047	NT	0.0306	0.0058	NT
Field Parameters	Dissolved Oxygen	None	None	mg/L	0.7	3	9.7	9	11.53	6.3
	ORP	None	None	mV	-22	240	260	220	185.5	-500
	pH	6 - 8.5 standard units	SMCL	pH	7.15	7.16	7.55	6.16	7.04	6.4
	Specific Conductance	None	None	us/cm	198	135	25	19	59	104
	Temperature	None	None	degC	11.8	13.9	6.1		8.48	8.9
Geochemical	Bicarbonate	None	None	mg/L	76	59	8	9	13	28
	Calcium	None	None	mg/L	13.6	11.1	1.5	1.5	3.3	5.4
	Carbonate	None	None	mg/L	2 U	2 U	2 U	2 U	2 U	2 U
	Chloride	250	SMCL, MML	mg/L	13	4	3	3	4	6
	Hardness (as CaCO3)	250	SMCL	mg/L	68	56	8	8	16	28
	Magnesium	None	None	mg/L	7.17	5.16	0.5	0.51	1.34	2.8
	Nitrate as N	10	MCL, MML	mg/L	0.9	0.7	0.5 U	0.5 U	0.7	0.7
	Nitrate+Nitrite	None	None	mg/L	0.9	0.7	0.01 U	0.01 U	0.76	0.7
	Nitrite as N	1	MCL	mg/L	0.01 U	0.01 U	0.01 U	0.01 U	0.06	0.01 U
	Potassium	None	None	mg/L	3	1.8	0.1	0.1	0.4	1.2
	Silica	None	None	mg/L	35.3	29	8.2	0.4	14.6	24.6
	Sodium	20	MCLG	mg/L	13.6	8.4	2.9	2.8	4.1	7
	Sulfate	250	SMCL, MML	mg/L	1.21	3.32	1 U	5 U	4.31	1.29
	Total Alkalinity	None	None	mg/L	77	59	8	9	13	28
	Total Dissolved Solids	500	SMCL, MML	mg/L	140	98	23	18	42	75
	Total Organic Carbon	None	None	mg/L	0.5 U	0.52	1.1	1.34	1.39	0.72
	Total Suspended Solids	None	None	mg/L	2	2	2	2 U	2 U	2 U
Metals	Aluminum	0.05	SMCL	mg/L	NT	0.05 U	NT	NT	0.05 U	NT
	Antimony	0.006	MCL	mg/L	NT	0.001 U	NT	NT	0.0015 U	NT
	Arsenic	0.01	MCL	mg/L	NT	0.003 U	NT	NT	0.003 U	NT
	Barium	1	MML	mg/L	NT	0.05 U	NT	NT	0.02 U	NT
	Beryllium	0.004	MCL	mg/L	NT	0.001 U	NT	NT	0.0005 U	NT
	Cadmium	0.005	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Chromium	0.05	MML	mg/L	NT	0.01 U	NT	NT	0.01 U	NT
	Copper	1	MCL	mg/L	NT	0.05 U	NT	NT	0.05 U	NT
	Iron, Dissolved	0.3	SMCL, MML	mg/L	NT	0.05 U	NT	NT	0.1	NT
	Iron, Total	None	None	mg/L	NT	0.05 U	NT	NT	0.23	NT
	Lead	0.015	Action Level	mg/L	NT	0.002 U	NT	NT	0.002 U	NT
	Manganese, Dissolved	0.05	SMCL, MML	mg/L	NT	0.02 U	NT	NT	0.01 U	NT
	Manganese, Total	None	None	mg/L	NT	0.02 U	NT	NT	0.01	NT
	Mercury	0.002	MCL, MML	mg/L	NT	0.0002 U	NT	NT	0.0005 U	NT
	Nickel	None	None	mg/L	NT	0.02 U	NT	NT	0.02 U	NT
	Selenium	0.01	MML	mg/L	NT	0.005 U	NT	NT	0.005 U	NT
	Silver	0.05	MML	mg/L	NT	0.02 U	NT	NT	0.02 U	NT
	Thallium	0.002	MCL	mg/L	NT	0.001 U	NT	NT	0.0008 U	NT
	Zinc	5	SMCL, MML	mg/L	NT	0.02 U	NT	NT	0.02 U	NT

Table 8
ASR2 Cycle 2 Water Quality Data
City of Tigard

Category	Analyte	Regulatory Standard	Regulatory Criteria	Units	Baseline Groundwater	Injection Period			Recovered Water	
					ASR2-C2GW 11/13/2006	ASR2-C2SW1 11/13/2006	ASR2-C2SW2 7/29/2007	ASR2-C2SW3 3/26/2007	ASR2-C2R1 5/30/2007	ASR2-C2R2 9/24/2007
Miscellaneous	Color	15 standard units	SMCL, MML	cu	5	5 U	NT	NT	9	NT
	Corrosivity	Noncorrosive	SMCL	mg/L	-0.58	-1	-3.22	-4	-2.68	-2.75
	Cyanide, Free	0.2	MCL, MML	mg/L	0.02 U	0.02 U	0.02 U	NT	0.02 U	NT
	Fluoride	2	MML, SMCL	mg/L	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
	Methylene Blue Active Substance	0.5	SMCL, MML	mg/L	0.05 U	0.05 U	NT	NT	0.05 U	NT
	Odor	3 threshold #s	SMCL, MML	ton	1	1	NT	NT	1 U	NT
Radionuclides	Gross Alpha	15	MCL, MML	pCi/L	NT	3 U	NT	NT	1 U	NT
	Gross Beta	50	MML	pCi/L	NT	2 U	NT	NT	2 U	NT
	Radium 226/228	5	MCL, MML	pCi/L	NT	1 U	NT	NT	1 U	NT
	Radon	None	None	pCi/L	339	94	NT	NT		NT
	Uranium	0.03	MCL	mg/L	NT	0.001 U	NT	NT	0.001 U	NT
Synthetic Organic Compounds	2,4,5-TP	0.01	MML	mg/L	NT	0.0004 U	NT	NT	0.0004 U	NT
	2,4-D	0.07	MCL	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	3-Hydroxycarbofuran	None	None	mg/L	NT	0.004 U	NT	NT	0.004 U	NT
	Alachlor (Lasso)	0.002	MCL	mg/L	NT	0.0004 U	NT	NT	0.0004 U	NT
	Aldicarb	None	None	mg/L	NT	0.002 U	NT	NT	0.002 U	NT
	Aldicarb Sulfone	None	None	mg/L	NT	0.001 U	NT	NT	0.001 U	NT
	Aldicarb Sulfoxide	None	None	mg/L	NT	0.003 U	NT	NT	0.003 U	NT
	Aldrin	None	None	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Atrazine	0.003	MCL	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	Benzo (a) pyrene	0.0002	MCL	mg/L	NT	0.00004 U	NT	NT	0.00004 U	NT
	BHC-gamma (Lindane)	0.0002	MCL, MML	mg/L	NT	0.00003	NT	NT	0.00002 U	NT
	Butachlor	None	None	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Carbaryl	None	None	mg/L	NT	0.004 U	NT	NT	0.004 U	NT
	Carbofuran	0.04	None	mg/L	NT	0.001 U	NT	NT	0.001 U	NT
	Chlordane	0.002	MCL	mg/L	NT	0.00004 U	NT	NT	0.00004 U	NT
	Dalapon	0.2	MCL	mg/L	NT	0.002 U	NT	NT	0.002 U	NT
	Di-(2-Ethylhexyl)adipate	0.4	MCL	mg/L	NT	0.001 U	NT	NT	0.001 U	NT
	Di-(2-Ethylhexyl)phthalate	0.006	MCL	mg/L	NT	0.006	0.001 U	NT	0.001 U	NT
	Dibromochloropropane (DBCP)	0.0002	MCL	mg/L	NT	0.00002 U	NT	NT	0.00002 U	NT
	Dicamba	None	None	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Dieldrin	None	None	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Dinoseb	0.007	MCL	mg/L	NT	0.0004 U	NT	NT	0.0004 U	NT
	Diquat	0.02	MCL	mg/L	NT	0.0004 U	NT	NT	0.0004 U	NT
	Endothall	0.1	MCL	mg/L	NT	0.01 U	NT	NT	0.01 U	NT
	Endrin	0.0002	MML	mg/L	NT	0.00002 U	NT	NT	0.00002 U	NT
	Ethylene Dibromide (EDB)	5.00E-05	MCL	mg/L	NT	0.00001 U	NT	NT	0.00001 U	NT
	Glyphosate	0.7	MCL	mg/L	NT	0.01 U	NT	NT	0.01 U	NT
	Heptachlor	0.0004	MCL	mg/L	NT	0.00004 U	NT	NT	0.00004 U	NT
	Heptachlor Epoxide	0.0002	MCL	mg/L	NT	0.00002 U	NT	NT	0.00002 U	NT
	Hexachlorobenzene	0.001	MCL	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Hexachlorocyclopentadiene	0.05	MCL	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	Methomyl	None	None	mg/L	NT	0.004 U	NT	NT	0.004 U	NT
	Methoxychlor	0.04	MCL	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	Metolachlor	None	None	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	Metribuzin	None	None	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Pentachlorophenol	0.001	MCL	mg/L	NT	0.00008 U	NT	NT	0.00008 U	NT
	Picloram	0.5	MCL	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	Polychlorinated Biphenyls (PCBs)	0.0005	MCL	mg/L	NT	0.0002 U	NT	NT	0.0002 U	NT
	Propachlor	None	None	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Simazine	0.004	MCL	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Toxaphene	0.003	MCL	mg/L	NT	0.0001 U	NT	NT	0.0001 U	NT
	Vydate	0.2	MCL	mg/L	NT	0.002 U	NT	NT	0.002 U	NT

Table 8
ASR2 Cycle 2 Water Quality Data
City of Tigard

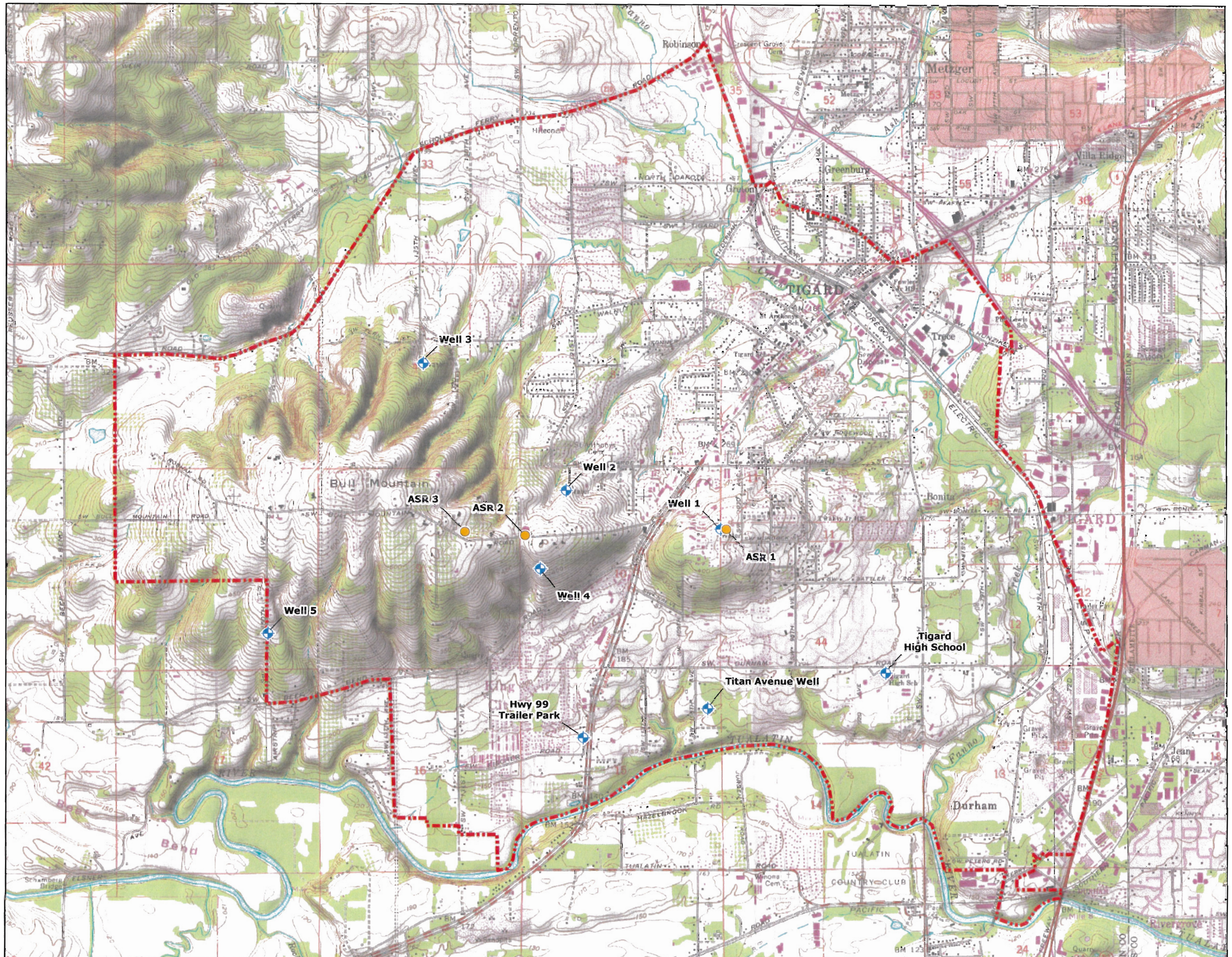
Category	Analyte	Regulatory Standard	Regulatory Criteria	Units	Baseline Groundwater ASR2-C2GW 11/13/2006	Injection Period ASR2-C2SW1 11/13/2006	Injection Period ASR2-C2SW2 7/29/2007	Injection Period ASR2-C2SW3 3/26/2007	Recovered Water ASR2-C2R1 6/30/2007	Recovered Water ASR2-C2R2 9/24/2007
Volatile Organic Compounds	1,1,1-Trichloroethane	0.2	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	1,1,2-Trichloroethane	0.005	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	1,1-Dichloroethene	0.007	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	1,2,4-Trichlorobenzene	0.07	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	1,2-Dichloroethane	0.005	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	1,2-Dichloroethene (Cis)	0.07	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	1,2-Dichloropropane	0.005	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Benzene	0.005	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Carbon Tetrachloride	0.005	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Dichloromethane	0.005	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Ethylbenzene	0.7	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Monochlorobenzene	0.1	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	O-Dichlorobenzene	0.6	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	P-Dichlorobenzene	0.075	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Styrene	0.1	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Tetrachloroethylene	0.005	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Toluene	1	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Trans-1,2-Dichloroethene	0.1	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Trichloroethene	0.005	MCL	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Vinyl Chloride	0.002	MCL, MML	mg/L	NT	0.0005 U	NT	NT	0.0005 U	NT
	Xylenes, Total	10	MCL	mg/L	NT	0.0015 U	NT	NT	0.0015 U	NT

Notes:
Blank cell indicates analyte not tested.
U = Analyte not detected at indicated detection limit.

FIGURE 1

Existing ASR Network

City of Tigard



LEGEND

- City of Tigard ASR Well
- ASR Observation Well
- City of Tigard Water Service Area Boundary

N

Scale

1:30,000

0 1250 2500 3750 5000

Feet

MAP NOTES:

Projection: Universal Transverse Mercator, Zone 10 North
Datum: North American Datum of 1983
Date: February 8, 2008
Data Sources: City of Tigard, USGS

GSI Water Solutions, Inc.

File Path: P:\103 - Tigard\008 - 2006-2007 ASR Ops Support\Project_GIS\Project_mxds\Figure1_Existing_ASR_Network_2006-07_Report.mxd, Date: February 8, 2008 2:20:27 PM

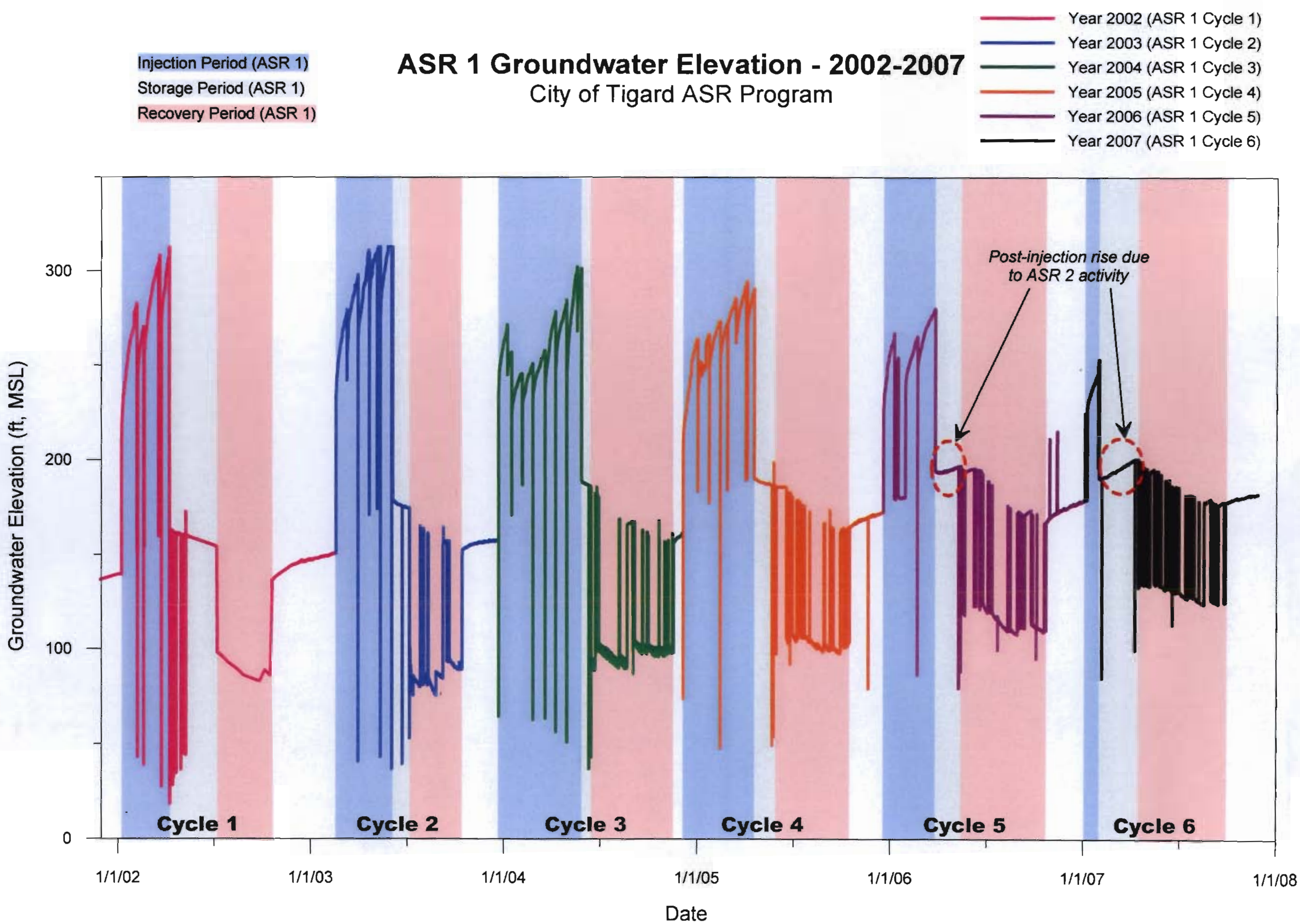


Figure 2

P:\103 - Tigard\ASR Tracking\Output Plots\ASR1_GW _ELEV.grf

GSI Water Solutions, Inc.

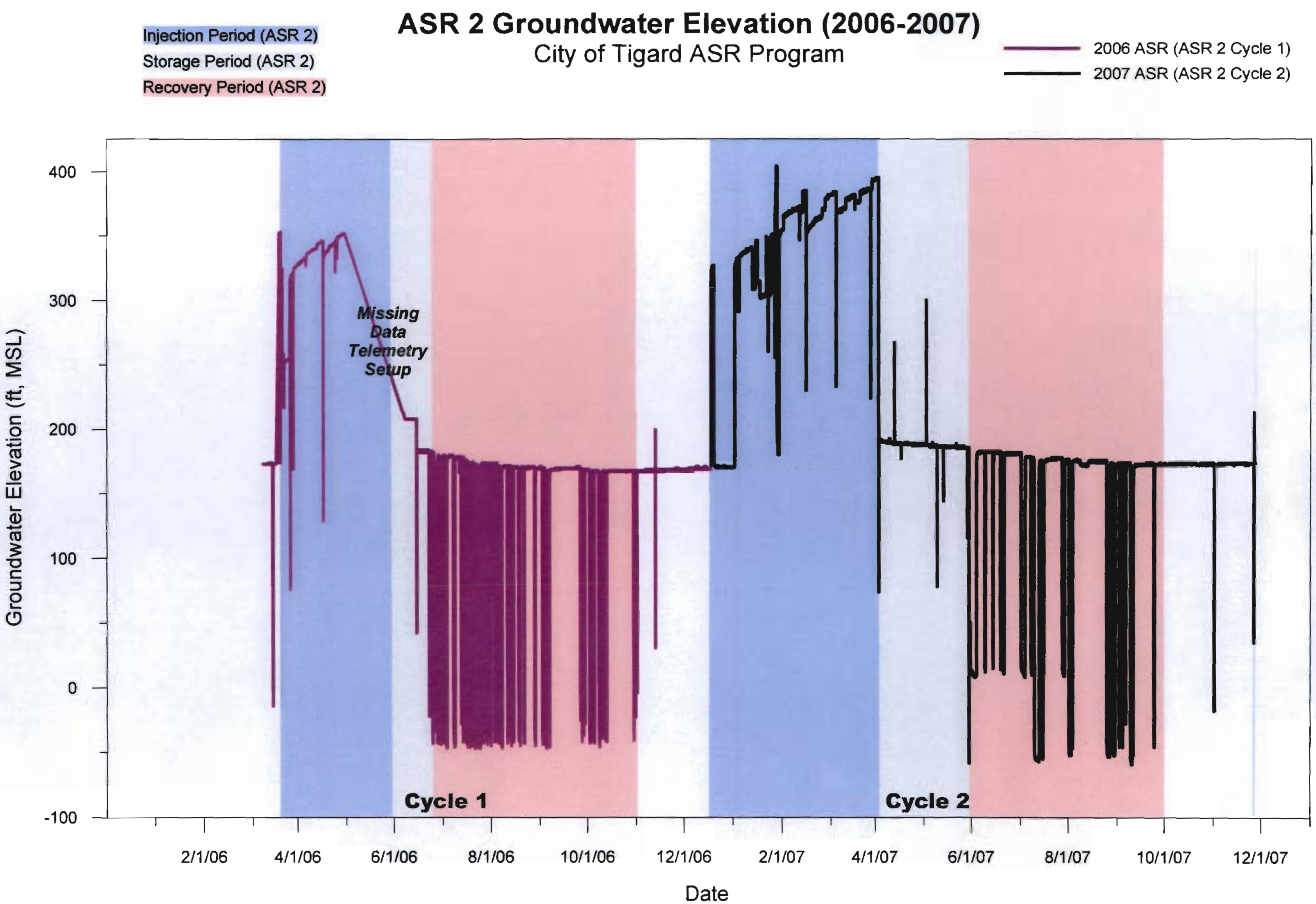


Figure 3

P:\103 - Tigard\ASR Tracking\Output Plots\ASR2_GW _ELEV.grf

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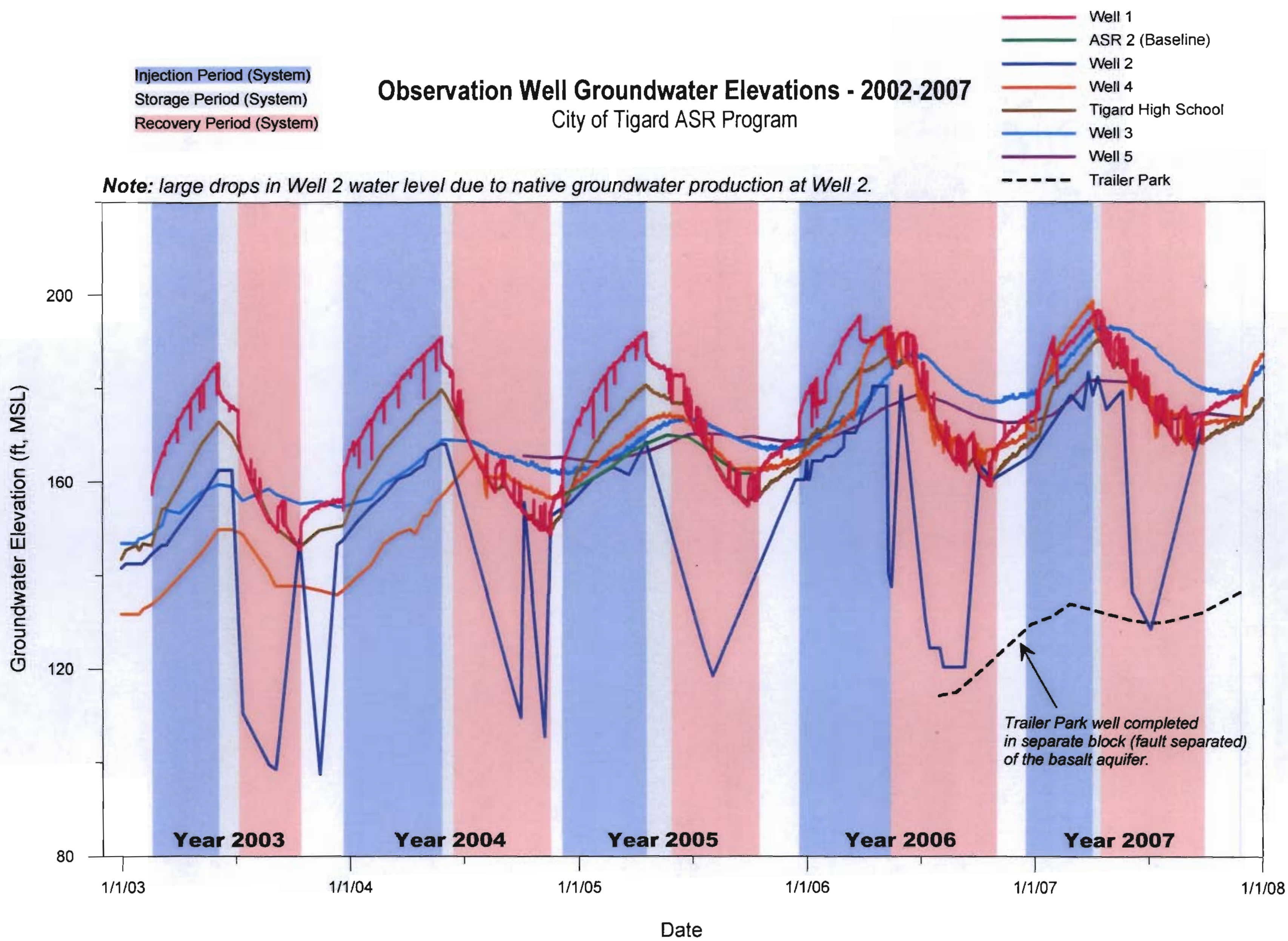

Figure 4

P:\103 - Tigard\ASR Tracking\Output Plots\Obs_Wells_Elev.grf

GSI Water Solutions, Inc.

ASR 1 Specific Capacity During Injection
City of Tigard ASR Program

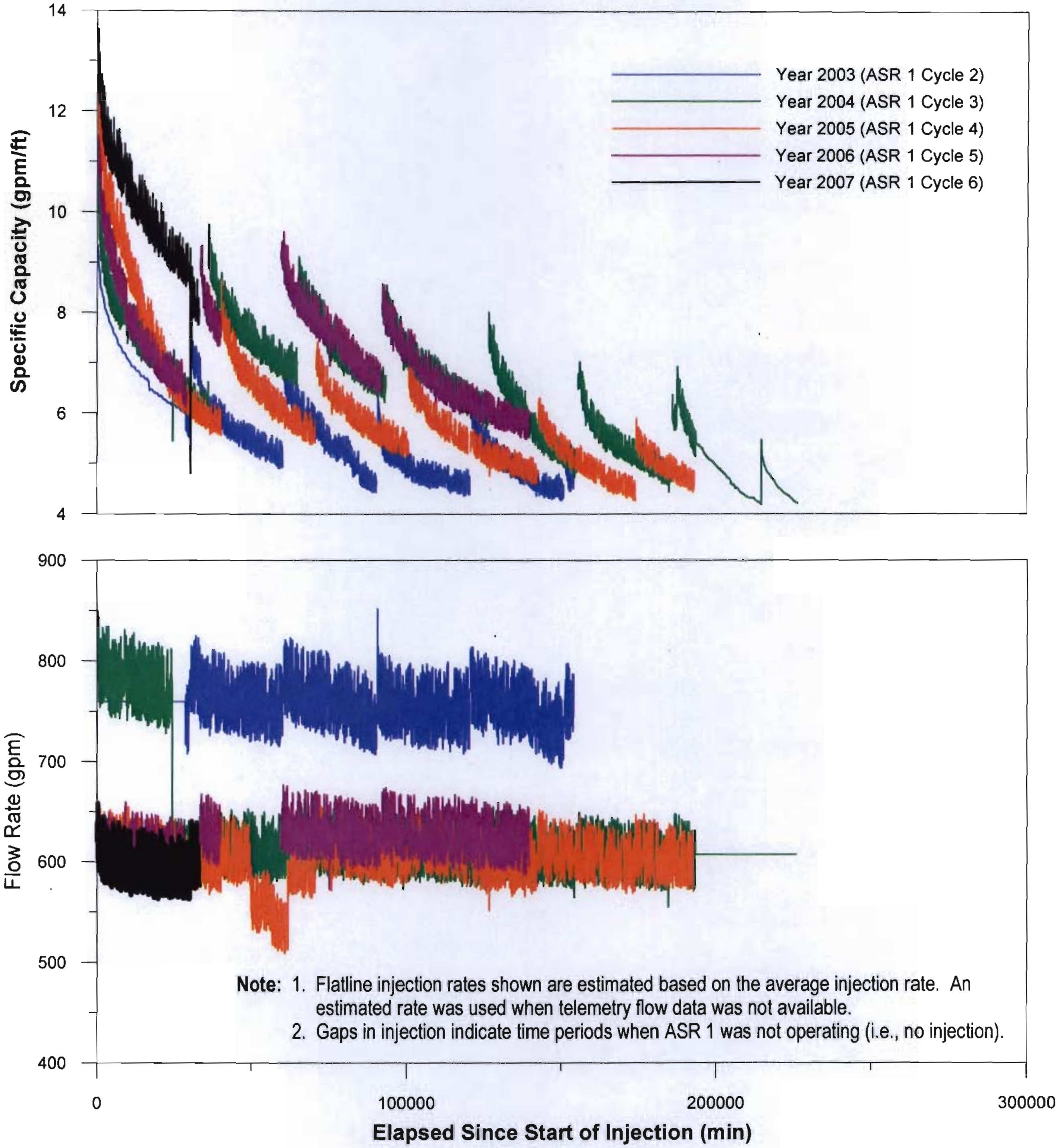

Figure 5

P:\103 - Tigard\ASR Tracking\Output Plots\ASR 1 Injection SC.grf

Water Solutions, Inc.

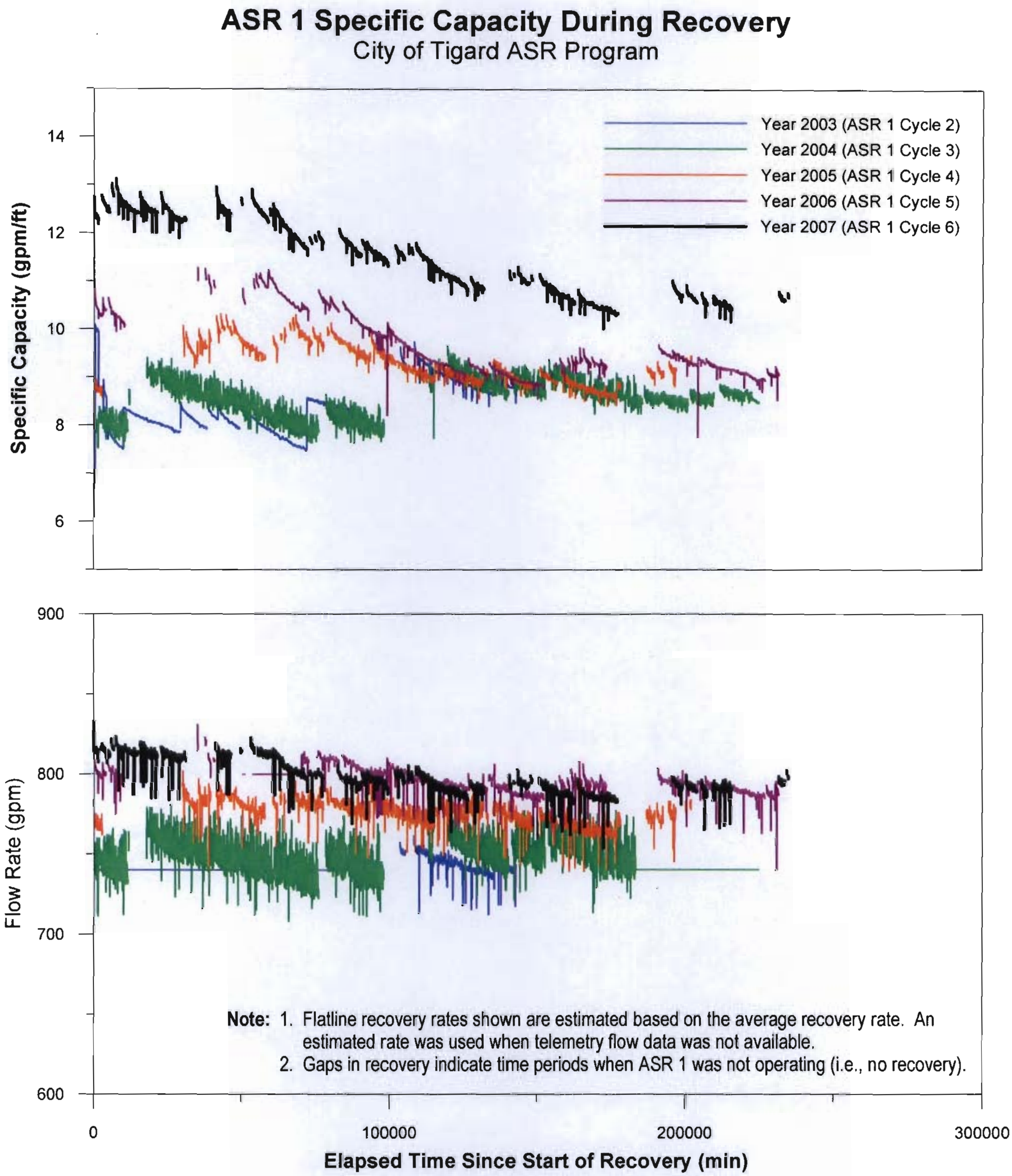

Figure 6

P:\103 - Tigard\ASR Tracking\Output Plots\ASR 1 Recovery SC.grf

GSI Water Solutions, Inc.

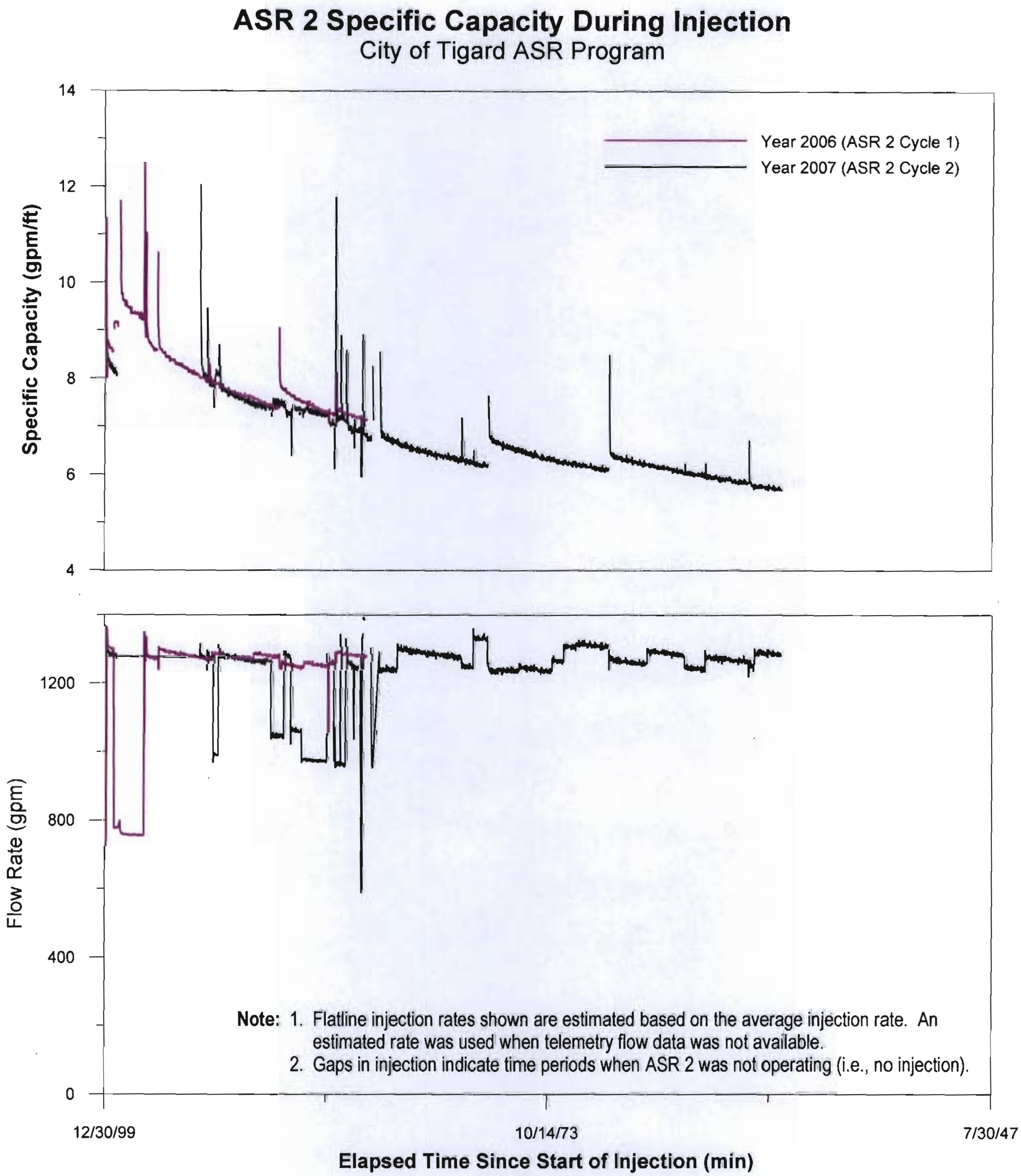

Figure 7

P:\103 - Tigard\ASR Tracking\Output Plots\ASR 2 Injection SC.grf

GSI Water Solutions, Inc.

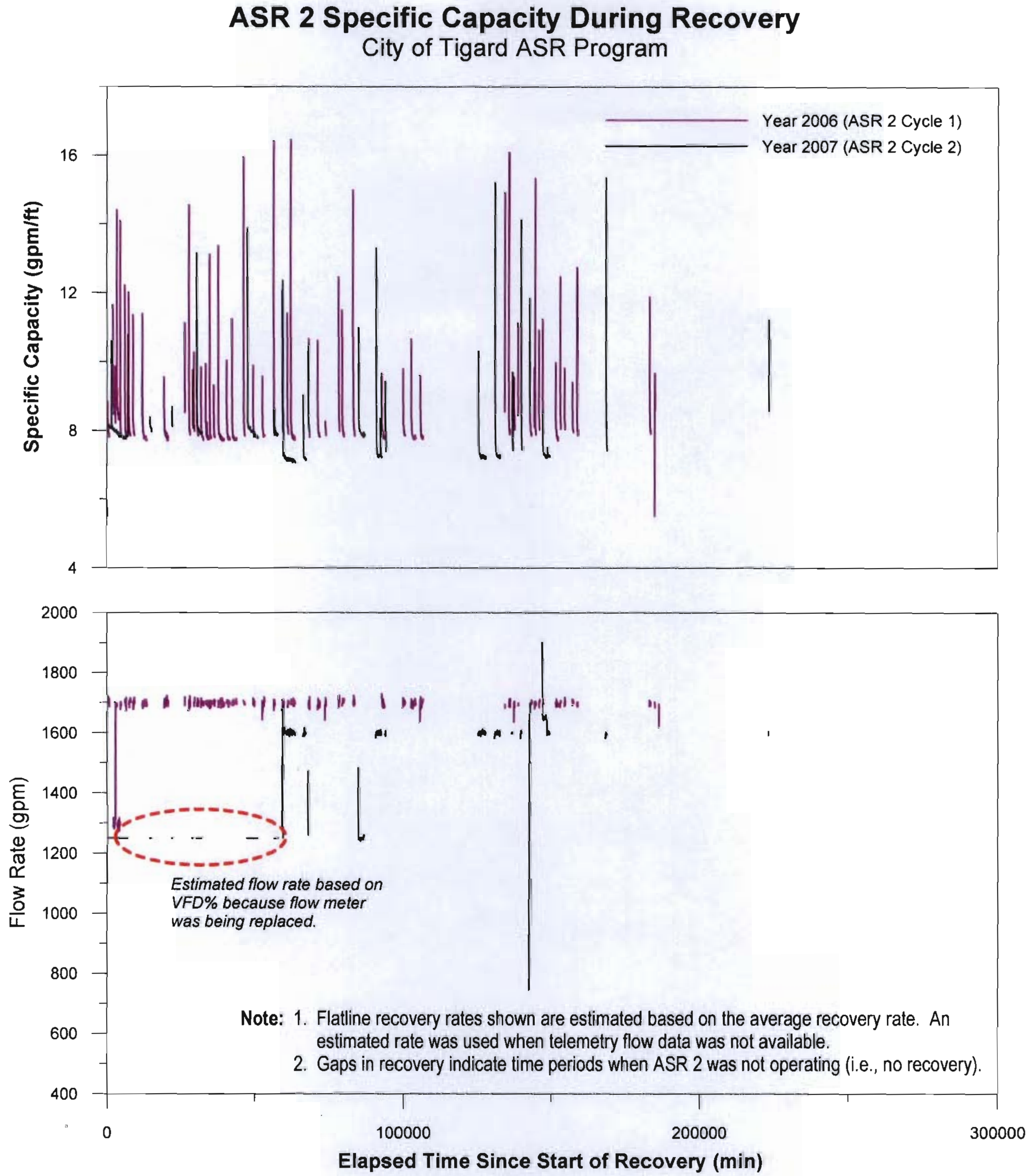

Figure 8

P:\103 - Tigard\ASR Tracking\Output Plots\ASR 2 Recovery SC.grf

GSI Water Solutions, Inc.

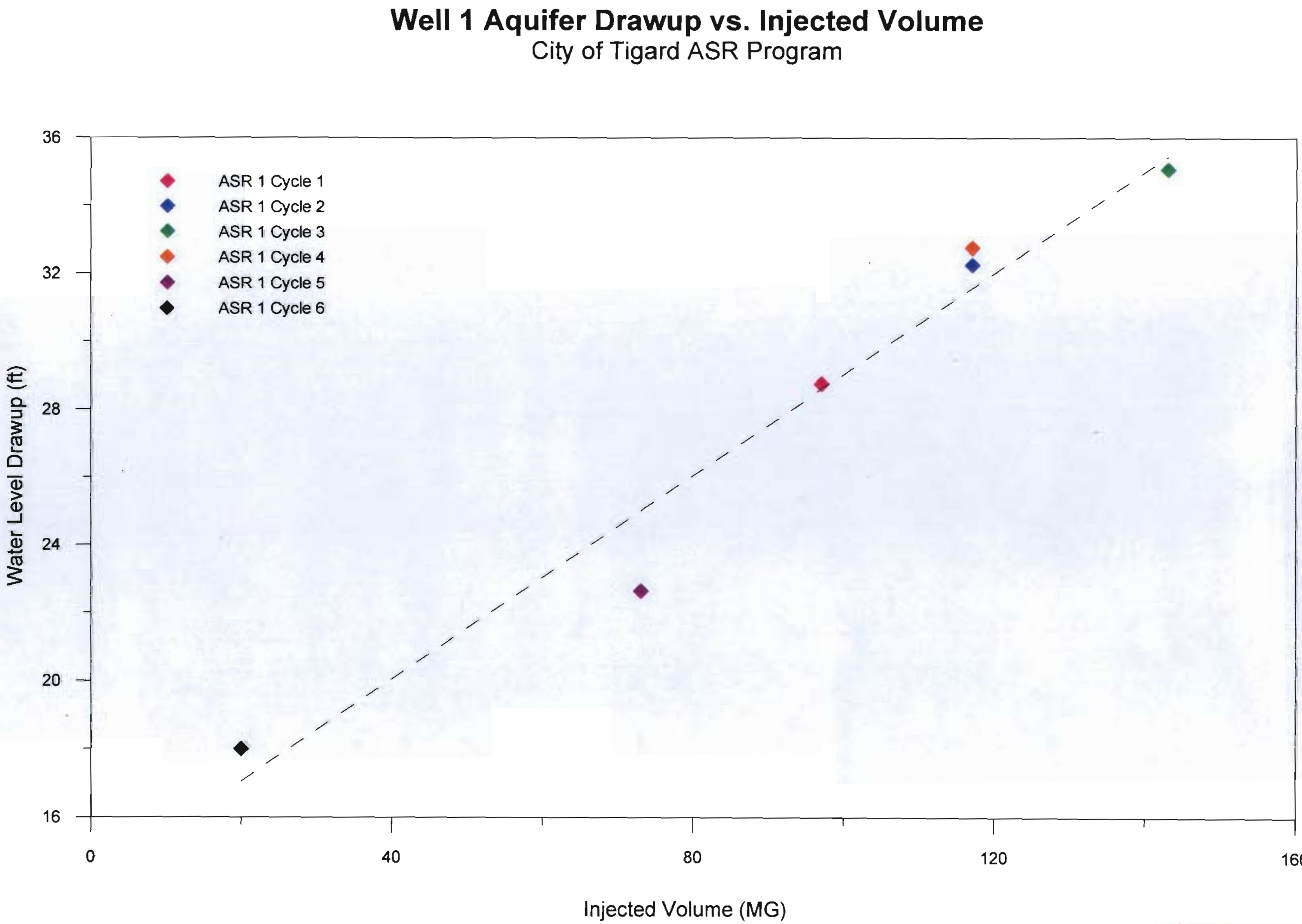

Figure 9

P:\103 - Tigard\ASR Tracking\Aquifer drawup.grf

GSI Water Solutions, Inc.

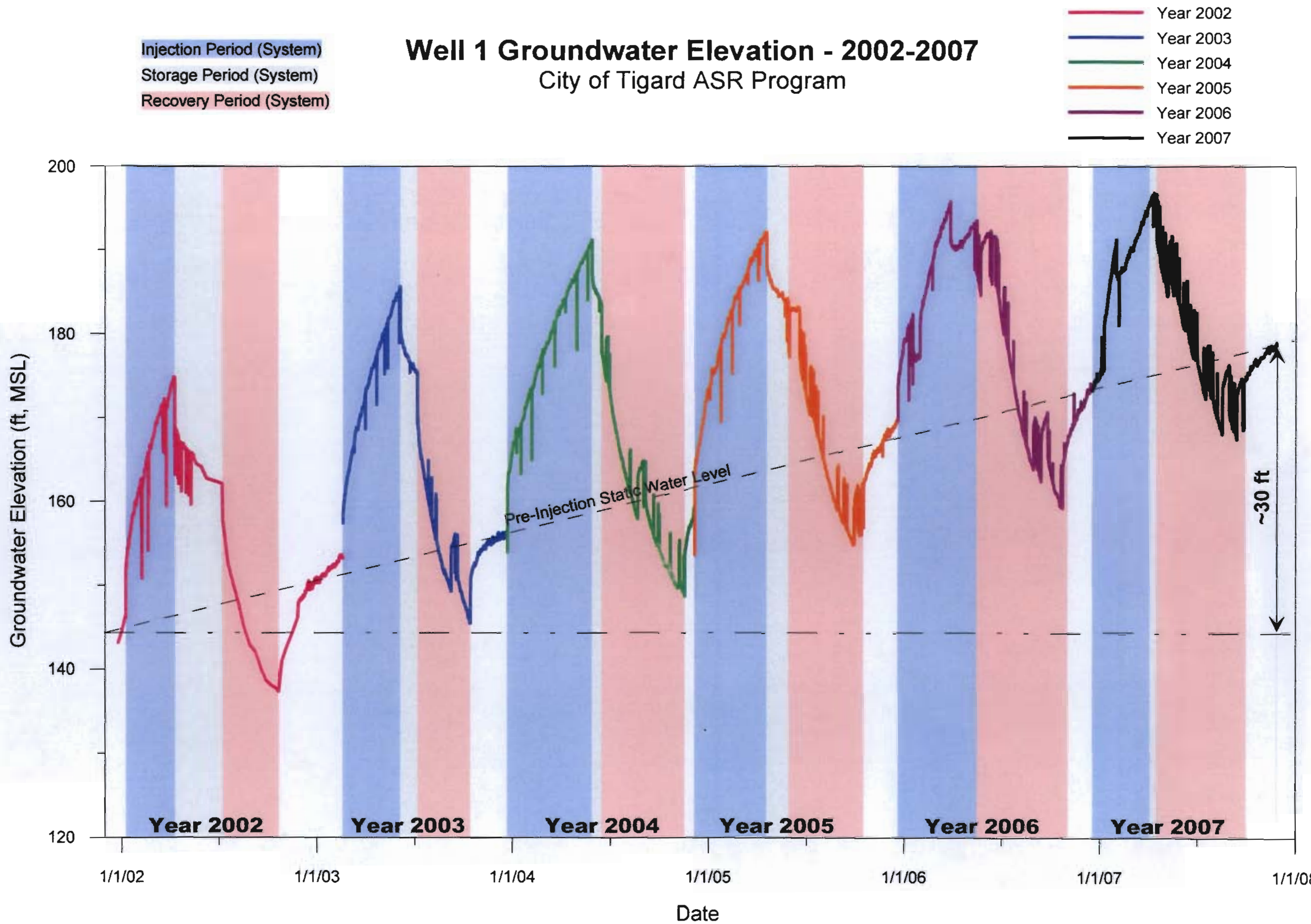

Figure 10

P:\103 - Tigard\ASR Tracking\Output Plots\Well1_GW_Elev.grf

GSI Water Solutions, Inc.

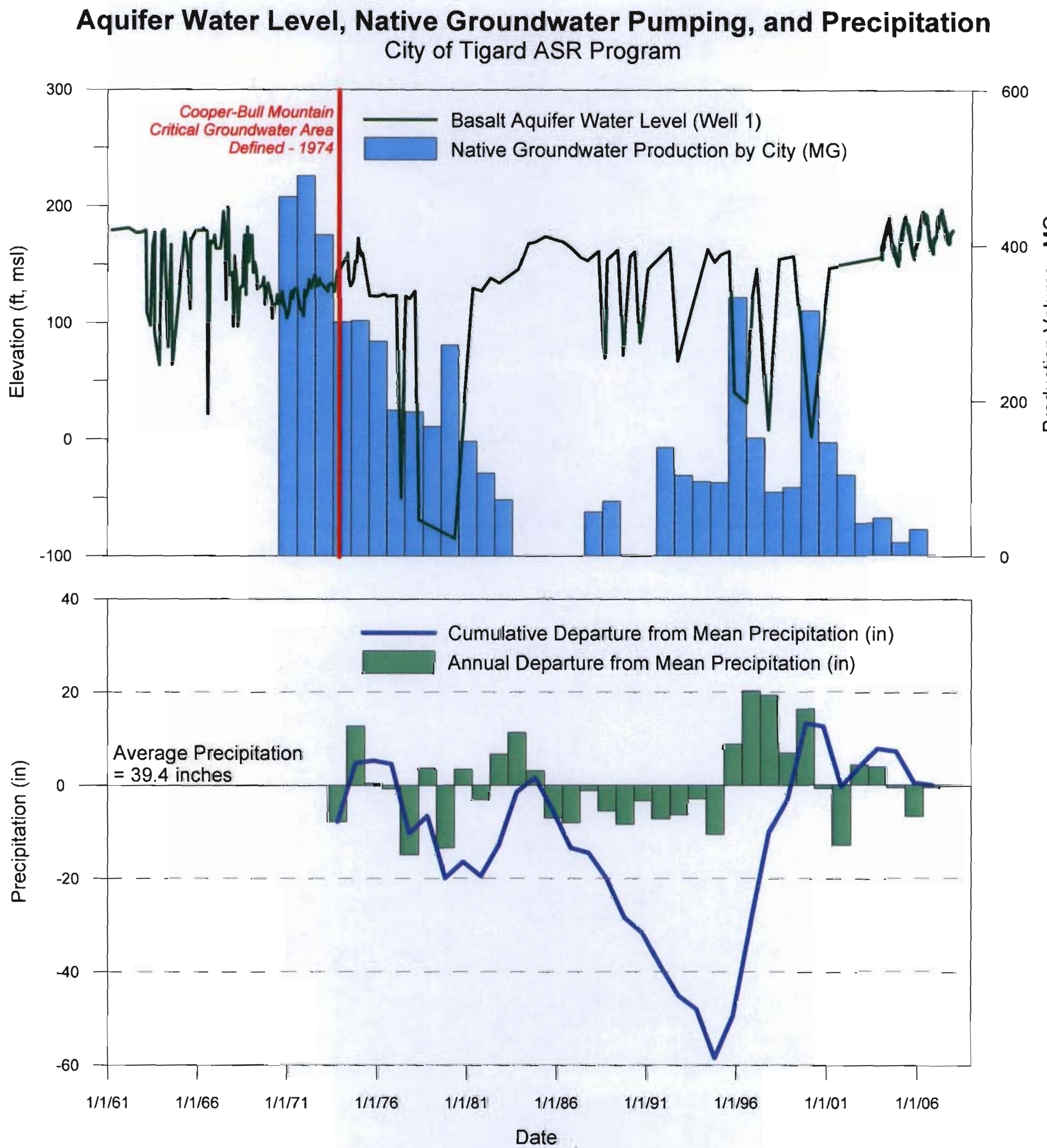

Figure 11

P:\103 - Tigard\ASR Tracking\Historic Data\WL_Q_Precip.grf

GSI Water Solutions, Inc.

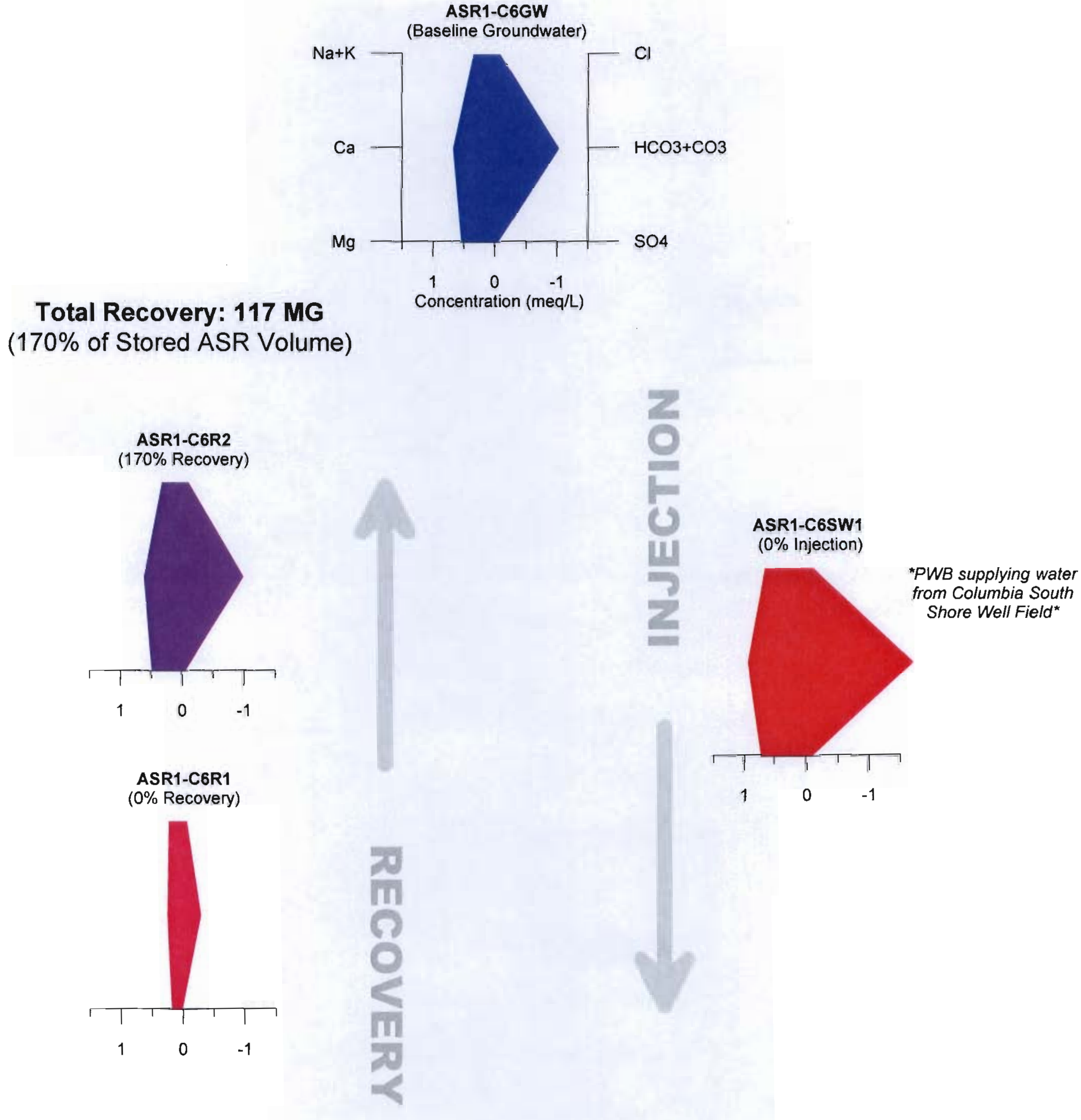

Figure 12
ASR 1 Cycle 6 (2007) Water Chemistry Trend

P:\103 - Tigard\008 - 2006-2007 ASR Ops Support\Data\Water Quality Data\ASR1_C6_Stiff.grf

GSI Water Solutions, Inc.

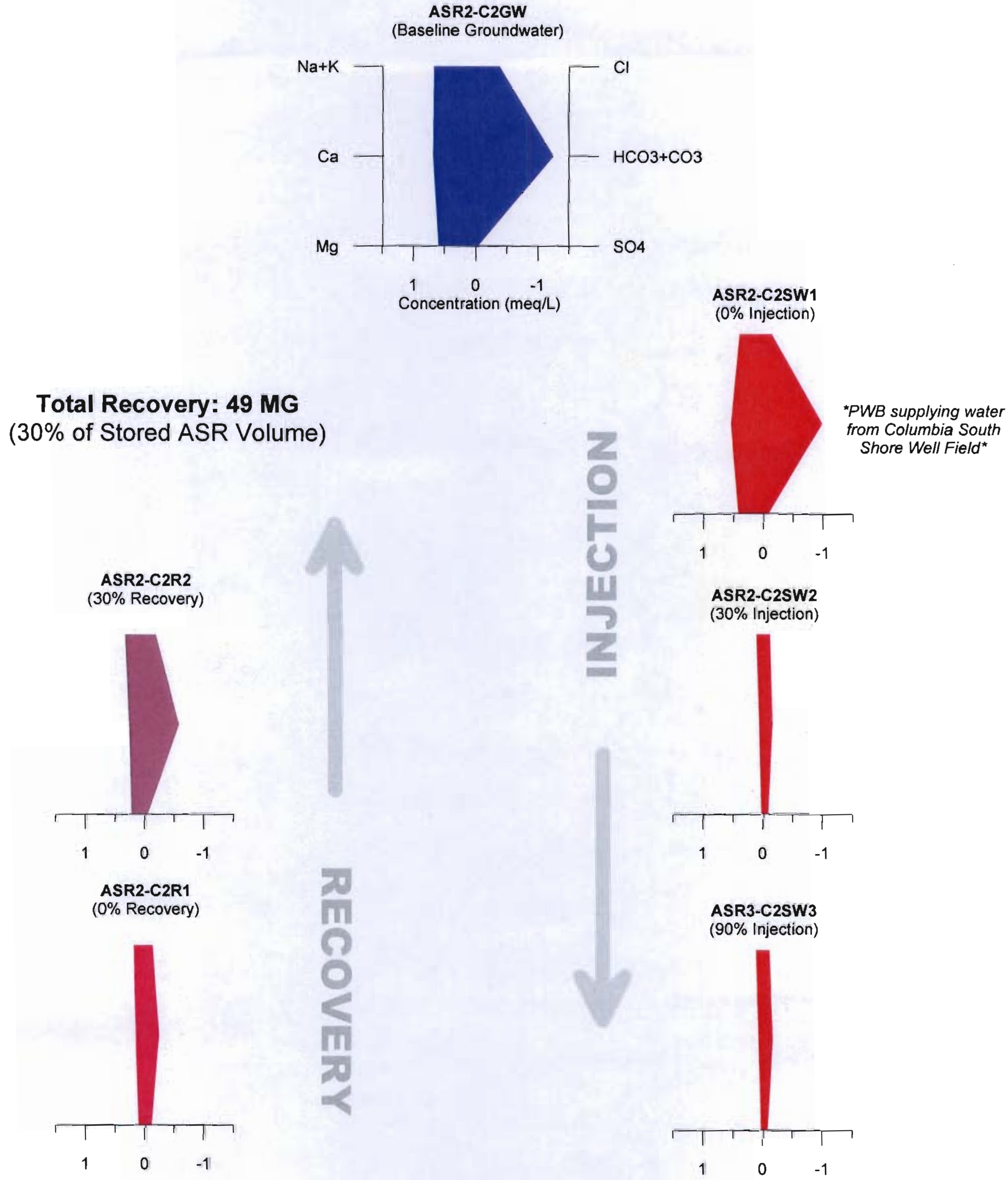

Figure 13
ASR 2 Cycle 2 (2007) Water Chemistry Trend

P:\103 - Tigard\008 - 2006-2007 ASR Ops Support\Data\Water Quality Data\ASR2_C2_Stiff.grf

GSI Water Solutions, Inc.

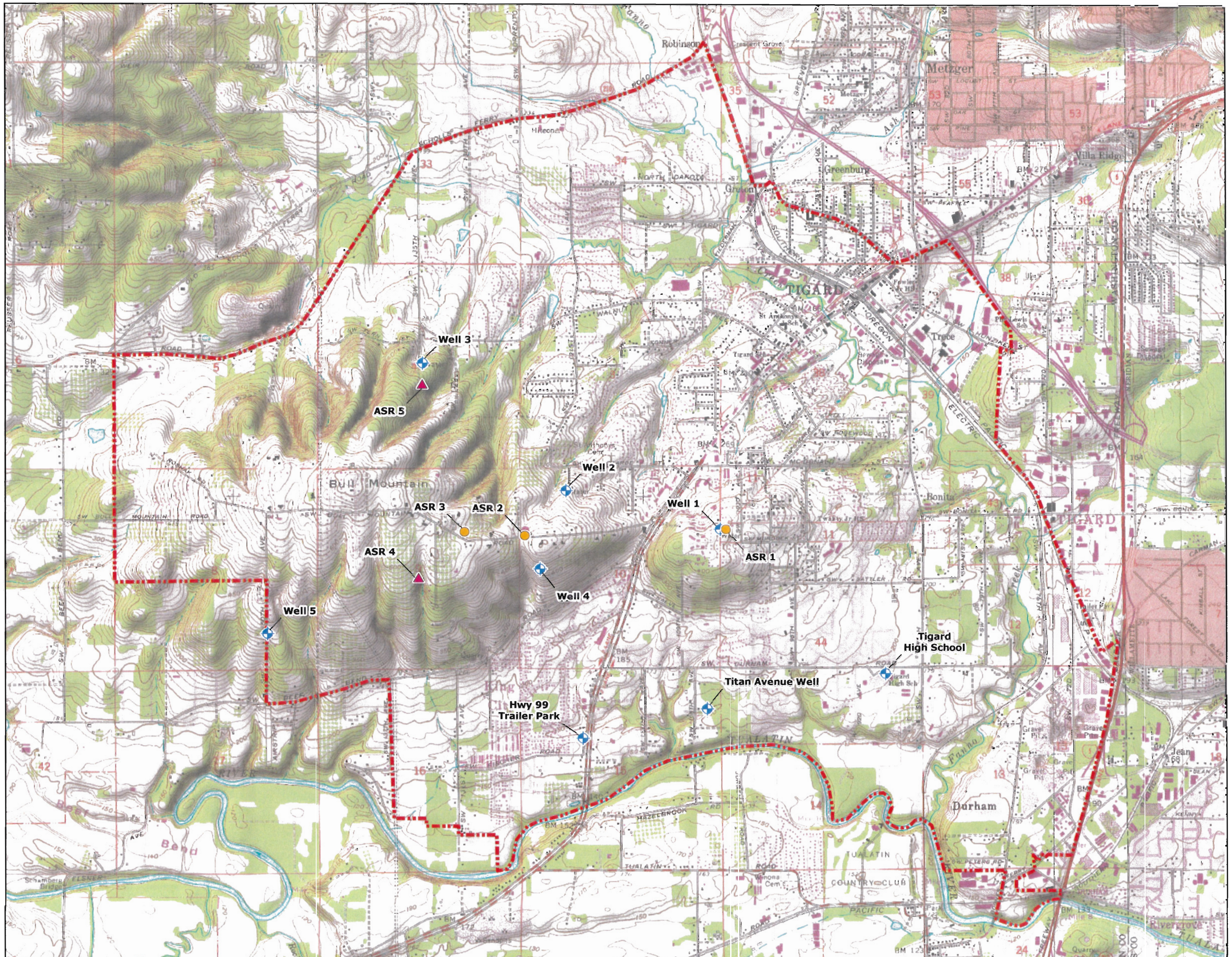

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FIGURE 14

ASR Planned Expansion

City of Tigard

LEGEND

- Planned Location
- City of Tigard ASR Well
- ASR Observation Well
- City of Tigard Water Service Area Boundary

N

Scale

1:30,000

0 1250 2500 3750 5000

Feet

MAP NOTES:
Projection: Universal Transverse Mercator, Zone 10 North
Datum: North American Datum of 1983
Date: February 8, 2008
Data Sources: City of Tigard, USGS

GSI Water Solutions, Inc.

Attachment A
Water Quality Monitoring Program for Year 7 (2008)

City of Tigard 2007-2008 ASR Operations
Schedule and Tracking Form

▶ Input Values in Yellow Cells ◀

Modified 11/15/2007

ASR 1

Injection	AVERAGE Injection Rate:	600	(gpm)	Injection volume per day	0.86 MGD
	Injection Start Date:	Wednesday 2/13/08 10:00 AM			
	Injection End Date:	Wednesday 3/19/08 10:00 AM			
	Elapsed Injection Days:	35.0	days	30 MG	Actual Stored Volume
	Elapsed Injection Hours:	840	hours	0.0 MG	ASR Account Carryover
	Injected Volume:	30	MG		
Storage	Storage Start Date	Wednesday 3/19/08 10:00 AM			
	Storage End Date	Sunday 6/1/08 10:00 AM			
	Elapsed Storage Days	74.0			
	Elapsed Storage Hours	1776			
Recovery	AVERAGE Recovery Rate:	800	(gpm)	Recovery volume per day	1.15 MGD
	Recovery Start Date:	Sunday 6/1/08 10:00 AM			
	Recovery End Date:	Wednesday 10/1/08 10:00 AM			
	Elapsed Days:	122.0	days		
	Elapsed Hours:	2928	hours		
	Recovered Volume:	141	MG		

ASR 2

Injection	AVERAGE Injection Rate:	1200	(gpm)	Injection volume per day	1.73 MGD
	Injection Start Date:	Monday 11/26/07 10:00 AM			
	Injection End Date:	Monday 2/11/08 10:00 AM			
	Elapsed Injection Days:	77.0	days	130 MG	Actual Stored Volume
	Elapsed Injection Hours:	1848	hours	120.0 MG	ASR Account Carryover
	Injected Volume:	133	MG		
Storage	Storage Start Date	Monday 2/11/08 10:00 AM			
	Storage End Date	Sunday 6/1/08 10:00 AM			
	Elapsed Storage Days	111.0			
	Elapsed Storage Hours	2664			
Recovery	AVERAGE Recovery Rate:	1700	(gpm)	Recovery volume per day	2.45 MGD
	Recovery Start Date:	Sunday 6/1/08 10:00 AM			
	Recovery End Date:	Wednesday 10/1/08 10:00 AM			
	Elapsed Days:	122.0	days		
	Elapsed Hours:	2928	hours		
	Recovered Volume:	299	MG		

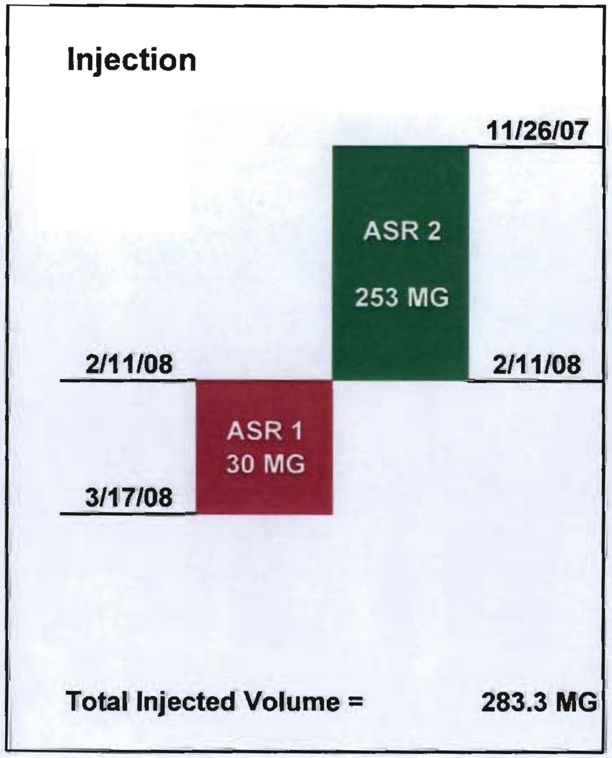
SYSTEM

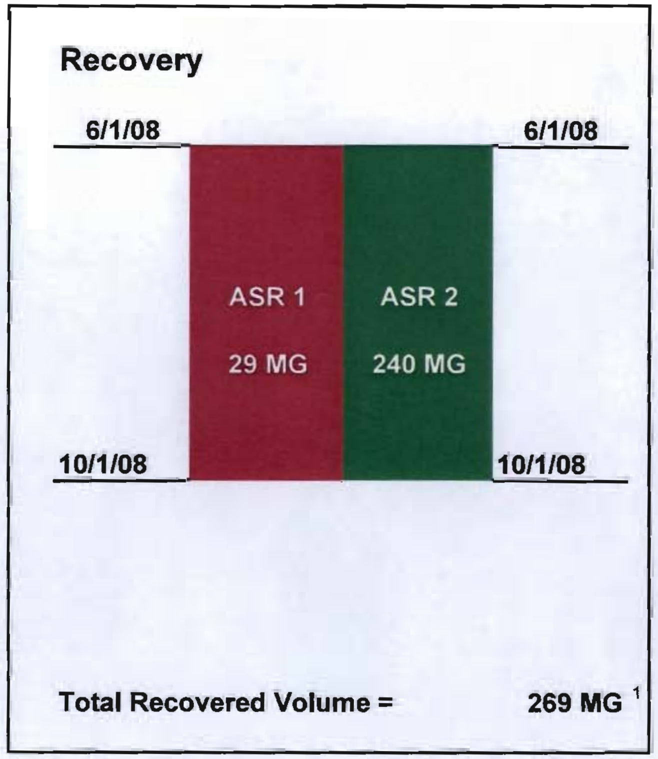
Total **PLANNED** ASR Injection Volume	283.3 MG
Total **PLANNED** ASR Recovery Volume	269.1 MG
ACTUAL ASR Account Volume	274.0 MG
ACTUAL ASR Volume Recovered	439.2 MG
ASR Account Remaining	-165.2 MG

Assumes 95% Recovered

ASR Operations Scheduling Flowchart

YEAR 2008 -- City of Tigard





[1] 95% of injection volume per limited license. Any additional produced will be 'native' groundwater

City of Tigard 2007-2008 ASR Operations
Water Quality Monitoring Program

► Input Values in Yellow Cells ◄

Modified 11/15/2007

ASR 1 - Cycle 7

Water Type	Progress Point		Date	Elapsed Time (days)		Water Analysis to be Completed					Sample ID	Date Collected	Comments
	% Complete (Injection or Recovery)	Million Gallons (Water injected or recovered)		ASR Phase	ASR Cycle	Field Parameters	General Chemistry	DBPs	SWDA Parameters	Radon			
Baseline Groundwater													
GW	-	-	Monday 1/14/08 10:00 AM	-30	-30	X	X	X		X	ASR1-C7GW		Native gw sample T _°C, pH _, DO _ mg/L, SC _ uS/cm, ORP _ mV
Injection Period													
Source	-	-	Monday 1/14/08 10:00 AM	-30	-30	X	X	X	X		ASR1-C7SW1		
Source	35%	0	Monday 2/25/08 4:00 PM	12	12	X	X				ASR1-C7SW2		
Source	70%	0	Saturday 3/8/08 10:00 PM	25	25	X	X	X			ASR1-C7SW3		
Storage Period													
Stored	99%		Saturday 5/31/08 4:14 PM	73	108			X			ASR1-C7ST1		
Recovery Period													
Recovered	-	-	Friday 5/2/08 10:00 AM	-30	79	X	X	X	X	X	ASR1-C7R1		
Recovered	35%	11	Monday 7/14/08 2:48 AM	43	152	X	X				ASR1-C7R2		
Recovered	70%	21	Monday 8/25/08 7:36 PM	85	194	X	X				ASR1-C7R3		
Recovered	95%	29	Thursday 9/25/08 7:36 AM	116	225	X	X	X		X	ASR1-C7R4		

ASR 2 - Cycle 3

Water Type	Progress Point		Date	Elapsed Time (days)		Water Analysis to be Completed					Sample ID	Date Collected	Comments
	% Complete (Injection or Recovery)	Million Gallons (Water injected or recovered)		ASR Phase	ASR Cycle	Field Parameters	General Chemistry	DBPs	SWDA Parameters	Radon			
Baseline Groundwater													
GW	-	-	Saturday 10/27/07 10:00 AM	-30	-30	X	X	X		X	ASR2-C3GW		Native gw sample T _°C, pH _, DO _ mg/L, SC _ uS/cm, ORP _ mV
Injection Period													
Source	-	-	Saturday 10/27/07 10:00 AM	-30	-30	X	X	X	X		ASR2-C3SW1		
Source	35%	0	Sunday 12/23/07 8:48 AM	27	27	X	X				ASR2-C3SW2		
Source	70%	0	Saturday 1/19/08 7:36 AM	54	54	X	X	X			ASR2-C3SW3		
Storage Period													
Stored	99%		Saturday 5/31/08 7:21 AM	110	167			X			ASR2-C3ST1		
Recovery Period													
Recovered	-	-	Friday 5/2/08 10:00 AM	-30	158	X	X	X	X	X	ASR2-C3R1		
Recovered	35%	46	Monday 7/14/08 2:48 AM	43	231	X	X				ASR2-C3R2		
Recovered	70%	91	Monday 8/25/08 7:36 PM	85	273	X	X				ASR2-C3R3		
Recovered	95%	124	Thursday 9/25/08 7:36 AM	116	304	X	X	X		X	ASR2-C3R4		

Notes:

DBP = Disinfection By-Products
SDWA = Safe Drinking Water Act Parameters (OHD, DEQ MML, Federal SMCL)
UCMR = EPA Unregulated Contaminant Monitoring Regulations parameters