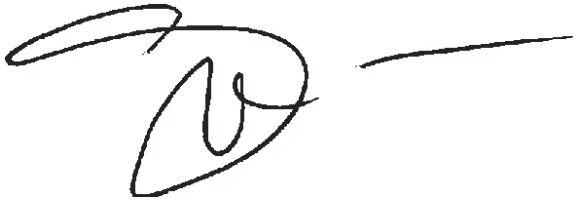
MEMORANDUM

Project No.: 140369

September 1, 2017

To: Cami Apfelbeck, City of Bainbridge Island (COBI)
Charles Krumheuer, COBI
Martin Sebren, Kitsap County PUD (KPUD)
Mark Morgan, KPUD

From:



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Re: **Groundwater Production Field Test Summary and Comparison**

This memorandum describes the findings from the field test conducted to evaluate changes in groundwater conditions associated with temporarily transferring groundwater production from the deeper Fletcher Bay Aquifer to the Sea Level Aquifer for the two largest water systems on Bainbridge Island. These two systems include the City of Bainbridge Island (COBI) Winslow Water System, and the Kitsap Public Utility District (KPUD) North Bainbridge Water System. The field test results are summarized, with reference to simulated conditions using the Bainbridge Island groundwater model reported in a memorandum dated December 2, 2016 (Aspect, 2016b). Aspect Consulting, LLC (Aspect) conducted this analysis and reporting under a cost-sharing agreement between the COBI and the KPUD.

Summary of Findings

The COBI Winslow Water System and the KPUD North Bainbridge Water System successfully conducted a field test of temporarily transferring production from the Fletcher Bay Aquifer to the Sea Level Aquifer. The field test was designed to address issues of water system and aquifer system resiliency, as well as the accuracy of the Bainbridge Island groundwater model results. The field test was conducted from January through April 2017 with production rates approximating planned and simulated conditions, followed by normal operations. Observed groundwater conditions were

provided through May 2017. Above normal precipitation was reported regionally before and during the aquifer test.

Overall, the aquifer test was a good demonstration of how the water systems and aquifer systems respond to temporarily transferring production from the Fletcher Bay Aquifer to the Sea Level Aquifer. Based on the results of the field test, the Sea Level Aquifer appears resilient to temporary increases in production, and the benefits and risks for seasonally transferring production from the Fletcher Bay aquifer to the Sea Level Aquifer appear neutral. We recommend continued monitoring of water levels and water quality to confirm the sustainable use of the aquifer resources as sole-source drinking water supplies.

The Bainbridge Island groundwater model generally simulated the changes in conditions observed during the field test. Differences between model results and actual conditions were attributable to differences between planned and actual production, above normal precipitation, and model bias.

Field Test Description

The groundwater production field test started on January 17, 2017, and ended on April 24, 2017. During the field test, production from wells completed in the Fletcher Bay Aquifer were safely reduced, and water demand was met by safely increasing production from wells completed in the Sea Level Aquifer. Groundwater conditions in production wells and nearby monitoring wells were monitored through May 31, 2017. Production and monitoring wells are listed in Attachment 1, and their mapped locations are shown on Figure 1.

COBI Winslow Water System

For the field test, COBI's Winslow Water System planned to meet demand with 50 percent of production from wells completed in the Sea Level Aquifer and 50 percent of production from the wells completed in the Fletcher Bay Aquifer. This planned production distribution was also used to simulate the field test (Aspect, 2016b). Under actual field conditions, the distribution of production operationally achieved was 43 percent from Sea Level Aquifer wells and 57 percent from Fletcher Bay Aquifer wells. Table 1 shows the average production distribution for the COBI Winslow Water System, and compares the distribution from January through May 2016, the planned distribution, and the actual distribution during the field test in 2017.

Production from the COBI Winslow Water System wells in the Fletcher Bay Aquifer was distributed very differently during the field test compared to the previous year. Due to maintenance activities, Sands Well 1 and Sands Well 2 were not operated from November 2015 through February 2016, and production was limited in April and May 2016. As a result, the Fletcher Bay well delivered nearly half of the water supply from January to April 2016.

Table 1. Average Production Distribution for COBI Winslow Water System

Well Name	Ecology Well ID	Production Distribution from January to April 2016	Planned/Modeled Distribution of Production during Operational Scenario	Actual Production Distribution during Field Test from January to April 2016
Sea Level Aquifer Wells				
Head of Bay Well 1A	AAC860	9%	0%	1%
Head of Bay Well 1	AAC869	2%	0%	0%
Head of Bay Well 2	AAC870	0%	16.7%	16%
Head of Bay Well 3	AAC871	20%	16.7%	19%
Head of Bay Well 4	AAC872	6%	0%	1%
Head of Bay Well 5	AAC873	0%	16.7%	7%
Head of Bay Well 6	AAC874	0%	0%	0%
Fletcher Bay Aquifer Wells				
Fletcher Bay Well	AAC733	49%	21.5%	31%
Sands Well 1	AAC875	6%	14.0%	13%
Sands Well 2	AAC876	6%	14.5%	14%

For context, Figure 2 shows the COBI Winslow Water System production from 2015 through the field test. Figure 3 shows the distribution of COBI production between wells completed in the Sea Level Aquifer (upper graph) and the Fletcher Bay Aquifer (lower graph).

KPUD North Bainbridge Water System.

For the field test, KPUD's North Bainbridge Water System planned to meet demand with 100 percent production from wells completed in the Sea Level Aquifer. Under actual field conditions, the distribution of production operationally achieved was 90 percent from the Sea Level Aquifer wells and 10 percent from the Fletcher Bay Aquifer well. Table 2 shows the average production distribution for the KPUD North Bainbridge Water System, and compares the distribution from January through May of 2016, the planned distribution, and the actual distribution during the field test in 2017.

Table 2. Average Production Distribution for KPUD North Bainbridge Water System

Well Name	Ecology Well ID	Production Distribution from January to April 2016	Planned/Modeled Distribution of Production during Operational Scenario	Actual Production Distribution during Field Test
Sea Level Aquifer Wells				
Well 3	AEK853	16%	38%	30%
Well 7	AEK852	29%	62%	61%
Fletcher Bay Aquifer Wells				
Well 9	AAB455	55%	0%	10%

For context, Figure 4 shows the KPUD North Bainbridge Water System production from 2015 through the field test. Figure 5 shows the distribution of KPUD production between wells completed in the Sea Level Aquifer (upper graph) and the Fletcher Bay Aquifer (lower graph).

Observed Precipitation

During the field test, the precipitation rates were generally greater than normal, indicating that recharge rates were greater than normal. The effects of above normal recharge would vary spatially depending on infiltration rates, depth to groundwater, aquifer thickness, and relative aquifer depth. In general, above normal recharge would result in increased groundwater levels, which would be more pronounced in shallower aquifers than in deeper aquifers. The cumulative rainfall starting January 1 is shown for both 2016 and 2017 in Figure 6.

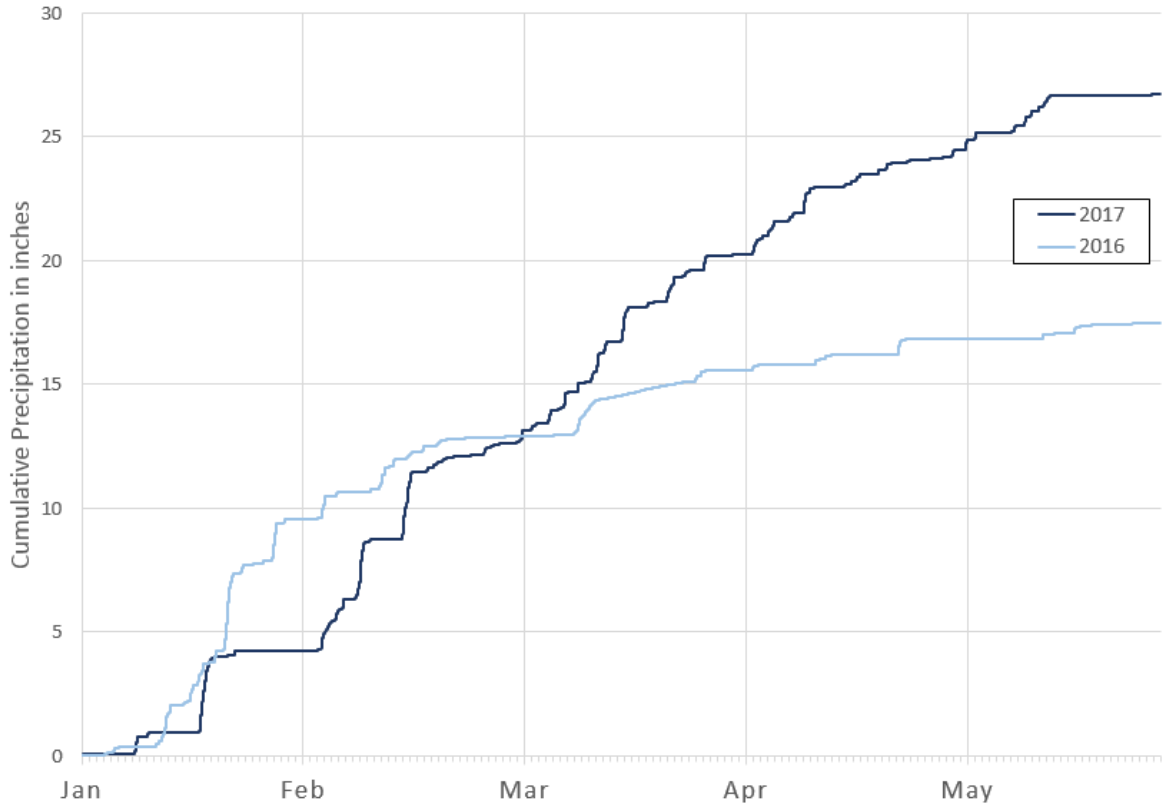

Figure 6: Cumulative Precipitation as Indication of Recharge

Field Test Results

Both the COBI and the KPUD water systems provided groundwater monitoring data from production wells, and the COBI Groundwater Monitoring Program provided data for nearby monitoring wells (Figure 1). This data included water levels and groundwater quality. The monitoring schedule is provided as Attachment 1.

Observed Changes in Groundwater Levels

To assess changes in groundwater levels, the static water levels observed in 2017 during the field test were compared to 2016 static water levels. Static water levels do not account for potential head losses during pumping associated with the well screen.

Similar to the groundwater model results, observed water levels were lower at wells with greater production in 2017 than in 2016, and water levels were higher at wells with lower production. However, quantitative comparison between groundwater model results and observed conditions should be made in the context of differences between simulated groundwater production and recharge rates, and actual conditions.

COBI Winslow Water System

At COBI's Fletcher Bay well in the Fletcher Bay Aquifer, water levels in 2017 were between approximately 3 and 6 feet higher than in 2016. At Sands Well 1 and Sands Well 2, also in the Fletcher Bay Aquifer, water levels in 2017 were between approximately 1 and 9 feet lower than in 2016. These observed changes were not accurately simulated during the modeling effort primarily due to the substantial differences in production distribution between 2016 and 2017. As previously mentioned, Sands Well 1 and Sands Well 2 had lower than normal production during early 2016 due to maintenance activities.

In the Sea Level Aquifer, average water levels observed in 2017 at the Head of the Bay (including wells #2, #3, and #5) were similar to those observed in 2016. These stable water levels for the Head of the Bay wells were not simulated during the modeling effort, due to one or more of the following factors: lower than planned production, above normal recharge, and model bias.

Figure 7 shows the monthly average changes in groundwater levels for the COBI Winslow Water System during and just after the field test.

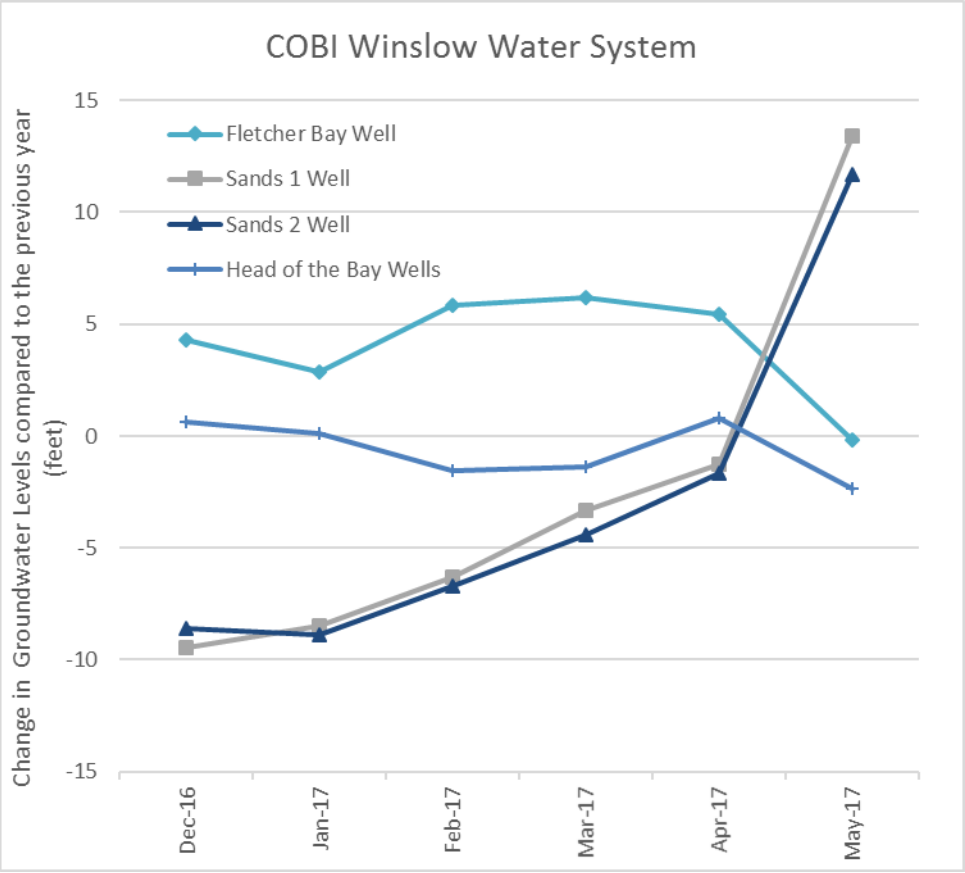

Figure 7. Observed Groundwater Level Changes—COBI Winslow Water System

KPUD North Bainbridge Water System

At KPUD's Well 9 in the Fletcher Bay Aquifer, water levels observed in 2017, during the field test, were between approximately 4 and 8 feet higher than in 2016, reflecting lower production during the field test. Model results indicated higher water levels (approximately 12 feet).

At Well 7 in the Sea Level Aquifer, water levels in 2017 were between 3 and 6 feet lower than in 2016, reflecting the increased production during the field test. Comparable water levels at Well 3[1] were not available for 2016, so a similar comparison could not be made. Following the test, the water level in Well 7 recovered to levels above those measured in 2016. Model results indicated water levels would have been up to 20 and 25 feet below normal at Wells 3 and 7, respectively.

Differences between simulated and actual water levels for the KPUD North Bainbridge Water System may reflect one or more of the following factors: slightly different production than planned, above normal recharge during 2017, and model bias. Figure 8 shows the changes in groundwater levels for the KPUD North Bainbridge Water System during and just after the field test.

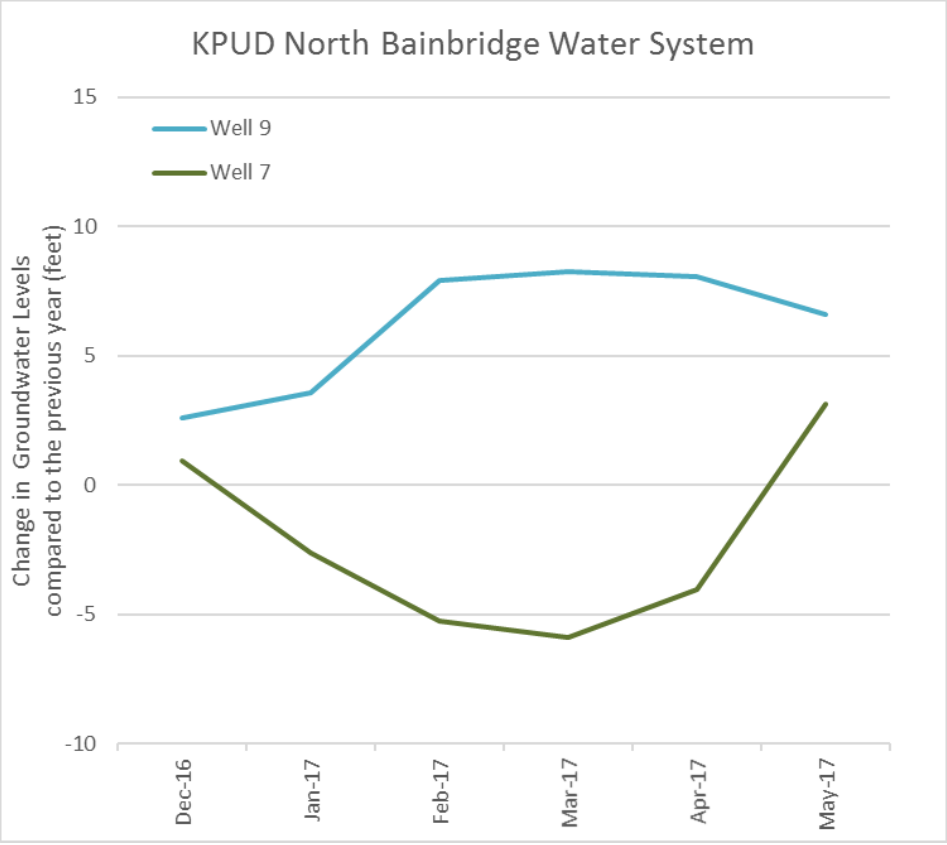

Figure 8. Observed Groundwater Level Changes—KPUD North Bainbridge Water System

[1] Comparisons of Well 7 and Well 9 water levels were made using monthly averages of continuous data from 2016 and 2017, but continuous data for Well 3 from 2016 was not available. Monthly water level measurements at Well 3 from 2016 and 2017 are available, however, measurements during 2016 and 2017 were not made during comparable conditions: measurements from 2016 were primarily collected during static conditions, while measurements from 2017 were collected during pumping or recovery conditions.

Groundwater Level Changes at Nearby Monitoring Wells

Groundwater levels in monitoring wells near production wells did not appear influenced by changes in production during the field test. Groundwater levels in some monitoring wells completed in the Perched Aquifer, the Semi-Perched Aquifer, and the Sea Level Aquifer increased during the field test, possibly reflecting the above average recharge to groundwater. Groundwater levels in other monitoring wells appeared stable.

Cost Analysis of Field Test

Cost analysis results indicate that the costs for the COBI Winslow Water System were temporarily greater during the field test than during 2016 operations, and the costs for the KPUD North Bainbridge Water System were temporarily less during the field test than during 2016 operations. However, it appears both water systems returned to little-to-no cost benefit by May 2017, compared to 2016 operations. This cost analysis was based on changes in static water levels, and does not consider the well efficiency and actual pumping lift costs. We recommend that costs for electricity and operations/maintenance be compared for a more accurate analysis. The cumulative projected pumping costs for each water system were calculated starting in January 2017, and are shown in Figure 9.

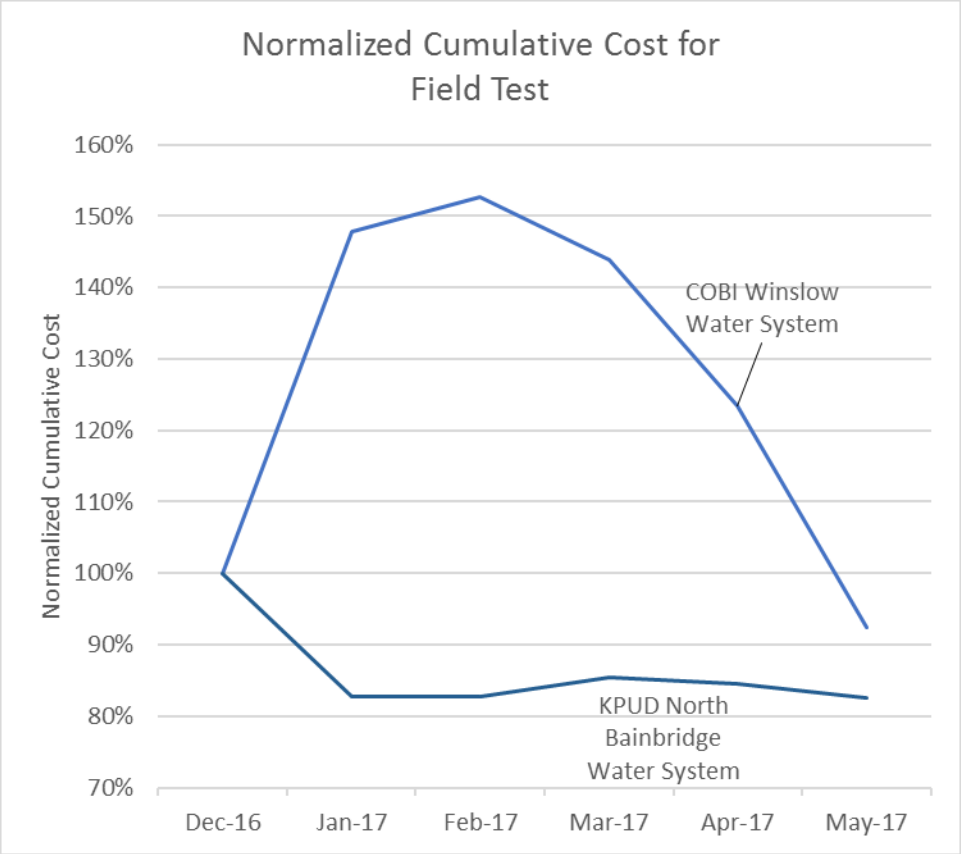

Figure 9. Groundwater Production Field Test Cost Analysis

Observed Water Quality

The field test observations showed no trend in water quality associated with seawater intrusion during this exercise, similar to model results. Higher frequency monitoring during the field test provided additional information regarding the ranges in observed specific conductance and/or chloride. In all cases, chloride concentrations at production wells were significantly less than the regulatory threshold.

The Bainbridge Island groundwater model simulated Puget Sound as a potential source of seawater, and did not simulate other sources of chloride or other water quality parameters. Observed water quality and operational scenario model results are consistent with results from the long-term modeling analysis supporting the aquifer system carrying capacity assessment (Aspect, 2016a). The temporary operational changes field-tested as part of this exercise do not appear to pose a risk of causing seawater intrusion.

Conclusions

The COBI Winslow Water System and the KPUD North Bainbridge Water System conducted a field test of temporarily transferring production from the Fletcher Bay Aquifer to the Sea Level Aquifer. The field test was designed to address issues of water system and aquifer resiliency, as well as the accuracy of the Bainbridge Island groundwater model results. The field test was successfully conducted from January through April 2017, followed by normal production.

Overall, the aquifer test was a good demonstration of how the water systems and aquifer systems respond to temporarily transferring production from the Fletcher Bay Aquifer to the Sea Level Aquifer. The field test did not appear to influence water levels in monitoring wells near the production wells, and there was no indication of seawater intrusion. Based on the results of the field test, the Sea Level Aquifer appears resilient to temporary increases in production, and the benefits and risks for seasonally transferring production from the Fletcher Bay aquifer to the Sea Level Aquifer appear neutral. We recommend continued monitoring of water levels and water quality to confirm the sustainable use of the aquifer resources as sole-source drinking water supplies.

The Bainbridge Island groundwater model generally simulated the changes in conditions observed during the field test. Differences between model results and actual conditions were attributable to differences between planned and actual production, above normal precipitation, and model bias.

References

Aspect, 2016a, Bainbridge Island Groundwater Model: Aquifer System Carrying Capacity Assessment (Task 3 Scenario), Prepared for the City of Bainbridge Island, March 2, 2016.

Aspect, 2016b, Bainbridge Island Groundwater Model: Modeling Support for Operational Scenario Analysis, Prepared for the City of Bainbridge Island and Kitsap Public Utility District, December 2, 2016.

Limitations

Work for this project was performed for the City of Bainbridge Island and the Kitsap Public Utility District (Clients), and this memorandum was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar

localities, at the time the work was performed. This memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

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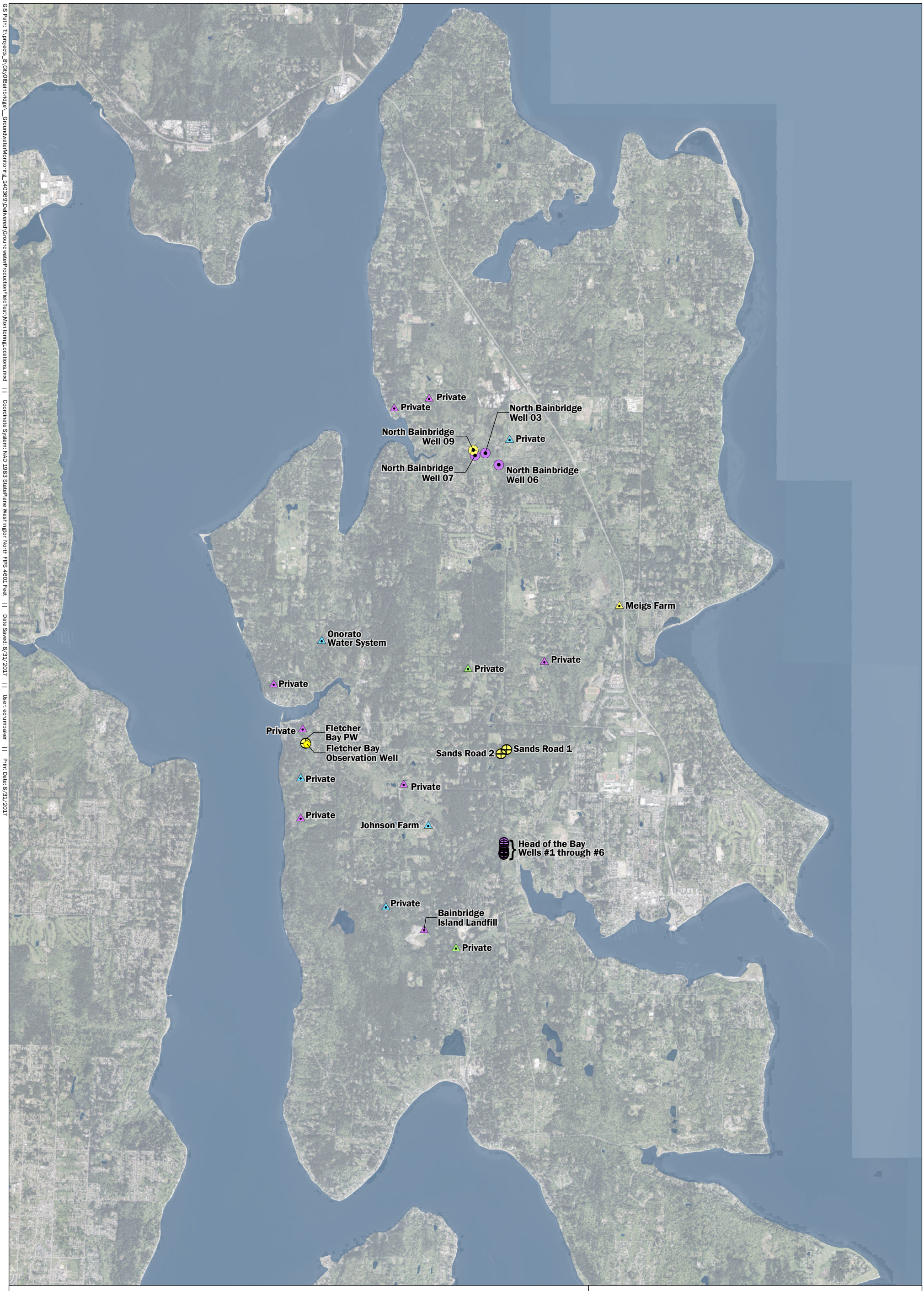
Attachments

V:\140369 COBI - GW Assessment and Modeling Support\Deliverables\Aquifer Test Technical Memo\Aquifer Test Tech Memo_Final.docx

FIGURES



Well Type (Indicated by Symbol)

- ⊕ City of Bainbridge Island Production Well
- ⊙ KPUD Production Well
- ⬠ KPUD Observation Well
- ◬ Private and Exempt Wells

Aquifer (Indicated by Color)

- Fletcher Bay Aquifer
- Sea Level Aquifer
- Semi-perched Aquifer
- Perched Aquifer

N

0 2,000 4,000

Feet

Monitoring Locations

Groundwater Production Field Test
City of Bainbridge Island
Bainbridge Island, Washington

Aspect CONSULTING	AUG-2017	BY: SDM / RAP	FIGURE NO. 1
	PROJECT NO. 140369	REVISED BY: ---	

Basemap Layer Credits | | Copyright (C) 2015 - Kitsap County, Puget Sound Aerial Mapping Project

GIS Path: T:\projects_8\CityOfBainbridge__GroundwaterMonitoring_140369\Delivered\GroundwaterProductionFieldTest\MonitoringLocations.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 8/31/2017 || User: ecrumbaker || Print Date: 8/31/2017

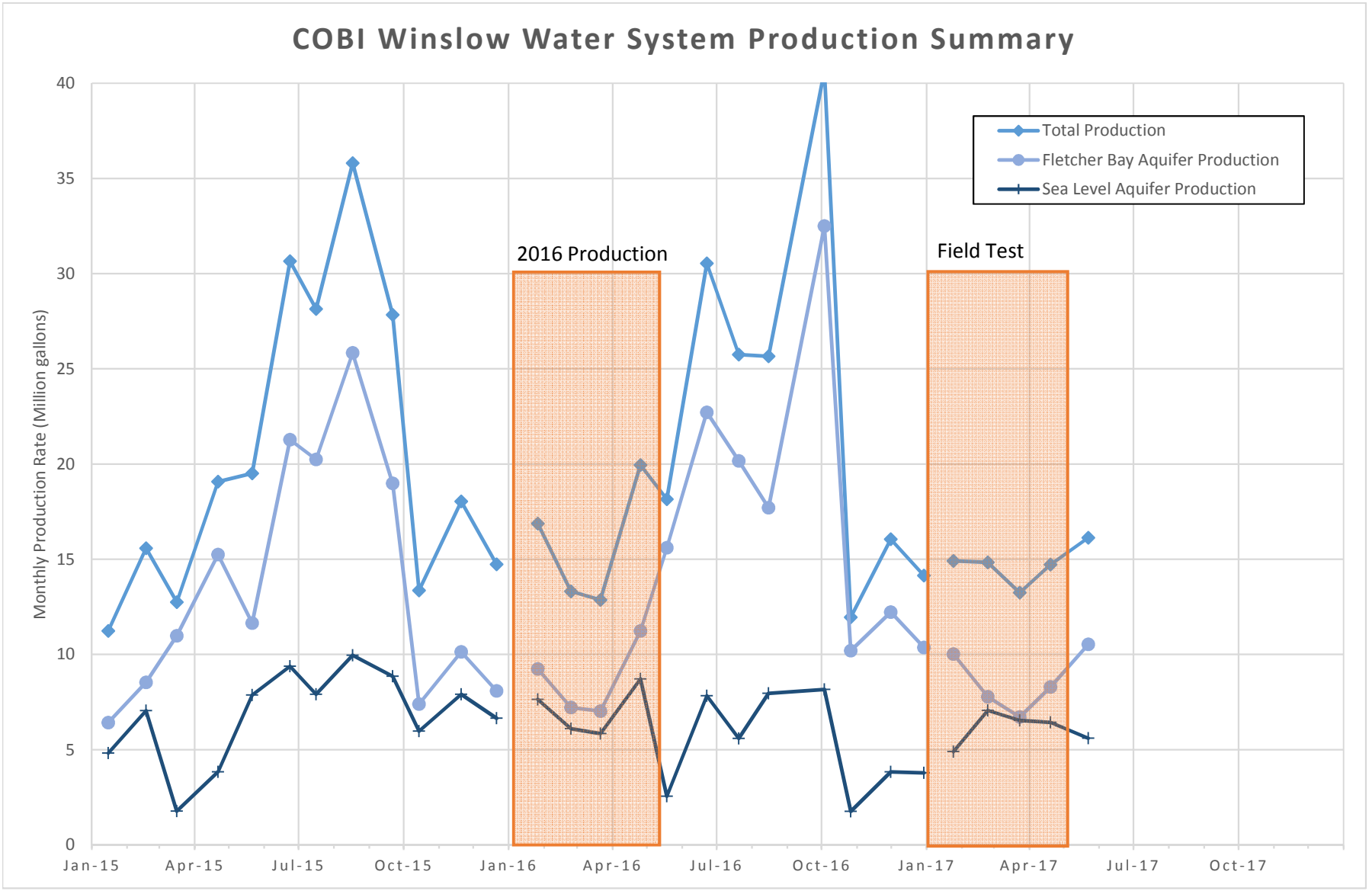


Figure 2

COBI Winslow Water System Production Summary

Groundwater Production Field Test

Bainbridge Island, WA

Aspect Consulting

8/9/2017

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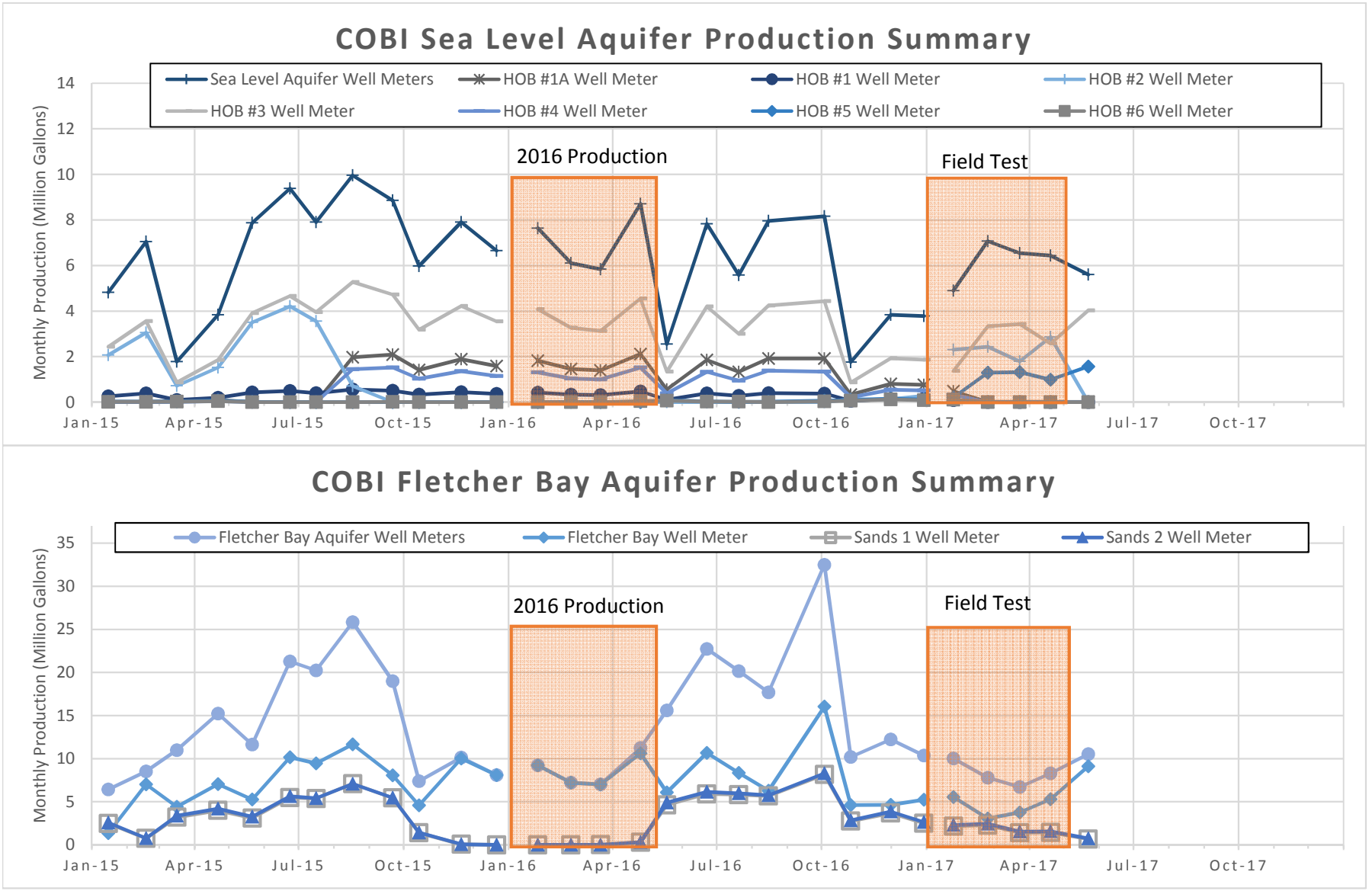

Figure 3

COBI Production Distribution by Aquifer

Groundwater Production Field Test

Bainbridge Island, WA

Aspect Consulting

8/9/2017

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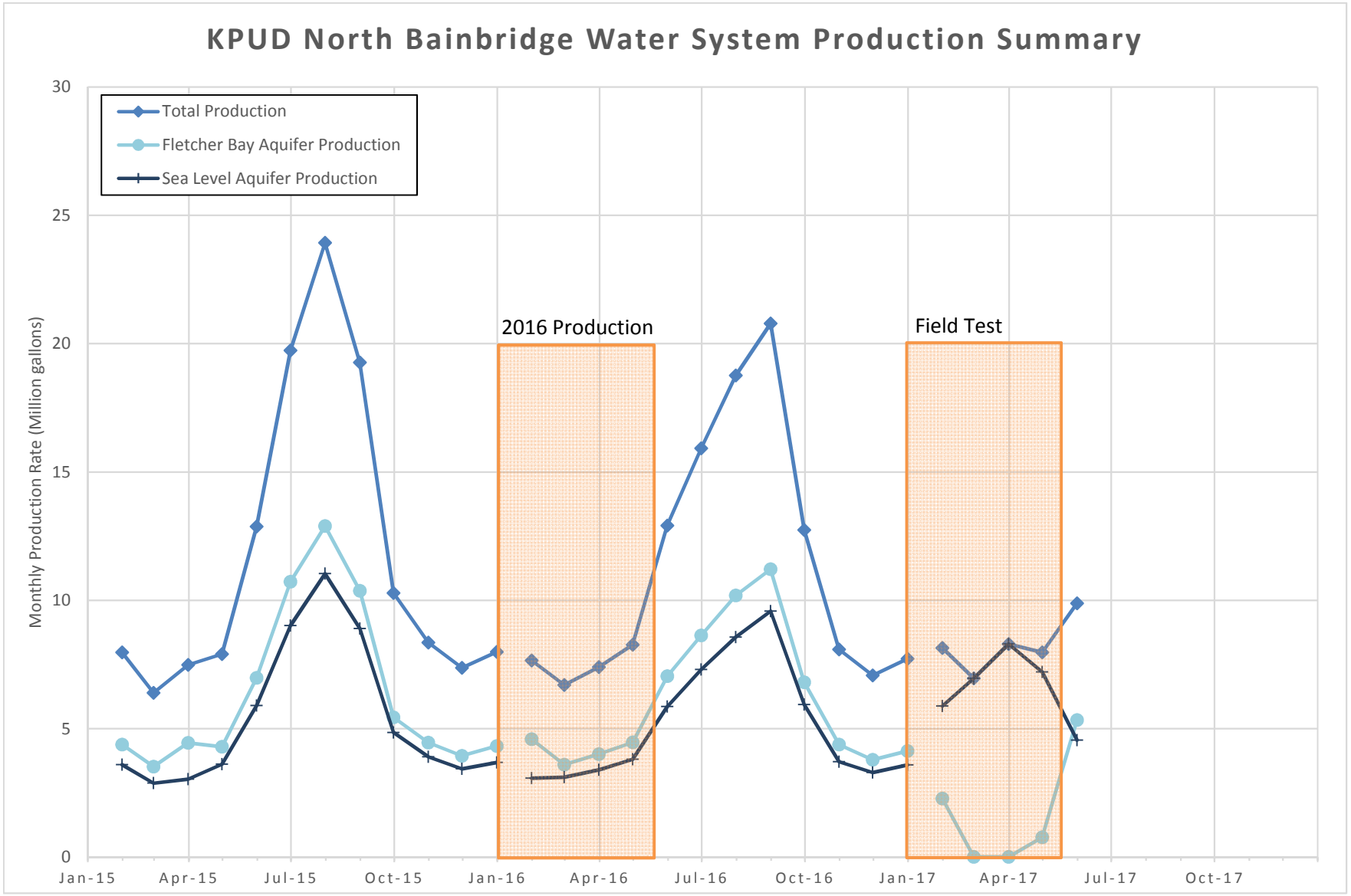

Figure 4

KPUD North Bainbridge Water System Production Summary

Groundwater Production Field Test

Bainbridge Island, WA

Aspect Consulting

8/9/2017

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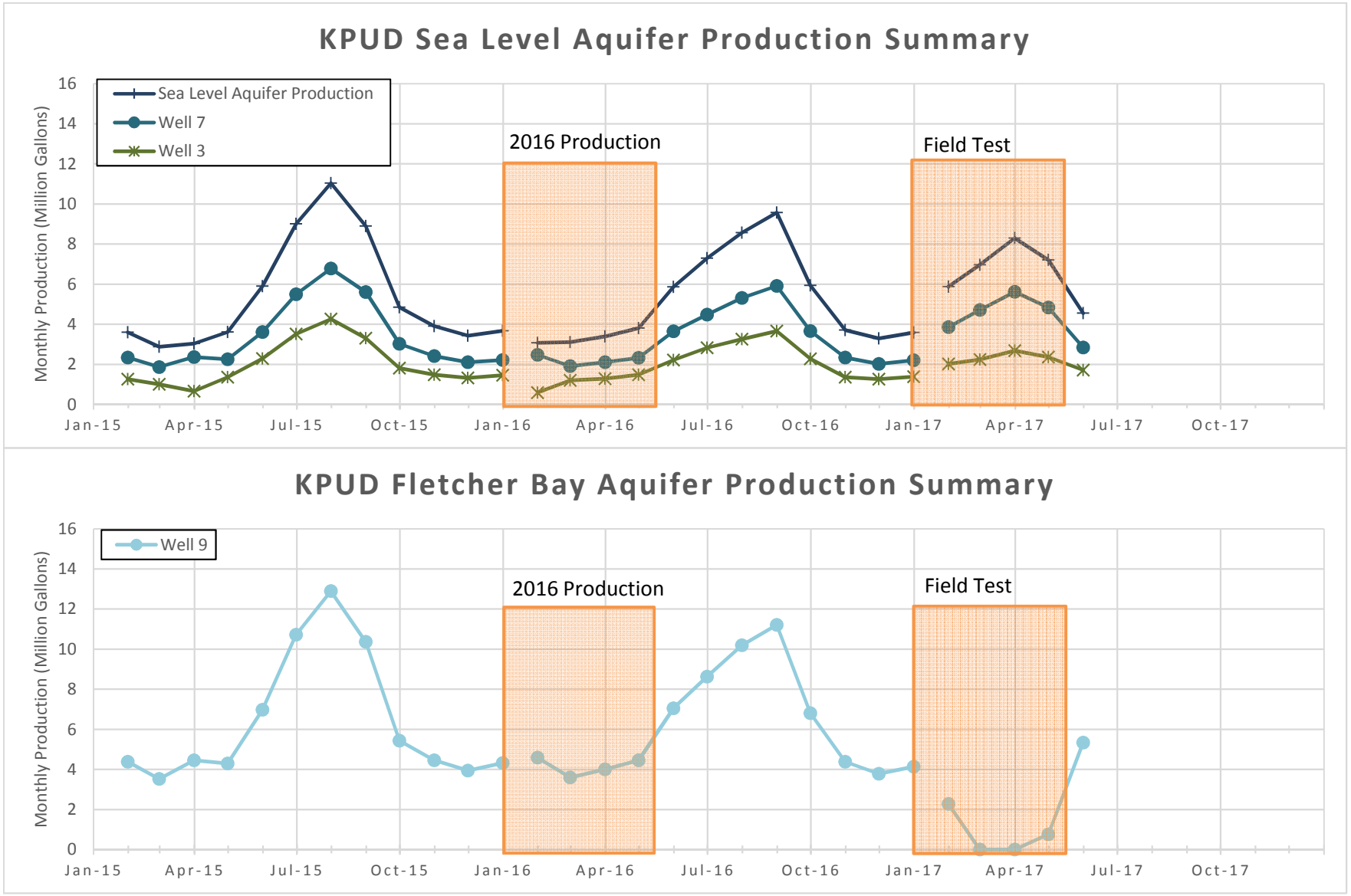

Figure 5

KPUD Production Distribution by Aquifer

Groundwater Production Field Test

Bainbridge Island, WA

Aspect Consulting

8/9/2017

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ATTACHMENT 1

Observation Monitoring Network

Attachment 1 - Observation Monitoring Network (Jan 17 - Apr 24, 2017)

140369 Groundwater Production Field Test

Bainbridge Island, WA

Full Well IDs	DOE Tag	Latitude	Longitude	Local Number	Surface Elevation (NAVD 88)	Aquifer	Monitoring					
							Water Level	Frequency	Chloride	Frequency	Specific Conductance	Frequency
Johnson Farm		47.63204475	-122.5542631	25N/02E-28F	154	PA	COBI-Eng	Monthly	---	---	---	---
Onorato Water System	AAC862	47.65197124	-122.5721743	25N/02E-17Q01	86	PA	COBI-Eng	Monthly	COBI-Eng	Yearly (Sept)	COBI-Eng	Yearly (Sept)
Private		47.67441472	-122.5425047	25N/02E-10E	94	PA	COBI-Eng	Monthly	COBI-Eng	Yearly (Sept)	COBI-Eng	Yearly (Sept)
Private		47.63693748	-122.5750999	25N/02E-20P2	213	PA	COBI-Eng	Monthly	---	---	---	---
Private		47.62302739	-122.560826	25N/02E-28N02	315	PA	COBI-Eng	Monthly	---	---	---	---
Private		47.64926261	-122.5483955	25N/02E-21B	314	SPA	COBI-Eng	Monthly	---	---	---	---
Private		47.61873637	-122.5493531	25N/02E-33B02	167	SPA	COBI-Eng	Monthly	---	---	---	---
Private		47.67871727	-122.5556762	25N/02E-09C	65	SLA	COBI-Eng	Monthly	---	---	---	---
Private		47.67758914	-122.5612811	25N/02E-09D01	29	SLA	COBI-Eng	Monthly	---	---	---	---
Private		47.64707906	-122.5797882	25N/02E-20D	114	SLA	COBI-Eng	Monthly	COBI-Eng	Yearly (Sept)	COBI-Eng	Yearly (Sept)
Private		47.63647988	-122.5584006	25N/02E-21P03	70	SLA	COBI-Eng	Monthly	COBI-Eng	Yearly (Sept)	COBI-Eng	Yearly (Sept)
Private		47.65021641	-122.5360803	25N/02E-22C01	159	SLA	COBI-Eng	Monthly	COBI-Eng	Yearly (Sept)	COBI-Eng	Yearly (Sept)
Private		47.63255656	-122.5749229	25N/02E-29C	281	SLA	COBI-Eng	Monthly	---	---	---	---
Private		47.64230599	-122.5749341	25N/02E-20L07	61	SLA	COBI-Eng	Monthly	COBI-Eng	Yearly (Sept)	COBI-Eng	Yearly (Sept)
Bainbridge Island Landfill		47.62062394	-122.5545541	25N/02E-33C	269	SLA	COBI-Eng	Monthly	---	---	---	---
Head of the Bay Well #1		47.62912223	-122.5420349	25N/02E-27E21	34	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Head of the Bay Well #1A	AAC860	47.62931472	-122.5419462	25N/02E-27E15	32	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Head of the Bay Well #2	AAC870	47.62910175	-122.5418904	25N/02E-27E16	30	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Head of the Bay Well #3	AAC871	47.63032187	-122.5419878	25N/02E-27E17	47	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Head of the Bay Well #4	AAC872	47.62898348	-122.5419656	25N/02E-27E18	29	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Head of the Bay Well #5	AAC873	47.62953631	-122.5419302	25N/02E-27E19	31	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Head of the Bay Well #6	AAC874	47.63007014	-122.5419437	25N/02E-27E20	42	SLA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Fletcher Bay PW	AAC733	47.64068333	-122.5744056	25N/02E-20K04	85	FBA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Sands Road 1	AAC875	47.64043056	-122.5418639	25N/02E-21J06	165	FBA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
Sands Road 2	AAC876	47.64	-122.5427778	25N/02E-21J07	170	FBA	COBI-O&M	Daily	COBI-O&M	Weekly	COBI-O&M	Daily
North Bainbridge Well 03	AEK853	47.6727778	-122.5463889	25N/02E-09H01	87	SLA	KPUD	Hourly[1]	KPUD	Yearly (Apr)[2]	KPUD	Yearly (Apr)[2]
North Bainbridge Well 06	AAA113	47.67154446	-122.544175	25N/02E-09K02	91	SLA	KPUD	Hourly[1]	KPUD	Yearly (Apr)[2]	KPUD	Yearly (Apr)[2]
North Bainbridge Well 07	AEK852	47.6725	-122.5480556	25N/02E-09G07	125	SLA	KPUD	Hourly	KPUD	Yearly (Apr)[2]	KPUD	Yearly (Apr)[2]
Fletcher Bay Observation Well	AAA111	47.64055555	-122.5741667	25N/02E-20K03	80	FBA	KPUD	Hourly	KPUD	---	KPUD	---
Meigs Farm	AAA112	47.65654925	-122.5241579	25N/02E-15J02	49	FBA	KPUD	Hourly	KPUD	---	KPUD	---
North Bainbridge Well 09	AAB455	47.67305558	-122.5483334	25N/02E-09G04	125	FBA	KPUD	Hourly	KPUD	Yearly (Apr)[2]	KPUD	Yearly (Apr)[2]

[1]New water level transducers were installed in North Bainbridge 3 and North Bainbridge 6 in Jan 2017 and Dec 2016 respectively. They were previously monitored monthly.

[2]May add second round of sampling in Sept or Oct 2017 during future monitoring.