MEMORANDUM

Project No.: 140369

December 2, 2016

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

From:

Peter Bannister, PE
Associate Groundwater Resources Engineer
pbannister@aspectconsulting.com

Timothy Flynn, LHG, CGWP
Principal Hydrogeologist
tflynn@aspectconsulting.com

Re: **Bainbridge Island Groundwater Model:**
Modeling Support for Operational Scenario Analysis

This memorandum describes the findings from the operational scenario analysis using the updated Bainbridge Island groundwater model (hereafter: Bainbridge Island model). The operational scenario was designed 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. This groundwater modeling effort was conducted to assess the feasibility and value of temporarily transferring water supply production between aquifers, in advance of actually conducting the test.

The Bainbridge Island model was originally developed and published in 2011 by the U.S. Geological Survey (USGS) in cooperation with the City of Bainbridge Island (COBI). Under Contract #21500009, Aspect Consulting, LLC (Aspect) has compiled and analyzed groundwater data (Aspect, 2015a), updated the Bainbridge Island model (Aspect 2015b), provided modeling support for the COBI planning effort (Aspect 2015b, Aspect 2016), including this analysis. Under a cost-sharing agreement between the COBI and the Kitsap Public Utility District (KPUD), Aspect is also conducting this analysis for KPUD.

Summary of Findings

In summary, the Bainbridge Island model was used to assess short-term changes in groundwater conditions associated with an operational scenario of seasonally resting water system wells completed in the Fletcher Bay Aquifer. During the operational scenario, water system demand was met by transferring production to wells completed in the Sea Level Aquifer.

Model results showed recovery in the Fletcher Bay Aquifer near the resting wells, and drawdown in the Sea Level Aquifer near wells with greater production. After the end of the operational scenario time frame, localized residual drawdown in the Sea Level Aquifer was greater than residual recovery in the Fletcher Bay Aquifer. These water levels changes directly affect pumping costs.

The projected pumping costs calculated for the COBI Winslow Water System are greater than normal operations because of the higher costs to extract groundwater from the water system wells completed in the Sea Level Aquifer. Simply put, it appears to cost COBI less to withdraw water from the wells in Fletcher Bay Aquifer. In contrast, the operational scenario costs for the KPUD North Bainbridge Water System are less than normal operations because of the higher costs to withdraw water from the Fletcher Bay Aquifer. Simply put, it appears to cost KPUD less to withdraw water from the wells in the Sea Level Aquifer.

No changes in water quality associated with seawater intrusion were shown in the model results for the operational scenario. This is consistent with previous results of modeling analysis.

The water balance for the operational scenario showed aquifer storage (changes in groundwater levels) accounted for most of the production volume. The changes in the water balance were at or below resolution of the groundwater model, and additional water balance analysis was not explored further.

The Bainbridge Island model is a simplified representation of naturally complex subsurface conditions. As such, the findings based on groundwater modeling should be considered along with historically observed conditions and professional judgement to support the decision-making process. After interpreting all of the model findings, we recommend that COBI and KPUD actually implement the operational scenario to demonstrate the ability to transfer production between aquifers. This empirical information can then be used by water system managers to support groundwater production strategies and plan for emergency response. Observations from the actual test would also support future development of the groundwater model tool.

Operational Scenario Definition

A kickoff meeting was held August 25, 2016 to define the operational scenario of temporarily transferring water supply production between aquifers. Charles Krumheuer and Cami Apfelbeck represented the COBI. Martin Sebren and Mark Morgan represented KPUD. Peter Bannister represented Aspect at the meeting. There was a general understanding that transferring production between aquifers could be beneficial.

The selected scenario was to safely reduce production from wells completed in the Fletcher Bay Aquifer and meet demand by safely increasing production from wells completed in the Sea Level Aquifer. The selected operational scenario timeframe was from January through May 2017.

The model was used to simulate groundwater conditions through December 2017 to show residual effects of the operational scenario. The water system managers provided historical water system operations information and specified operational scenario pumping rates for selected wells in their water supply systems, as described below.

Projected Pumping Rates

The Bainbridge Island model was updated with observed pumping rates from 2015 through July or August 2016, and with projected pumping rates through the end of 2017. Except during the operational scenario time frame (January through May 2017), future monthly production was assumed to be the most recent historical monthly value. For example, September 2016 production was assumed to be equal to September 2015 production.

COBI Winslow Water System

Historical production values were provided by COBI through August 2016. For the operational scenario time frame, COBI's Winslow Water System is to meet demand by 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. For context, Figure 1 shows the COBI production from 2015 and projected through 2017. Figure 2 shows the distribution of COBI production between wells completed in the Sea Level Aquifer (upper graph) and the Fletcher Bay Aquifer (lower graph). For the operational scenario time frame, Sea Level Aquifer production was assigned to 3 wells in the Head of the Bay wellfield, per COBI's instructions. However, the wells in the Head of the Bay wellfield are in close proximity and withdraw water from the same aquifer. Thus, the model is not sensitive to which specific wells in the wellfield are active. Based on the 10-year monthly average pumping rate, Fletcher Bay Aquifer production during the operational scenario time frame was distributed between the Fletcher Bay well, the Sands Well 1, and the Sands Well 2. Table 1 shows the distribution of pumping, on average, during the operational scenario for the COBI Winslow water system.

Table 1. Average Pumping Distribution for COBI Winslow Water System Operational Scenario

Well Name	Ecology Well ID	Assigned Proportion of Pumping during Operational Scenario
Head of Bay Well 1A	AAC860	0%
Head of Bay Well 1	AAC869	0%
Head of Bay Well 2	AAC870	16.7%
Head of Bay Well 3	AAC871	16.7%
Head of Bay Well 4	AAC872	0%
Head of Bay Well 5	AAC873	16.7%
Head of Bay Well 6	AAC874	0%
Fletcher Bay Well	AAC733	21.5%
Sands Well 1	AAC875	14.0%
Sands Well 2	AAC876	14.5%

KPUD North Bainbridge Water System. Historical production values were provided by KPUD through July 2016. For the operational scenario time frame, KPUD's North Bainbridge wellfield is to meet demand with 100 percent production from wells completed in the Sea Level Aquifer. For context, Figure 3 shows the KPUD production from 2015 and projected through 2017. Figure 4

shows the distribution of KPUD production between wells completed in the Sea Level Aquifer (upper graph) and the Fletcher Bay Aquifer (lower graph). During the operational scenario time frame, the Sea Level Aquifer production was distributed between Well 3 and Well 7, as specified by KPUD. Table 2 shows the distribution of pumping, on average, during the operational scenario for the KPUD North Bainbridge water system.

Table 2. Average Pumping Distribution for KPUD North Bainbridge Water system Operational Scenario

Well Name	Ecology Well ID	Assigned Proportion of Pumping during Operational Scenario
Well 3	AEK853	38%
Well 7	AEK852	62%
Well 9	AAB455	0%

Projected Recharge Rates

The monthly average recharge rates assigned in the Bainbridge Island model were updated based on observations through August 2016, using methods consistent with those used previously (Aspect, 2015b). Future monthly average recharge rates, through December 2017, were assumed to be equal to the most recent historical monthly values. For example, September 2016 recharge was assumed to be equal to September 2015 recharge.

Model Results

The Bainbridge Island model simulated projected conditions with and without the operational scenario. This allowed results to be compared for changes in water levels (recovery or drawdown) and water quality associated with potential seawater intrusion.

Projected Changes in Groundwater Levels

The model results showed water level drawdown at wells with projected greater-than-normal production, and water level recovery at wells with projected less-than-normal production. The calculated groundwater levels are relative to assumed pumping distributions and recharge conditions described above, and do not account for potential head losses associated with the well screen, which can require more drawdown in the aquifer to yield the same production in the well.

Some model bias was observed in the results. The model bias is generally attributed to the simplifications in aquifer parameters and model architecture (cell size and layer thicknesses).

COBI Winslow Water System

During the operational scenario time frame, model results indicate approximately 10 feet of recovery at the Fletcher Bay well, almost no recovery at the Sands Well 1 and Sands Well 2, and up to 10 feet of drawdown for the Head of the Bay wellfield. Figure 5 (below) shows the changes in groundwater levels for the COBI Winslow water system during and after the operational scenario time frame. After the end of the operational scenario time frame, the Fletcher Bay Aquifer wells show less than 1 foot of residual recovery, whereas the Sea Level Aquifer wells show residual drawdown tapering from approximately 5 feet in June 2017 to less than 2 feet by December 2017. Model bias was observed at Head of the Bay wells in May 2017, and results were interpolated

between April and June 2017 (dashed line on Figure 5). Model bias may also explain the slight bump in residual drawdown at the Head of the Bay wellfield calculated for July 2017.

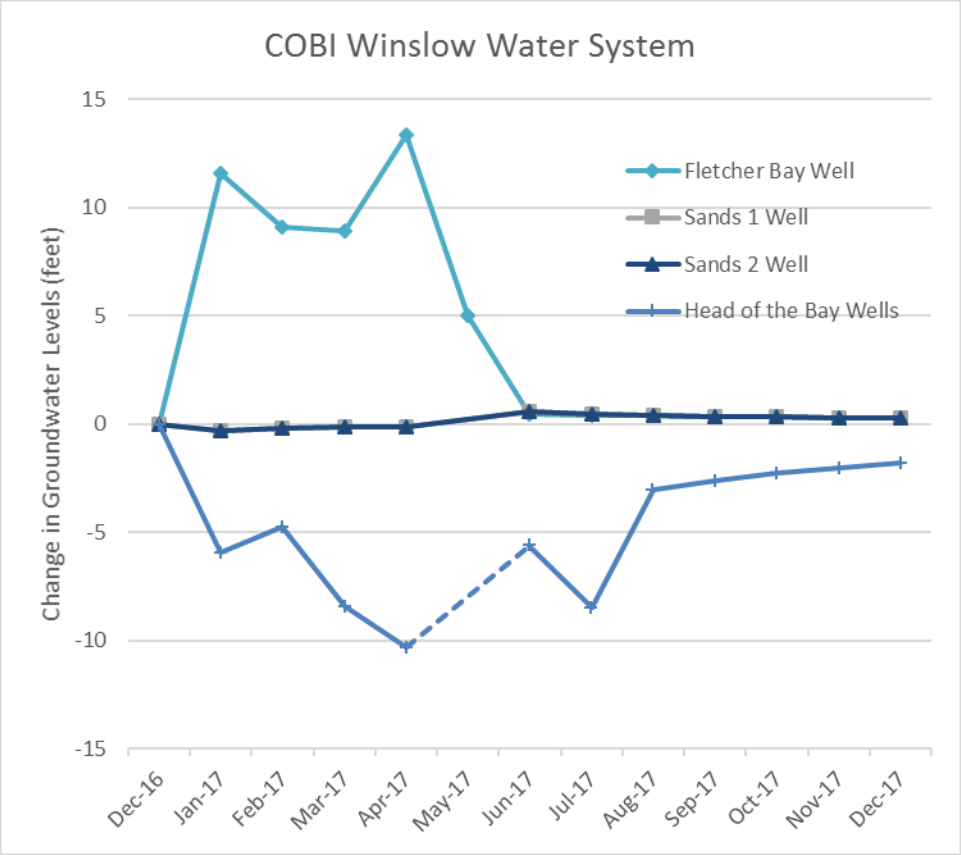

Figure 5. Projected Groundwater Level Changes—COBI Winslow Water System

KPUD North Bainbridge Water System

During the operational scenario time frame, model results indicate approximately 12 feet of recovery at Well 9, and up to 20 and 25 feet of drawdown at Wells 3 and 7, respectively. Figure 6 (below) shows the changes in groundwater levels for the KPUD North Bainbridge water system during and after the operational scenario time frame. After the end of the operational scenario time frame, there is less than 1 foot of residual recovery at Well 9, whereas Wells 3 and 7 show residual drawdown tapering from approximately 5 feet in June 2017 to less than 3 feet by December 2017. Model bias may explain the slight bump in residual drawdown at Well 7 calculated for September and October 2017.

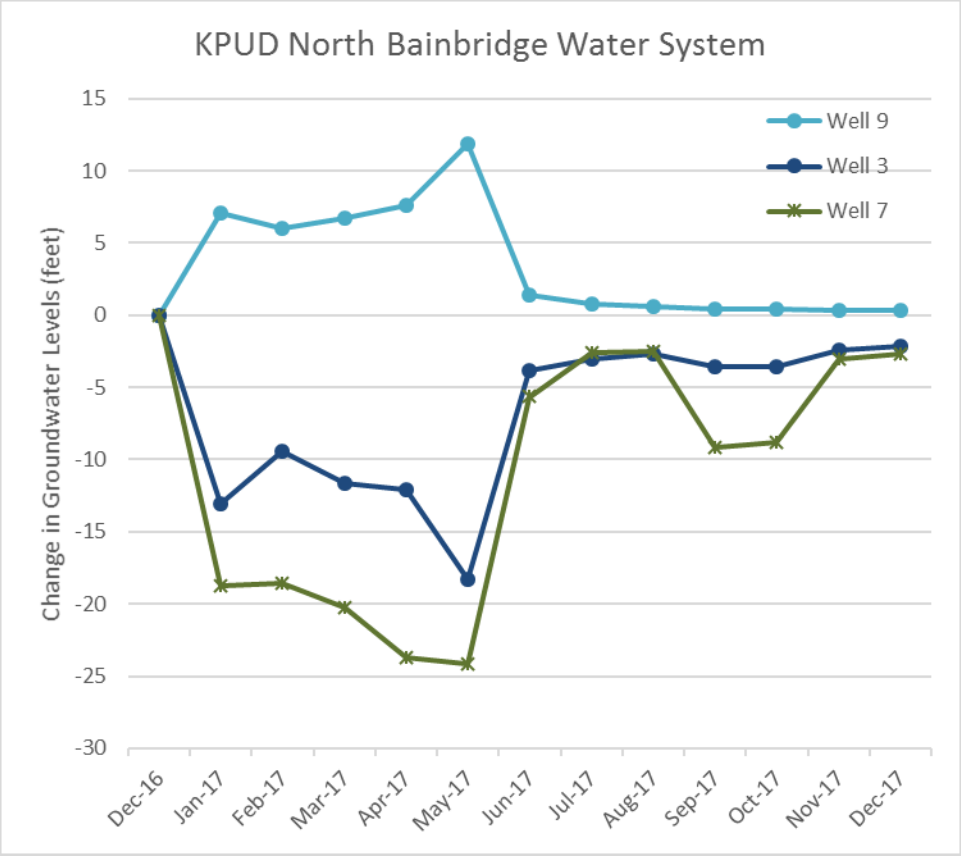

Figure 6. Projected Groundwater Level Changes—KPUD North Bainbridge Water System

Model-Calculated Extent of Groundwater Level Changes

Model results indicate changes in groundwater levels extend several thousand feet from the wells included in the operational scenario. Figures 7 and 8 show maps of maximum water level changes across Bainbridge Island[1] in the Sea Level Aquifer and the Fletcher Bay Aquifer, respectively. Blue contours around the wells or wellfields show the extent of -1 foot water level change. Within the contours, water level change is calculated to be greater than 1 foot.

Cost Analysis of Modeled Operational Scenario

To assess the potential value of the proposed operational scenario, the projected pumping costs were calculated as the product of monthly production rates and pumping lift. Pumping lift is defined as the distance that groundwater must be raised to reach ground surface at the well. Costs were normalized by dividing the projected pumping costs for the operational scenario by pumping costs without the operational scenario, and do not factor in distribution costs. For the normalized calculation, a number larger than one indicates that the operational scenario is costlier than without the operational scenario, and a number less than one indicates that the operational scenario is less costly than without the operational scenario. The cumulative projected pumping costs for each water system were calculated starting in January 2017, and are shown in Figure 9.

[1] Roads are shown on the maps to provide geographical reference points.

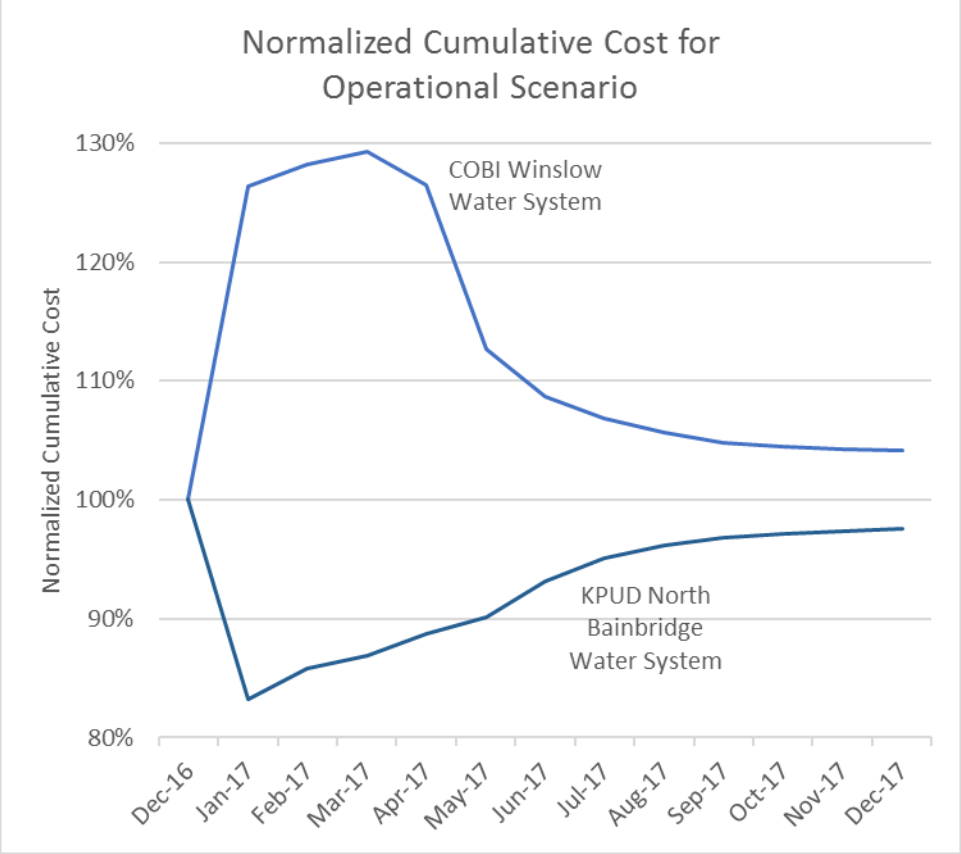

Figure 9. Projected Pumping Cost Analysis

COBI Winslow Water System Costs

During the operational scenario time frame, the COBI pumping costs are projected to be between 20 and 30 percent greater than normal. This reflects the higher cost to produce groundwater from the Head of the Bay wellfield compared to the water system wells completed in the Fletcher Bay Aquifer. By the end of 2017, the projected cumulative costs are calculated to be approximately 4 percent greater than normal.

KPUD North Bainbridge Water System Cost/Benefit

During the operational scenario time frame, the KPUD pumping costs are projected to be between 80 and 90 percent of normal. This reflects the higher cost to produce groundwater from Well 9 in the Fletcher Bay Aquifer compared to Wells 3 and 7 in the Sea Level Aquifer. By the end of 2017, the projected cumulative costs are calculated to be approximately 2 percent less than normal.

Model-Calculated Change in Water Quality

The model results show no change in water quality associated with seawater intrusion. The Bainbridge Island model simulates Puget Sound as a potential source of seawater, and does not simulate other sources of chloride or other water quality parameters. These results are consistent

with the long-term modeling analysis supporting the aquifer system carrying capacity assessment (Aspect, 2016).

Model-Calculated Water Balance Analysis

The water balance for the operational scenario showed that aquifer storage (changes in groundwater levels) accounted for most of the changes in production. The changes in the water balance were at or below resolution of the groundwater model, which was approximately 0.06 cubic feet per second, on average, during the operational scenario. Additional water balance analysis was not explored further.

References

Aspect, 2015a, Hydrogeological Assessment of Groundwater Quantity, Quality, and Production, Prepared for the City of Bainbridge Island, December 21, 2015.

Aspect, 2015b, Bainbridge Island Groundwater Model: Review Findings and Recommendations; Critical Aquifer Recharge Area Assessment, Prepared for the City of Bainbridge Island, December 21, 2015.

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

U.S. Geological Survey (USGS), 2011, Conceptual Model and Numerical Simulation of the Groundwater-Flow System of Bainbridge Island, Washington, 2011.

Limitations

Work for this project was performed for the City of Bainbridge Island and 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.

All reports prepared by Aspect Consulting for the Client apply only to the services described in the Agreement(s) with the Client. Any use or reuse by any party other than the Client is at the sole risk of that party, and without liability to Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

Attachments

Figure 1—COBI Winslow Water System Production Summary
Figure 2—COBI Production Summary by Aquifer
Figure 3—KPUD North Bainbridge Water System Production Summary
Figure 4—KPUD Production Summary by Aquifer
Figure 7—Map of Maximum Drawdown Extent in Sea Level Aquifer
Figure 8—Map of Maximum Recovery Extent in Fletcher Bay Aquifer

FIGURES

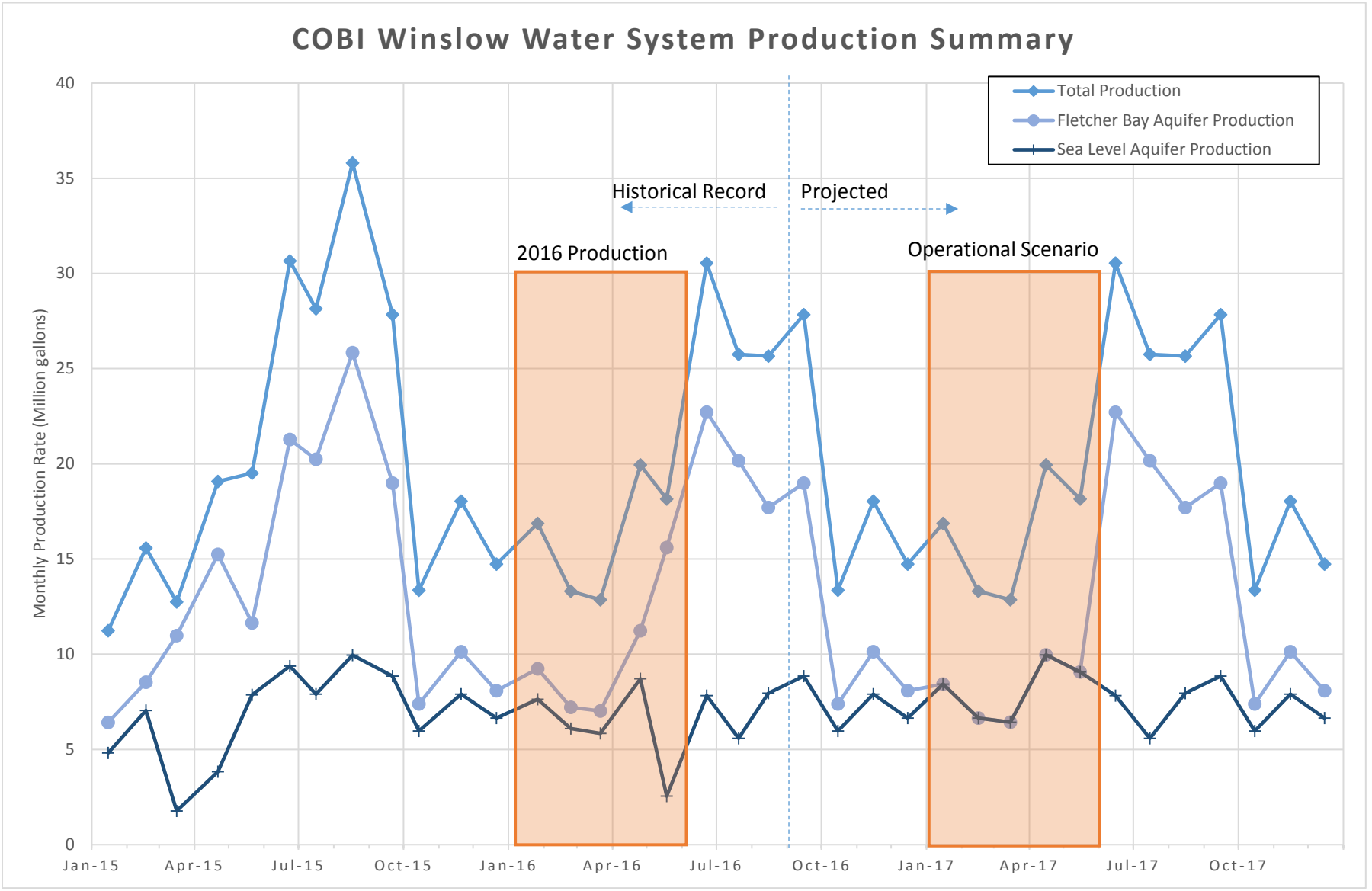

Figure 1

COBI Winslow Water System Production

Modeling Support for Operational Scenario Analysis

Bainbridge Island, WA

Aspect Consulting

12/1/2016

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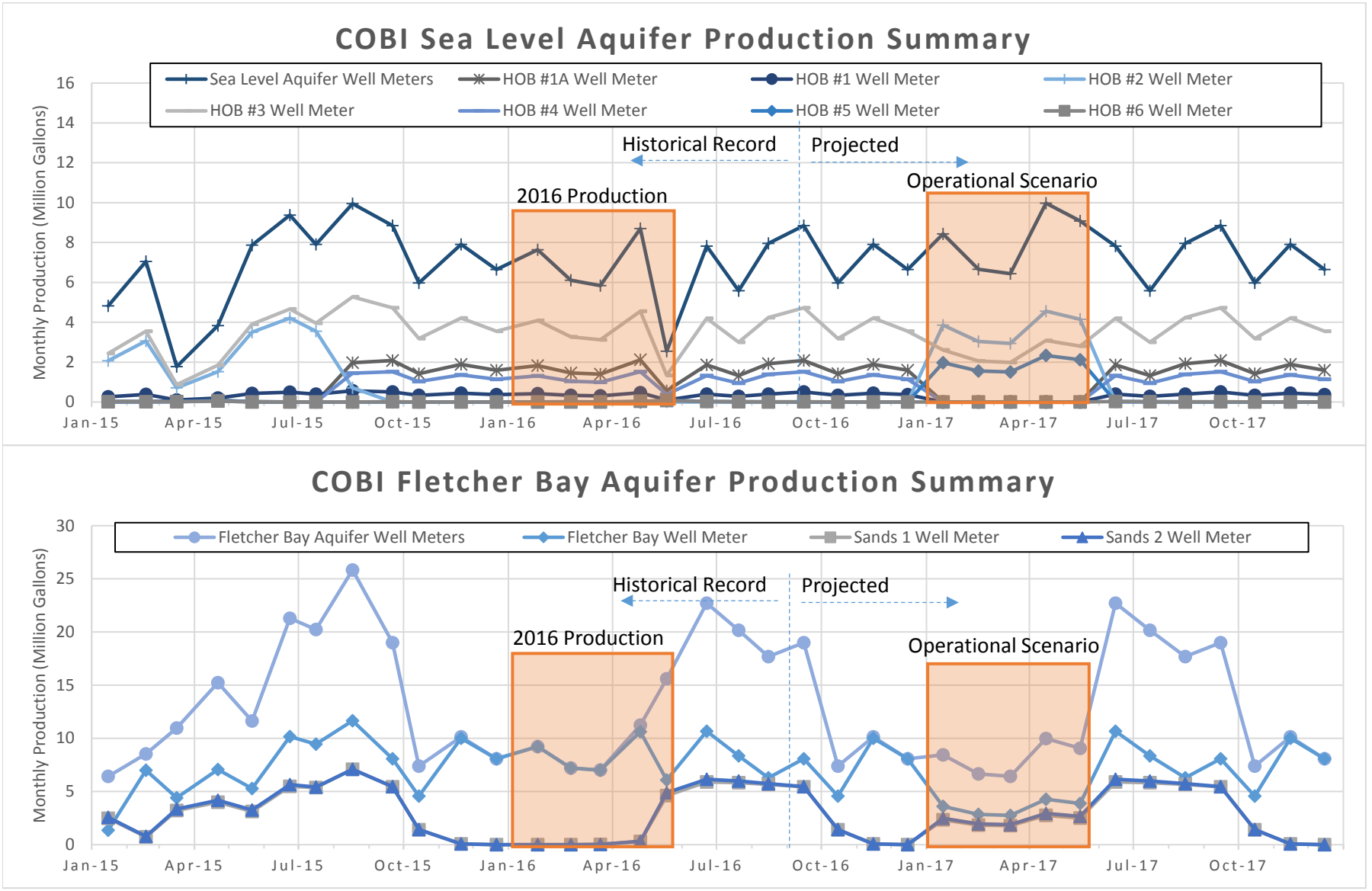

Figure 2

COBI Production Summary by Aquifer

Modeling Support for Operational Scenario Analysis

Bainbridge Island, WA

Aspect Consulting

12/1/2016

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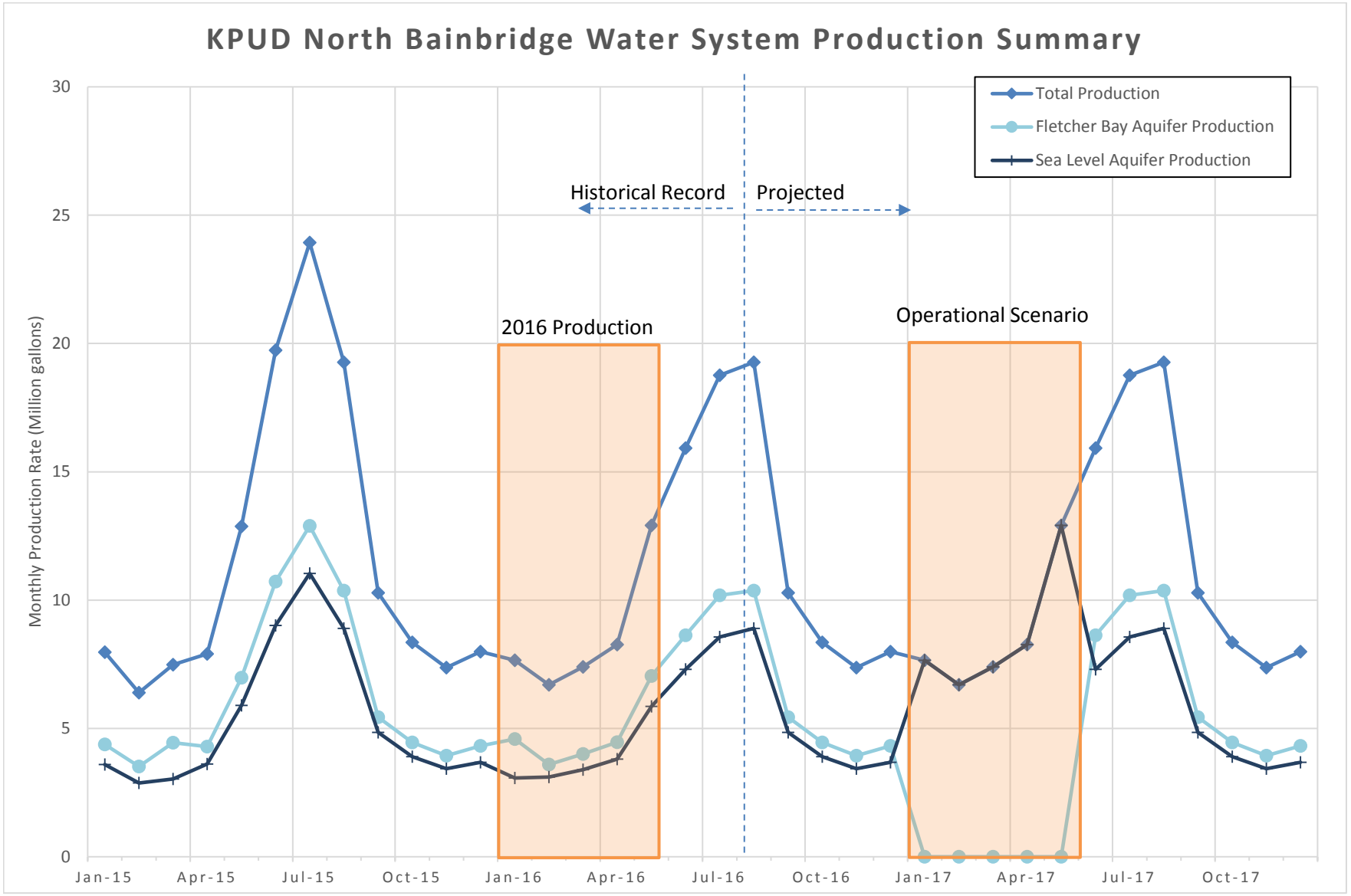

Figure 3

KPUD North Bainbridge Water System Production Summary

Modeling Support for Operational Scenario Analysis

Bainbridge Island, WA

Aspect Consulting

12/1/2016

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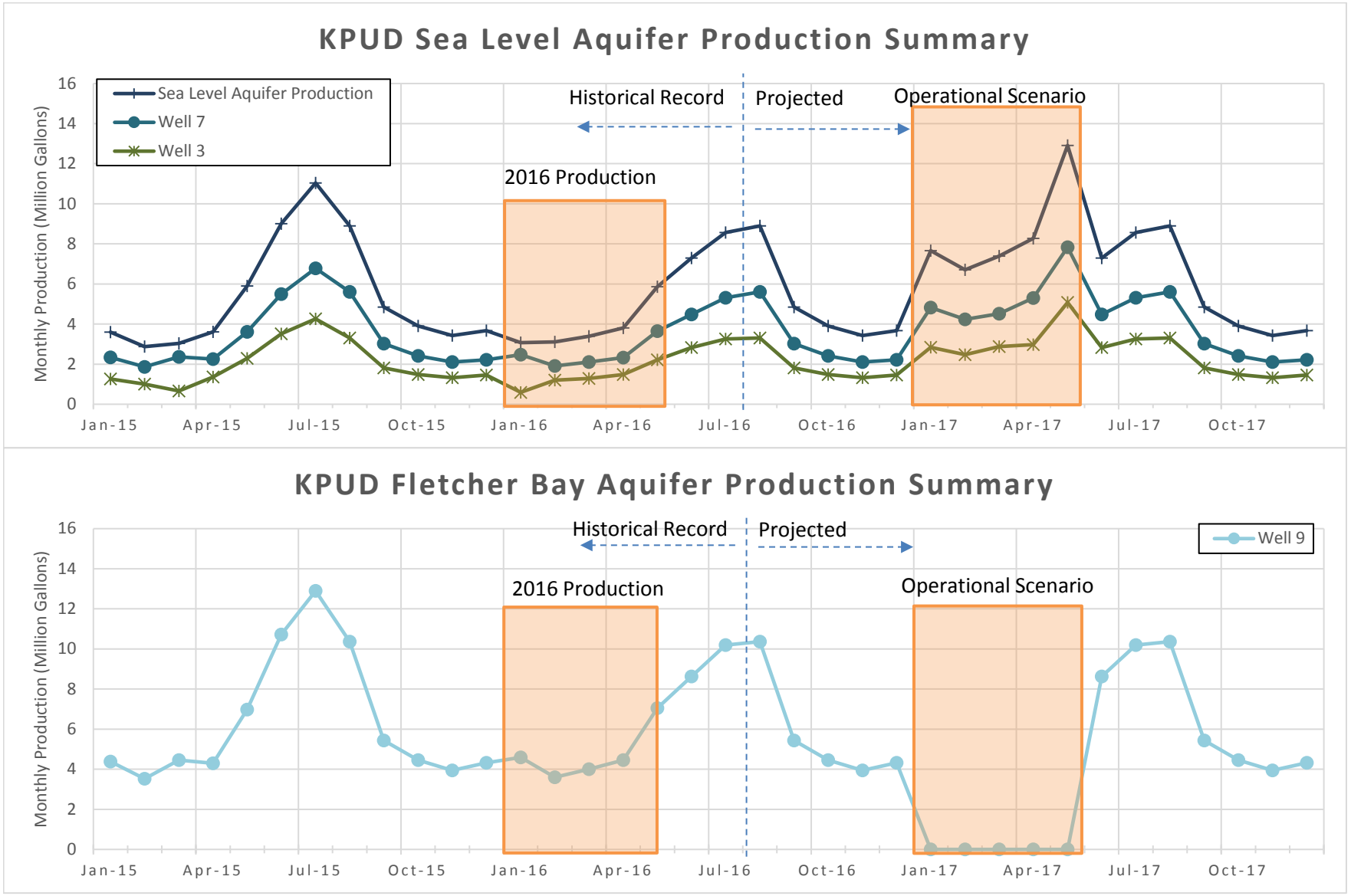

Figure 4

KPUD Operational Summary by Aquifer

Modeling Support for Operational Scenario Analysis

Bainbridge Island, WA

Aspect Consulting

12/1/2016

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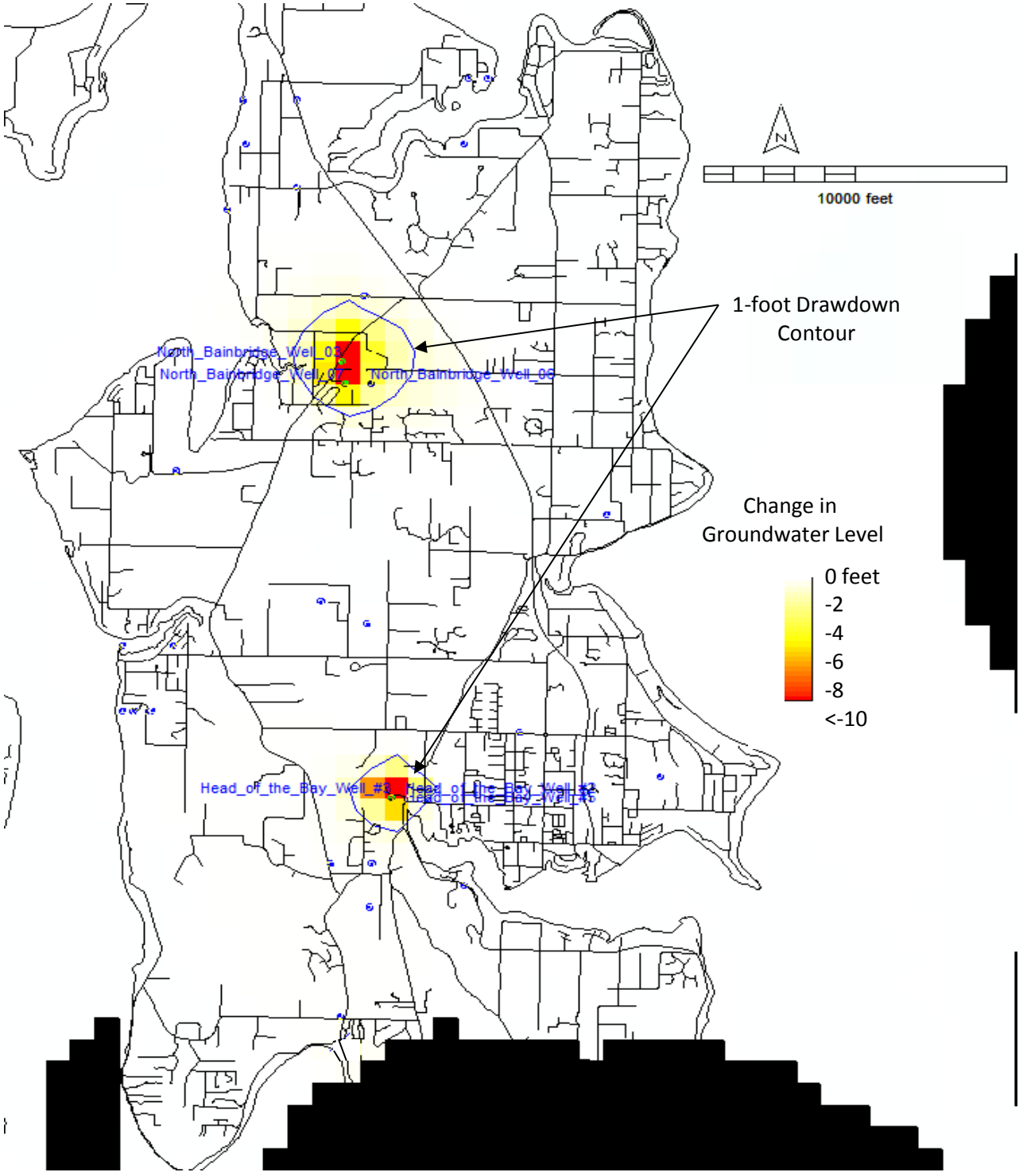

Figure 7
Maximum Drawdown Extent in Sea Level Aquifer
Modeling Support

Aspect Consulting
12/1/2016
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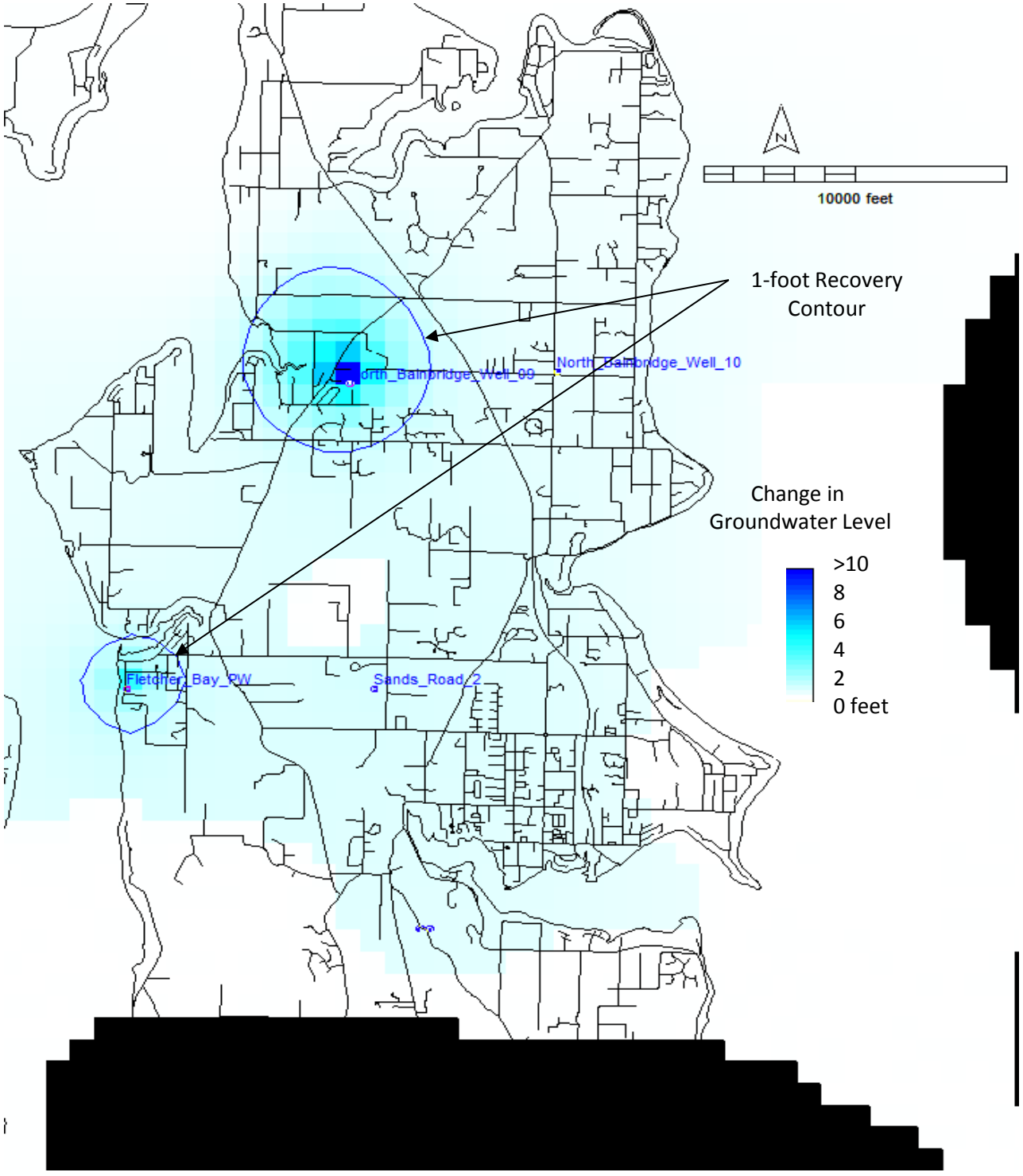

Figure 8

Map of Maximum Recovery Extent in Fletcher Bay Aquifer

Modeling Support

Aspect Consulting

12/1/2016

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