MEMORANDUM

Project No.: 140369

March 2, 2016
Revised March 25, 2016

To: Cami Apfelbeck

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:**
Aquifer System Carrying Capacity Assessment (Task 3 Scenario)
Revised March 25, 2016

This memorandum describes the findings from the aquifer system carrying capacity assessment using the updated Bainbridge Island groundwater model (hereafter: Bainbridge Island model). The findings and recommendations discussed below will be used to address the sustainability of the Bainbridge Island aquifer system to support predicted population growth and water conservation trends. As with all groundwater models, the Bainbridge Island model is a simplified representation of complex subsurface conditions. As such, the findings based on groundwater modeling should be considered along with historically observed conditions to support the decision-making process. Thus, we recommend that the Groundwater Monitoring Program (COBI, 2009) be continued, and that the Bainbridge Island model be reviewed periodically, updated as needed, and predictive findings be reassessed.

In summary, the Bainbridge Island groundwater model was used to assess long-term changes in groundwater conditions associated with increased groundwater withdrawal rates. Adjustments to the model and input assumptions, described below, included consideration of future potential climate-change effects (decreased groundwater recharge rates and increased sea level) and a 50-percent increase in groundwater withdrawal across Bainbridge Island. The 100-year simulated model results indicated no seawater intrusion and the rates of groundwater level decreases were less than the Early Warning Level (EWL)[1].

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[1] According to COBI's 2009 *Groundwater Monitoring Program Update* (COBI, 2009), an EWL is a monitoring criteria that, if exceeded, would result in appropriate Management Responses, of which there

Project Background

The Bainbridge Island model was developed and published in 2011 by the United States Geological Survey (USGS) in cooperation with the City of Bainbridge Island (COBI). Aspect Consulting, LLC (Aspect) is supporting the COBI planning effort under Contract #21500009 to perform three tasks:

- Task 1: Compile and review recent groundwater data on Bainbridge Island;
- Task 2: Review the Bainbridge Island model and recommend updates and changes; and
- Task 3: Incorporate changes to the Bainbridge Island model as directed by COBI, and evaluate three scenarios supporting land-use planning selected by the COBI, including the following:
    1. Critical Aquifer Recharge Area (CARA) assessment;
    2. Aquifer System Carrying Capacity assessment; and
    3. Sea Level/Fletcher Bay Production Test.

Aspect has provided two memoranda under this contract, including the following:

- *Task 1—Hydrogeological Assessment of Groundwater Quantity, Quality, and Production* (Aspect, 2015a); and
- *Bainbridge Island Groundwater Model: Review Findings and Recommendations (Task 2) and Critical Aquifer Recharge Area Assessment (Task 3 Scenario)* (Aspect, 2015b).

The approach for assessing the Bainbridge Island aquifer system carrying capacity is described below, followed by summaries of model results. Because this assessment represents the first long-term prediction of groundwater conditions for the Bainbridge Island aquifer system, this memorandum also includes a set of recommendations for future carrying capacity assessments.

Defining Carrying Capacity

For groundwater modeling purposes, the concept of "carrying capacity" is defined as the safe yield for the aquifer system. The term "safe yield" has been used in previous reports (Aspect, 2006; Aspect, 2008) to support establishing COBI's EWLs. Essentially, the principle of safe yield can be considered the rate of groundwater withdrawal that is sustainable from multiple perspectives, such as water supply infrastructure, economics, ecological system health, and legal consideration. Indictors of safe yield can be measured by changes in groundwater availability and quality. For this memorandum, the EWLs (discussed in detail in the next section) adopted by the COBI—including consideration of potential seawater intrusion and decline in aquifer water levels—were used as safe-yield indicators. To address sustainability of the Bainbridge Island aquifer system to support predicted population growth and water conservation, the Bainbridge Island groundwater model was used to predict long-term (i.e., 100 years) groundwater flow conditions.

Approach for Assessing the Aquifer System Carrying Capacity

The approach for assessing the aquifer system carrying capacity involved simulating three concurrent stresses on the aquifer system:

are two types: (1) additional investigations in order to determine if a potential problem is developing, and (2) protective or remedial actions where appropriate.

- Long-term increased groundwater withdrawal rates,
- Reduced recharge rates, and
- Sea level rise.

The long-term projected increase in groundwater withdrawal rates was selected to reflect both the increase in water supply demand associated with population growth as well as water conservation (i.e., anticipated decrease in water use per capita). Recent information from the University of Washington (UW) Climate Impacts Group was used as the best available science for the effects of climate change on recharge and sea level rise in the Puget Sound area.

This approach was developed to quantify predicted changes in Bainbridge Island aquifer conditions for two safe-yield indicators with EWLs:

1. Seawater intrusion (with EWL of 100 milligrams per liter (mg/L) chloride); and
2. Rate of groundwater levels changes (with EWL of ½ foot per year for 10 years).

The on-Island groundwater balance for the entire aquifer system was also evaluated. The groundwater balance components do not have EWLs, and were evaluated to provide additional context on the predicted changes in groundwater conditions.

Predictive Timeframe

The USGS (USGS, 2011) simulated groundwater conditions from 2009 through 2035 to assess the aquifer system carrying capacity. The 27-year predictive timeframe was appropriate for the regulatory planning horizon (e.g., Washington State Department of Health Water System Plan). The USGS simulated groundwater withdrawal rates increasing annually. The USGS Report also made conclusions about long-term (more than the 27-year timeframe) groundwater conditions and carrying capacity. However, these conclusions are considered too speculative to predict issues such as seawater intrusion, because the 27-year timeframe is not long enough to accurately assess freshwater/seawater changes, which have a longer equilibration time, meaning the effects likely will not “show” until much later.

More conservative model assumptions were used in applying the updated model to assess safe yield (carrying capacity). The long-term stresses, including increased groundwater withdrawal, reduced aquifer recharge, and sea level rise were assumed to occur at the start of the simulation versus occurring gradually over time. In addition, the model simulation was run for a 100-year period, to evaluate the effects of seawater intrusion and climate change, which occur gradually over time.

The graphic below shows the updated Bainbridge Island model timeframes compared to the USGS model timeframes. Historical groundwater modeling was updated to extend through 2014. The groundwater conditions calculated for the end of 2014, including groundwater levels and saltwater concentrations, were used for initial conditions in the 100-year predictive model.

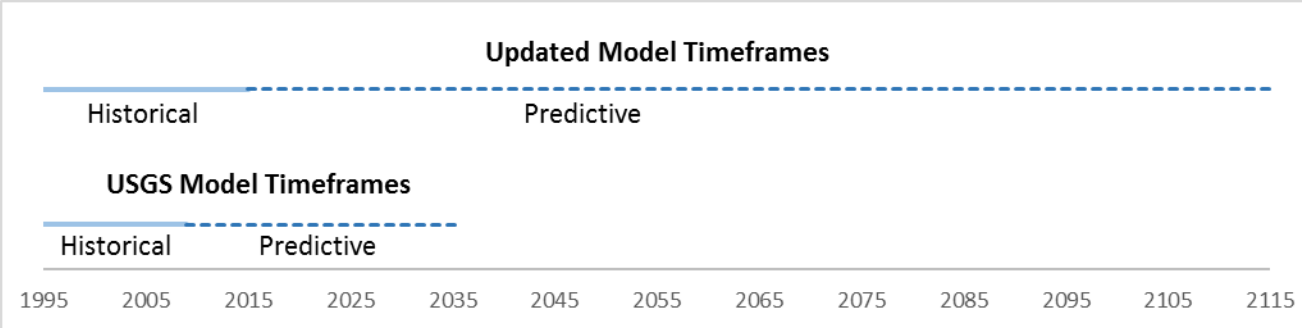


Figure 1. Comparison of Model Timeframes.

Increase in Groundwater Withdrawal Rates to Reflect Population Increase

The population on Bainbridge Island is projected to be approximately 28,660 persons by the year 2036, an increase of approximately 23 percent from the 2015 population estimate of 23,290 persons, or 1 percent per year (email from Jennifer Sutton, COBI). A similar rate of population growth is expected across Kitsap County.

Total groundwater withdrawal accounts for changes in population served and water conversation. Recent trends in water conservation, particularly public water supplies, indicate a decline in water use per capita resulting from a combination of infrastructure improvements to reduce losses, more efficient appliances, more efficient irrigation systems, and pricing. Total groundwater withdrawal for the COBI Winslow water system decreased approximately 1.6 percent annually between 2006 and 2013 (Carollo, 2015), although the system served a greater population. Other larger water systems within the Bainbridge Island groundwater model area reflect a range in water conservation trends. For example:

- The total withdrawals for the Kitsap PUD North Bainbridge water system increased approximately 0.2 percent annually between 2004 and 2014;
- The total withdrawals for the City of Poulsbo water system increased approximately 1.4 percent annually between 2010 and 2014, based on the City of Poulsbo 2015 Water Quality Report; and
- The total withdrawals for the Silverdale Water District decreased approximately 3 percent annually between 2006 and 2011, based on the 2013 Comprehensive Water System Plan (HDR, 2014).

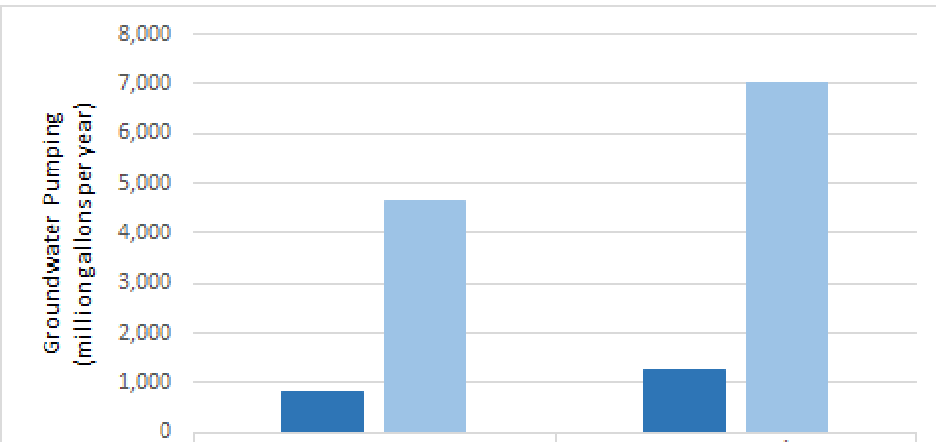
To reflect projected population growth and a reasonable trend in water conservation, this carrying capacity assessment assumed a 50-percent increase in groundwater withdrawals. This assumption reflects 100 years of compounded 0.4-percent average annual increase in groundwater demand, or a shorter period of time with greater average annual increase in groundwater demand. Simultaneous population growth and water conservation could take many forms yielding a total 50 percent increase in groundwater withdraws, including the following examples:

- 100 years of 1 percent annual population growth and 0.6 percent annual water conservation; or
- 56 years of 1 percent annual population growth and no increase in water conservation.

As described above, the USGS simulated the groundwater system in transition, with withdrawal rates increasing stepwise annually (USGS, 2011). This assessment simulated a total 50-percent increase in groundwater withdrawal rates for the entire 100-year simulation period. That is, the model simulated 100 years of groundwater withdrawals at 150 percent of current average rates.

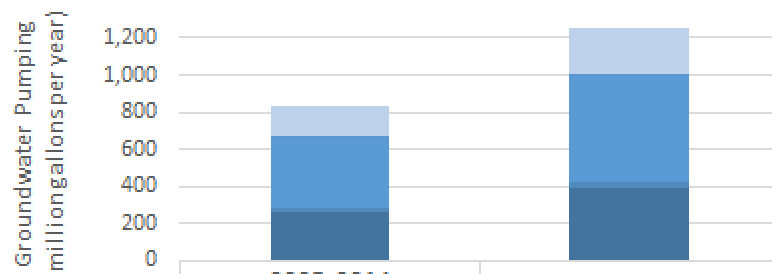
Although not illustrated in the 2011 USGS Report, the Bainbridge Island model simulates 1,480 wells on-Island and 3,537 wells off-Island (that portion of Kitsap County falling within the model domain). Groundwater withdrawal rates were increased by 50 percent for each well across the model area (Bainbridge Island and Kitsap Peninsula).

Figure 2 shows the current and projected groundwater withdrawal rates for on-Island and off-Island wells in units of millions of gallons per year. Figure 3 shows the current and projected distribution of on-Island groundwater withdrawal rates by aquifer.



	2005-2014 Average	Projected
On-Island	834	1,250
Off-Island	4,668	7,003

Figure 2. Current and Projected Groundwater Withdrawal Rates by Location.



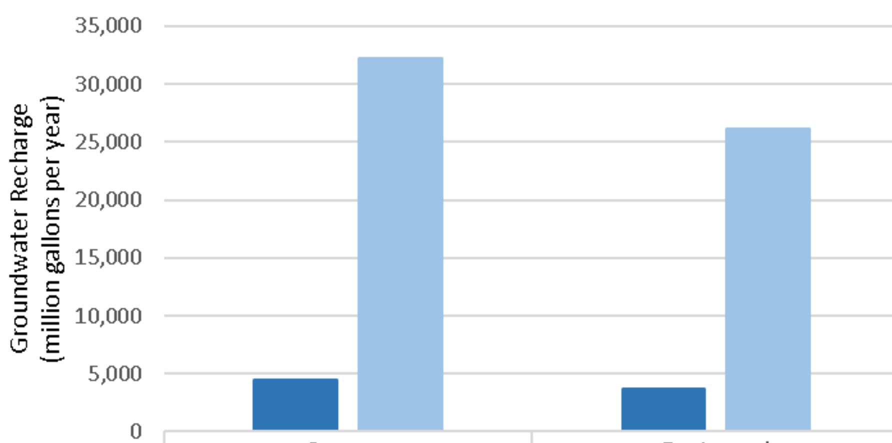
	2005-2014 Average	Projected
Perched Aquifer	160	240
Semi-Perched Aquifer	7	10
Sea Level Aquifer	387	581
Glaciomarine Aquifer	16	24
Fletcher Bay Aquifer	264	396

Figure 3. Current and Projected On-Island Groundwater Withdrawal Rates by Aquifer.

Change in Recharge due to Climate Change

The UW Climate Impacts Group (Mauger, et al., 2015) simulated future changes in precipitation and runoff for representative hydrologic basins across Washington. Their modeling analysis indicates that by the year 2100, winter runoff is expected to increase in the Puget Sound area by up to 20 percent due to more frequent, high-intensity (i.e., heavy) rain events. Warmer temperatures overall will also increase the evapotranspiration rates.

The predictive Bainbridge Island model simulated long-term groundwater conditions assuming a total 20 percent decrease in recharge rates across the model area due to climate change. That is, the model simulated 100 years of recharge at 80 percent of current average recharge rates.



	Current	Projected
On-Island	4,456	3,660
Off-Island	32,179	26,163

Figure 4. Current and Projected Recharge Distribution by Location.

Potential Sea Level Rise due to Climate Change

The UW Climate Impacts Group (Mauger, et al., 2015) projected sea level rise estimates ranging from 6 to 55 inches by the year 2100.

The Bainbridge Island groundwater model simulates long-term groundwater conditions assuming a 4-foot increase in mean sea level due to climate change. Specifically, the offshore conditions were increased from 4.4 feet to 8.4 feet NAVD88 to reflect sea level rise throughout the predictive timeframe. Because of the density of seawater, the assigned offshore conditions were adjusted for bathymetry.

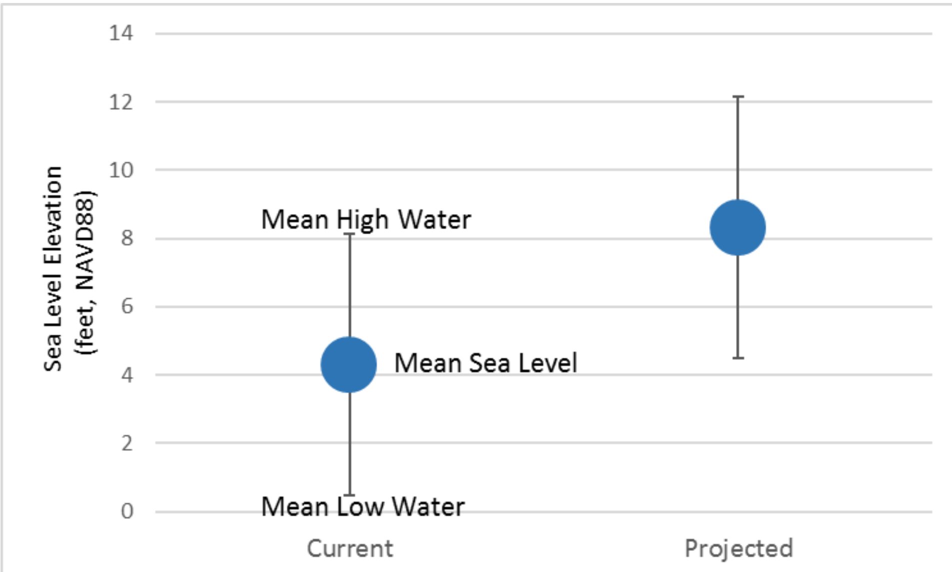


Figure 5. Current and Projected Sea Level.

Results of Aquifer System Carrying Capacity Assessment

The aquifer system carrying capacity assessment was based on those safe-yield indicators with EWLs adopted by the COBI, including the following:

1. Seawater intrusion (with EWL of 100 milligram per liter [mg/L] chloride); and
2. Rate of groundwater levels changes (with EWL of ½ foot per year for 10 years).

The on-Island groundwater balance for the entire aquifer system was also evaluated. The groundwater balance components do not have EWLs, but were evaluated to provide additional context on the predicted changes in groundwater conditions.

Seawater Intrusion

Seawater intrusion is a primary constraint on groundwater supply development and a key indicator of safe yield, because it can be assessed using the predictive model, directly measured (based on empirical water quality data), and compared to the COBI EWL of 100 mg/L chloride. Within the COBI groundwater monitoring program, observed chloride concentrations have generally been below the EWL (Aspect, 2015a). The one historical exception where elevated chloride was repeatedly measured includes a community well located near the shoreline and potentially tapping a thin water bearing zone near mean sea level. We understand this well has since been replaced with a deeper well that provides water with chloride concentrations less than the EWL.

Aspect updated the Bainbridge Island model to better simulate seawater intrusion across the model area. As a measure of model calibration, the Bainbridge Island model results agreed with the historically observed freshwater conditions for the COBI groundwater monitoring program (Aspect, 2015a).

The predictive model results indicate that groundwater from the Bainbridge Island aquifer system flows to Puget Sound and keeps the freshwater/seawater interface at a distance from the Bainbridge Island shoreline. All wells within the Bainbridge Island shoreline maintained chloride concentrations less than 100 mg/L, and no trend in concentrations was observed based on predictive model results. Due to model resolution constraints, the Bainbridge Island model is not able to simulate seawater intrusion at all near-shore wells tapping thin water-bearing zones near mean sea level. The following findings were based on the 100-year model results for seawater intrusion as part of the aquifer system carrying capacity assessment:

- The Perched Aquifer and Semi-Perched Aquifer systems are well above sea level, and did not show seawater intrusion.
- The Sea Level Aquifer system did not show seawater intrusion within the Bainbridge Island shoreline; the freshwater/seawater interface remained offshore at varying distances from the shoreline depending on location.
- The deeper aquifer systems (including the Glaciomarine Aquifer and the Fletcher Bay Aquifer) did not show seawater intrusion, because of thick aquitards and fresh groundwater flow sourced by off-Island recharge areas.

Rate of Groundwater Level Changes

The long-term rate of groundwater level changes is another indicator of the aquifer system carrying capacity. The COBI established an EWL of ½ foot per year for 10 years. Within the COBI groundwater monitoring program, observed groundwater level changes have been below the EWL (Aspect, 2015a). One potential exception previously identified has been the Island Utilities Well No. 1 (Aspect, 2006), which we understand is now operated by the Kitsap Public Utilities District.

Aspect updated the Bainbridge Island model and compared observed and simulated water levels during model validation (Aspect, 2015b). Differences between observed and calculated groundwater levels were within the standard-of-practice thresholds, and demonstrated the effects of simplifications required to simulate the complex Bainbridge Island aquifer system. Therefore, the model was validated for predictive simulations.

The following rates of groundwater level change were based on comparing current and predicted groundwater levels in 100 years:

- The Perched Aquifer system showed an average 0.10 foot per year of water level decrease at 25 locations simulated across the Island;
- The Semi-Perched Aquifer system showed an average 0.13 foot per year of water level decrease at 12 locations simulated across the Island;
- The Sea Level Aquifer system showed an average 0.09 foot per year of water level decrease at 49 locations simulated across the Island;
- The Glaciomarine Aquifer showed an average 0.02 foot per year of water level decrease at 6 locations simulated across the Island; and

- The Fletcher Bay Aquifer showed an average 0.15 foot per year of water level decrease at 9 locations simulated across the Island.

The predicted groundwater level changes over a 100-year timeframe were less than the COBI EWLs.

Groundwater Balance Changes

The groundwater balance is expected to change in the future due to increased groundwater withdrawals and decreased recharge rates. Groundwater balance components are typically difficult to measure directly (such as recharge and groundwater underflow). Thus, this groundwater balance assessment relies on modeling results without actual field measurements.

Based on the 2011 USGS Report, the relationship between groundwater balance inputs and outputs for the Bainbridge Island aquifer system is shown in the following equation:

$R_{ppt} = W_{ppg} + D_{sw} + (GW_{ps} - GW_{kp})$

Where:

Inputs include:

R_{ppt} is precipitation recharge.

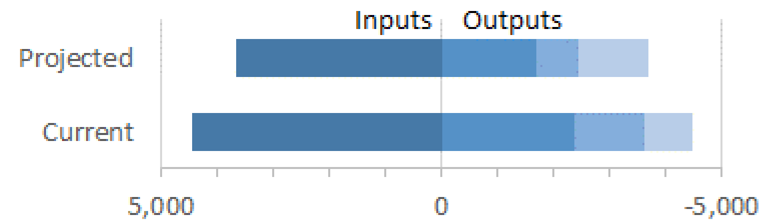
Outputs include:

W_{ppg} is groundwater withdrawals;
D_{sw} is groundwater drainage to surface water (such as seeps to bluffs, creeks, streams, etc.); and
$(GW_{ps} - GW_{kp})$ is the net lateral groundwater underflow (groundwater flow toward Puget Sound submarine seeps (GW_{ps}) and groundwater flowing from the Kitsap peninsula in deeper aquifers (GW_{kp})).

To balance the 50-percent increase in groundwater withdrawals and the 20-percent decrease in recharge, the model showed projected changes in groundwater drainage to surface water (approximately 40-percent decrease) and lateral groundwater flow (approximately 24-percent decrease). Figure 6 compares the water balance components under current and projected conditions, based on model results[2].

The Bainbridge Island groundwater model results showed aquifer storage will be reduced by approximately 11,000 million gallons between current and projected conditions, reflecting the water level decreases described above. These groundwater balance results should be carefully interpreted, considering that the limited grid resolution may not be sufficient to accurately simulate groundwater discharge to surface water, and that the model has not been calibrated to observed flows.

[2] The difference between groundwater balance inputs and outputs reflects the modeling methods, and results are within an acceptable level of accuracy for predictive purposes.



	Current	Projected
Recharge	4,456	3,660
GW underflow	-2,362	-1,673
Drainage, Surface Water	-1,261	-751
Well Pumping	-834	-1,251

Water Balance Components
(million gallons per year)

Figure 6. Current and Projected Groundwater Balance Components.

Recommendations for Future Assessments

The Bainbridge Island aquifer system carrying-capacity assessment described above provides an evaluation of long-term changes in groundwater conditions predicted with concurrent stresses on the aquifer system, including increased groundwater withdrawal rates, decreased recharge rates, and sea level rise. To address the sustainability of the Bainbridge Island aquifer system to support predicted population growth and water conservation, our recommendations for future assessments are listed below:

1. Implement recommendations provided in the previous memorandum *Bainbridge Island Groundwater Model: Review Findings and Recommendations (Task 2) and Critical Aquifer Recharge Area Assessment (Task 3 Scenario)* (Aspect, 2015b), including the following:

    a. Focus model extent and grid;

    b. Refine model layering; and

    c. Adjust aquifer parameters.

    These recommendations would likely improve model resolution and calibration—thereby improving reliability of predictive modeling results.

2. Simulate a range of projected future groundwater withdrawal rates, based on input from COBI staff. The assumption of a 50-percent increase over current withdrawal rates was based on a balance of projected population growth and water conservation trends. This assessment did not account for the possible decommissioning of shallow private wells on parcels to be served by expanded public water systems in the future.

3. Refine the groundwater model to better characterize the effects of decreasing groundwater levels on shallow wells (e.g. domestic). The groundwater model can be set up to identify those wells where water levels are calculated below the shallow aquifer. This information may support focused groundwater level monitoring.

4. Refine the groundwater model to quantify groundwater discharge to streams. Improved model resolution would provide better simulation of groundwater discharge to streams and seeps. The groundwater model can also be set up to account for groundwater discharge to different stream basins and groundwater seeps near the shoreline. This information can be used to help calibrate or validate the groundwater model to observed stream baseflow if that information becomes available. Predictive model results can quantify the change in stream baseflow to support focused monitoring and/or mitigation efforts.

5. Provide periodic Bainbridge Island model review, updating the model as needed with new wells, groundwater withdrawal schedules, and groundwater monitoring data. Predictive scenarios should be re-assessed using refined assumptions about projected groundwater withdrawal rates, recharge rates, and sea level rise.

6. Continue to implement the Groundwater Monitoring Program. These data provide critical information to support model updates and the decision making process.

References

Aspect Consulting, LLC (Aspect), 2006, Groundwater Monitoring Program, City of Bainbridge Island, December 12, 2006.

Aspect Consulting, LLC (Aspect), 2008, Groundwater Monitoring Program, Program Update—December 2008, City of Bainbridge Island, December 2008 (revised March 2009).

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

Aspect Consulting, LLC (Aspect), 2015b, Bainbridge Island Groundwater Model: Review Findings and Recommendations; Critical Aquifer Recharge Area Assessment, Prepared for the City of Bainbridge Island, December 21, 2105b.

Carollo, 2015, City of Bainbridge Island Water System Plan, City Review Draft, November 2015.

HDR, 2014, 2013 Comprehensive Water System Plan, accessed January 15, 2016, http://www.swd16.org/Comp%20Plan/2015/Silverdale%20WSP_Final_2014-08.pdf

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover, 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. doi:10.7915/CIG93777D

City of Poulsbo (Poulsbo), 2015, 2015 Consumer Confidence Report, accessed January 15, 2016, https://www.cityofpoulsbo.com/publicworks/documents/2015ConsumerConfidenceReport.pdf

Sutton, Jennifer, 1999, Email correspondence between Jennifer Sutton of City of Bainbridge Island and Peter Bannister, January 12, 2016.

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

United State Geological Survey (USGS), 2014, Hydrogeologic Framework, Groundwater Movements, and Water Budget of the Kitsap Peninsula, West-Central Washington, 2014.

Limitations

Work for this project was performed for the City of Bainbridge Island (Client), 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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