MEMORANDUM

Project No.: 140369

December 21, 2015

To: Cami Apfelbeck

From:

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Re: **Bainbridge Island Groundwater Model:**

Review Findings and Recommendations (Task 2) and Critical Aquifer Recharge Area Assessment (Task 3 Scenario)

This memorandum provides recommendations to update and improve the Bainbridge Island groundwater model (hereafter: Bainbridge Island model) to assist the City of Bainbridge Island (COBI) with land-use planning. This memorandum also describes the findings from the critical aquifer recharge area assessment. The Bainbridge Island model was developed and published in 2011 by the United States Geological Survey (USGS) in cooperation with the COBI. Aspect Consulting, LLC (Aspect) is supporting the COBI 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.

In parallel with COBI's review and utilization of the Bainbridge Island model, the USGS is currently developing a separate groundwater model of the entire Kitsap Peninsula including Bainbridge Island (USGS, 2014). The peninsula groundwater model is anticipated to be released in spring 2016, based on email communications with USGS personnel.

The following sections of this memo describe the data sources used for our model review, summarize the original USGS groundwater model and its limitations, summarize Aspect's model review findings and recommendations to improve the original model, describe improvements made as directed by COBI, summarize results of the first land-use planning scenario to assess CARA, and offer alternative approaches to simulate the other land-use planning scenarios for City discussion and direction.

Data Sources

The data sources for the Bainbridge Island model review included:

- Conceptual Model and Numerical Simulation of the Groundwater-Flow System of Bainbridge Island, Washington (USGS, 2011; hereafter: 2011 USGS Model Report).
- Input files for the Bainbridge Island model, dated July 2010, including:
  - The calibration model ("2008 conditions") and
  - Future scenario models ("2035_low_impact," "2035_mid_impact," and "2035_high_impact").
- *Hydrogeologic Framework, Groundwater Movements, and Water Budget of the Kitsap Peninsula, West-Central Washington* (USGS, 2014; hereafter: 2014 Kitsap Peninsula Report), including digital files for select figures in the 2014 Kitsap Peninsula Report.

Summary of Original Bainbridge Island Groundwater Model

The Bainbridge Island model (USGS, 2011) was developed as a tool to be used in making water resource management decisions. Under the Water Resources Element, Goals, and Policies section of the COBI Comprehensive Plan (2004), Goal 1 states:

> "Protection of water resources is of primary importance to the Island. Therefore, the goal is to manage the water resources of Bainbridge Island for present and projected land uses, recognizing Island water resources are the sole water supply and that:
>
> - Degradation of groundwater quality and quantity is not allowed.
> - Water supplies and systems are efficiently utilized.
> - The long-term sustainability of the Island's water resources is maintained.
> - The water needs of new development approved under the Comprehensive Plan are adequately met.
> - Adequate data of the water resource is available."

The USGS and COBI identified three sets of scenarios to evaluate using the Bainbridge Island model, including the following:

1. To establish baseline conditions that likely represent predevelopment conditions and 2008 conditions to determine the effects of existing pumping stresses on the groundwater system;
2. To assess the potential effects of expected pumping and climatic changes on the groundwater system; and
3. To gain an understanding of the groundwater system under minimal and maximum pumping stress and climatic change during the years 2009 to 2035.

To address these scenarios, the USGS simulated a 2,500-year, predevelopment period, current conditions for the period from 1995 through 2008, and future conditions from 2009 through 2035. The findings from the USGS report are summarized below:

- No saltwater intrusion was evident since predevelopment with the saltwater/freshwater interface remaining offshore.
- No saltwater intrusion was simulated to occur by 2035 in any aquifer under the maximum impact scenario with the saltwater/freshwater interface remaining offshore. However, given the flow reversal that was simulated to occur, saltwater intrusion likely would occur at a future date under continued exposure to these conditions.
- Aquifer recharge areas were not delineated because COBI water supply wells are withdrawing ancient water (greater than 1,000 years old), and protecting certain areas of the Island from land-use changes would have no effect on the water levels expected in these wells by 2035.

Original Model Limitations Identified by USGS

As with all groundwater models, the Bainbridge Island model is a simplified representation of complex subsurface conditions. The limitations identified in the 2011 USGS Model Report were attributed to three reasons, as described by Troutman (1985): *"Hydrologic-modeling errors typically are the consequence of (1) input data, (2) representation of the physical processes by the algorithms of the model, and (3) parameters estimation during the calibration procedure."*

The USGS specifically limited the use of the Bainbridge Island model to regional-scale evaluations, and cautioned against its use for local-scale evaluation. Based on our model review, Aspect provided a set of recommendations to update and refine the Bainbridge Island model, addressing many limitations with the original Bainbridge Island groundwater model.

Review Findings, Recommendations, and Implemented Changes

Based on Aspect's evaluation of the data sources, we provided our highest-priority recommendations for refining and updating the Bainbridge Island model to improve COBI's evaluation of future land-use planning scenarios. They were as follows:

1. Updating recharge data based on new estimates provided by the USGS in 2014;
2. Updating well pumping rates based on data collected by COBI and other water purveyors since 2008;
3. Revising the modeling approach to better simulate groundwater flow;
4. Validating the model with all available groundwater monitoring data collected by COBI and other water purveyors; and
5. Modifying approach to future scenario analysis.

A summary of the original Bainbridge Island model description, implications of model setup on findings, recommendations, and implementation, is shown in Table 1. Aspect implemented selected recommended changes as directed by the COBI to improve the Bainbridge Island model. Some changes were recommended by Aspect to be implemented at a later date. Additional detail of the model review findings, recommendations, and implemented changes is provided below.

Recommendation 1—Assign recharge rates based on 2014 Kitsap Peninsula Report

In the original Bainbridge Island model, the USGS assigned an average precipitation recharge rate for the predevelopment period that resulted in 3.6 million cubic feet per day (cf/d) spread across Bainbridge Island. This was approximately 79 percent more than the 2.0 million cf/d assigned to Bainbridge Island in the 2014 Kitsap Peninsula Report (USGS, 2014). Assigning greater recharge in the Bainbridge Island model may underestimate the potential for saltwater intrusion, underestimate the effect from pumping, overestimate hydraulic conductivity values, and ultimately overestimate the sustainable pumping rates. Improved recharge analysis methods were described by the USGS in the 2014 Kitsap Peninsula Report. Therefore, we recommended and implemented assigning updated recharge rates consistent with the 2014 Kitsap Peninsula Report[1].

In the original Bainbridge Island model, the USGS-assigned average precipitation recharge rates from 1995 through 2008 (postdevelopment period) averaged 4.9 million cf/d, or 2.4 times the value in the 2014 Kitsap Peninsula Report. To address this potential overestimate of recharge, monthly recharge rates were reassigned as a multiplier of the average precipitation recharge rate presented in the 2014 Kitsap Peninsula Report. The multiplier was calculated based on the average 1980 to 2010 precipitation observed at the climate station in Bremerton[2].

In the original Bainbridge Island model, the USGS assigned return flows from septic systems. On Bainbridge Island, return flows from septic systems were calculated to be approximately 5 percent of total recharge assigned. To simplify the modeling analysis, septic return flow was removed from the total recharge values assigned in the model.

Recommendation 2—Update well pumping rates

Aspect recommended and implemented updating monthly pumping rates from 2009 to 2014 at all wells within the original Bainbridge Island model[3]. Monthly pumping rates at wells operated by COBI and Kitsap Public Utilities District (KPUD) were requested and compiled as part of Task 1 under this contract. The annualized pumped volumes were approximately 2 percent less from 2009 through 2014 than from 2004 through 2008. Monthly pumping rates at other Group A and B wells, and at domestic water supply wells, were assigned the monthly average from 2004 through 2008 used by the USGS in the original model.

Recommendation 3—Revise modeling approach

There were several examples of modeling approaches the USGS selected that could reduce the potential for simulating saltwater intrusion or overcomplicate the model. Aspect recommended and implemented revising the modeling approach to more reliably simulate groundwater conditions, including the potential for saltwater intrusion.

- In the original Bainbridge Island model, the USGS used code which simulated density-dependent groundwater flow. However, based on model results, there did not appear to be any areas of density-dependent groundwater flow that warranted the use of this code. In fact, the complexities of groundwater flow through glacial deposits required that the USGS employ many work-around solutions. To better simulate groundwater flow, Aspect used an alternative groundwater modeling code to simulate complex groundwater flow and transport conditions. The effects of dense saltwater will be simulated for offshore conditions using freshwater-equivalent heads.

[1] Average precipitation provided by USGS is included as Appendix A in electronic deliverable.
[2] Recharge multipliers included as Appendix B in electronic deliverable.
[3] Wells and monthly pumping rates included as Appendix C in electronic deliverable.

- Although the USGS likely intended to simulate mean sea level in the original model, the offshore conditions were assigned 0 feet elevation relative to the NAVD88 vertical datum. However, this reflects approximately mean lower-low sea level, not mean sea level, and reduces the potential for saltwater intrusion. Therefore, Aspect assigned offshore conditions at 4.4 feet NAVD88 to reflect mean sea level. Because of the density of saltwater, the assigned offshore conditions will be adjusted for bathymetry.
- In the original Bainbridge Island model, the USGS simulated a connection for deeper aquifers eastward across Puget Sound. This assumption of aquifer connections between Bainbridge Island and the Seattle area may reduce the potential for saltwater intrusion. To avoid the complications associated with this assumption, Aspect simulated a no-flow boundary at the model edge.
- The USGS simulated bedrock with very low hydraulic conductivities and unusually thick layers in the original model. Model results indicated almost no interaction with surrounding aquifers and aquitards. Therefore, Aspect simulated only the major aquifers and aquitards composed of glacial and interglacial deposits.
- In the original Bainbridge Island model, the USGS simulated lakes as source terms to the groundwater system. The contribution of lakes to groundwater may double-count precipitation recharge, and reduce the potential for saltwater intrusion. Therefore, Aspect simulated only precipitation recharge.
- In the original Bainbridge Island model, the USGS assigned a model top elevation that does not reflect ground surface, based on a comparison with available topographic data. Topography greatly influences surface water flow and groundwater discharge to surface water. Topography across Bainbridge Island has been reliably measured using aerial methods (LiDAR) as recently as July, 2015, and the COBI has these data. Therefore, Aspect assigned the model top elevation based on topographic LiDAR data.

Recommendation 4—Validate the Updated Model

Following implementation of the above recommended changes, Aspect recommended and validated the model using all of the available water level observations. The USGS used observed water levels from December 2001 through 2008 to calibrate the original model. Aspect included observed water level data before December 2001 and after 2008. The model validation statistics were compared with calibration statistics provided by the USGS, and are provided in Table 2.

Recommendation 5—Modify Approach to Scenarios

The USGS simulated conditions from 2009 through 2035 to analyze future scenarios. Their findings regarding CARA and aquifer system carrying capacity were limited by the relatively short simulation timeframe. Aspect recommended assessing these land-use planning scenarios with expanded timeframes as described below. Only the CARA assessment was implemented by Aspect as of the date of this memorandum, as directed by the COBI.

CARA Assessment

For the CARA assessment, Aspect recommended simulating equilibrium groundwater flow conditions based on average recent pumping (2005 to 2014) and average recharge. Simulating recent conditions supports land-use planning for the near-term. The CARA assessment included all wells simulated on Bainbridge Island using modeling techniques similar to those described in the 2011 USGS Model Report for the Head of the Bay wellfield. These recommendations were implemented by Aspect, as directed by the COBI. Results of the CARA assessment are summarized in the next section of this memorandum.

Aquifer System Carrying Capacity Assessment

For the Aquifer System Carrying Capacity assessment, Aspect recommends assessing the potential for saltwater intrusion on Bainbridge Island for three potential future changes:

- **Increase Groundwater Pumping**—Aspect recommends increasing groundwater pumping by up to 50 percent across model area to reflect greater-than-anticipated future changes in groundwater demand for modeling purposes;
- **Decrease Recharge**—Aspect recommends decreasing recharge by up to 20 percent to reflect shorter, more intense rainfall events (Mauger, et al., 2015); and
- **Increase Sea Level**—Aspect recommends increasing sea level by up to 4 feet to reflect high-end projected changes (Mauger, et al., 2015).

The model results of the Aquifer System Carrying Capacity assessment may be evaluated by quantifying changes in saltwater content in water supply wells, the change in location of the freshwater/saltwater interface, and/or the change in CARA.

Sea Level/Fletcher Bay Aquifer Production Test

For the Sea Level/Fletcher Bay Aquifer Production Test, Aspect recommends simulating potential benefits of alternating major withdrawals between the Fletcher Bay Aquifer and the Sea Level Aquifer. These benefits may be quantified based on in-well pumping lift, water quality, and pumping effects. To simulate potential monthly climate variability, Aspect recommends applying the historical recharge record (described under Recommendation 1) for this scenario.

Recommendations to Consider for Future Model Improvements

Based on Aspect's review of the original Bainbridge Island model, there were several potential improvements that we recommend considering in the future. The USGS is currently developing an updated model of the Kitsap Peninsula, due to be released in spring 2016, which may influence these recommendations. Aspect recommends the efforts below be considered during future groundwater model updates.

Focus Model Extent and Grid

Bainbridge Island represents a small area within the existing model extent. Greater resolution of groundwater conditions on Bainbridge Island may be provided by employing a modeling technique known as "telescopic mesh refinement."

Refine Model Layering

In the existing Bainbridge Island model, the USGS assigned eight sublayers for aquifers and one layer for aquitards. Given the relative thickness of aquifers and aquitards, this layering may be refined to balance the resolution of the aquifers and aquitards. In addition, it appears aquifer thicknesses may have been revised by the USGS for the 2014 Kitsap Peninsula report, based on reinterpretation of existing subsurface data or new subsurface data. We recommend comparing the layering in the existing Bainbridge Island model with the 2016 USGS Kitsap Peninsula model, and determining if layer refinement is warranted.

Adjust Aquifer Parameters

The USGS calibrated aquifer parameters in the existing Bainbridge Island model using a relatively new technique called "highly parameterized inversion" (USGS, 2010). This calibration resulted in an unusual range of hydraulic conductivities and vertical anisotropies (inconsistencies). The 2016 USGS Kitsap Peninsula model may reflect different aquifer parameters based on a refined calibration process, re-interpretation of existing data, or new data. We recommend comparing the aquifer parameters in the

existing Bainbridge Island model with those assigned in the 2016 USGS Kitsap Peninsula model, and determining if adjusting aquifer parameters is warranted.

CARA Assessment

This section provides a summary of our findings based on results of the CARA assessment using the Bainbridge Island groundwater model updated by Aspect. A CARA is defined by the Growth Management Act as "areas with a critical recharging effect on aquifers used for potable water." The Washington Administrative Code (WAC) Chapter 365-190 uses the following definition: "Areas with a critical recharging effect on aquifers used for potable water are areas where an aquifer that is a source of drinking water is vulnerable to contamination that would affect the potability of the water."

Summary of Findings

The Bainbridge Island model results indicate that areas across much of the Bainbridge Island area may have a critical recharging effect on aquifers that are sources of drinking water. Primary findings include:

- Wells in shallow aquifers (including the Sea Level Aquifer and above) may withdraw water that originates as recharge relatively close to the well head and is younger than 100 years old. See Figure 1 which shows the CARA for shallow aquifers (shaded area) and bedrock (hatched area).
- Wells in deep aquifers (including the Glacio-Marine Aquifer and the Fletcher Bay Aquifer) may withdraw water that originates as recharge relatively distant from the wellhead and is greater than 100 years old. See Figure 2 which shows the CARA for deep aquifers (shaded area) and bedrock (hatched area).
- Not all groundwater on Bainbridge Island comes from recharge on Bainbridge Island. Model results indicate several wells tapping the deeper aquifers withdraw water that originates as recharge from areas on the Kitsap Peninsula and is greater than 1,000 years old.

Wells in bedrock were not simulated in the Bainbridge Island model for reasons described above. However, the bedrock is also considered a CARA because water supply wells have been installed at various depths in bedrock, and potable water supply is from recharge.

Methods Summary

For this analysis, Aspect used a common modeling technique called particle tracking analysis, wherein hypothetical particles follow model-calculated groundwater flow paths. Paths were traced from a water supply well to the point of recharge, which are shown as shaded areas in Figures 1 and 2. This method also provides information on timing from the point of recharge to the water supply well.

Future Work

Following direction from COBI, Aspect will implement any additional changes necessary and utilize the updated model for the remaining scenarios: the Aquifer System Carrying Capacity assessment and the Sea Level/Fletcher Bay Aquifer Production Test. Aspect will summarize model findings for these model scenarios in a future technical memorandum.

References

Aspect Consulting, LLC (Aspect), 2015, Hydrogeological Assessment of Groundwater Quantity, Quality, and Production, Prepared for the City of Bainbridge Island, October 22, 2015

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

United States Geological Survey (USGS), 2010, Approaches to highly parameterized inversion – A guide to using PEST for groundwater model calibration: USGS Scientific Investigation Report 2010-5169, 2010.

USGS, 2011, Conceptual Model and Numerical Simulation of the Groundwater-Flow System of Bainbridge Island, Washington, 2011.

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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Attachments

Table 1—Bainbridge Island Groundwater Model Review Summary Table

Table 2—Bainbridge Island Groundwater Model Validation

Figure 1—CARA for Shallow Aquifers

Figure 2—CARA for Deep Aquifers

Appendices A, B, C—electronic deliverable

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Topic	Existing Model Description	Implications on Model Findings	Recommendations	Implementation Schedule
Update Recharge[1]	The USGS simulated average recharge rates on Bainbridge Island that were 79% greater than indicated in the 2014 Kitsap Peninsula Report.	Using the older recharge rates may underestimate the potential for salt water intrusion and overestimate the water budget for Bainbridge Island.	Recommend assigning recharge rates based on updated values presented in the 2014 Kitsap Peninsula Report.	Implemented, as directed by COBI
Update Well Pumping Rates[2]	The USGS simulated wells from January 1995 through December 2008.	Groundwater withdrawal data influence the potential for salt water intrusion and the water budget for Bainbridge Island.	Recommend updating pumping rates to reflect values from January 2009 through December 2014, based on data collected under Task 1.	Implemented, as directed by COBI
Revise Modeling Approach	• The USGS used SEAWAT-2000 to simulate saltwater intrusion • The USGS simulated Puget Sound at 0 ft NAVD88. • The USGS simulated a potential connection to aquifers across Puget Sound. • The USGS simulated bedrock. • The USGS simulated lakes as potential sources of water. • The USGS assigned a model top elevation that does not reflect available topographic LiDAR data.	• Model results do not indicate density-dependent flow, but complex partially-saturated flow. • Assigning mean lower-low sea level reduces potential for saltwater intrusion. • Assigning a potential connection with aquifers across Puget Sound may affect saltwater intrusion. • Model results indicate limited ability to simulate bedrock. • Assigning lakes as sources may double count recharge. • Model top elevation influences simulation of stream drainage.	• Recommend using MODFLOW-SURFACT to simulate complex partially saturated flow and transport. • Recommend simulating Puget Sound based on Mean Sea Level of 4.4 ft NAVD88. • Recommend removing potential connection with aquifers across Puget Sound. • Recommend only simulating major aquifers and aquitards. • Recommend only simulating precipitation recharge. • Recommend using available LiDAR data to re-assign “model top” elevation.	Implemented, as directed by COBI
Validate Updated Model using Water Level Observations[3]	Water levels observed from January 2006 through December 2008 were used by the USGS for calibration.	Water level observations before 2006 and after 2008 help validate the model calibration over a longer period.	Recommend using all available water level data, including recent data collected under Task 1 of this contract, to validate model calibration.	Implemented, as directed by COBI

1. Recharge is the amount of precipitation that infiltrates into the ground and adds water to the water table.

2. Well pumping is specified for water supply wells. Pumping rates may change due to seasonal demand patterns or changes in population served.

3. Water level observations are used to assess the state of the groundwater system. Observations are key to ensure the model provides a reasonable representation of reality.

Table 1. Bainbridge Island Groundwater Model Review Summary Table

Topic	Existing Model Description	Implications on Model Findings	Recommendations	Implementation Schedule
Modify Approach to Future Scenario Analysis	For future scenario analysis, the USGS simulated 27 one-year periods from 2009 through 2035 starting with freshwater conditions.	Model findings were limited by the future scenario timeframe.	Recommend simulating 100 years for critical aquifer recharge areas and sustainability scenarios, starting with final seawater conditions from calibration model as initial conditions. For operations scenario, simulate monthly stress periods using 1995-2014 recharge.	Implemented, as directed by COBI
Focus Model Extent[4] and Grid to Provide Greater Resolution of Bainbridge Island	Model extent is regional and not local – Bainbridge Island represents approximately 10 percent of active model area. Positional accuracy is approximately +/- 800 feet, based on model grid spacing.	The regional scale and grid spacing (each model cell is 14.7 acres) limits the clarity of groundwater flow and transport specific to Bainbridge Island.	Recommend maintaining model extent and grid at this time. Interpretation of model results must reflect the model scale. Modeling techniques are available if additional resolution is desired by COBI.	Consider for future work, based on 2016 USGS Kitsap Peninsula Model report
Refine Model Layering[5]	The USGS modified layer thicknesses, based on the 2014 Kitsap Peninsula Report.	Layer thicknesses affect groundwater flow patterns.	Recommend maintaining layer thicknesses at this time. Interpretation of model results must reflect on-going changes in hydrostratigraphic understanding.	Consider for future work, based on 2016 USGS Kitsap Peninsula Model report
Adjust Aquifer Parameters[6]	Model calibration resulted in unusual values.	The use of unusual aquifer parameter values to force a calibration reflects potential problems with the calibration techniques.	Recommend maintaining aquifer parameters at this time. The scope of model changes required to address this issue are beyond the existing budget.	Consider for future work, based on 2016 USGS Kitsap Peninsula Model report

[4] The model extent/grid/layering is the framework of a groundwater model. The model extent describes the location and area represented by the model including the depth and height. Grid spacing defines the horizontal resolution of model inputs and results.

[5] Layer thickness defines the vertical resolution of model inputs and results, and also represents geologic layering in the model. The layers provide the vertical resolution of model inputs and results.

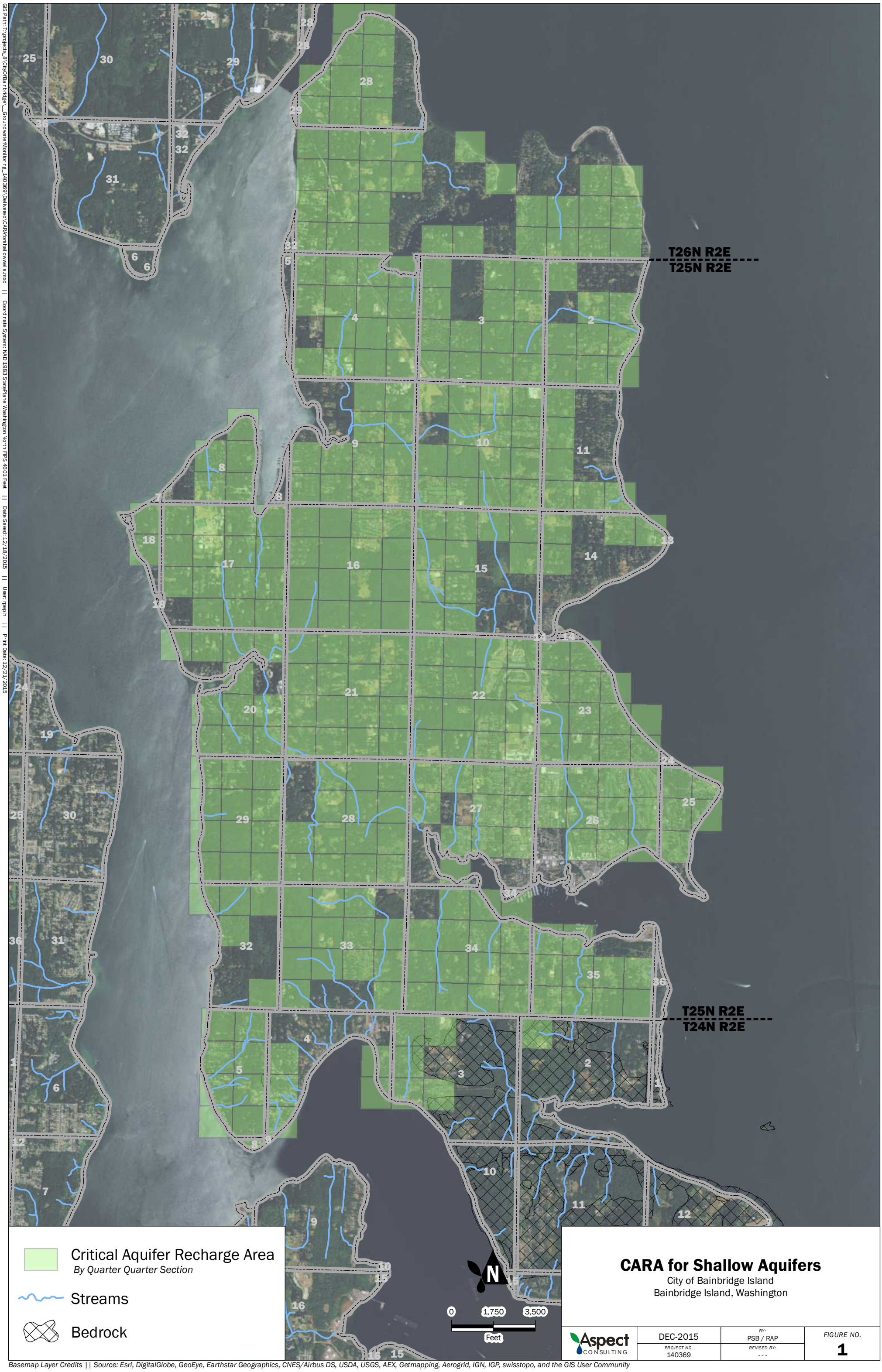
[6.] Aquifer parameters are the properties of soil that effect how groundwater flows. Parameter values vary with geology type; for example, groundwater flows easily through sand, but more slowly through mud. Aquifer parameter values are adjusted during calibration so that model results more closely match observed water level measurements.

	Model Calibration based on Table 6 in 2011 USGS Report				
Aquifer Designation	PA	SPA	SLA	GMA	FBA
Number of Observations	705	127	1184	341	292
Minimum Residual (feet)	-64	-37	-81	-24	-32
Maximum residual (feet)	41	102	85	36	27
Mean Residual (feet)	-2.8	46.8	-5.2	4.1	0.7
Simulated values within ±20 feet	78%	16.5%	80.8%	100%	98.3%
Standard Deviation of residuals (ft)	19	44	20.2	13	7.7
Observed water level range (feet)	278.4	205.1	230.5	132.4	48.7
Calibration fit	6.8%	21.4%	8.8%	9.8%	15.7%

	Model Validation based on updates implemented by Aspect				
Aquifer Designation	PA	SPA	SLA	GMA	FBA
Number of Observations	1708	895	3614	582	1051
Minimum Residual (feet)	-128	-36	-42	-33	-72
Maximum residual (feet)	126	122	90	20	-7
Mean Residual (feet)	1.4	31.2	3.4	-1.4	-23.2
Simulated values within ±20 feet	60%	11%	71%	99%	42%
Standard Deviation of residuals (ft)	42	34	25	11	9
Observed water level range (feet)	283	239	190	56	75
Calibration fit	14.8%	14.2%	13.2%	19.2%	12.2%

Notes:
Aquifer designation follows naming convention used by COBI.
Number of observations is based on the number of observations over time at wells completed within the aquifer.
Residual is calculated as the observed water level minus the calculated water level.
Calibration fit is calculated as the standard deviation of residuals divided by the observed water level range.

Table 2. Bainbridge Island Groundwater Model Validation



CARA for Shallow Aquifers

City of Bainbridge Island
Bainbridge Island, Washington

Aspect CONSULTING	DEC-2015	BY: PSB / RAP	FIGURE NO. 1
	PROJECT NO. 140369	REVISED BY: ---	

Basemap Layer Credits || Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

GIS Path: T:\projects_8\CityOfBainbridge__GroundwaterMonitoring_140369\Delivered\CARAforshallowwells.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 12/18/2015 || User: rpepin || Print Date: 12/21/2015

GIS Path: T:\projects_8\CityOfBainbridge__GroundwaterMonitoring_140369\Delivered\CARAfordeepwells.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 12/18/2015 || User: rpepin || Print Date: 12/21/2015

T26N R2E
T25N R2E
T25N R2E
T24N R2E

Critical Aquifer Recharge Area
By Quarter Quarter Section

Streams

Bedrock

N

0 1,750 3,500
Feet

CARA for Deep Aquifers

City of Bainbridge Island
Bainbridge Island, Washington

Aspect Consulting	DEC-2015	BY: PSB / RAP	FIGURE NO. 2
	PROJECT NO. 140369	REVISED BY: ---	

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