

July 2025

TECHNICAL MEMORANDUM

TO: Chris Wierzbicki, Public Works Director, City of Bainbridge Island

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SUBJECT: Groundwater Flow Model Technical Memorandum
City of Bainbridge Island, Kitsap County

1. PURPOSE AND SCOPE

EA Engineering, Science, and Technology, Inc., PBC (EA) has been contracted by the City of Bainbridge Island (COBI) to develop the island's comprehensive Groundwater Management Plan (GWMP). As part of this effort, an existing groundwater flow model was updated and used to run predictive scenarios in aid of the GWMP. The objective of the modeling effort was to provide: (1) a well calibrated groundwater flow that adequately represents subsurface conditions for future use by COBI to evaluate current groundwater flow conditions, (2) reasonable estimates of possible future climatic and aquifer stress conditions (sea levels, groundwater recharge, and extraction rates), and (3) interpretations of the impacts that these possible future conditions will have on groundwater resources on Bainbridge Island. This technical memorandum should be interpreted solely in the context of the GWMP and, on its own, does not seek to provide recommendations regarding groundwater use on Bainbridge Island. Formalized recommendations are outlined in the GWMP, which this groundwater flow model and technical memorandum only seek to augment and provide guidance for.

2. BACKGROUND

A brief history of the groundwater model to be discussed in this technical memorandum is provided. In 2011, U.S. Geological Survey (USGS) in conjunction with COBI developed a groundwater flow model using the open-source software MODFLOW-2000 (Frans et al. 2011; Harbaugh et al. 2000). This model is referred to as the **2011 USGS model**. In 2016, USGS updated the **2011 USGS model** with a new numerical solver, MODFLOW-NWT (Niswonger et. al. 2011; Frans and Olsen 2016), and is referred to as the **2016 USGS model**. In 2023, Aspect Consulting, LLC (Aspect) began performing assessments to address the sustainability of Bainbridge Island's aquifer systems. As part of Aspect's evaluation, the **2016 USGS model** was utilized after a series of revisions were made to the model. The revised **2016 USGS model** is now referred to as the **2023 Aspect model** (Aspect 2023).

Aspect's revisions include (but are not necessarily limited to):

- Converting the MODFLOW-NWT model into a MODFLOW-USG model (“USG” refers to “unstructured grid” and to be described in more detail in Section 4).
- Removing stream boundary conditions and converting all model cells in model layer 1 (the ground surface layer) into drain boundary conditions. This enforces groundwater levels simulated above ground level to be instantaneously removed from the model. This revision has led to the misunderstanding that the model is capable of simulating streamflow; however, as will be discussed in Section 4, this is an inaccurate characterization of the revision.
- The **2016 USGS model** simulated annual stress periods from 1984 through 2004, followed by monthly stress periods from January 2005 through December 2012. Aspect increased the simulation period with monthly stress periods from January 2013 through December 2021. Adding additional stress periods necessitates imposing the necessary and relevant physical boundary conditions over the added time period, specifically groundwater recharge rates and extraction and injection rates. Sea levels were assumed to remain constant over this eight-year period. Spatially and temporally varying precipitation was obtained via the PRISM dataset (PRISM Climate Group 2022) and regression equations relating precipitation to groundwater recharge from Bidlake and Payne (2001) were applied to assign recharge rates in the model. This is the same methodology implemented within the **2016 USGS model**. Extraction rates at individual pumping wells were assigned based on public supplier extraction records when available. When historic extraction rates were not available the last simulated extraction rate (December 2012) was assigned to a linear growth rate proportional to average growth across the water system in which the well is a member. It is not clear how this growth rate was calculated (e.g., population based, number of connections, etc.)
- The *Allow Automatic Flow Reduction* function was implemented in the **2023 Aspect model**. This functionality automatically reduces the assigned pumping rate when either model convergence is not achieved or the model cell where pumping is applied runs dry (simulated groundwater levels are below the bottom elevation of the cell).

Aspect (2023) provides a more detailed review of the revisions made to the **2016 USGS model** which led to the **2023 Aspect model**.

After revisions were made to the model, Aspect performed a hypothetical model run to predict future groundwater conditions based on possible future climate and growth scenarios. This predictive scenario run simulated the time from 2022 through 2121 and was based on annual stress periods. The scenario assumed a 50 percent (%) increase in extraction rates, a 20% decrease in recharge, and a 4-foot increase in mean sea level. All three changes were modeled to occur instantaneously and were not increased or decreased over time. However, with implementation of the *Allow Automatic Flow Reduction* function described above the extraction rate increase was limited to 38%.

EA received the **2023 Aspect model** in April 2023 and as part of EA’s task order a comprehensive review of the model was performed prior to using the model. This review

identified several deficiencies and limitations within the **2023 Aspect model** which hindered achievement of the stated modeling objectives. As a result, EA revised the model to satisfy project objectives outlined in this technical memorandum (memo).

The format of this memo is as follows. Section 3 provides the conceptual site model which forms the basis for the groundwater flow model, including climate and hydrogeology. Section 4 outlines every component of the groundwater model used in this analysis and, when relevant, the revisions that were made to the **2023 Aspect model**. Predictive model scenarios were simulated to aid in the development of the GWMP. These scenarios (their representation and development) and associated results are provided in Section 5.

3. CONCEPTUAL SITE MODEL

Bainbridge Island is a 30-square-mile island within Kitsap County, Washington. The island is located within Puget Sound. The City of Seattle is to the east of the island and the Kitsap Peninsula is to the west, separated by the 2-mile wide Port Orchard. Bainbridge Island has a population of approximately 25,000 people as of the 2020 census. There is no major industry located on the island and the economy is primarily service industry based. All drinking water on the island is sourced from on-island groundwater extraction wells meaning all aquifers underling Bainbridge Island are sole source aquifers.

3.1 PHYSIOGRAPHIC SETTING

Bainbridge Island is within the Puget Lowland, a subset of the Pacific Border physiographic province. The Puget Lowland is a north-south running depression formed by multiple glacial advances and retreats, up to and including the most recent glacial period (approximately 10,000 to 15,000 years ago). The depression is bound by the Olympic Mountains to the west and the Cascade Mountain Range to the east. Topographic relief is relatively low to moderate within the lowland. The province has warm and dry summers and mild, wet winters, with an average annual precipitation of around 45 inches (Washington Department of Natural Resources 2025). Over 80% of this precipitation falls within October and March, with most of this precipitation falling as rain. Pre-European American settlement the region was largely enveloped by coniferous forest, dominated by Douglas Fir, Western Hemlock, and Western Red Cedar. On Bainbridge Island specifically, industrial logging began in the late 19th century and continued into the first half of the 20th Century. Most of the trees on the island today are not original “legacy” forest trees but have been reestablished post-deforestation (Bainbridge Island Metro Park and Recreation District 2025). At least 59 named streams exist on Bainbridge Island, with 27 of these being identified as perennial and the remaining 32 as seasonal or ephemeral. Currently, no streams on the island are continually gauged or monitored for streamflow or stage.

3.2 HYDROGEOLOGY

The groundwater model domain (to be described in Section 4.1) includes Bainbridge Island and a significant portion of the Kitsap Peninsula. As a result, this section outlines the hydrogeologic setting of both the Kitsap Peninsula and Bainbridge Island as it pertains to the groundwater flow model. Moreover, this discussion is not meant to be exhaustive and is only meant to provide a

context for the technical memorandum. A more detailed overview of the local geology is provided in Welch et al. (2014), Frans et al. (2011), and Frans and Olsen (2016).

The Kitsap Peninsula's aquifer system is an alternating sequence of aquifers and fine-grained confining units. This sequence is outlined below in order from youngest (closest to ground surface) to oldest (deepest).

Vashon Recessional Aquifer, Qvr

The Vashon Recessional Aquifer (Qvr) is a Quaternary surficial aquifer across small areas of Kitsap Peninsula, typically along streams and drainage pathways. The Qvr was formed primarily from glacial recessional outwash but may also include elements formed by more recent alluvial processes. The Qvr is not present on Bainbridge Island.

Vashon Till Confining Unit, Qvt

The Vashon Till Confining Unit (Qvt) is a finely packed Quaternary clay till matrix containing sands and gravels. The Qvt is present across both the Kitsap Peninsula and Bainbridge Island and is present at land surface throughout much of the model domain. Due to historical and ongoing present-day erosion the Qvt is eroded in areas throughout the model and is therefore considered continuous on a regional scale but discontinuous on a local scale.

Vashon Advance Aquifer, Qva

The Vashon Advance Aquifer (Qva) is a shallow sand and gravel Quaternary aquifer that exists ubiquitously across Kitsap Peninsula and Bainbridge Island. Although present on both, the Qva is not connected between Kitsap Peninsula and Bainbridge Island due to local groundwater discharge into Port Orchard. The Qva is the most used aquifer for domestic use within the model study area. No public groundwater supply well extracts water from the Qva on Bainbridge Island.

Upper Confining Unit, QC1, and Permeable Interbeds, QC1pi

The Upper Confining Unit (QC1) is a competent unit of clay and silt and is present across all of the study area and is sometimes referred to as the Lawton Clay unit. The presence of peat within QC1 suggests a possible Quaternary lacustrine origin. The average thickness of the QC1 is 120 feet but is as thick as 300 feet in some areas of the model domain. Notably, in the northern areas of Kitsap Peninsula and within Bainbridge Island, local coarse-grained discontinuities are present within the QC1 that is sufficiently water bearing for domestic extraction. These permeable lenses are referred to as the Permeable Interbeds (QC1pi) and are likely the result of an ancestral braided stream complex. No public groundwater supply well extracts water from the QC1pi on Bainbridge Island.

Sea Level Aquifer, SLA

The Sea Level Aquifer (SLA) is a widely present and used aquifer on Kitsap Peninsula and Bainbridge Island. The SLA consists of sands and gravels but contains local fine grained interbeds. As its name implies, the SLA intersects Puget Sound to the east, with depths ranging to approximately 200 feet below sea level. In addition, the SLA is likely connected between the Kitsap Peninsula and Bainbridge Island under the Agate Passage, at the northern extent of the island. On Bainbridge Island, the largest public water supply well system screened within the SLA is the Head of the Bay well network.

Middle Confining Unit, QC2

The Middle Confining Unit (QC2) is a very thick low-permeability aquitard underlying the SLA. QC2 has thickness ranging from 100 to 600 feet, with some of greatest thicknesses present on Bainbridge Island.

Glaciomarine Aquifer, GMA

The Glaciomarine Aquifer (GMA), below the QC2, is present at depths greater than 650 feet below sea level. The GMA is not as thick or continuous at the SLA (or the Fletcher Bay Aquifer below it) and yields less water. As a result, only one public water supply well is screened within the GMA (Taylor Road Well). The GMA is continuous across Port Orchard, connecting Kitsap Peninsula and Bainbridge Island.

Lower Confining Unit, QC3

The GMA is underlain by the Lower Confining Unit (QC3), an approximately 200-foot-thick unit consisting of clays and silts.

Fletcher Bay Aquifer, FBA

The Fletcher Bay Aquifer (FBA) is the deepest aquifer across the model study area, with depths up to 900 feet below sea level. The FBA is present across the entire model (except where bedrock outcrops) and is continuous between the Kitsap Peninsula and Bainbridge Island across Port Orchard. Public water supply wells Sands Road 1 and 2, Fletcher Bay Well, and Island Utility Well 1 and 3 all extract water from the FBA on Bainbridge Island.

Basal Units

Underlying the FBA is another extensive unit of clay and silt which extends to depths at least 1,200 feet below sea level. Below this low permeability unit is a bedrock unit consisting of marine sedimentary rocks and volcanic rocks. The bedrock is present everywhere and outcrops as Green Mountain and Gold Mountain on Kitsap Peninsula as well as on the southern extent of Bainbridge Island. This means the southern area of the island has no named aquifer or aquitard, only bedrock. Although water bearing fractures exist in the shallow portions of this outcrop, for

the purposes of the modeling effort, the bedrock is assumed to be fully competent and incapable of transmitting water at a significant rate.

4. GROUNDWATER MODEL REVISIONS AND DEVELOPMENT

This section describes the components of the groundwater model design which includes the model domain (horizontal and vertical), geologic layers, aquifer parameter assignment (e.g., hydraulic conductivity), boundary conditions, and aquifer stresses (such as recharge and pumping). For each subsection the model received by EA (the **2023 Aspect model**) will be briefly described followed by any revisions made by EA. If a revision was made, a justification for that revision is also provided. The model described in this section will be referred to as the **2025 EA model**. Moreover, this section only describes the baseline model (1984 to 2021) and the associated inputs. The predictive model (2022 to 2121) and the associated input datasets are described in Section 5.

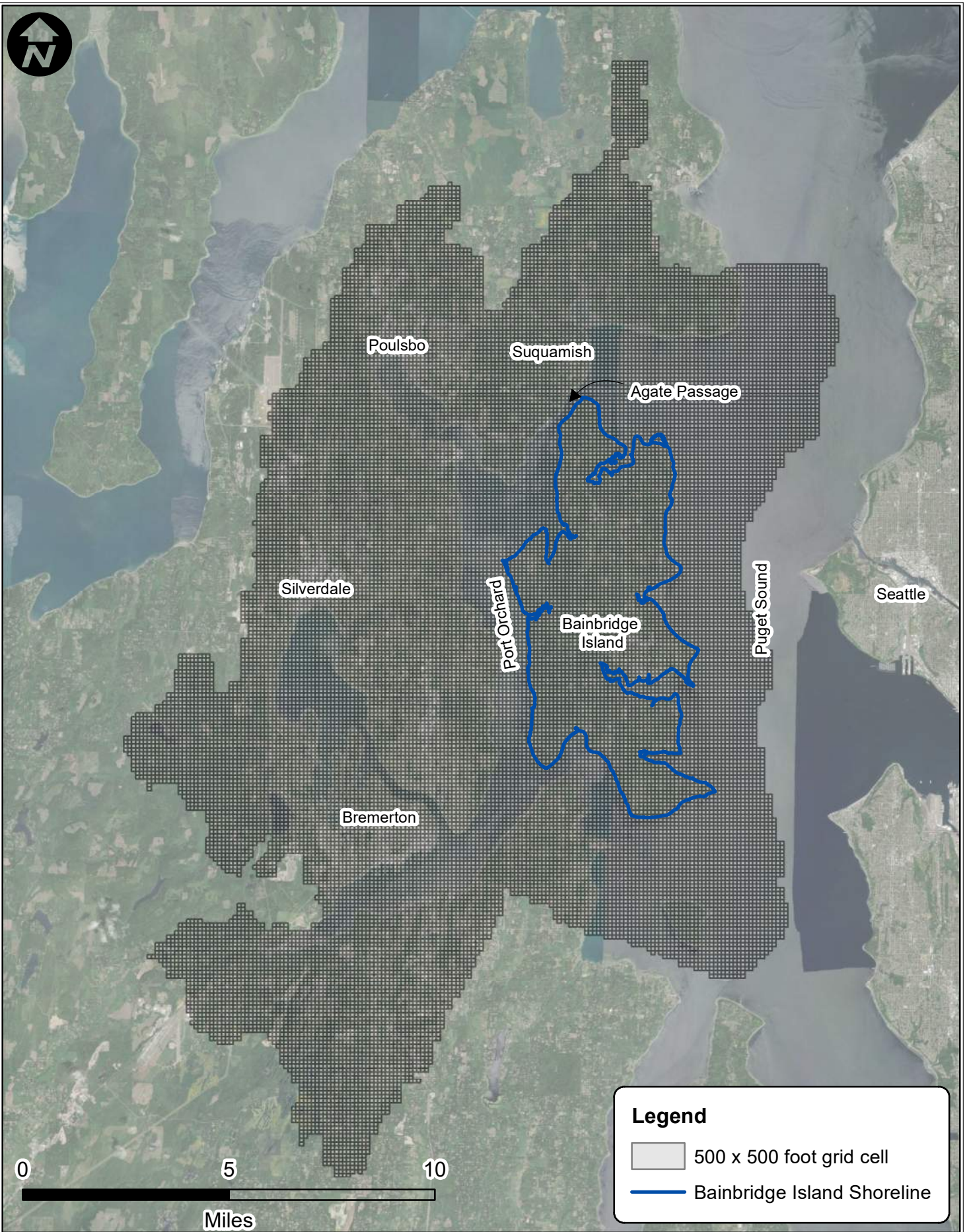
4.1 MODEL SPECIFICATIONS

The **2023 Aspect model** is a MODFLOW-USG model. This means it uses an unstructured grid, and the associated unstructured grid solver (Panday et al. 2013). During the model review it was noted that despite the -USG version of MODFLOW being used, the grid structure of the model was still rectilinear. It was further realized that this component of the model severely increased the model's run time (approximately 3-4 times longer). Typically, an unstructured grid (of any groundwater model) is implemented to better simulate localized areas of sharp hydraulic gradients (e.g., around an extraction well) by allowing for small spatial discretization of the feature locally. Given that this feature was not used, EA did not see the value in maintaining the unstructured grid and converted the model back to a rectilinear cell-based grid. The **2025 EA Model** is a MODFLOW-NWT model, using the NWT solver to solve the system of groundwater flow equations.

The **2023 Aspect model** simulated annual stress periods from 1984 through 2012 and monthly stress periods from January 2013 through December 2021, for a total of 225 stress periods. This was not revised over the course of this effort.

4.2 MODEL DOMAIN AND GRID

The horizontal groundwater model domain is shown on **Figure 1** which is the same groundwater model domain of the **2023 Aspect model**. As discussed above, the **2025 EA model** uses a rectilinear grid. This grid has a cell spacing of 500 by 500 feet and there are 315 rows and 216 columns.



4.3 MODEL LAYERS

The **2023 Aspect model** has 14 model layers, which is derived from the **2016 USGS model**. Several changes were made to this layer structure in the **2025 EA model**. It is noted that in all of these models (**2023 Aspect model**, **2016 USGS model**, and **2025 EA model**), model layers correspond to the hydrogeologic units described in Section 3.2. The layers are not uniform, or “flat,” but follow the top and bottom elevations of individual aquifer and confining units. These elevations were identified in drillers logs by USGS as part of their modeling efforts going back to the **2011 USGS model**. However, during EA’s model review, several discrepancies were identified where the model assigned layer elevations did not correspond to the inferred drillers log interpretation of hydrogeologic layers. Two examples of the more significant discrepancies are provided below.

North Bainbridge Well #9

The North Bainbridge Well #9 (NB9) pumping well is part of the Kitsap Public Utility District (KPUD) serving the northern areas of Bainbridge Island. The borehole was drilled in 1992. Based on the NB9 drillers log and the hydrogeologic CSM outlined in Section 3, EA determined that the FBA ranges from 1,125 to 1,394 feet below ground surface, for a total FBA thickness of 270 feet at this location. This interval corresponds to driller identified sands and gravels. Above and below this coarse-grained interval are driller identified clays and silts, which are fine-grained and less permeable. This suggests the presence of confining units, specifically the QC3 confining unit above and the basal clay unit below. However, in the **2023 Aspect model** (based on the **2016 USGS model**), the FBA at the location of NB9 is located between 888 and 1,342 feet below ground surface (454 feet thick). Overestimating portions of model layers (especially where pumping is occurring) can lead to large misinterpretations regarding available water supply, necessitating that incorrect model layer thickness (such as this one) to be revised and corrected.

South Bainbridge Well #8

The South Bainbridge Well #8 (SB8) pumping well is a part of KPUD serving the southern areas of Bainbridge Island near the bedrock outcropping. The **2023 Aspect model** (based on the **2016 USGS model**) has the well screened at a depth range of 157.6 to 189 feet below ground surface, which is accurate, and corresponds to the SLA. However, within the model, bedrock is present and therefore SB8 was modeled to be pumping from bedrock material and not the SLA. Based on the drillers log, bedrock material cannot be inferred to be present from 0 to 192 feet below ground surface.

Further, the bedrock layer near SB8 in the **2023 Aspect model** is assigned a low hydraulic conductivity value of 0.01 feet per day. It follows that because the *Allow Automatic Flow Reduction* functionality results in no model-assigned pumping rates being simulated at SB8. The model could not converge due to a public supply extraction well attempting to extract water from a low conductivity bedrock. The model cannot achieve its stated objectives (evaluating the impacts of increased groundwater pumping) given this inaccurate model layer configuration.

Model design issues required correction before moving forward with any additional model runs and associated interpretations. Ultimately, over 350 drillers logs were reviewed, and model layer depth corrections were assigned based on driller identified lithologic descriptions.

Beyond model layer elevation and thicknesses corrections there were also two additional changes to model layer configuration. First, because the Qvr is absent and the Qvt is not continuous across Bainbridge Island, EA decided to combined the Qvr, Qvt, and Qva into one model layer to improve model run time. Second, the **2023 Aspect model** had two bedrock layers that did not serve any purpose in the overall model water budget. As a result, the **2025 EA model** removes both bedrock units and the FBA serves as the bottom model layer. This change resulted in a total of 9-model layers in the **2025 EA model** in comparison to the 14-model layers in the **2023 Aspect model**. Model layers are outlined in **Table 1**.

Table 1. Hydrogeologic Units and Associated Model Layers

Hydrogeologic Unit	Model Layer in Aspect 2023 Model	Model Layer in EA 2025 Model
Vashon Recessional Aquifer, Qvr	1	1
Vashon Till Confining Unit, Qvt	2	
Vashon Advance Aquifer, Qva	3	
Upper Confining Unit, QC1 (1)	4	2
Permeable Interbeds, QC1pi	5	3
Upper Confining Unit, QC1 (2)	6	4
Sea Level Aquifer, SLA	7	5
Middle Confining Unit, QC2	8	6
Glaciomarine Aquifer, GMA	9	7
Lower Confining Unit, QC3	10	8
Fletcher Bay Aquifer, FBA	11	9
Clay Basal Unit	12	NA
Bedrock (1)	13	NA
Bedrock (2)	14	NA

Notes:

NA = not applicable

4.4 MODEL BOUNDARY CONDITIONS

Boundary conditions in groundwater models are how the aquifer system(s) within the model domain interact with water outside of the model and how water can move into or out of the model. There are three types of boundary conditions within the **2023 Aspect model**. The first is that the edge of the model in all model layers is a no-flow boundary condition. That is, water cannot move into or out of the model laterally. Along the extent of the model on the Kitsap Peninsula, these boundaries coincide with topographic divides (watershed boundaries). In general, this is a valid assumption in shallow aquifer systems where groundwater levels are

strongly controlled by recharge and topography. However, this assumption weakens within deeper aquifers where the impacts of recharge are less prominent and immediate. That is, the assumption of a no-flow boundary condition at all boundaries and depths of the model may not be valid. However, the analysis necessary to determine appropriate boundary conditions in the deeper aquifers fall outside this scope of work. As a result, the **2025 EA model** also assumes that no water may flow into or out of the model laterally at all depths.

The second type of boundary condition is a general head boundary condition, simulated using the *ghb* package within MODFLOW, and is the means by which Puget Sound and other associated canals and inlets are simulated in the groundwater model. This boundary condition allows for water to enter or leave the aquifer system based on an external surface water level (i.e., sea level). The **2025 EA model** did not change any general head boundary conditions from the **2023 Aspect model**.

The third boundary condition simulated in the groundwater model is through use of the *drain* package within MODFLOW. As discussed in Section 2, the initial **2016 USGS model** contained explicit representations of streams within the model, however the **2023 Aspect model** removed the streams within the model due to issues related to model convergence when MODFLOW-USG was implemented. As a result, the entirety of model layer 1 (the ground surface) was assigned as a drain cell which forces simulated groundwater levels above ground surface to be immediately removed from the model (and treated indirectly as runoff). EA does not believe this is the correct way to simulate this process and would have preferred to have explicitly represented stream networks as was done in the **2016 USGS model**. However, this revision was ultimately out of scope of this effort and was not made in the **EA 2025 model**. As a result all cells in model layer 1 are still assigned as drain cells.

4.5 MODEL STRESSES

There are two external stresses simulated in the groundwater model: recharge and extraction/return flows.

Groundwater recharge is the amount of water (usually expressed in units of length per time, e.g., inches per year) that infiltrates the ground surface and reaches the groundwater table or aquifer. Not all infiltrated water reaches the groundwater aquifer because a portion of the infiltrated water will discharge to streams or other surface water bodies, is taken up by vegetation (transpiration), or is evaporated into the atmosphere. In general, groundwater recharge is not an easily measurable quantity in the field and therefore there is always uncertainty in its assigned value. In the **2023 Aspect model**, groundwater recharge was assigned in the same manner as it was assigned in the **2016 USGS model**. Spatially variable precipitation was obtained from the PRISM model (PRISM Climate Group 2012), an open source publicly available dataset, and further downscaled using weather stations throughout the Kitsap Peninsula to provide greater spatial resolution. Regression equations developed by Bidlake and Payne (2001) were then used, which relate precipitation to groundwater recharge for soils in western Washington. **Figure 2** (taken from Welch et al. 2014) shows the four regression equations (expressed as lines on the graph) developed by Bidlake and Payne (2001).

Figure 2. Relationship between precipitation and groundwater recharge used to estimate model assigned recharge (taken from Welch et al. 2014)

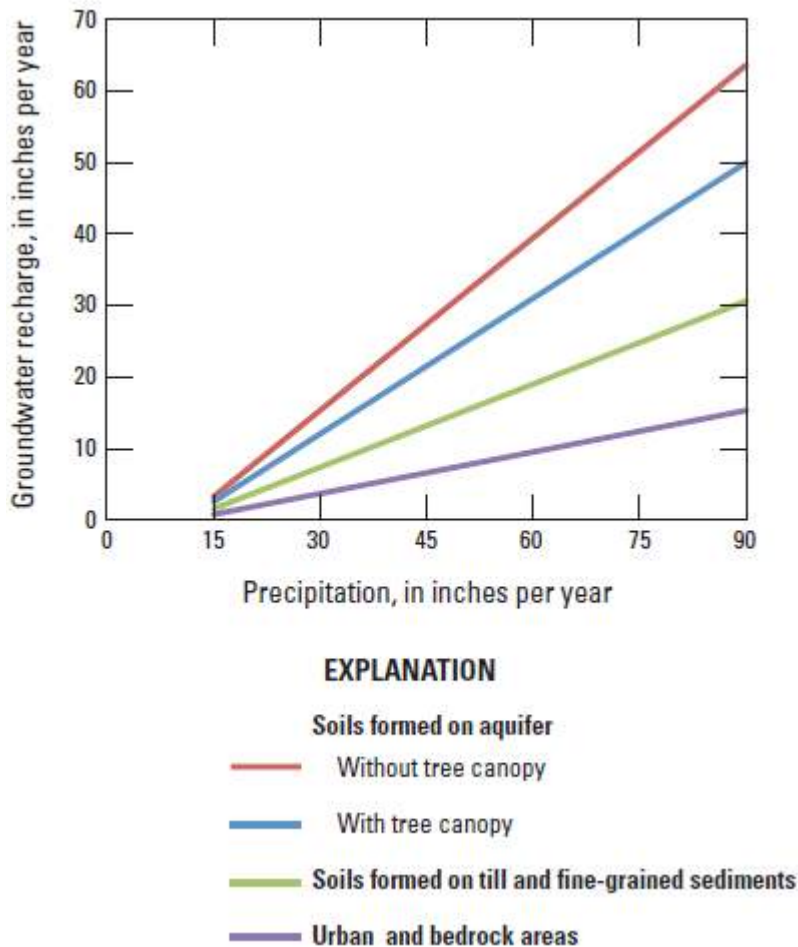


Figure 3 shows the spatially distributed model assigned average annual groundwater recharge rate from 1984 to 2021, expressed in units of inches per year. The distribution of recharge is dependent on the spatial distribution of precipitation derived from the PRISM dataset (which explains the generally increasing “banded” trends in the south-southwest direction) as well as the land use regressions established by Bidlake and Payne (2001) (which explains the variability within a precipitation band). Groundwater recharge is not constant, but rather changes on a yearly time step from 1984 to 2004 and then a monthly time step from 2005 to 2021. However, the relative differences as shown on **Figure 3** hold constant over the entire model simulation period. This element of the model was not changed in developing the **2025 EA model**.

Model assigned pumping and return (septic) flows were pre-defined in the **2023 Aspect model**. As outlined in Section 2, the model assigned extraction and return flow rates were provided in the **2016 USGS model** from 1984 to 2004 on an annual scale and from 2005 to 2012 on a monthly scale. Aspect added to this dataset and added monthly extraction/return flow rates from 2013 to 2021 for select wells. When reported extraction rates were not found by Aspect the pumping rates from the last year of the **2016 USGS model** (corresponding to 2012) were

assigned to the 2013 to 2021 time period. While updating the groundwater model, EA identified additional monthly volumetric extraction rates at the following wells (Sand Road 1-2, Island Utilities Well 1-3, North Bainbridge Well 3, 6, 7, 9, 10, Fletcher Bay Pumping Well, Head of the Bay Well 1, 1A, 2, 3, 4, 5, 6, South Bainbridge Well 7-8, Taylor Road Well, Bloedel Reserve Deep Well), and pumping rates were updated accordingly and are a part of the **EA 2025 model**.

In addition, the **EA 2025 model** has disabled the *Allow Automatic Flow Reduction* function in the model. This enforces that assigned extraction rates are always simulated unless the model fails to converge on a solution. The model always converged so flow reduction was not required.

4.6 MODEL HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is an aquifer property that quantifies the ease in which groundwater can travel through a subsurface material. The **2023 Aspect model** used a spatially continuous conductivity distribution based on the concept of pilot points which was also used in the **2016 USGS model**. Frans and Olsen (2016) provides a detailed description of the pilot point methodology in general and as it was specifically applied in the **2016 USGS model**.

Given the necessary changes made in layer thicknesses (Section 4.3) and extraction rates (Section 4.5) it follows that changes to hydraulic conductivity distributions were required for model calibration. In particular, the **2023 Aspect model** contained hydraulic conductivity assignments as high as 500 feet per day for the FBA. However, while evaluating FBA specific capacity estimates it became apparent that actual hydraulic conductivity values in the FBA are at least one order of magnitude less than 500 feet per day. Similar discrepancies exist in other aquifer units. As an example, **Table 2** provides estimates of hydraulic conductivity of some of the largest supply wells across Bainbridge Island completed in the SLA, GMA, and FBA. These estimates are derived from pump tests performed after well installation. Also provided is the assigned horizontal hydraulic conductivity in the **2023 Aspect model** cell.

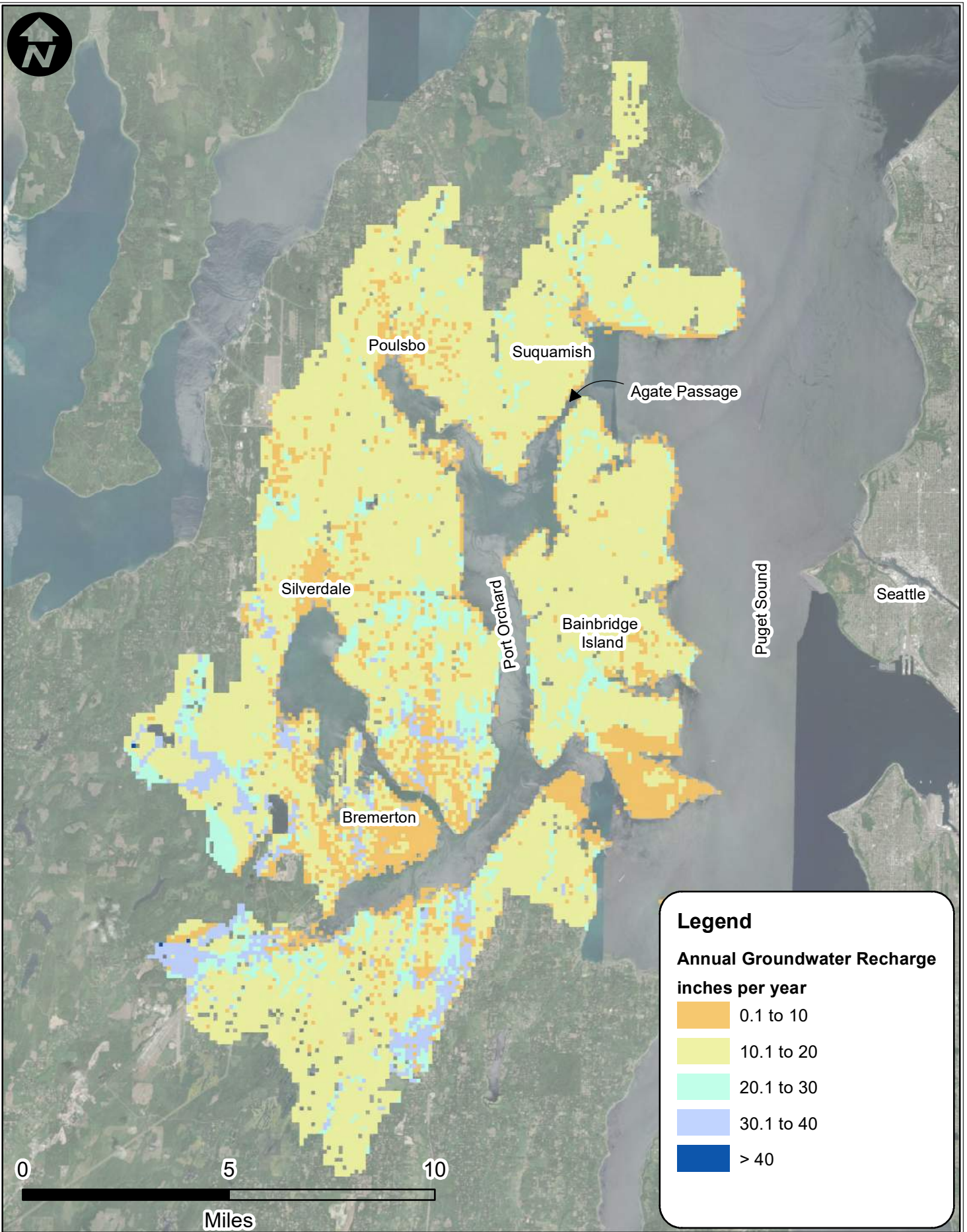


Table 2. Hydraulic Conductivity Estimates From Pump Tests Versus Model Assigned Hydraulic Conductivity

Aquifer	Supply Well	Estimated Hydraulic Conductivity from Pump Test (feet per day)	Assigned Hydraulic Conductivity in 2023 Aspect model (feet per day)	Assigned Hydraulic Conductivity in 2025 EA model (feet per day)
FBA	Sands Road 1/2	16	388	15
	North Bainbridge 9	12.7	157	8
	Island Utility Well 1	7.3	280	20
	Fletcher Bay Pumping Well	23.2	14	15
GMA	Taylor Road Pumping Well	0.9	89	13
SLA	Head of the Bay Well 1/1A/3	24.6	0.7	55
	North Bainbridge 3/6/7	24.8	3.4	55

Pump test derived hydraulic conductivity values were redistributed throughout the model layers using spatial zones around supply wells where the hydraulic conductivity was assumed to be constant. The hydraulic conductivity within each zone was allowed to vary during model calibration but was always held to be within a factor of 2 or 3 of the specific capacity estimated hydraulic conductivity value (see Section 4.7).

4.7 MODEL CALIBRATION

Based on the model design changes it was necessary to perform calibration before use. Model calibration is performed by changing model parameters in such a way that model results begin to converge to a solution that satisfies the objectives of the model. In this analysis, the hydraulic conductivity in all nine model layers were varied across Bainbridge Island, both in distribution and values. Off-island hydraulic conductivity was not varied. Model calibration is quantified by minimizing the difference between observed and simulated values. This difference for one monitoring point is called a residual. There are 93 monitoring locations (monitoring wells and pumping wells) that have been gauged since 1984 corresponding to 9,574 individual water level measurements in space and time. The error of the model was expressed using the normalized root mean squared deviation (NRMSD) between the observed groundwater levels and the simulated groundwater levels. The NRMSD is calculated as:

$$NRMSD = \frac{\sqrt{\sum_{i=1}^N (h_{obs,i} - h_{sim,i})^2}}{\max(h_{obs}) - \min(h_{obs})}$$

where:

$h_{obs,i}$ is the observed groundwater level at a measured point i

$h_{sim,i}$ is the simulated groundwater level at a corresponding modeled point in space i

N is the total number of measuring points (in this case, $N = 9,574$)

$\max(h_{obs})$ and $\min(h_{obs})$ are the maximum and minimum observed groundwater levels for the simulation period

An acceptable NRMSD is typically 10% or less. Calibration was performed iteratively by changing initial parameter values sequentially until the NRMSD for groundwater levels settled below 10%. At the end of model calibration, the NRMSD of the **2025 EA model** for on-island samples is 3.98%. An observed versus simulated graph of groundwater levels is shown on **Figure 4** along with two dashed lines showing the 5% and 10% error. Ideally, all monitoring points would lie within a 10% error. For this model, 97% of modeled points fall within 10% error (9,259 out of 9,574). The final calibrated hydraulic conductivity distributions for all nine model layers are provided on **Figures 5A through 5I**.

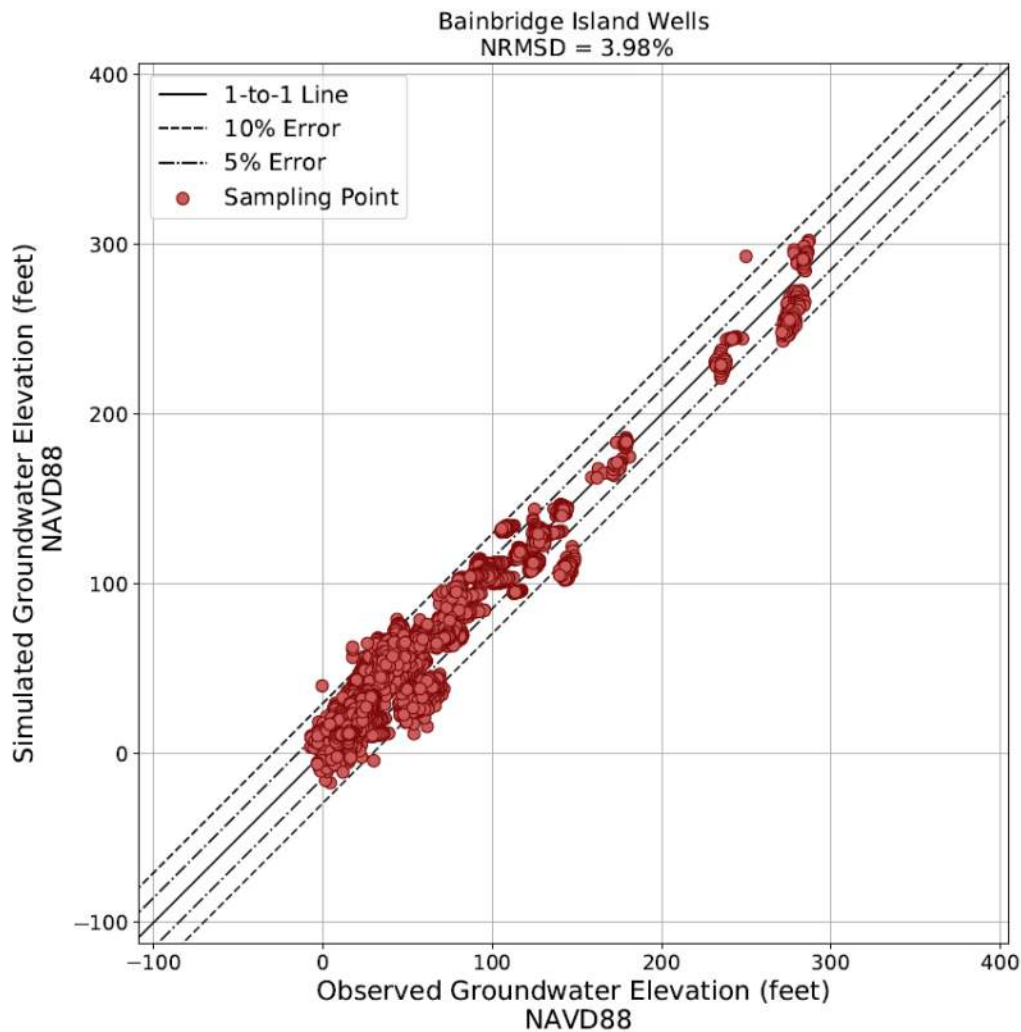


Figure 4. Observed versus Simulated Groundwater Levels on Bainbridge Island

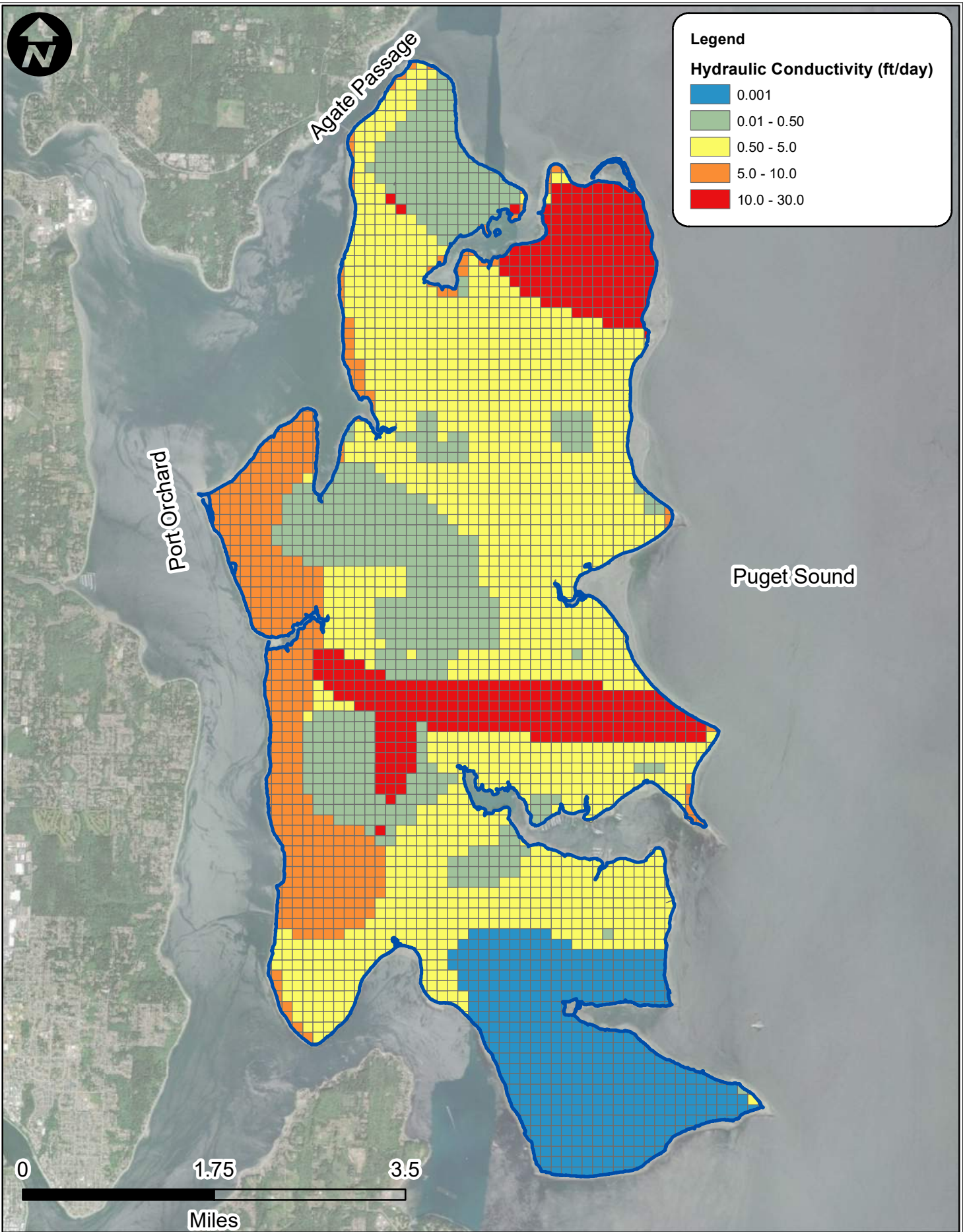
4.8 MODEL RESULTS

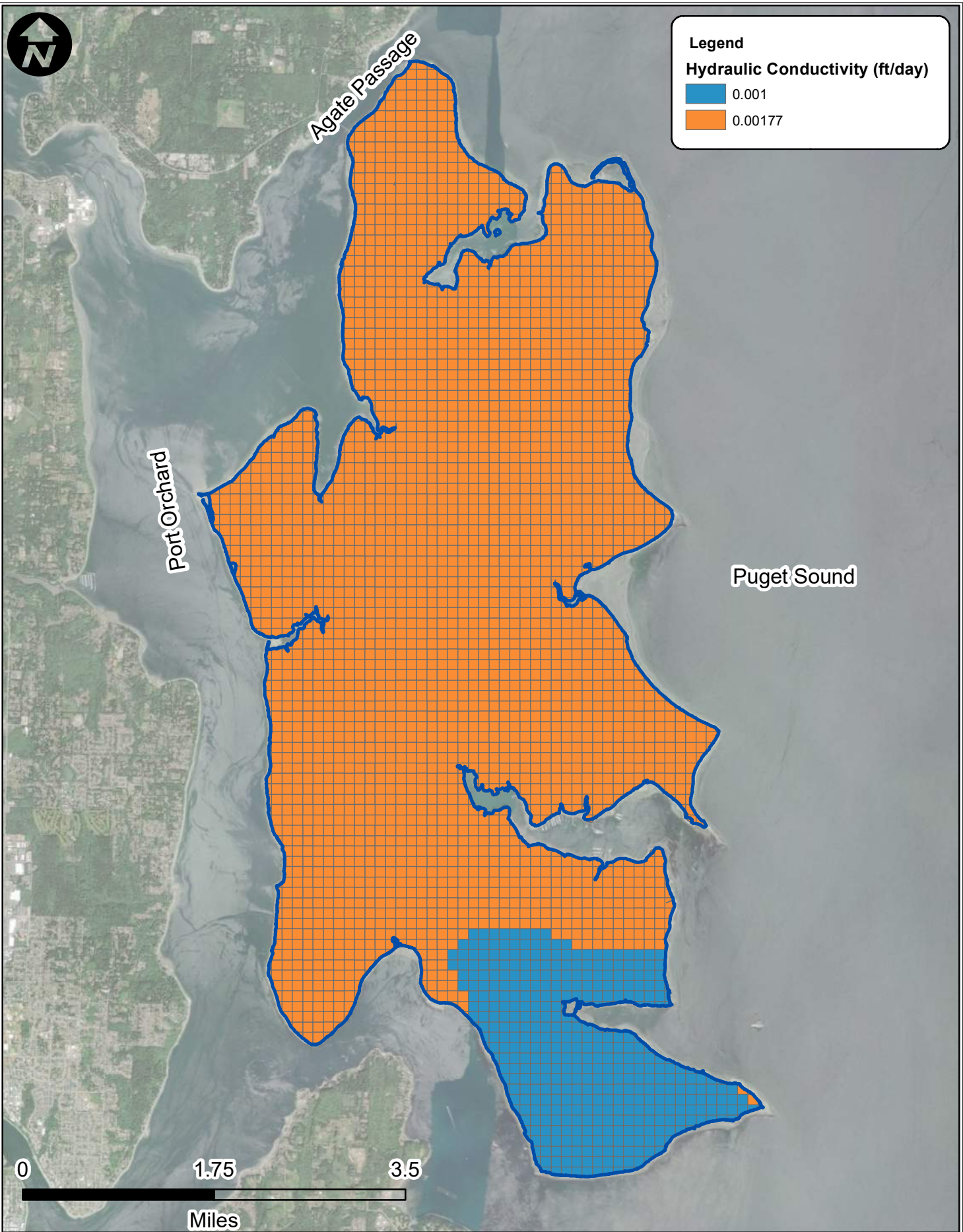
Output from the calibrated **2025 EA model** will serve as the point of comparison for the predictive modeling in Section 5. Simulated groundwater contours in the Qva, SLA, GMA, and FBA at the final stress period (corresponding to December 2021) are shown on **Figures 6 through 9**, respectively. In reference to **Figures 6 through 9**, a ubiquitous downward hydraulic

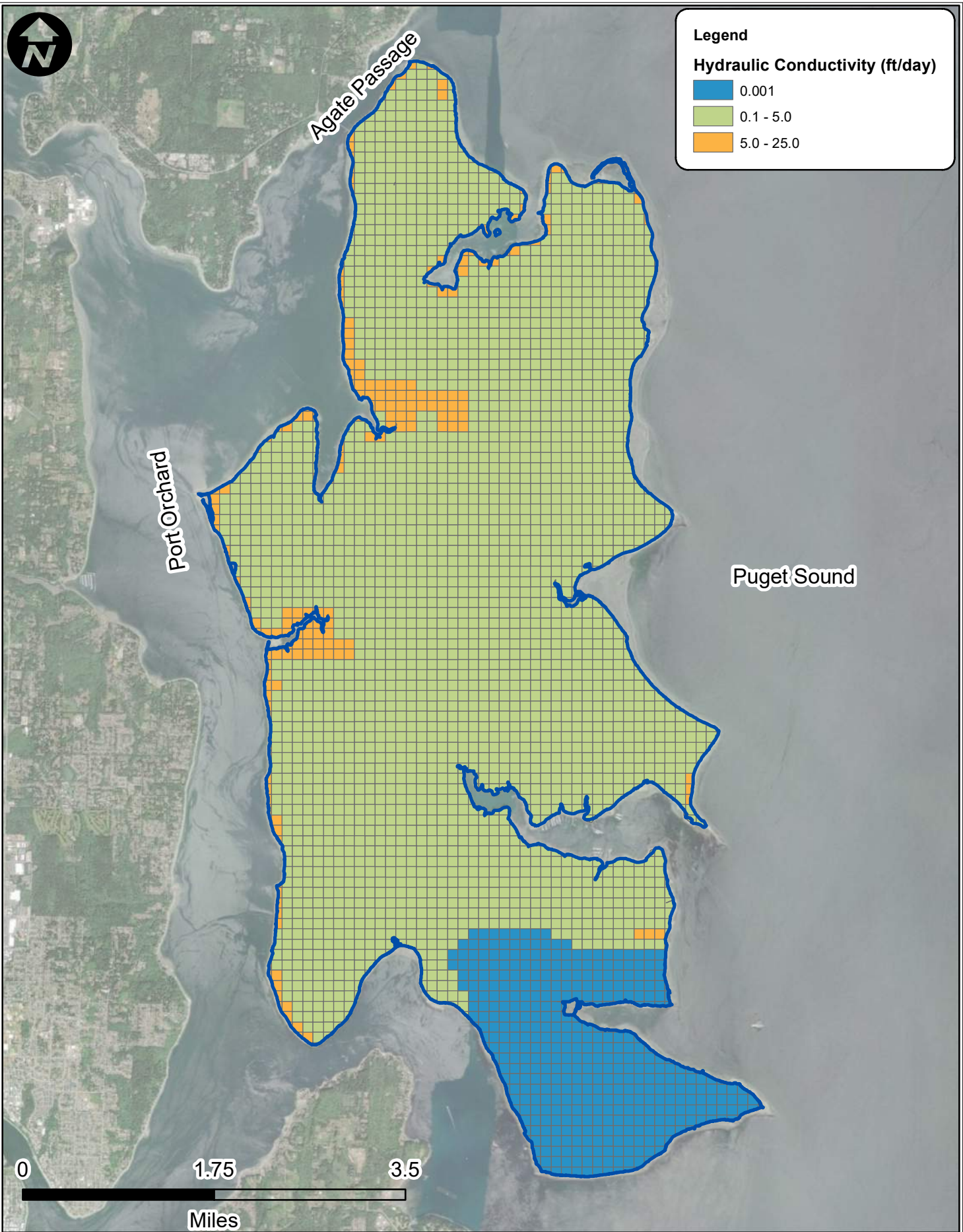
gradient exists across Bainbridge Island, meaning groundwater levels are higher within the hydrogeologic units closer to land surface. Average groundwater levels within the four water bearing units are provided below in **Table 3** showing the monotonic downward gradient between units.

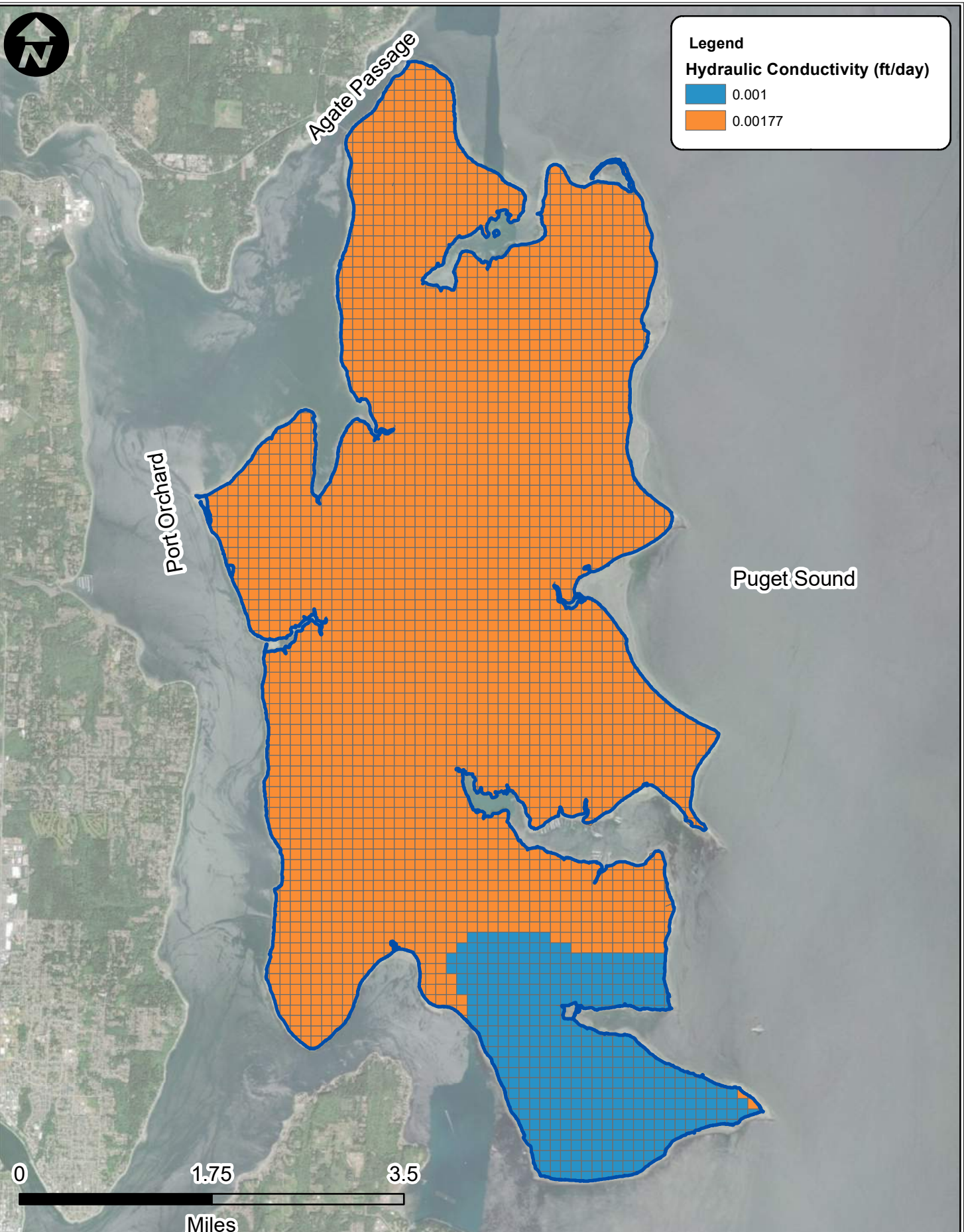
Table 3. Simulated Current Average Groundwater Levels In Primary Hydrogeologic Units Across Bainbridge Island

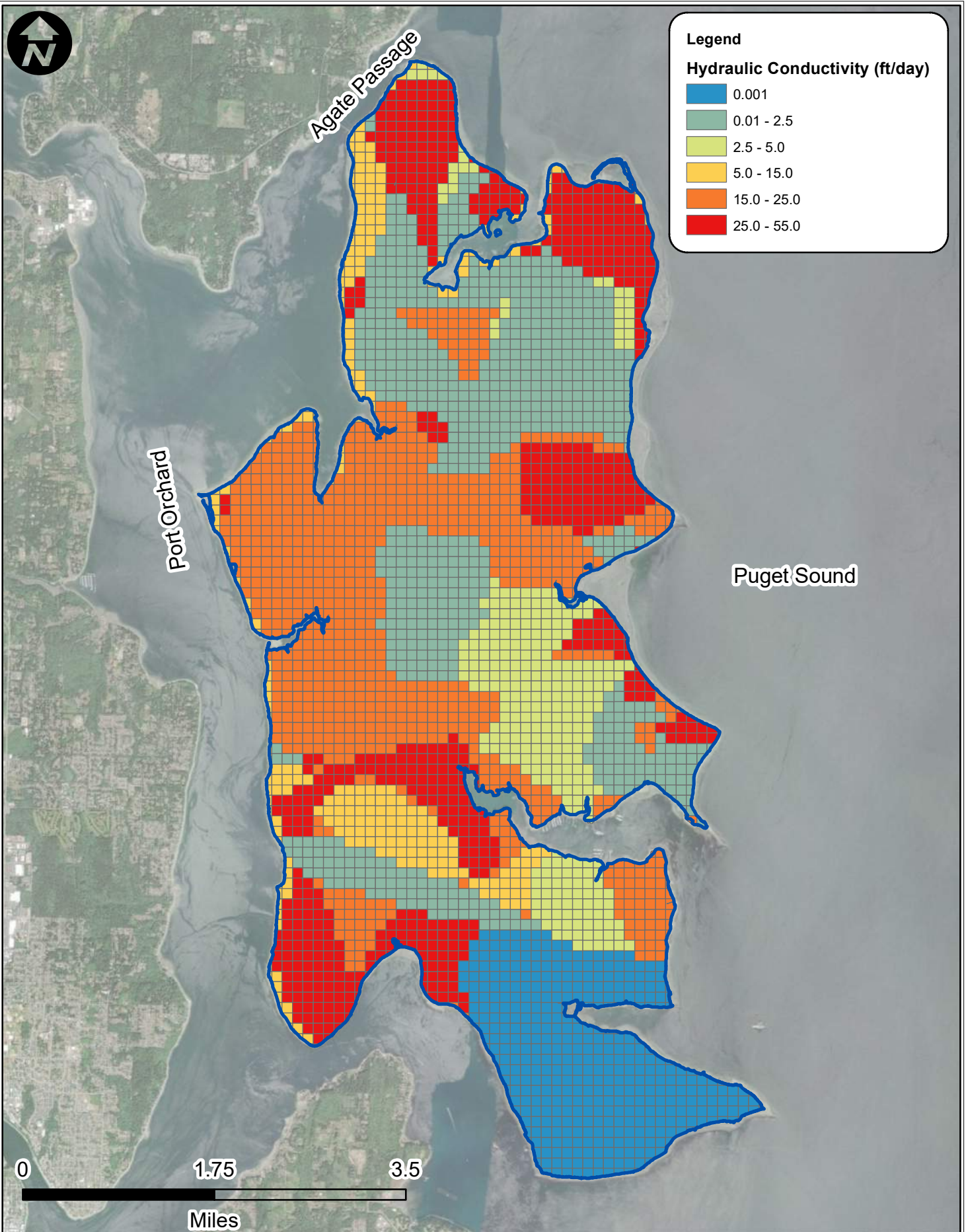
Mean Groundwater Level (feet above mean sea level)	
Hydrogeologic Unit	Current
Qva	102.2
SLA	43.4
GMA	37.2
FBA	36.8

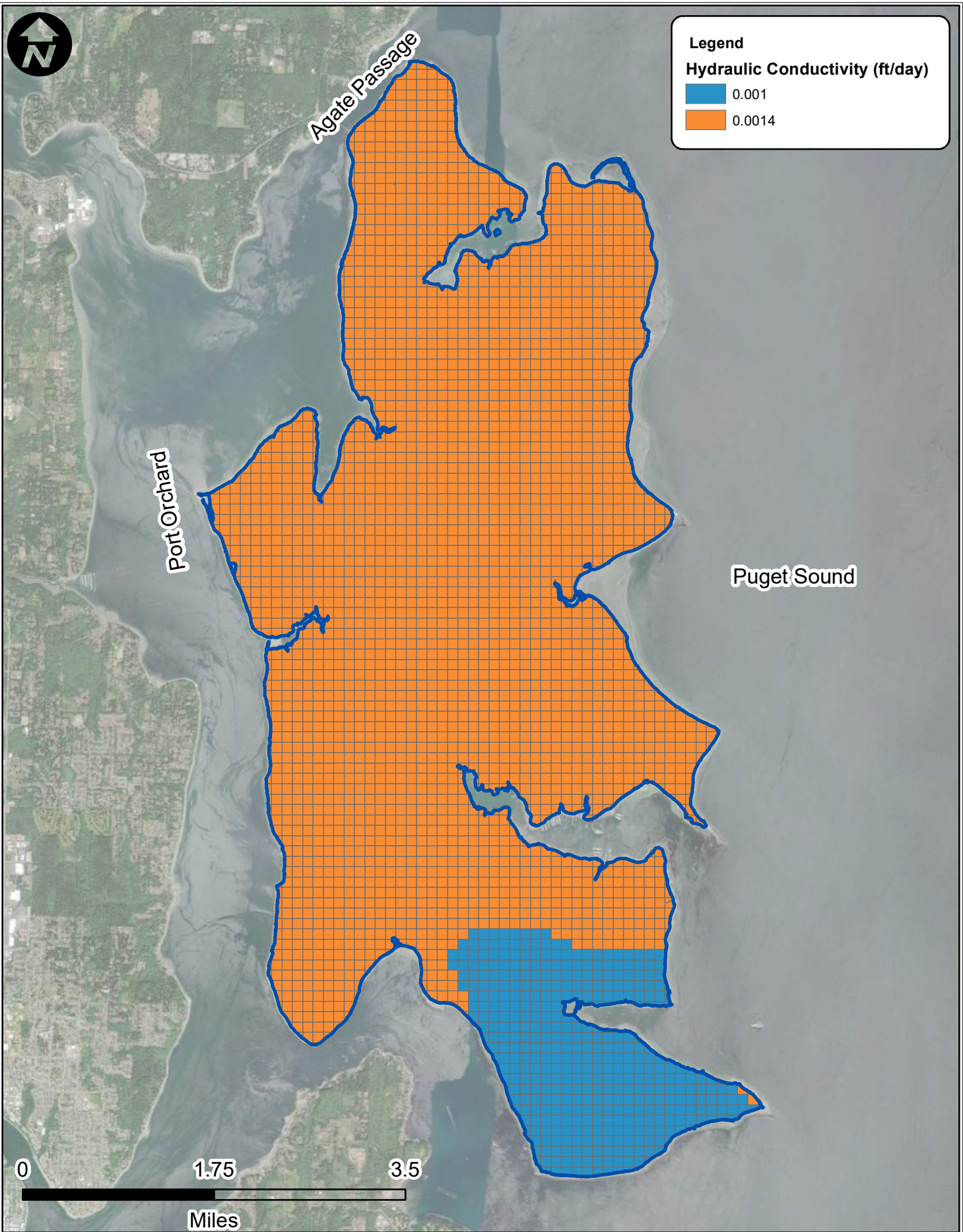


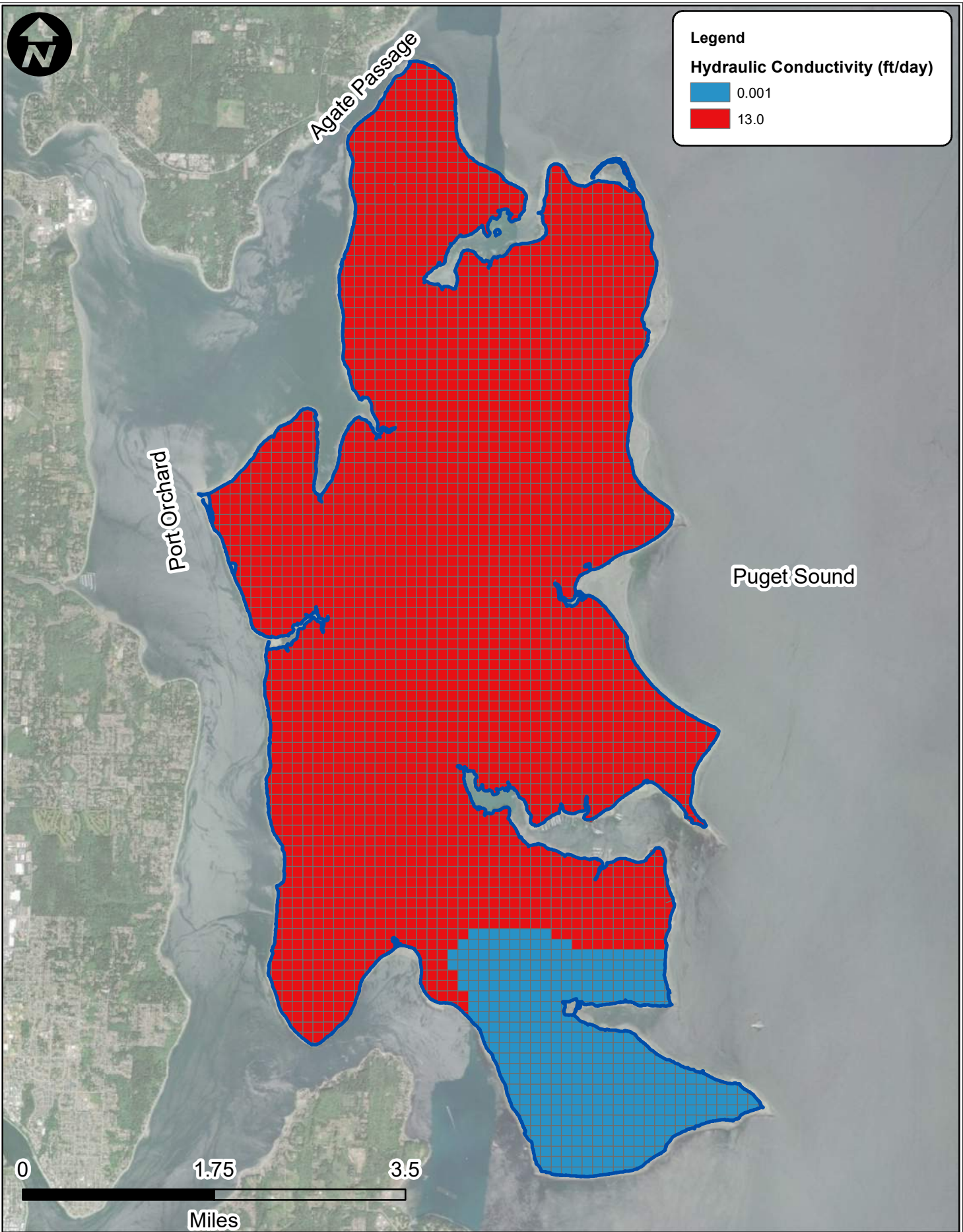


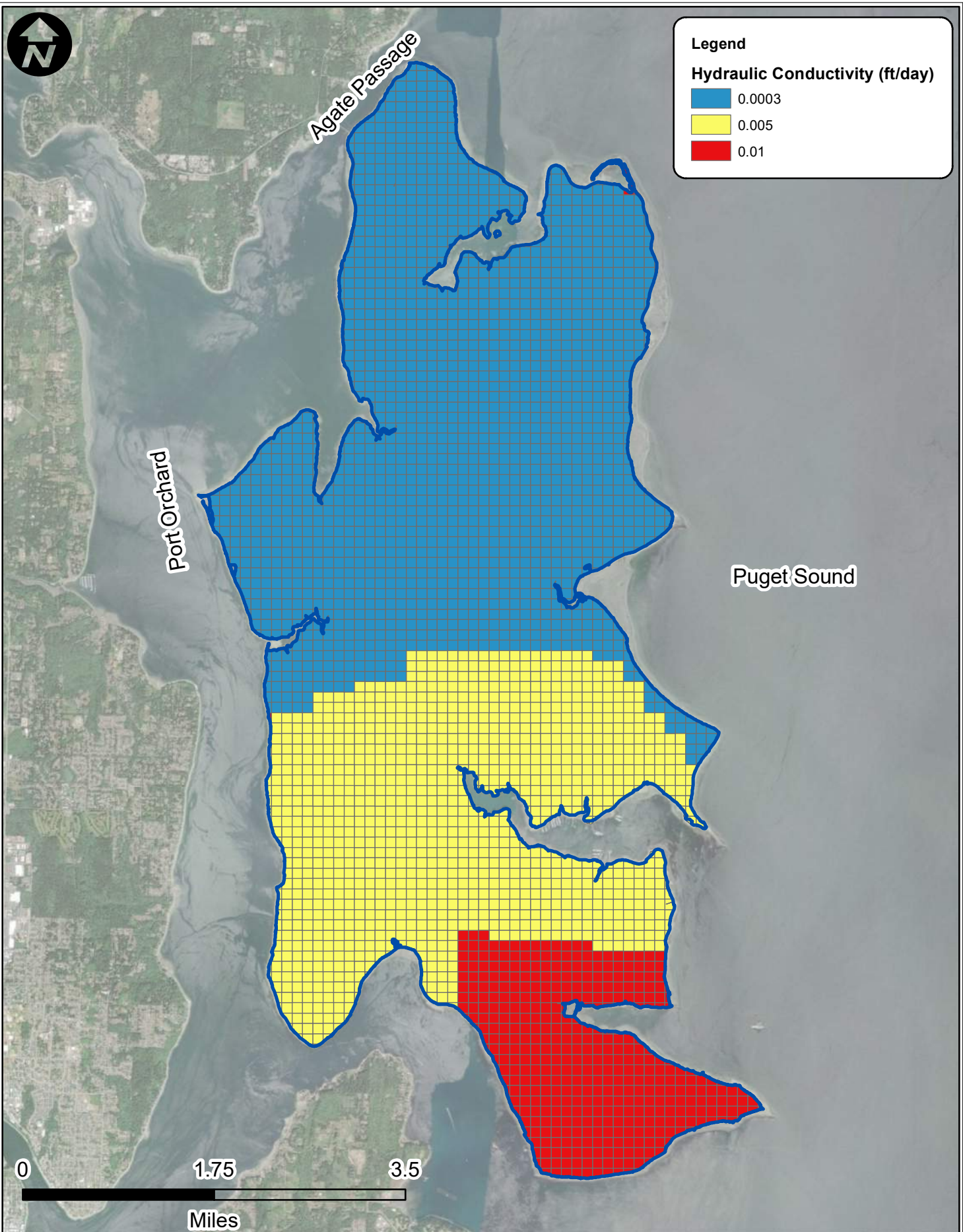


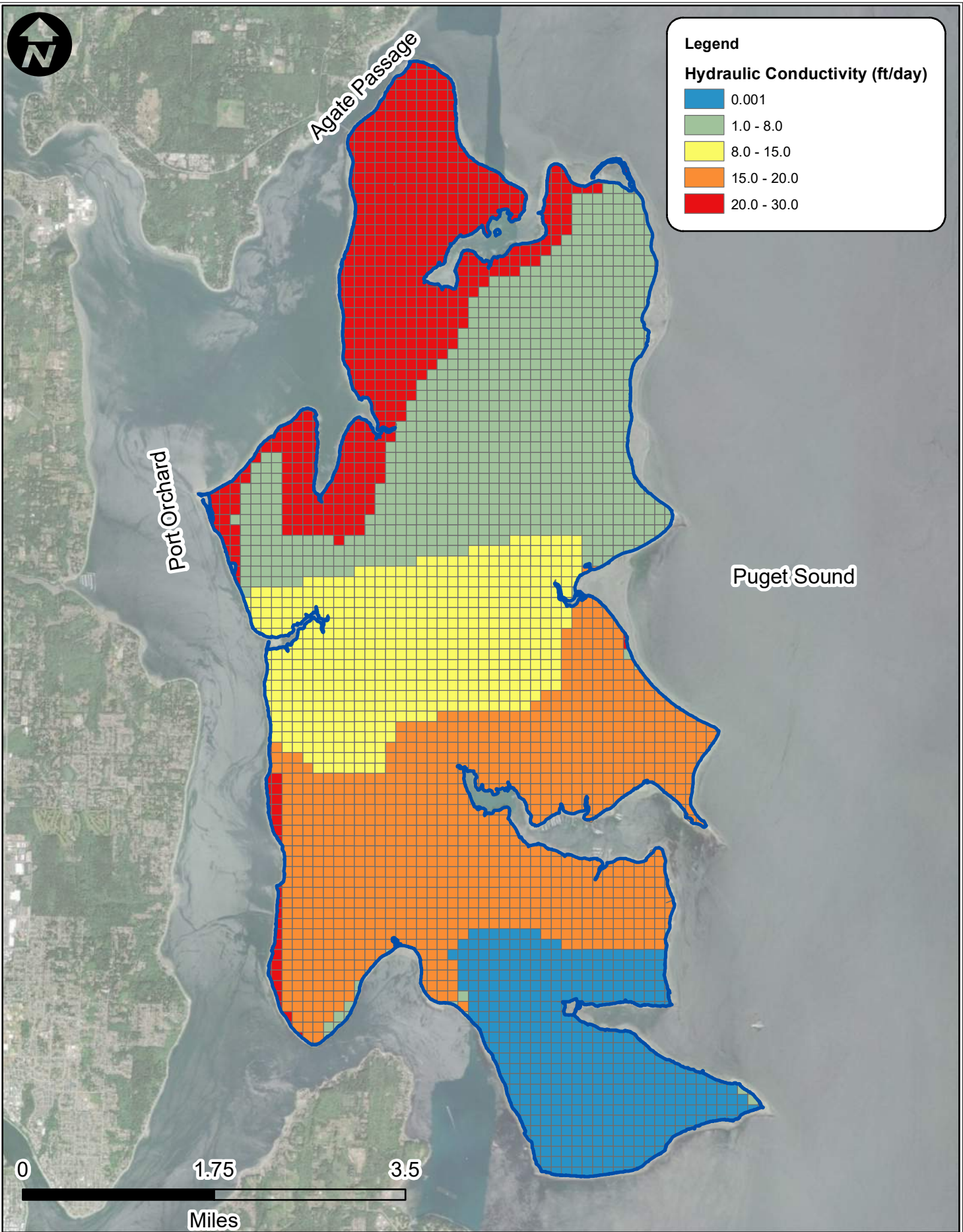










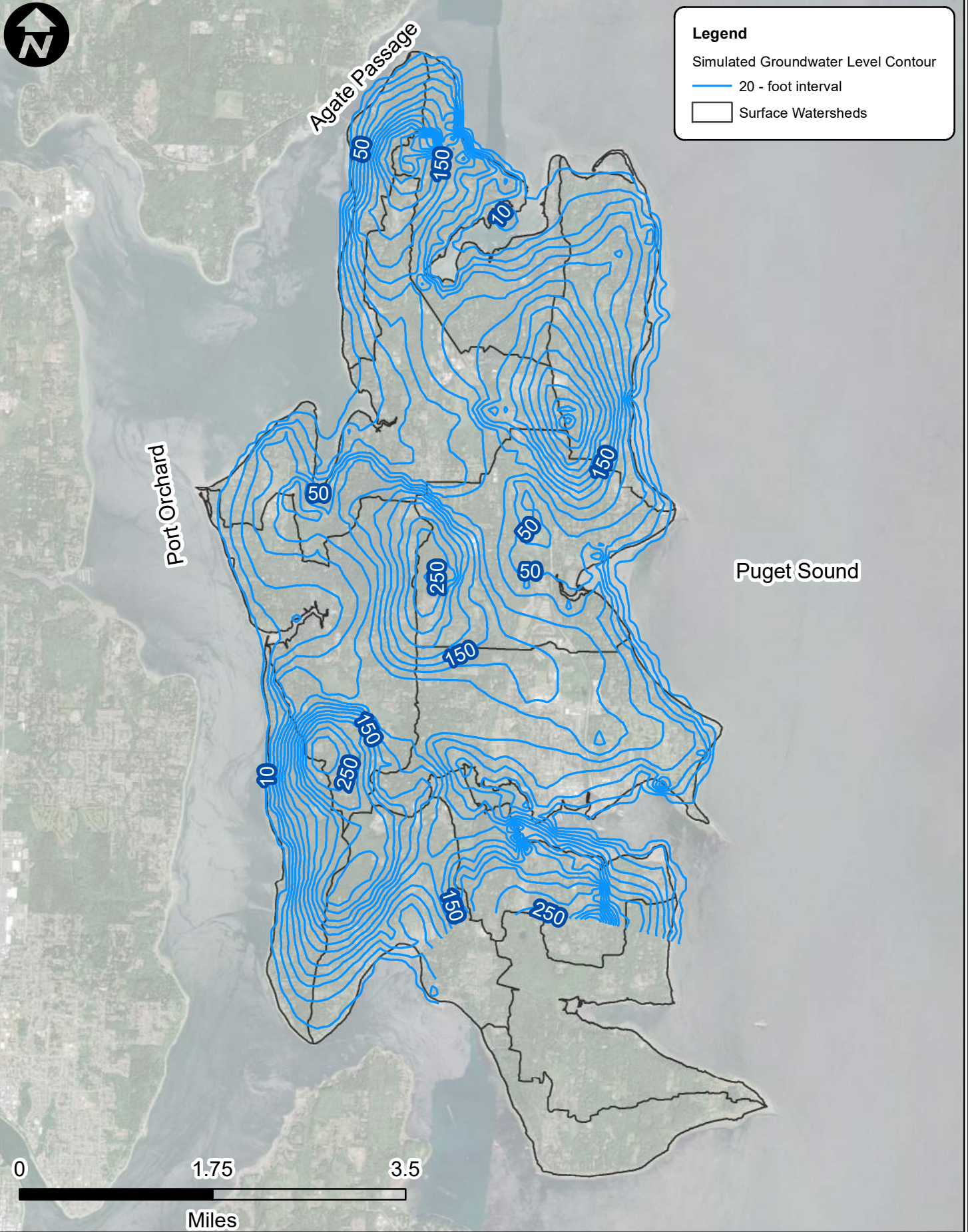




Legend

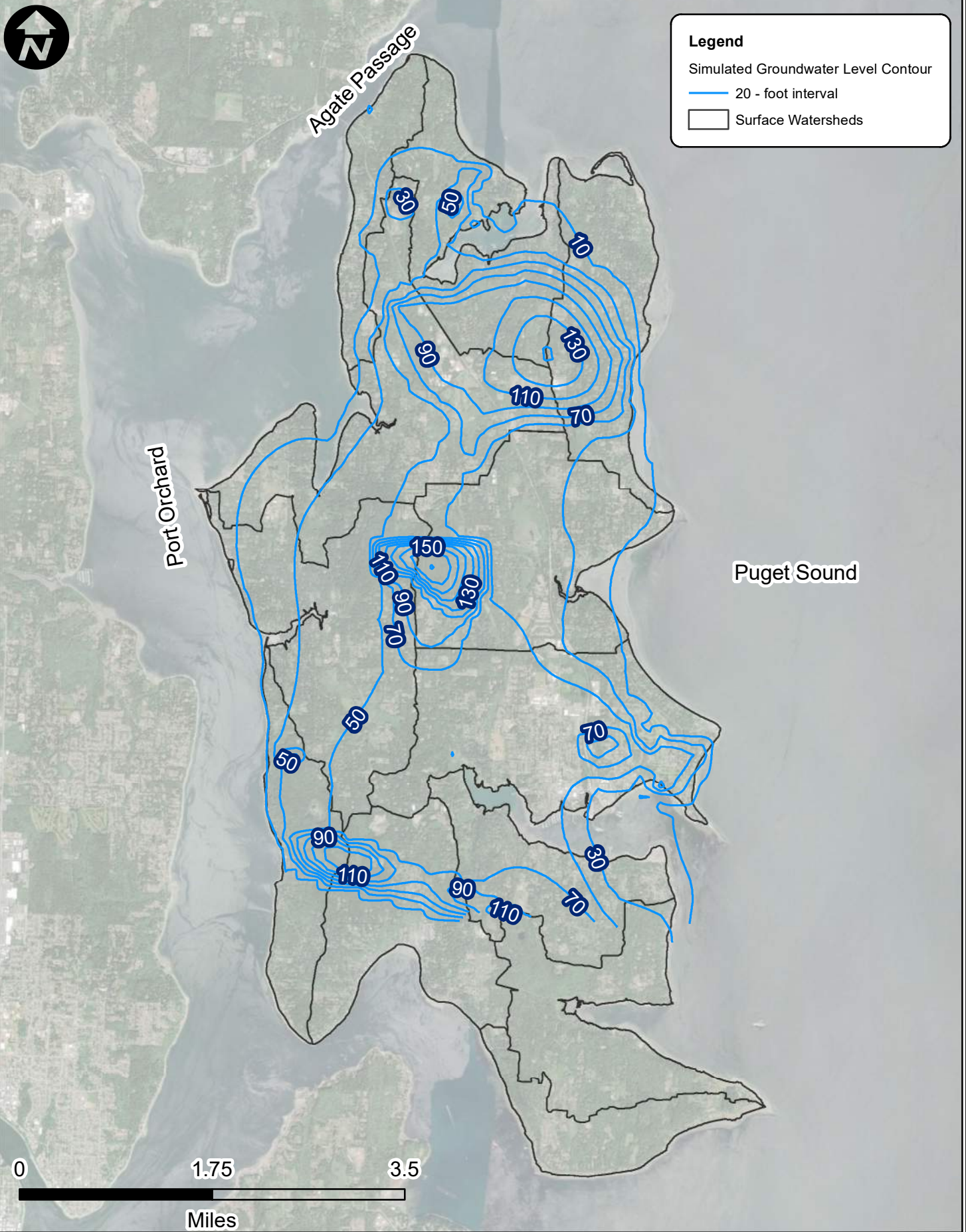
Simulated Groundwater Level Contour

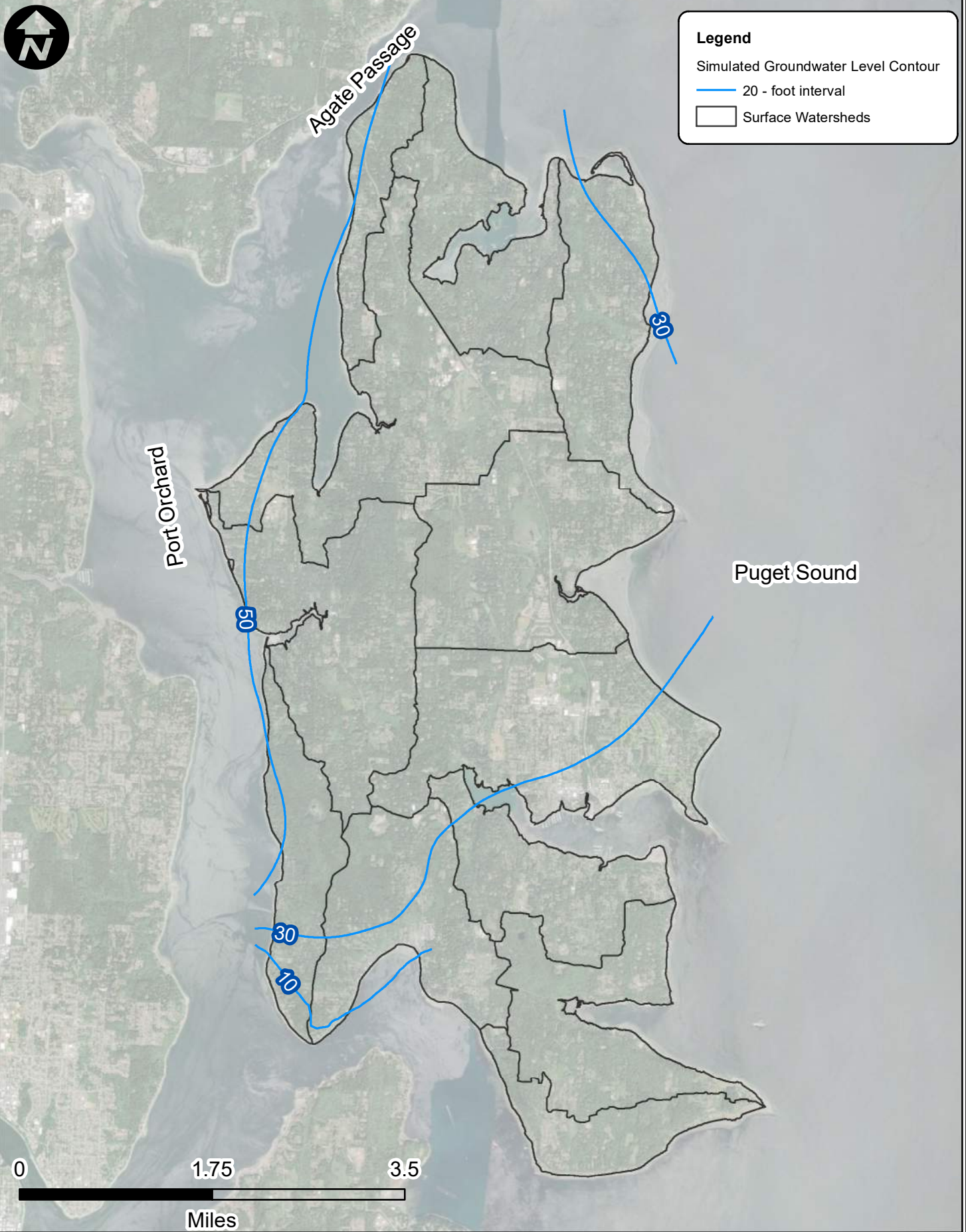
- 20 - foot interval
- Surface Watersheds



Simulated Current Groundwater Levels in Qva

Figure 6

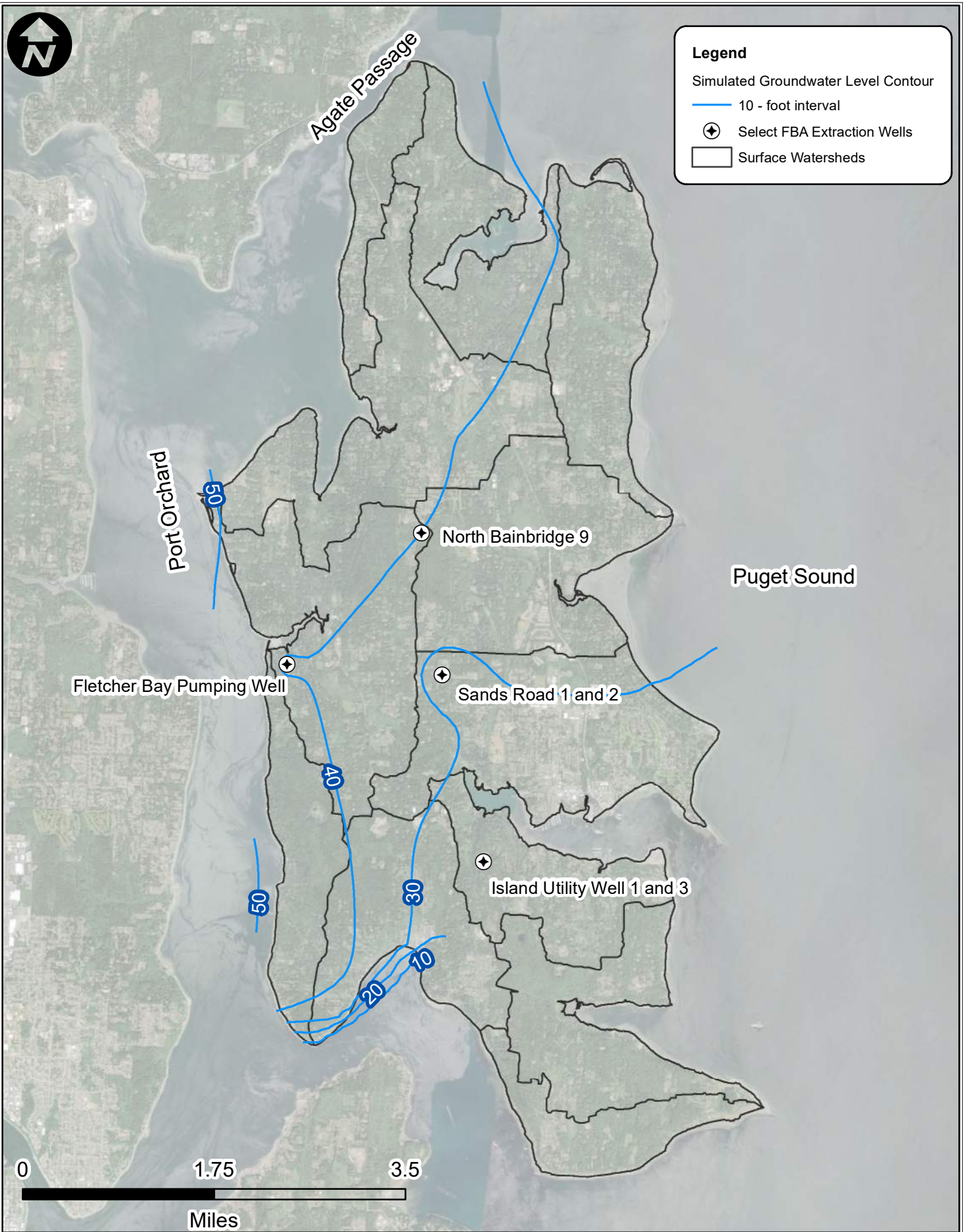






Legend

- Simulated Groundwater Level Contour
- 10 - foot interval
- Select FBA Extraction Wells
- Surface Watersheds



Simulated Current Groundwater Levels in FBA

Figure 9

5. GROUNDWATER MODEL APPLICATION

Following the revisions to the groundwater model and updated calibration (Section 4), the **2025 EA model** was used as a tool to simulate planning scenarios of the time period 2022 to 2121. Multiple datasets were used to represent possible future climatic and population growth scenarios. Predictive models are developed to provide insights into how the groundwater system may behave based on a given set of hypothetical (but possible) conditions. That is to say, the scenarios evaluated as part of this effort are not predicted to occur with absolute certainty; they are evaluated to improve the understanding of how groundwater resources can be better protected and managed in the context of a changing and uncertain future.

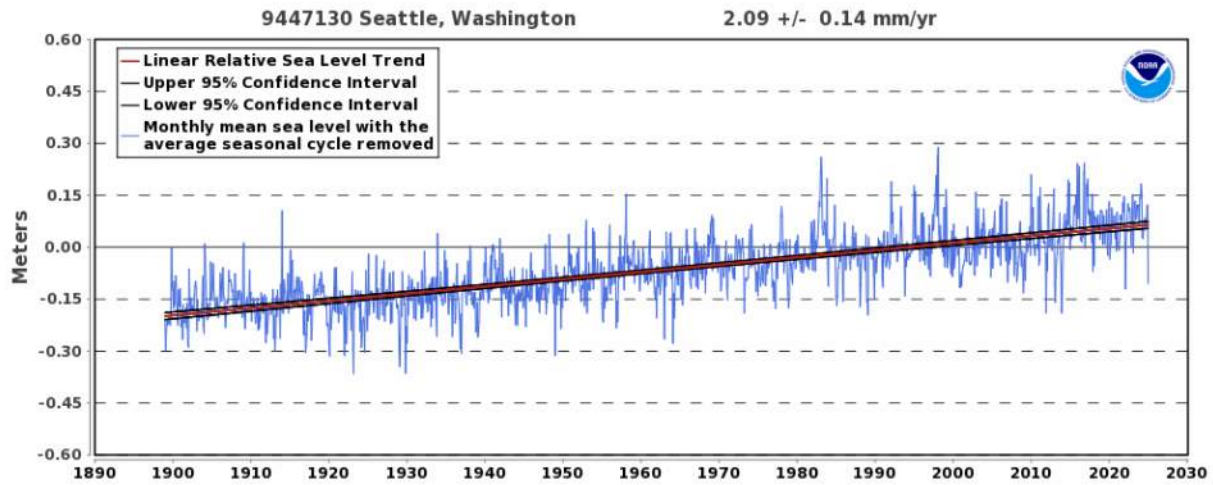
In all of the predictive scenario runs, three variables were altered from their baseline or current value: groundwater recharge rates, groundwater pumping rates (and associated return flow rates), and sea level. Possible future changes to these three variables—and the methodologies, datasets, and/or sources used to evaluate these changes—are discussed in Section 5.1. Three different planning scenarios were simulated in this analysis and are characterized by different combinations of future groundwater recharge rates, pumping rates, and sea level rise. The three planning scenarios are described in Section 5.2. In addition, prior to simulating the planning scenarios, a sensitivity analysis was performed wherein one variable (groundwater recharge, pumping, sea levels) was altered from its nominal or baseline value while the other two variables were held to their baseline value to assess how the aquifer system on Bainbridge Island responded.

Note, climate change models were used for predictions on groundwater recharge and sea level rise. These models are based on a metric called *representative concentration pathways (RCPs)*. RCPs are possible trends of global greenhouse gas concentrations in the atmosphere, generally over the next 100 to 150 years. Briefly, RCP8.5 represents a rate of global carbon emissions that does not change from the current rate over time and therefore is often viewed as the “worst-case climate change scenario”. Scenario RCP4.5 represents a global carbon emission trend that continues to rise logarithmically to the year 2045 at which points emissions then flatline and steadily decline. The RCP4.5 scenario is often seen as the most likely emission scenario due to many nations already implementing carbon emission regulations and the inherent fact that many carbon emitting energy sources are finite in abundance (Höök and Tang 2010). Vuuren et al. (2011) provides a detailed overview of RCPs, their physical representation, and climate models in general.

5.1 SCENARIO DESIGN

5.1.1 Sea Level Rise

Anthropogenic climate change has, and will continue to, result in increased sea levels around the world. Near Seattle sea levels have risen approximately 0.70 feet in the past 100 years (0.08 inches per year). **Figure 10** shows observed sea levels at National Oceanic and Atmospheric Administration (NOAA) Station 9447130. Sea levels dictate groundwater levels because they determine the groundwater level at which discharge to the sea occurs and where the freshwater-saltwater interface occurs.

Figure 10. Relative Sea Level Trend at NOAA Station 9447130 near Seattle, Washington

Source: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9447130

To simulate possible future sea level conditions in Puget Sound an analysis performed by the University of Washington Climate Impacts Group (CIG) was used that predicts relative sea level rise (RSLR) to the nearest tenth of a foot for the next 150 years (Miller et.al. 2018). **Table 5** summarizes model predicted RSLR based on global emission scenarios RCP8.5 and RCP4.5. In each case, an associated probability of exceedance is provided which can be interpreted as the probability that a given RSLR will *at least* occur. For example, under the RCP8.5 scenario there is a 99% probability that there will be at least a 0.1-foot RSLR in 2050, a 0.2-foot RLSR in 2060, a 0.4-foot RSLR in 2080, etc. Similarly, there is only a 1% probability that there will be a 1.6-foot RLSR in 2050, a 2.1-foot RLSR in 2060, a 3.4-foot RLSR in 208, etc.

Table 5. Relative Sea Level Rise Exceedance Probability Projections by RCP

RSLR Projections (in feet)						
Year	Global Emission Scenario RCP8.5			Global Emission Scenario RCP4.5		
	1%	50%	99%	1%	50%	99%
2020	0.5	0.2	0.0	0.5	0.2	-0.1
2030	0.8	0.4	1.0	0.8	0.4	0.0
2040	1.1	0.6	1.0	1.1	0.6	0.0
2050	1.6	0.8	0.1	1.5	0.7	0.0
2060	2.1	1.0	0.2	2.0	0.9	0.1
2070	2.7	1.3	0.2	2.5	1.2	0.1
2080	3.4	1.6	0.3	3.1	1.4	0.1
2090	4.2	1.9	0.4	3.7	1.6	0.1
2100	5.2	2.3	0.5	4.5	1.8	0.2
2110	5.8	2.4	0.6	5.3	2.0	0.2
2120	6.9	2.8	0.7	6.1	2.3	0.2
2130	8.0	3.1	0.8	7.0	2.5	0.1
2140	9.1	3.5	0.9	8.0	2.7	0.0
2150	10.4	3.8	0.9	8.9	2.9	0.0

Based on consultation with COBI and stakeholders, it was decided to run groundwater modeling scenarios in which 1% and 50% exceedance probability of the RCP8.5 scenario were applied to sea levels (in bold in **Table 5**). That is, over 100 years (year 2121 in the model), RSLR is simulated to be 6.9 feet and 2.8 feet, respectively. Sea level was changed within the model according to **Table 5** over time and between decades the change was modeled to occur linearly. As discussed in Section 4.4, the groundwater model represents sea levels through a boundary condition referred to as the general head boundary conditions (*ghb* package within MODFLOW).

5.1.2 Groundwater Recharge

Groundwater recharge is the dominant source of external water for most aquifer systems. It follows that changes in long-term precipitation rates will have an impact on recharge. The relationship between precipitation and recharge is a complicated one and is dependent on many factors including soil and land use type, antecedent soil moisture, canopy coverage, evapotranspiration rates, and the intensity of storm events.

To estimate possible changes to groundwater recharge over time it is first necessary to obtain estimates of changes to precipitation over time. These data were obtained from CIG with the prediction applying to Bainbridge Island and the eastern half of the Kitsap Peninsula. **Tables 6 and 7** show expected total precipitation from October-March and April-September, respectively, for RCP8.5 and RCP4.5. Under both RCPs, total precipitation between October-March is expected to increase 9-13% between 1990 conditions and the year 2099. Under both RCPs, total precipitation between April and September is expected to decrease from 1990 baseline

conditions by approximately 5-6%. Given that more than 75% of precipitation occurs between October and March, it follows that on an annual scale that total precipitation is expected to increase between 6% and 9% over the next 80 years.

Table 6. Predicted Changes In Precipitation Between October And March (2010-2099)

Condition	Total Precipitation (October through March)		
	Years	Depth (inches)	Change (inches)
Historic	--	34.3	
RCP4.5	2010-2039	35.5	+1.1
RCP4.5	2040-2069	36.8	+2.5
RCP4.5	2070-2099	37.4	+3.1
RCP8.5	2010-2039	35.4	+1.0
RCP8.5	2040-2069	36.8	+2.4
RCP8.5	2070-2099	38.9	+4.6

Table 7. Predicted Changes In Precipitation Between April And September (2010-2099)

Condition	Total Precipitation (April through September)		
	Years	Depth (inches)	Change (inches)
Historic	--	10.1	
RCP4.5	2010-2039	10	-0.1
RCP4.5	2040-2069	9.8	-0.3
RCP4.5	2070-2099	9.6	-0.5
RCP8.5	2010-2039	9.9	-0.2
RCP8.5	2040-2069	9.8	-0.3
RCP8.5	2070-2099	9.5	-0.6

Despite these predictions, increased precipitation does not always correspond to increased groundwater recharge. When precipitation events are very intense (i.e., a large amount of precipitation over a very short period of time), a relatively greater portion of precipitation results in runoff (which flows to creeks, rivers, and the Sound) than recharge. This occurs when the rate of precipitation greatly exceeds the infiltration capacity of the soil. This is germane because many climate models have predicted that the occurrence of high intensity storms will increase in a warmer climate, including in western Washington (Miller et. al. 2018). Specifically, CIG predicts an average increase of three high-intensity storms per year, increasing from the current average of four storms per year to seven storms per year.

Despite a conceptual understanding of how precipitation, runoff, and infiltration relate, it is not a trivial exercise to quantitatively predict how groundwater recharge will change based on (a) increased expected precipitation over the next 100 years, and (b) the predicted number of high-intensity storms increasing over the next 100 years. Whereas prediction (a) would be expected to result in more groundwater recharge, prediction (b) suggests the potential for less groundwater recharge. Further complicating the matter is that the groundwater model used in this analysis

uses monthly stress periods. This means, individual storm events are not explicitly modeled, only total monthly precipitation.

Ultimately, there are not sufficient data to definitively quantify which portion of increased precipitation is sourced from high-intensity storms (conceptually leading to less potential for recharge) versus which portion is sourced from low- or medium-intensity storms (conceptually leading to more potential for recharge). As a result, it was conservatively decided that four different groundwater recharge scenarios would be evaluated to provide insight into how the aquifer systems respond to changes in recharge: 7.5% increase, 7.5% decrease, 15% decrease, and 20% decrease. These relative changes to recharge were based on the average monthly recharge rate from 2012 to 2021 already assigned in the **2023 Aspect model**. Changes to recharge were modeled to occur linearly on an annual basis (uniform increment of change each year totaling the scenario percent change) from 2022 to 2121.

5.1.3 Production Rate Growth

As part of an evaluation of how groundwater resources on Bainbridge Island are expected to change over the next 100 years, estimates of how groundwater production will change over this time frame had to be developed. Groundwater production is dependent on the need for water both by the residential population (residential use) and by services that support and cater to the residential population (nonresidential use). Nonresidential use includes, but is not limited to, commercial use, government use, industrial use, and irrigation of private and public lands. Total use is the sum of residential and nonresidential use.

As shown in **Figure 1**, the **2025 EA Model** domain covers all of Bainbridge Island and a large portion of the Kitsap Peninsula to the west, north, and south of the island. While the primary concern of the production growth rate scenarios was to estimate production increase for Bainbridge Island water users over the next 100 years, production increases for peninsula water users had to also be considered due to the interconnectivity of the aquifer system. Groundwater baseflow from the Kitsap Peninsula to Bainbridge Island can occur in the deeper GMA, and FBA as they are continuous hydrogeologic units under the Agate Passage, and Port Orchard Bay. For example, model simulated groundwater elevations under recent conditions are higher in the FBA under the Kitsap Peninsula than in the FBA under Bainbridge Island. This creates a groundwater flow gradient from west to east. If only Bainbridge Island production increases are simulated, drawdown in the FBA under the island will increase, increasing the gradient between the island and the peninsula and increasing the west to east groundwater flow. Therefore, if production rates in these aquifers are also modeled to increase off-island, then a more reasonable gradient between the peninsula and the island will be simulated. In addition, peninsula production in the shallower Qva and SLA intercept recharge that could otherwise migrate downward into the GMA and FBA systems, thus further reducing the volume of water available to flow towards on-island points of extraction. The following sections describe how production rate increases, for both Bainbridge Island and Kitsap Peninsula water users, were estimated and assigned in the model for the planning scenarios.

5.1.3.1 Bainbridge Island Production

Estimated Bainbridge Island production was based on projected island population growth. Population is connected to production using a consumption rate (gallons per day [gpd]) to equivalent residential unit (ERU) ratio, gpd/ERU. A single ERU represents a connection to a single-family residence which is generally assumed to represent 2.5 people. If the residential population of an area is known, it can be converted to ERUs by dividing by 2.5. If the average rate of consumption for single-family residences is known, then the gpd/ERU ratio for that population can be calculated. Once the gpd/ERU ratio is calculated, nonresidential use can be converted into a representative nonresidential population value by dividing the nonresidential use rate (gpd) by the gpd/ERU value, yielding an ERU value which is then multiplied by 2.5. All water systems in Kitsap County provide the most recent residential and nonresidential population values for their service area on the individual system webpage on the Washington State Department of Health (WADOH), Division of Environmental Health, Office of Drinking Water website (WADOH 2024).

In Washington State, water systems are divided into Group A and Group B systems. Group A water systems have 15 or more service connections or serve 25 or more people 60 or more days per year, while Group B water systems serve fewer than 15 connections and fewer than 25 people per day. Group A water systems are further divided into three types: community (COMM), transient non-community (TNC), and non-transient, non-community (NTNC). Compiled Group A and Group B water system data available on the WADOH, Division of Environmental Health, Office of Drinking Water website reveals that, at the time of this analysis, there are 33 active Group A and 146 active Group B water systems on Bainbridge Island servicing a residential population of 20,459 and a total service population (residential and nonresidential) of 28,914 with Group A water systems providing water to 95% of the total population. Of the 33 Group A water systems, 21 are of the community type, servicing 87% of the total service population.

Only Group A community systems provide both population data and historical production data via the WADOH, Division of Environmental Health, Office of Drinking Water website. Because of this, and because Group A community water systems service nearly all the service area population on Bainbridge Island, only Group A community water systems were considered in developing the 100-year production growth rate scenarios. For all remaining Group A water systems, and for all Group B water systems, the service population, and therefore the annual rate of production, was considered to remain unchanged from the 2021 production rates in the **2023 Aspect Model**.

For Group A community water systems, an individual water system total gpd/ERU ratio was calculated by one of two methods:

1. If historical water production and total ERU values have been provided by the water system – dividing the total water production rate for each year, converted to gallons per day (gpd) by dividing the total annual production (gallons) by the number of days in the year, by the annual total ERU value and then averaging the historical gpd/ERU ratios.

2. If historical data have not been provided by the water system – dividing the reported total volume of water produced for the most recent year by the number of days in that year (gpd) and dividing that rate by the most recent reported total service area population (residential plus nonresidential) divided by 2.5 (ERU).

The gpd/ERU ratio for three of the Bainbridge Island water systems—City of Bainbridge Island, North Bainbridge Water Company, and South Bainbridge—were calculated using method one.

Table 8 shows the total production and ERU growth rate, the gpd/ERU ratio, and the historical data from which each is calculated for these three water systems. The gpd/ERU ratio for the remaining 16 Group A community water systems were calculated using method two, and the data is shown in **Table 9**.

Table 8. Water System GPD/ERU Ratio Calculated From Historical Data

Year	NORTH BAINBRIDGE WATER CO		SOUTH BAINBRIDGE**		CITY OF BAINBRIDGE ISLAND*	
	Total Production (MGY)	ERU	Total Production (MGY)	ERU	Total Production (MGY)	ERU
2006	--	--	--	--	241.6	3,536
2007	--	--	--	--	234.6	3,733
2008	--	--	--	--	224.3	3,762
2009	134.0	1,735	--	--	233.2	3,772
2010	--	--	--	--	215.5	3,984
2011	--	--	--	--	216.7	4,003
2012	123.1	1,749	--	--	223.1	4,037
2013	128.4	1,761	--	--	213.8	4,037
2014	138.6	1,831	--	--	230.6	3,972
2015	145.5	1,854	--	--	246.7	4,164
2016	133.4	1,871	118.7	1,371	245.9	4,217
2017	140.7	1,883	150.3	1,619	252.6	4,309
2018	146.0	1,899	167.1	1,637	269.2	4,245
2019	138.0	1,922	160.1	1,645	266.1	4,505
2020	140.1	1,928	174.1	1,742	264.7	4,287
2021	163.9	1,941	187.0	1,762	282.3	4,218
2022	147.5	1,943	169.3	1,773	255.6	--
2023	149.1	1,948	186.0	1,777	--	--
Growth Rate	2.2	18	7.6	49	5.5	49
gpd/ERU	206		269		164	

Notes:

ERU data were received from KPUD via the City of Bainbridge Island

Production values were downloaded from WADOH, Division of

Environmental Health Office of Drinking Water website

MGY = million gallons per year

* Production growth rate calculated from 2013-2022 data because from 2006-2013 production went down

** Production growth rate GPD/ERU calculated from 2017-2023 data

because ERU value did not include Island Utility population prior to 2017

-- data not available at the time of analysis and therefore not included in the Growth Rate and/or gpd/ERU calculations.

Table 9. Water System GPD/ERU Ratio Calculated From Recent Population And Production Data

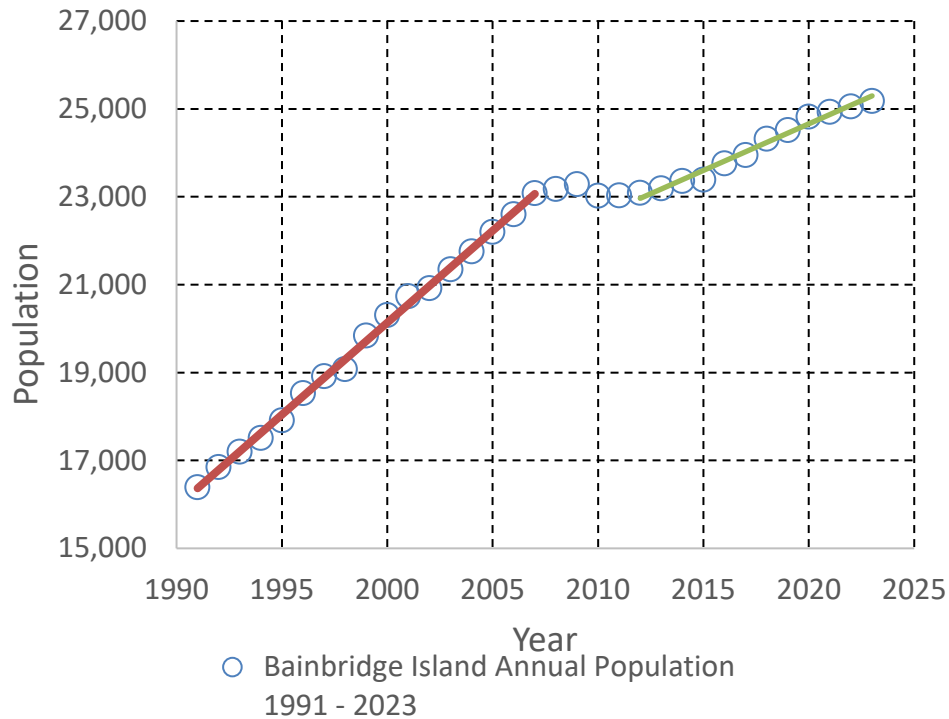
Water System	Residential Population	Total Population	ERU	Total Production (MGY)	Production Rate (gpd)	gpd/ERU Ratio
BUCKLIN	286	407	163	12.7	34,883	214
DERBY DOWNS	30	30	12	3.7	10,259	855
EMERALD HEIGHTS	250	251	100	7.3	20,003	199
FERNCLIFF	40	40	16	1.9	5,226	327
GRAHAM PLACE	34	34	14	1.4	3,845	283
HARBOR CREST	53	53	21	1.4	3,902	184
HIDDEN HEIGHTS	36	36	14	2.3	6,240	433
ISLANDWOOD ESTATES	40	40	16	2.6	7,076	442
MEADOWMEER	897	1137	455	30.2	82,640	182
PHELPS ROAD	58	58	23	1.3	3,635	157
PLACE EIGHTEEN HOA	32	34	14	0.7	1,842	135
PORT MADISON WATER COMPANY	233	233	93	11.1	30,471	327
RAVENS REACH	42	42	17	1.5	4,050	241
ROCKAWAY BEACH WATER	175	175	70	7.9	21,674	310
ROSE AVENUE WATER ASSOCIATION	53	53	21	2.0	5,426	256
WALDEN WATER	34	34	14	0.7	2,022	149

Notes:

Population and production values were downloaded from WADOH Division of Environmental Health Office of Drinking Water website

Once the gpd/ERU ratio for each water system has been defined, 100-year population-based production estimates can be calculated. The 100-year production growth scenarios are based on annual postcensal estimates and decennial census counts for Bainbridge Island obtained from the Washington State Office of Financial Management, Forecasting and Research Division. **Figure 11** shows a plot of Bainbridge Island population over a 33-year period, from 1991 to 2023. The plot shows that, during this time frame, Bainbridge Island has experienced three distinct population growth periods, a relatively high growth rate from 1991 to 2007, followed by a 5-year period of relatively no growth, followed by a second period of lower population growth from 2012 to 2023. Based on this data, it was decided to develop three population based 100-year production scenarios; 1) a high production growth scenario based on the 1991 to 2007 population, 2) a low production growth scenario based on the 2012 to 2023 population data, and 3) a median production growth scenario that equally splits the high and low growth rates. A linear regression of the 1991 to 2007 and the 2012 to 2023 population data results in a high population growth rate of 419 people per year and a low population growth rate of 212 people per year, respectively. These rates yield a median population growth rate of 315 people per year.

Population is not uniformly distributed across Bainbridge Island. Population density is highest in the Winslow and Eagle Harbor areas in the central part of the island and becomes less dense moving towards the north and the south. Estimates of total annual population for census tracts, obtained from the Washington State Office of Financial Management, Small Area Estimate Program, were used to define the distribution of population growth across the island. Bainbridge Island is divided into four census tracts, 907, 908, 909, and 910. Tracts 907 and 908 cover the northern half of the island and are grouped together for this analysis, tract 909 covers most of the Winslow area, and tract 910 covers the southern half of the island (**Figure 12**). **Figure 13** shows a plot of the estimated annual population for each tract from 2000 to 2023. Linear regression of the population data from each tract provides a growth rate of 27 people per year, 111 people per year, and 59 people per year, for tracts 907/908, 909, and 910, respectively. The total population growth rate for the island over this time frame is 197 people per year, meaning that on average tracts 907/908, 909, and 910, account for 14%, 56%, and 30% of the total Bainbridge Island population growth, respectively. These percentages are used to estimate the population growth rate in each tract from the high, median, and low total island growth rates defined above. Note that the 2000 to 2023 growth rate is lower than the 1991 to 2023 median growth rate (315 people per year) because it does not include the high population growth observed from 1991 to 2000.

Figure 11. Bainbridge Island Annual Population 1991 – 2023

Defining a population-based production growth rate requires that the population growth in each water system service area be defined. Therefore, each of the 19 Group A community water systems identified as production growth systems above were assigned to a census tract based on their location and service area. **Figure 12** shows the location and extent of each Group A community water system on Bainbridge Island in relationship to the census tract boundaries. Nine water systems are contained within the 907/908 tract, nine are contained within the 910 tract, and one is contained within the 909 tract. The majority of the City of Bainbridge Island water system service area is within the 909 tract and is considered to be represented by tract 909 derived population growth.

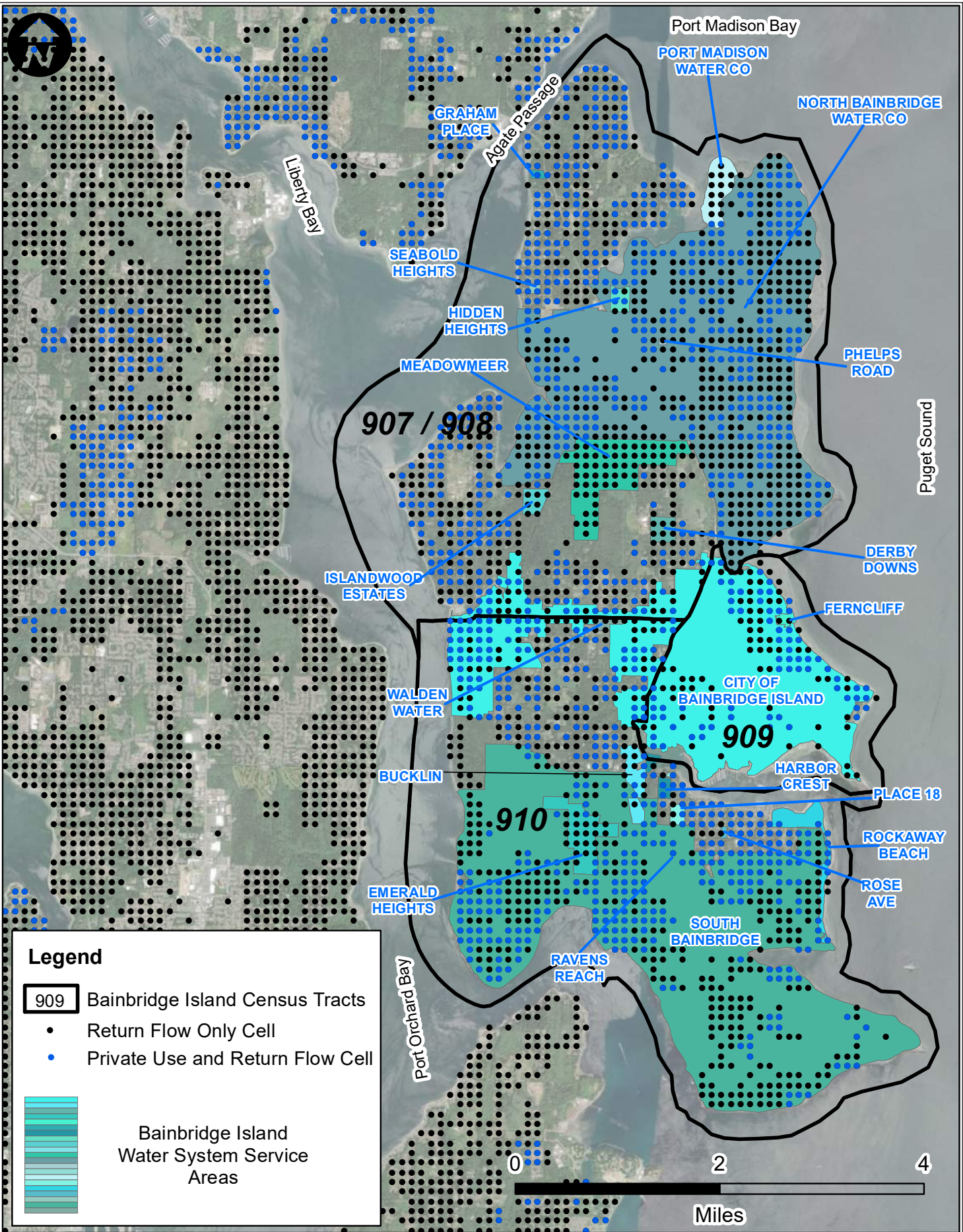
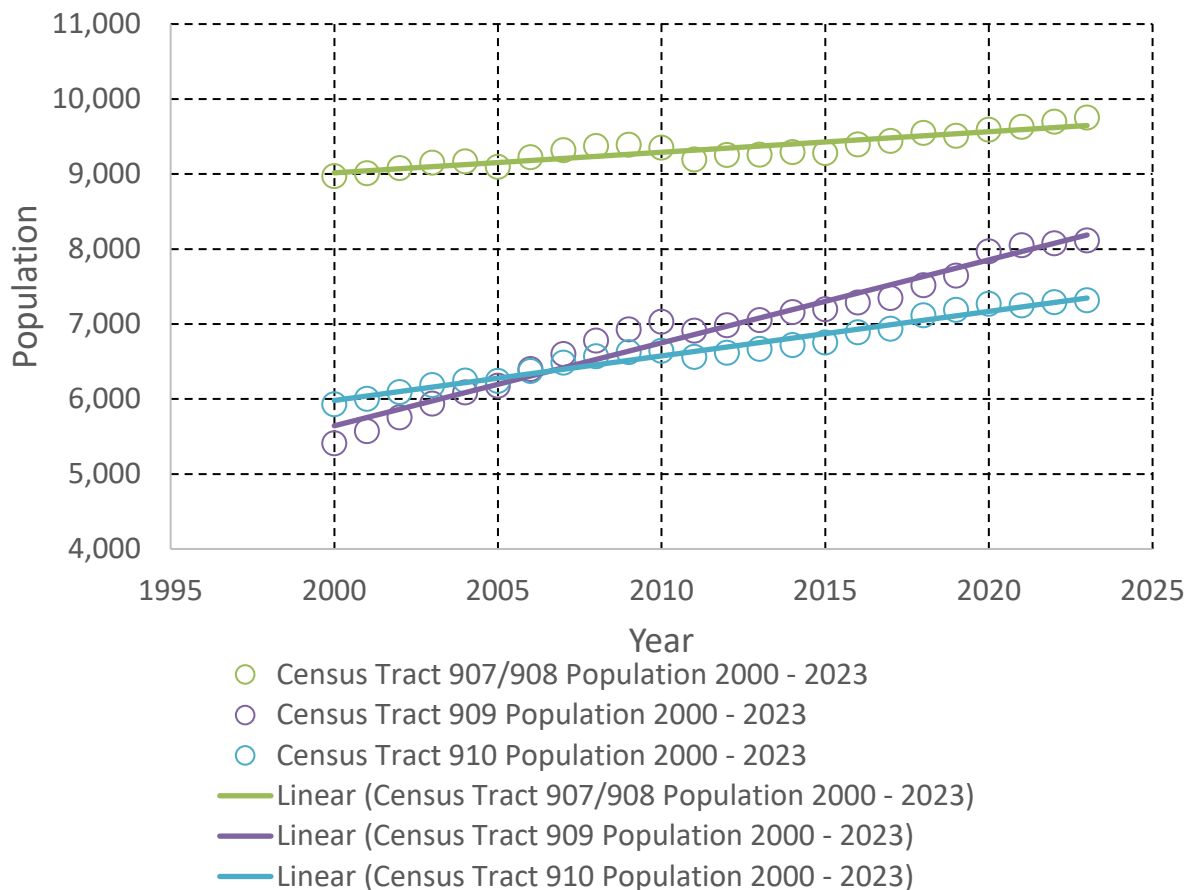


Figure 13. Bainbridge Island Annual Census Tract Population 2000 – 2023

Once each water system had been assigned to a census tract, the estimated population growth for that tract had to be distributed to each of the water systems and to private users within each tract. Through discussions with the City of Bainbridge Island, it was decided to assign 5% of the total estimated growth rate for each growth scenario to private users, meaning that the private user population growth rate is 11 people per year, 16 people per year, and 21 people per year for the low, median, and high growth scenarios, respectively. Spatial cross-referencing of tax parcel zoning information with the census tracts revealed that 48%, 17%, and 35% of the low to medium density population (zoning codes R-0.4, R-1, R-2, R-2.9, and R-3.5) were contained within tracts 907/908, 909, and 910, respectively. These percentages were assumed to represent the distribution of private users across the island and were used to define the private user population growth rate in each census tract.

After private user growth has been accounted for, the small Group A community water systems (residential population less than 1,000) were assigned a growth rate using the following process; 1) water systems with a residential population less than 250 were assumed to have a growth rate of less than one person per year due to the assumption of limited opportunity to expand the resident count, 2) water systems with a residential population between 250 and 499 were assumed to have a growth rate of 1 person per year, and 3) water systems with a residential

population between 500 and 999 were assumed to have a growth rate of 2 people per year. After both private user and small community water systems were assigned a growth rate, the remainder of the census tract growth rate estimate was assigned to water systems with residential populations greater than 1,000 people. **Tables 10, 11, and 12** show the annual residential population growth rate assigned to private users and each Bainbridge Island community water system and the relationship with census tract and island-wide residential population growth rate estimates for each of the three production growth rate scenarios.

Table 10. Bainbridge Island Water Systems Estimated Annual Population Growth: Low-Rate Scenario

Census Tract	Water System Name	Annual Population Growth Rate (person per year)			
		Bainbridge Island	Census Tract	Water System Residential	Water System Total
907 / 908	DERBY DOWNS	212	29	<1	<1
	Fieldstone Memory Care Bainbridge			<1	<1
	GRAHAM PLACE			<1	<1
	HIDDEN HEIGHTS			<1	<1
	ISLANDWOOD ESTATES			<1	<1
	MEADOWMEER			2	2
	NORTH BAINBRIDGE WATER CO			22	29
	PHELPS ROAD			<1	<1
	PORT MADISON WATER COMPANY			<1	<1
	SEABOLD HEIGHTS			<1	<1
Private Users	5	5			
909	BAINBRIDGE ISLAND CITY OF	212	119	117	172
	FERNCLIFF			<1	<1
	Private Users			2	2
910	BUCKLIN	212	64	1	1
	EMERALD HEIGHTS			<1	<1
	HARBOR CREST			<1	<1
	PLACE EIGHTEEN HOA			<1	<1
	RAVENS REACH			<1	<1
	ROCKAWAY BEACH WATER			<1	<1
	ROSE AVENUE WATER ASSOCIATION			<1	<1
	SOUTH BAINBRIDGE			59	76
	WALDEN WATER			<1	<1
Private Users	4	4			
Total Annual Island Growth Rate		212	212	212	291

Table 11. Bainbridge Island Water Systems Estimated Annual Population Growth: Median-Rate Scenario

Census Tract	Water System Name	Annual Population Growth Rate			
		Bainbridge Island	Census Tract	Water System Residential	Water System Total
907 / 908	DERBY DOWNS	315	44	<1	<1
	Fieldstone Memory Care Bainbridge			<1	<1
	GRAHAM PLACE			<1	<1
	HIDDEN HEIGHTS			<1	<1
	ISLANDWOOD ESTATES			<1	<1
	MEADOWMEER			2	2
	NORTH BAINBRIDGE WATER CO			34	45
	PHELPS ROAD			<1	<1
	PORT MADISON WATER COMPANY			<1	<1
	SEABOLD HEIGHTS			<1	<1
Private Users	8	8			
909	BAINBRIDGE ISLAND CITY OF	315	176	173	260
	FERNCLIFF			<1	<1
	Private Users			3	3
910	BUCKLIN	315	95	1	1
	EMERALD HEIGHTS			<1	<1
	HARBOR CREST PLACE EIGHTEEN HOA			<1	<1
	RAVENS REACH			<1	<1
	ROCKAWAY BEACH WATER			<1	<1
	ROSE AVENUE WATER ASSOCIATION			<1	<1
	SOUTH BAINBRIDGE			88	112
	WALDEN WATER			<1	<1
	Private Users			6	6
	Total Annual Island Growth Rate			315	315

Table 12. Bainbridge Island Water Systems Estimated Annual Population Growth: High-Rate Scenario

Census Tract	Water System Name	Annual Population Growth Rate			
		Bainbridge Island	Census Tract	Water System Residential	Water System Total
907 / 908	DERBY DOWNS	419	58	<1	<1
	Fieldstone Memory Care Bainbridge			<1	<1
	GRAHAM PLACE			<1	<1
	HIDDEN HEIGHTS			<1	<1
	ISLANDWOOD ESTATES			<1	<1
	MEADOWMEER			2	2
	NORTH BAINBRIDGE WATER CO			46	58
	PHELPS ROAD			<1	<1
	PORT MADISON WATER COMPANY			<1	<1
	SEABOLD HEIGHTS			<1	<1
Private Users	10	10			
909	BAINBRIDGE ISLAND CITY OF	419	235	Year 1-20:361 Year 21-100: 214	Year 1-20:576 Year 21-100: 342
	FERNCLIFF			<1	<1
	Private Users			4	4
910	BUCKLIN	419	126	1	1
	EMERALD HEIGHTS			<1	<1
	HARBOR CREST			<1	<1
	PLACE EIGHTEEN HOA			<1	<1
	RAVENS REACH			<1	<1
	ROCKAWAY BEACH WATER			<1	<1
	ROSE AVENUE WATER ASSOCIATION			<1	<1
	SOUTH BAINBRIDGE			118	149
	WALDEN WATER			<1	<1
Private Users	7	7			

Census Tract	Water System Name	Annual Population Growth Rate			
		Bainbridge Island	Census Tract	Water System Residential	Water System Total
Total Annual Island Growth Rate		419	419	Year 1-20: 550 Year 21-100: 403	Year 1-20: 807 Year 21-100: 573

There are two residential and total population growth rates for the City of Bainbridge Island water system in the high 100-year production growth rate scenario (**Table 12**). For this scenario, the City provided a residential growth rate of 316 people per year for the first 20 years, followed by 214 people per year for the last 80 years. This averages out to 243 people per year over 100 years, which is greater than the high growth rate estimated for the census tract. **Figures A1 and A2 in Appendix A** show the estimated annual growth rates for Bainbridge Island residential and nonresidential populations, respectively, for each scenario.

Table 13 shows the residential population for each Bainbridge Island Group A community water system, all other Group A and all Group B water systems, and all private users in Year-1 (same for all scenarios) and Year-100 of each production rate growth scenario based on the estimated population growth rates shown in **Tables 10, 11, and 12**. **Table 13** also shows that Bainbridge Island is estimated to increase by factors of 1.8X, 2.2X, and 2.7X over the next 100 years in the Low-Rate, Median-Rate, and High-Rate production scenarios, respectively. **Figure A3 in Appendix A** shows the estimated annual growth rate for Bainbridge Island use population for each scenario.

Table 13. Bainbridge Island Residential Population Estimates for each Production Rate Scenario

Water System Name	Year 1 Island Population	Year-100 Residential Population per Scenario			Percent Increase per Scenario		
		Low Rate Scenario	Median Rate Scenario	High Rate Scenario	Low Rate Scenario	Median Rate Scenario	High Rate Scenario
DERBY DOWNS	30	35	35	35	17%	17%	17%
Fieldstone Memory Care Bainbridge	96	96	96	96	0%	0%	0%
GRAHAM PLACE	34	40	40	40	18%	18%	18%
HIDDEN HEIGHTS	40	47	47	47	18%	18%	18%
ISLANDWOOD ESTATES	40	47	47	47	18%	18%	18%
MEADOWMEER	897	1,063	1,063	1,063	19%	19%	19%
NORTH BAINBRIDGE WATER CO	4,770	6,938	8,114	9,290	45%	70%	95%
PHELPS ROAD	58	68	68	68	17%	17%	17%
PORT MADISON	233	273	273	273	17%	17%	17%

Water System Name	Year 1 Island Population	Year-100 Residential Population per Scenario			Percent Increase per Scenario		
		Low Rate Scenario	Median Rate Scenario	High Rate Scenario	Low Rate Scenario	Median Rate Scenario	High Rate Scenario
WATER COMPANY							
SEABOLD HEIGHTS	36	36	36	36	0%	0%	0%
BAINBRIDGE ISLAND CITY OF	7,787	19,321	24,941	31,766	148%	220%	308%
FERNCLIFF	40	47	47	47	18%	18%	18%
BUCKLIN	286	348	348	348	22%	22%	22%
EMERALD HEIGHTS	250	293	293	293	17%	17%	17%
HARBOR CREST	53	61	61	61	15%	15%	15%
PLACE EIGHTEEN HOA	32	32	32	32	0%	0%	0%
RAVENS REACH	42	49	49	49	17%	17%	17%
ROCKAWAY BEACH WATER	175	205	205	205	17%	17%	17%
ROSE AVENUE WATER ASSOCIATION	53	62	62	62	17%	17%	17%
SOUTH BAINBRIDGE	3,973	9,765	12,685	15,655	146%	219%	294%
WALDEN WATER	34	40	40	40	18%	18%	18%
Group A Non-Community	25	29	29	29	16%	16%	16%
Group B	1,479	1,479	1,479	1,479	0%	0%	0%
Census Tract 707/708 Private Use	2,299	2,821	3,059	3,297	23%	33%	43%
Census Tract 709 Private Use	814	999	1,083	1,168	23%	33%	43%
Census Tract 710 Private Use	1,676	2,057	2,231	2,404	23%	33%	43%
Totals	25,252	46,215	56,436	67,929	83%	123%	169%

As described earlier in the section, groundwater production is dependent on both residential and nonresidential use. Nonresidential population growth was calculated as a function of residential population growth for the three community water systems servicing a significant nonresidential population, North Bainbridge Water Company, City of Bainbridge Island, and South Bainbridge. The City of Bainbridge Island consumption by customer class data for 2006 through 2015 (COBI 2017) suggested that total consumption for the water system could range from 1.5 to 1.6 times residential consumption. Therefore, total population to residential population ratios of 1.5, 1.5, and 1.6 were applied to calculate the total population growth rate for the City of Bainbridge Island water system for the low, median, and high growth scenarios, respectively. Similar data

was not available for North Bainbridge Water Company and South Bainbridge, but based on tax parcel zoning types it was assumed that nonresidential water use represented a lower percentage of total production in these two water systems. Therefore, a lower total population to residential population ratio of 1.3 was applied to calculate the total population growth rate for both water systems for all three growth scenarios. The total service population growth rate (residential plus nonresidential) for each water system is provided in **Tables 10, 11, and 12**.

The annual total service population growth rate for each Group A community water system is converted to an annual total production growth rate using the gpd/ERU ratio for each water system shown in **Tables 8 and 9**. For all other Group A and all Group B water systems, a gpd/ERU ratio was calculated using the most recent annual production rate provided in the base groundwater flow model (gpd) and the current total reported service population for the system divided by 2.5 (ERU). A gpd/ERU ratio was calculated for all water systems, even if they were assumed to have no population growth, because in addition to increasing production based on population growth, production was also increased based on an estimated increase in the gpd/ERU ratio. Through discussions with the City of Bainbridge Island, it was decided that reduced recharge due to climate change induced temperature increases and extended growing seasons over the next 100 years could result in an increase in the amount of water each residence or commercial connection uses. In discussions with COBI, the estimate of a 7% increase in the gpd/ERU ratio over 100 years was determined to be representative of this possibility and therefore the Year-1 gpd/ERU value was increased by 0.07% each year of the 100-year production growth scenarios. **Table 14** lists the population-based production rate estimates in Year-1 and Year-100 for Bainbridge Island Group A water systems, Group B water systems, and private users for all three production growth rate scenarios. With respect to Bainbridge Island as a whole, extraction increases by factors of 2.2X, 2.7X, and 3.3X over 100 years in the Low-Rate, Median-Rate, and High-Rate scenarios, respectively. These increases are greater than the estimated residential population increase because production is based on both residential and nonresidential population and because of the assumed gpd/ERU ratio increase. The estimated annual increase in Bainbridge Island production for each scenario is shown in **Figure A4** in **Appendix A**.

Table 14. Bainbridge Island Groundwater Production Estimates for each Production Rate Scenario

Water System Name	Year 1 Island Production (MGY)	Year-100 Production (MGY) per Scenario			Percent Increase per Scenario		
		Low Rate Scenario	Median Rate Scenario	High Rate Scenario	Low Rate Scenario	Median Rate Scenario	High Rate Scenario
DERBY DOWNS	3.7	4.7	4.7	4.7	25%	25%	25%
Fieldstone Memory Care Bainbridge	2.5	2.6	2.6	2.6	7%	7%	7%
GRAHAM PLACE	1.4	1.8	1.8	1.8	25%	25%	25%
HIDDEN HEIGHTS	2.3	2.9	2.9	2.9	26%	26%	26%
ISLANDWOOD ESTATES	2.6	3.3	3.3	3.3	26%	26%	26%
MEADOWMEER	30.2	38.2	38.2	38.2	27%	27%	27%

Water System Name	Year 1 Island Production (MGY)	Year-100 Production (MGY) per Scenario			Percent Increase per Scenario		
		Low Rate Scenario	Median Rate Scenario	High Rate Scenario	Low Rate Scenario	Median Rate Scenario	High Rate Scenario
NORTH BAINBRIDGE WATER CO	147.5	237.0	282.0	317.4	61%	91%	115%
PHELPS ROAD	1.3	1.7	1.7	1.7	26%	26%	26%
PORT MADISON WATER COMPANY	11.1	13.9	13.9	13.9	25%	25%	25%
SEABOLD HEIGHTS	1.2	1.3	1.3	1.3	7%	7%	7%
BAINBRIDGE ISLAND CITY OF	255.6	747.7	967.1	1,284.1	193%	278%	402%
FERNCLIFF	1.9	2.4	2.4	2.4	26%	26%	26%
BUCKLIN	12.8	16.6	16.6	16.6	30%	30%	30%
EMERALD HEIGHTS	7.3	9.2	9.2	9.2	25%	25%	25%
HARBOR CREST	1.4	1.8	1.8	1.8	23%	23%	23%
PLACE EIGHTEEN HOA	0.7	0.7	0.7	0.7	7%	7%	7%
RAVENS REACH	1.7	1.8	1.8	1.8	7%	7%	7%
ROCKAWAY BEACH WATER	7.9	9.9	9.9	9.9	25%	25%	25%
ROSE AVENUE WATER ASSOCIATION	2.0	2.5	2.5	2.5	25%	25%	25%
SOUTH BAINBRIDGE	169.3	498.2	649.7	801.2	194%	284%	373%
WALDEN WATER	0.7	0.9	0.9	0.9	26%	26%	26%
Group A Non-Community	4.3	4.6	4.6	4.6	7%	7%	7%
Group B	36.6	39.2	39.2	39.2	7%	7%	7%
Census Tract 707/708 Private Use	66.5	87.4	94.7	102.1	31%	42%	53%
Census Tract 709 Private Use	23.6	30.9	33.5	36.2	31%	42%	53%
Census Tract 710 Private Use	48.5	63.7	69.1	74.4	31%	42%	53%
Totals	845	1,825	2,256	2,775	116%	167%	229%

The transient 100-year production growth rate scenarios simulate monthly production conditions over 100 years (1,200 timesteps). Therefore, the annual production value calculated for each water system must be distributed monthly each year. However, water use throughout the year is not uniform, with higher usage rates usually occurring in the warmer months. Monthly production can also vary due to each water system’s storage capacity. For each 100-year production scenario the monthly production rate is calculated based on an average monthly usage percentage calculated through two methods:

1. If historical monthly production data is available for the water system, the total usage volume for each individual month, over the time period of the dataset, is summed, as is the total usage volume for the dataset time period. Then each month is assigned a percentage of the total, which is used to distribute annual production monthly in the 100-year scenarios.
2. If historical monthly production data was not available, the monthly percentages assigned in the **2023 Aspect Model** for each water system were used to distribute annual production monthly in the 100-year scenarios.

Finally, once the monthly production values are calculated for each water system, production must be distributed over the water system's well network. A review of historical well production values showed that production from individual wells is highly variable, being dependent on several seasonal, climate, and infrastructure factors. Therefore, to simplify scenario development, annual production volumes were distributed to wells based on reported well capacity. The Individual System web page on the WADOH, Division of Environmental Health, Office of Drinking Water website provides a link to each water systems well inventory report. This report lists all the wells currently in the water system's well network and identifies their status as active, inactive, or decommissioned and their use as permanent, seasonal, or emergency. Wells assigned a percentage of the monthly production are reported as active and permanent or pre-active meaning that there is a plan to develop the well and that it is expected to come on-line within the next 100-years.

For all Group A and Group B island water systems, except North Bainbridge Water Company and the City of Bainbridge Island, the monthly distribution of production is held constant in each 100-year production growth scenario. **Table 15** lists the active, permanent wells for each of the Group A community water systems with a constant monthly distribution, each well's reported capacity, the system's capacity, and the percentage of production distribution applied to each well in the production growth rate scenarios.

Table 15. Group A Community Water System Wells and System Capacity

Water System	System Well Name and Tag ID Number	System Capacity (gpm)	Well Capacity (gpm)	Production Distribution (% of total)
BUCKLIN	Well #2 AES320	106	106	100%
DERBY DOWNS	DERBY DOWNS #1 ABP966	96	60	63%
	DERBY DOWNS #2 / ABP985		36	38%
EMERALD HEIGHTS	WELL A WW AAC777	122	12	10%
	WELL B WW AAC778		30	25%
	WELL C WW AAC779		35	29%
	WELL D WW AEN678		45	37%
FERNCLIFF	WELL #1 AES132	10	10	100%
Fieldstone Memory Care Bainbridge	WELL #1 AAC053	25	25	100%
GRAHAM PLACE	WELL #1 AAC462	17	17	100%
HARBOR CREST	WELL #1 ACD357 HC	47	47	100%

Water System	System Well Name and Tag ID Number	System Capacity (gpm)	Well Capacity (gpm)	Production Distribution (% of total)
HIDDEN HEIGHTS	WELL #1 HH West AAC782	45	23	50%
	WELL #2 HH East AAC783		23	50%
ISLANDWOOD ESTATES	WELL #1 AAC026	104	68	65%
	WELL #2 AAC025		36	35%
MEADOWMEER	WELL #2 AAC448	332	162	49%
	WELL #5 AKR023		170	51%
PHELPS ROAD	WELL #2 AAC013 PHELPS RD	17	17	100%
PLACE EIGHTEEN HOA	WELL #1 AAC761	30	30	100%
PORT MADISON WATER COMPANY	WELL #1 AES318	133	50	38%
	WELL #4 AEA544		83	62%
RAVENS REACH	Well #1 AAC020	20	20	100%
ROCKAWAY BEACH WATER	WELL #1 AAC879 Taylor Well	70	70	100%
ROSE AVENUE WATER ASSOCIATION	WELL #2 ACP291	20	20	100%
SEABOLD HEIGHTS	WELL #1 AEK741	45	40	89%
	WELL #2 AAC795		5	11%
WALDEN WATER	Well #1 AAC653	50	50	100%

Notes:

Data from Individual System webpages on the WADOH, Division of Environmental Health, Office of Drinking Water website

For the North Bainbridge Water Company water system, the monthly well distribution had to be modified to handle the higher estimated production rates. This is because as the annual production rate increased, production during the months with the highest usage rates exceeded the capacity of the water system. Therefore, as the production growth rate increased between scenarios, wells with remaining capacity under the initial monthly distribution had to be given more of the total water system production. **Table 16** lists the wells in the North Bainbridge Water Company network, the individual well and system capacity, and the well distribution percentages for each scenario.

Table 16. North Bainbridge Water Company Water System Wells and System Capacity

System Well Name and Tag ID Number	Model Well ID	System Capacity (gpm)	Well Capacity (gpm)	Production Growth Rate Scenario Distribution %		
				Low	Median	high
WELL #3 AEK853 MANZANITA	North Bainbridge Well 03	1,260	120	12%	11%	10%
WELL #6 AAA113 LOVEGREN	North Bainbridge Well 06		120	10%	11%	10%
WELL #7 AEK852	North Bainbridge Well 07		200	23%	19%	17%

WELL #9 AAB455	North Bainbridge Well 09		700	51%	52%	56%
WELL #10 AAC110 Madison	North Bainbridge Well 10		120	4%	7%	7%

Notes:

Data from Individual System webpages on the WADOH, Division of Environmental Health, Office of Drinking Water website

For the South Bainbridge water system, the well/water system capacity had to be modified to handle the higher estimated production rate requirements. **Table 17** lists wells in the South Bainbridge network, the reported individual well and system capacity, the increased well and system capacity assigned in each of the production growth scenarios, and the well distribution percentages for each scenario.

Table 17. South Bainbridge Water System Wells and System Capacity

System Well Name and Tag ID Number	Model Well ID	Reported System Capacity (gpm)	Reported Well Capacity (gpm)	Scenario System Capacity (gpm)	Scenario Well Capacity (gpm)	Scenario Production Distribution (% of total)
IU WELL #1 AAA109	Island Utilities Well 1	1,253	70	1,863	200	11%
IU WELL #2 AAC113	Island Utilities Well 2		115		250	13%
IU WELL #3 AAS286	Island Utilities Well 3		125		250	13%
Well #10 BKY882	South Bainbridge Well 10		270		270	14%
LYNWOOD #7 ACK364	South Bainbridge WS Well 7		280		300	16%
WELL #8 ACW030	South Bainbridge WS Well 8		300		300	16%
Well #9 APP319	South Bainbridge WS Well 9		50		50	3%
pre-active	Deep Path		0		200	11%
WELL #3 WW AAA238	Bill Point #3		20		20	1%
WELL #4 WW AES348	Bill Point #4		23		23	1%

Notes:

Data from Individual System webpages on the WADOH, Division of Environmental Health, Office of Drinking Water website

For the City of Bainbridge Island water system, both the monthly well distribution and the well/water system capacity had to be modified to handle the higher estimated production rate requirements. **Table 18** lists wells in the City of Bainbridge Island network, the individual well and system capacity, and the well distribution percentages for each scenario. For the median production rate increase scenario, only the well percentages had to be modified. However, for the high production rate increase scenario, the system's capacity needed to be increased to meet peak monthly demand. Therefore, the system's existing wells were assumed to be modified with higher capacity pumps to meet the production requirements, focusing the largest increases on wells completed in the deeper aquifers (GMA and FBA) and on wells with the largest diameters.

Table 18. The City of Bainbridge Island Water System Wells and System Capacity

System Well Name and Tag ID Number	Model Well ID	Low Rate Scenario		Median Rate Scenario		High Rate Scenario	
		Well Capacity (gpm)	Distribution %	Well Capacity (gpm)	Distribution %	Well Capacity (gpm)	Distribution %
HEAD OF BAY #1 AAC869	COBI Head of Bay1	34	2%	34	2%	50	1%
HEAD OF BAY #1A AAC860	COBI Head of Bay1A	111	5%	111	5%	150	4%
HEAD OF BAY #2 AAC870	COBI Head of Bay2	183	8%	183	8%	250	6%
#3 HEAD OF BAY AAC871	COBI Head of Bay3	264	12%	264	12%	264	9%
HEAD OF BAY #4 AAC872	COBI Head of Bay4	83	4%	83	4%	140	4%
HEAD OF BAY #5 AAC873	COBI Head of Bay5	125	6%	125	6%	140	4%
HEAD OF BAY #6 AAC874	COBI Head of Bay6	85	4%	85	4%	135	4%
SAND AVE. #1 AAC875	COBI Sands Ave1	351	17%	351	17%	500	17%
SAND AVE. #2 AAC876	COBI Sands Ave2	377	18%	377	18%	750	26%
FLETCHER BAY AAC733	COBI Fletcher Bay	591	27%	591	27%	750	26%
Total System Capacity (gpm)		2,204		2,204		3,129	

Notes:

Data from Individual System webpages on the WADOH, Division of Environmental Health, Office of Drinking Water website

5.1.3.2 Kitsap Peninsula Production

Unlike on-island production growth estimates, Kitsap Peninsula production growth was not based on population growth estimates. Annual population values were available for Kitsap County as a whole, for unincorporated Kitsap County, and for the incorporated cities of Bremerton, Port Orchard, and Poulsbo. However, the model domain does not include all of Kitsap County or all the unincorporated county areas, or all of the cities of Bremerton and Port Orchard. Therefore, off-island production increases were based on either historical water system ERU counts, connection counts, or total production volumes. Because of this, only single, “expected” production growth rates were estimated for off-island water systems and these were used in the low, median, and high 100-year production growth scenarios.

The model domain includes many Group A and Group B water systems, as well as private users, on the Kitsap Peninsula but as with Bainbridge Island water systems, production rates for only the Group A community water systems on the peninsula were increased in the 100-year production growth scenarios. Production at all other Group A water systems, all Group B water systems, and all private residences was assumed to remain constant at rates in the **2023 Aspect Model**. However, production for these users does increase by 7% over the 100-year scenario period as the same estimated climate change increase in the gpd/ERU ratio applied to on-island users was applied to all off-island users.

Of the 53 Group A community water systems on Kitsap Peninsula within the model domain, only six had both historical total production and ERU data (**Table 19**). From this information, an ERU growth rate and a gpd/ERU ratio for each water system was calculated and is shown in **Table 19**.

Table 19. Kitsap Peninsula Water Systems with historical Production and ERU data

Year	INDIANOLA		MILLER BAY		SUQUAMISH*		SILVERDALE WATER DIST 16		KEYPORT WATER		CITY OF BREMERTON*	
	Total Prod. (MGY)	ERU	Total Prod. (MGY)	ERU	Total Prod. (MGY)	ERU	Total Prod. (MGY)	ERU	Total Prod. (MGY)	ERU	Total Prod. (MGY)	ERU
2009	--	--	--	--	88	--	807	--	--	--	2,489	--
2010	--	--	--	--	82	--	709	--	--	--	2,409	--
2011	--	--	--	--	--	--	712	--	--	--	2,542	--
2012	--	--	21	--	81	1,471	746	9,577	33	424	2,237	42,145
2013	39	--	21	--	79	1,479	713	10,052	33	428	2,121	40,085
2014	36	--	22	--	84	1,484	747	10,174	34	428	2,160	41,092
2015	40	--	22	420	88	1,488	782	10,318	37	429	2,186	39,658
2016	41	--	21	422	79	1,491	758	10,088	35	429	2,158	42,729
2017	45	--	25	423	82	1,498	752	10,784	35	429	2,230	44,924
2018	42	650	22	424	84	1,511	742	10,617	34	430	2,246	42,435
2019	40	660	21	426	80	1,520	739	10,816	32	432	2,306	44,498
2020	42	666	22	426	85	1,531	777	10,902	32	432	2,205	41,837
2021	46	676	23	428	90	1,546	776	10,760	--	--	2,236	41,119
2022	43	680	21	429	84	1,548	758	10,518	--	--	2,325	46,493
2023	42	682	21	429	88	1,551	803	11,221	--	--	2,425	45,498
Annual Growth Rate	0.5	7	0.05	1	0.5	8	3	110	-0.1	1	23	379
gpd/ERU	174		141		152		198		216		144	

Notes:

ERU data was received from KPUD via the City of Bainbridge Island

Production values were downloaded from WADOH, Division of Environmental Health, Office of Drinking Water website

Prod. = Production

* Production growth rate calculated from 2013-2022 data because from 2009-2012 production went down

In addition to the six water systems with historical ERU data, two water systems had historical connection and production data available (**Table 20**). From this information, a connection growth rate and a gpd/connection ratio for each water system was calculated. For the purposes of this analysis, connections were used in the same way as ERUs in the calculation of a production growth rate.

Table 20. Kitsap Peninsula Water Systems With Historical Production And Connection Data

Year	CITY OF POULSBO		NORTH PERRY AVE WATER DISTRICT	
	Total Prod. (MGY)	Connection	Total Prod. (MGY)	Connection
2009	--	--	565	--
2010	--	--	516	--
2011	--	--	504	--
2012	--	--	494	6,576
2013	--	--	505	6,601
2014	338	3,476	498	6,666
2015	350	3,635	514	6,675
2016	343	3,699	492	6,704
2017	356	3,834	496	6,725
2018	376	3,935	539	6,758
2019	354	4,001	517	6,794
2020	350	4,025	517	6,816
2021	392	4,075	554	6,817
2022	381	4,154	533	6,842
2023	--	4,272	510	6,900
Annual Growth Rate	5	81	0.6	27
gpd/Connection	255		209	

Notes:

Connection data was received from KPUD via the City of Bainbridge Island

Production values were downloaded from WADOH, Division of Environmental Health, Office of Drinking Water website

For water systems with historical ERU or connection counts, the ERU or connection growth rate was derived by linear regression of the ERU/connection data versus time. An average gpd/ERU ratio or gpd/connection ratio was developed by dividing annual total production rates by the associated ERU or connection count and taking the average of these ratios. 100-year scenario production rates were then calculated by increasing the ERU or connection count in each year after Year-1 by the calculated growth rate and multiplying the ERU or connection count by the average gpd/ERU or gpd/connection ratio.

For the remaining 48 Group A community water systems, only historical production data was available from the WADOH Office of Drinking Water website (WADOH 2024). The average annual production growth rate for each of these water systems was derived directly from the total production data using a linear regression of yearly total production rates versus time. Total production data was available for the timeframe of 2009 through 2023, but not all water systems had reported total production volumes for every year in this time frame. The linear regression yielded a negative production growth rate for many of the water systems. In these cases, it was assumed that production has not, and therefore will not, increase, and production for these water systems only increased by 7% over the 100-year scenarios due to the climate change increase in

the gpd/ERU ratio. **Table 19** lists the estimated annual production growth rate for the 20 (out of 53) Kitsap Peninsula Group A community water systems that were found to have increasing production rates along with the Year-1 and estimated Year-100 production rates and the percent increase in production over the 100-year scenario time frame for these water systems. Also provided in **Table 19** is the summed Year-1 and Year-100 production rates for all remaining Kitsap Peninsula Group A water systems, all Kitsap Peninsula Group B water systems, and all Kitsap Peninsula private users in the model domain. As shown in **Table 21**, Kitsap Peninsula production was more than doubled over the 100-year time frame in each of the three production growth rate scenarios.

Table 21. Kitsap Peninsula Water Systems With Historical Production And Connection Data

Kitsap Peninsula Group A Community Water System Name	Annual Production Growth Rate (gpd)	Year-1 Production (MGY)	Year-100 Production (MGY)	100-Year % increase	Data Source
BREMERTON CITY OF	24,982	963	2,123	120%	Total Production & gpd/ERU ratio; 2012 - 2023
SILVERDALE WATER DIST 16	26,032	758	1,900	151%	ERU count; 2012-2024
POULSBO CITY OF	20,576	381	1,211	218%	Connection count; 2014 - 2023
West Sound Utility District #1	13,517	615	1,195	94%	Total production; 2010 - 2023
NORTH PERRY AVE WATER DISTRICT	5,693	533	779	46%	Connection count; 2012 - 2023
NORTH PENINSULA*	11,137	350	742	112%	Total production; 2009 - 2023
PORT ORCHARD WATER DEPT*	7,864	287	612	113%	Total production; 2009 - 2023
MANCHESTER WATER DISTRICT	6,160	223	464	108%	Total production; 2010 - 2023
VINLAND*	4,786	116	308	165%	Total production; 2009 - 2023
MCCORMICK WOODS*	3,351	113	240	113%	Total production; 2009 - 2023
SUQUAMISH	1,197	84	138	65%	ERU count; 2012-2023
ERLAND POINT WATER CO	1,286	47	98	108%	Total production; 2010 - 2023
INDIANOLA WATER	1,143	43	90	109%	ERU count; 2018-2023
NEWBERRY HILL*	858	30	66	124%	Total production; 2009 - 2023
ELDORADO HILLS	803	20	45	125%	Total production; 2009 - 2023
MILLER BAY	162	21	30	40%	ERU count; 2015-2023
ISLAND LAKE*	110	18	24	29%	Total production; 2012 - 2022
INDIAN HILLS ESTATES	218	9	19	113%	Total production; 2012 - 2023
JOHANSON*	389	5	17	219%	Total production; 2009 - 2023
NAVY YARD PARK	108	9	15	63%	Total production; 2009 - 2023
Group A	0	189	202	7%	--
Group B	0	128	137	7%	--
Private Users	0	206	221	7%	--
Totals	130,371	5,150	10,675	107%	--

Notes:

* Initial production growth rate reduced due to water system capacity limitation

Estimating a production growth rate for the City of Bremerton's water system was more complex than for the other peninsula water systems because it draws from both surface water and groundwater. The City of Bremerton provided annual gpd/ERU ratios, annual total production volumes (surface and ground water), and the annual percentage of the total production that was represented by surface water for 2012 through 2023. From these data, an ERU growth rate and an average gpd/ERU ratio were calculated for the total water system production (**Table 13**) and an average percentage of total for groundwater of 46% was calculated. Annual total production was calculated for each year of the production growth rate scenario and 46% of the total production was assigned as groundwater production for the water system.

The distribution of the estimated annual production volumes to monthly production and to individual well production for peninsula water systems was performed using the same process

described above for Bainbridge Island water systems. For some water systems (identified in **Table 19**) the initially calculated production growth rate resulted in monthly extraction rates that exceeded the water system's total capacity. For these systems, the growth rate was reduced such that extraction during these months could meet but not exceed system capacity.

5.1.3.3 Production Returns

Groundwater production also creates groundwater recharge through return flow of water at or near the land surface. On Bainbridge Island and the Kitsap Peninsula, this includes water system leaks, septic systems and outdoor irrigation return flows. The consumptive use rate for indoor domestic use was assumed to be 10% (WASDOE 2009), and the consumptive use rate for outdoor use was set at 80%. Consumptive use is the amount of water that is lost from the system through processes such as evapotranspiration.

Return flow was assigned in the model as injections into the uppermost Qva layer. Using land-use and sewer line maps, model cells that represented water use areas, such as residential zones, commercial zones, school zones, and industrial zones, that did not have sewer connections available, were selected as return flow cells. These cells were assigned layer-1 injection wells and were categorized based on their location with respect to water system service areas. If the centroid of a return flow cell was within a water system service area, it was assigned an injection rate based on the total production of that water system. If the centroid of the return flow cell was outside of any water system service areas, it was assigned an injection rate based on the summed total private use production for that area, defined by census tracts.

The amount of production considered as return flow was dependent on the gpd/ERU ratio calculated for the water system or individual user. The gpd/ERU ratio for private users was assumed to equal 198. The method for estimating the gpd/ERU ratio for Group A and Group B water systems was described in Section 5.1.3.1. A uniform gpd/ERU ratio of 162 was assumed to represent indoor use for all water users. Therefore, if a water system had a gpd/ERU ratio of 162 or less, it was considered that all water use within the water system service area was for indoor use and the return flow gpd/ERU ratio was equal to 90% of the water system gpd/ERU ratio. If a water system had a gpd/ERU ratio greater than 162, then the indoor use return flow gpd/ERU ratio was 146 (90% of 162) and the outdoor use return flow ratio was equal to 20% of the difference between the water system ratio and 162. This was converted to a percentage of total production attributed to return flow for the water system by dividing the water system gpd/ERU ratio by the sum of the indoor use return and outdoor use return gpd/ERU ratios. For example, the private user gpd/ERU ratio was assumed to be 198. This yields an indoor use gpd/ERU ratio of 162 and an outdoor use gpd/ERU ratio of 34. The indoor use return gpd/ERU ratio is 146 (90% of 162) and the outdoor use return gpd/ERU ratio is 7 (20% of 34). The resulting percentage of total production assigned as return flow is 78% $[(146+7)/198]$.

For private users and water systems without sewer service, the total return flow for the water use area was calculated as the return flow percentage times the total production for the water use area. For example, the area outside of water system service areas in census tract 907/908 is represented by 2,299 people or 919 private users (ERUs) in Year-1 of the production growth rate scenarios (**Table 13**). The return flow percentage for private users is 78% of total production,

which is 66.5 MGY for private users in census tract 907/908 (**Table 14**). Therefore, the total return flow for these private users is 51.9 MGY, proportioned to injection wells in all return flow cells outside of water system serve areas in census tract 907/908 based on the number of ERUs that are represented in the cell.

In some areas of Bainbridge Island and the Kitsap Peninsula return flow is prevented from returning to the flow system by wastewater treatment systems. On Bainbridge Island, the City of Bainbridge Island operates a wastewater treatment plant (WTP) that discharges to the Puget Sound and the Kitsap County Sewer District No.7 operates a WTP that discharges to Rich Passage in Puget Sound (Washington State Department of Ecology [WASDOE] 2017a, 2023). The City of Bainbridge WTP treats water from connections in the Winslow area of the City of Bainbridge Island water system and the Kitsap County Sewer District No.7 WTP treats water from South Bainbridge, Emerald Heights, and Rockaway Beach water system service.

On Kitsap Peninsula there are five wastewater treatment plants: Manchester WTP which treats water from the Manchester water system and discharges into Rich Passage – Puget Sound (WASDOE 2018a), Bremerton West WTP which treats water from the City of Bremerton water system and discharges into Sinclair Inlet – Puget Sound (WASDOE 2018b), Suquamish WTP which treats water from the Suquamish water system and discharges into Port Madison Bay – Puget Sound (U.S. Environmental Protection Agency 2019), South Kitsap WTP which treats water from the City of Port Orchard and the West Sound Utility District water systems and discharge into Sinclair Inlet – Puget Sound (WASDOE 2019), and Central Kitsap WTP which treats water from portions of the Silverdale Water District 16, City of Poulsbo, North Perry Ave. Water District, Keyport Water, Erland Point Water Company, and Eldorado Hills water systems and discharges into Port Orchard Bay, Puget Sound (WASDOE 2017b). All of these sewage systems capture return flow and channel it to the Puget Sound and therefore must be accounted for when estimating return flow rates in the model.

It should be noted here that total water system production includes both the portion of production that is delivered to water system users and is metered (authorized production), and the portion that is lost due to leakage in the distribution lines. In this way, return rates based on total production account for water returned to the flow system through underground leaks. However, for water systems where some or all of the return water is collected by wastewater treatment sewage lines, the initial return rate has to be based on authorized production as distribution system leakage occurs before delivery to users. For these water systems, an initial authorized return rate is calculated based on authorized production, the percentage of authorized return going to wastewater treatment collection is calculated and subtracted from the authorized return rate, and then the distribution leakage rate is added to the remaining authorized return to derive the total production return rate to the flow system from the water system service area. A description of this process follows.

In order to modify return flow rates to account for wastewater treatment system flow, an average wastewater treatment system flow rate (gpd) was calculated for each WTP by dividing the summed historical daily volume treated (gallons) by the total number of days in the historical record. The authorized production rate for the wastewater treatment system was then divided by

the average wastewater treatment system flow rate to derive a percent of production that goes to wastewater treatment. The remainder is attributed, along with the distribution leakage rate, to return flow injections in the model.

For wastewater treatment systems that service portions of multiple water system service areas, the portion of authorized production from each water system that went to the wastewater treatment system had to be calculated. This was done by graphically calculating the percentage of the WTP collection system that was located in each water system service area and then applying that percentage to the average wastewater treatment system flow rate to derive an average wastewater treatment system flow rate for each water system area. **Table 22** shows the series of steps that were performed to calculate the return flow injection rates for water systems with wastewater treatment collection. If a wastewater treatment system flow rate was greater than the authorized production rate, it was assumed that all return flow was captured by the wastewater treatment system and any return flows from the system represents distribution leakage only. Note that the City of Bremerton water system service area has wastewater treatment service from two WTPs, Bremerton West and Central Kitsap. For this water system, the flow rate captured by the Central Kitsap WTP system was calculated first and then added to the Bremerton West WTP flow rate. This resulted in wastewater treatment system flow being greater than authorized flow and the 6% return flow only represents distribution leakage.

Table 22. Process To Calculate Return Flow Injection Rates For Water Systems With Partial Wastewater Treatment Service

Wastewater Treatment System	Water System	TP	L	AP	RF%	WTF	WTF%	TRF (RF%*AP)	WSWTF (WTF%*WTF)	WSRF (TRF-WSWTF)	TWSRF (WSRF+L)	TWSRF% (RRT/TP)
Bremerton West WTP	BREMERTON CITY OF	6.26	0.38	5.88	90%	5.29	100%	5.29	5.86	-0.56	0.38	6%
Bainbridge Island WTP	BAINBRIDGE ISLAND CITY OF	0.66	0.03	0.63	89%	0.56	100%	0.56	0.56	0.00	0.03	5%
Suquamish WTP	SUQUAMISH	0.23	0.01	0.22	90%	0.24	100%	0.19	0.24	-0.05	0.01	6%
Manchester WTP	MANCHESTER WATER DISTRICT	0.56	0.02	0.53	90%	0.30	100%	0.48	0.30	0.18	0.20	36%
Central Kitsap WTP	NORTH PERRY AVE WATER DISTRICT	1.42	0.08	1.33	90%	3.45	26%	1.20	0.89	0.30	0.39	27%
	KEYPORT WATER	0.11	0.01	0.10	90%	3.45	1%	0.09	0.04	0.05	0.05	50%
	POULSBO CITY OF	0.96	0.06	0.90	90%	3.45	23%	0.81	0.78	0.04	0.09	10%
	BREMERTON CITY OF	6.26	0.38	5.88	90%	3.45	16%	5.29	0.56	4.73	5.11	--
	SILVERDALE WATER DIST 16	2.03	0.06	1.97	77%	3.45	33%	1.52	1.13	0.39	0.45	22%
	ERLAND POINT WATER CO	0.18	0.01	0.17	90%	3.45	1%	0.15	0.02	0.13	0.14	79%
	ELDORADO HILLS	0.04	0.003	0.03	64%	3.45	1%	0.02	0.02	0.0003	0.003	9%
Kitsap County Sewer District No. 7 WTP	SOUTH BAINBRIDGE	0.47	0.07	0.40	59%	0.10	90%	0.24	0.09	0.14	0.21	45%
	EMERALD HEIGHTS	0.02	0.001	0.02	80%	0.10	5%	0.01	0.01	0.01	0.01	50%
	ROCKAWAY BEACH	0.02	0.002	0.02	72%	0.10	5%	0.01	0.00	0.01	0.01	50%

Wastewater Treatment System	Water System	TP	L	AP	RF%	WTF	WTF%	TRF (RF%*AP)	WSWTF (WTF%*WTF)	WSRF (TRF-WSWTF)	TWSRF (WSRF+L)	TWSRF% (RRT/TP)
South Kitsap WTP	West Sound Utility District #1	1.67	0.12	1.54	90%	1.89	69%	1.39	1.29	0.09	0.22	13%
	PORT ORCHARD WATER DEPT	0.77	0.05	0.72	90%	1.89	32%	0.65	0.60	0.05	0.10	13%

Notes:

- TP = Average water system total production (million gallons per day)
- L = Average distribution system leakage rate (million gallons per day)
- AP = Average water system authorized production (million gallons per day)
- RF% = Water system return flow as a percentage of authorized flow
- WTF = Average wastewater treatment system flow (million gallons per day)
- WTF% = Percent of wastewater treatment flow attributed to water system return flow
- TRF = Total water system return flow (million gallons per day)
- WSWTF = Wastewater treatment flow from water system (million gallons per day)
- WSRF = Water system return flow (million gallons per day)
- TWSRF = Total water system return flow including distribution leakage (million gallons per day)
- %TWSRF = Total water system return flow as a percentage of total water system production

Table 23 summarizes how production and return flow changes for the entire model domain in the low, median, and high production growth rate scenarios from Year-1 to Year-100. The Low, Median, and High Production Growth scenarios will simulate a progressive increase in both production and return flow. This is expected as return flow has been shown to be a function of production. However, due to a portion of return flow being captured by wastewater treatment systems, production increases at a greater rate than return flow. Overall, the production growth rate scenarios simulate a 2.2X, 2.3X, and 2.4X increase in net production (gross production minus return flow) in the Low, Median, and High production growth scenarios, respectively.

Section 5.1 provides a description of the methodology and design of a series of scenarios developed to represent a reasonable range of impacts to the Bainbridge Island groundwater flow system due to climate change and population growth over the next one hundred years. Each of the scenarios described above were run as single impact simulations in order to understand the flow system's sensitivity to each type of impact, however, on their own, these simulations do not represent the total impact climate change and population growth is predicted to have on the flow system. It is beyond the scope of this technical memorandum to review the impacts of each single impact simulation, but Section 5.2 presents how these scenarios were combined to develop three impact planning scenarios and describes the resulting combined impact on the flow system.

Table 23. Summary Of Production And Return Flow Rates Assigned In The Low, Median, And High Production Growth Rate Scenarios.

Rate Type	Year 1 Rates (MGY)	Year-100 Rates (MGY) per Scenario			Percent Increase per Scenario		
		Low Rate Scenario	Median Rate Scenario	High Rate Scenario	Low Rate Scenario	Median Rate Scenario	High Rate Scenario
Return Flow	2,062	3,748	3,853	3,951	82%	87%	92%
Gross Production	5,993	12,496	12,926	13,444	108%	116%	124%
Net Production	3,931	8,748	9,073	9,493	123%	131%	141%

5.2 SCENARIO RESULTS

Three planning scenarios were designed to represent possible future conditions on and around Bainbridge Island (**Table 24**). The results and interpretations of each scenario are below.

Table 24. Planning Scenario datasets after 100 years

Scenario	Sea Level Rise	Recharge	Pumping
Low Impact Planning Scenario	+2.8 ft	0% change	122% increase
Mid Impact Planning Scenario	+6.9 ft	-7.5% decrease	167% increase
High Impact Planning Scenario	+6.9 ft	-20% decrease	167% increase

5.2.1 Low Impact Planning Scenario

The Low Impact Planning Scenario represents a RLSR of 2.8 feet corresponding to the 50% exceedance probability of the RCP 8.5 climate scenario and no change in groundwater recharge. The simulated production growth of 122% represents the median expected growth rate on

Bainbridge Island. **Figures 14 through 17** show the simulated groundwater levels in the Qva, SLA, GMA, and FBA after 20, 50, and 100 years. The model's grid spacing of 500 ft by 500 ft does not allow for representation of water use by or impact to individual water users on Bainbridge Island. Rather, the model simulations represent impacts on the scale of aquifer units. Therefore, with respect to simulated groundwater levels, scenario impacts are quantified by calculating the mean groundwater elevation across Bainbridge Island for each aquifer unit at 20, 50, and 100 years into the simulation and comparing that to the mean groundwater elevation of each aquifer unit in the current condition simulation (**Table 25**). Simulated localized impacts associated with water supply wells will be discussed as will drawdown impacts to the confined FBA.

Under the Low Impact Planning Scenario (**Figure 14**), there are negligible changes to the Qva unit relative to current conditions (**Figure 6**). Mean groundwater levels are simulated to increase 0.1 feet in the Qva after 100 years (**Table 25**) under the Low Impact Planning Scenario. The increase is due primarily to the projected 2.8-foot rise in RLSR.

Mean decreases in groundwater levels in the SLA range from 1 foot after 20 years to 6 feet after 100 years (**Table 25**). This decrease is primarily centered around the South Bainbridge Wellfield (**Figure 15**). Groundwater elevations drop below sea level around the South Bainbridge Wellfield by year 50 of the simulation.

Within the deeper aquifers (GMA and FBA) extraction-induced drawdowns are greater. Mean decreases in groundwater levels in the GMA range from 5 feet after 20 years to 33 feet after 100 years (**Table 25**). This decrease is primarily centered around the Island Utility Wellfield. Even though these wells are screened in the deeper FBA (**Figure 16**), drawdown is being induced vertically across the aquitard that separates the FBA from the GMA. Due to this, groundwater elevations in this unit drop below sea level in the southern portion of the island between year 50 and year 100 of the simulation.

Mean decreases in groundwater levels in the FBA range from 8 feet after 20 years to 50 feet after 100 years (**Table 25**). This decrease is due to production at the large capacity municipal supply wells; Sands Road 1 and 2, Island Utility Well 1 and 3, Fletcher Bay Pumping Well, and North Bainbridge 9 (**Figure 17**). This simulation estimates that by year 100, the cones of depression around these wells will result in aquifer groundwater levels below mean sea level across the central portion of the island. Near the Sands Road well cluster, groundwater levels are simulated to decrease by as much as 60 feet after 100 years of the Low Impact Planning Scenario conditions. Across most of the island, drawdown in the FBA is from 40 to 60 feet (**Figure 18**). Moreover, it can be inferred from **Table 25** that the mean groundwater level within the FBA drops below sea level at approximate simulation year 75 (corresponding to calendar year 2097) under the Low Impact Planning Scenario conditions.

Table 25. Mean Groundwater Levels Under Different Planning Scenarios

Hydrogeologic Unit	Mean Groundwater Level (feet above mean seal level)									
	Current	Low Impact Planning Scenario			Mid Impact Planning Scenario			High Impact Planning Scenario		
		20 years	50 years	100 years	20 years	50 years	100 years	20 years	50 years	100 years
Qva	102.2	102.6	102.3	102.3	102.4	101.7	101.4	102.0	100.4	97.4
SLA	43.4	42.2	40.2	37.2	41.9	39.8	37.3	41.7	39.1	33.1
GMA	37.2	32.0	21.6	4.1	26.9	13.3	-8.8	26.8	12.8	-12.9
FBA	36.8	28.9	13.3	-13.4	20.7	-0.1	-34.6	20.6	-0.7	-38.7

5.2.2 Mid Impact Planning Scenario

The Mid Planning Scenario represents a RLSR of 6.9 feet corresponding to the 1% exceedance probability of the RCP 8.5 climate scenario and a 7.5% decrease in groundwater recharge. The simulated production growth of 167% represents the high growth rate on Bainbridge Island. **Figures 19 through 22** show the simulated groundwater levels in the Qva, SLA, GMA, and FBA after 20, 50, and 100 years.

Under the Mid Impact Planning Scenario (**Figure 19**), there are negligible changes to the Qva unit relative to current conditions (**Figure 6**). This demonstrates the Qva's minimal sensitivity to increasing extraction within the deeper aquifers. Mean decreases in groundwater levels in the SLA remained approximately the same for the Low Impact Planning Scenario, ranging from 2 feet after 20 years to 6 feet after 100 years (**Table 25**). This decrease remains primarily centered around the South Bainbridge Wellfield (**Figure 20**). The results suggest that the increase in mean sea level offsets the effects of decreased recharge and increased pumping in the SLA.

Mean decreases in groundwater levels in the GMA increased in the Mid Impact Planning Scenario (as compared to the Low Impact Planning Scenario), ranging from 10 feet after 20 years to 46 feet after 100 years (**Table 25**). Again, this decrease is primarily centered around the Island Utility Wellfield, even though these wells are screened in the deeper FBA (**Figure 21**). The portion of the aquifer unit with groundwater elevations below mean sea level expands past the footprint of the island quicker (by year 50), and to a greater overall extent (by year 100) in the Mid Impact Planning simulation as compared to the Low Impact Planning simulation results.

Mean decreases in groundwater levels in the FBA also increased, ranging from 16 feet after 20 years to 71 feet after 100 years (**Table 25**). This increase is due to increased production at the large capacity municipal supply wells; Sands Road 1 and 2, Island Utility Well 1 and 3, Fletcher Bay Pumping Well, and North Bainbridge 9 (**Figure 22**). Similar to the GMA results, the portion of the aquifer unit with groundwater elevations below mean sea level expands past the footprint of the island quicker (by year 50), and to a greater overall extent (by year 100) in the Mid Impact Planning simulation as compared to the Low Impact Planning simulation results.

Figure 23 shows island-wide drawdown in the FBA with local drawdowns exceeding 100 feet around the Sands Road and Island Utility pumping centers. **Table 25** suggests that mean

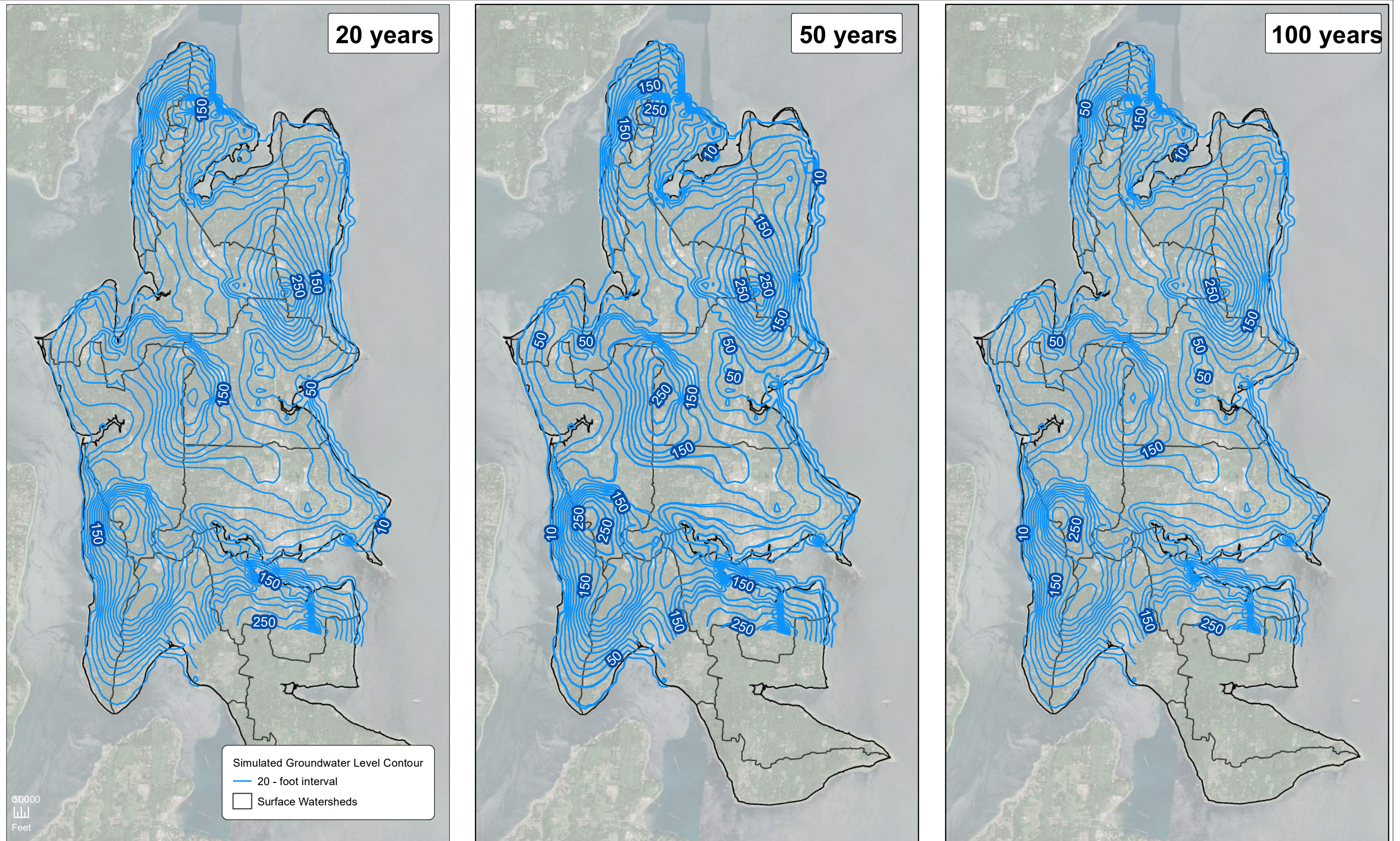
groundwater levels within the FBA and GMA will drop below sea level at approximately 50 simulation years (corresponding to calendar year 2072) and at approximately 75 years (corresponding to calendar year 2097), respectively.

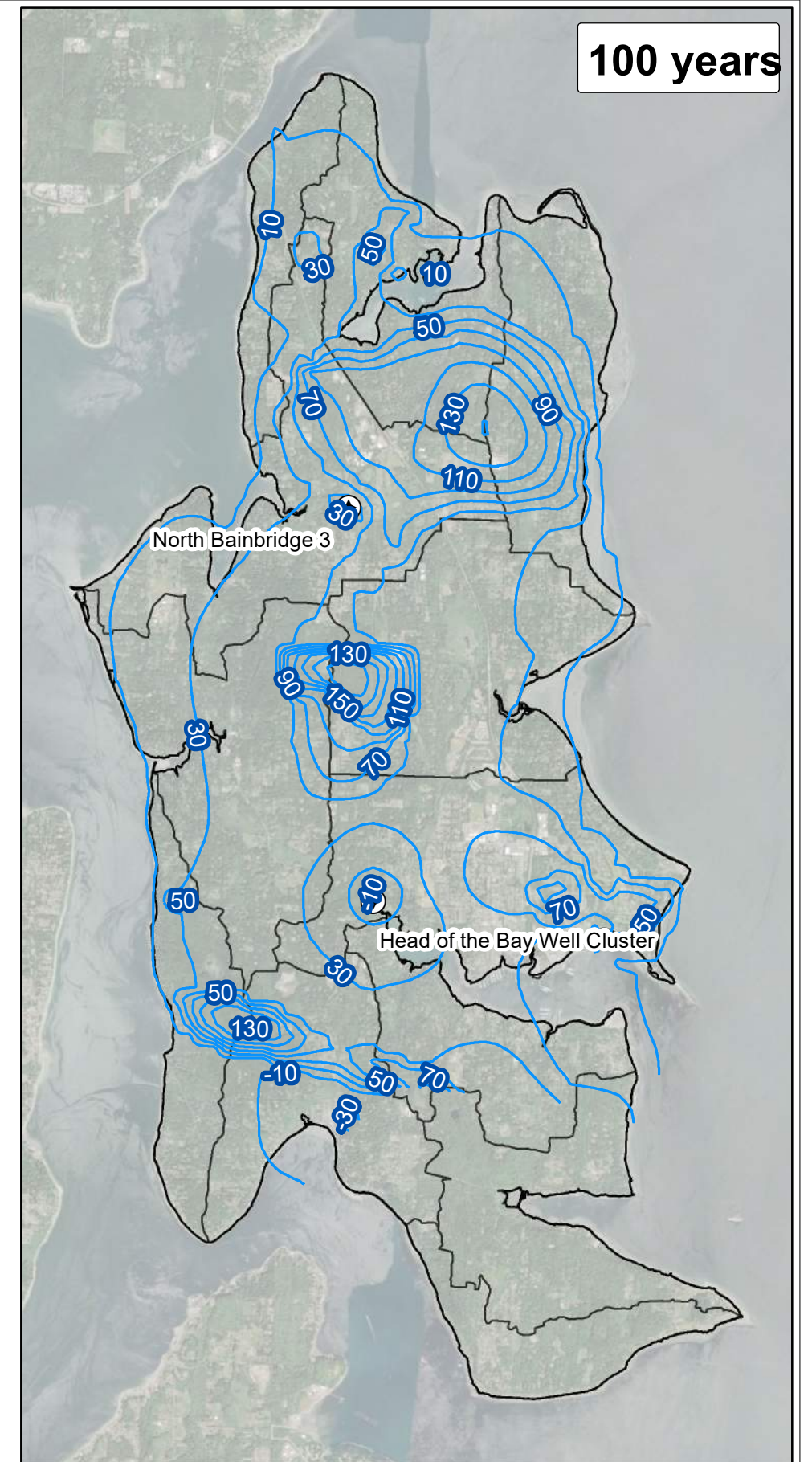
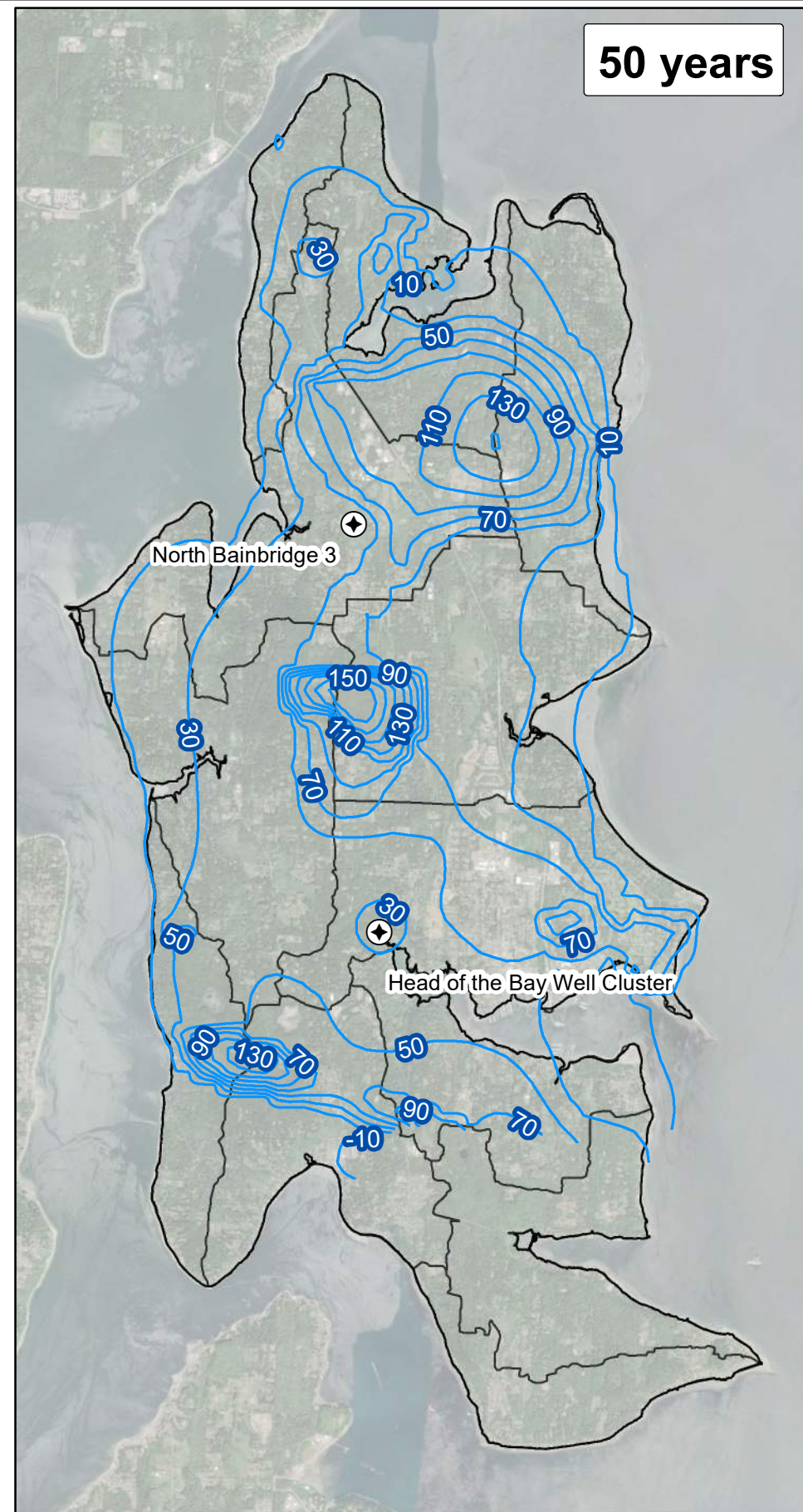
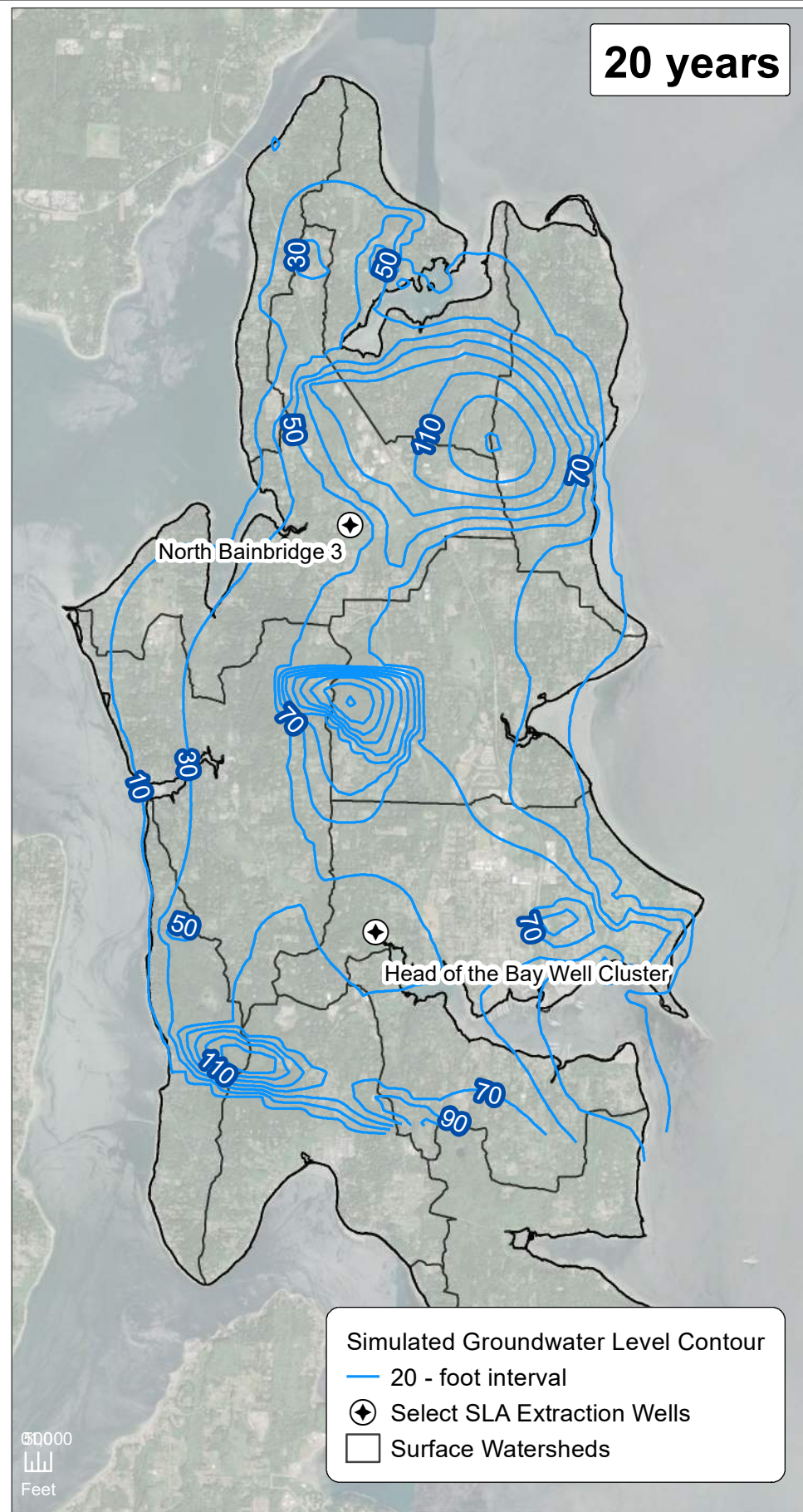
5.2.3 High Impact Planning Scenario

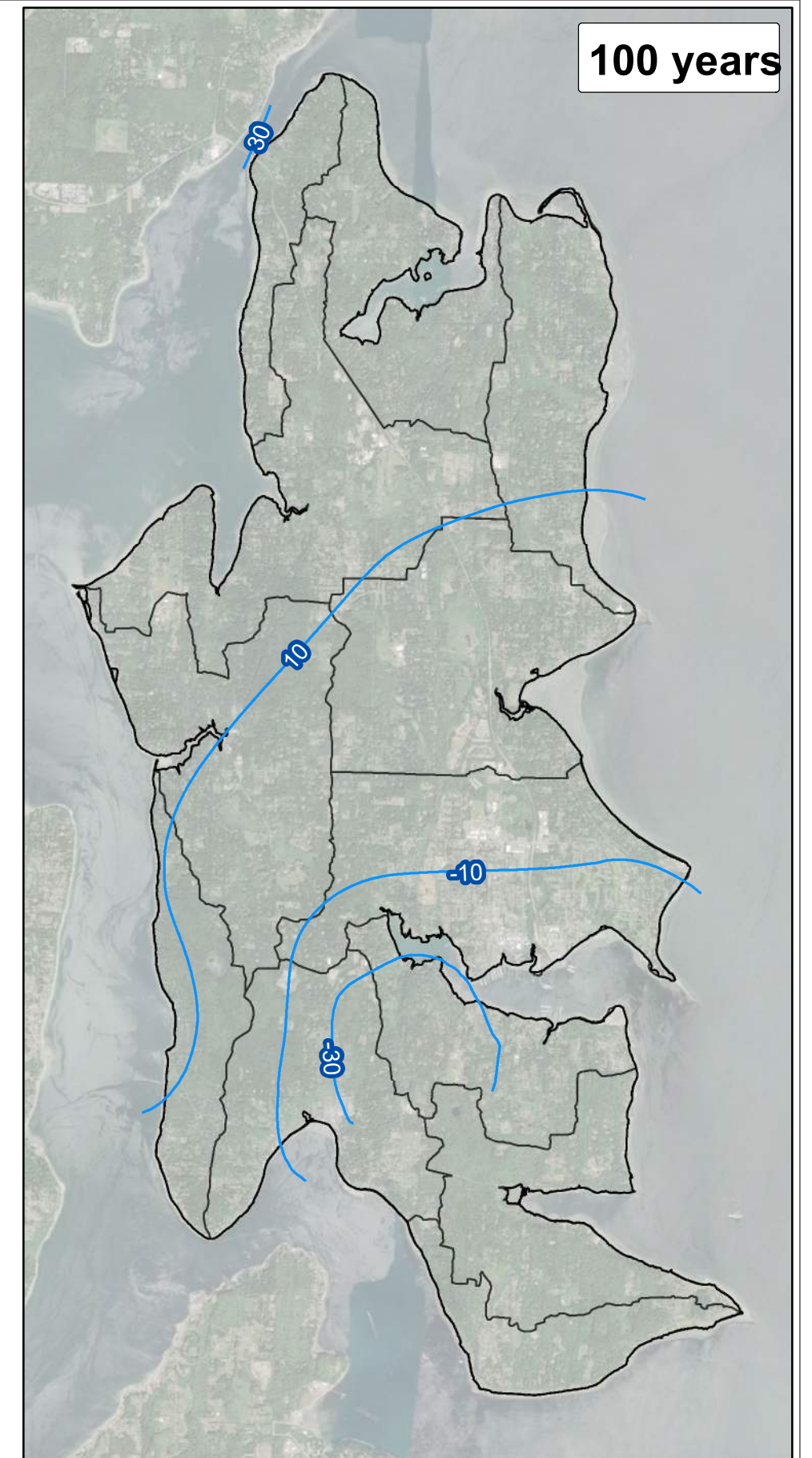
The High Planning Scenario represents a RLSR of 6.9 feet corresponding to the 1% exceedance probability of the RCP 8.5 climate scenario and a 20% decrease in groundwater recharge. The simulated production growth of 167% represents the high growth rate on Bainbridge Island. **Figures 24 through 27** show the simulated groundwater levels in the Qva, SLA, GMA, and FBA after 20, 50, and 100 years.

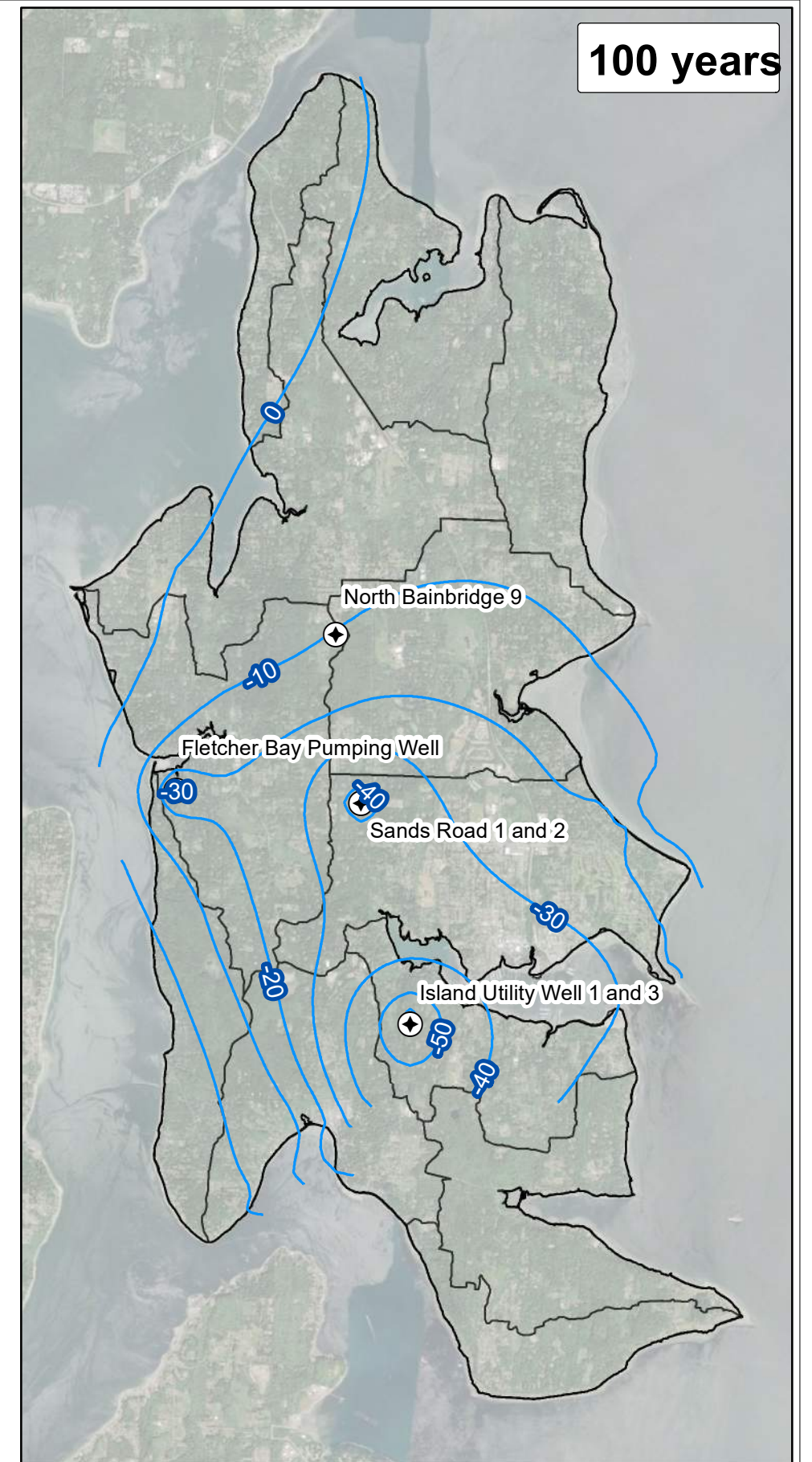
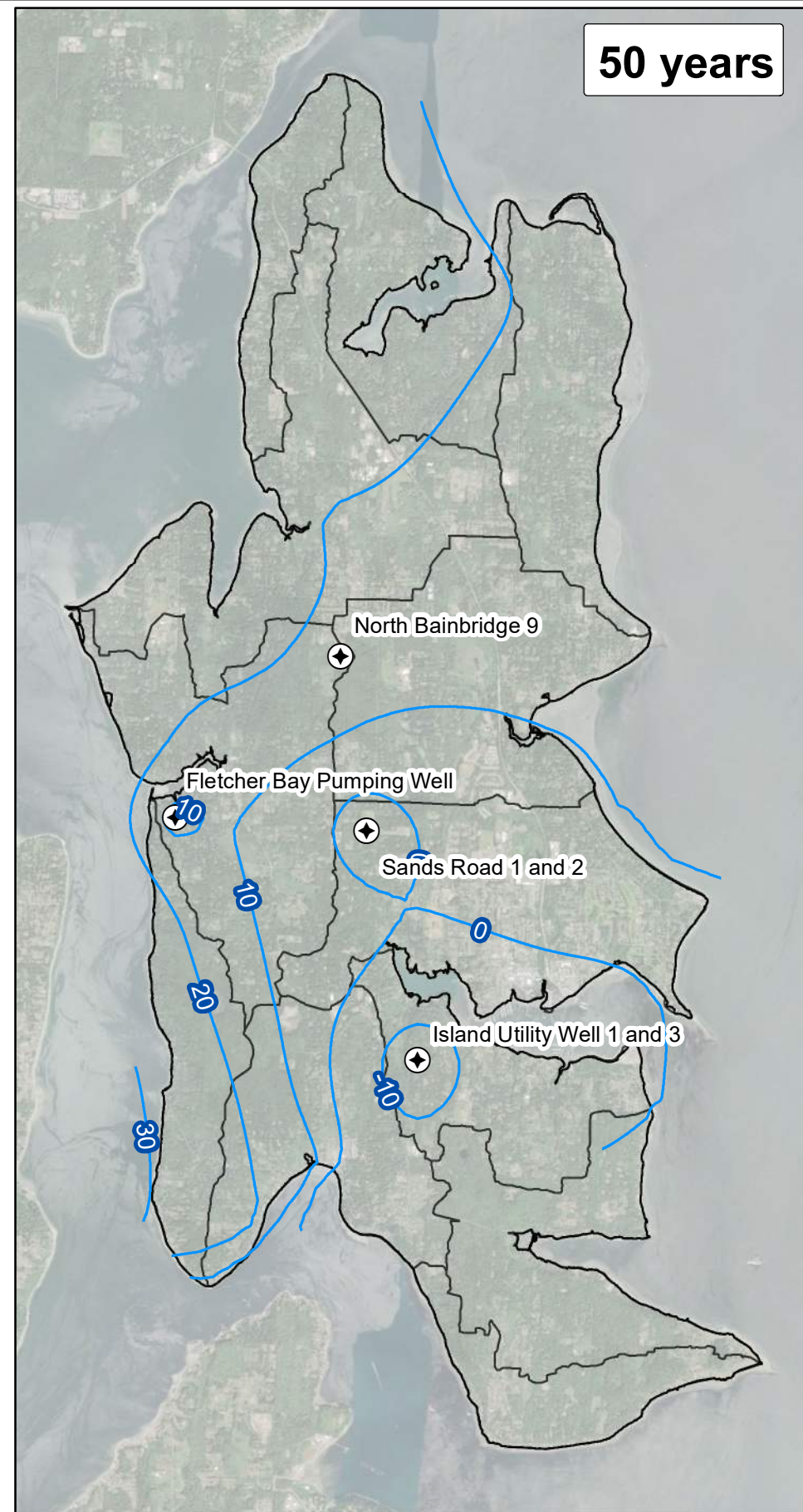
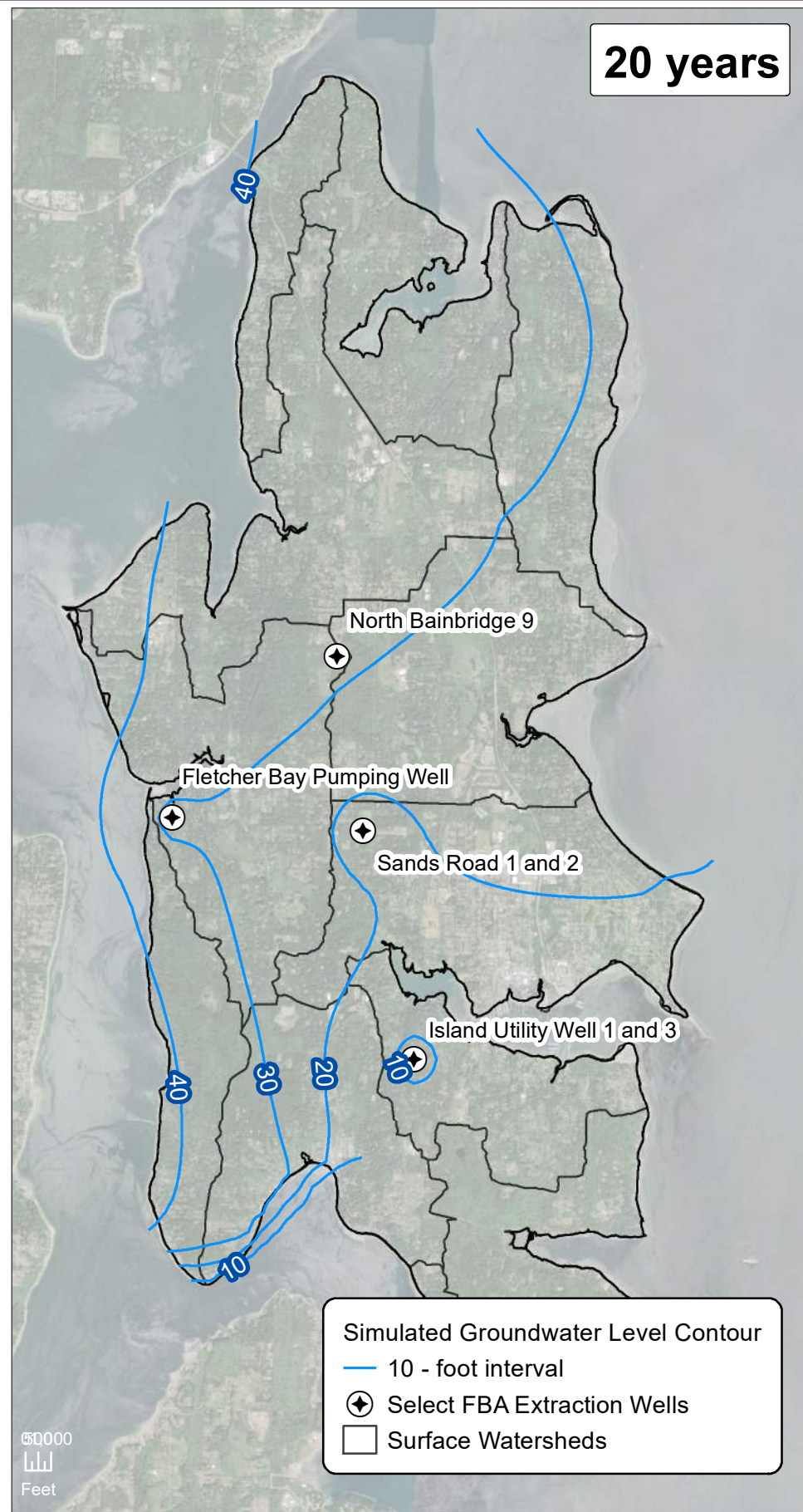
The large decrease in groundwater recharge had the greatest impact on the groundwater levels in the Qva unit with a decrease of 5 feet by year 100 (**Table 25**). However, this is relatively small considering mean groundwater levels within the unit are still nearly 100 feet above sea level (**Figure 24**). Mean groundwater levels in the SLA did not show an increased impact due to reduced recharge until year 100 when mean groundwater levels were simulated to be 10 feet below current conditions. The additional decrease by year 100 is due primarily to groundwater levels around the Head of Bay Wellfield dropping below mean sea level and the area of groundwater levels below mean sea level around the South Bainbridge wellfield expanding to the west (**Figure 25**).

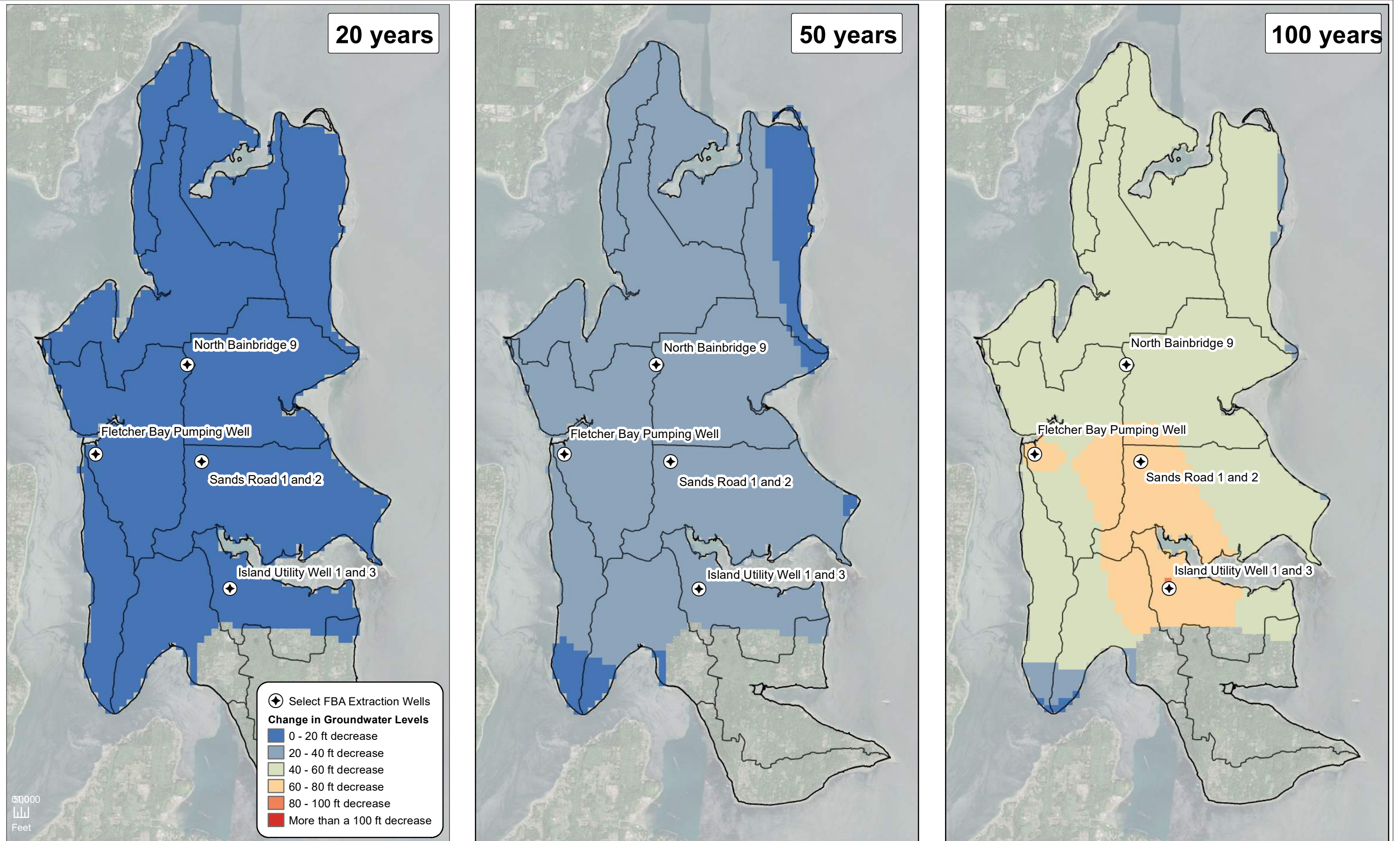
Similarly, the reduction in recharge resulted in an additional mean groundwater level decrease of 4 feet and 5 feet in the GMA and FBA, respectively, by year 100 (**Table 25**). This is due to a slight expansion of the cone of depression around the Island Utility wellfield in the GMA (**Figure 26**) and the slight deepening of the cones of depression around the FBA production centers (**Figure 27**). In general, the timing of when the mean groundwater level in the GMA and FBA drops below mean sea level, and the extent of drawdown in the FBA (**Figure 28**) was not significantly impacted by the further reduction in recharge.

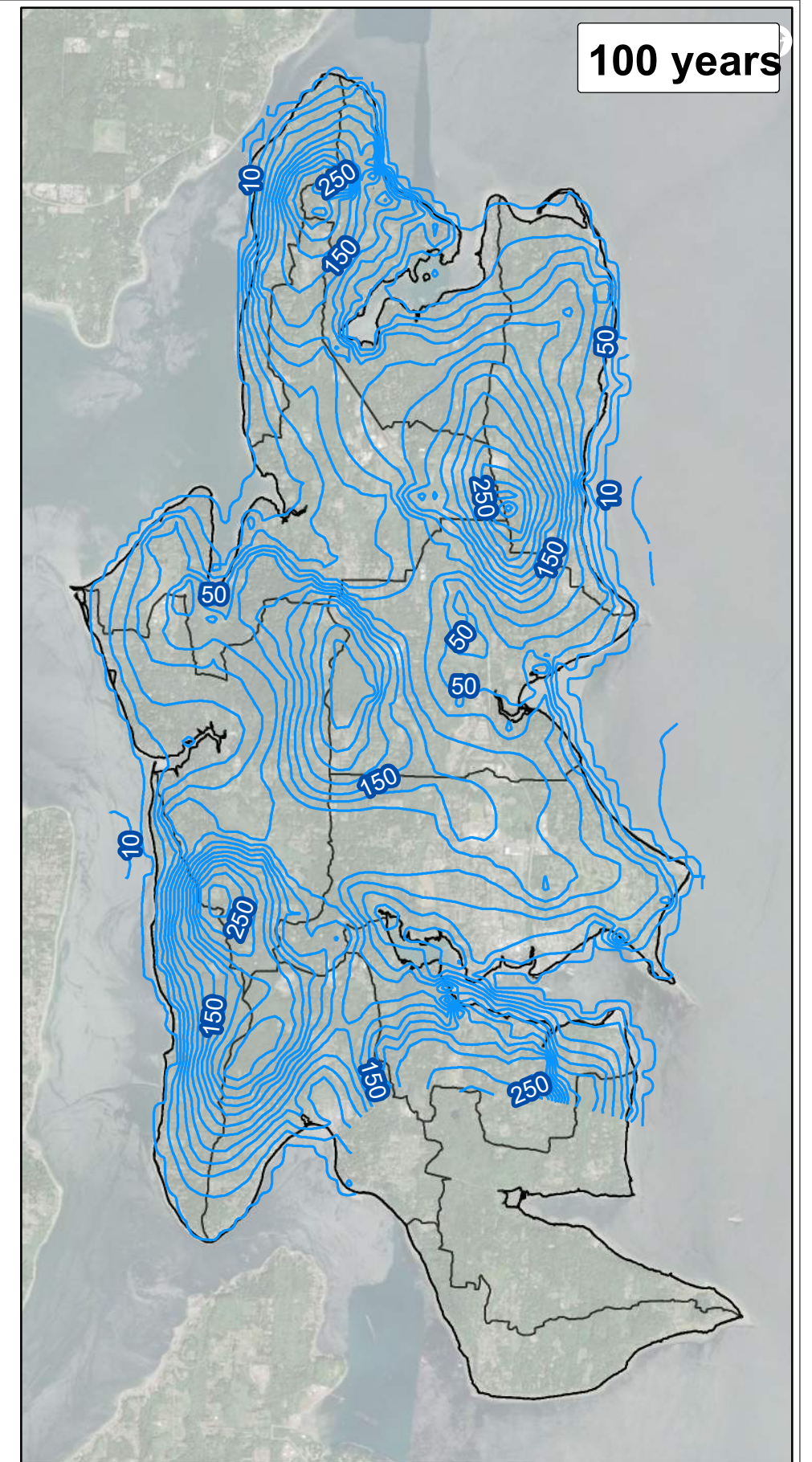
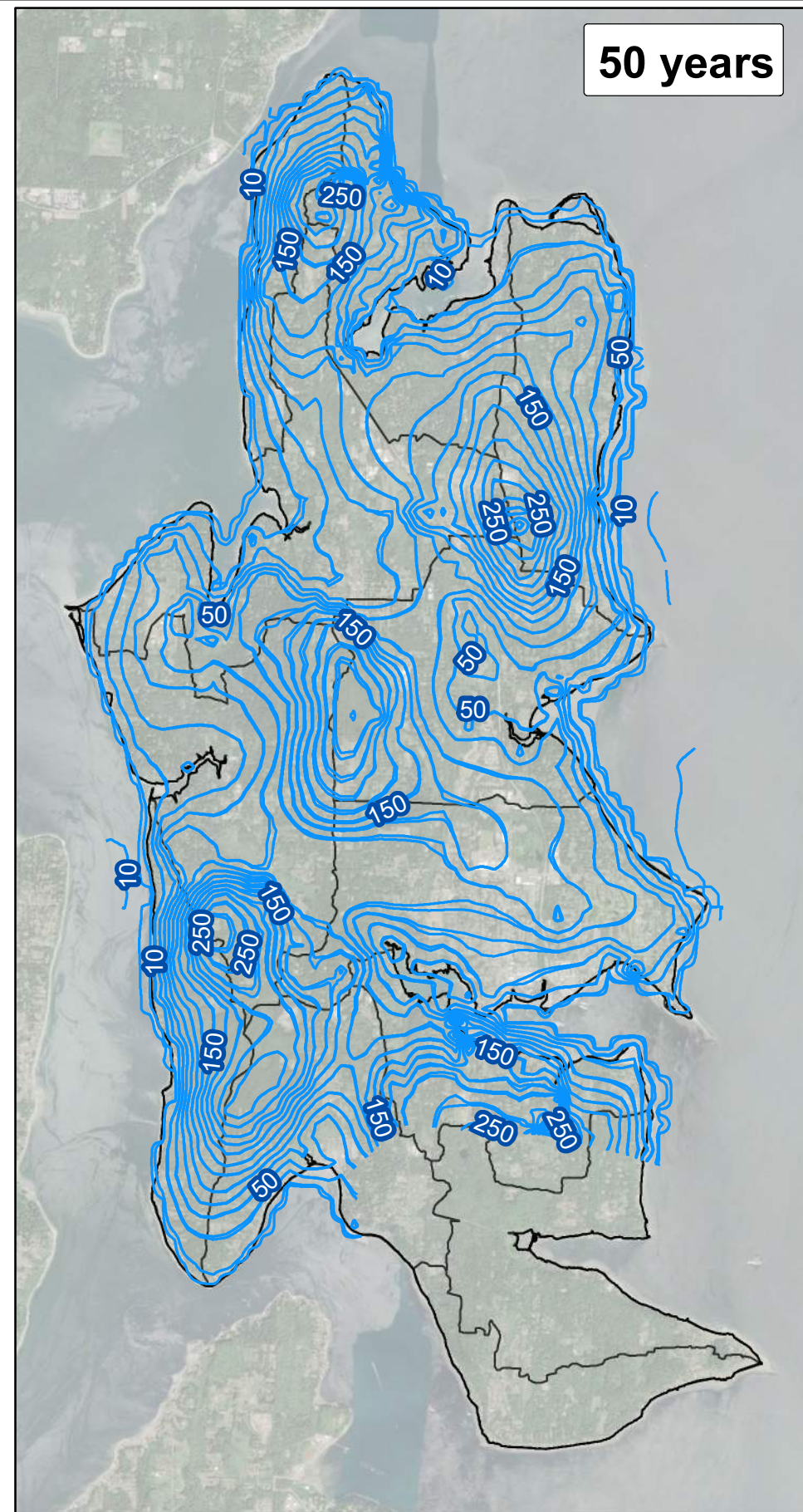
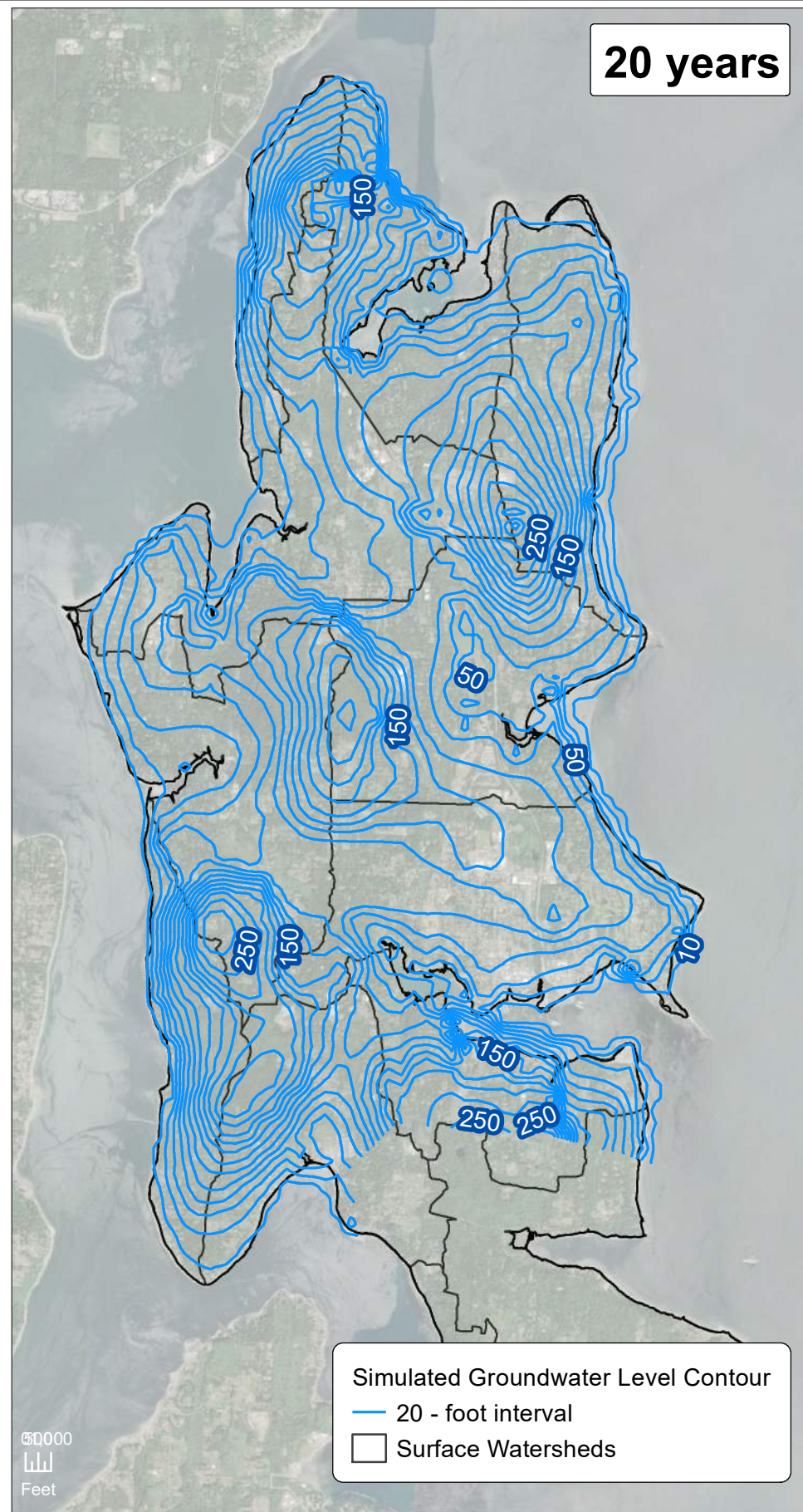


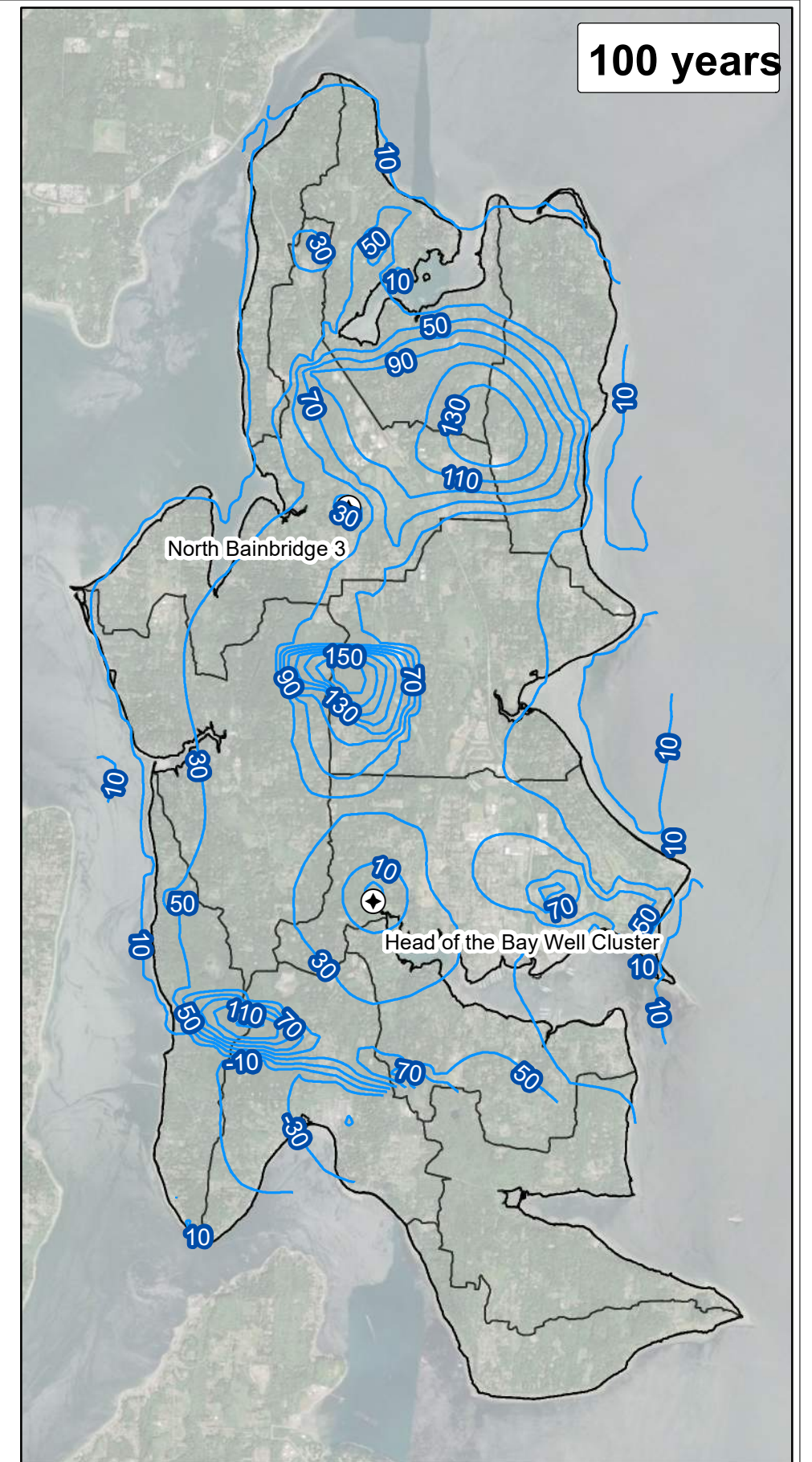
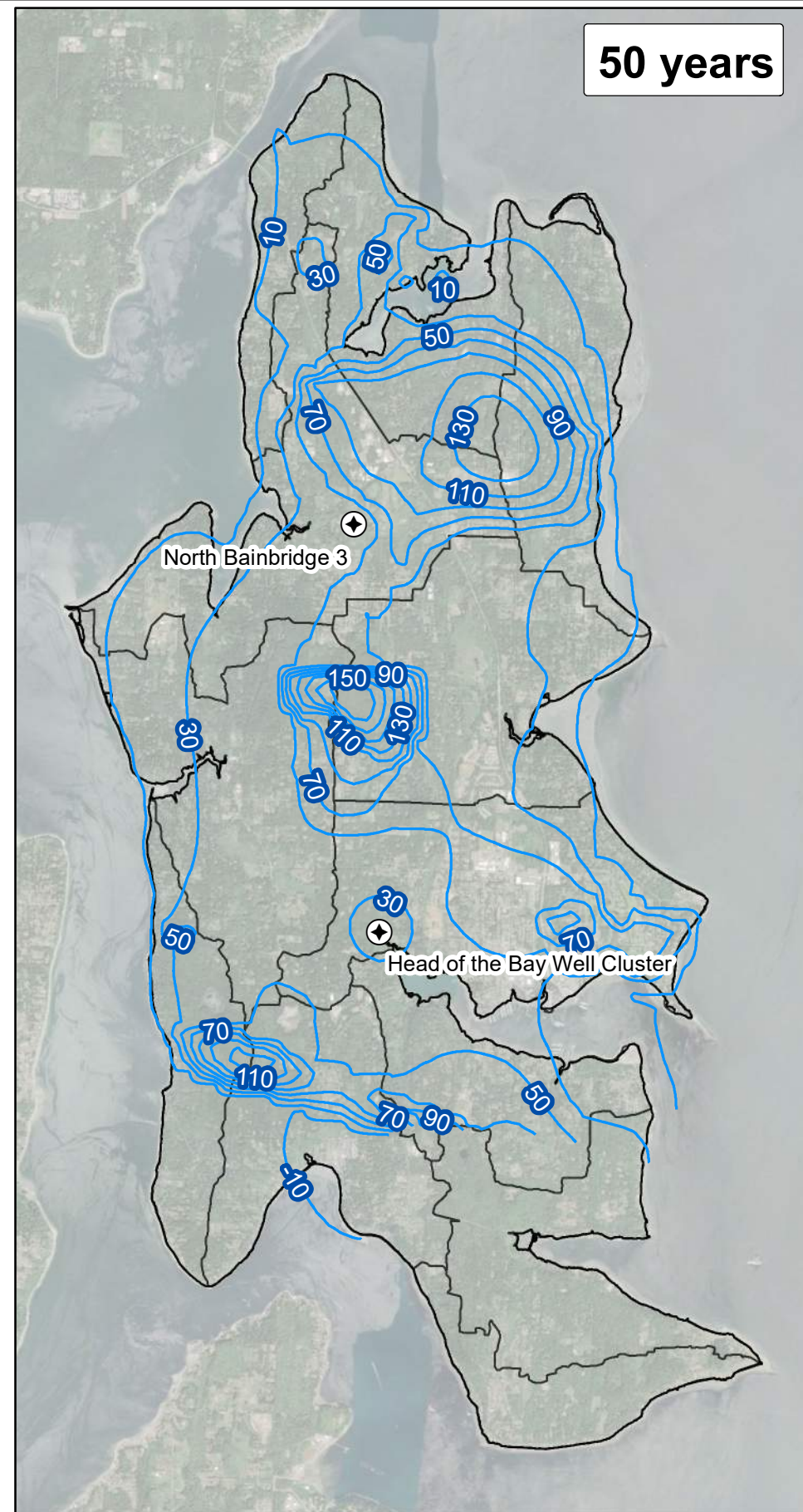
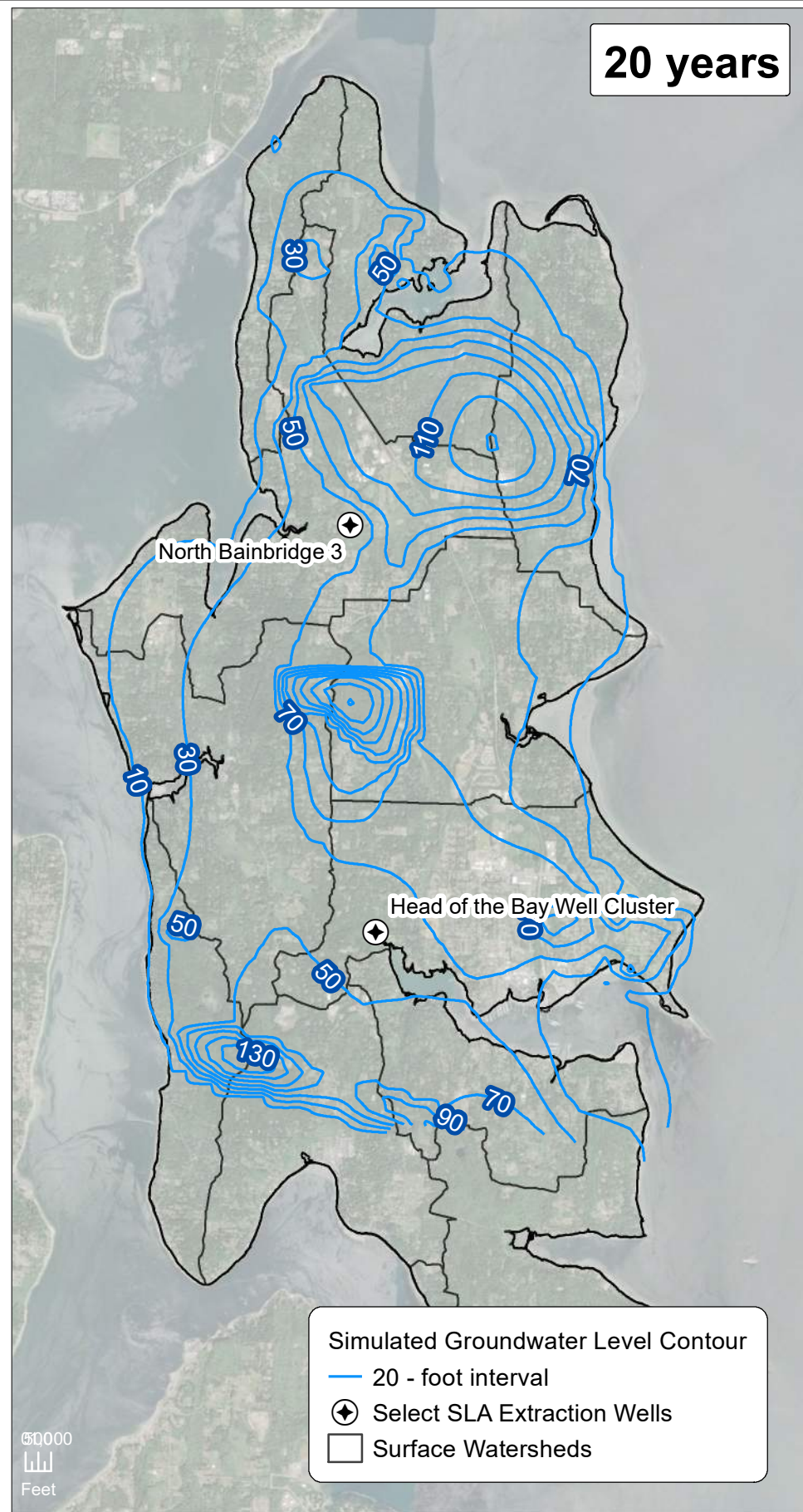


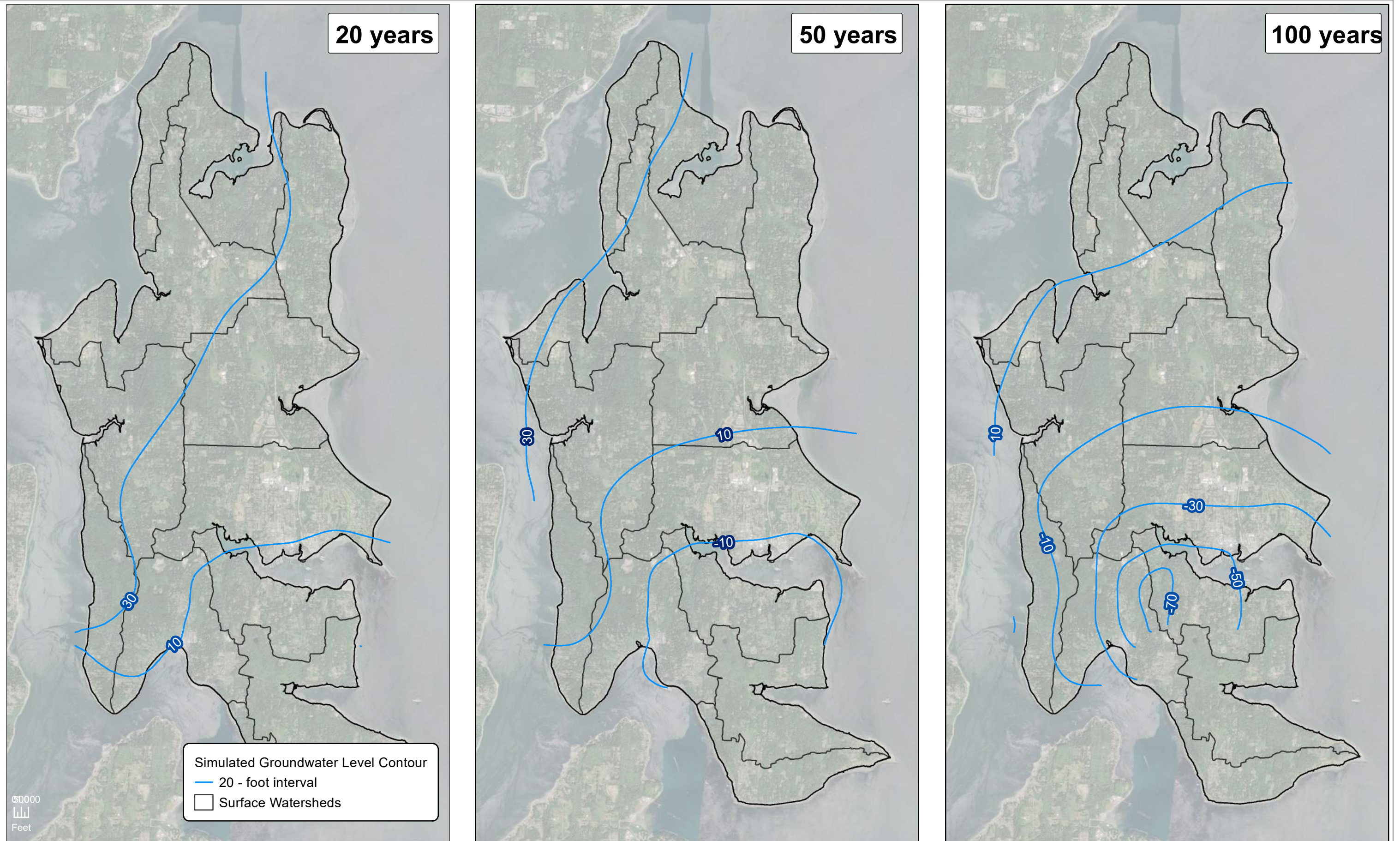


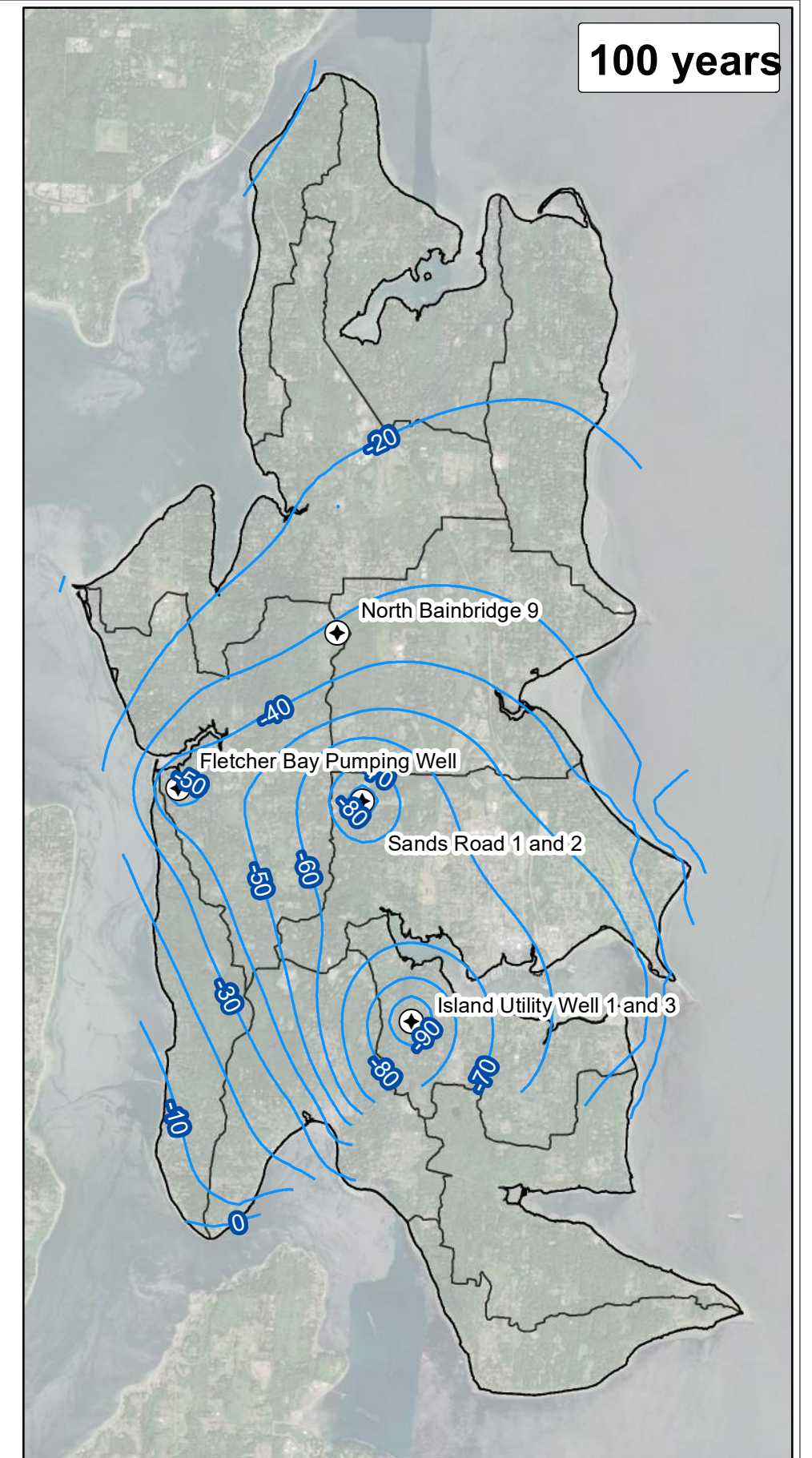
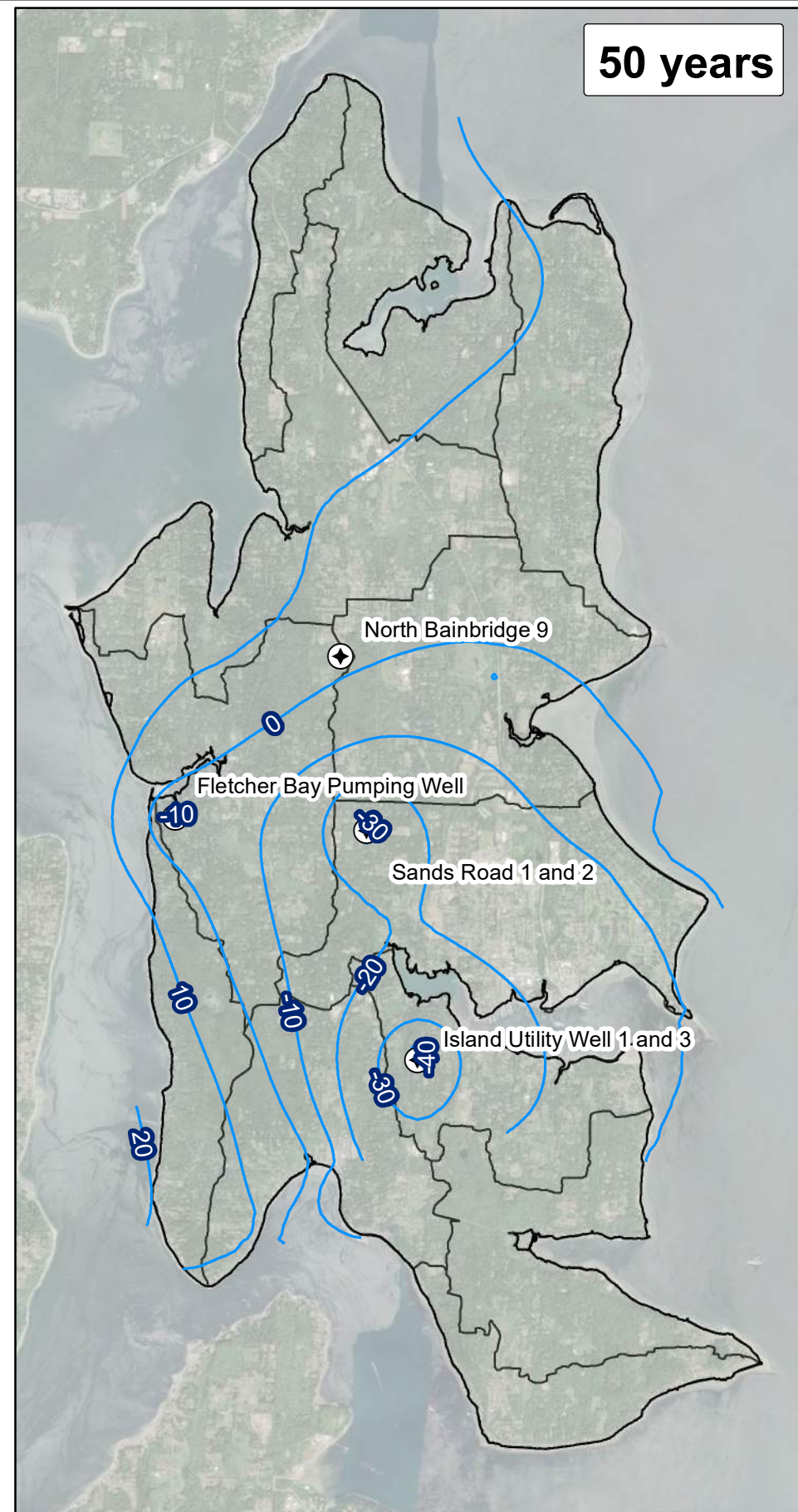
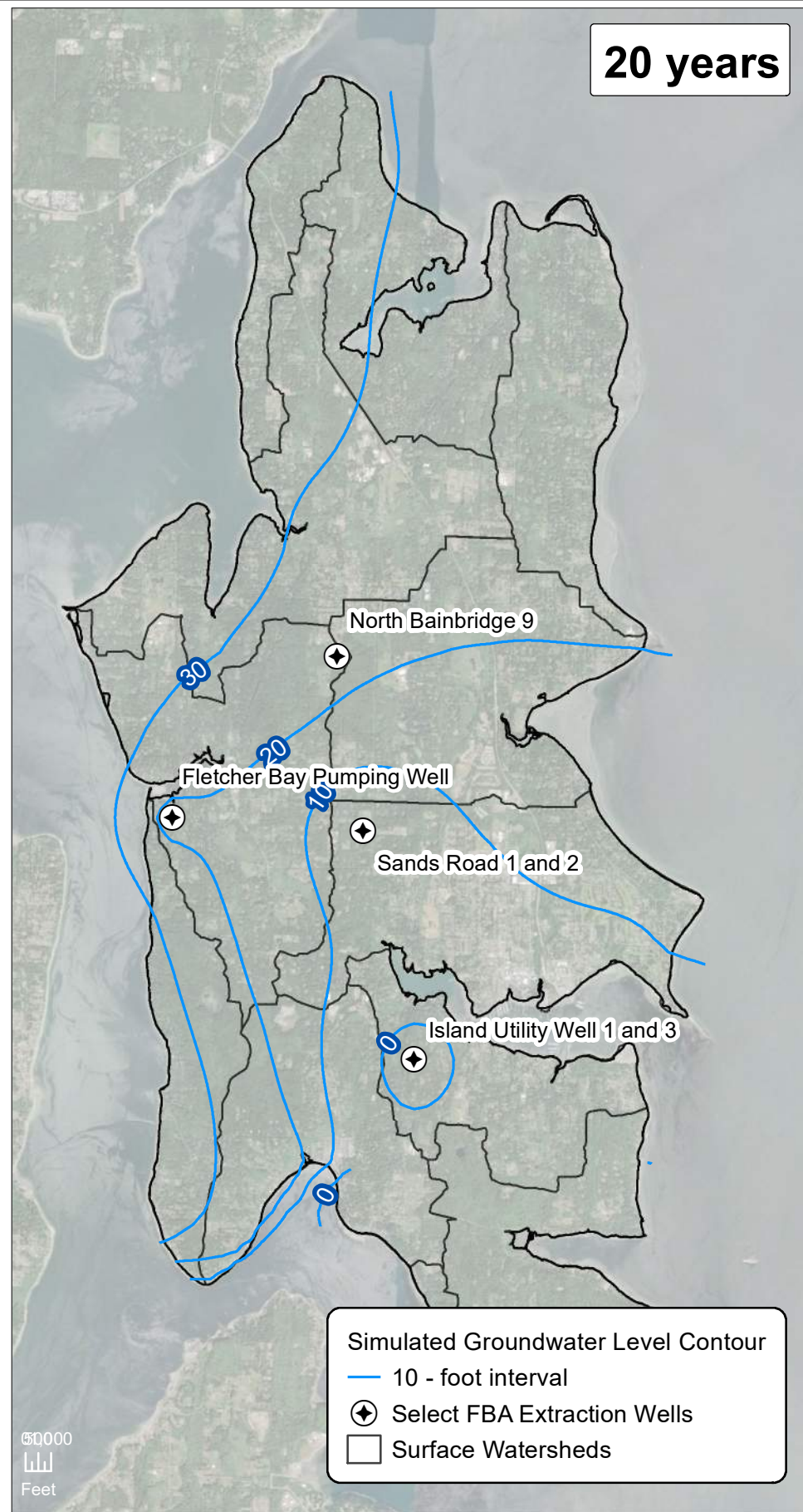


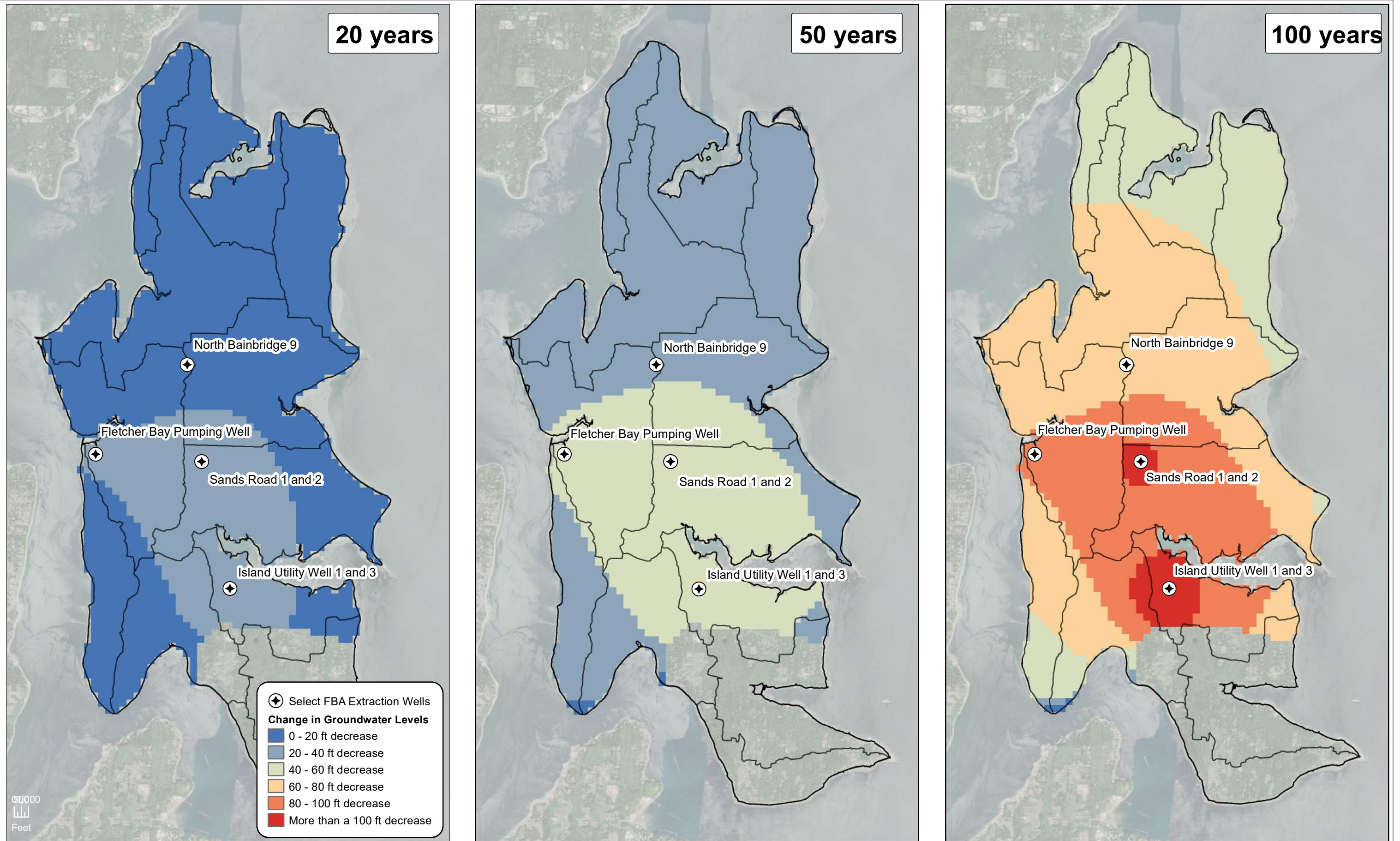


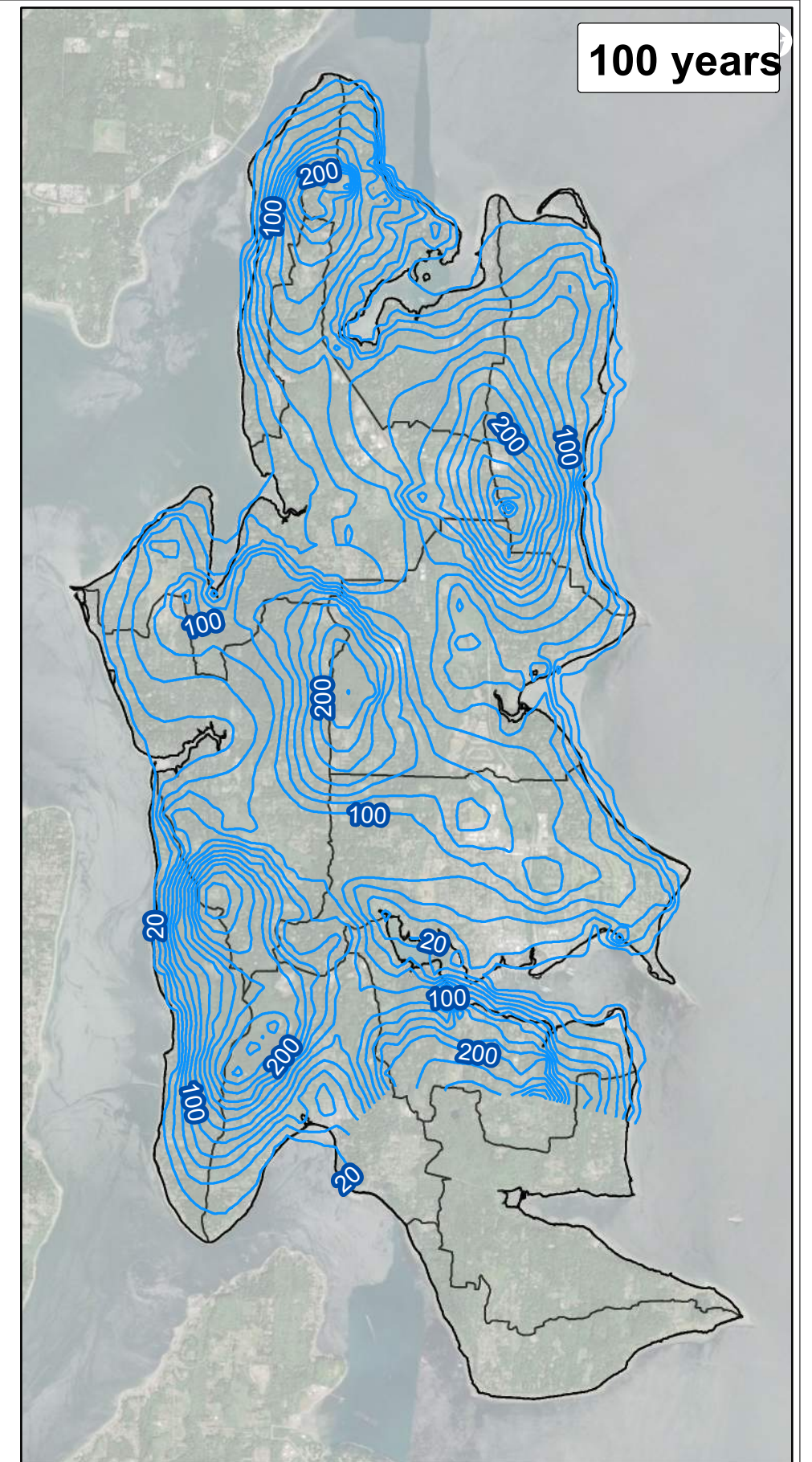
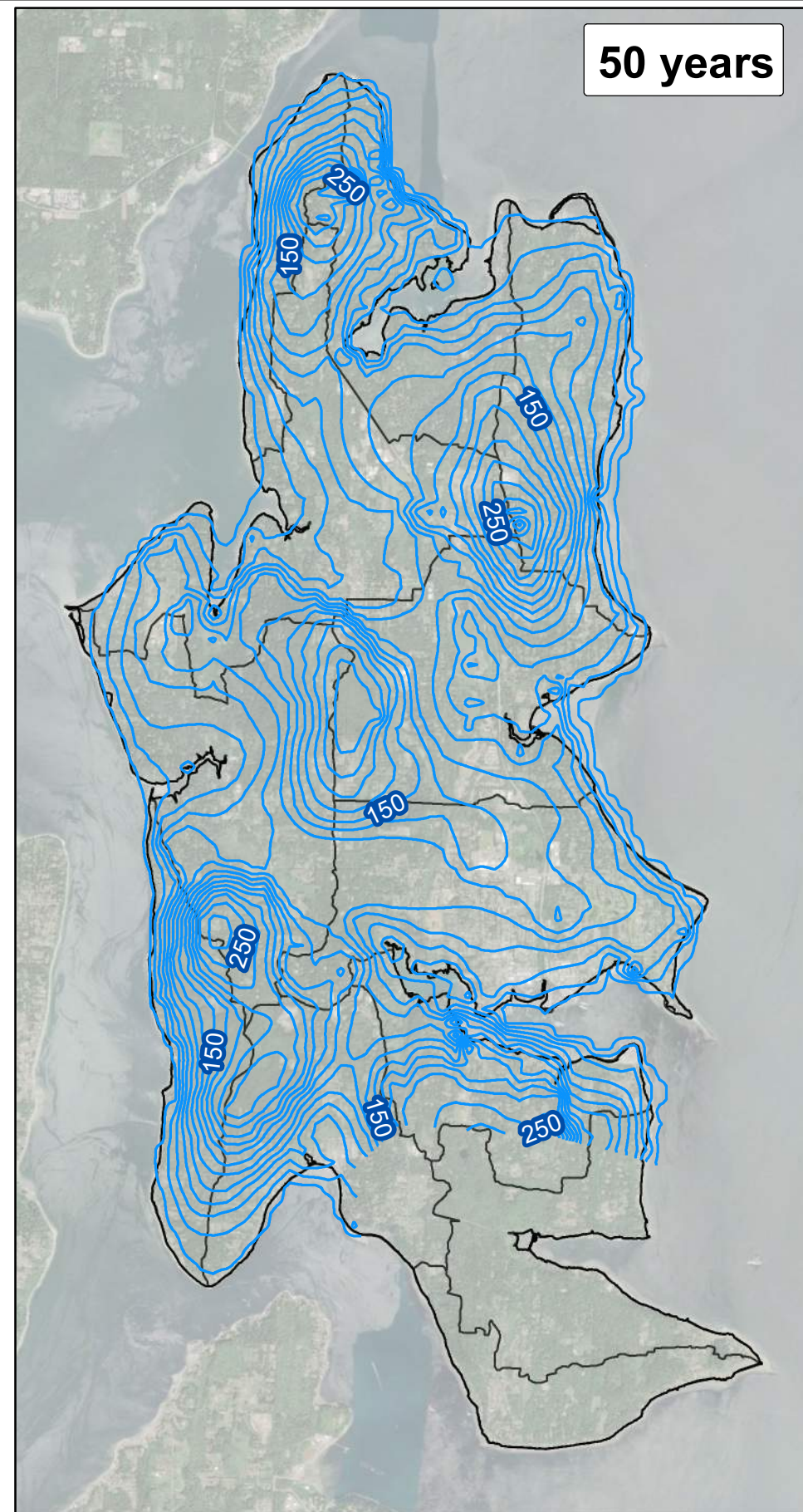


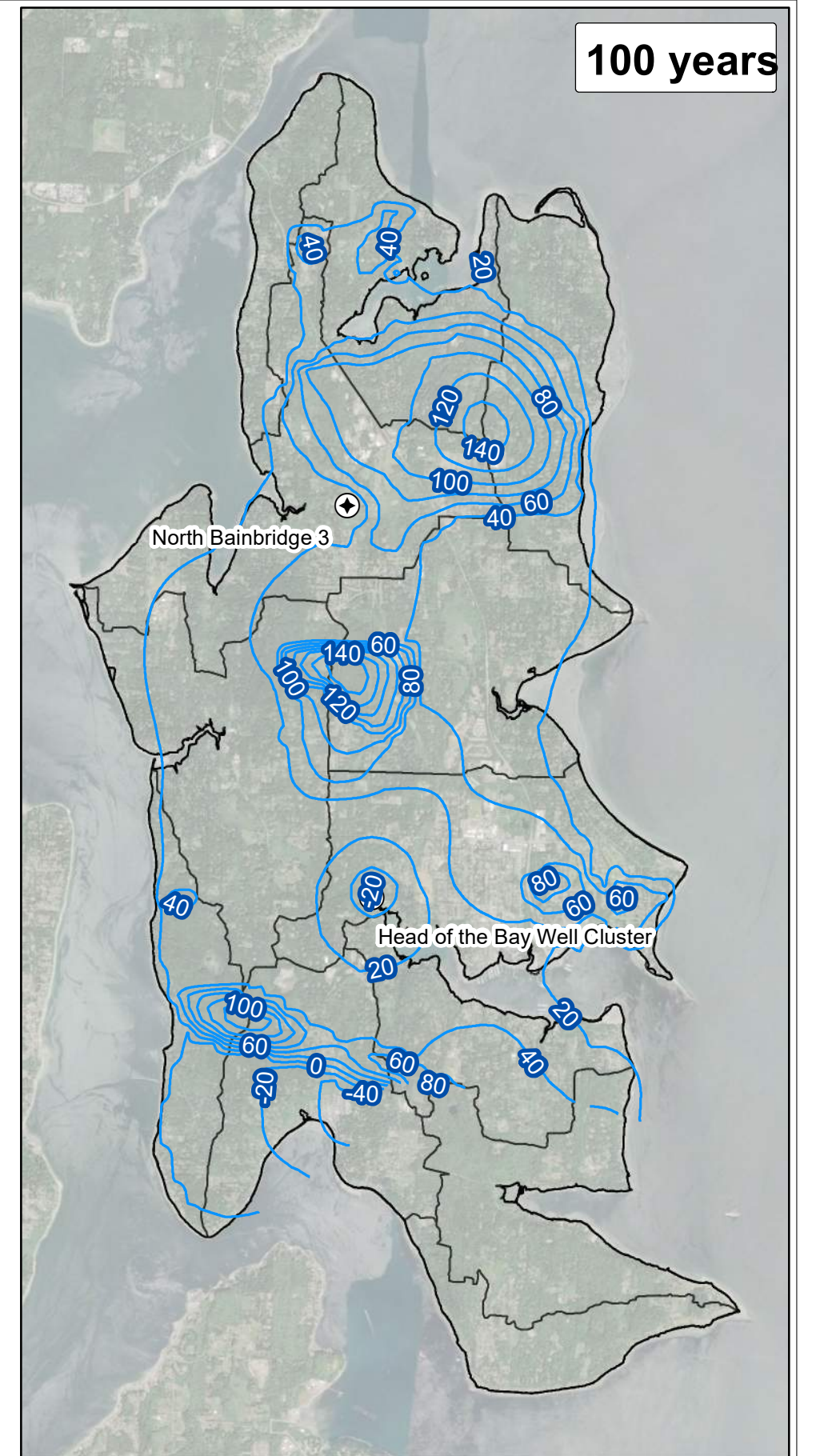
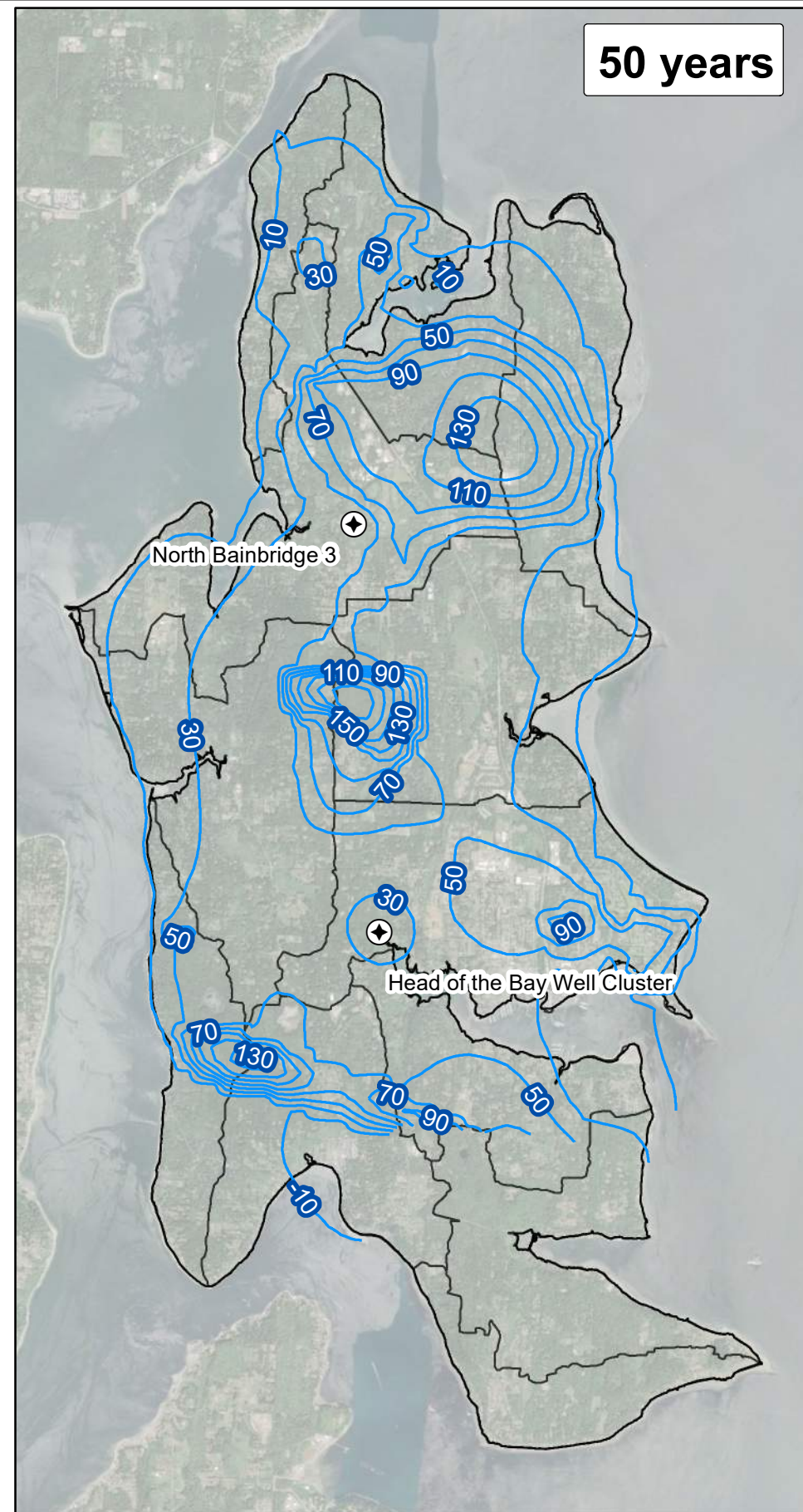
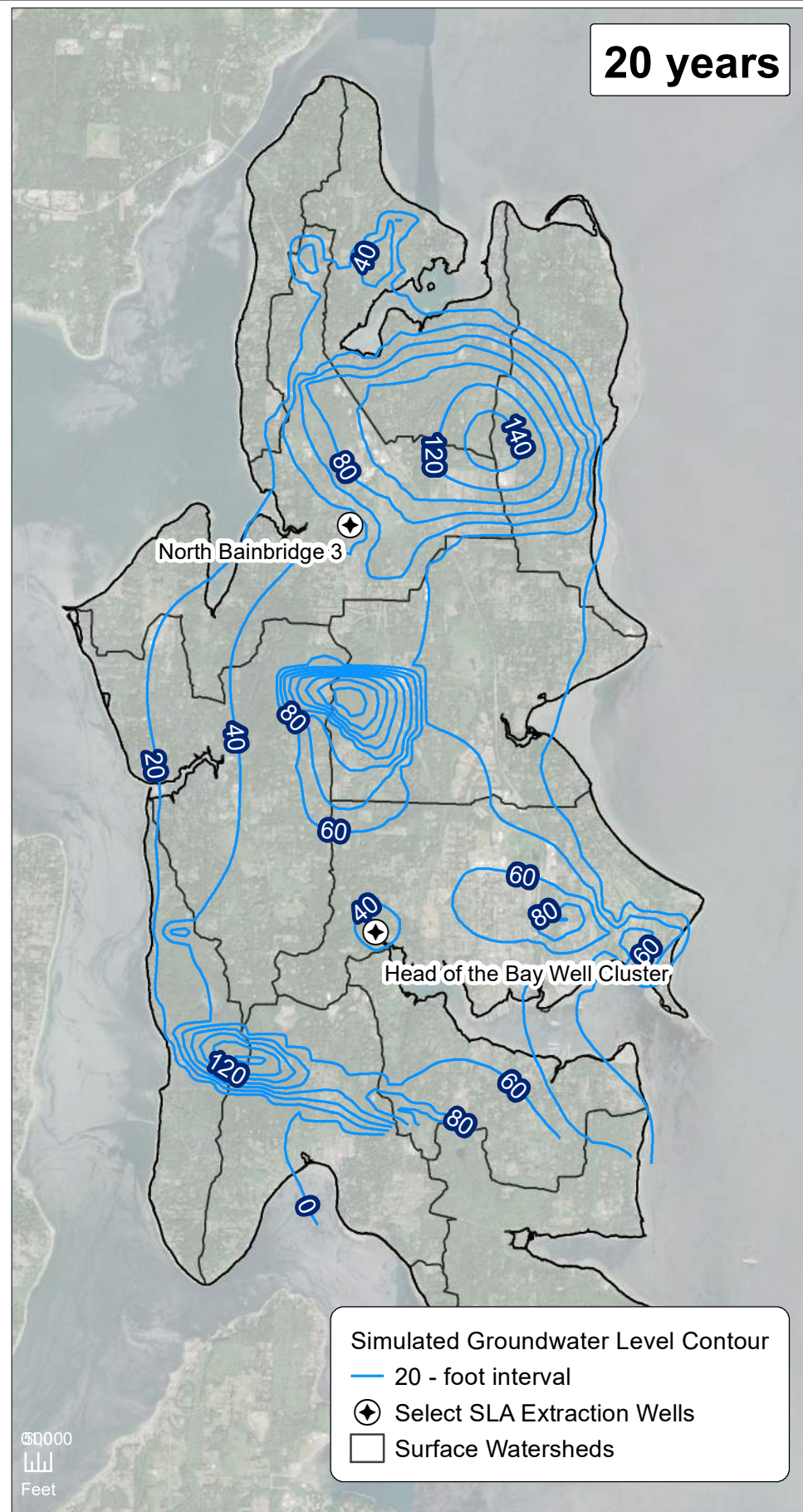


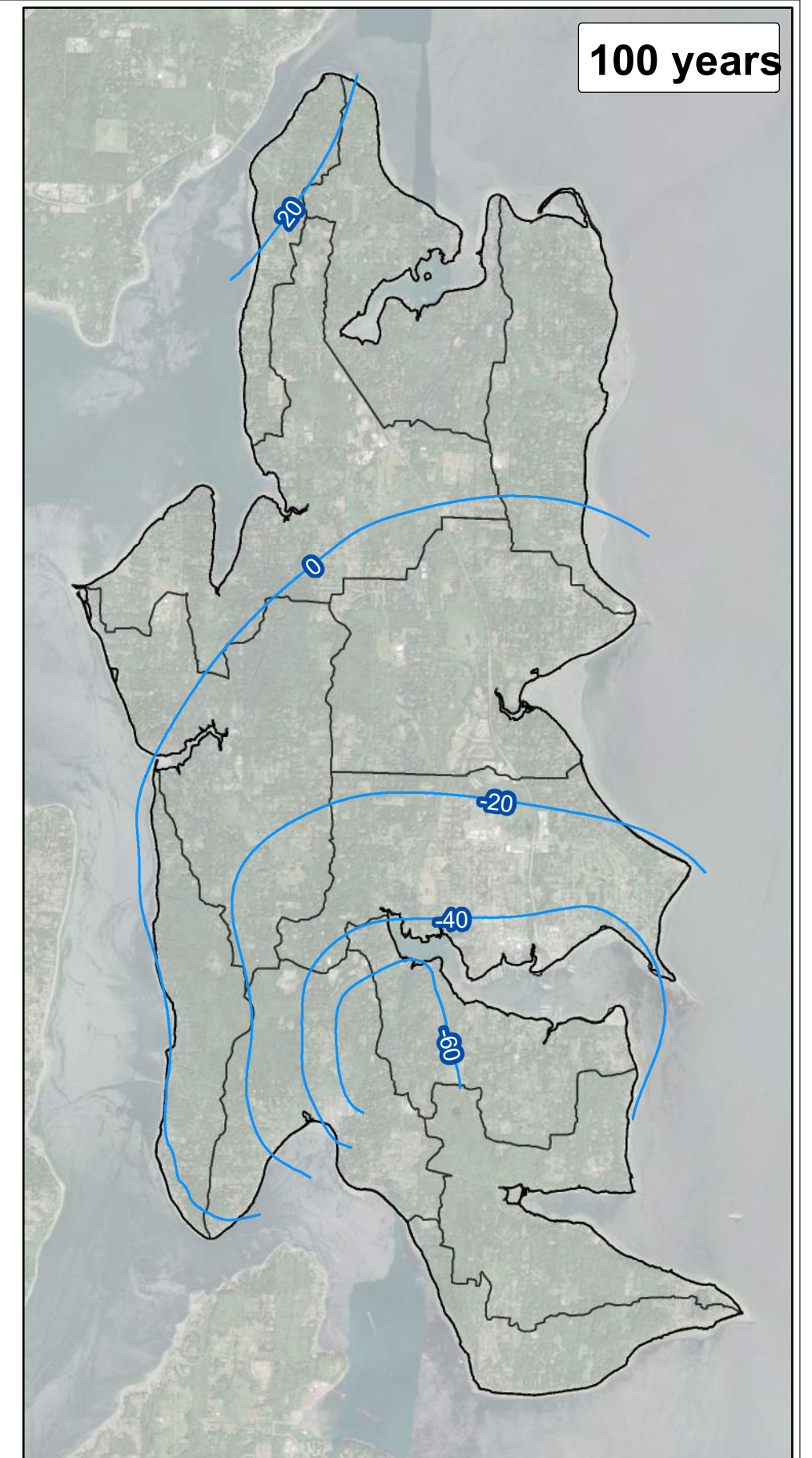
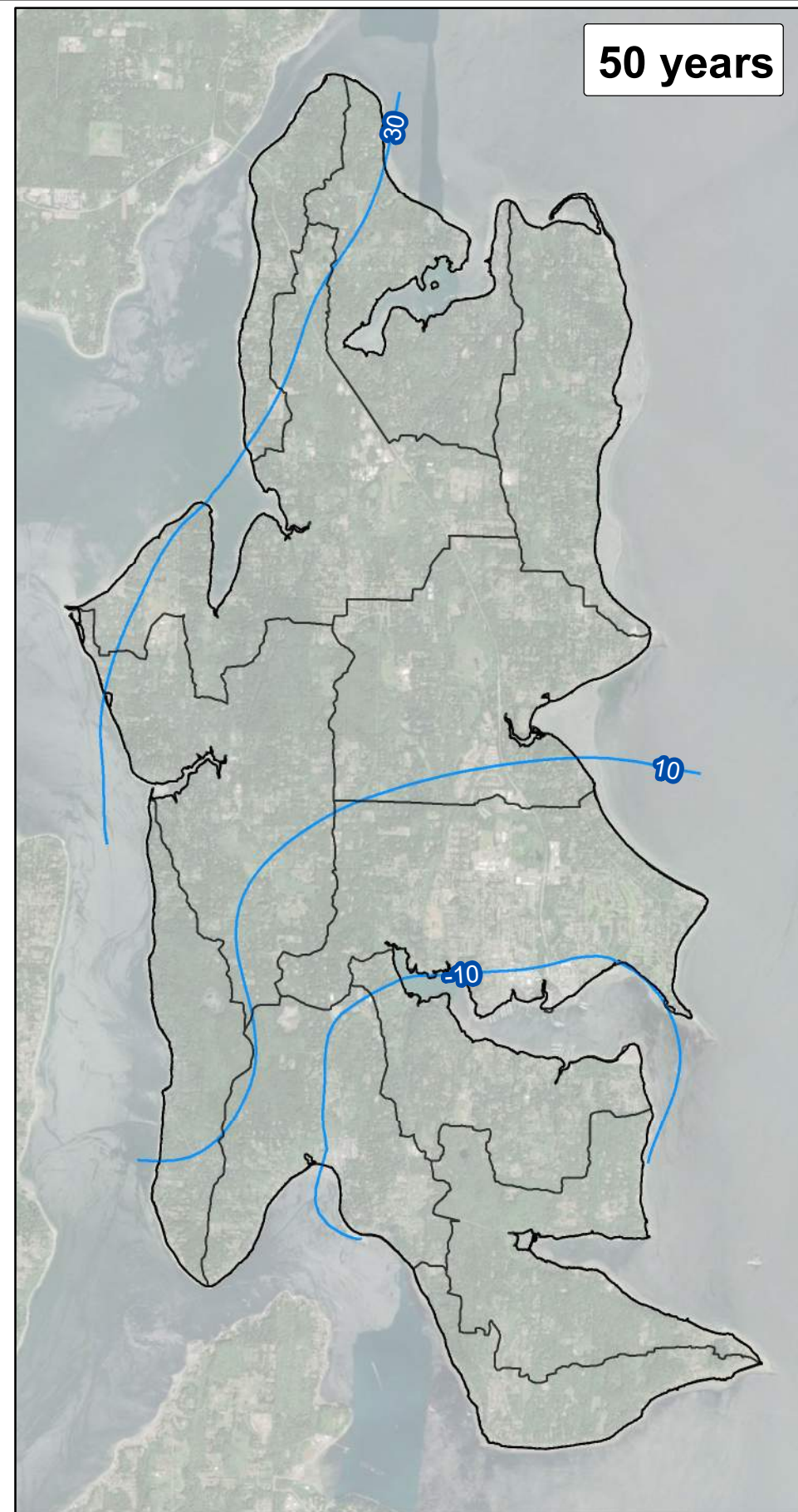
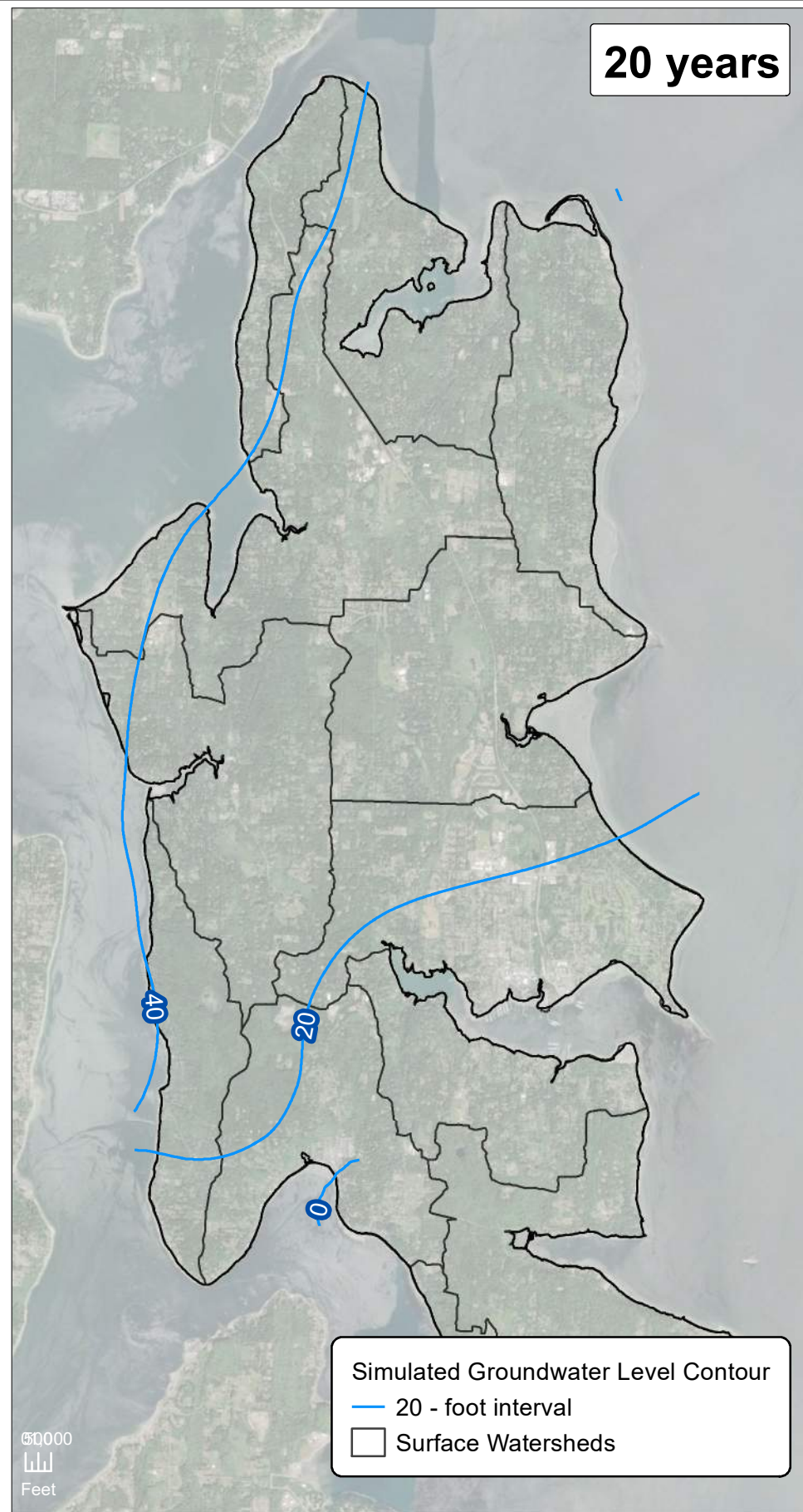


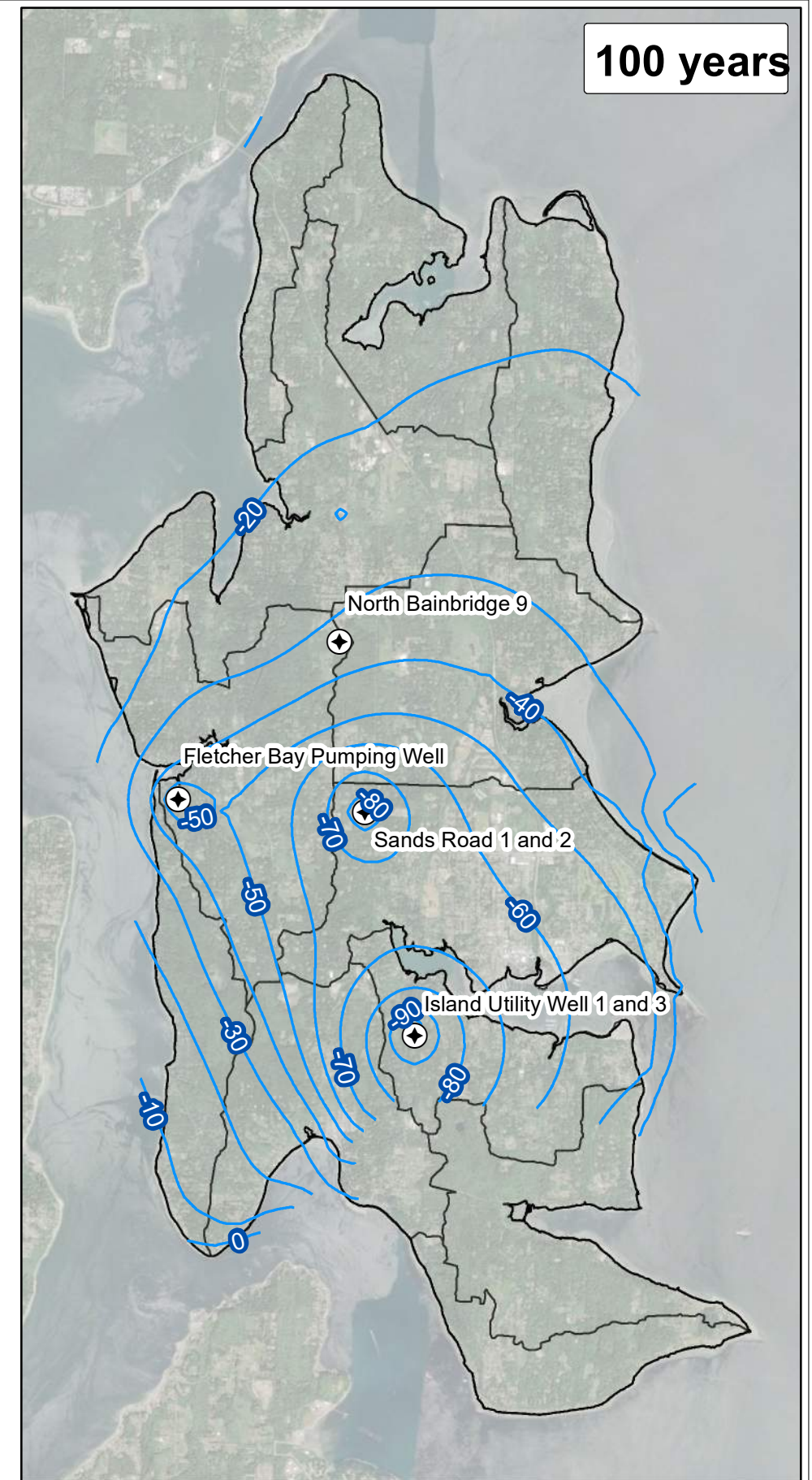
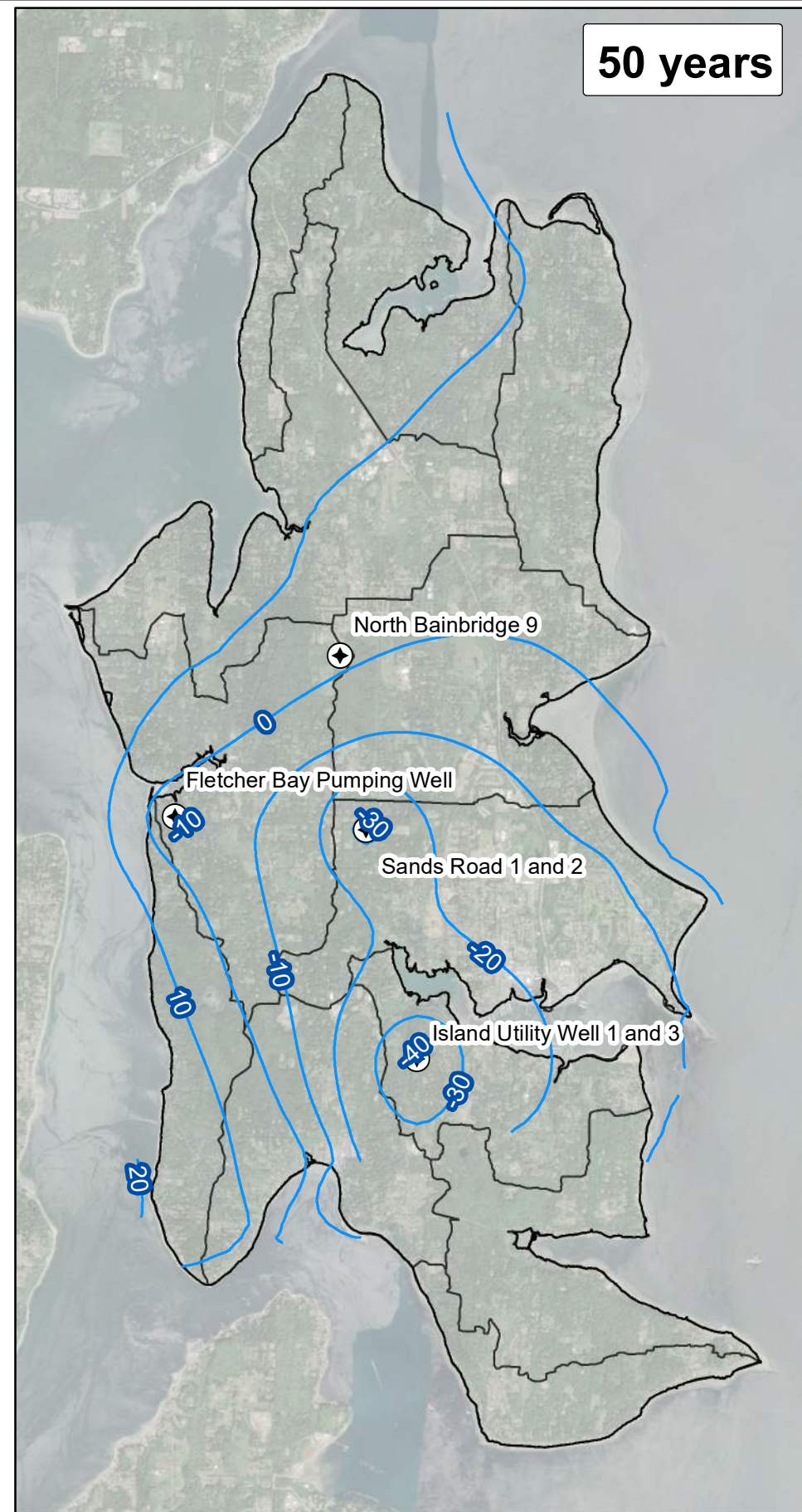
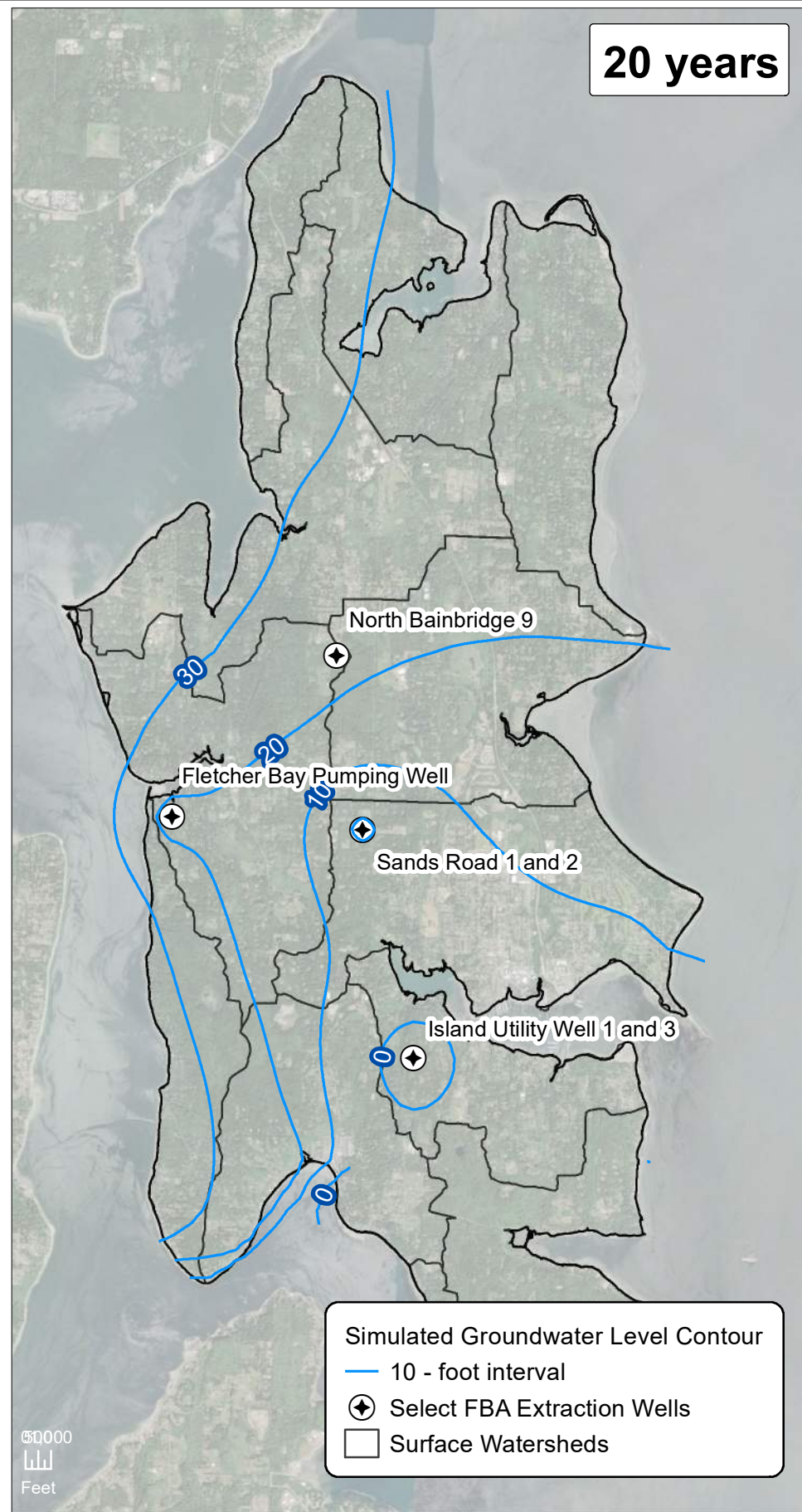


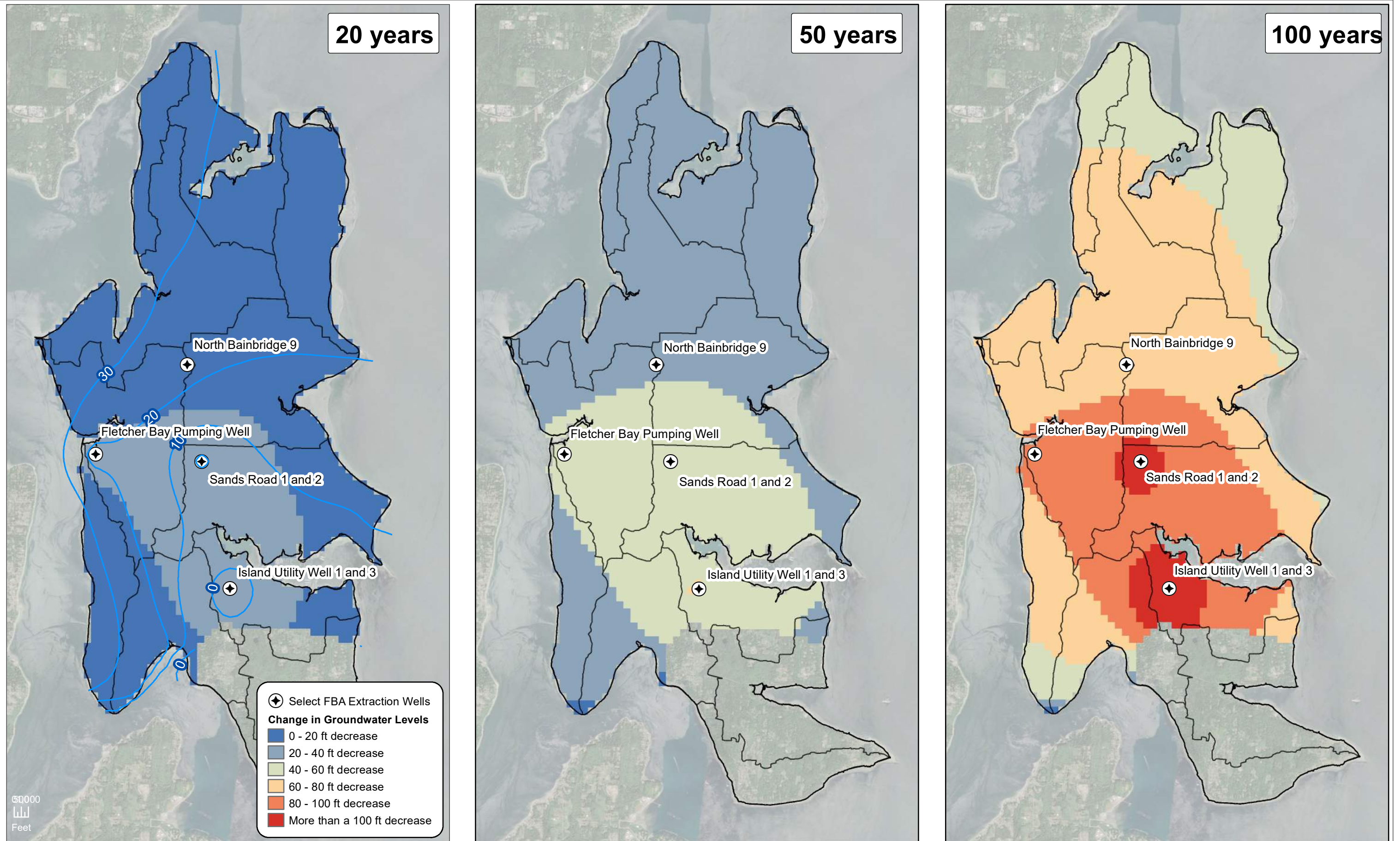












6. CONCLUSIONS

With the development of the **2025 EA Model**, EA has provided COBI with a well calibrated groundwater flow modeling tool that simulates groundwater flow across Bainbridge Island. The structure of the model accurately represents the available aquifer system information and reasonably represents what is known of the aquifer flow properties. The impact scenarios provide reasonable estimates of possible future climatic and water use conditions based on available climate change studies and historic population and production changes. Based on this information, the Low Impact Planning Scenario probably represents the most likely future conditions, representing the 50% exceedance sea level rise, a minimal change in recharge, and the median population growth estimate. The Mid and High Impact Planning Scenarios represent the most conservative, yet reasonable, future conditions with both simulating the maximum estimated sea level rise and the high population growth estimate, and both simulating recharge reduction beyond what is predicted by CIG.

Impact scenarios show that under all simulated future conditions, the Qva is minimally impacted, primarily due to the absence of large water system extraction and the increase in return water associated with increased production offsetting recharge reduction. The SLA is negatively impacted in two locations centered around water system well fields located close to the shoreline, the Head of the Bay wellfield and the South Bainbridge wellfield. Groundwater elevations around the South Bainbridge wellfield are estimated to fall below sea level by year 50 in all three impact scenarios. Groundwater elevations around the Head of the Bay wellfield are estimated to fall below sea level by year 100 in the Low and High Impact Scenarios. Groundwater levels below sea level suggest the potential for sea water intrusion exists which may eventually impact water quality for these water systems.

The impact scenarios also show a significantly greater drawdown in the deeper GMA and FBA units associated with the estimated increased production for the North Bainbridge, COBI, and South Bainbridge water systems. Drawdown is centered around the Sands Road and Island Utility wellfields. While the estimated drawdown does not threaten to dewater these units, it does increase the potential for sea water intrusion. However, both hydrogeologic units are separated from Puget Sound sea water by thick aquitards composed of clays and silts that will inhibit the vertical intrusion of sea water. The model cannot simulate the migration of chloride concentrations over time, it only suggests that the potential for sea water intrusion exists under the future conditions.

The **2025 EA model** described in this technical memorandum was used to simulate potential groundwater conditions under different climate and population growth scenarios. These results are presented to improve the understanding of groundwater resources on Bainbridge Island and should not be interpreted as “the future.” There are large uncertainties both in how climate change will impact the hydrologic cycle (sea level rise and the interactions between precipitation and recharge) and how populations will change on Bainbridge Island over the next 100 years. Even if these parameters could be forecasted without error there would still be uncertainty in the results predicted by the groundwater model itself. *That is, the groundwater model is a useful but imperfect representation of reality that inevitably contains error.* It follows that the groundwater

model cannot provide interpretations or decisions on policy and planning; it can only provide one set of data to support those decisions.

The Bainbridge Island Groundwater Management Plan provides further interpretations and discussions related to the future planning of groundwater resources on Bainbridge Island.

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Appendix A
Supplementary Material

Figure A4 - Bainbridge Island Estimated Production Growth

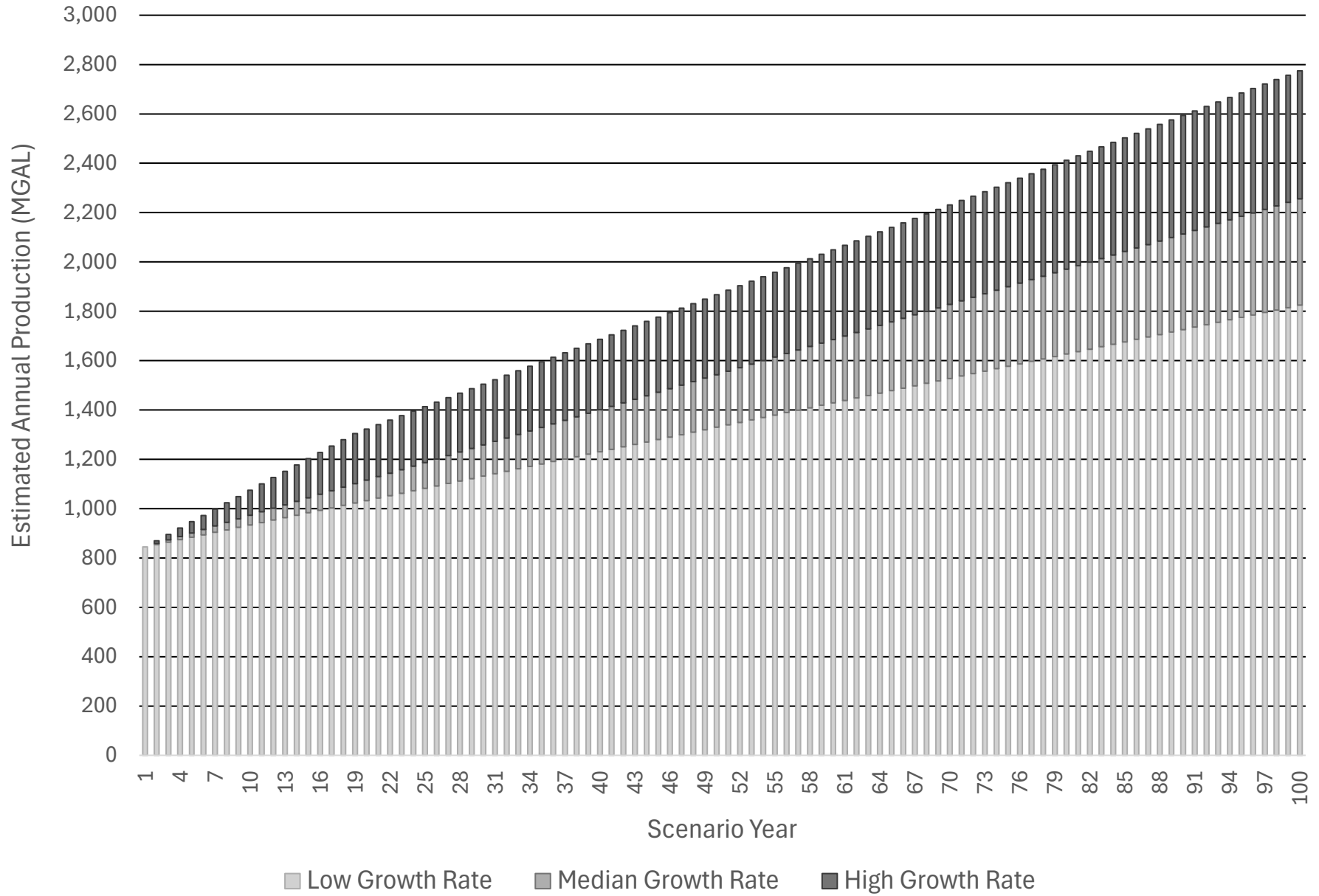


Figure A1 - Bainbridge Island Estimated Residential Population Growth

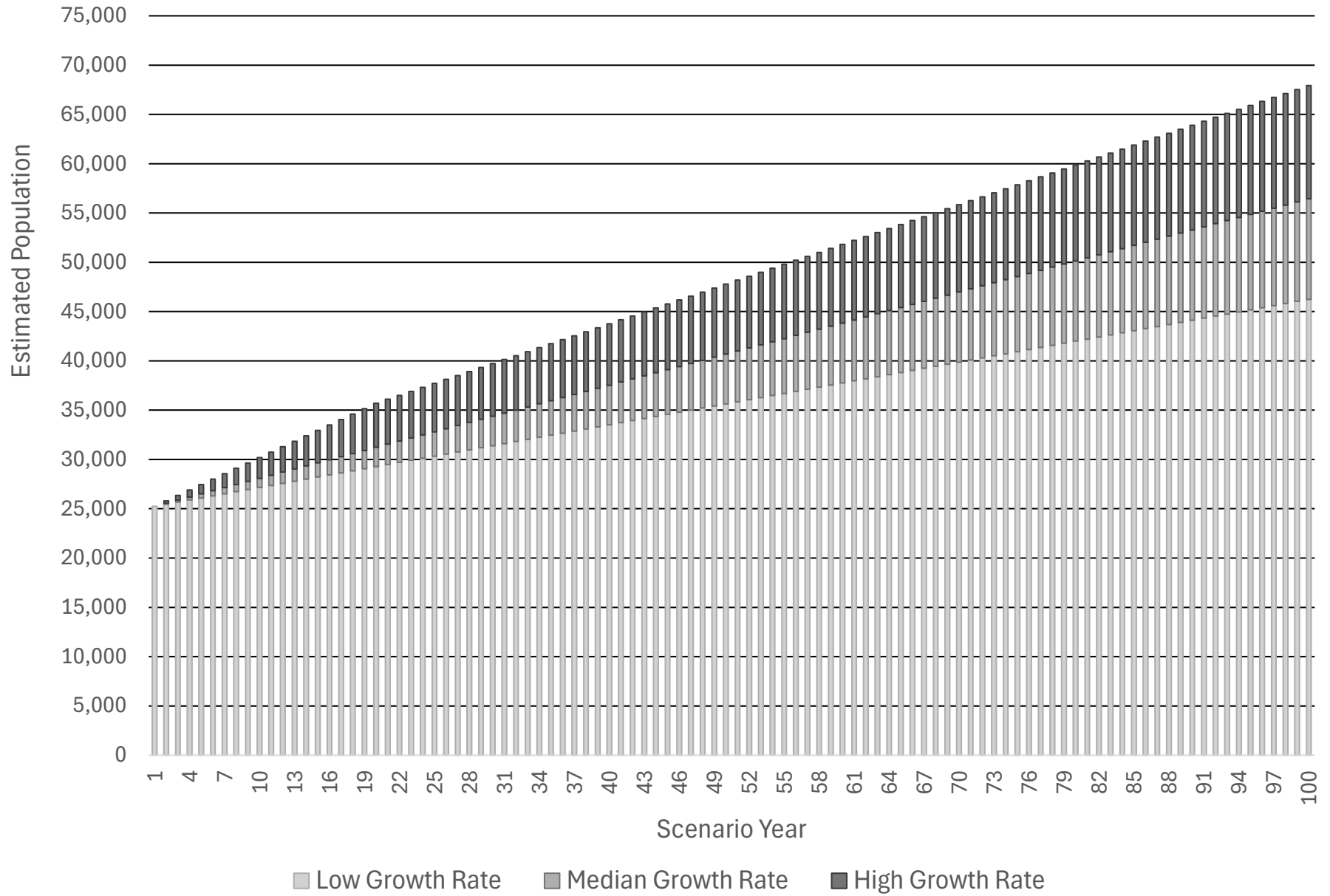


Figure A2 - Bainbridge Island Estimated Nonresidential Population Growth

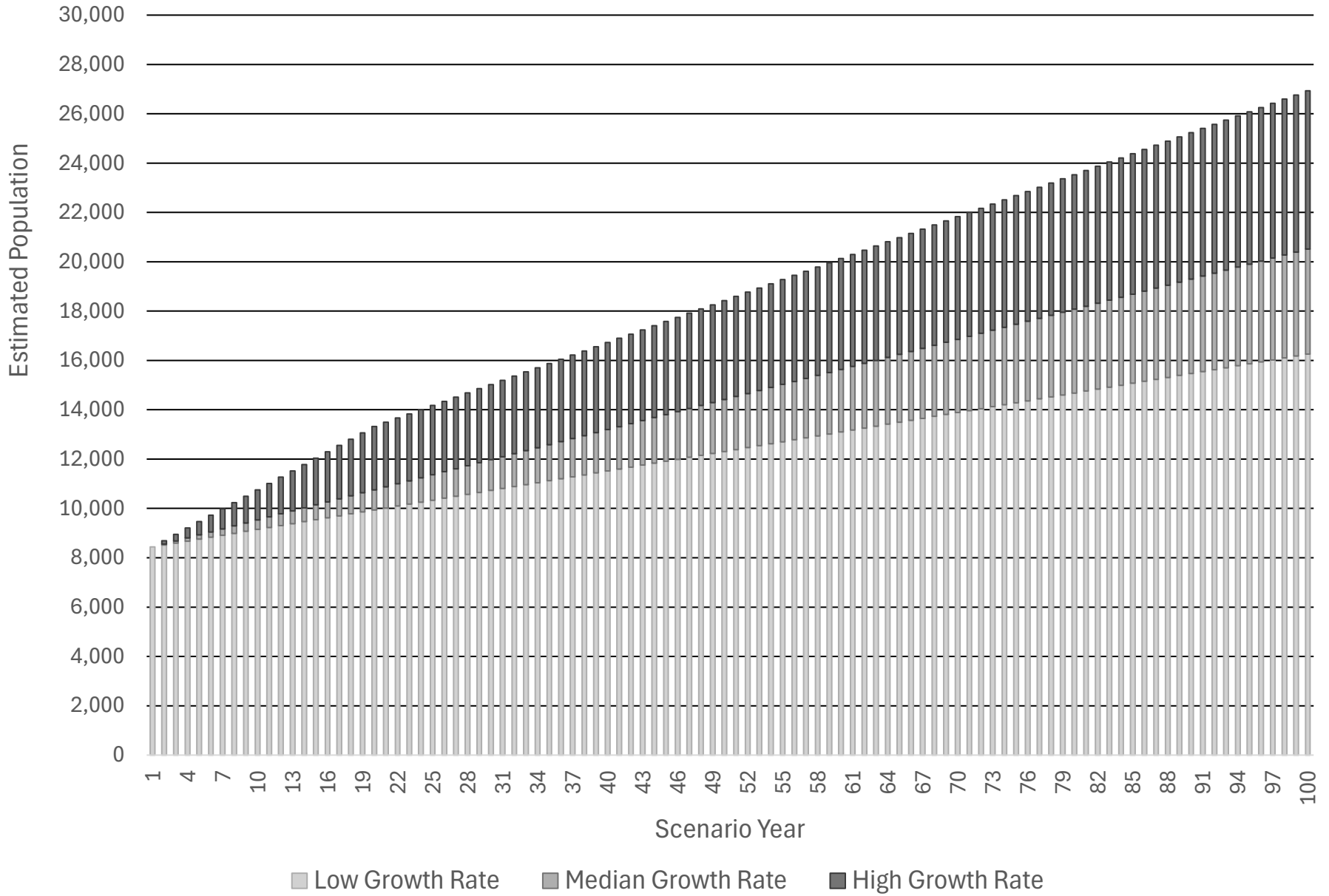
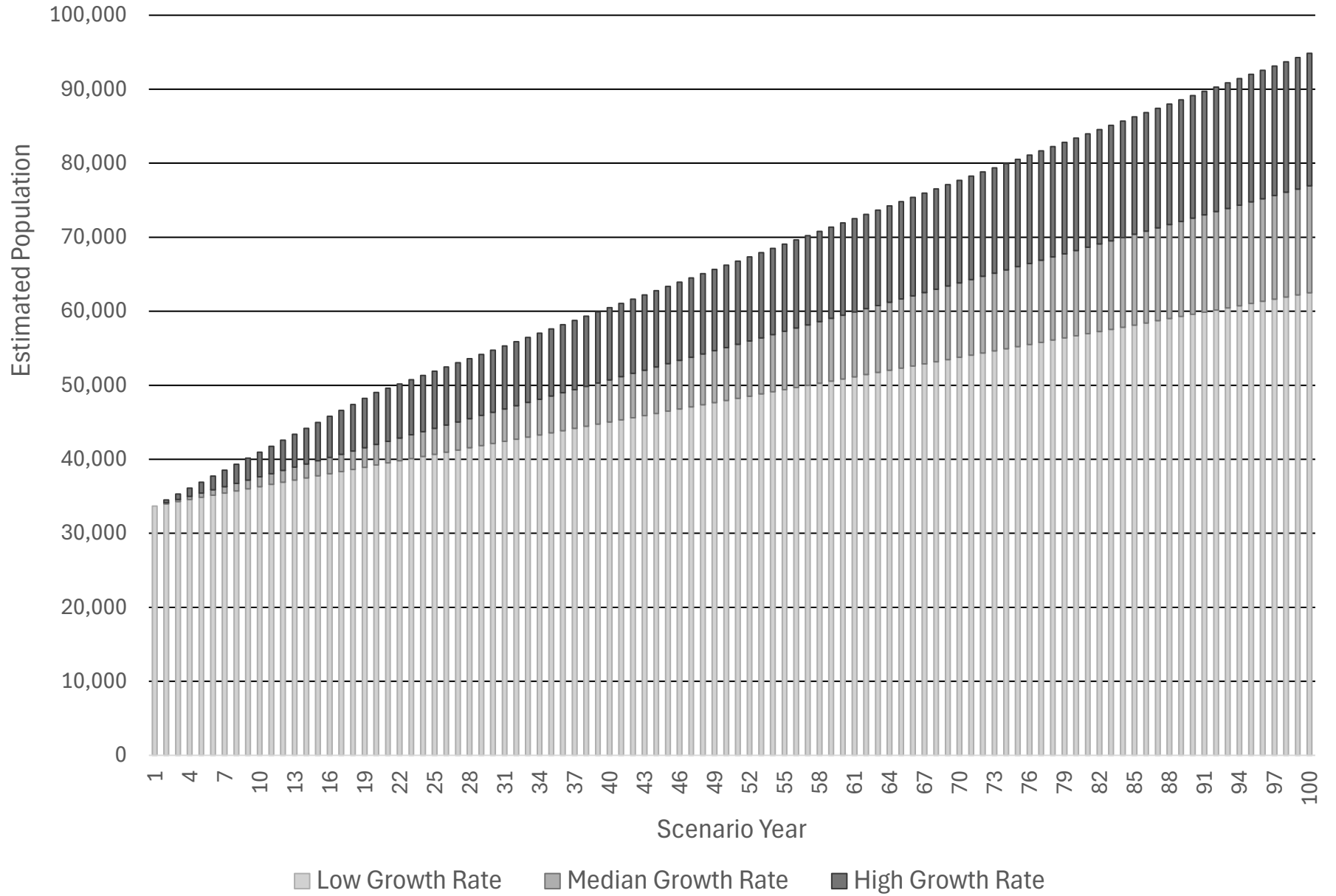


Figure A3 - Bainbridge Island Estimated Use Population Growth



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