Groundwater under Bainbridge Island: The Big Picture

Charlie Kratzer

Open Mic Science

December 12, 2023

Objectives for tonight’s talk:

- Big picture understanding of BI’s groundwater
- What sustainability means and what environmental tradeoffs are involved
- Why a GWMP is a good idea for BI

EPA

United States
Environmental Protection
Agency
March 2013

Region 10
1200 Sixth Avenue, Suite 900
Seattle WA 98101
EPA 910-R-13-003

SUPPORT DOCUMENT FOR SOLE SOURCE AQUIFER DESIGNATION OF THE BAINBRIDGE ISLAND AQUIFER SYSTEM

As an EPA-designated Sole Source Aquifer, BI has no other reasonable source of freshwater

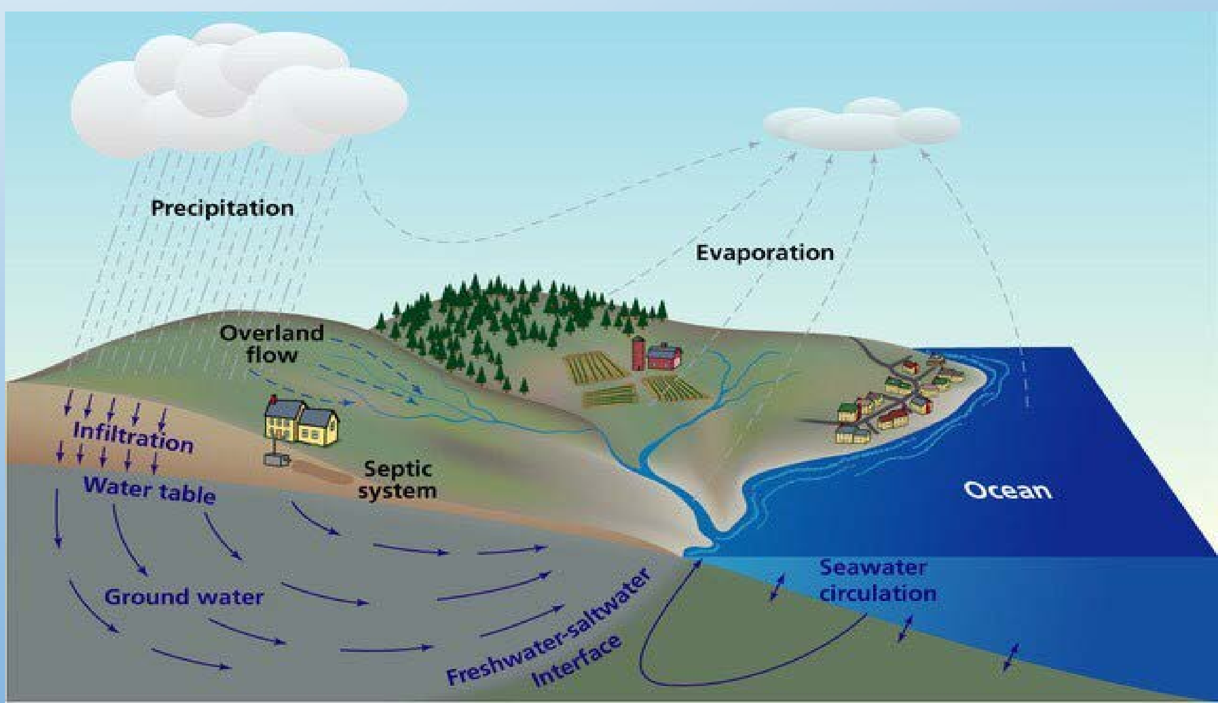
Talk Outline

- Groundwater in General and Under Bainbridge Island
- Model Results and Water Budget Analysis
- Groundwater Sustainability
- Groundwater Monitoring and Management Plan for Bainbridge Island
- Suggested Reading Material
- Questions?

What is Groundwater?

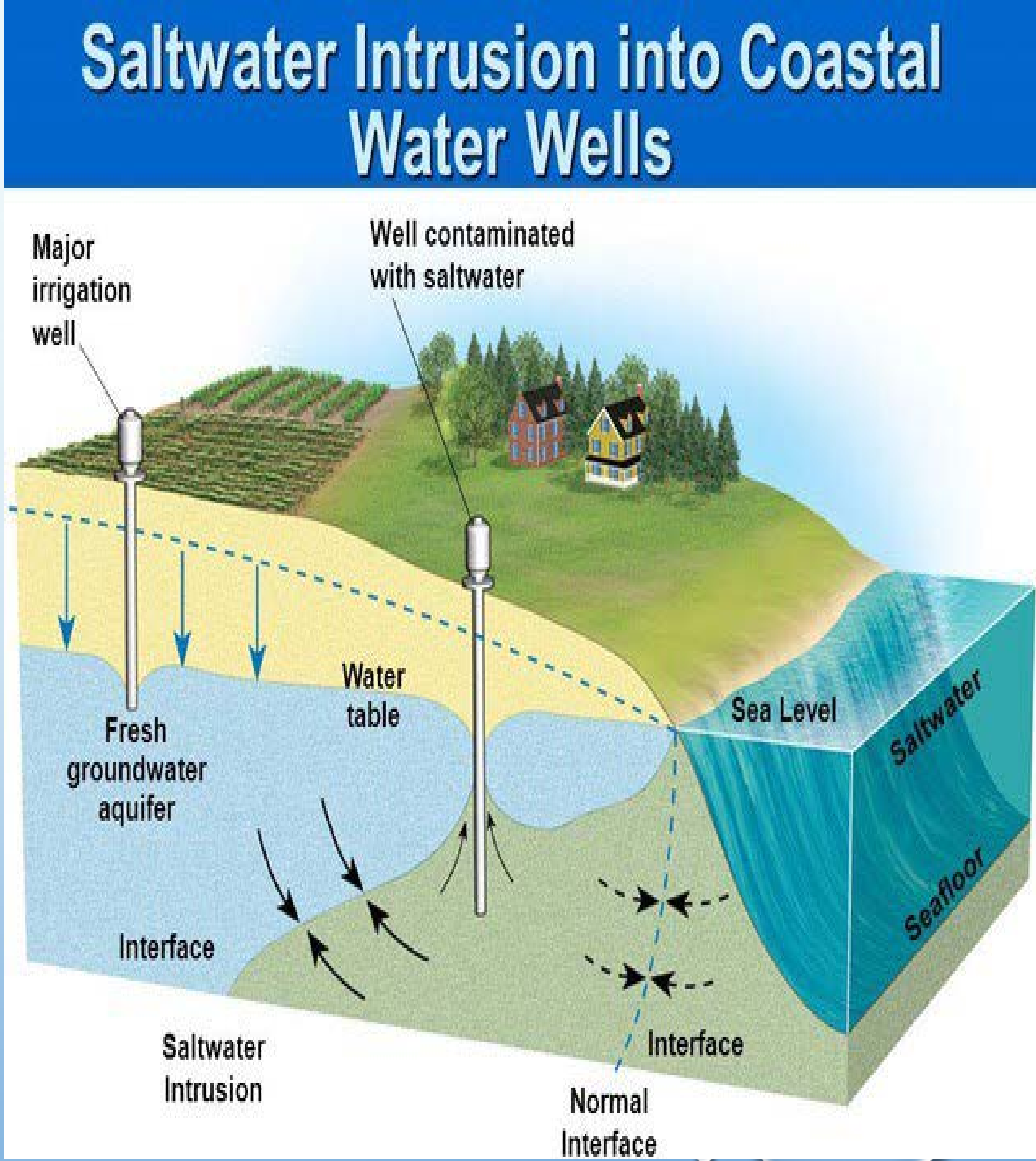
- Groundwater is water that exists underground in saturated zones beneath the land surface. The upper surface of the saturated zone is called the water table. Contrary to popular belief, groundwater does not form underground rivers. It fills the pores and fractures in underground materials such as sand, gravel, and other rock, much the same way that water fills a sponge. If groundwater flows naturally out of rock materials or if it can be removed by pumping (in useful amounts), the rock materials are called aquifers. Groundwater moves slowly from higher to lower water levels, typically at rates of 3 to 25 inches per day in an aquifer. As a result, water could remain in an aquifer for hundreds or thousands of years.

- Aquifers are separated by layers of soil or rock called confining layers.
- Groundwater quantity is estimated by measuring water levels. Water levels vary seasonally due to rainfall and pumping, so measurements at the same time each year will give the best information on changes in the amount of groundwater on an annual basis.



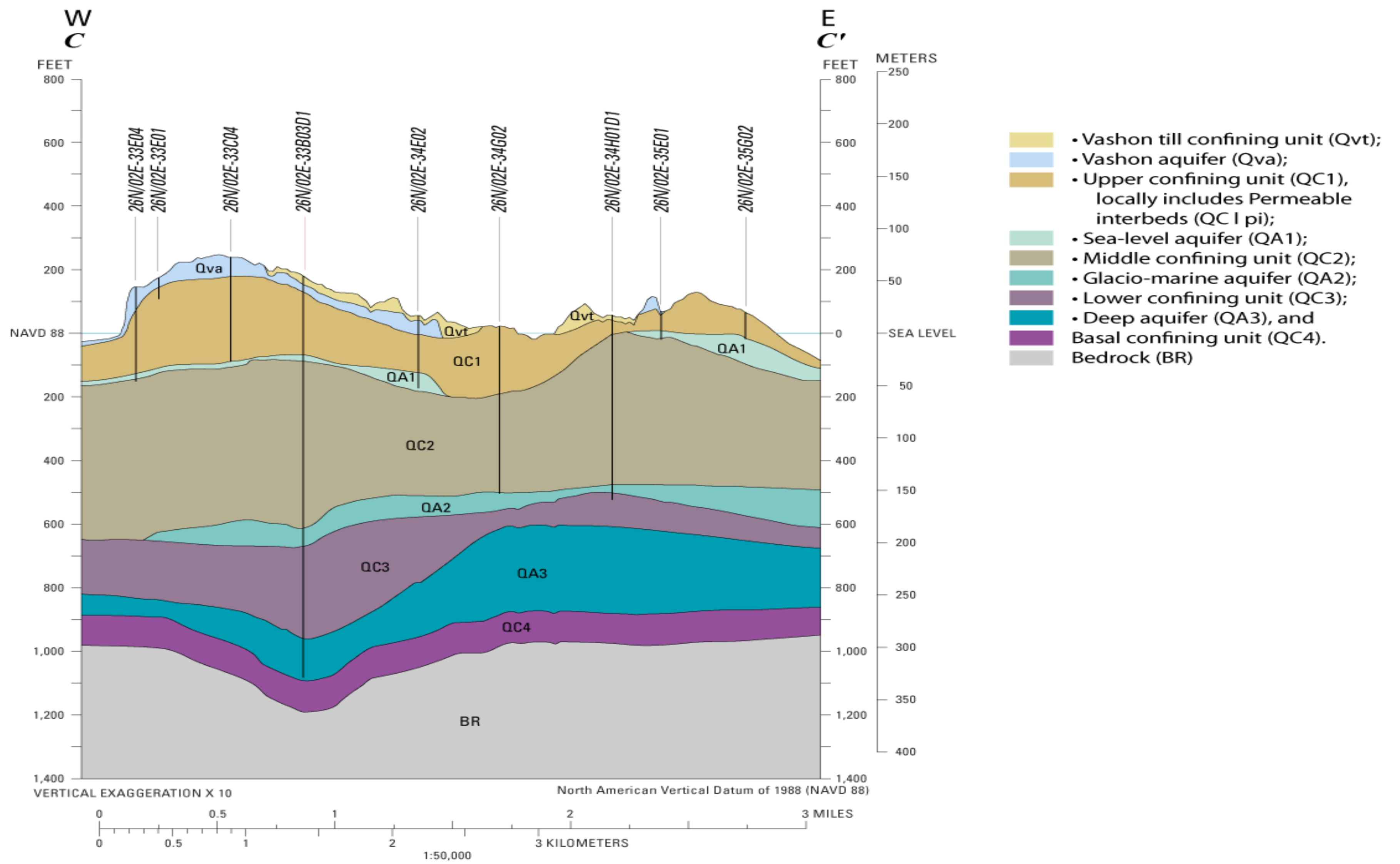
Seawater Intrusion

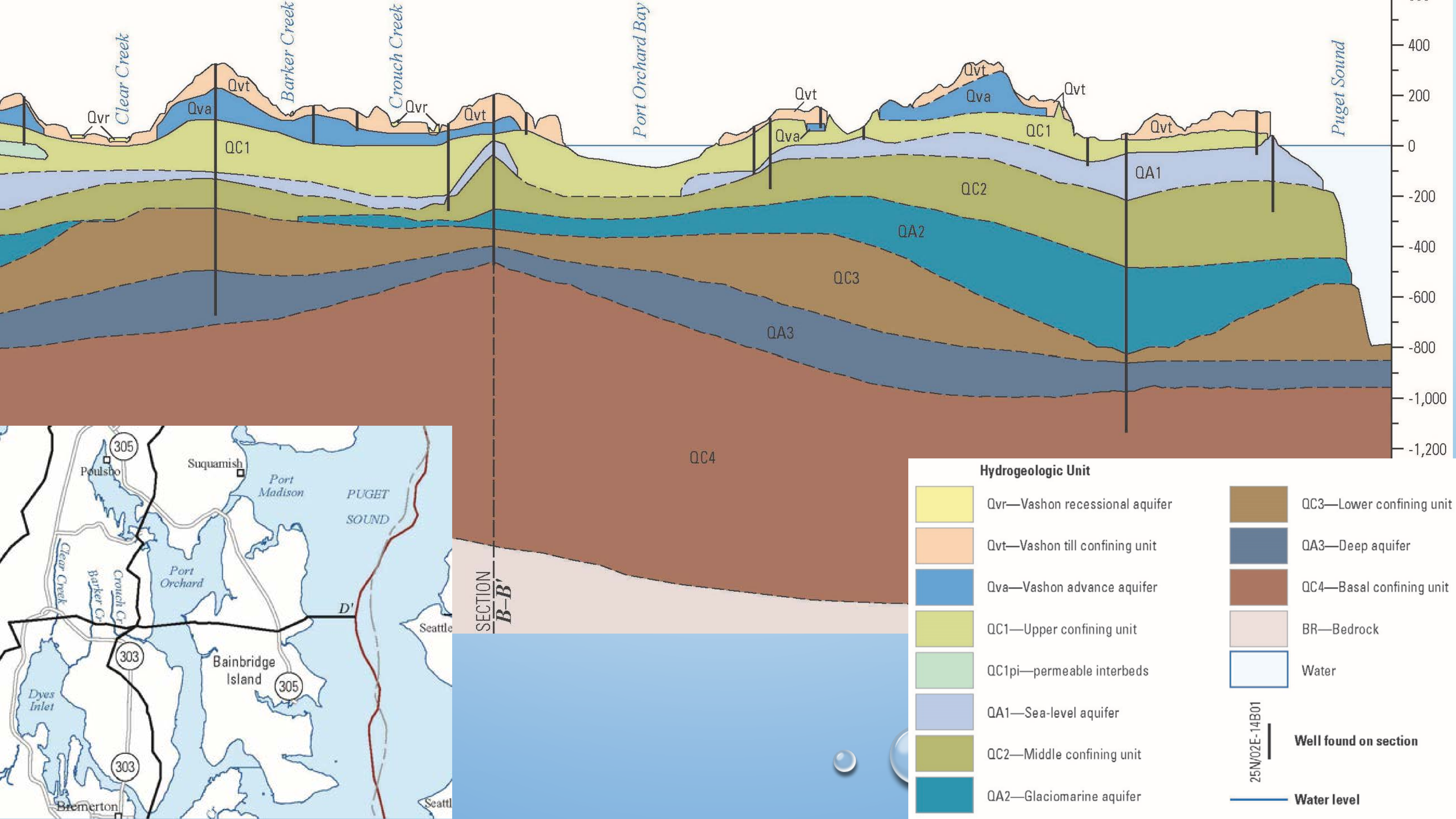
- Seawater can potentially be drawn into near-shoreline wells if groundwater is overpumped
- COBI checks for potential seawater intrusion by monitoring chloride as a surrogate for seawater in near-shoreline wells (Cl<10 mg/L is normal; Cl>100 indicates seawater intrusion; seawater has Cl of 15,000)
- Historically, seawater intrusion has not been a pervasive problem, but as an island this issue is always of concern
- Freshwater lens on top of seawater due to density differences; for every 1' of GW above sea level, GW extends 40' below sea level (Ghyben-Herzberg principle)



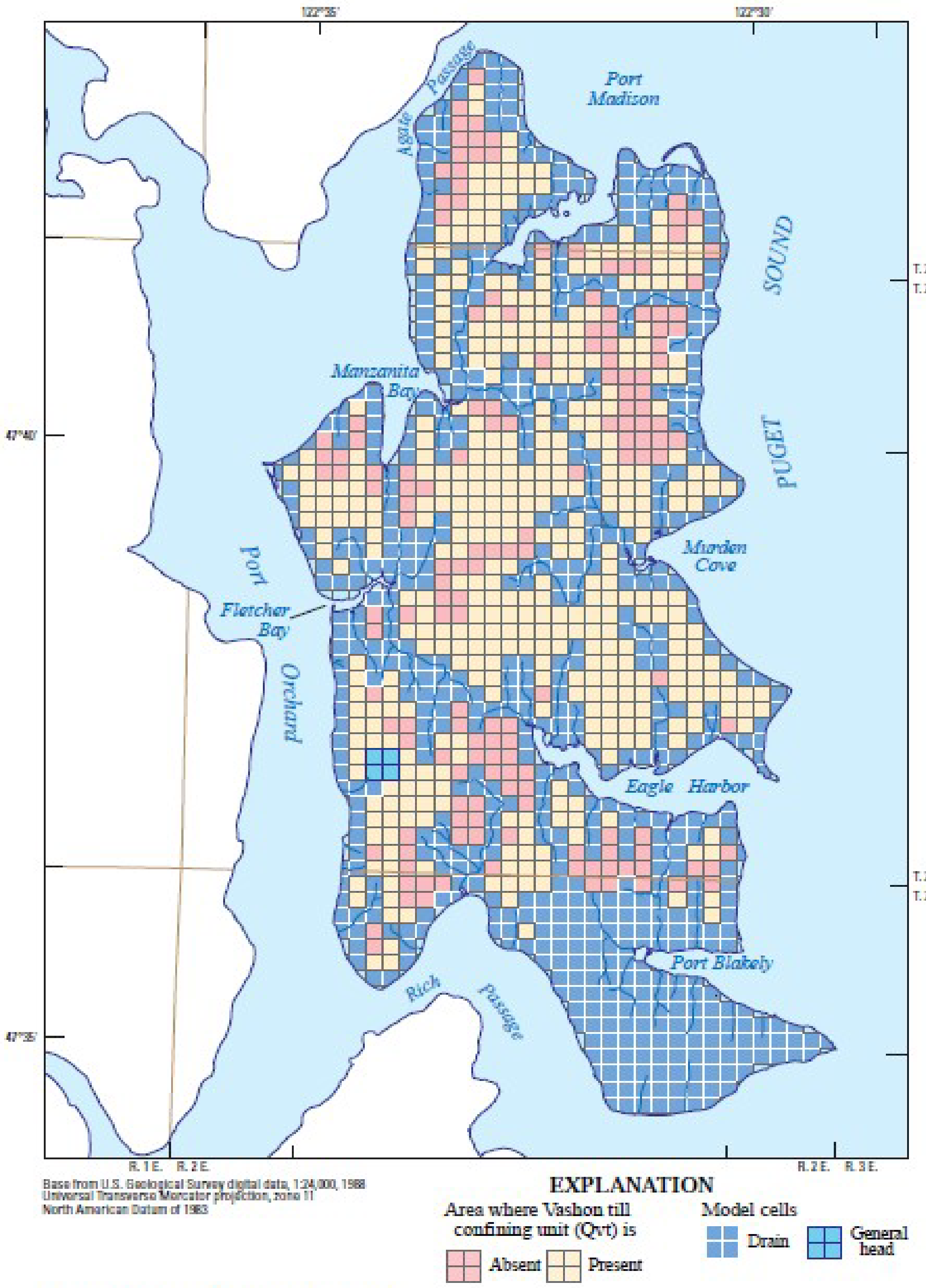
Groundwater under Bainbridge Island

- 4 principal aquifers – perched (water table at elevation 0 to 300 ft), sea level (-200 to +200 ft), glaciomarine (-500 to -300 ft), and Fletcher Bay (-900 to -600 ft)
- 97% of usage (pumped well water) from the perched, sea level, and Fletcher Bay aquifers
- All recharge water for the aquifers originates on the island, except for about 5% that flows under Port Orchard Bay from the Kitsap Peninsula to the sea level, glaciomarine, and Fletcher Bay aquifers




Clear Creek
Barker Creek
Crouch Creek
Port Orchard Bay
Puget Sound
Qvr
Qvt
Qva
QC1
QA1
QC2
QA2
QC3
QA3
QC4
400
200
0
-200
-400
-600
-800
-1,000
-1,200
SECTION B–B′
305
Poulsbo
Suquamish
Port Madison
PUGET SOUND
Clear Creek
Barker Cr
Crouch Cr
Port Orchard
D′
Seattle
303
Bainbridge Island
Dyes Inlet
Bremerton
Hydrogeologic Unit
Qvr—Vashon recessional aquifer
Qvt—Vashon till confining unit
Qva—Vashon advance aquifer
QC1—Upper confining unit
QC1pi—permeable interbeds
QA1—Sea-level aquifer
QC2—Middle confining unit
QA2—Glaciomarine aquifer
QC3—Lower confining unit
QA3—Deep aquifer
QC4—Basal confining unit
BR—Bedrock
Water
25N/02E-14B01
Well found on section
Water level

Model Results and Water Budget Analysis



A. Model layer 1 – Qvt confining unit (Qvt)

USGS Modflow Model

- 800’ x 800’ cell grid size
- 139 columns by 197 rows
- 33 layers from land surface to bedrock
- Inputs – monthly precip, soils, SW features, streamflow, wells and monthly pumping, measured monthly water levels
- Outputs – simulated monthly water levels
- Calibration – matching simulated water levels to measured water levels; adjust inputs until optimized match

- **Presence (yellow cells) or absence (red cells) of Vashon till in the surface layer**
- **Cells bordering surface waters (streams, coastline) are specified “drains” (flows from GW to SW)(blue cells)**

Sea-Level Aquifer

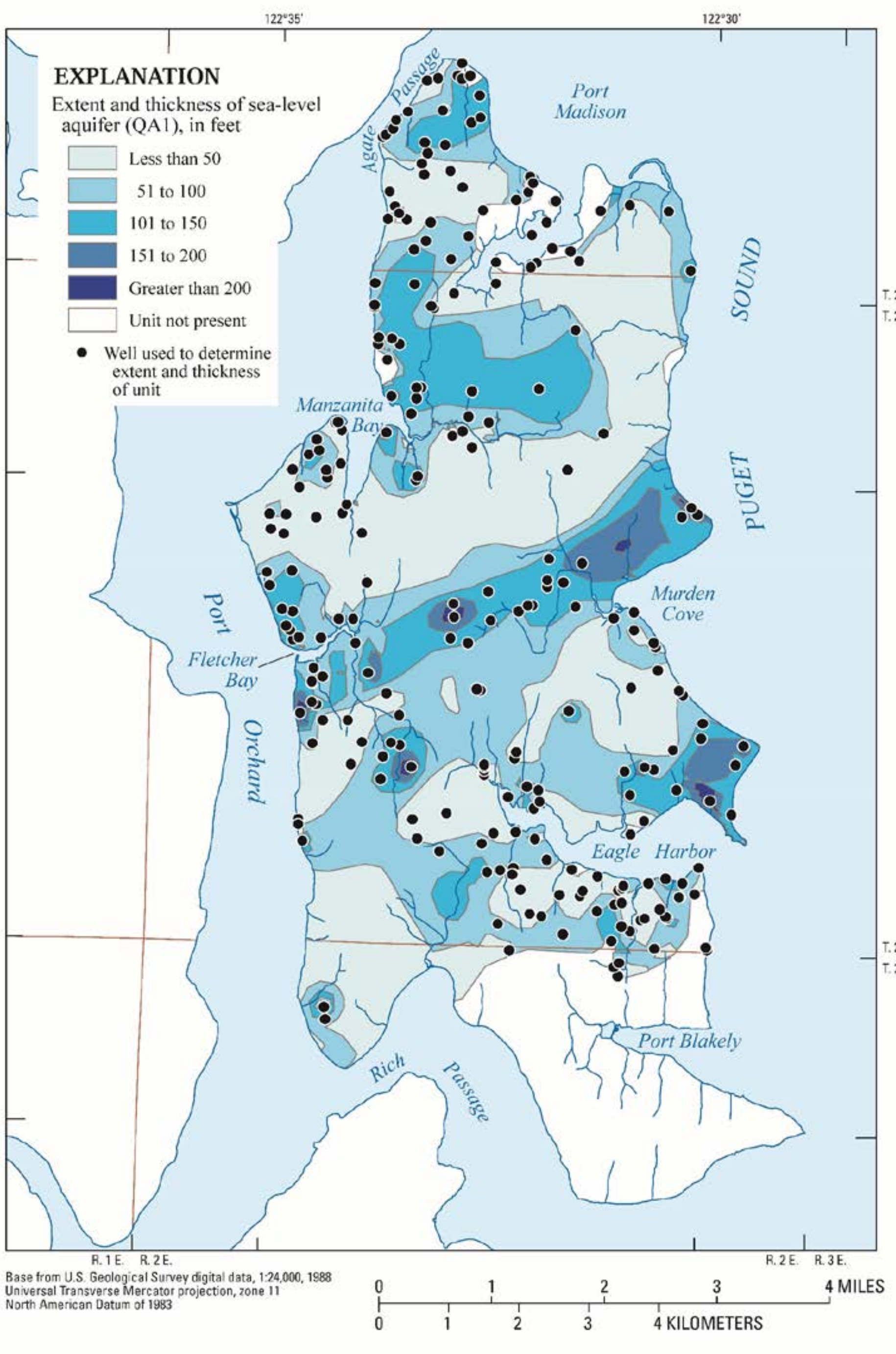


Figure 13. Extent and thickness of the sea-level aquifer (QA1), Bainbridge Island, Washington.

Deep (Fletcher Bay) Aquifer

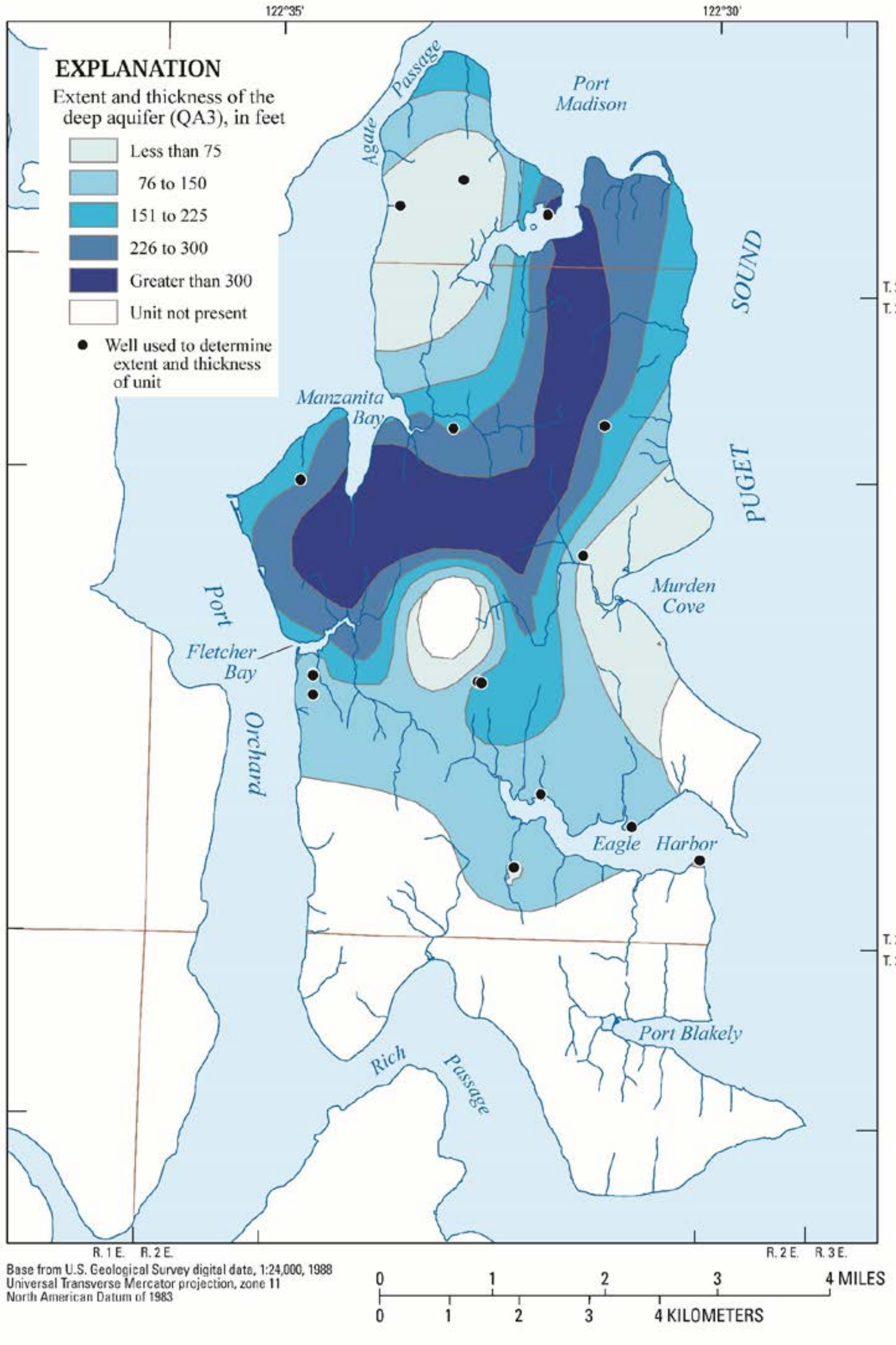


Figure 17. Extent and thickness of the deep aquifer (QA3), Bainbridge Island, Washington.

Model Limitations

"All models are wrong, but some are useful" --- George Box, Statistician, 1976

Types of model errors:

- Input data on types and thicknesses of hydrogeologic units, water levels, and hydraulic properties
- Representation of physical processes by the model algorithms
- Parameter estimation during calibration procedure

Most appropriate uses of the model:

- Regional-scale analyses
- Changes in model results instead of specific results (i.e., changes over time; changes between "what-if" scenarios)

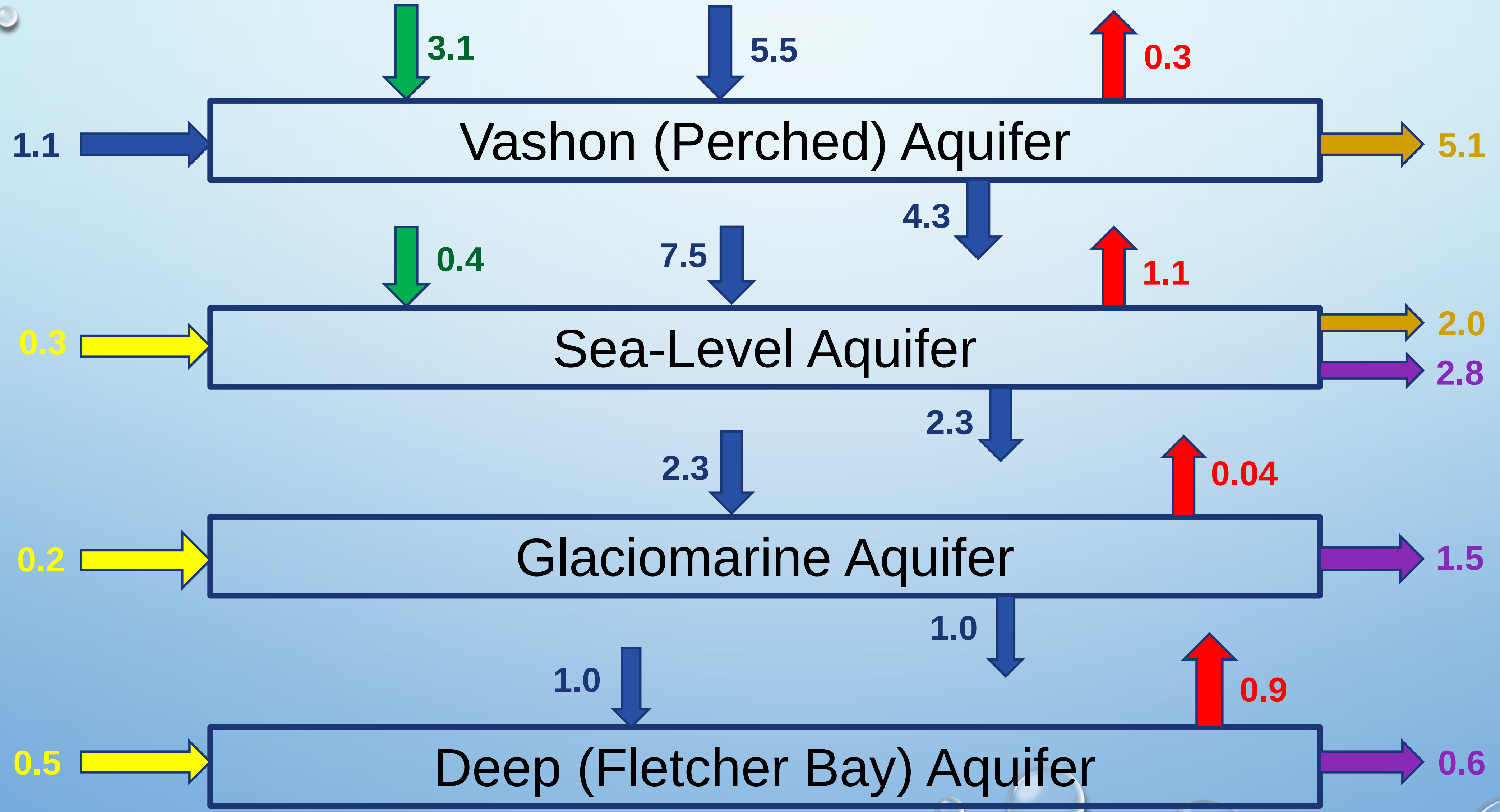
Water Budget Analysis

Inflows – Outflows = Change in Storage

- **Inflows: recharge from precipitation (85-90%); recharge from septic systems (5-10%); off-island aquifer flow to BI from Kitsap Peninsula (5%)**
- **Outflows: pumping (5-10%); discharge to BI surface waters (50-60%); discharge to Puget Sound (30-40%)**
- **Change in Storage: reflected in (calculated from) change in water levels**

SIMULATED WATER BUDGETS FOR 4 PRINCIPAL AQUIFERS (IN TAF/YR)

(Recharge; GW Flow; Wells; to SW; to Puget Sound; from Kitsap)



2008 conditions

modified from Frans and Bachman, 2011

USGS findings from Kitsap model

- Changes in recharge (95% of inputs) has a much greater impact on groundwater levels and discharge to surface waters than changes in pumping (only 7% of outputs).
- Modeling runs with a 15% decrease in annual recharge resulted in a 16-18% decrease in GW discharge to surface waters
- Modeling runs with an 80% decrease in summer pumping (for outdoor use) resulted in only a 0.5% increase in GW discharge to surface waters

Aspect findings in “Carrying Capacity Assessment” for COBI (4/19/23)

Aspect made three simultaneous changes to the MODFLOW groundwater model for Bainbridge Island: (1) increased GW pumping by 50%, (2) reduced recharge by 20%, and (3) increased sea level by 4 feet. After running a 100-year simulation, Aspect found the following changes in the water budget:

- 15 to 58% decrease in groundwater discharge to surface waters in BI’s 12 watersheds
- 20% decrease in groundwater discharge to Puget Sound
- 32.3 billion gallons reduction in aquifer storage

Groundwater Sustainability

Some Definitions of Groundwater Sustainability

- USGS Circular 1186: "Sustainability of Groundwater Resources" by Alley and others, 1999

"development and use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences"

- California 2014 Sustainable Groundwater Management Act

"sustainable groundwater management is the management and use of groundwater in a manner that can be maintained without causing undesirable results"

(e.g., chronic lowering of groundwater levels; significant and unreasonable seawater intrusion; surface water depletions that have significant and unreasonable adverse impacts on beneficial uses)

groundwater

NGWA

The Groundwater Association

The Journey from Safe Yield to Sustainability

William M. Alley, Stanley A. Leake

Dr. Bill Alley
2012 – Present: Director of Science and Technology, NGWA
1993-2011: Chief of Office of Groundwater, USGS

- Changing from safe yield to sustainability has increased concerns about the long-term effects of groundwater development on lakes, wetlands, springs, and estuaries
- Sustainable development encourages integrated water management approaches such as artificial recharge, conjunctive use of surface water and groundwater, and use of recycled or reclaimed water
- It is widely recognized that pumping can affect not only surface water supply for human consumption, but also the maintenance of streamflow requirements for fish and other aquatic species, the health of riparian and wetland areas, and other environmental needs

Groundwater Sustainability in the News

OPINION

Be skeptical, ask questions about BI's 'sustainable water'

By Charlie Kratzer • October 20, 2023 1:30 am

NY Times, August 28, 2023

UNCHARTED WATERS

America Is Using Up Its Groundwater Like There's No Tomorrow

Overuse is draining and damaging aquifers nationwide, a New York Times data investigation revealed.

NEWS

AGU Eos, January 2020

Modeling How Groundwater Pumping Will Affect Aquatic Ecosystems

"We expect that by 2050 more than half of the regions with groundwater abstractions will not be able to maintain healthy ecosystems."

nounts of groundwater are used for
on, such as the upper Ganges and
asins on the Indian subcontinent. But
water pumping has also affected river

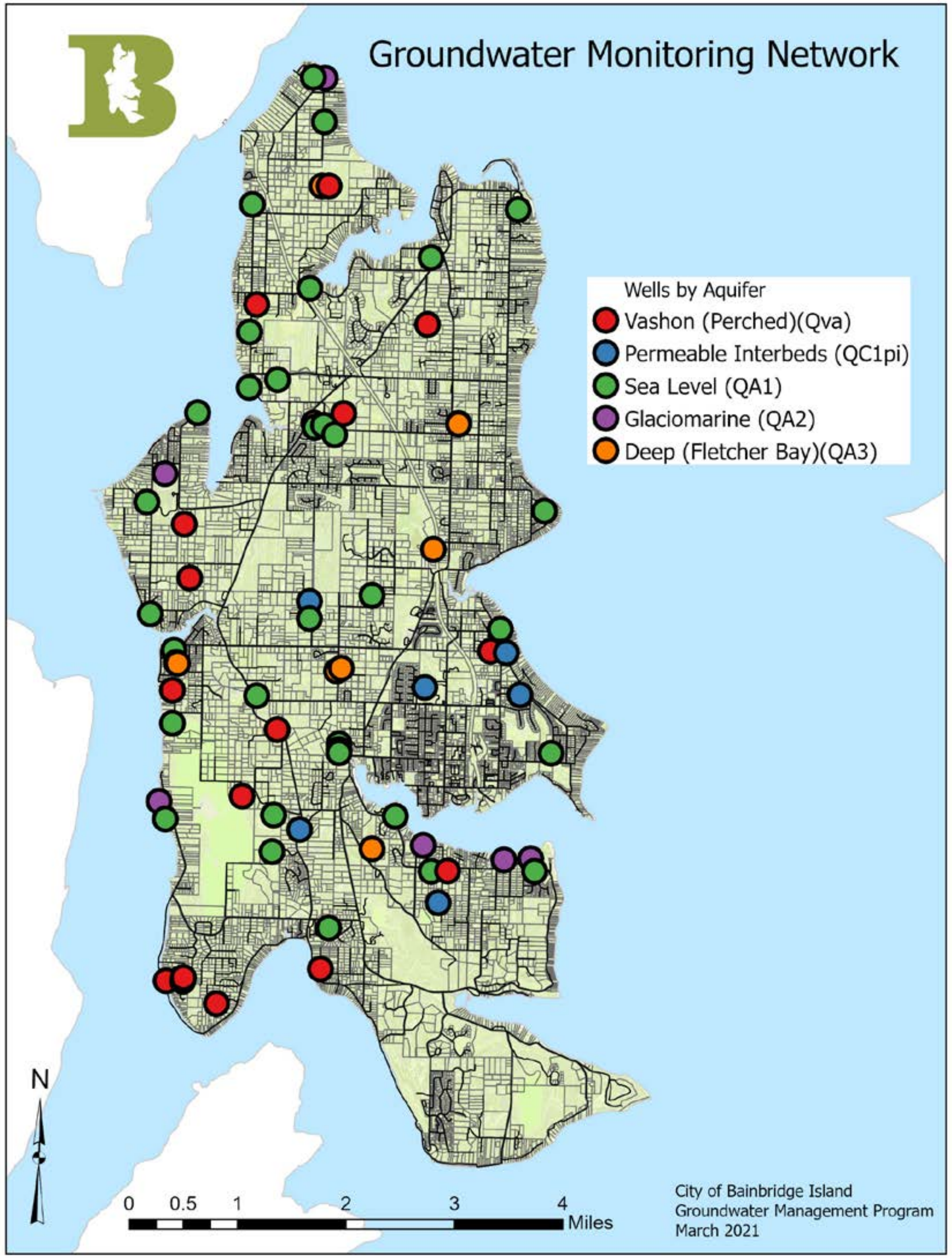
ity of the world's irrigated crops.
Groundwater is also an inextrical
the global water cycle. In many ar
charge from groundwater repl
streams and rivers, helping sustai
ecosystems. Many of these ecosys
now under threat, according to a ne
Inge de Graaf, a hydrological envi
tal systems researcher at the Univ
Freiburg, and colleagues simulated o

"Only a small drop of groundwater level will already cause these critical river flows."

Groundwater Monitoring and Management Plan for Bainbridge Island

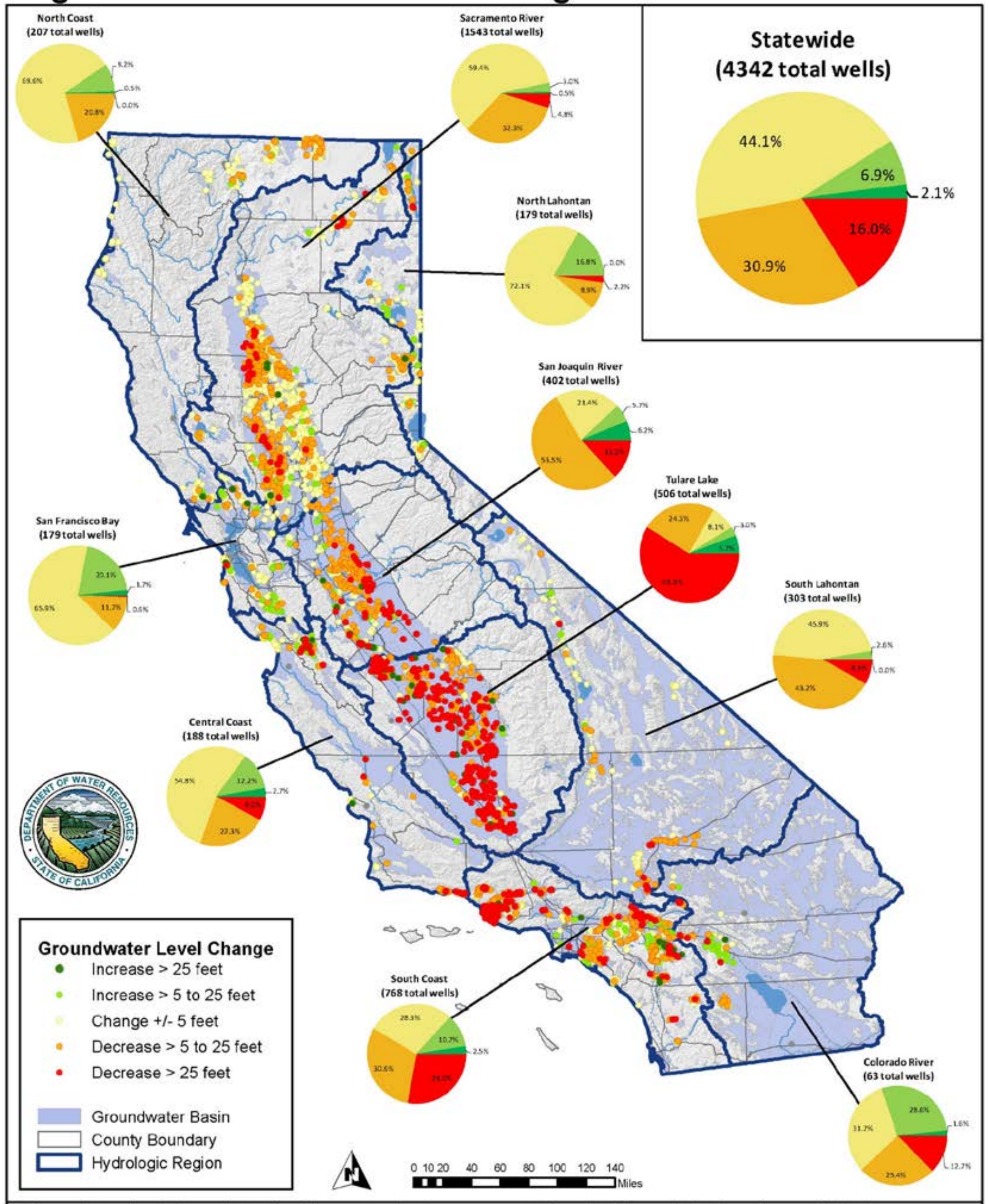
IMPORTANCE OF MONITORING

- Changes in water levels over the long-term provide an indication of potential issues (water availability, seawater intrusion)
- Continue the water-level and water-quality monitoring by COBI and KPUD
- Expand the monitoring to include more near-shoreline wells
- Monitor water levels in Fall (lowest) and Spring (highest)



A Cool Way to Present a Large Dataset on Changes in Groundwater Levels in an Understandable Form

Figure 5. Groundwater Level Change* - Fall 2011 to Fall 2017



*Groundwater level change determined from water level measurements in wells. Map and chart based on available data from the DWR Water Data Library as of 02/21/2018. Document Name: PIEMAP_F1711_25ft
Updated: 2/26/2018. Data subject to change without notice.

What is in a GWMP?

- WAC 173-100-100 (1985) (“Groundwater management areas and programs”) recommends the following six sections be included in a GWMP:

  - Section 1. Area Characterization
  - Section 2. Problem Definition
  - Section 3. Water Quantity and Quality Goals and Objectives
  - Section 4. Alternatives
  - Section 5. Recommendations
  - Section 6. Implementation

Section 5. Recommendations

- **Management strategies from Section 4 that are recommended for implementation**
- ***Possible recommendations include:***

  - expand GW and SW monitoring program

  - create aquifer conservation zones

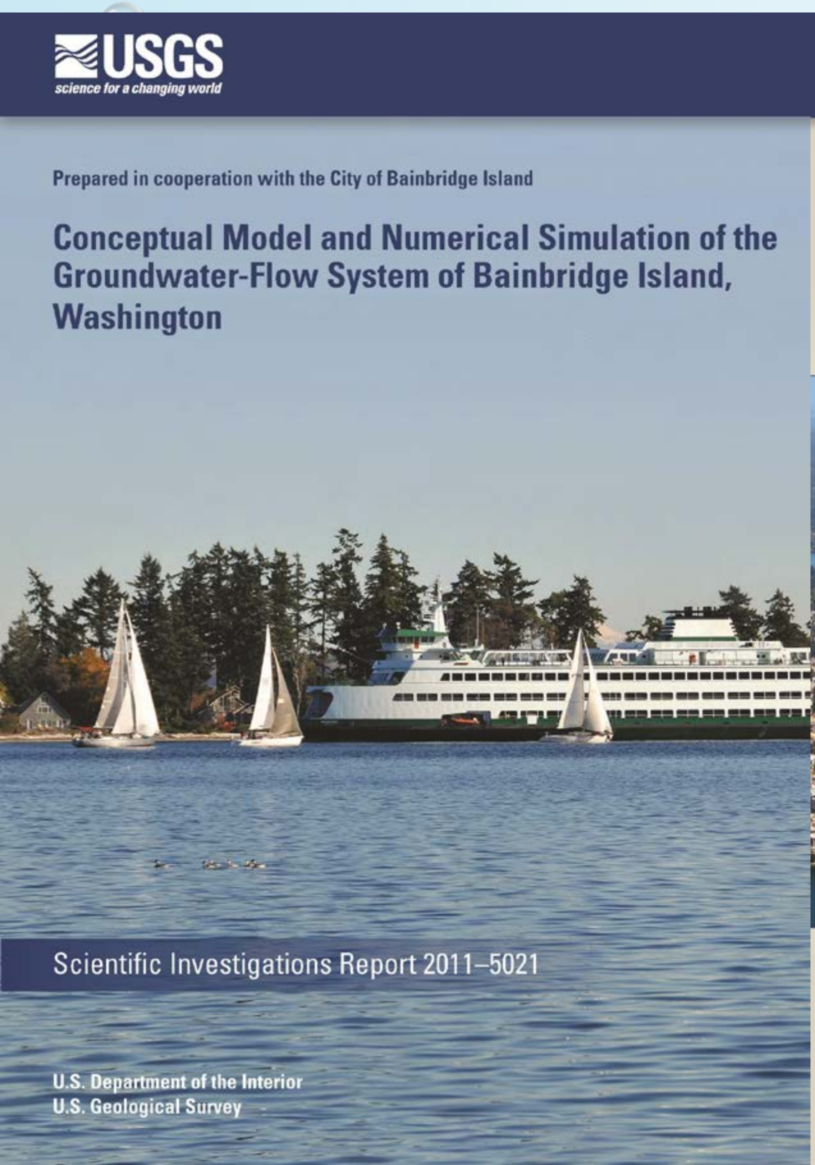
  - develop a water conservation program

  - develop a program to incentivize and facilitate the reuse of stormwater and grey water

  - improve wastewater treatment to tertiary and recharge GW with effluent instead of discharging to Puget Sound

  - develop a community-wide education program on aquifers of BI

Suggested Reading Material

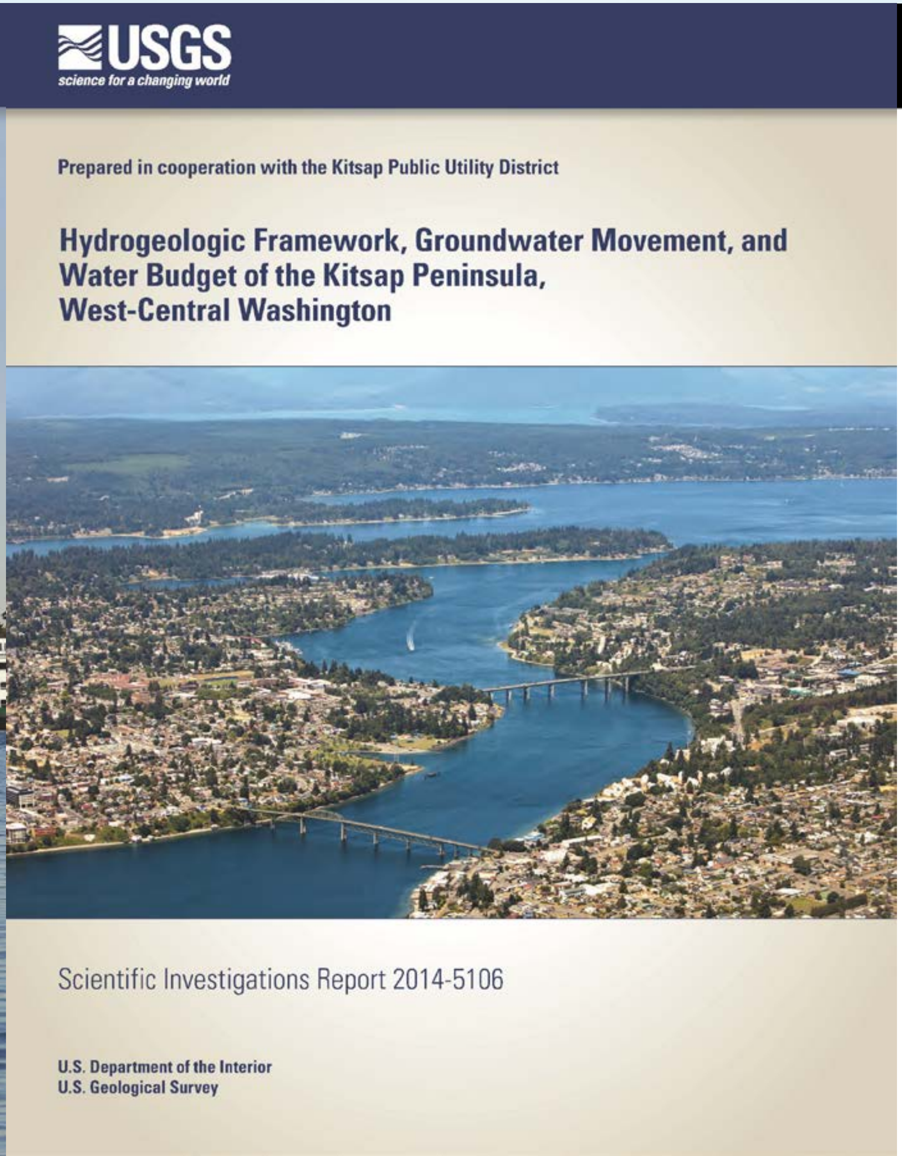

USGS
science for a changing world

Prepared in cooperation with the City of Bainbridge Island

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

Scientific Investigations Report 2011–5021

U.S. Department of the Interior
U.S. Geological Survey

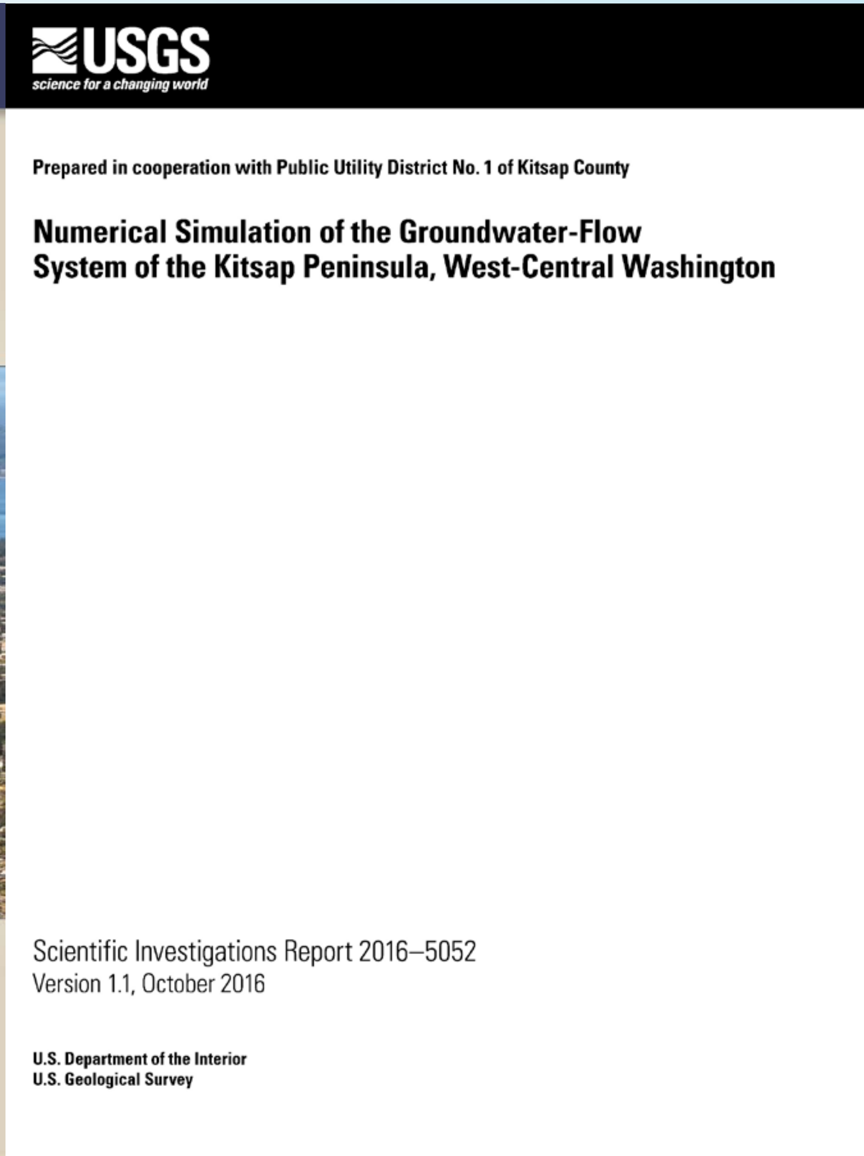

USGS
science for a changing world

Prepared in cooperation with the Kitsap Public Utility District

Hydrogeologic Framework, Groundwater Movement, and Water Budget of the Kitsap Peninsula, West-Central Washington

Scientific Investigations Report 2014-5106

U.S. Department of the Interior
U.S. Geological Survey


USGS
science for a changing world

Prepared in cooperation with Public Utility District No. 1 of Kitsap County

Numerical Simulation of the Groundwater-Flow System of the Kitsap Peninsula, West-Central Washington

Scientific Investigations Report 2016–5052
Version 1.1, October 2016

U.S. Department of the Interior
U.S. Geological Survey

Groundwater on Bainbridge Island: A Fact Sheet

CITY OF BAINBRIDGE ISLAND

We depend on groundwater for all our water-supply needs on Bainbridge Island. Groundwater also supports our streams and wetlands. The Environmental Technical Advisory Committee (ETAC) for the City of Bainbridge Island consists of community volunteers with expertise in environmental issues. ETAC prepared this fact sheet to provide a summary of our understanding of the groundwater system and as a starting point for the development of a Groundwater Management Plan (GWMP). The GWMP will provide the necessary framework to responsibly manage this precious resource today and into the future.

What is Groundwater?

- According to the USGS, groundwater is water that exists underground in saturated zones beneath the land surface (Fig. 1). The upper surface of the saturated zone is called the water table. Contrary to popular belief, groundwater generally does not form underground rivers. It fills the pores and fractures in underground materials (soil, sand, gravel, and rocks), much the same way that water fills a sponge. If groundwater flows naturally out of rock materials or if it can be removed by pumping (in useful amounts), the permeable saturated zones are called aquifers. Groundwater moves slowly from higher to lower water levels, typically at rates of 3 to 25 inches per day. As a result, water could remain in an aquifer for hundreds or thousands of years.
- Aquifers are separated by less permeable layers of soil or rock called confining layers. Despite these confining layers, there is usually some water exchange between aquifers.
- Groundwater quantity (storage in aquifers) is estimated by measuring water levels in wells. Water levels vary seasonally due to rainfall and pumping, so measurements at the same time each year will give the best information on changes in the amount of groundwater storage in aquifers on an annual basis (from: USGS FAQs; www.usgs.gov/faq/water).
- Some surface waters (i.e., ponds, wetlands, streams) receive significant contributions from groundwater depending on groundwater levels.

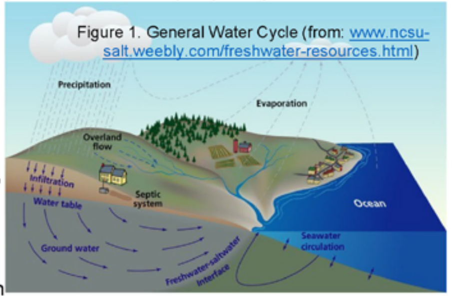
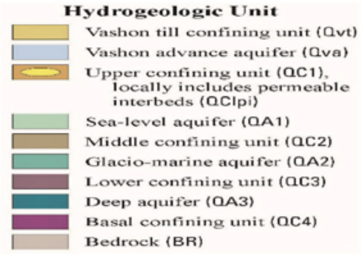


Figure 1. General Water Cycle (from: www.ncsu-salt.weebly.com/freshwater-resources.html)

Groundwater on Bainbridge Island

- According to the USGS, there are five aquifers on Bainbridge Island (shown in Fig. 2 cross-section of BI from Port Orchard Bay on the left to Puget Sound on the right). However, the permeable interbeds (QC1pi) aquifer produces little water. The four main aquifers are:
  - **Vashon (Perched)(Qva)** (water table at elevation 0 to 300 ft),
  - **Sea Level (QA1)** (-200 to +200 ft),
  - **Glaciomarine (QA2)** (-500 to -300 ft), and
  - **Deep (Fletcher Bay)(QA3)** (-900 to -600 ft)



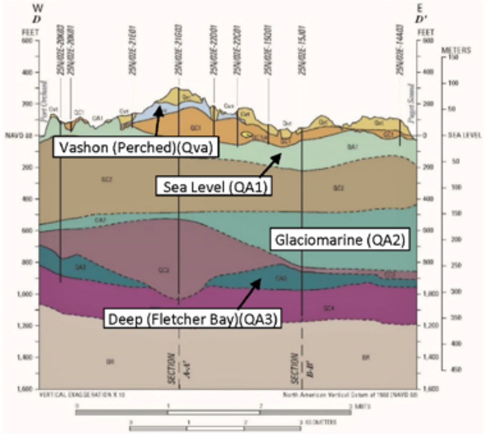


Figure 2. Hydrogeologic Units on Bainbridge Island (from: Frans and others, 2011)

Fact Sheet concept approved by COBI City Council in November 2018; reviewed by USGS and KPUD in December 2020; revised and approved by ETAC in February 2021; approved by COBI City Council in April 2021

- The four major aquifers are separated by five confining layers: Qvt (Vashon till near ground surface), QC1, QC2, QC3, and QC4.
- 97% of usage (pumped well water) comes from the Vashon (Qva), sea level (QA1), and deep aquifers (QA3).
- All the recharge water for the aquifers originates as precipitation (and septic-system returns) on the island, except for about 5% that flows under Port Orchard Bay from the Kitsap Peninsula to the sea level, glaciomarine, and deep aquifers (from: Frans and others, 2011).

Sole Source Aquifer Designation

- In 2013, USEPA designated the aquifers of BI as a sole source aquifer, meaning that it "supplies at least 50% of the drinking water consumed in the area overlying the aquifer, and for which there is no alternative source or combination of alternative drinking water sources which could physically, legally, and economically supply those dependent upon the aquifer" (from: www.epa.gov/dwssa).
- Sole source designation can affect Federal funding for any project with the potential to contaminate the groundwater on Bainbridge Island.

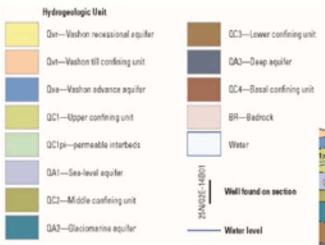
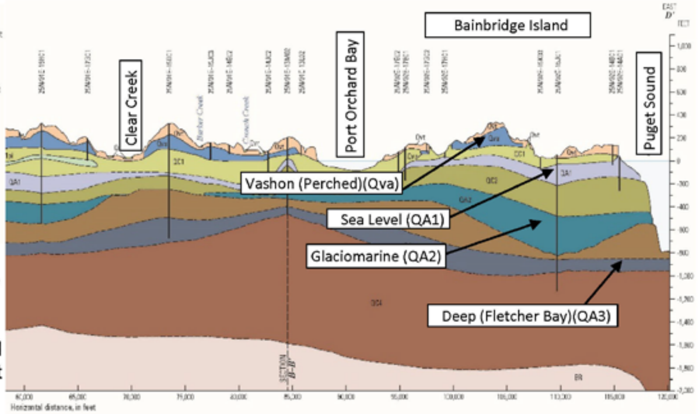



Figure 3. Hydrogeologic Units on Kitsap Peninsula (modified from: Welch and others, 2014)

- Based on this designation, ETAC believes that Bainbridge Island should have the goal of remaining self-sufficient with respect to water resources and that alternative sources are not advisable (i.e., a pipeline across Agate Pass Bridge or desalination of seawater).
- The cross-section of the Kitsap Peninsula (Fig. 3) from Clear Creek (Silverdale) on the left to BI/Puget Sound on the right depicts the connection of the glaciomarine and deep aquifers under Port Orchard Bay. However, as stated above the contribution of off-island water from these aquifers is only about 5% of the total GW recharge for BI aquifers, as the actual movement towards BI depends on several factors – pumping rates, recharge rates, and head/pressure differences between BI and Kitsap Peninsula.

Seawater Intrusion

- Seawater can potentially be drawn into near-shoreline wells if groundwater is over-pumped.
- COBI checks for potential seawater intrusion (Fig. 4) by monitoring chloride as a surrogate for seawater in near-shoreline wells (Cl>100 mg/L is used as an early warning level for potential seawater intrusion).
- Historically, seawater intrusion has not been a significant problem, but as an island this issue is always of concern.
- Freshwater sits on top of seawater due to density differences; hence, for every 1 foot of GW above sea level, GW extends roughly 40 feet below sea level.

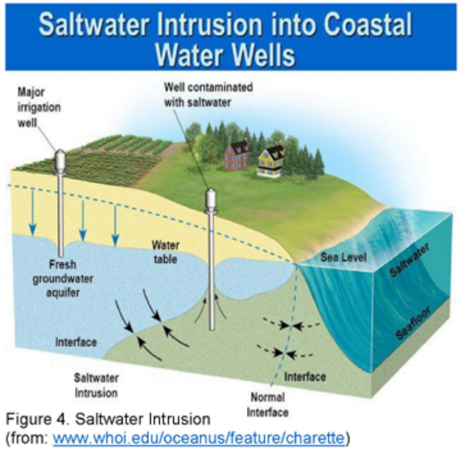


Figure 4. Saltwater Intrusion (from: www.whoi.edu/oceanus/feature/charette)

USGS Bainbridge Island Groundwater Model

The numerical groundwater models developed by USGS to model both Bainbridge Island and the entire Kitsap Peninsula use the free, publicly-available, industry-standard MODFLOW program (https://www.usgs.gov/mission-areas/water-resources/science/modflow-and-related-programs?qt-science_center_objects=0#qt-science_center_objects). The model specifics for the Bainbridge Island application are (Fig. 5):

- Horizontal discretization (grid size) – 800 feet by 800 feet; total of 139 columns by 197 rows for all of Bainbridge Island. Cells are categorized by:
  1. bordering surface waters (streams, coastline) are specified “drains” (flows from GW to SW),
  2. presence or absence of the Vashon till confining layer in the surface layer, and
  3. Gazzam Lake represented by “general head” recharge source (flows from SW to GW)
- Vertical discretization – 33 layers from land surface to bedrock
- Model inputs – monthly precipitation, soils, surface water features, streamflow, wells and monthly pumping, measured monthly water levels
- Model outputs – simulated monthly water levels
- Model calibration – calibrate simulated water levels to measured water levels; adjust model inputs until there is an optimized match of water levels

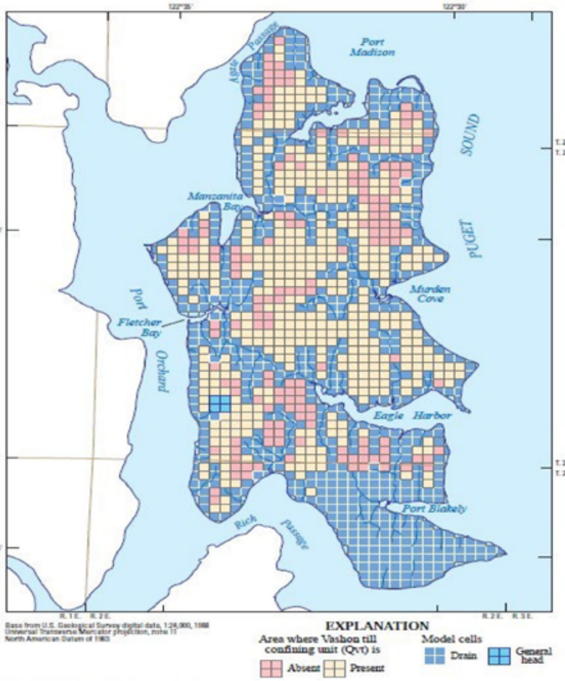


Figure 5. MODFLOW Grid for BI (from: Frans and others, 2011)

Water Budget for Bainbridge Island

In its’ simplest terms, the simulated water budget for Bainbridge Island from the USGS model can be expressed as (Fig. 6):

Inflows – Outflows = Change in Storage

- Inflows: recharge from precipitation (85-90%); recharge from septic systems (5-10%); off-island aquifer flow to BI from Kitsap Peninsula (5%)
- Outflows: pumping (5-10%); discharge to BI surface waters (50-60%); discharge to Puget Sound (30-40%)
- Change in Storage: reflected in (calculated from) change in water levels

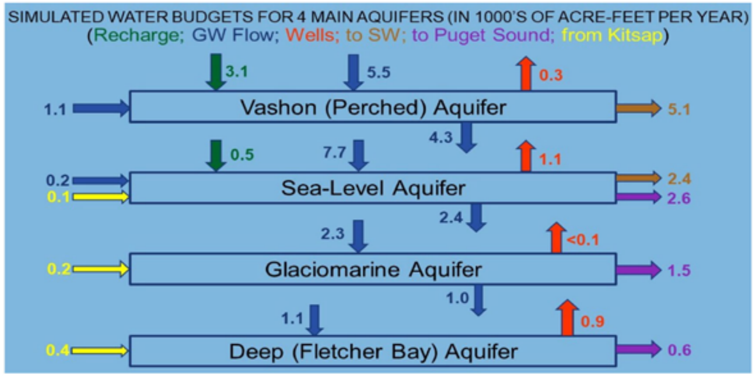


Figure 6. Water Budget for Bainbridge Island Aquifers (modified from: Frans and others, 2011)

USGS Kitsap Groundwater Model

- Simulations using the MODFLOW program indicate that changes in groundwater recharge have a larger effect on water levels than changes in groundwater pumping.
- Two examples of this for the Kitsap Peninsula: A 15% decrease in long-term annual recharge resulted in up to an 18% decrease in stream baseflow over seven years, while a 15% increase in long-term annual groundwater pumping resulted in up to a 0.3% decrease in stream baseflow over seven years (Frans and Olsen, 2016).

Importance of Monitoring

Although the number and frequency of water-level monitoring wells is in flux, long-term monitoring wells are shown in Fig. 7 by aquifer.

- Changes in water levels over the long-term provide an indication of potential issues (water availability, seawater intrusion).
- Thus, COBI and KPUD should continue monitoring water levels and water quality, and expand the monitoring to include more near-shoreline wells.
- Monitoring of water levels in Fall (lowest) and Spring (highest) is most important, depending on specific precipitation trends.

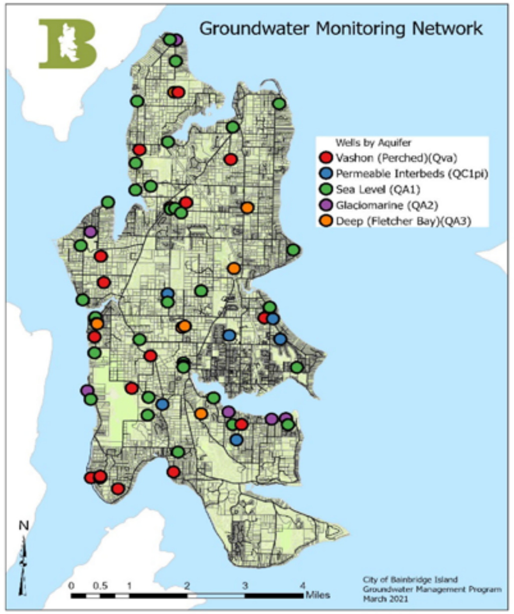


Figure 7. Long-term Monitoring Wells on Bainbridge Island (from: Christian Berg, COBI GW Management Program, written communication, March 9, 2021)

Recommendations for the Groundwater Management Plan

- COBI and KPUD should expand their groundwater and surface water monitoring program
- COBI should create aquifer conservation zones to enhance recharge, develop a water conservation program to reduce water usage, incentivize and facilitate the reuse of stormwater and grey water, and develop a community-wide education program on the aquifers of BI
- COBI should improve wastewater treatment to tertiary and recharge GW with effluent via surface infiltration instead of discharging the effluent to Puget Sound
- COBI should improve stormwater management to keep more stormwater on BI for recharging the aquifers instead of running off to Puget Sound
- COBI should coordinate recommendations in the GWMP with those in the Climate Action Plan (https://www.bainbridgewa.gov/DocumentCenter/View/14270/Draft-Bainbridge-Island-Climate-Action-Plan-for-City-Council-Review-October-22nd-2020)

References:

- Frans, L.M., Bachmann, M.P., Sumioka, S.S., and Olsen, T.D., 2011, Conceptual model and numerical simulation of the groundwater-flow system of Bainbridge Island, Washington: USGS Scientific Investigations Report 2011-5021, 96 p., www.doi.org/10.3133/sir20115021
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Abbreviations: BI – Bainbridge Island; SW – surface water; GW – groundwater; COBI – City of Bainbridge Island; KPUD – Kitsap Public Utility District; USGS – U.S. Geological Survey; CI – chloride; ETAC – Environmental Technical Advisory Committee; USEPA – U.S. Environmental Protection Agency; GWMP – Groundwater Management Plan

Fact Sheet available on COBI website:

Engage Bainbridge/Groundwater/Supporting Docs

Questions?