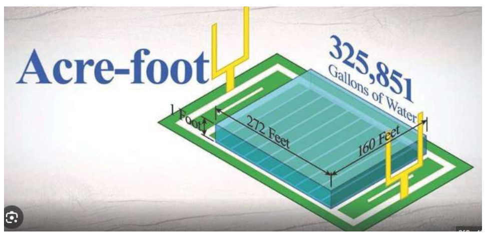
Glossary of Groundwater Terms

Pumping/extraction/water use—Water removed from an aquifer through a well.

Acre foot—An acre-foot is commonly used to measure water volume. It is the amount of water needed to cover one acre (43,560 square feet) with one foot of water. One acre-foot is equal to 325,851 gallons of water, enough to cover a football field with a foot of water.



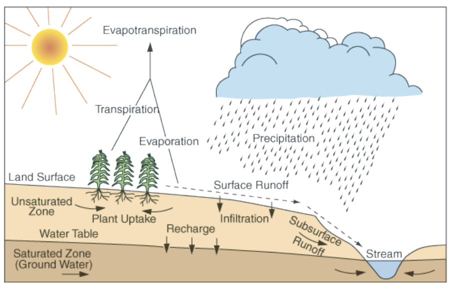
Groundwater—water that exists underground in saturated zones beneath the land surface.

Aquifer—An aquifer is a body of porous material, such as sand and gravel or fractured bedrock, that will yield water in a usable quantity to a well or spring.

Discharge—volume of water flowing in a stream or through an aquifer past a specific point during a given time period

Recharge—water entering the groundwater system, generally from precipitation with secondary recharge from septic systems and/or irrigation.

Bainbridge Recharge



Seawater intrusion—the movement of seawater into freshwater aquifers due to natural processes or human activities. The boundary between seawater and fresh water is usually a zone of mixing between the two.

Beneficial uses—Water uses of water for domestic, stock watering, industrial, commercial, agricultural, irrigation, fish and wildlife maintenance, recreational, and preservation of environmental and aesthetic values, and all ther uses compatible with the enjoyment of the public waters of the state.

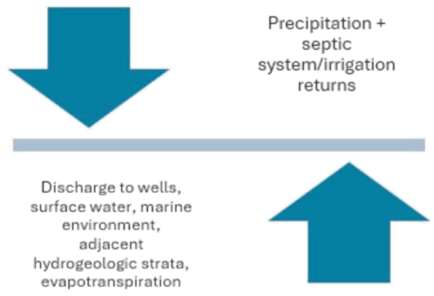
Consumptive use—Water use that does not return to the local environment, typically due to evaporation, plant uptake or marine discharge.

Aquifer Recharge Protection Area (ARPA)—areas where native vegetation is retained as a way to maintain or closely mimic the natural hydrologic function of the site and watershed.

Impervious Surface—a non-vegetated surface which either prevents or retards the entry of water into the soil. Common impervious surfaces include, but are not limited to roof tops, driveways and parking lots.

Sustainable yield—use of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences.

Water budget /Water Balance Components—mathematical representation of the hydrologic cycle for a given area.

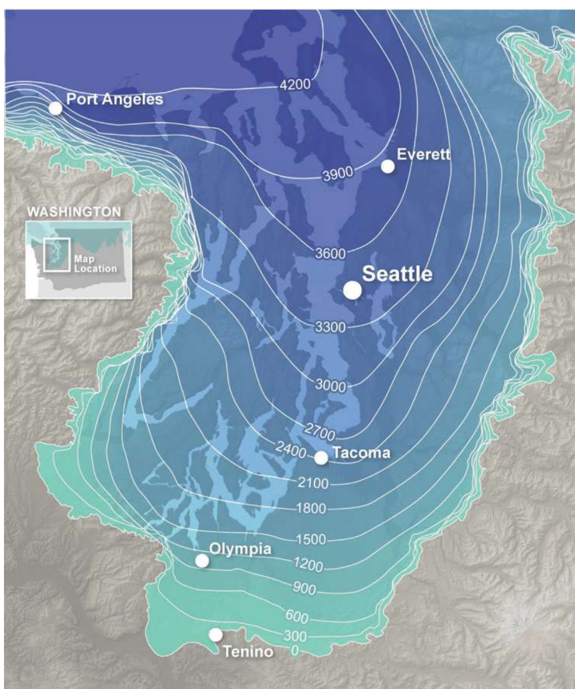


Bainbridge Island Aquifer Names

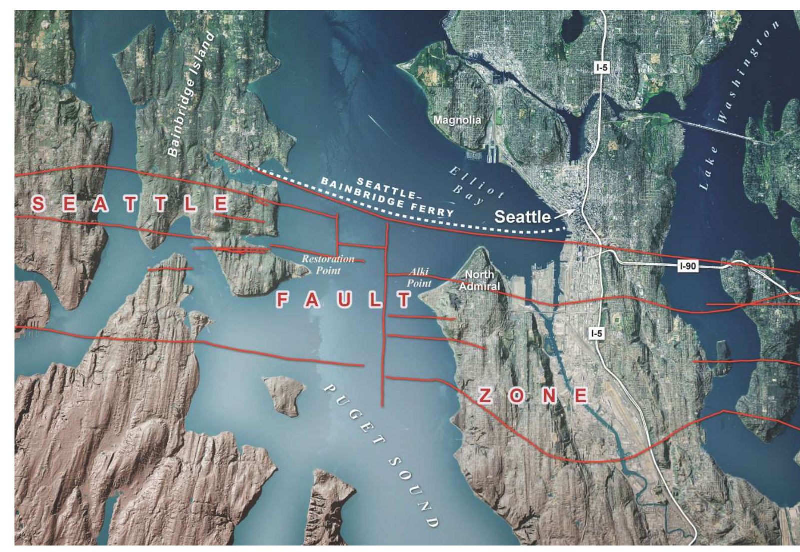
Name	Abbreviation
Perched Aquifer or Vashon Advance	Qva or PA
Semi-Perched Aquifer or Permeable Interbeds	QC1pi or SPA
Sea Level Aquifer	QA1 or SLA
Glaciomarine Aquifer	QA2 or GMA
Flecher Bay Aquifer	QA3 or FBA
Bedrock Aquifer	BR

Geologic History and previous Studies 1957–1991

Aquifers under Bainbridge Island were formed by multiple advances and retreats of glaciers. Figure shows the maximum depth and extent of ice. USGS 1980



The Seattle Fault Zone causes the south end of the island to have more bedrock near the surface and much less productive aquifers. WA Department of Natural Resources



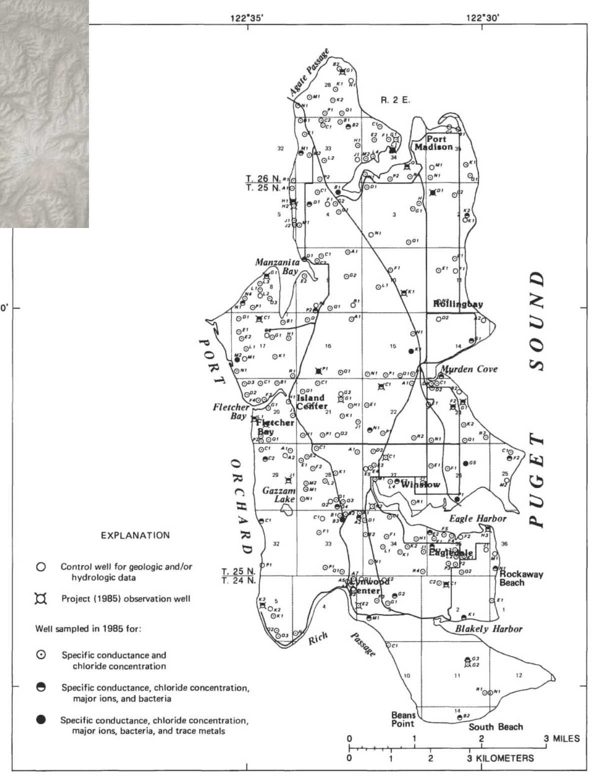


Figure 5.--Locations of wells used to collect geologic and hydrologic data (see page 3 for explanation of well-numbering system).

11

First published depiction of geology under the Kitsap region. USGS 1957

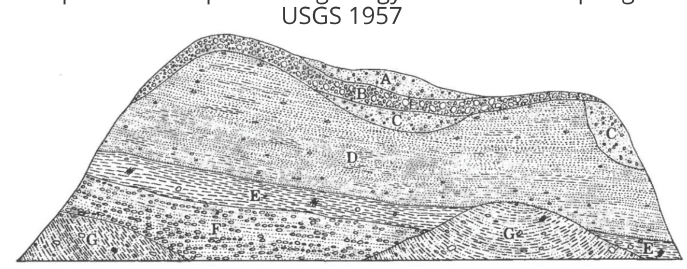


FIGURE 15.—Summary and diagrammatic cross section of Pleistocene depositional units, Kitsap County, Wash.

Depiction of wells, groundwater flow and relative depth of glacial deposits on Bainbridge island. USGS 1988

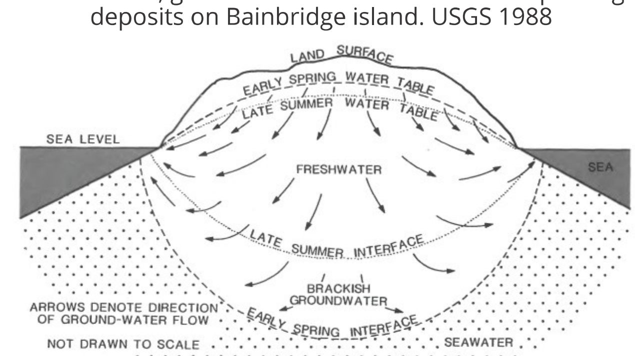


Figure 19.--Seasonal fluctuation of water table and freshwater-seawater interface in a homogeneous, unconfined island aquifer.

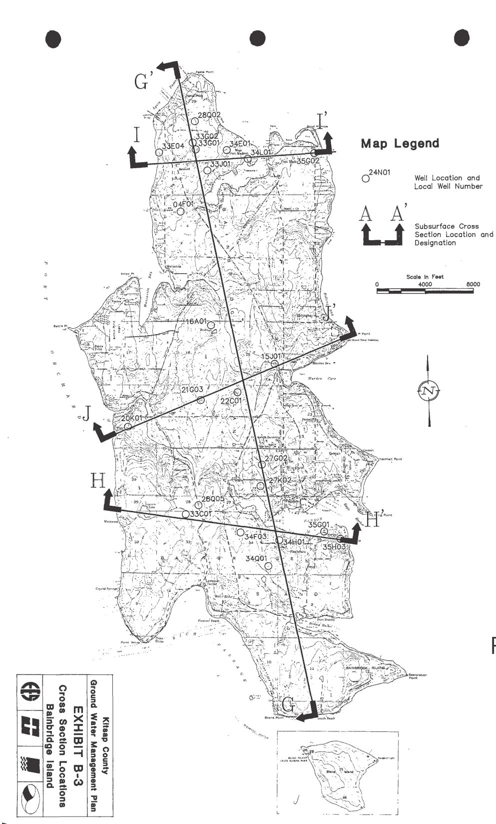


Figure showing locations of cross sections where the aquifers are described on Bainbridge island. Kitsap County 1991

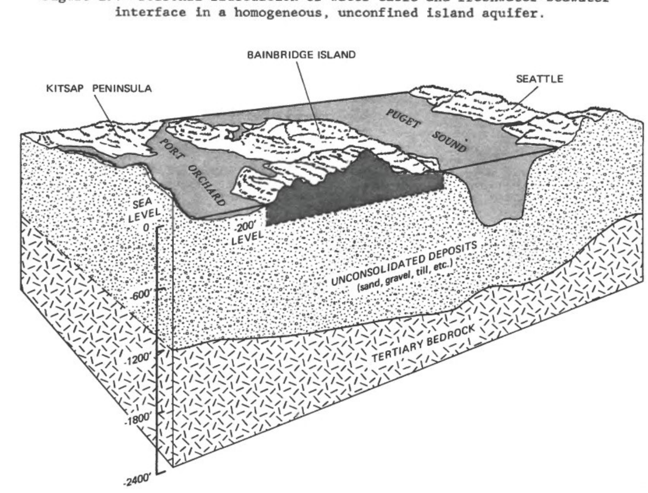


Figure 10.--Conceptual sketch showing relation of bedrock, unconsolidated deposits, and surface topography in the study area.

Previous Studies Conducted by City of Bainbridge Island 2001–2023

CITY OF BAINBRIDGE ISLAND

2001 Level II Assessment

By Kato and Warren, Robinson and Noble

The City hired two consultants, Kato and Warren and Robison and Noble, to increase groundwater monitoring and study how groundwater and surface water are connected.

Results:
- No seawater intrusion
- Recharge 19,000 Acre-Feet/Year (AFY)
- Streamflow 1,012 AFY
- Beneficial Use 2,326 AF
- Available groundwater 8,894 AFY

Recommendation	Status
Monitor septic systems	Ongoing
Test for nitrate levels	Ongoing
Monitor streamflows	Partially Complete
Expand well monitoring	Complete
Collect water level, quality and production data	Complete
Assess impacts from stormwater runoff	Partially Complete

Table 5.1. Hydrostratigraphic Unit Terminology Used in Groundwater Studies in the Bainbridge Island Area

Sceva, 1957 (Kitsap County)	Garling and others, 1965 (Kitsap Peninsula)	Dion and others, 1988 (Bainbridge Island)	Kitsap County Groundwater Advisory Committee and others, 1991 (Kitsap County)	This Study
Alluvium	Alluvium	1	Qn1, alluvium and recessional deposits	---
A, recessional outwash	Qvr, recessional outwash			Qvr
B. till	Qvt, till	2	Qg1, till	Qvt
C, advance outwash	Qva, advance outwash	3	Qg1a, advance outwash/shallow aquifer	PA, perched aquifer system
D, Puyallup Sand	Qc, Colvos Sand			
---	---	4	Qn2, 1st nonglacial deposits	C1, upper confining unit
ORTING GRAVEL: E, Kitsap Clay member	Qg/Qk, unnamed gravel/Kitsap Formation		Qg2, 2nd glacial deposits[1]	SPA, semi-perched aquifer system
			Qn3, 2nd nonglacial deposits	C2, lower confining unit
ORTING GRAVEL: F, Orting gravel member	Qss, SalmonSprings (?) Drift	5	Qg3, 3rd glacial deposits/sea-level aquifer[2]	SLA, sea level aquifer
---	Qpu, pre-Salmon Springs (?) deposits	6	Qn4, 3rd nonglacial deposits	C3, confining unit
		Pleistocene deposits (undifferentiated)	Qg4, 4th glacial deposits/deep aquifer[3]; Qg4m marine/glaciomarine deposits	GMA glaciomarine aquifer system
G, Admiralty Drift			Qn5, 4th nonglacial deposits	C4, confining unit
Pre-Orting deposits, undifferentiated			Qg5, 5th glacial deposits[4]	FBA, Fletcher Bay Aquifer
			Qn6, ancient nonglacial deposits	C5, confining unit
Tertiary Blakeley Formation of Weaver, 1916	Tertiary Blakeley Formation of Weaver, 1916	Tertiary Blakeley Formation of Weaver, 1916	Tertiary Blakeley Formation of Weaver, 1916	Blakeley Harbor Formation of Fulmer, 1975
				Blakeley Formation of Fulmer, 1975

Established our current common aquifer names.

2011 Conceptual Model and Numerical Simulation of the Groundwater-Flow System

By U.S. Geologic Service

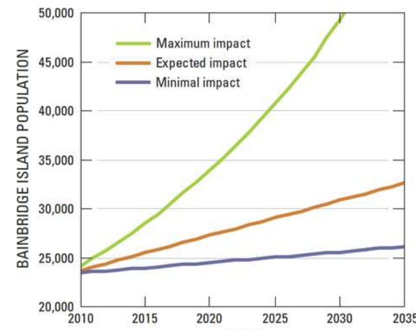
The U.S. Geological Survey created the first groundwater model specifically for Bainbridge Island in partnership with the City. The model looked at different scenarios and helped predict how the groundwater system could respond to increased pumping, reduced recharge, and protecting recharge areas through conservation.

Results from 2008 Existing Conditions
- No saltwater intrusion
- 5% of water flows from off-island to the island
- 95% of recharge occurs on the island
- 10–25 ft water level decline since pre-development

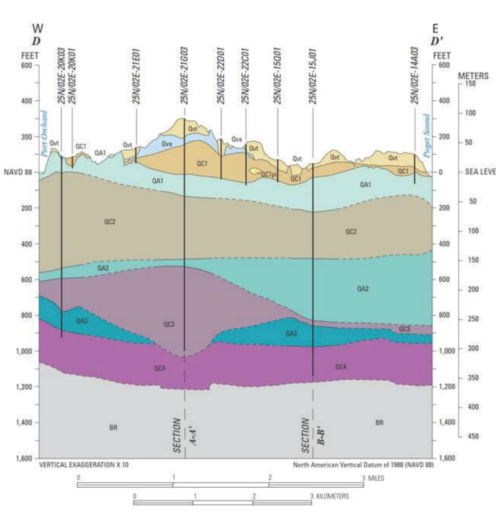
Results from Expected Impact Scenario 2035
- No saltwater intrusion
- Shallow aquifer declines up to 5 ft
- Deep aquifer declines up to 10 ft
- More water flowing from the island to the Kitsap peninsula

- No specific recommendations

3 Scenarios of Population Growth from 2011Current population close to minimal impact scenario



A. Projected population growth



Depiction of the aquifers across the center of the island, West to East

2015–2023 Groundwater Model Updates

By Aspect Consulting

From 2015-2023 Aspect Consulting was hired by the City to refine and run the groundwater model for Bainbridge Island with the purpose of predicting impacts from sea level rise decreased recharge, increased pumping and also looked at sustainability metrics and testing management strategies.

Aspect updated and calibrated the model with field data collected by the City.

Results:
- The modeling showed how groundwater affects streamflow (Drainage to Surface Waters is groundwater contribute to streams and wetlands in Figure 9 and Table 3).
- Important groundwater recharge happens all across Bainbridge Island, not just in one area. Protecting and conserving this natural process is strongly recommended to help maintain healthy groundwater and streams.

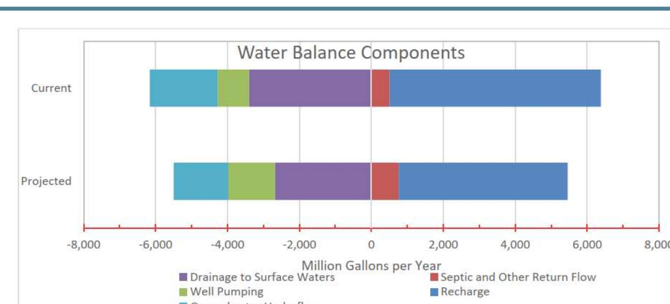


Figure 9. Current and Projected Groundwater Balance Components (Bainbridge Island Only)

Table 3. Water Balance Components (Million Gallons per Year)

Water Balance Component (Million Gallons per Year)	Projected	Current
Recharge	4,700	5,875
Septic and Other Return Flow	759	506
Well Pumping	-1,297	-873
Drainage to Surface Waters	-2,681	-3,401
Groundwater Underflow	-1,519	-1,886

Model run was 100 years

Groundwater Management Plan Development

2017

- City staff proposes Groundwater Management Plan

2018

- City Council directs Environmental Technical Advisory Committee (ETAC) to draft Scope of Work for the Plan

2021

- City Council approves temporary staff position to begin the plan (Maureen Whalen Hired)
- Staff develops goals for the Plan with City Council
- City Council creates Subcommittee to guide plan development

2022

- Staff convenes Technical Advisory Committee to review aspects of the plan

2023

- Aspect Consulting runs groundwater model
- City hires EA Engineering to complete plan

2025

- EA Engineering refines groundwater model and runs predictive scenarios
- City hires Keta Waters for Peer Review

2026

- City retains Keta Waters for additional modeling and plan completion

Groundwater Predictive Scenarios

EA refined, calibrated the groundwater model and ran predictive scenarios in 2025

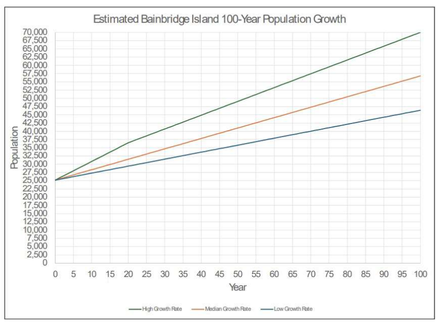
Variables

Population growth was allocated based on historic growth rates of census tracts and water systems.

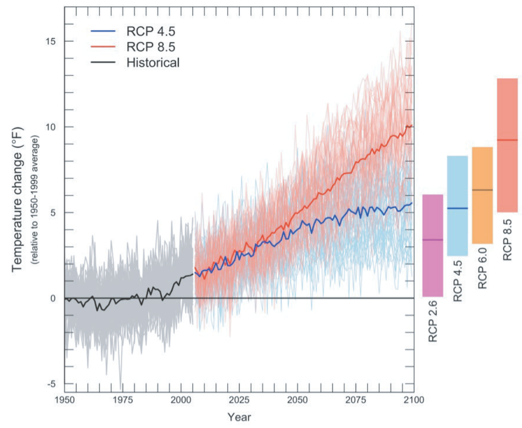
Low growth based on 30-yr historic low rate (blue):
• 212 people per year

Med. growth based on 30-yr historic high rate (orange):
• 315 people per year

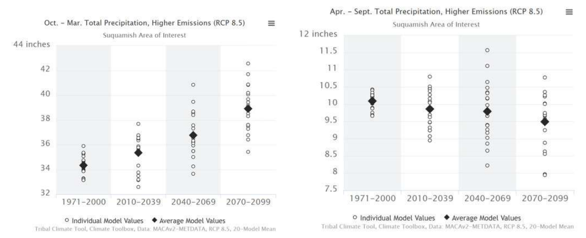
High growth based on 20-year Sub-Area plan projection + med. growth rate (green):
• 419 people per year

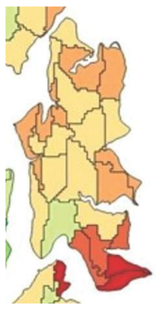


If nothing changed—no new conservation measures, no changes in watering habits, and continued temperature increases—water use is projected to be about 7% higher per person in 100 years than it is today. (figure source UW Climate Impacts Group)



Precipitation drives groundwater recharge, and precipitation patterns are changing. Models predict wetter winters, drier summers, and slightly more total rainfall each year, but with more intense storms. Because heavy rain can lead to more runoff and less water soaking into the ground, especially in developed areas, the model looked at scenarios with up to 20% less groundwater recharge. Researchers are still studying how these more intense storms may affect recharge in semi-rural and undeveloped and forested areas.





Sea level rise can increase the risk of saltwater intrusion into shallow shoreline wells and can also raise the shallow groundwater table. Groundwater systems are complex, so as the City plans groundwater management, it considers both likely and higher-impact sea level rise scenarios to reduce long-term risk and build a more resilient plan.

The groundwater model looked at two sea level rise variables:
- 2.8 ft rise in 100 years
- 6.9 ft rise in 100 years

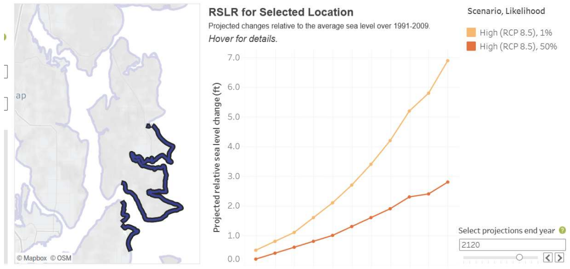
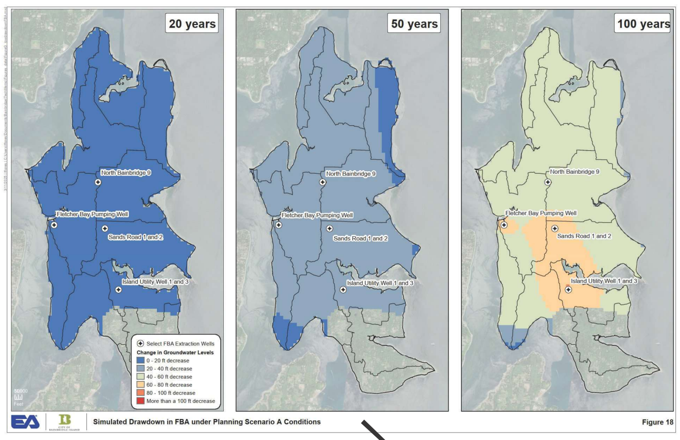
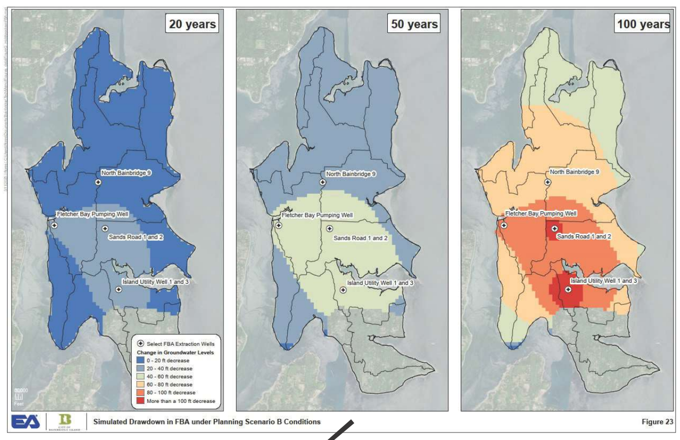


Table 24. Planning Scenario datasets after 100 years

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





Model findings indicate that the City is not currently in a groundwater crisis. If managed responsibly, the Island's water supply for human consumption is secure for the 20-year planning horizon given steady population growth combined with changes in climate. Increased water conservation and managed aquifer recharge are necessary today to prevent impacts on surface water and streams, and to provide resiliency for human consumption in the 50-year horizon and beyond.

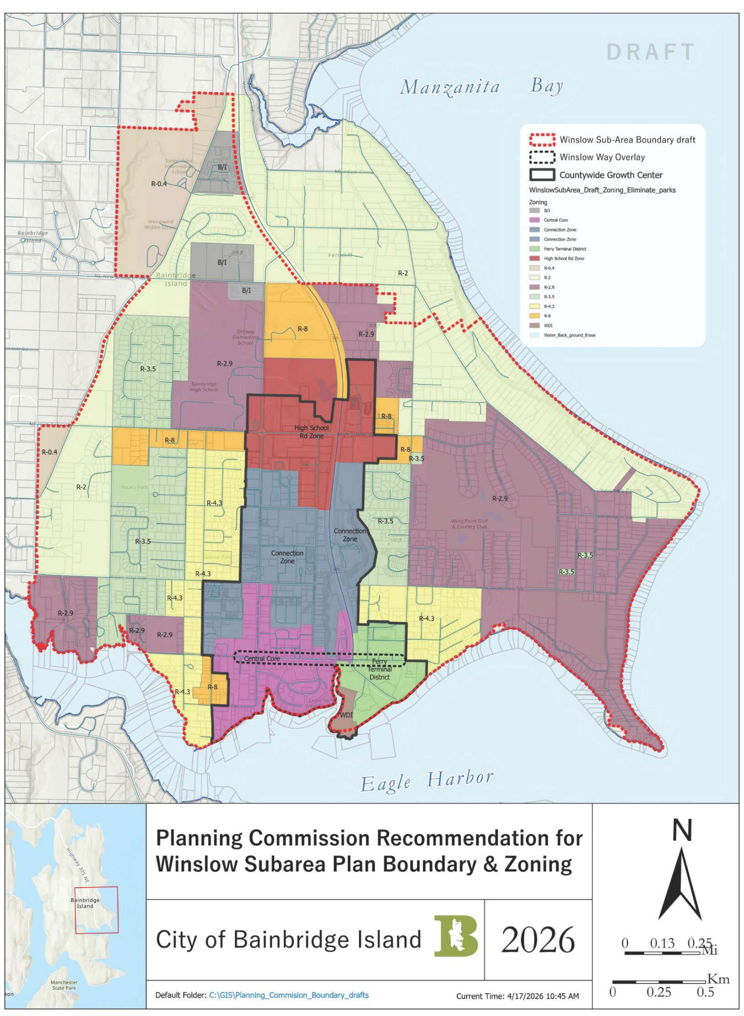
Table 25. Mean Groundwater Levels Under Different Planning Scenarios

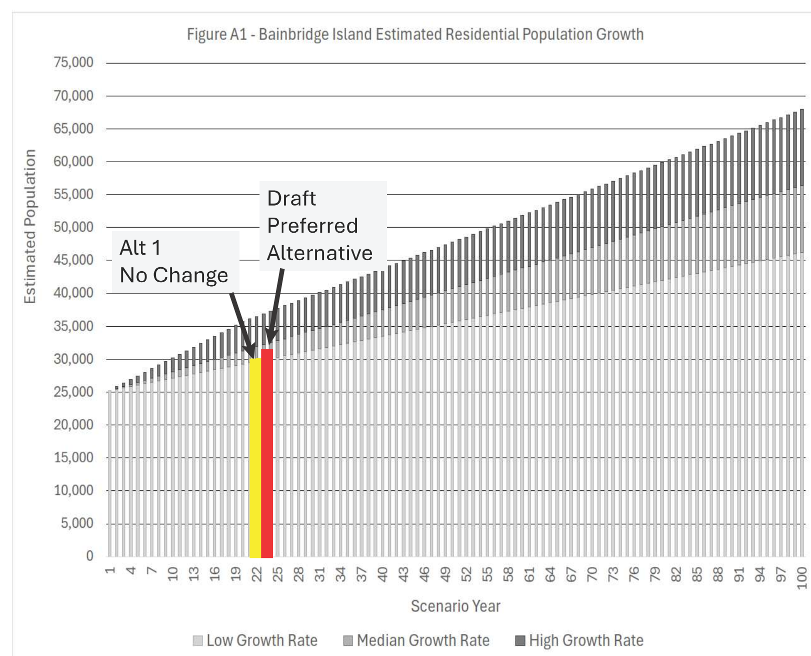
	Mean Groundwater Level (feet above mean seal level)									
		Low Impact Planning Scenario			Mid Impact Planning Scenario			High Impact Planning Scenario		
Hydrogeologic Unit	Current	20 years	50 years	100 years	20 years	50 years	100 years	20 years	50 years	100 years
Qva	102.2	102.6	102.3	102.3	102.4	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

Comprehensive Plan Connection

The High Impact growth scenario (Figure A1) in the EA groundwater model was based on the 2024 Draft Environmental Impact Statement Dense Centers/“Go Up” alternative, which concentrated most new growth in the Winslow city center. This scenario was designed to study a maximum potential impact early in the planning process—not necessarily the most likely future growth pattern—to help identify ways to reduce impacts and improve long-term planning outcomes.

The growth rate in this scenario is higher than the current draft preferred alternative in the Draft Comprehensive Plan and Draft Winslow Subarea Plan, which have not yet been adopted. The current preferred alternative more closely aligns with the median growth rate used in the Mid Impact scenario (Figure A1), which is based on the Planning Commission’s preferred alternative recommendation.





Multifamily residential units use about **77 gallons of water per day** (2023 Winslow Water System).

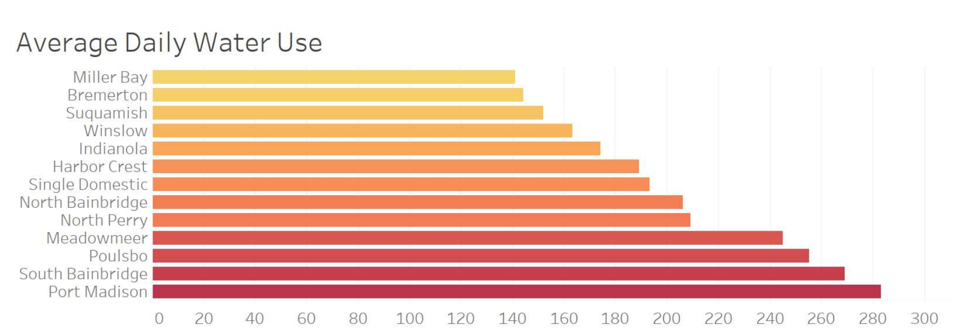
Single-family residential units use about **167–269 gallons of water per day**, with some systems averaging 350 gallons or more. On peak summer days, some households use significantly more water, mainly due to outdoor irrigation (2023 City and KPUD data).

Most potential new housing units in the draft preferred alternative would be located in the Winslow Subarea. These homes are more likely to be on smaller lots or in multifamily buildings with less landscaping and lower outdoor water use. However, more developed areas also allow less water to naturally soak back into the ground.

Both conservation and enhanced recharge methods are needed for long term sustainability.

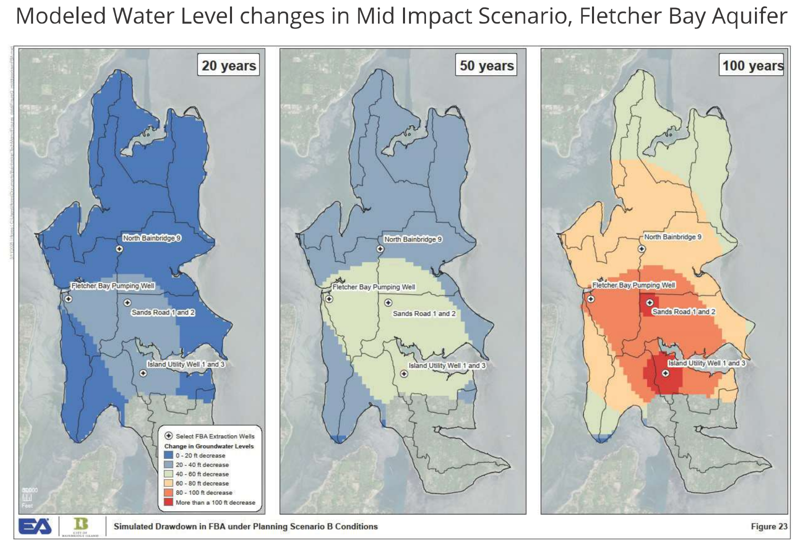
Table 1
Draft Planning Commission Preferred Land Use Alternative:
Land Capacity Analysis Summary 2020–2044

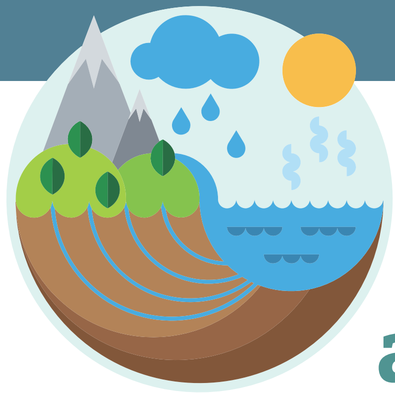
Land Use Area		Dwelling Units		Population		Jobs	
		Alt. 1 No Change	Draft *Pref. Alternative*	Alt. 1 No Change	Draft *Pref. Alternative*	Alt. 1 No Change	Draft *Pref. Alternative*
Outside Winslow	Neighborhood Centers & R-5	128	137	232	289	1,283	795
	Business/Industrial	-	-	-	0	1,243	1,485
	Conservation Area	1,774	1,720	4,074	3,969	19	19
Total Pref. Alt. Outside Winslow		1,902	1,857	4,306	4,257	2,545	2,299
Total Preferred Alt. Winslow (5/14 PC PH Draft)		592	1,272	1,334	2,726	67	732
CITYWIDE TOTALS		2,494	3,129	5,640	6,983	2,612	3,031



Water Usage of select Bainbridge Island and Kitsap Peninsula water systems in gallons, 2023

Modeled Water Level changes in Mid Impact Scenario, Fletcher Bay Aquifer

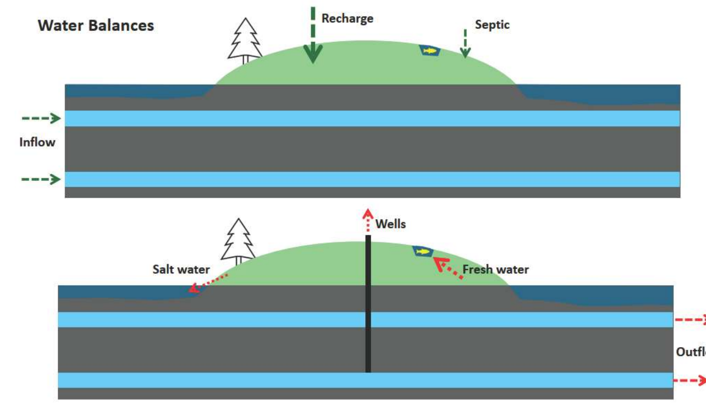




Keta Waters Steady-State Modeling and Water Budget Analysis

Keta Waters compared ranges of recharge and pumping rates from previous reports and compared these values to concepts of long-term sustainability.

- A rough estimate of sustainable yield is 1,200–3,000 AFY
- Current consumptive use is 1,000–1,800 AFY
- The overlap suggests there is uncertainty about whether current water use levels are fully sustainable over the long term if nothing changes.



For a Sustainable Water Budget

Diving into the details, available Input determines sustainable yield, which must be greater than the Output

Input

Recharge (AFY)	Source
7,331–24,045	Vashon Island recharge (King County 2026) re-scaled to BI area
13,675	Aspect 2016, based on USGS model
17,337	KW estimate from EA model
18,726	KW estimate from Aspect model
18,000	Pg. 68 of Frans et al. 2011; for 2008 (drier year)
18,920	"Empirical method" of KWRN 2000
19,067	"budget method" of KWRN 2000
23,100	Pg. 39 of Frans et al. 2011; average of 2007–2008
24,053	"regression method" of KWRN 2000
30,000	Pg. 68 of Frans et al. 2011; pre-development: 1970–2000 climatology, developed land replaced with conifer forest.

Yield

Sustainable yield (AFY)	Method
1,026-1,232	2% of precipitation (35-42 in/yr)
1,367-3,000	10% of recharge (Table 14)
2,043	GMA deep percolation (Figure 30)
589	FBA deep percolation (Figure 30)
1,232	FBA outflow to Sound (Figure 30)
3,024	FBA + GMA outflow to Sound (Figure 30)

Output

Output is Consumptive Use, which is pumping minus return flow

Pumping (AFY)	Source
2,000	2008 conditions, pg. 68 of Frans et al. 2011
2,267	KW estimate from EA model
2,560	Aspect 2016, based on USGS model
2,590	KW estimate from Aspect model
2,593	Table 14 of EA 2025
3,329	KWRN 2000-based projection for 2014

Return flow (AFY) [% of pumping]	Source
1,360 [68%]	KW estimate from EA model
1,570 [61%]	KW estimate from Aspect model
1,220 [49%]	KW estimate: EA 2025 indoor use (162 GPD/ERU) 80% consumptive outdoor use
856 [34%]	KW estimate: 100 GPD/ERU indoor use; 90% consumptive outdoor use (WADOE 2009)

Keta Waters compared two recent groundwater models and developed an additional model to better understand how Bainbridge Island's aquifer system could respond over the long term under different conditions. The study also examined how reduced groundwater recharge could affect streamflow and wetlands. Because groundwater helps feed streams, changes in groundwater levels can directly affect stream health and fish habitat.

Results:

- Under current conditions, impacts to streamflow are relatively small because water returning to the ground from septic systems helps offset impacts from groundwater pumping.
- Changes in recharge have a nearly one-to-one effect on streams and wetlands. If groundwater recharge decreased by 20%, streams and wetlands would receive about 25% less water.
- If pumping from wells in the deep Fletcher Bay Aquifer increased by 50%, streams and wetlands would receive about 0.4% less water. (Over the past 10 years, water use in the Island's three largest water systems has increased by about 3% each year.)

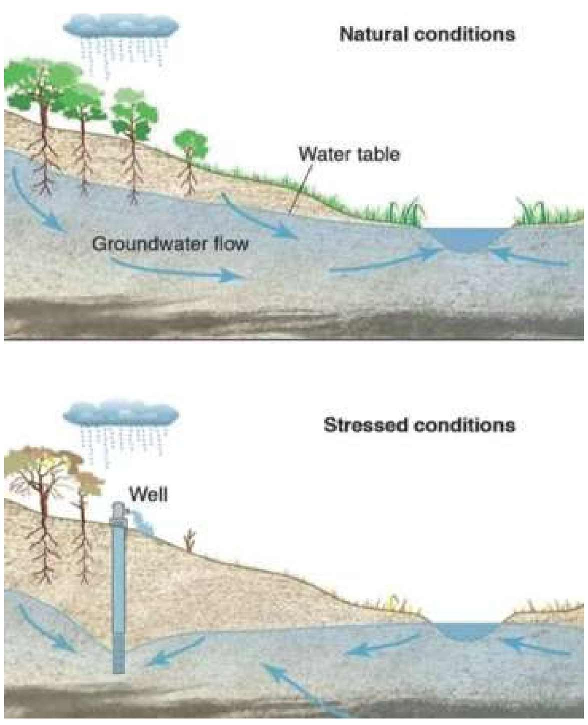
Summary of impacts to land surface water features.

		Model[1]			
		1	2	3	
#	Scenario description	Drain	Drain	Drain	Stream
1	Base case without wells	2.6%	0.3%	0.7%	4.4%
2	50% recharge with wells	-61.5%	-62.7%	-55.5%	-70.0%
3	50% recharge without wells	-60.0%	-62.8%	-55.0%	-68.1%
4	80% recharge with wells	-25.9%	-26.6%	-23.0%	-29.7%
5	80% recharge without wells	-23.6%	-26.1%	-22.4%	-25.6%
6	150% recharge with wells	69.4%	69.8%	61.7%	75.3%
7	150% recharge without wells	72.4%	70.0%	62.4%	80.1%
8	120% recharge with wells	27.2%	27.4%	24.3%	29.7%
9	120% recharge without wells	30.0%	27.7%	25.1%	34.3%
10	Well withdrawal and septic recharge reduced by 50%	0.2%	0.1%	-0.5%	1.6%
11	Well withdrawal and septic recharge reduced by 80%	0.1%	0.0%	-0.2%	0.6%
12	Well withdrawal and septic recharge increased by 50%	0.1%	0.0%	0.6%	-1.6%
13	FBA well withdrawal reduced by 50%	0.5%	0.4%	0.4%	0.4%
14	FBA well withdrawal increased by 50%	-0.5%	-0.2%	-0.4%	-0.4%
15	No septic return flow	-8.8%	-9.7%	-6.9%	-7.7%
16	Well withdrawal increased by 50% and no septic	-12.9%	-14.6%	-9.7%	-12.7%
17	Base case without BI wells	0.5%		-1.0%	3.1%
18	50% recharge without BI wells	-61.5%			
19	80% recharge without BI wells	-25.5%			
20	150% recharge without BI wells	69.9%			
21	120% recharge without BI wells	27.7%			

[1] 1: EA Model, 2: Aspect Model, 3: EA River Model

We can decide how to achieve Sustainable Groundwater

There is significant opportunity for water conservation on Bainbridge Island, as current water use is often higher than necessary and includes liberal use, especially from outdoor irrigation. Conservation efforts are needed even under lower population growth scenarios to limit additional impacts to streams, wetlands, and other surface waters and can also help allow future growth. Increasing groundwater recharge and reducing water use through conservation are the most effective and reliable ways to help ensure clean, sustainable groundwater for both the natural environment and future generations.



Gorelick and Zheng 2025

Here's what we want to avoid: Undesirable Impacts

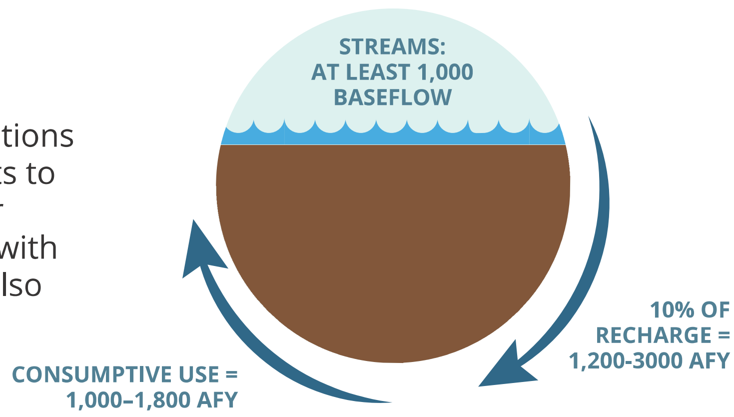
- **ECONOMIC:** Rising water costs and unequal access to reliable water service
- **ECOLOGICAL:** Loss of streams, wetlands, and fish habitat
- **SOCIETAL:** Declining groundwater levels and reduced long-term water security

Staying Sustainable: Recommended Groundwater Indicators

- **RECHARGE:** 10% of recharge or about 1,200–3,000 AFY, can be "consumptively used"
- **STREAMFLOW:** 1,000 AFY should be reserved for baseflow in streams

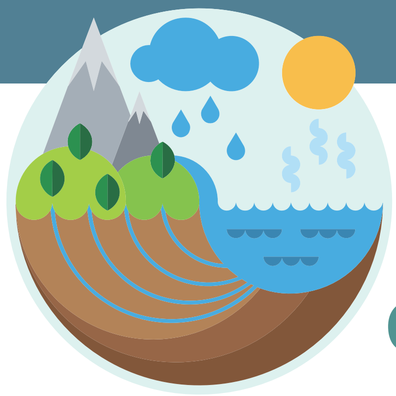
Monitoring for Indicators

More data and monitoring are needed to better understand groundwater conditions and reduce uncertainty so we can more clearly identify whether harmful impacts to groundwater are occurring. The City already monitors streamflow and saltwater intrusion, but additional monitoring is needed across more areas of the Island, with more frequent testing and expanded data collection. Additional resources will also be needed to support this work.



Groundwater Management takes all of us!

Doing nothing carries the most risk.
Small conservation efforts help,
but long-term planning, investment, and stronger conservation actions
provide the most reliable path forward for protecting
Bainbridge Island's water future.



Management Actions
A subset of actions from the Groundwater Management Plan

What would it look like if Bainbridge Island became a role model in sustainable water use?

Proactive Action that Can Be Taken Today

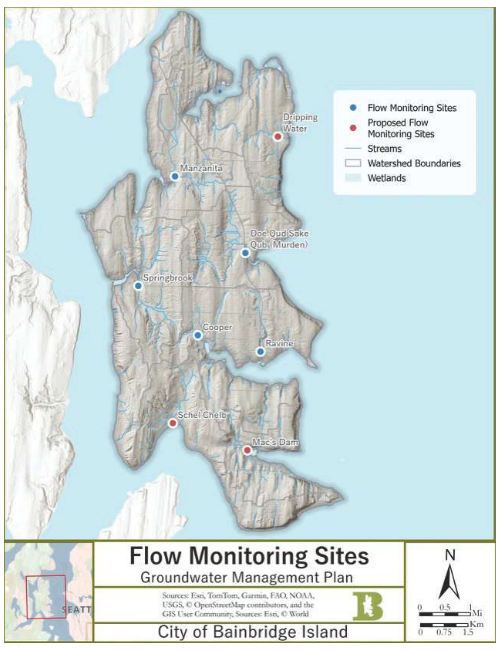
- **Water Conservation Initiatives (With Kitsap Public Utility District)**
  - —Update the water conservation plan outlined in the Water System Plan
  - —Develop a water conservation goal
  - —Develop and implement water conservation public outreach plan
  - —Evaluate past conservation measures for effectiveness
  - —Evaluate conservation impacts on water rates
- **Enhance storm and surface water management**
  - —Offer rebates for new rain gardens
  - —Incentivize repair and retrofit of existing facilities
  - —Continue the pollution prevention program with a focus on wellhead protection and priority recharge areas.
- **Evaluate and Implement Managed Aquifer Recharge**
  - —Construct Manzanita Stormwater Recharge Park
  - —Design recharge facilities in all watersheds
  - —Work toward offset targets from Kitsap Streamflow Restoration plan

Preventative Actions to Prepare for the Future

- **Develop Seawater Intrusion Policy (with Kitsap Public Health District)**
  - —Draft policy for the City's response to neighborhood scale intrusion
  - —Draft policy to protect water quality in existing wells from new nearby extraction
- **Reform Critical Aquifer Recharge Area Municipal Code**
  - —Analyze existing Aquifer Recharge Protection Area code
  - —Discuss potential for new recharge protection areas
- **Support Septic System Monitoring and Maintenance (with Kitsap Public Health District)**
  - —Consider expanding frequency of monitoring for some systems

Data Collection Actions Tell Us if our Strategies are Working

- **Expand Groundwater Monitoring**
  - —Add more locations for seawater intrusion monitoring
- **Increase Data on Water Use**
  - —Offer rebates for smart water meters i.e. Flume
  - —Create a system to accept more use data
- **Expand Surface Water Monitoring**
  - —Add 3-6 more long term stream monitoring sites
- **Create a Dashboard for Results**



Groundwater Values
Choose your top 3

Cost

Reliability

Water for fish

Prevention of seawater intrusion

Protected recharge areas

Equitable use of shared resources

Innovative water practices/ Enigneered solutions

Irrigated landscape

Drought tolerant landscape

Independence

Wetlands