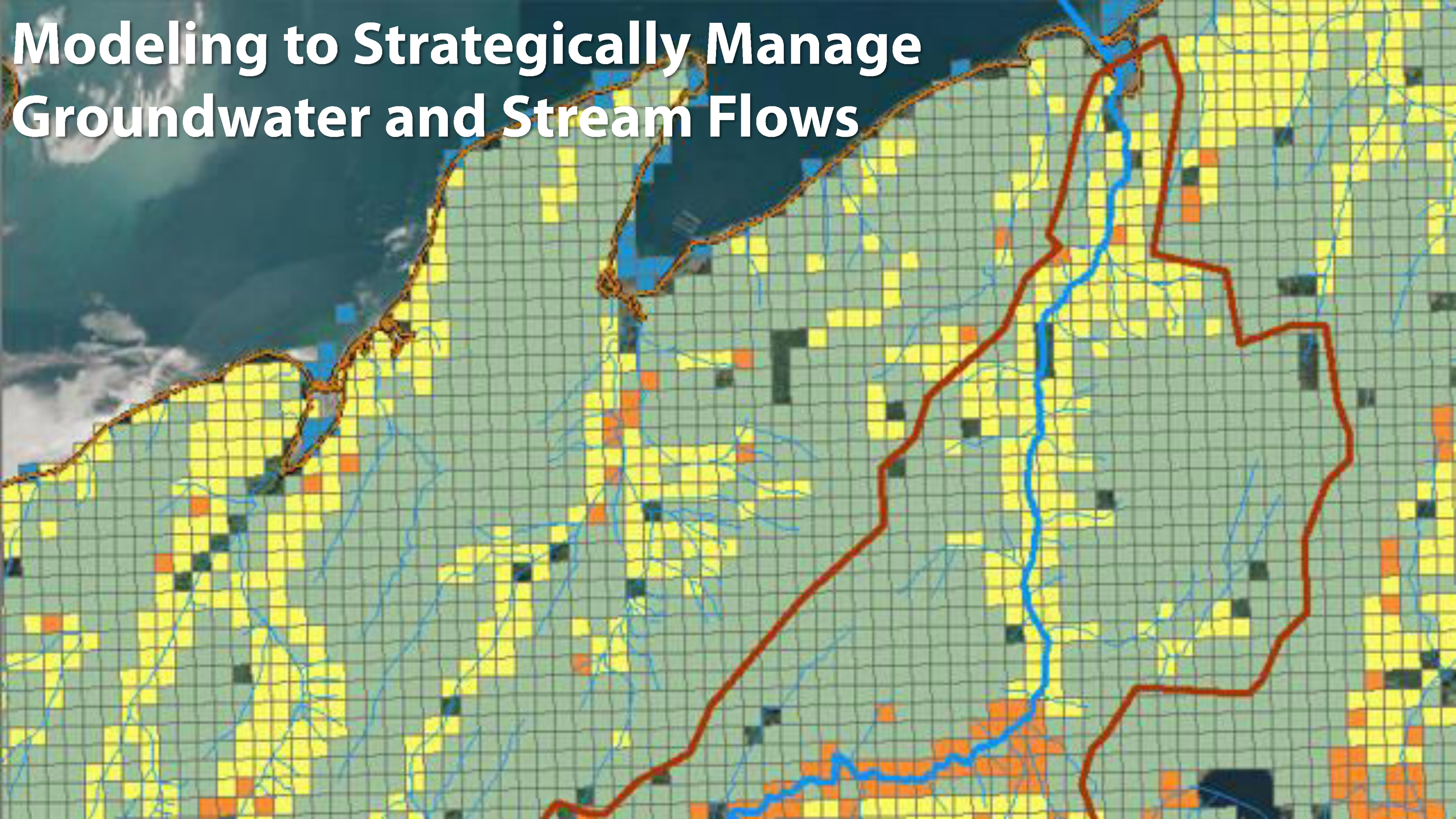
Salish Sea
Science Roundtable

Modeling to Strategically Manage Groundwater and Stream Flows



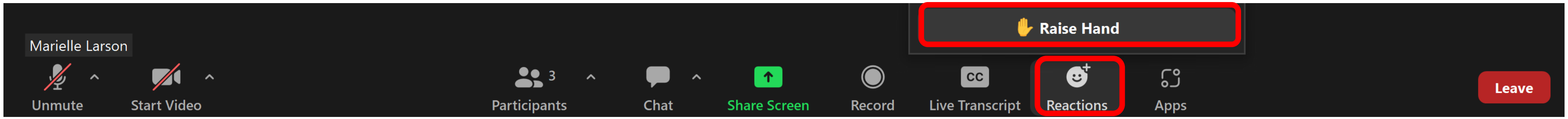
Navigating the Roundtable

Welcome! While we wait, please:

- Update your name to include your pronouns and organization
- Message Marielle with any access needs
- Introduce yourself in the chat. We've muted participants to minimize technical issues, so we encourage you to use the chat to say hello instead

Questions or Comments?

- Add them to the chat
- Raise your hand and we'll unmute you



The slides and recording will be available on [Puget Sound Institute's website]

Land Acknowledgement

The UW Tacoma community acknowledges that we learn, teach, work and live on the ancestral land of the Coast Salish people. In particular, our campus is situated on traditional lands of the Puyallup Tribe of Indians. We recognize that this is a difficult and painful history, and we understand we must play an active role in remembering, not just what happened to Indigenous communities; post settlement, but also the rich history that existed long before colonization. This land acknowledgement is one small act in an ongoing process of honoring the past while working together with local Tribes to build a more inclusive and thoughtful community.

The Role of Simulation Models

- **Template for Integrating Science and Decision Making to 2099**
- **Modeling to Strategically Manage Groundwater and Stream Flows**

Salish Sea Science Roundtable

Sono Hashisaki and Philip Murphy

April 2, 2024

DECISION ECOSYSTEM

What's the problem today?

Start where you're at – your locale
What's the current condition?
How do we know?

Monitoring Data

Deciders – What future do we want?

How do we meet the needs of humans and the ecosystems we depend on?
Do we bring everyone along, who's at the table?
How do we leave the most options/resources for the next generation of leaders?
Who are our partners? How do we share resources, knowledge & experience?

Principles, Values, and Leadership

DECISION ECOSYSTEM

<u>Deciders – What future do we want?</u>

How do we meet the needs of humans and the ecosystems we depend on?
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Principles, Values, and Leadership

<u>What's the problem today?</u>

Start where you're at – your locale
What's the current condition?
How do we know?

Monitoring Data

<u>What's the problem tomorrow?</u>

How will things change? What are the drivers? What are the trends and what scenarios will be helpful?
What will change at your locale
What's the future condition?
How do we know what is projected?

Process and Change Models

Hashisaki 4-2-24

DECISION ECOSYSTEM

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Principles, Values, and Leadership

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What's the current condition?
How do we know?

Monitoring Data

What's the problem tomorrow?

How will things change? What are the drivers? What are the trends and what scenarios will be helpful?
What will change at your locale
What's the future condition?
How do we know what is projected?

Process and Change Models

What should we do today for a better tomorrow?

What can we do that will be effective?
Test assumptions and possible solutions using Simulation Modeling.
How do we know when our assumptions don't hold and what do we do then?
What should we fund and implement today?

Monitoring, Costs, and Funding

Hashisaki 4-2-24

Land-based Sectors – Leadership and Stakeholders

Community Values & Guiding Principles
Mandates, Targets, Budgets,
X-sector Connections, Scenarios

2024

Decision Context

LAND-BASED SECTORS LEADERSHIP AND STAKEHOLDERS
Community Values & Guiding Principles
Mandates, Targets, Budgets, X-sector Connections, & Scenarios

Agreement on Baseline Conditions as described by Data, Models, Indicators, and Change Drivers

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Science, Indicators Trends & Solutions

ECOSYSTEM
targets & indicators for fish
Strategy/Types of Action
E1 | E2 | E3

DEVELOPMENT
targets & indicators for housing
Strategy/Types of Action
D1 | **D2** | D3

AGRICULTURE
targets and indicators
Strategy/Types of Action
A1 | A2 | A3

Policy and Planning

CHANGE IN INDICATORS from ACTIONS SIMULATED for EVERY YEAR THROUGH 2099

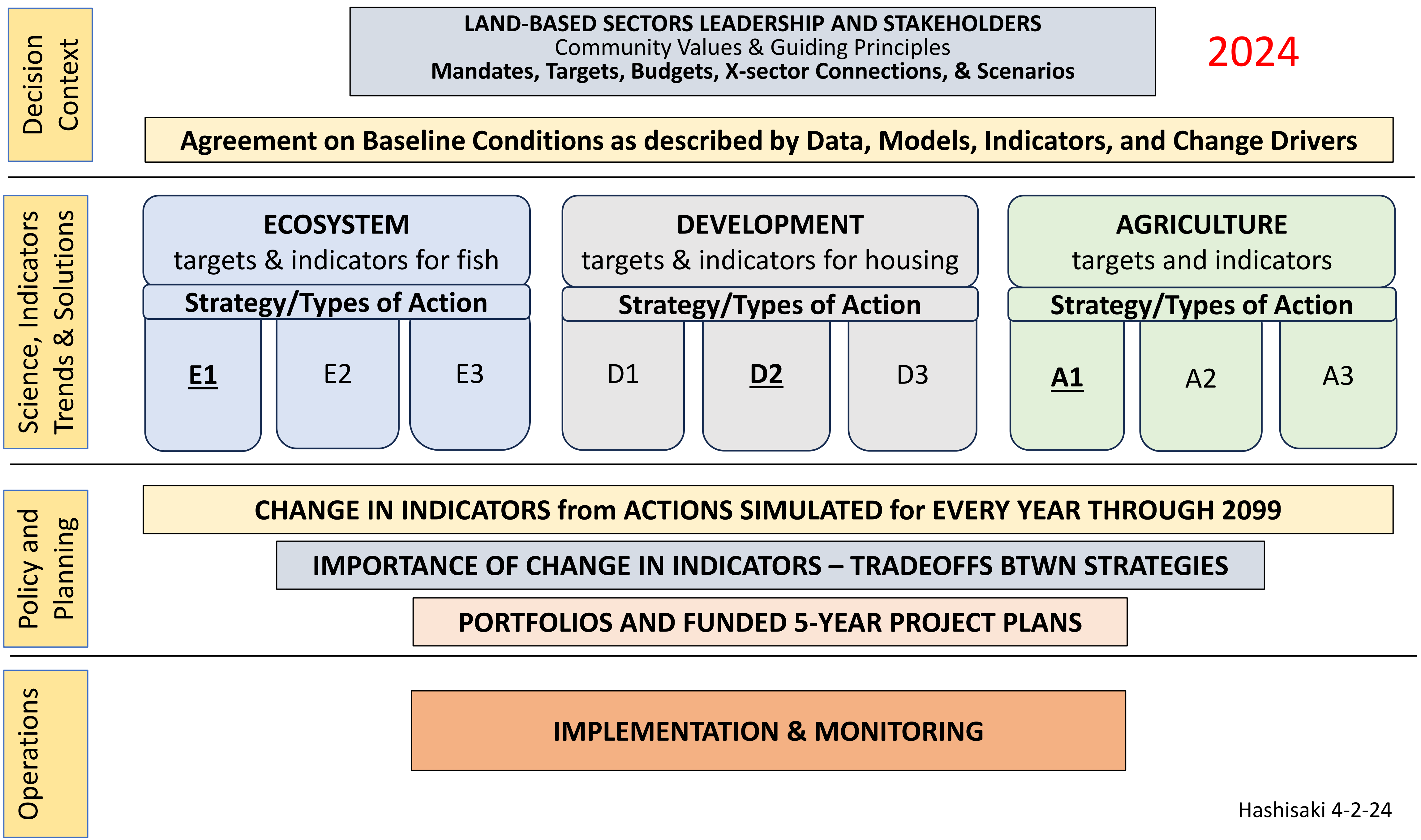
IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BTWN STRATEGIES

PORTFOLIOS AND FUNDED 5-YEAR PROJECT PLANS

Operations

IMPLEMENTATION & MONITORING

Hashisaki 4-2-24



Decision Context
LAND-BASED SECTORS LEADERSHIP AND STAKEHOLDERS
Community Values & Guiding Principles
Mandates, Targets, Budgets, X-sector Connections, & Scenarios
2024
Agreement on Baseline Conditions as described by Data, Models, Indicators, and Change Drivers
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Hashisaki 4-2-24

Decision Context

LAND-BASED SECTORS LEADERSHIP AND STAKEHOLDERS
Community Values & Guiding Principles
New Mandates, Targets, Budgets, X-sector Connections, & Scenarios

2099

Compare 2099 Projected Conditions with Actual 2099 Conditions described by Monitoring Data:
Update Assumptions, Models and Indicators, New Problem Identification

Science, Indicators Trends & Solutions

ECOSYSTEM
targets & indicators for fish
Strategy/Types of Action
E21.x | E32 | **E34**

DEVELOPMENT
targets & indicators for housing
Strategy/Types of Action
D32.x | D41 | **D43**

AGRICULTURE
targets and indicators
Strategy/Types of Action
A31 | **A42** | A46

Policy and Planning

CHANGE IN INDICATORS from ACTIONS SIMULATED for 2099

IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BTWN STRATEGIES

UPDATED PORTFOLIOS
FUNDED 5-YEAR PROJECT PLANS

Hashisaki 4-2-24

Decision Context

LAND-BASED SECTORS LEADERSHIP AND STAKEHOLDERS
Community Values & Guiding Principles
Mandates, Targets, Budgets, X-sector Connections, & Scenarios

2030

Compare Projected 2030 Conditions with Actual 2030 Conditions described by Monitoring Data
Update Models and Indicators; Test Assumptions, Identify Critical Opportunities & Threshold Issues

Science, Indicators Trends & Solutions

ECOSYSTEM
targets & indicators for fish
Strategy/Types of Action
E1.x | E2 | **E6**

DEVELOPMENT
targets & indicators for housing
Strategy/Types of Action
D2.x | D5 | **D7**

AGRICULTURE
targets and indicators
Strategy/Types of Action
A1.x | **A4** | A6

Policy and Planning

CHANGE IN INDICATORS from ACTIONS SIMULATED for 2030

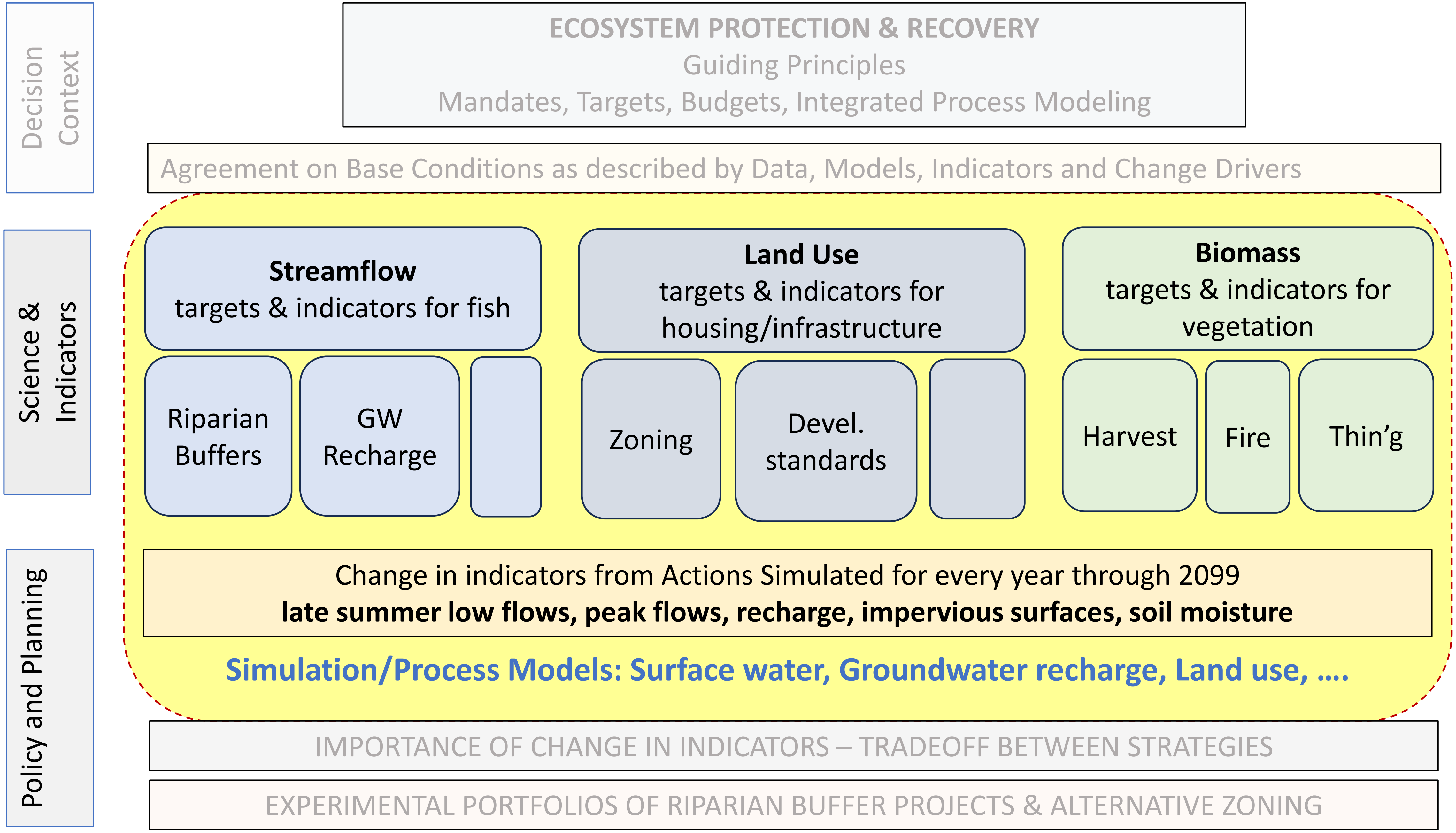
IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BTWN STRATEGIES

UPDATED PORTFOLIOS / FUNDED 5-YEAR PROJECT PLANS

Operations

IMPLEMENTATION & CONTINUED MONITORING

Hashisaki 4-2-24



Hashisaki 4-2-24

Decision Context

Field of shared Knowledge

LAND-BASED SECTORS LEADERSHIP AND STAKEHOLDERS
Community Values & Guiding Principles
Mandates, Targets, Budgets, X-sector Connections, & Scenarios

2024

Agreement on Baseline Conditions as described by Data, Models, Indicators, and Change Drivers

Science, Indicators Trends & Solutions

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E1 | E2 | E3

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Strategy/Types of Action
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Policy and Planning

CHANGE IN INDICATORS from ACTIONS SIMULATED for EVERY YEAR THROUGH 2099

IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BTWN STRATEGIES

PORTFOLIOS AND FUNDED 5-YEAR PROJECT PLANS

Operations

IMPLEMENTATION & MONITORING

Find & Share Information in Open Knowledge Network

Hashisaki 4-2-24

Using the Kitsap MODFLOW model to enhance VELMA model Calibration

A Suquamish Project: Simulating Outcomes for the Future

Apr 2nd, 2024

Created by Philip Murphy, InfoHarvest Inc.

Philip.murphy@infoharvest.com

These slides describe exploratory work in progress. None are meant to be definitive.

“Simulating Outcomes for the Future” project

- Led by Paul Williams with the Suquamish Tribe
- BIA Resilience grant
- Aims
  - Create a simulation system for changes to landscape under climate change
  - Focus on terrestrial habitat for salmon
  - Test effectiveness of various long term strategies for preservation/restoration over time (1990-2099)
    - Riparian buffers, zoning (under population growth scenarios), forest harvest, …
  - Improve Calibration of VELMA by taking into account Groundwater
  - Provide best information on how actions will change the landscape

Collaborators on VELMA/MODFLOW work

- Suquamish: Paul Williams (lead), Steve Todd, Charles Kratzer and other staff and leadership,
  - Contractors Joel and Adam Massmann, Hydrologists
- EPA: Bob McKane, Sonali Choksi, Allen Brooks, Jonathan Halama
- USGS: Andy Long, Elise Wright, Wendy Welch and Chris Konrad
- InfoHarvest: Sono Hashisaki and Philip Murphy

Contents

- Issues with VELMA Calibration without Groundwater
- General Approach to using 2016 MODFLOW Results
- Initial VELMA Model Results for Big Beef Creek
- Matching GW Recharge and Flow in VELMA with MODFLOW
- Results: improvements to VELMA Calibration
- Transferability to the greater Puget Sound

 These slides describe exploratory work in progress. None are meant to be definitive.

Terminology for Water Cycle Modeling

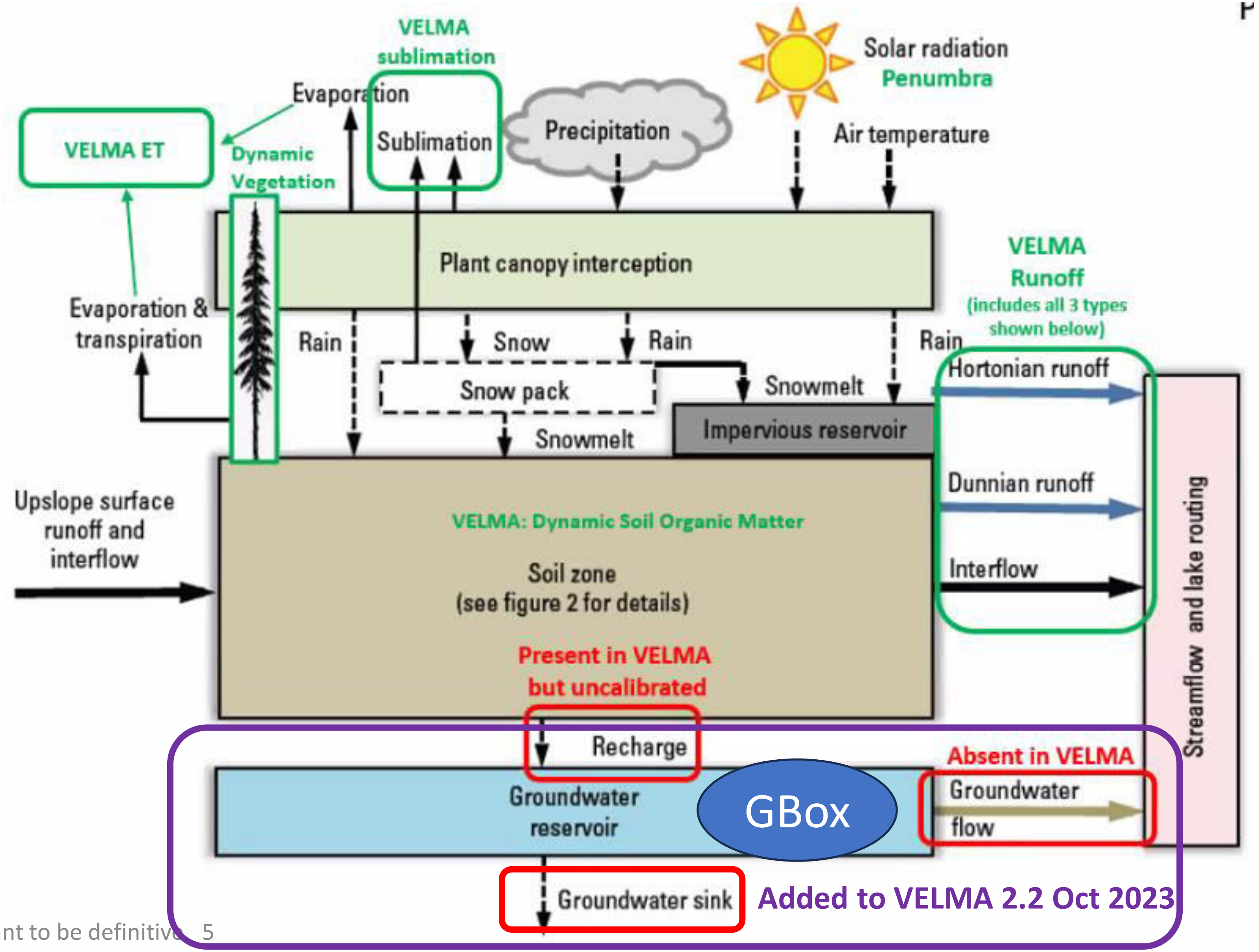
Recharge: Flow from soil layers into Groundwater Reservoir

Groundwater Flow: Flow from Groundwater Reservoir back to the surface

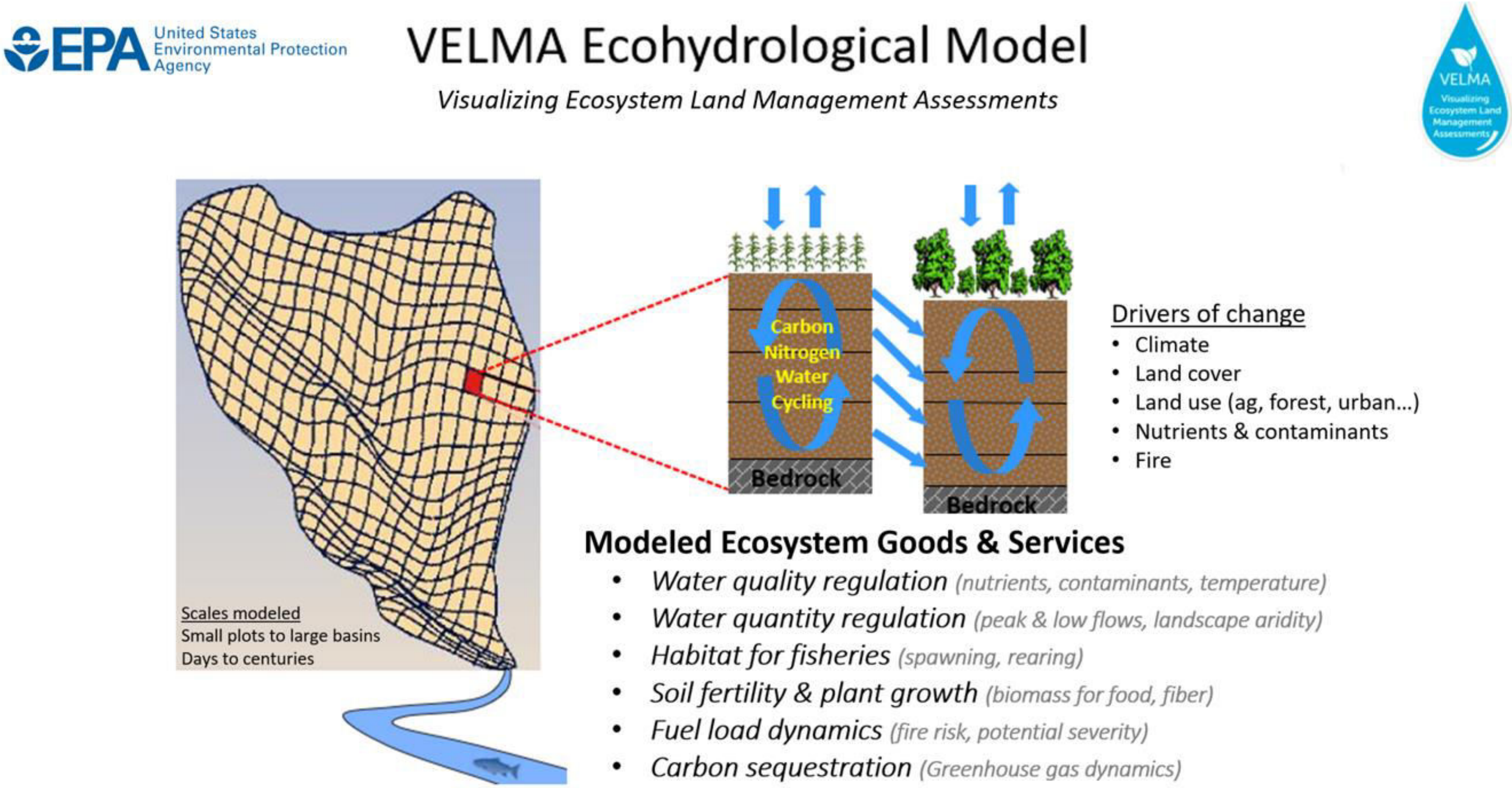
Groundwater Sink:
Flow from Groundwater Reservoir that does not return to surface

Gbox:
VELMA 2.2 functionality that mimics a Groundwater reservoir

Red Boxes show new groundwater flows in VELMA



VELMA Intro



meant to be definitive.

Core Annual Water Balance

Provided by weather data sets
(PRISM, Daymet, …)

- Precipitation = Evapo-transpiration (E/T)

+ RunOff << measured by stream gage

+ Groundwater Recharge { + Groundwater Flow; + Groundwater Sink }

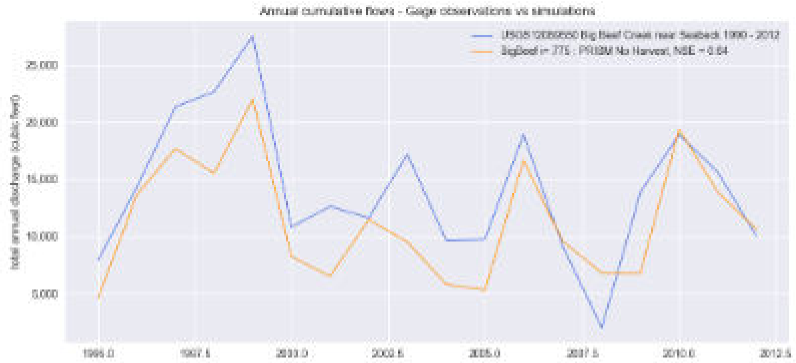
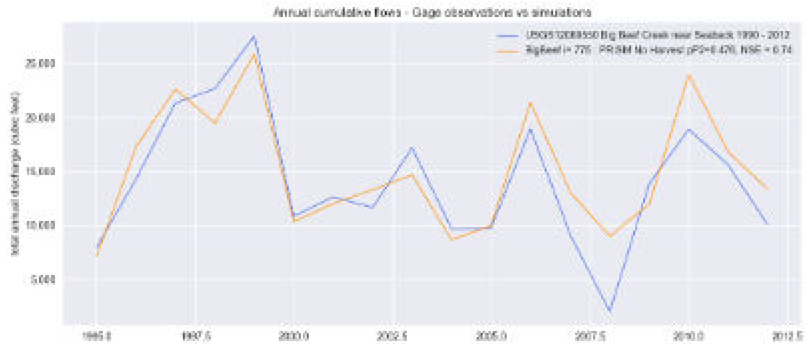
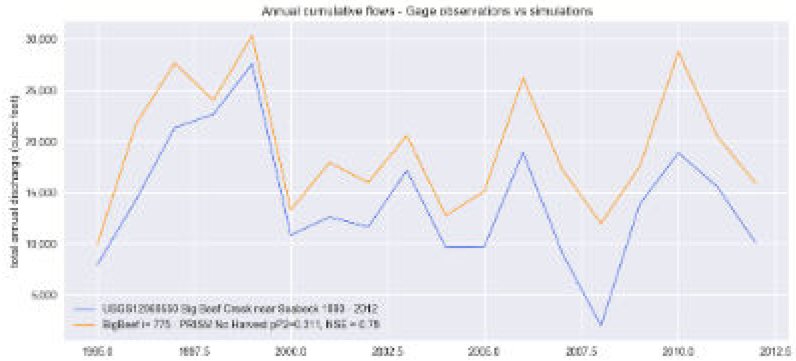
+ Snow sublimation ……

These slides describe exploraty work in progress. None are meant to be definitive.

Rough Calibration of E/T on Big Beef Creek

PetParam2 sets rate of E/T for each land cover

Dropping its value by a half has a dramatic effect on surface flows

petParam2	NSE	Annual Accumulated Flow
0.622 (Default)	0.64 Sim/Obs	
0.467 (75%)	0.74	
0.311 (50%)	0.79	

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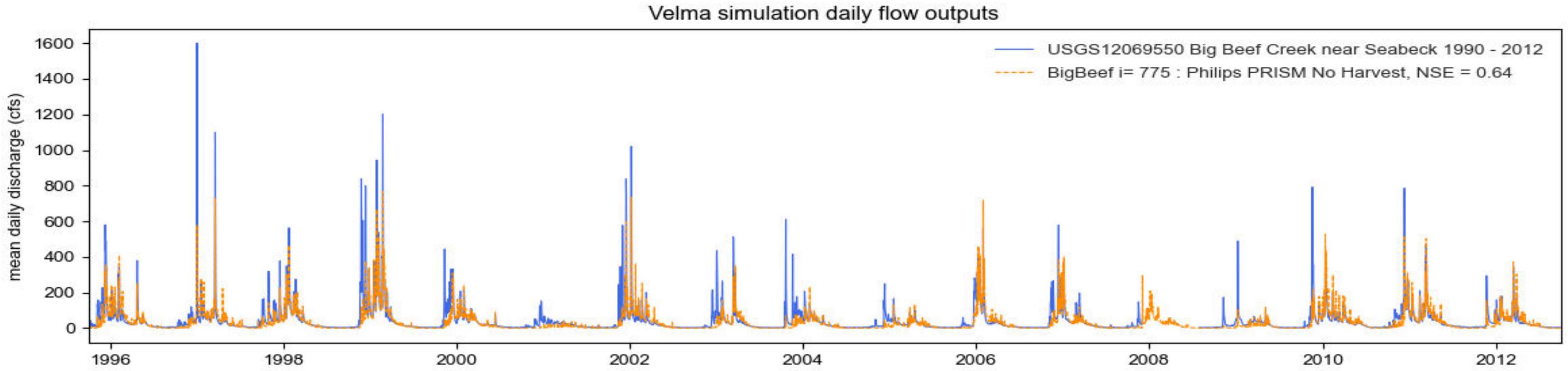
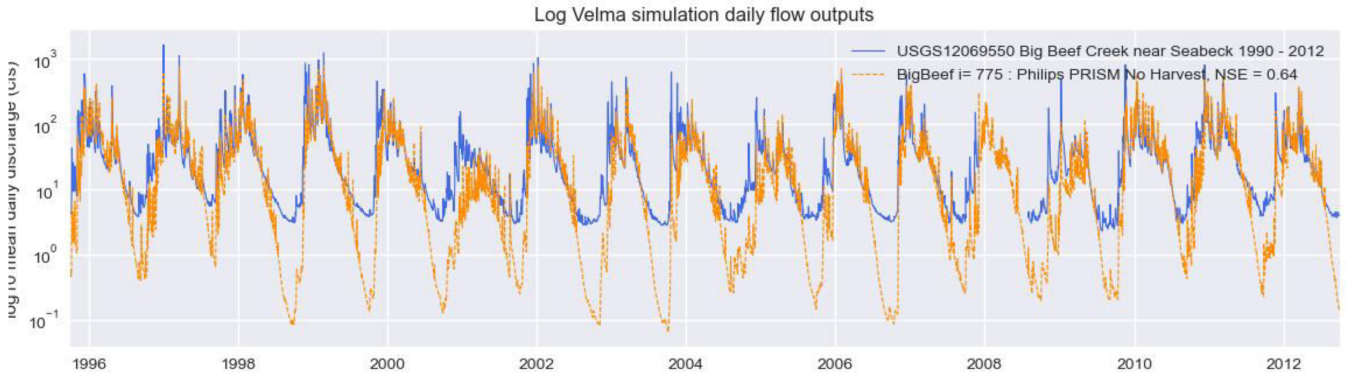
Issues with current VELMA Calibration

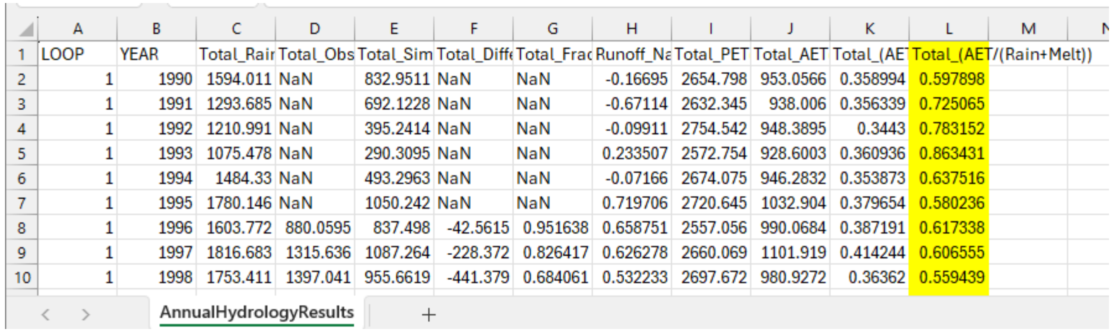
- NSC is middling ~~ 0.64
  - (Nash-Sutcliff Coefficient)



- Late summer low flows too low



- E/T to Precipitation flows too high
  - Should be in range 0.2- 0.4 for W. Cascades

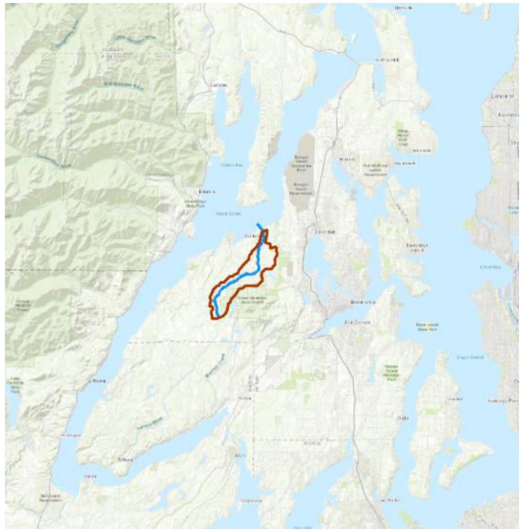


	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	LOOP	YEAR	Total_Rair	Total_Obs	Total_Sim	Total_Diffe	Total_Frac	Runoff_Na	Total_PET	Total_AET	Total_(AET	Total_(AET/(Rain+Melt))		
2	1	1990	1594.011	NaN	832.9511	NaN	NaN	-0.16695	2654.798	953.0566	0.358994	0.597898		
3	1	1991	1293.685	NaN	692.1228	NaN	NaN	-0.67114	2632.345	938.006	0.356339	0.725065		
4	1	1992	1210.991	NaN	395.2414	NaN	NaN	-0.09911	2754.542	948.3895	0.3443	0.783152		
5	1	1993	1075.478	NaN	290.3095	NaN	NaN	0.233507	2572.754	928.6003	0.360936	0.863431		
6	1	1994	1484.33	NaN	493.2963	NaN	NaN	-0.07166	2674.075	946.2832	0.353873	0.637516		
7	1	1995	1780.146	NaN	1050.242	NaN	NaN	0.719706	2720.645	1032.904	0.379654	0.580236		
8	1	1996	1603.772	880.0595	837.498	-42.5615	0.951638	0.658751	2557.056	990.0684	0.387191	0.617338		
9	1	1997	1816.683	1315.636	1087.264	-228.372	0.826417	0.626278	2660.069	1101.919	0.414244	0.606555		
10	1	1998	1753.411	1397.041	955.6619	-441.379	0.684061	0.532233	2697.672	980.9272	0.36362	0.559439		

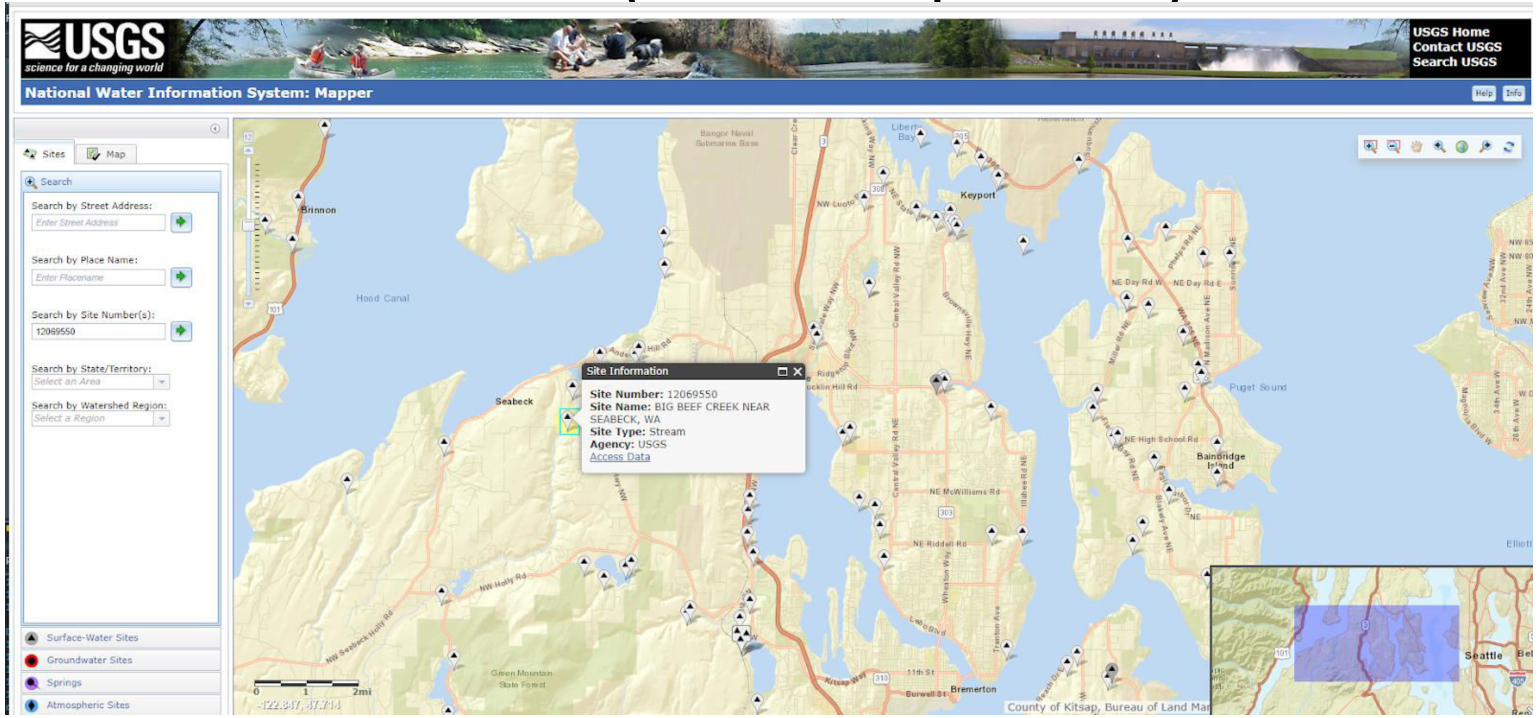
AnnualHydrologyResults

- There is Recharge, GW Flow and GW Sink Flow on Kitsap Peninsula
  - Annual Recharge/Precipitation ~~ 30%, GW Flow/Precipitation ~~ 19%

Initial VELMA Model for Big Beef Creek



- 90m Resolution (DEM)
- Calibrate for 1990 -2012
- USGS Gage 12069550 (near Seabeck)
- Built on model calibrated for Snohomish Basin (The Tulalip Tribes)
  - Conifer Land Cover
  - Sandy Loam soil
  - LandTrendr TreeAge
  - PRISM weather data



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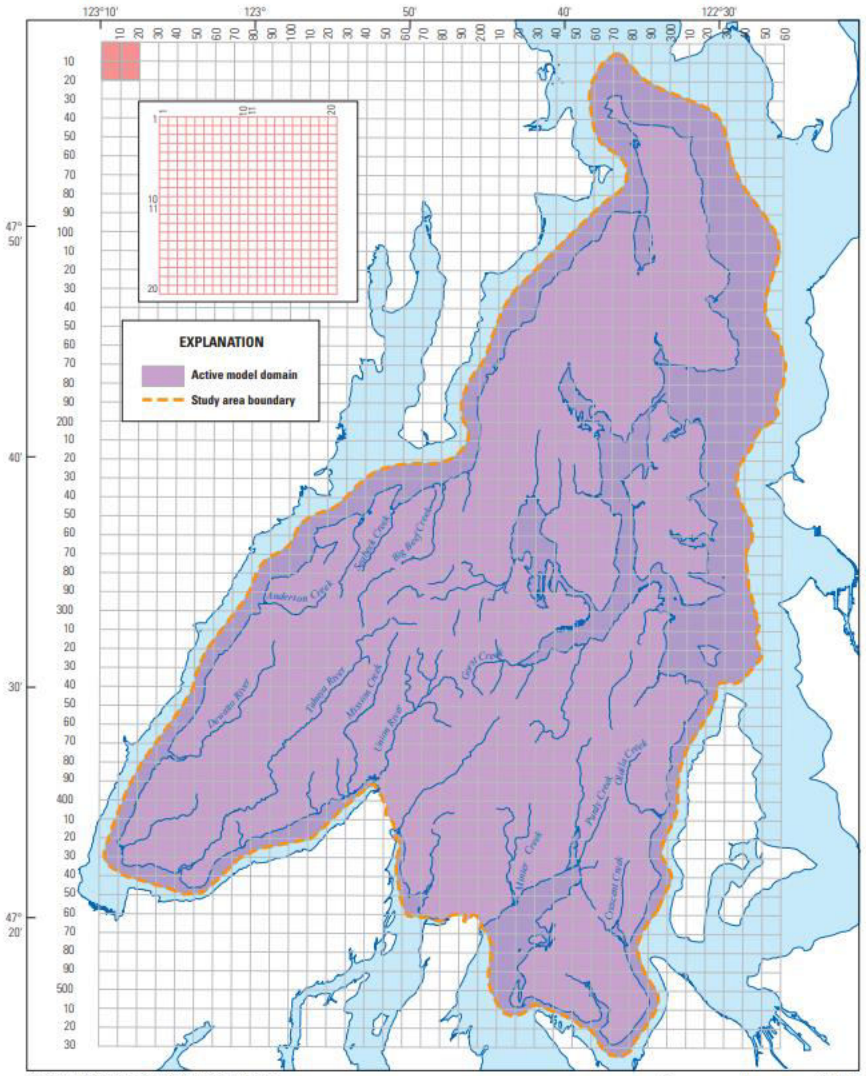
USGS Kitsap MODLOW Model - 2016

- *Numerical Simulation of the Groundwater-Flow System of the Kitsap Peninsula, West-Central Washington* by Lonna M. Frans and Theresa D. Olsen
  - Calibrated on measurements from the survey report:
    - *Hydrogeologic framework, groundwater movement, and water budget of the Kitsap Peninsula, west-central Washington*
    - Authors: Wendy B. Welch, Lonna M. Frans, Theresa D. Olsen w Kitsap PUD
  - https://www.usgs.gov/centers/washington-water-science-center/science/kitsap-groundwater-model
  - Uses Bidlake & Payne equations to estimate recharge : Recharge vs Precipitation
  - Uses MODFLOW-NWT to model groundwater flow in complex system of aquifers
  - Generated
    - a Steady State Model
    - Annual Transient Model 1985-2004
    - **Monthly Transient Model 2005-2012 – Fully Calibrated**

USGS Kitsap MODFLOW Model -AOI



Base from U.S. Geological Survey digital data, 1:400,000
Lambert Conformal Conic projection: State Plane Washington North
North American Datum of 1983

Figure 2. Location and extent of the groundwater model grid, west-central Washington. The insert depicts the detailed horizontal discretization for the first 20 rows and columns of the grid.

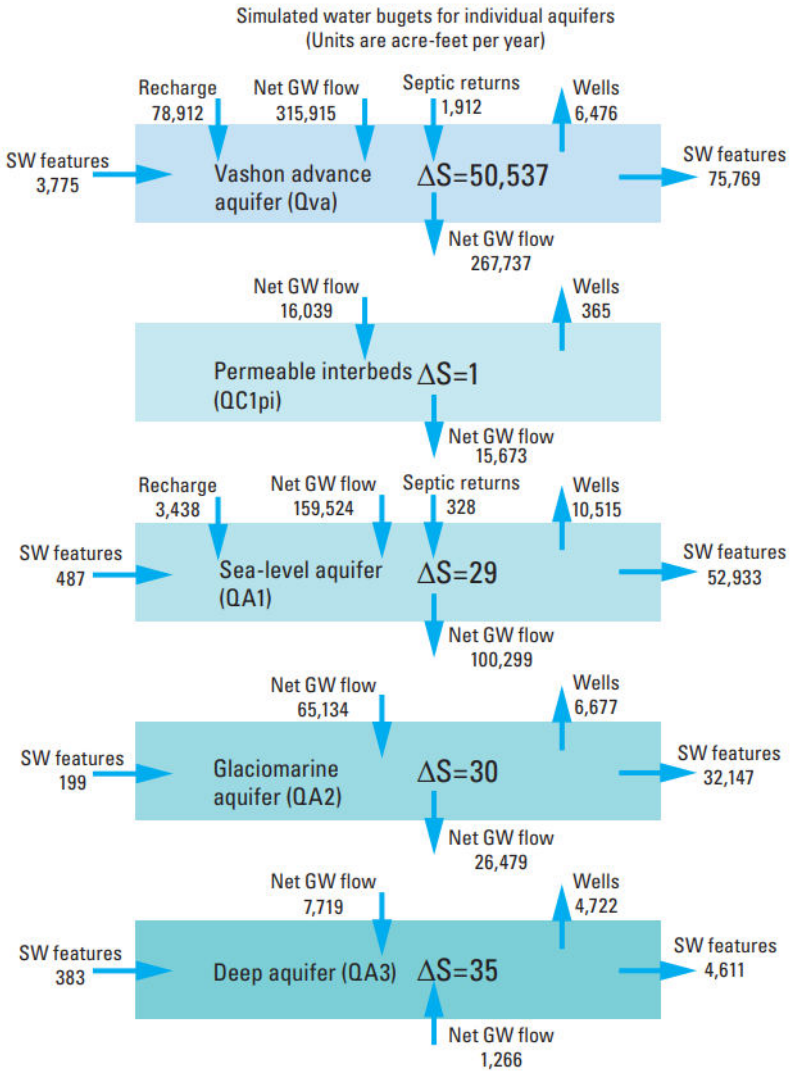
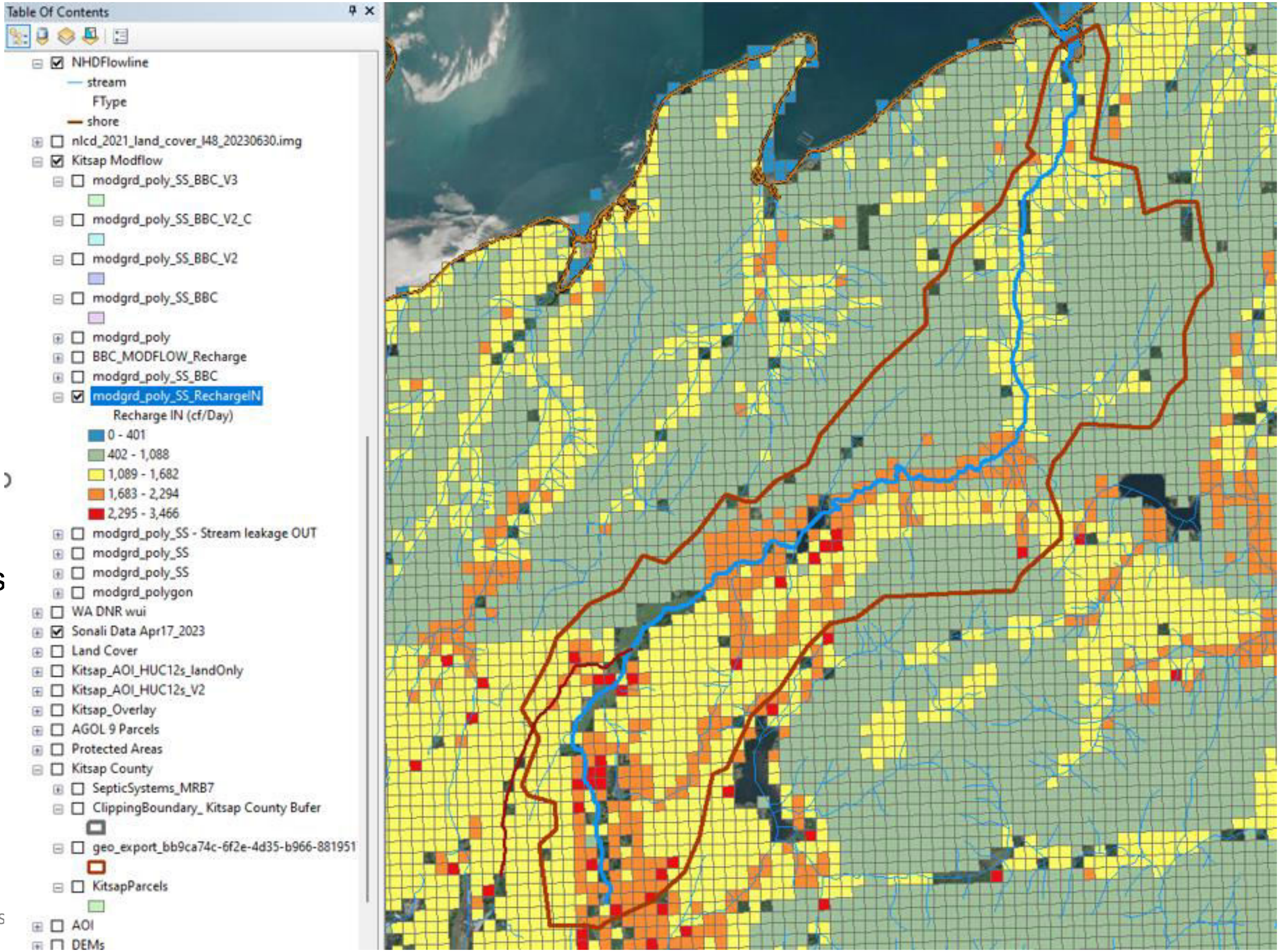


Figure 10. Simulated water budgets for individual aquifers, Kitsap Peninsula, west-central Washington, 2012. GW, groundwater; SW, surface water.

MODFLOW GW Recharge – Steady State model

- The total [Recharge IN] is 1504,595 cubic feet/Day = > 549.2 mcf per year.
- Average Precipitation (from PRISM data) for 1990-2005 was 1739.39 mcf per year.
- This suggests that 31% of the water that falls annually into the Big Beef Creek catchment goes to ground water as recharge.



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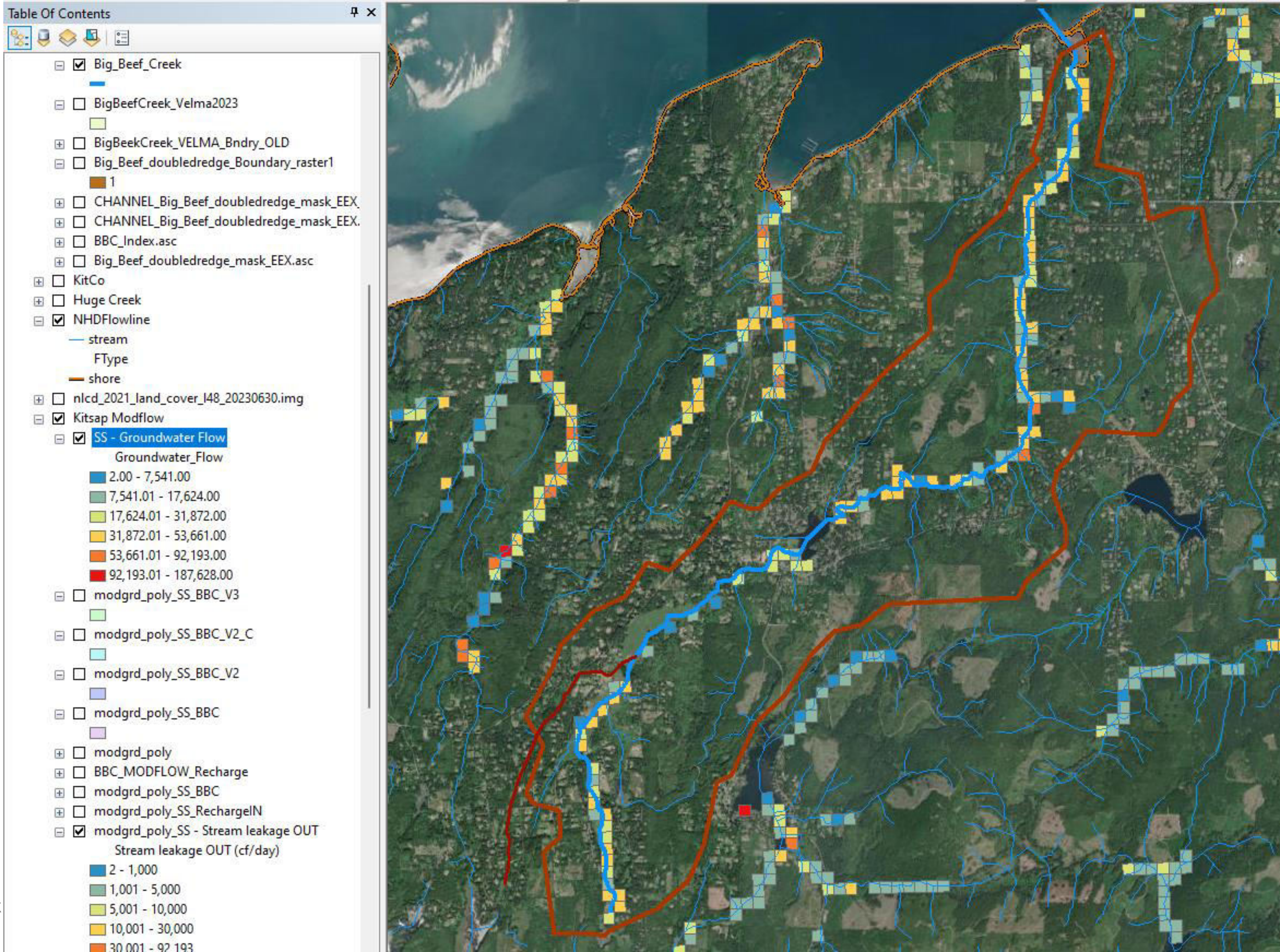
Kitsap MODFLOW Groundwater Flow – Steady State

While all 1316 cells contribute to Recharge, only 100 cells have Groundwater Flow from the aquifer



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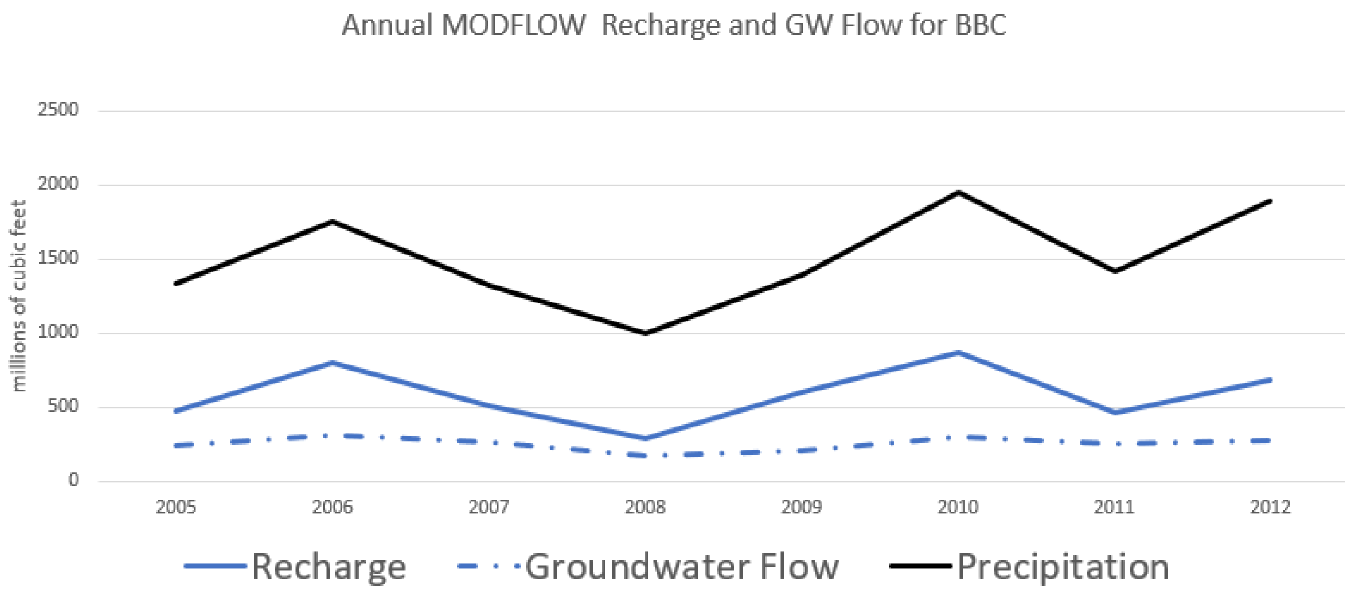
MODFLOW Average Annual Water Budget – Big Beef Creek w UPDATED BOUNDRY

Average Annual Precipitation	Average Annual Recharge	Average Annual Groundwater Flow
1,580 mcf	626 mcf	261 mcf
100%	39%	17%
	100%	42%



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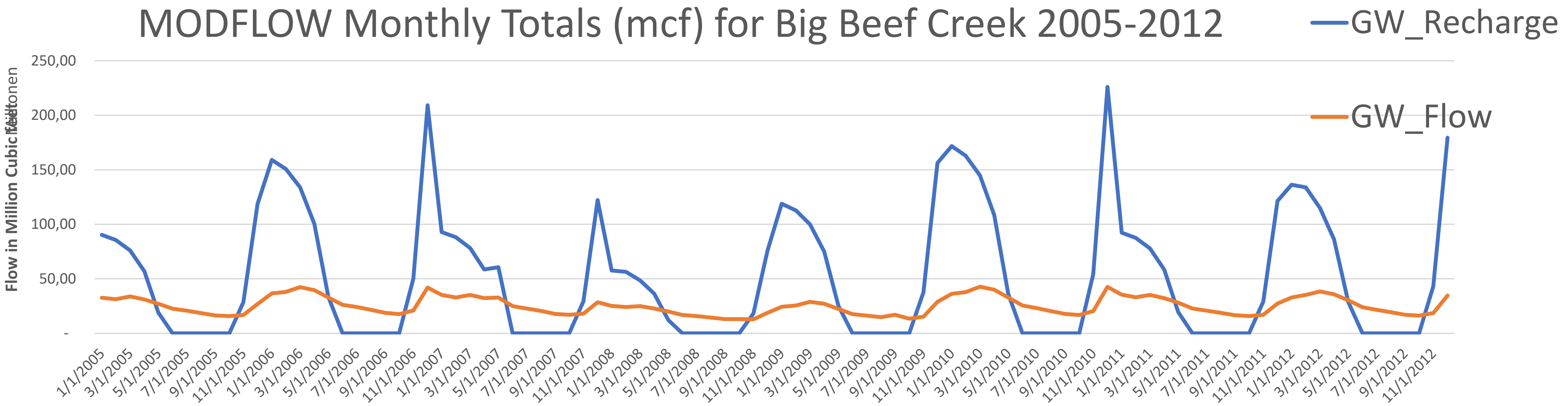
Kitsap MODFLOW – Transient Results



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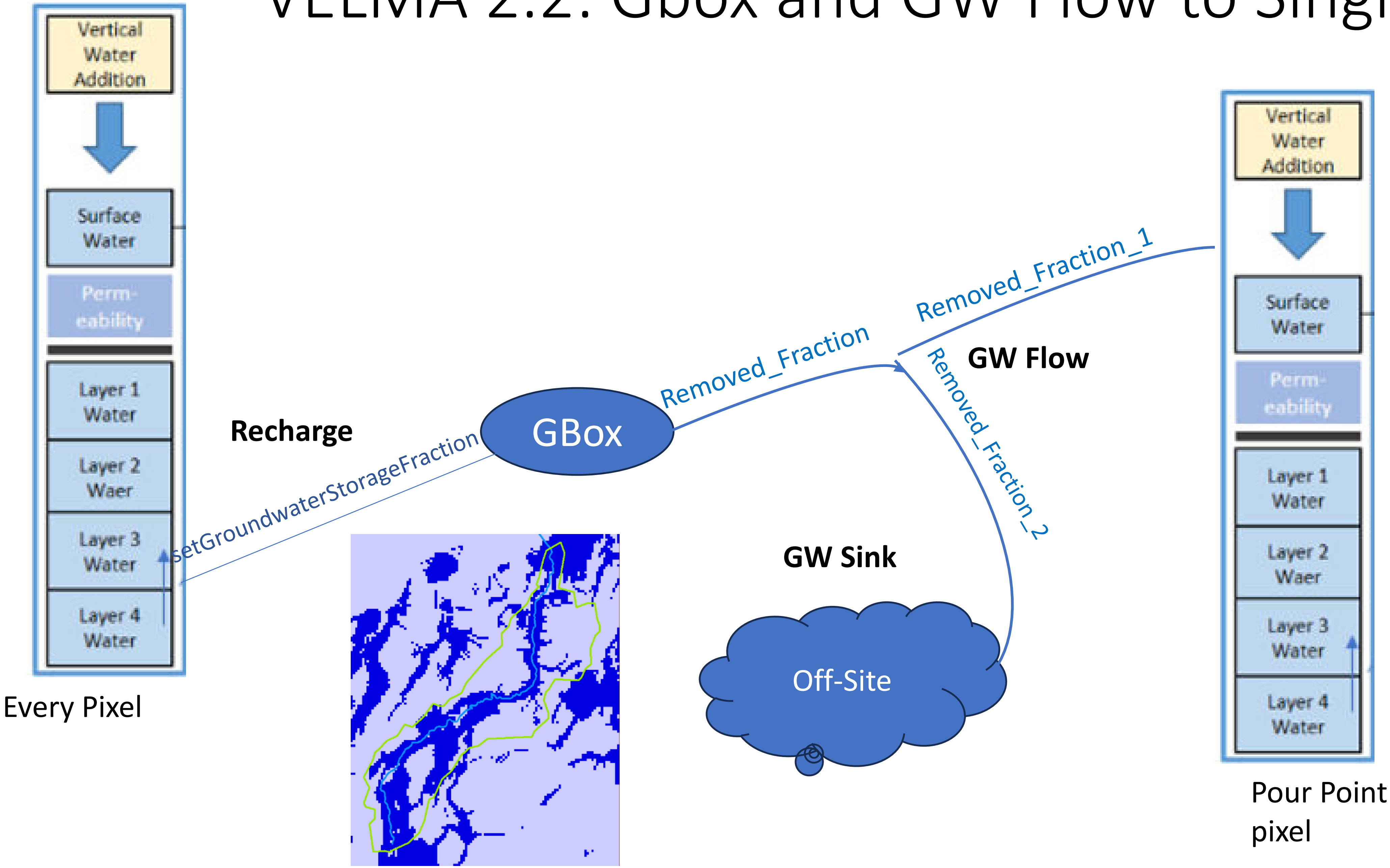
VELMA 2.2: Gbox and GW Flow to Single pixel



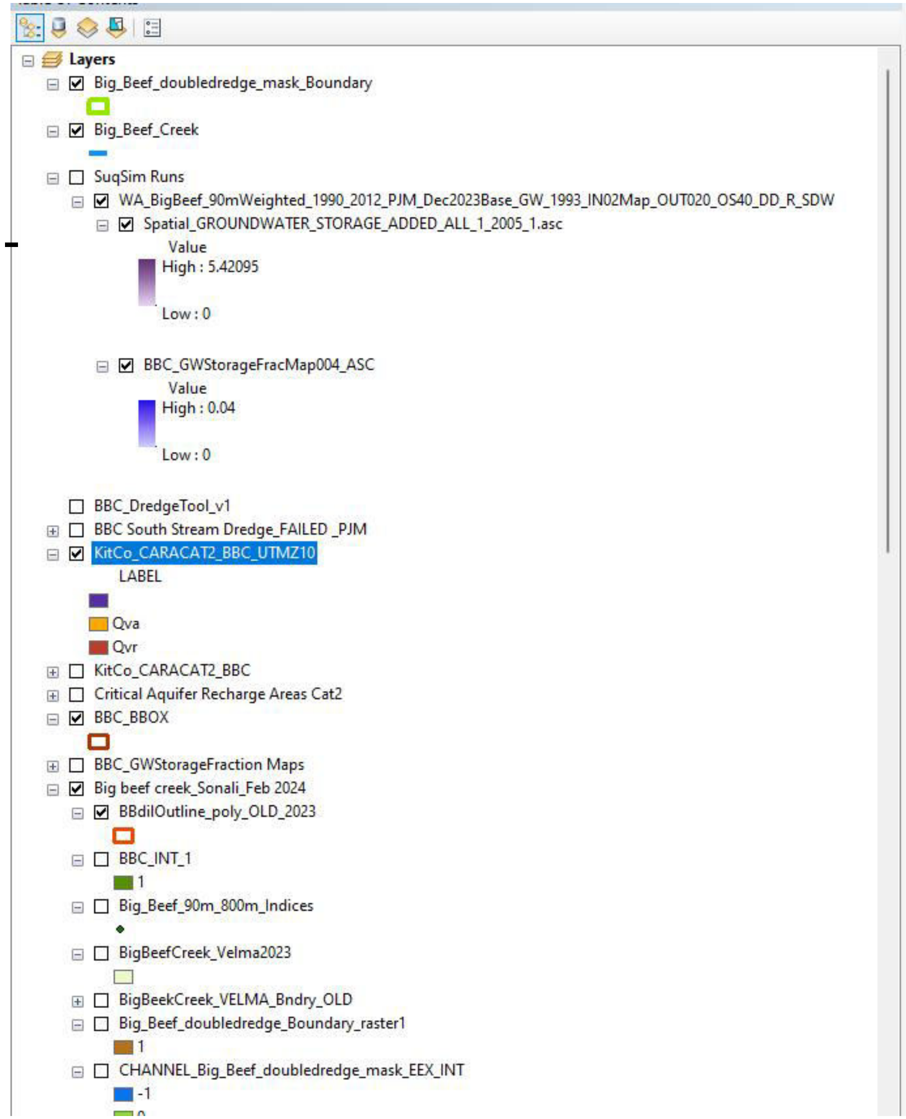
Basic Approach to “static” Integration

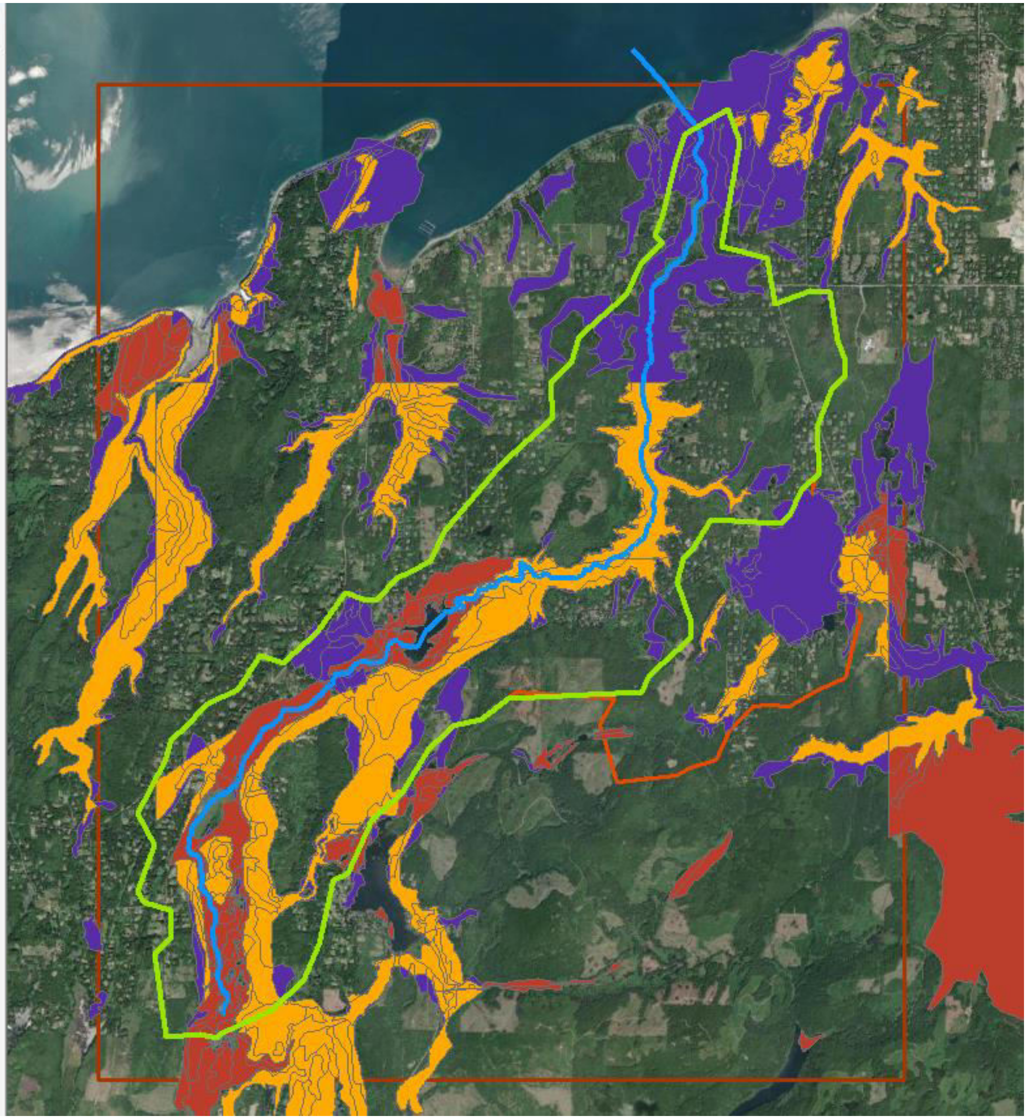
- Calibrate VELMA without Groundwater flow
- Turn on VELMA GroundwaterStorageFraction “knob” → Recharge
- Turn on VELMA 2.2 GBox “Disturbance” with Outflows → GW Flow
- Turn on VELMA 2.2 GBox with offsite Outflows → GW Flow + GW Sink
- Use USGS Kitsap MODFLOW Results 2005-2012 to set
  - Recharge to Precipitation Ratio at watershed level
  - Groundwater Flow Ratio to Precipitation at watershed level
- Recalibrate VELMA model while preserving ratios

VELMA Recharge – basis for GW Storage Fraction Map?

Kitsap County's Critical Aquifer Recharge Areas - Category 2

- Areas where shallow aquifers' confinement layers are poorly impermeable
- Highly Permeable Soils (Group A Hydrologic Soils).





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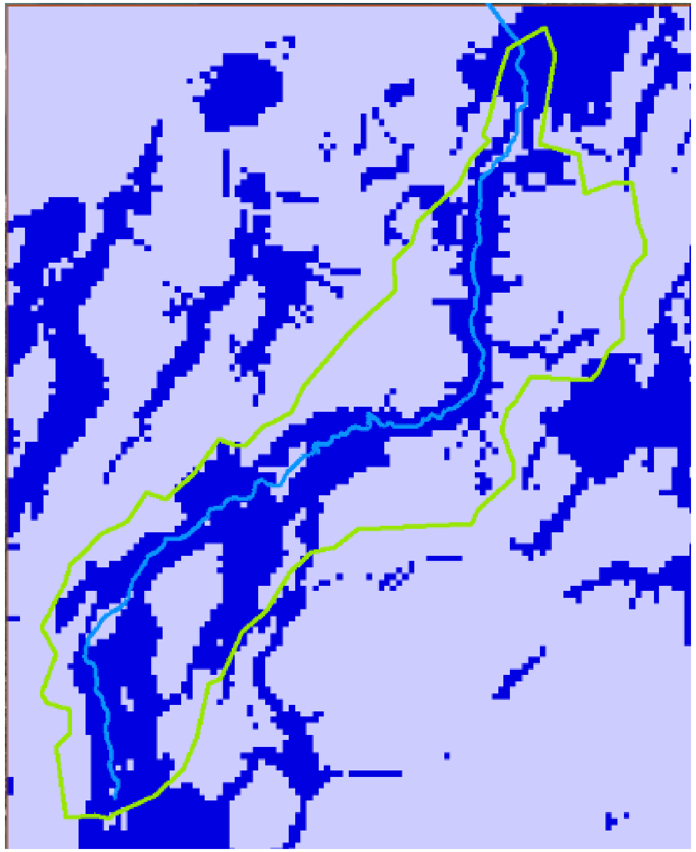
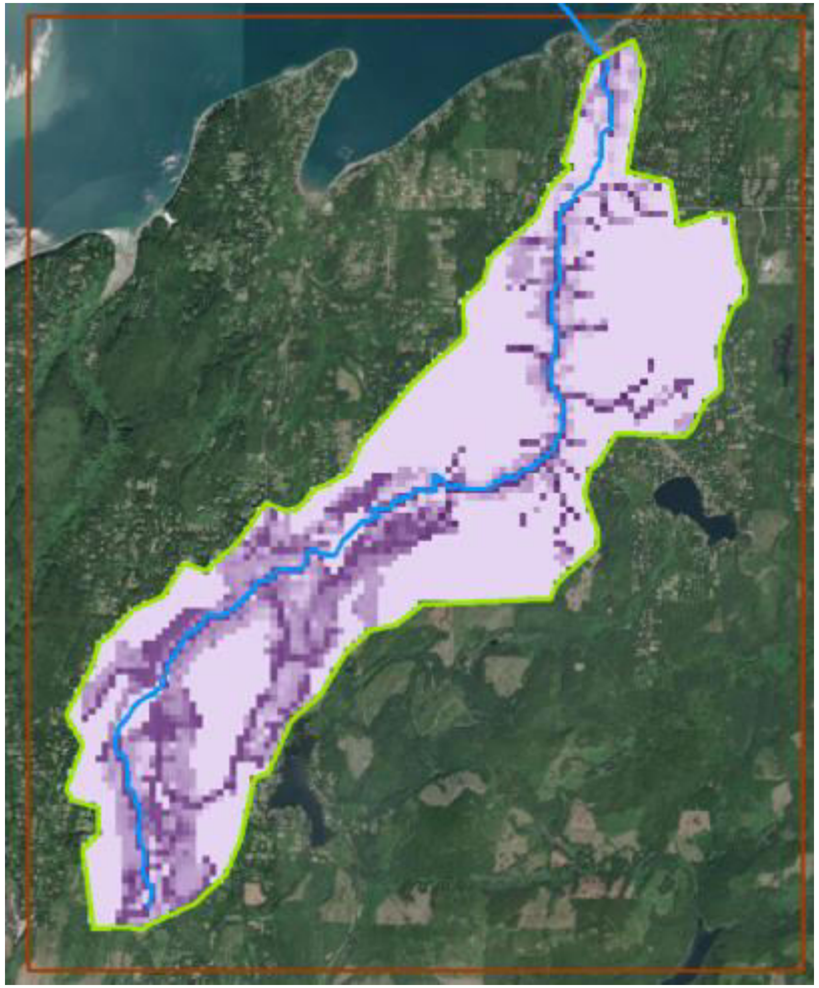
VELMA Recharge – recharge map for 0.04 map

- GroundwaterStorage Fraction Map:
- Set all the areas in previous layer to 0.04:



Run VELMA

VELMA Recharge map for Jan 1, 2005



GBox Behavior – let recharge accumulate to Jan 1, 2000, then….

GBOX Volume estimated from Aquifer data

- Big Beef Creek:
- Estimated at 20,000 mcf**
- Suggests Daily % withdrawal from GBox at 20%

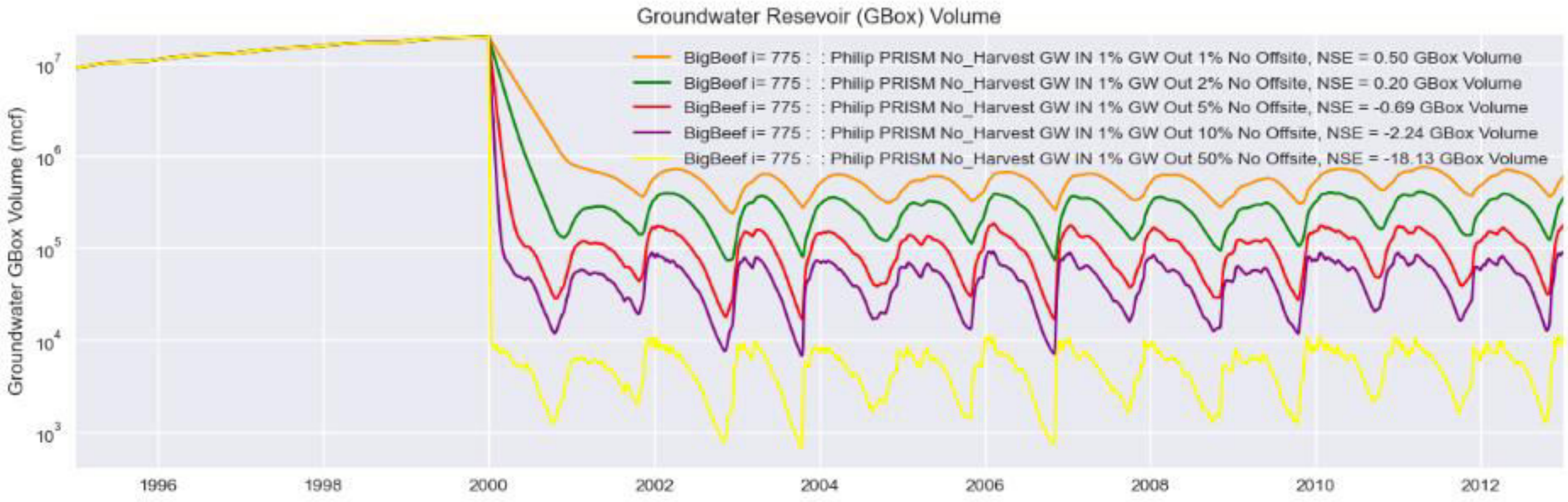
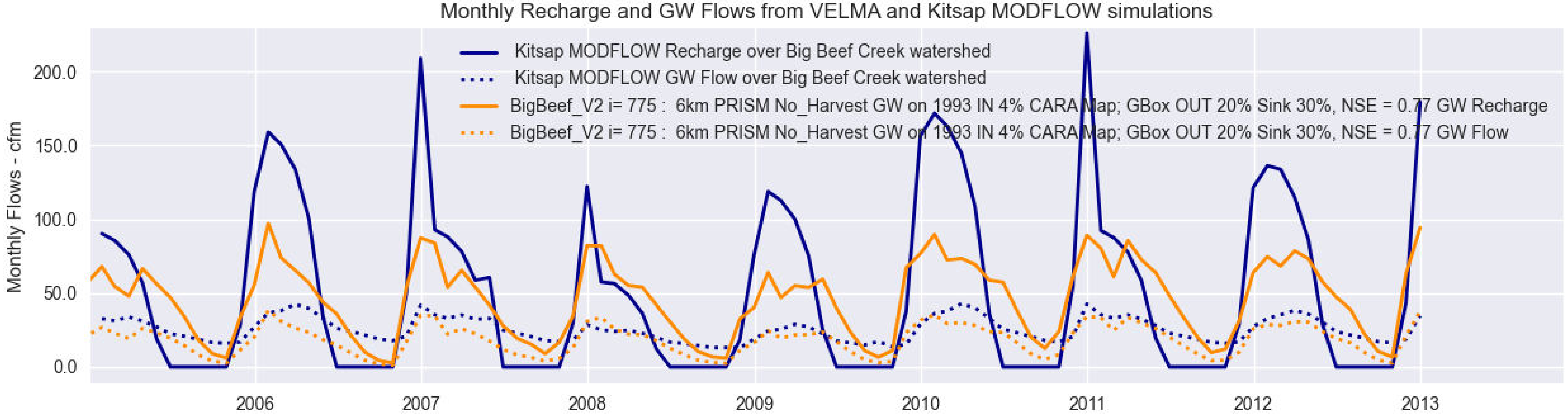


Figure 5B: Log of Volume (in million Cubic Feet) stored in GBOX for BBC VELMA models for different settings of Removed_Fraction in Table 2 above.

** by Joel Massmann

VELMA Groundwater Flow



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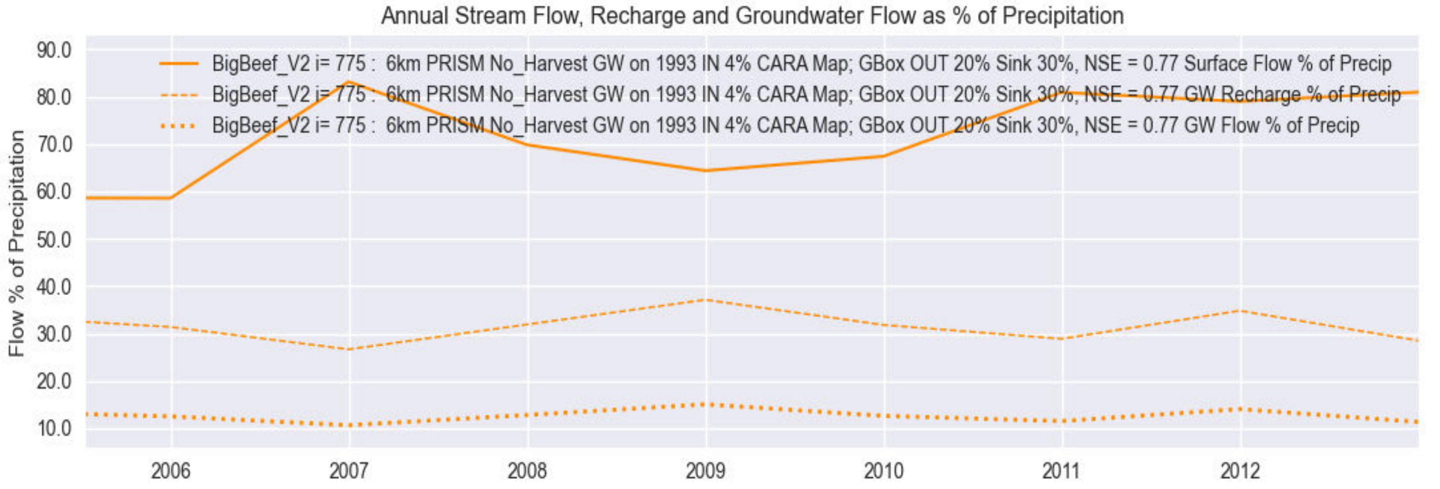

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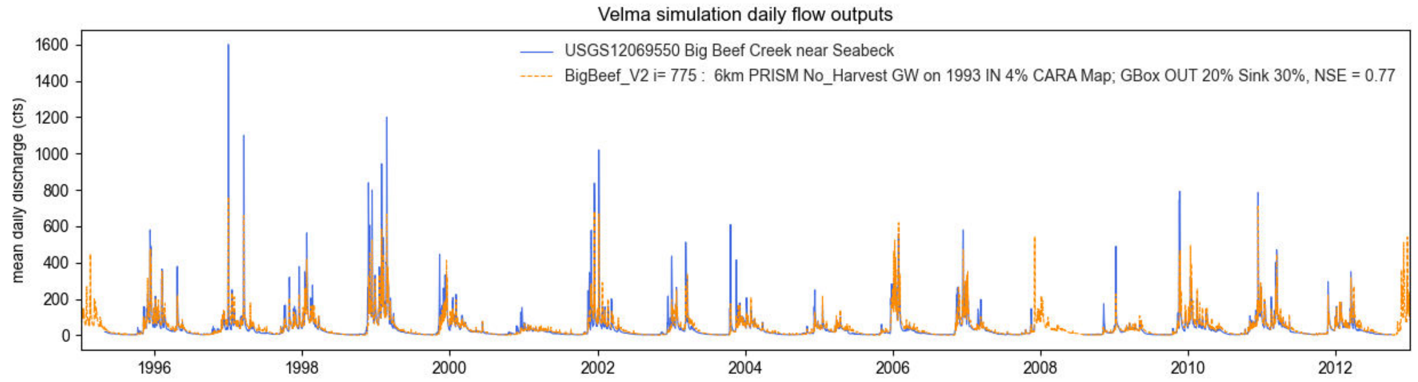
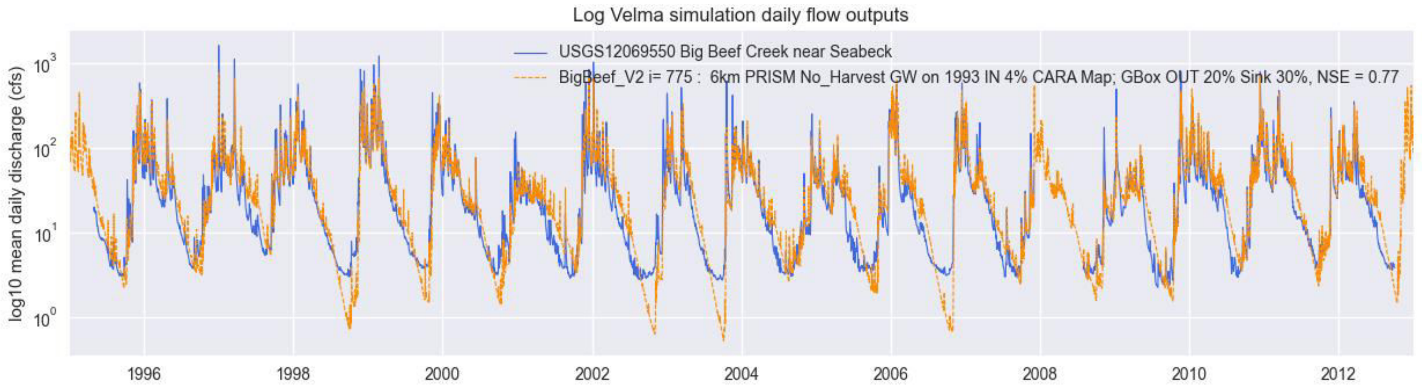
meant to be definitive.

Attained Improvements for VELMA Calibration

- NSC respectable ~~ 0.77
  - (NSE was middling ~~ 0.64)



- Late summer low flows better (high!)
  - (Late summer low flows were too low)



- E/T to Precipitation flows right on
  - (E/T to Precipitation flows were too hi

	LOOP	YEAR	Total_Rair	Total_Obs	Total_Sim	Total_Diffe	Total_Frac	Runoff_Na	Total_PET	Total_AET	Total_(AET	Total_(AET/(Rain+Melt))
7	1	2005	1338.108	600.1811	783.8864	183.7053	1.306083	0.7903104	1315.898	551.1484	0.418838	0.411886
8	1	2006	1754.679	1166.673	1459.216	292.5436	1.25075	0.6919253	1318.315	539.5664	0.409285	0.307502
9	1	2007	1322.818	NaN	932.3368	NaN	NaN	0.4627269	1265.113	525.3566	0.415265	0.39715
0	1	2008	994.4128	NaN	647.3665	NaN	NaN	0.4234034	1228.503	501.2582	0.408024	0.504075
1	1	2009	1393.781	854.2459	923.7369	69.49097	1.081348	0.6979482	1276.004	522.5768	0.409542	0.374935
2	1	2010	1950.075	1164.601	1578.086	413.4851	1.355045	0.7110569	1271.078	542.5885	0.426873	0.27824
3	1	2011	1415.901	961.3006	1118.521	157.22	1.163549	0.8189625	1200.82	497.4943	0.414296	0.351362
4	1	2012	1887.234	NaN	1527.9	NaN	NaN	0.6184713	1258.058	527.9655	0.419667	0.279756

- Accounts for Groundwater Recharge, GW Flow and GW Sink Flow on Kitsap Peninsula
  - Annual Recharge/Precipitation ~~ 34%, GW Flow/Precipitation ~~ 17%

Why VELMA Simulations? Projected Indicators

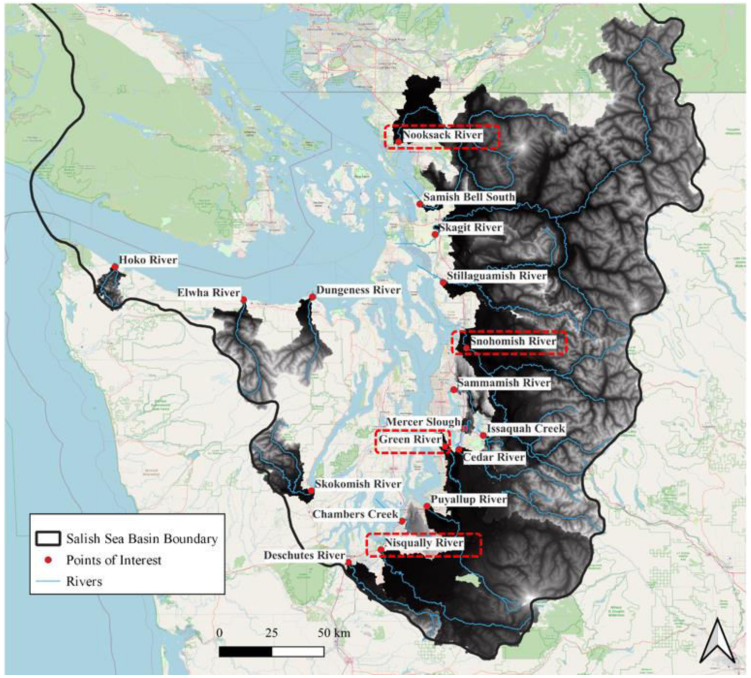
- VELMA can output daily maps of more than 20 variables
  - Air Temperature, Precipitation
  - Recharge, Snow Water Equivalent, Soil Moisture (all or each soil layers),…
  - C and N pools…
- VELMA can out put daily values for more than 100 variables at specified pixels
  - Rain, Snow, Melt, Air Temperature
  - Run Off, E/T, Saturation, GW Storage, Stream Temperature, ….
- Post Analysis can generate many useful indicators and their trends
  - Low Flows, Peak Flows, Max Summer Stream Temperatures, …
  - Maps of growing season, days under snow, frost free days,…

Next Steps for Improved Calibration

- Plan to include in Current Suquamish Project
  - 800m PRISM weather station grid (currently 6km PRISM grid) << EPA
  - MACA weather station data to 2099 << EPA
  - Land Cover: Conifer > Impervious Surfaces + Conifer
  - ~ 10 watersheds on Kitsap Peninsula (Huge Creek, Chico Creek, …)
- Next Suquamish Project
  - 30m DEM (currently 90m)
  - Land Cover – 18 Classes….
  - SOLUS soil types (currently Lowland Loam)
  - Toxicant transportation

Extending Groundwater "Static" Integration to any watershed in the Puget Sound?

- What to do when we don't have the luxury of a MODFLOW model?
  - Recharge/Precipitation ratio (Bidlake & Payne, Soil Water Balance, VELMA)?
  - Groundwater Flow/ Precipitation ratio ← USGS Baseflow Separation Tool



Average Annual Precipitation	Average Annual Recharge	Average Annual Groundwater Flow
1,580 mcf	626 mcf	261 mcf
100%	39%	17%
	100%	42%

Thank you!

- Questions?
- Suggestions?
- Thoughts on where you might use a VELMA model with Groundwater?
- What other terrestrial process models to integrate?
  - Fire?
  - Population Growth?
  - ??

Estimating Recharge from Precipitation

- Kitsap MODFLOW model used Bidlake and Payne
  - Regression equations
  - Soil + land cover pairs
  - No flow, saturation
- Soil Water Balance Models
  - NRCS w saturation
  - No flow
- VELMA

Bidlake & Payne, 2001, Kitsap peninsula

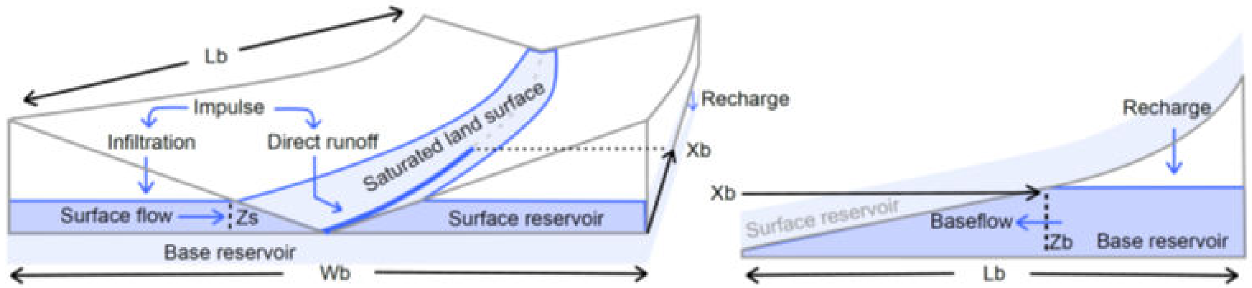
Table 4. Relations for predicting annual recharge to ground water from annual precipitation

Soil and land-cover group	Equation for predicting annual recharge (R, in inches) as a function of annual precipitation (P, in inches)
Nonforest vegetation on soils formed on glacial outwash and other alluvium	$R = 0.806P - 8.87$
Forest vegetation and soils formed on glacial outwash and other alluvium	$R = 0.633P - 6.96$
Forest and nonforest vegetation on soils formed on glacial till or fine-grained sediments	$R = 0.388P - 4.27$
Developed or urban land	$R = 0.194P - 2.13$
Water and wetlands	R assumed to equal 0

These slides describe exploraty work in progress. None are meant to be definitive.

Baseflow separation as a proxy for Groundwater Flow – Chris Konrad

Baseflow Separation Model (BFS)



Oblique view looking upstream from the outlet

Longitudinal section of the stream basin

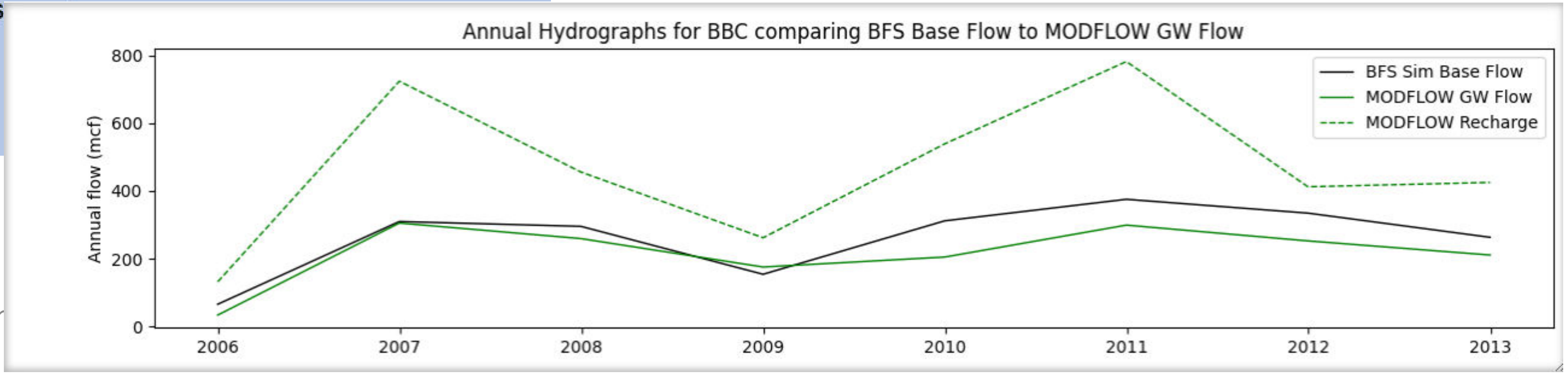
The BFS model is a “state-space” model that represents a stream basin as two storage reservoirs that drain to a stream and simulates streamflow at the outlet of the basin. Streamflow is the sum of three components: direct runoff from the land surface, discharge from the surface reservoir, discharge from the base res

USGS
science for a changing world

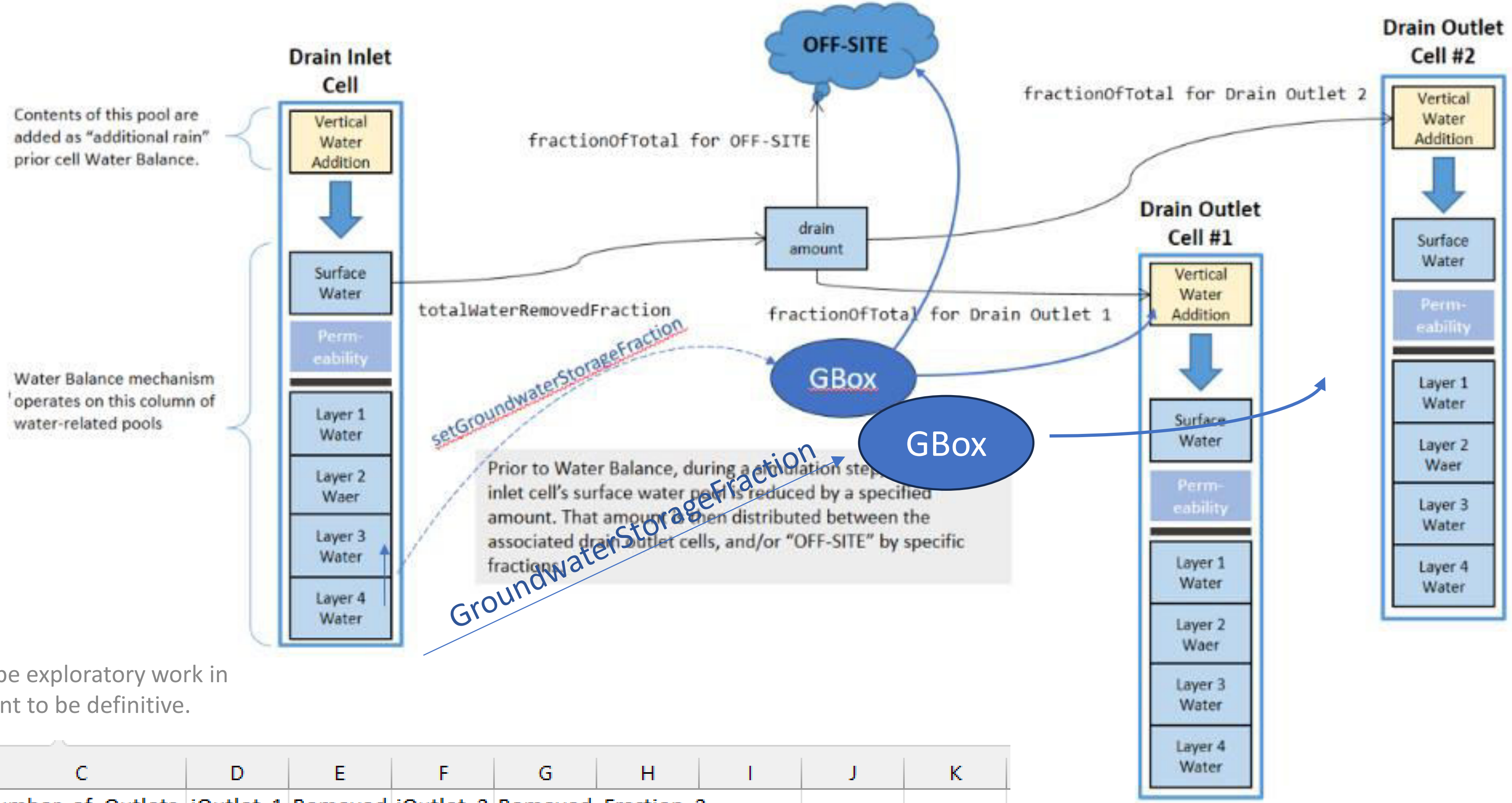
BFS Tool has been calibrated (via Machine Learning) on over 13,000 streams with USGS gages

- Freely downloadable
- Written in R language

Th



Adding GW Flow to VELMA – Oct 2023 v2.2



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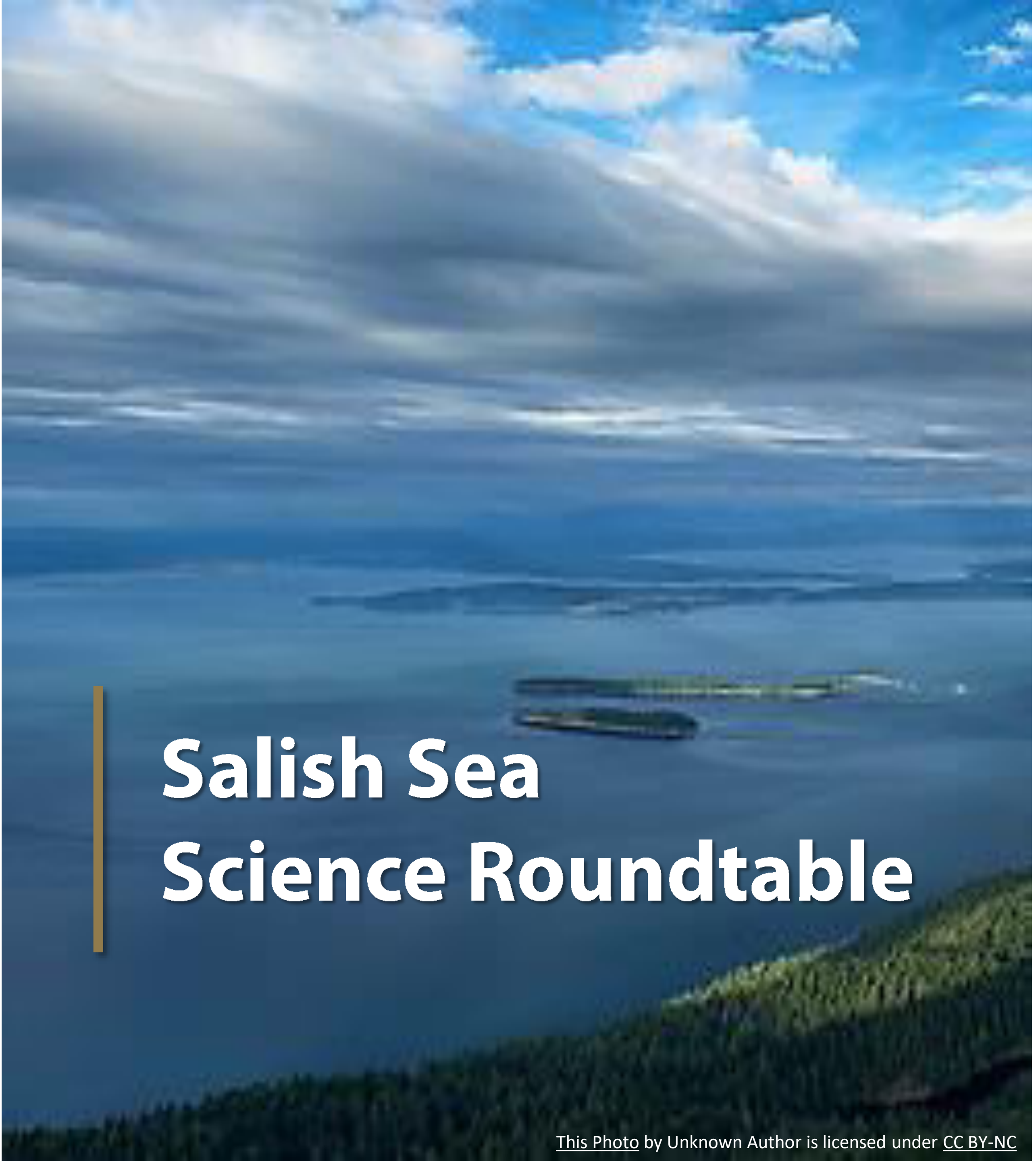
	A	B	C	D	E	F	G	H	I	J	K
1	iInlet	Removed_	Number_of_Outlets	iOutlet_1	Removed_	iOutlet_2	Removed_Fraction_2				
2	GBOX	0.01	4	1688	0.25	2612	0.25	4032	0.25	4343	0.25
3	GBOX	0.01	1	-1	1						
4	3235	1	1	2612	1						
5	GBOX	0.01	1	3235	1						



Salish Sea Science Roundtable

Tuesday, May 7

eDNA in the Salish Sea

Ryan Kelly, Director of the eDNA Collaborative

12:30 – 1:30 pm on Zoom

Subscribe to UW Puget Sound Institute's listserv to receive updates on future Salish Sea Science Roundtables

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