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
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
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

What’s the problem today?
Start where you’re at – your locale
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

Deciders – What future do we want?
How do we meet the needs of humans and the ecosystems we depend on?
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Principles, Values, and Leadership
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Process and Change Models

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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

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
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

#### Decision Context
- Science, Indicators, Trends & Solutions
- Policy and Planning

#### 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

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### CHANGE IN INDICATORS from ACTIONS SIMULATED for EVERY YEAR THROUGH 2099

- **Importance of Change in Indicators – Tradeoffs Between Strategies**
- Portfolios and Funded 5-Year Project Plans

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### IMPLEMENTATION & MONITORING

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Hashisaki 4-2-24
<table>
<thead>
<tr>
<th>Decision Context</th>
<th>Agreement on Baseline Conditions as described by Data, Models, Indicators, and Change Drivers</th>
</tr>
</thead>
</table>
| Science, Indicators Trends & Solutions | LAND-BASED SECTORS LEADERSHIP AND STAKEHOLDERS  
Community Values & Guiding Principles  
Mandates, Targets, Budgets, X-sector Connections, & Scenarios |
| Strategy/Types of Action | Strategy/Types of Action | Strategy/Types of Action |
| ECOSYSTEM targets & indicators for fish | DEVELOPMENT targets & indicators for housing | AGRICULTURE targets and indicators |
| E1 | D1 | A1 |
| E2 | D2 | A2 |
| E3 | D3 | 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
Compare 2099 Projected Conditions with Actual 2099 Conditions described by Monitoring Data: Update Assumptions, Models and Indicators, New Problem Identification

Decision Context

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

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

CHANGE IN INDICATORS from ACTIONS SIMULATED for 2099

IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BTWN STRATEGIES

UPDATED PORTFOLIOS
FUNDED 5-YEAR PROJECT PLANS

Policy and planning

Hashisaki 4-2-24
DEVELOPMENT targets & indicators for housing
ECOSYSTEM targets & indicators for fish
AGRICULTURE targets and indicators

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

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

CHANGE IN INDICATORS from ACTIONS SIMULATED for 2030
IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BTWN STRATEGIES
UPDATED PORTFOLIOS / FUNDED 5-YEAR PROJECT PLANS

IMPLEMENTATION & CONTINUED MONITORING

Science, Indicators Trends & Solutions
Decision Context
Policy and Planning
Operations

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

Decision
Context

2030

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ECOSYSTEM PROTECTION & RECOVERY
Guiding Principles
Mandates, Targets, Budgets, Integrated Process Modeling

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

Streamflow targets & indicators for fish
Riparian Buffers
GW Recharge
Land Use targets & indicators for housing/infrastructure
Zoning
Devel. standards
Biomass targets & indicators for vegetation
Harvest
Fire
Thin’g

Change in indicators from Actions Simulated for every year through 2099
late summer low flows, peak flows, recharge, impervious surfaces, soil moisture

Simulation/Process Models: Surface water, Groundwater recharge, Land use, ....

IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFF BETWEEN STRATEGIES

EXPERIMENTAL PORTFOLIOS OF RIPARIAN BUFFER PROJECTS & ALTERNATIVE ZONING

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

ECOSYSTEM targets & indicators for fish
- E1
- E2
- E3

DEVELOPMENT targets & indicators for housing
- D1
- D2
- D3

AGRICULTURE targets and indicators
- A1
- A2
- A3

CHANGE IN INDICATORS from ACTIONS SIMULATED for EVERY YEAR THROUGH 2099

IMPORTANCE OF CHANGE IN INDICATORS – TRADEOFFS BETWEEN STRATEGIES

PORTFOLIOS AND FUNDED 5-YEAR PROJECT PLANS

IMPLEMENTATION & MONITORING
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

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

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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

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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

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VELMA Intro

VELMA Ecohydrological Model

Visualizing Ecosystem Land Management Assessments

Drivers of change
- Climate
- Land cover
- Land use (ag, forest, urban...)
- Nutrients & contaminants
- Fire

Modeled Ecosystem Goods & Services

- Water quality regulation (nutrients, contaminants, temperature)
- Water quantity regulation (peak & low flows, landscape aridity)
- Habitat for fisheries (spawning, rearing)
- Soil fertility & plant growth (biomass for food, fiber)
- Fuel load dynamics (fire risk, potential severity)
- Carbon sequestration (Greenhouse gas dynamics)

meant to be definitive.
Core Annual Water Balance

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

• Precipitation = Evapo-transpiration (E/T)
  + RunOff  \(\ll\) measured by stream gage
  + Groundwater Recharge \(\ll\) [Groundwater Flow, Groundwater Sink]
  + Snow sublimation ......
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

<table>
<thead>
<tr>
<th>petParam2</th>
<th>NSE</th>
<th>Annual Accumulated Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.622 (Default)</td>
<td>0.64 Sim/Obs</td>
<td></td>
</tr>
<tr>
<td>0.467 (75%)</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>0.311 (50%)</td>
<td>0.79</td>
<td></td>
</tr>
</tbody>
</table>
Issues with current VELMA Calibration

• NSC is middling \( \approx 0.64 \)
  • (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

• There is Recharge, GW Flow and GW Sink Flow on Kitsap Peninsula
  • Annual Recharge/Precipitation \( \approx 30\% \), GW Flow/Precipitation \( \approx 19\% \)
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
USGS Kitsap MODLOW Model - 2016


  • 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

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• 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.
While all 1316 cells contribute to Recharge, only 100 cells have Groundwater Flow from the aquifer.
These slides describe exploratory work in progress. None are meant to be definitive.
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MODFLOW Monthly Totals (mcf) for Big Beef Creek 2005-2012

- GW_Recharge
- GW_Flow
VELMA 2.2: Gbox and GW Flow to Single pixel

Every Pixel

GW Flow

Off-Site

GW Sink

Pour Point pixel

Vertical Water Addition
Surface Water
Permeability
Layer 1 Water
Layer 2 Water
Layer 3 Water
Layer 4 Water

GBox

Recharge

Removed_Fraction

Removed_Fraction_1

Removed_Fraction_2
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).

These slides describe exploratory work in progress. None are meant to be definitive.
VELMA Recharge – recharge map for 0.04 map

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

These slides describe exploratory work in progress. None are meant to be definitive.
GBox Behavior – let recharge accumulate to Jan 1, 2000, then....

These slides describe exploratory work in progress. None are meant to be definitive.
GBOX Volume estimated from Aquifer data

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

** by Joel Massmann

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.

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**Average Annual Precipitation**: 1,580 mcf
**Average Annual Recharge**: 626 mcf
**Average Annual Groundwater Flow**: 261 mcf
Attained Improvements for VELMA Calibration

• NSC respectable  \( \approx 0.77 \)
  • (NSE was middling  \( \approx 0.64 \))

• 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 high)

• Accounts for Groundwater Recharge, GW Flow and GW Sink Flow on Kitsap Peninsula
  • Annual Recharge/Precipitation  \( \approx 34\% \), GW Flow/Precipitation  \( \approx 17\% \)
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 output 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,...

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

<table>
<thead>
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<th>Average Annual Precipitation</th>
<th>Average Annual Recharge</th>
<th>Average Annual Groundwater Flow</th>
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</thead>
<tbody>
<tr>
<td>1,580 mcf</td>
<td>626 mcf</td>
<td>261 mcf</td>
</tr>
<tr>
<td>100%</td>
<td>39%</td>
<td>17%</td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td>42%</td>
</tr>
</tbody>
</table>
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?
  • ??

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

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Baseflow separation as a proxy for Groundwater Flow – Chris Konrad

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 reservoir.

BFS Tool has been calibrated (via Machine Learning) on over 13,000 streams with USGS gages
- Freely downloadable
- Written in R language
These slides describe exploratory work in progress. None are meant to be definitive.
Salish Sea Science Roundtable

eDNA in the Salish Sea
Ryan Kelly, Director of the eDNA Collaborative
12:30 – 1:30 pm on Zoom

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