Puget Sound Ecosystem Portfolio Model

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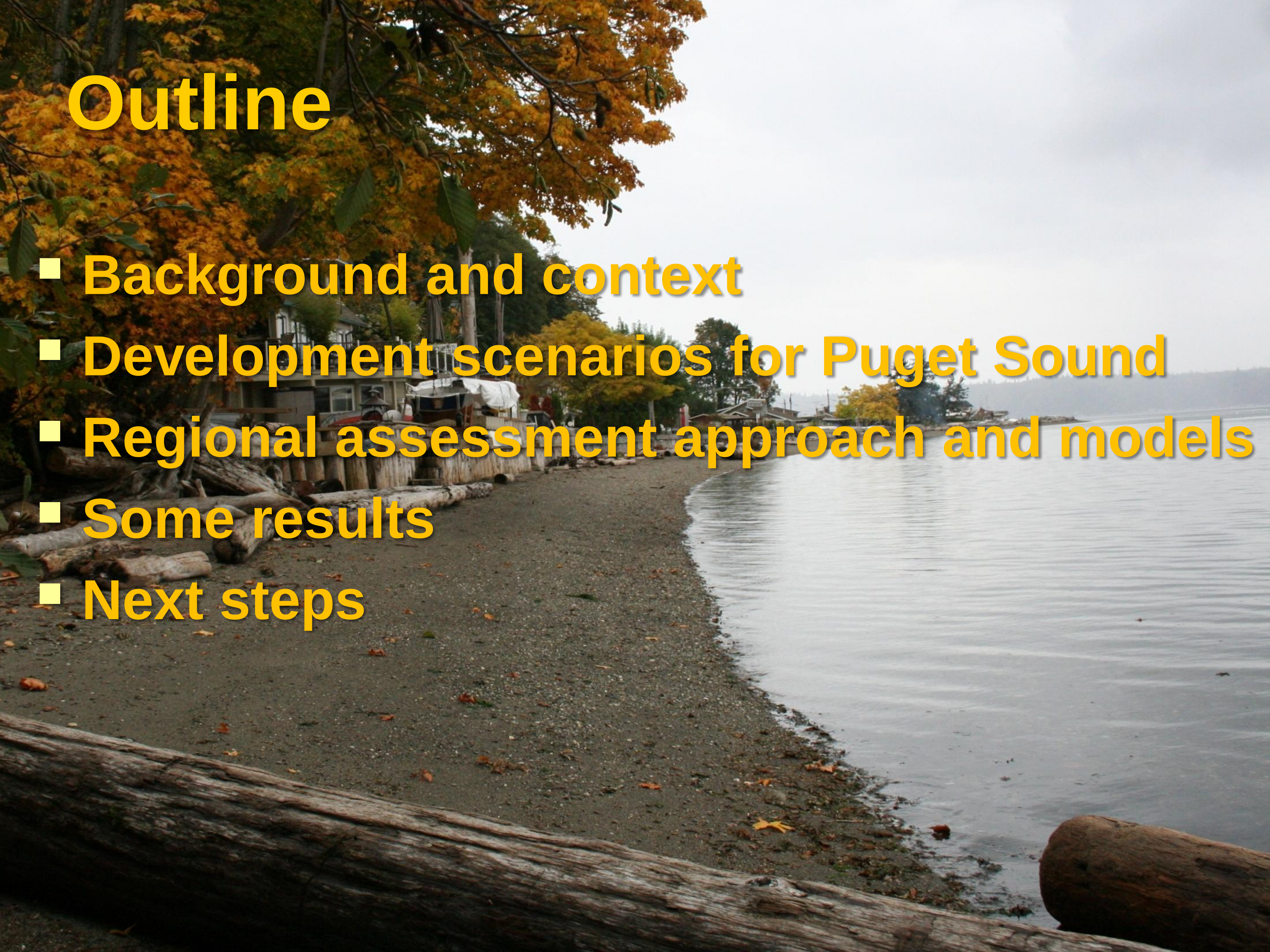


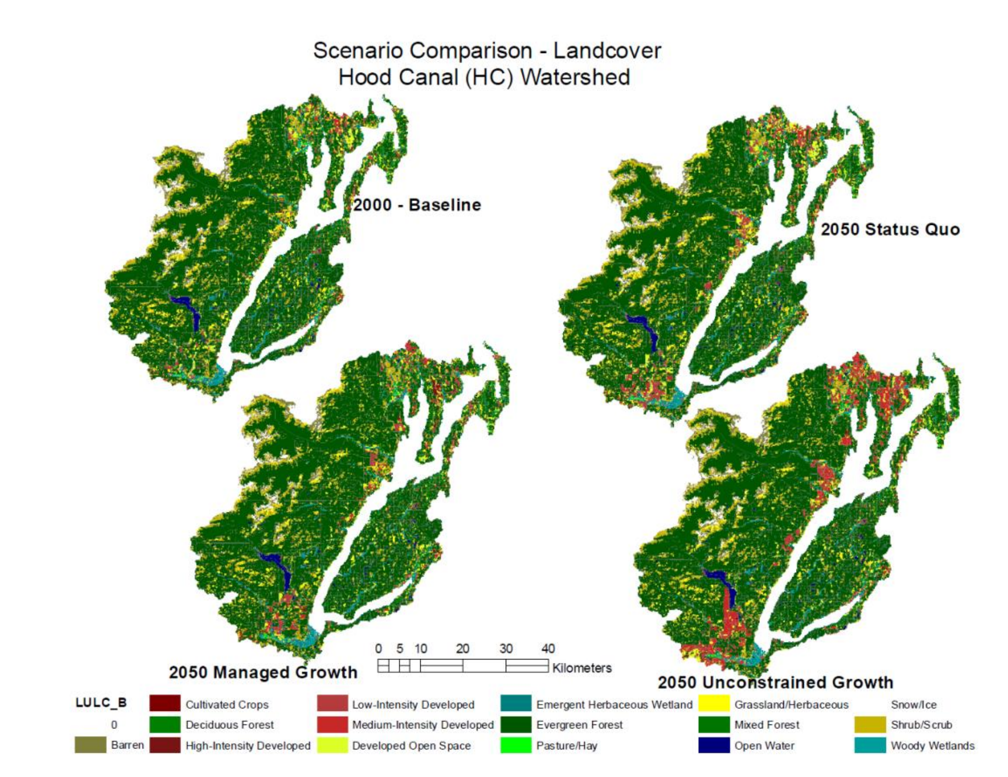
Outline

- Background and context
- Development scenarios for Puget Sound
- Regional assessment approach and models
- Some results
- Next steps

The Puget Sound Ecosystem Portfolio Model:
A Regional Tool for Supporting Ecological Restoration Planning

- Land-use/nearshore scenario evaluation
- Comprised of set of spatially explicit model-based metrics for relating land-use/ nearshore change to changes in human well-being
- PS EPM to be used by PSNERP for its General Investigation; other users and uses…

Hood Canal 2000 - 2050



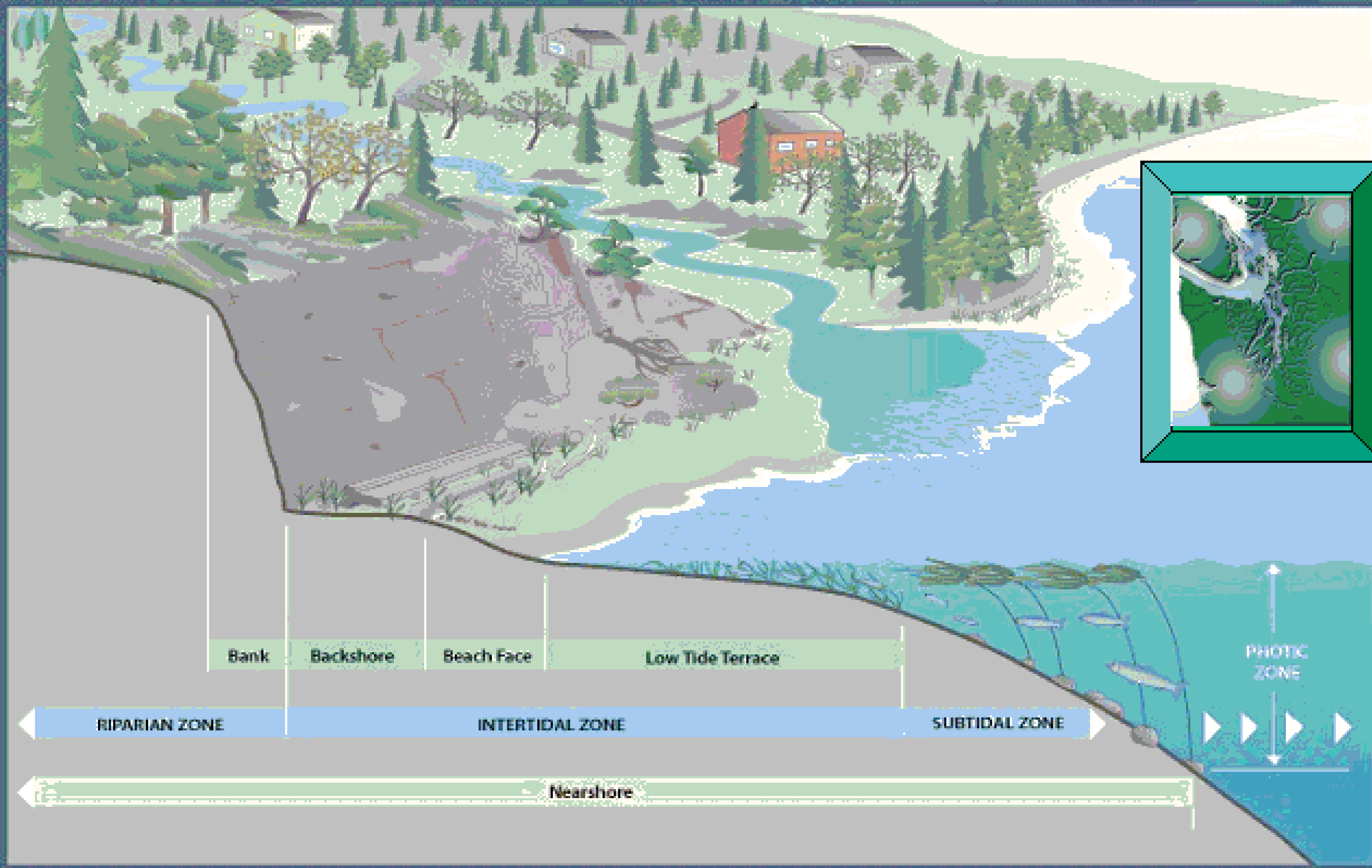
Puget Sound Nearshore Ecosystem Restoration Project

US Army Corps of Engineers®

Washington Department of FISH and WILDLIFE

Mission

Restore nearshore habitat of Puget Sound for the benefit of the biological resources and the integrity of the ecosystem, including the functions and natural processes of the basin.



Puget Sound Nearshore Project

Graphic courtesy of King County

Project Phases

- Reconnaissance Study
- General Investigation (Feasibility)
- Preliminary Engineering and Design
- Construction (General)
- Operations, Maintenance and Monitoring

PSNERP Analysis

- **Past – current “Change Analysis”:**
  what has changed in nearshore since 1850s?
- **Future development scenarios: land-use change and nearshore modifications**
  what might change in next 40 – 50 years?
- **Model-based evaluation of scenarios: EPM**
  what do changes mean?

PSNERP Change Analysis

PSNERP Change Analysis

- Geodatabase developed for reconstructed 1850s maps and layers and “current” (2000) maps and layers
- Major data:
  - Shoreforms (Shorezone database)
  - Nearshore modifications and buffer zones (many data sources/lots of data cleanup)
  - Landcover (Landsat, C-CAP, PRISM)
  - Elevation and bathymetry (PRISM, Finlayson)

PSNERP alternative development futures for Puget Sound

Three scenarios

- **Status Quo/Plan Trend** – use Puget Sound Action Agenda, Puget Sound Regional Council Vision 2040, current trends, existing plan elements for growth, nearshore modifications, moderate restoration/conservation emphasis
- **Managed Growth** – compact growth pattern, reduced placement, impact of nearshore modifications, aggressive restoration/conservation policies.
- **Unconstrained Growth**– less restrictive development pattern and nearshore modification policies, limited conservation orientation

Development scenarios vs. predicted development

- Scenarios are not predictions
  - Plausible
  - Divergent
  - Useful, meaningful
- Development/environmental protection policies are the major drivers of interest
- Major limitation: climate change impacts/sea level rise ignored (future work)

ENVISION scenario generation

EPM

Landscape Evaluation Models

Metrics relevant to changes in regional Human Well-Being

Multiagent Decision-making

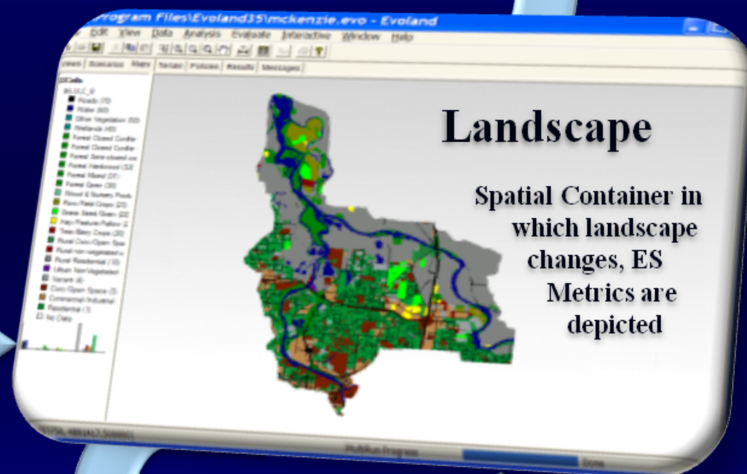
Select policies and generate land management decision affecting landscape pattern

Landscape Feedbacks

Actors

Decision-makers managing the landscape by selecting policies responsive to their objectives

Scenario Definition



Policies

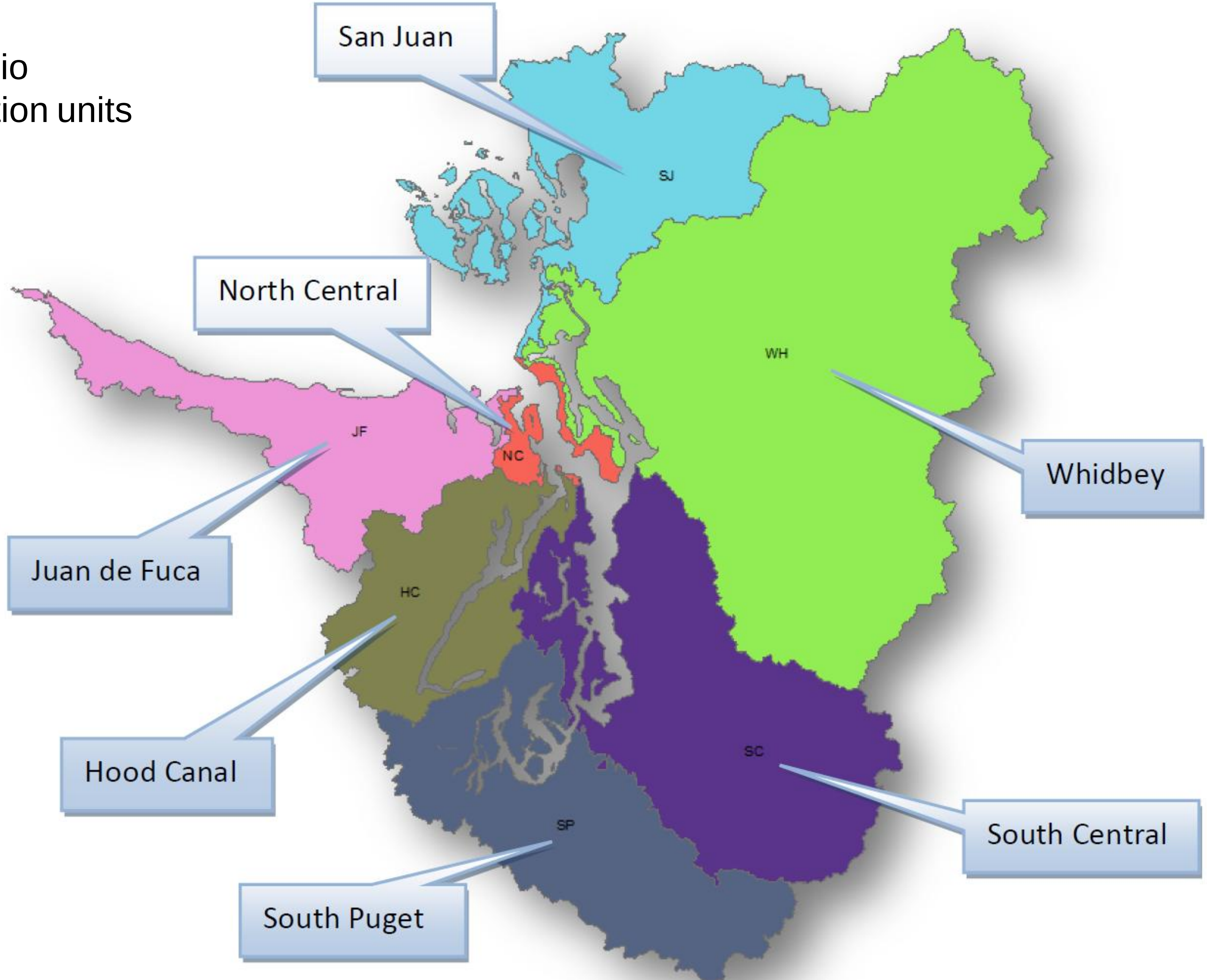
Fundamental Descriptors of constraints and actions defining land use management decisionmaking

Autonomous Change Processes

Models of Non-anthropogenic Landscape Change

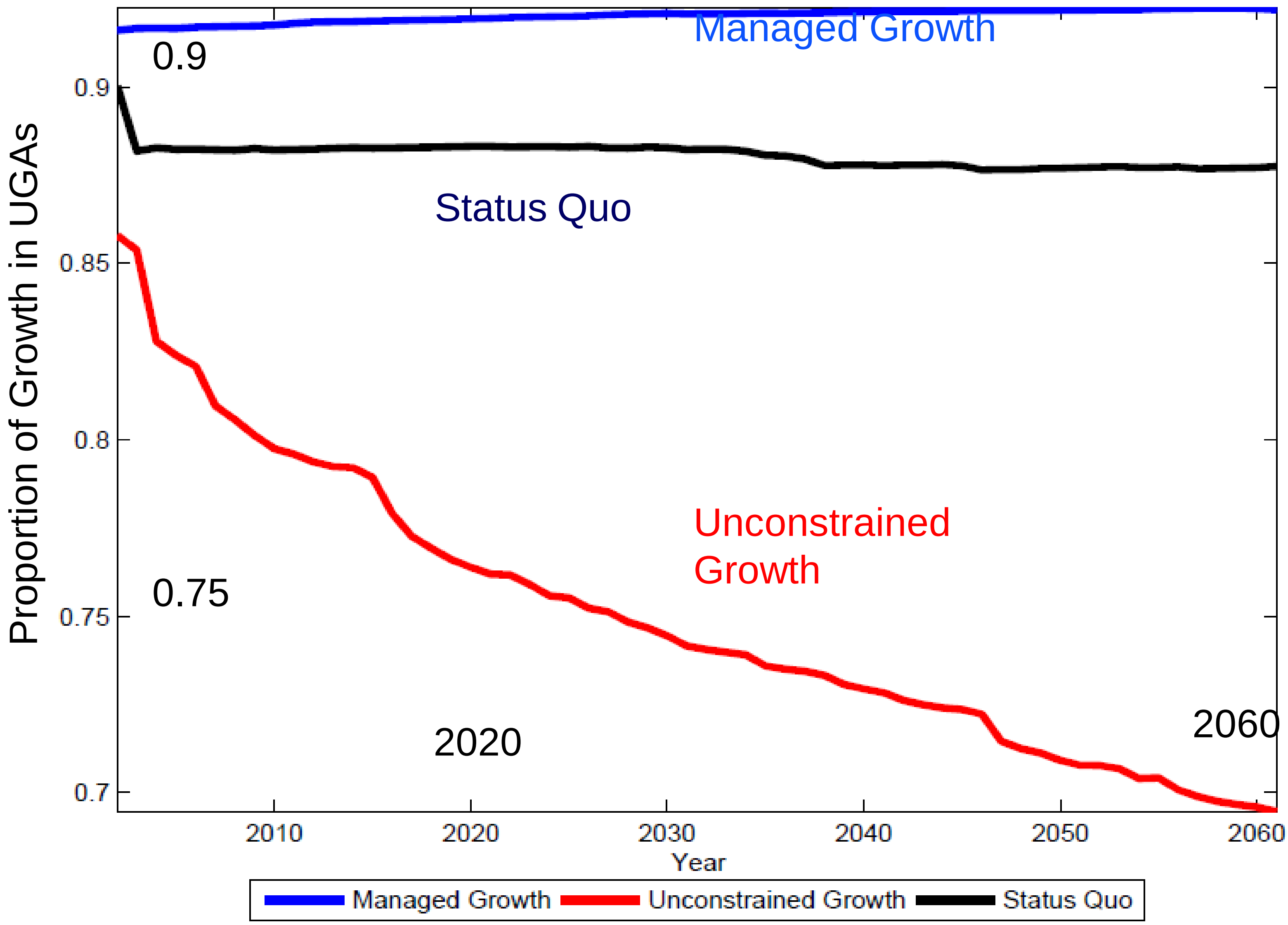
John Bolte - Oregon State University

Scenario simulation units



PSNERP Final Report, Bolte et al.

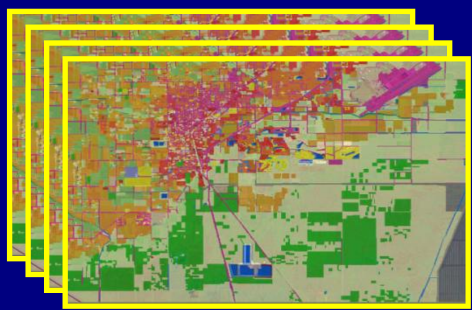
South Puget Sound scenarios



EPM evaluation metrics and models

Puget Sound EPM

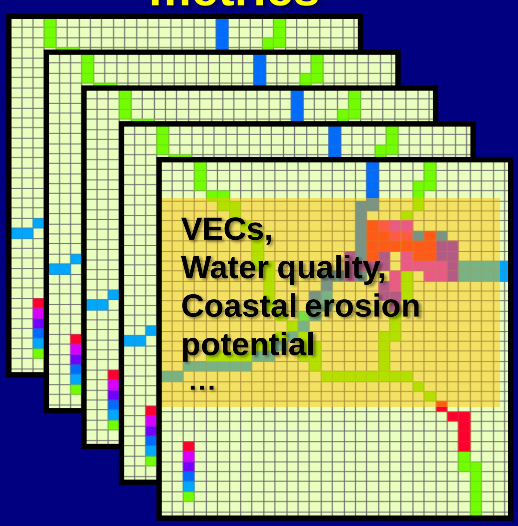
1. Multiple development scenarios considered



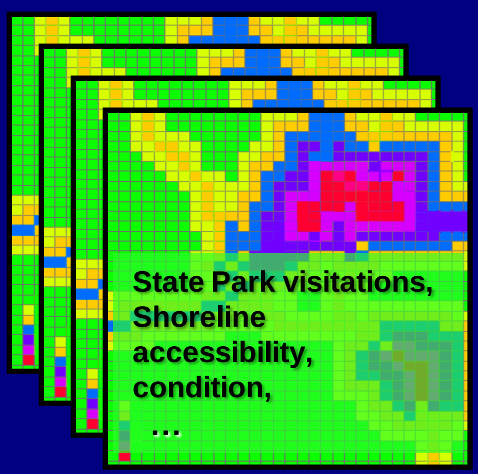
Land-use/nearshore change

2. Scenarios evaluated against multiple metrics

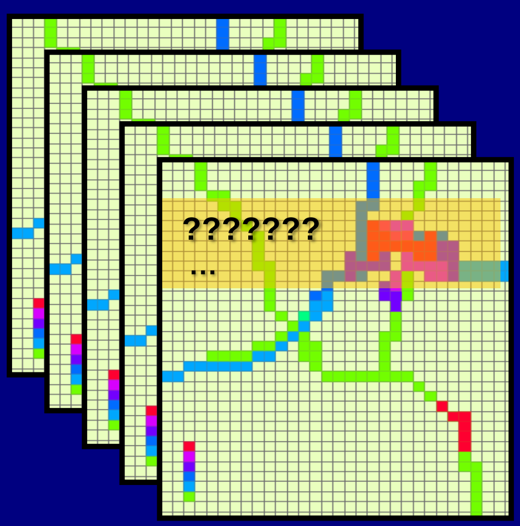
Nearshore condition metrics



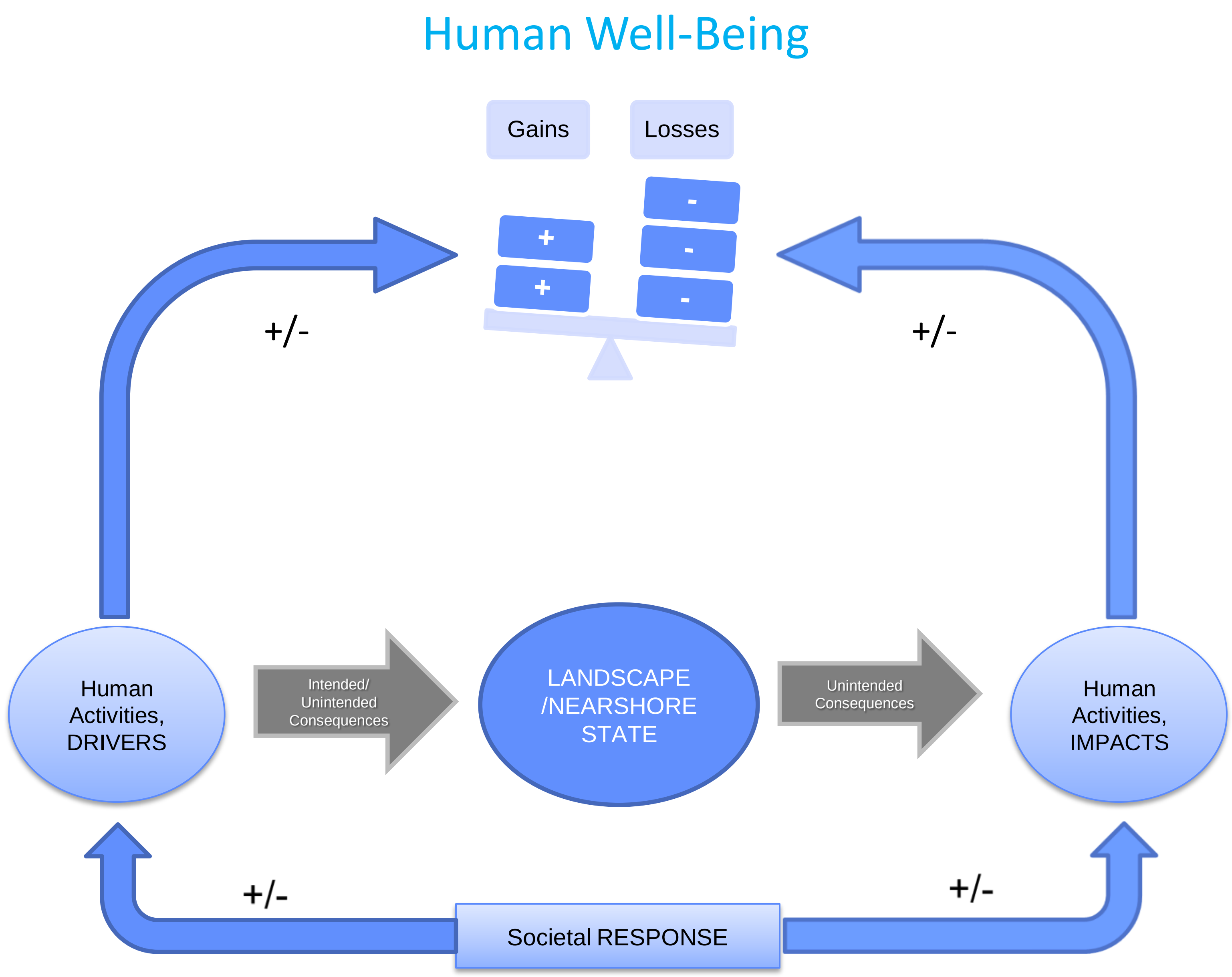
Recreation metrics



Water, Economy, …….??



DPSIR view of Human Well-Being



Modified from Schneidler and Plummer, HWB Indicators, PSP Report, 2009

Choosing metrics

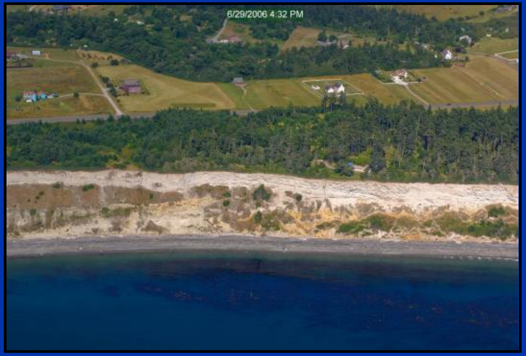
- Puget Sound Partnership indicators development
- Puget Sound/Georgia Basin Human Dimensions Forum
- Workshop held at the University of Washington last April
  - Participants: PSNERP, PSP, NST, consultants
  - Whose values?
- Metric modeling workshops and meetings
  - Eelgrass habitat suitability workshop in April
  - Forage fish spawning workshop in August
  - Beach erosion index workshop in October
- Very ambitious project goals, limited resources
  - The best we can do this year
  - Additional HWB criteria/metrics/measures in future work

PSEPM metrics, Phase 1

EPM Criteria	Related to VEC or Ecosystem Service	Model
Eelgrass habitat suitability	Biodiversity; habitat, provisioning of food	Controlling Factors Model (PNNL, R. Thom)
Forage fish spawning potential	Relevant to provisioning of food, food web support, iconic species	WDFW data and modeling collaboration between WDFW and USGS
Fecal pathogen index, Shellfish growing area closures	Provisioning of food; recreation	Statistical model based on data from WA Depts of Ecology; Health
Beach erosion index	Erosion control; beach condition; recreation	Index; PSNERP data
Nearshore recreational visits	Recreation; tourism	Statistical model based on data from WA State Parks
Nutrient loadings to nearshore	Beach condition (eutrophication, ulval algae, …), DO, etc.	USGS SPARROW model for nutrients (Wise et al.)

USGS

The Land-Water-Human Connection
An example: Bluff-backed Beaches



Scenarios of shoreline modifications/ Land use change

- **Beach geomorphology changes/ Changes in erosion potential**
  - Recreational beach use
  - Forage fish habitat
  - Shoreline stability/ Landslide risk
- **Beach water quality changes/ Increased pathogen concentrations**
  - Recreational beach use
  - Commercial/Tribal shellfish harvest

Nearshore recreational visits

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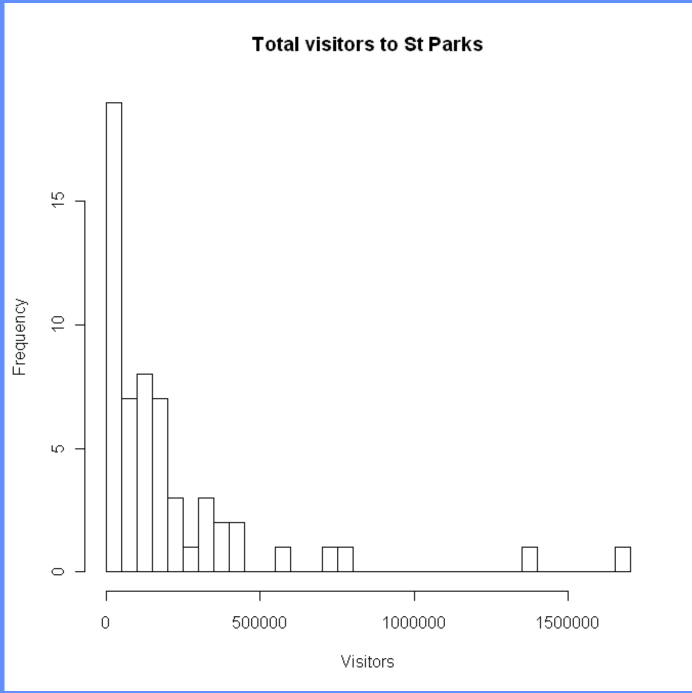
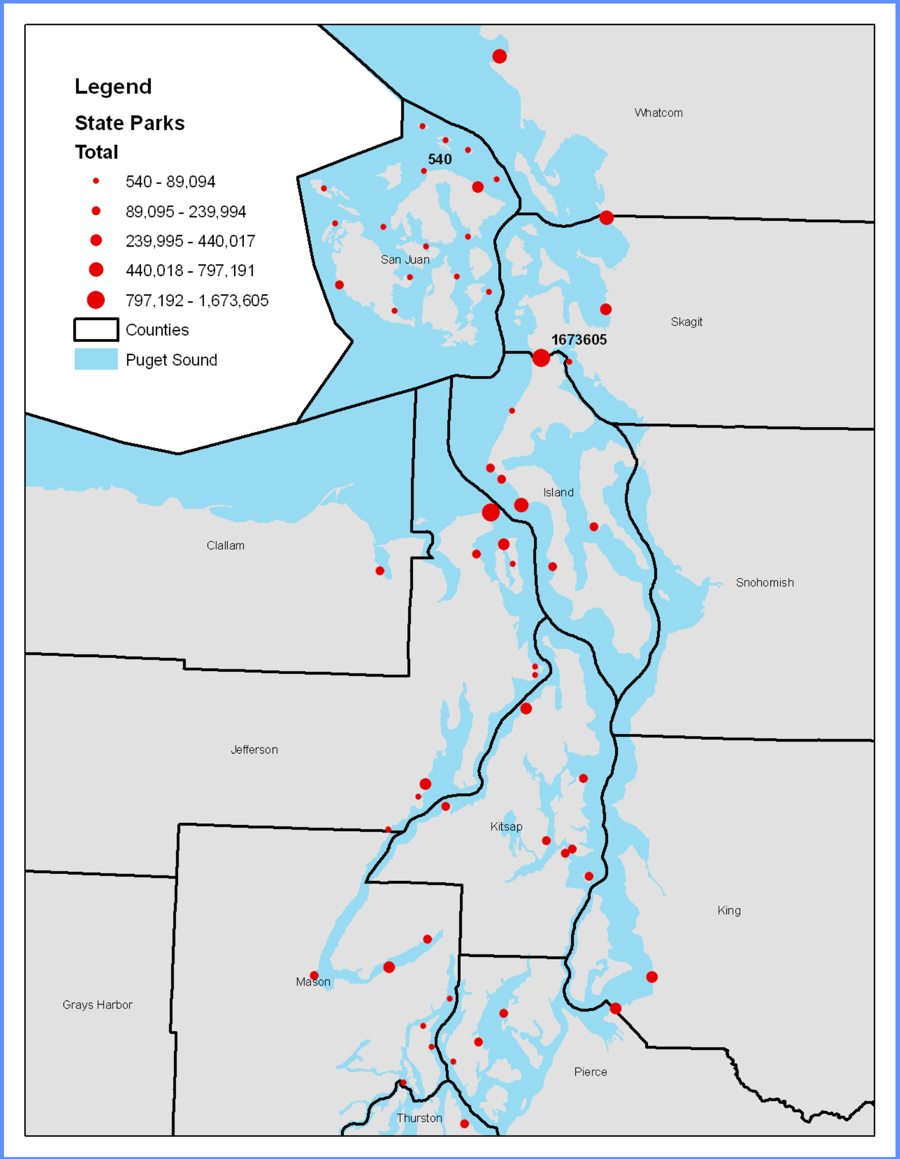
State Park recreational visits

- How does recreation change with development?
- What direction and where?
- How important is the future land use pattern?
- The PS EPM recreation model attempts to:
  - determine the factors responsible for current patterns of coastal recreational use
  - forecast how changes in population and land use may affect annual visitation rate

Visitation to PS State Parks

- 540 / 200,000 / 1.6 million (Min / mean / max)
- 11.7 million in 2008 for coastal parks or ~ 3 per capita



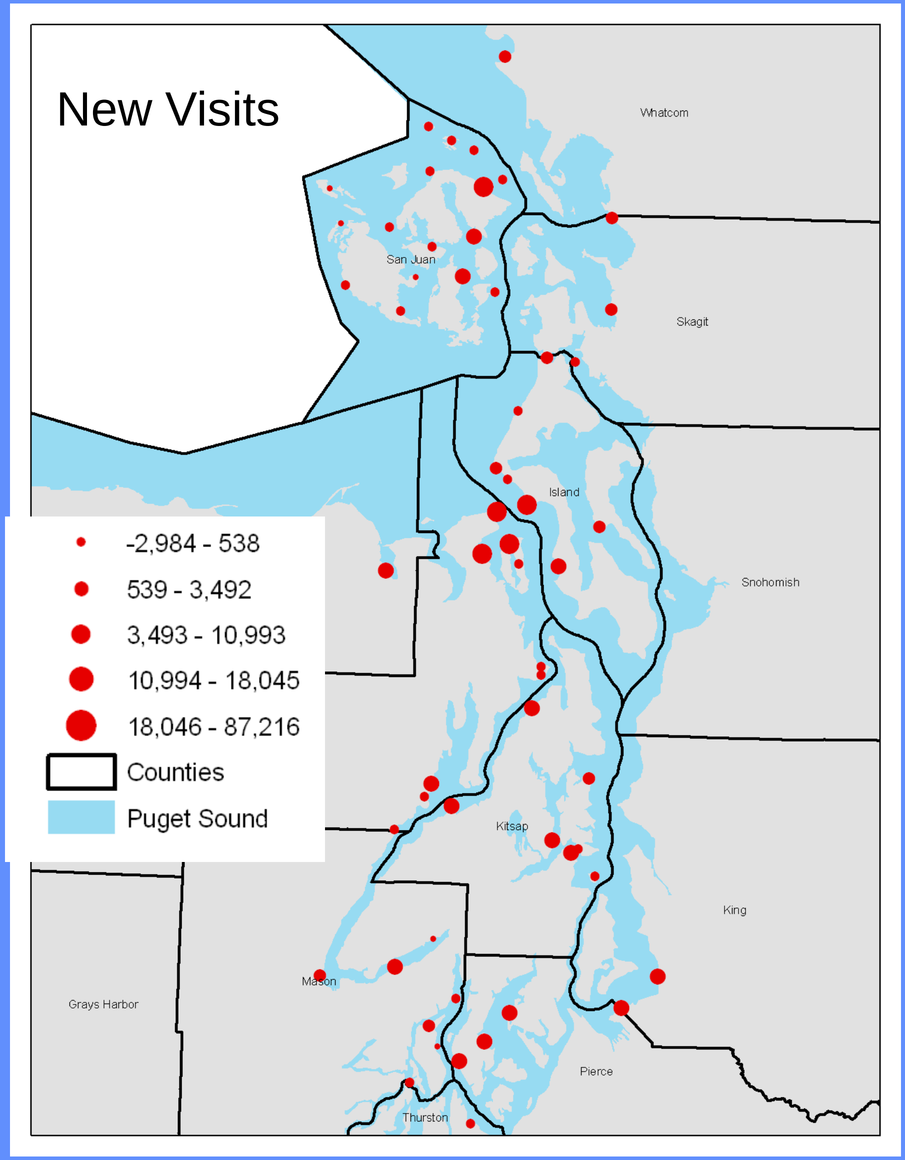


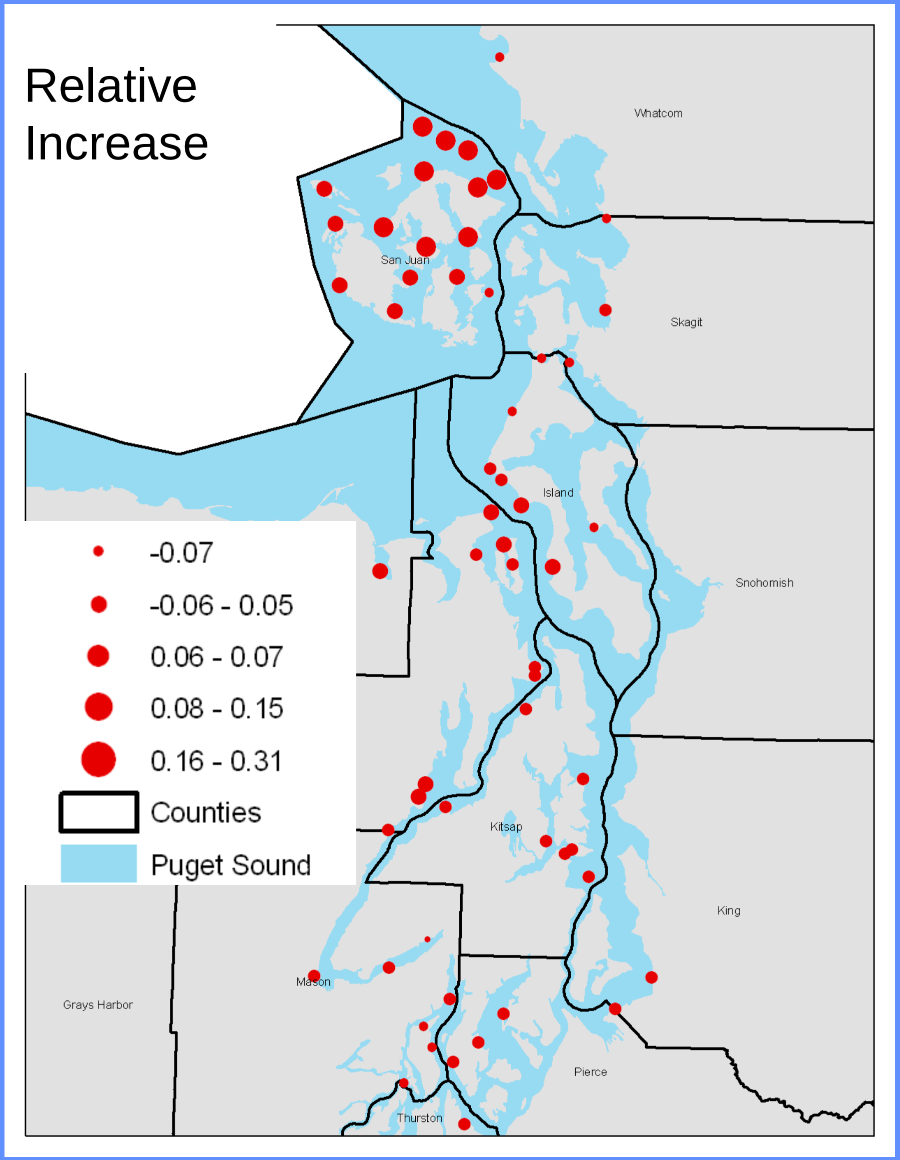
Recreation Visitation Model

- Visitation rate ~ condition, demand, and access
  - Condition: env quality, park characteristics and amenities
  - Demand: # of people nearby
  - Access: travel cost and legal access

  - Other variables: shell fishing effort, beach/fishing warnings & closures, shore length, park acres, sandy substrate, ferry access, travel distance.

Forecasted future visitation: Example Managed Growth now and 2060



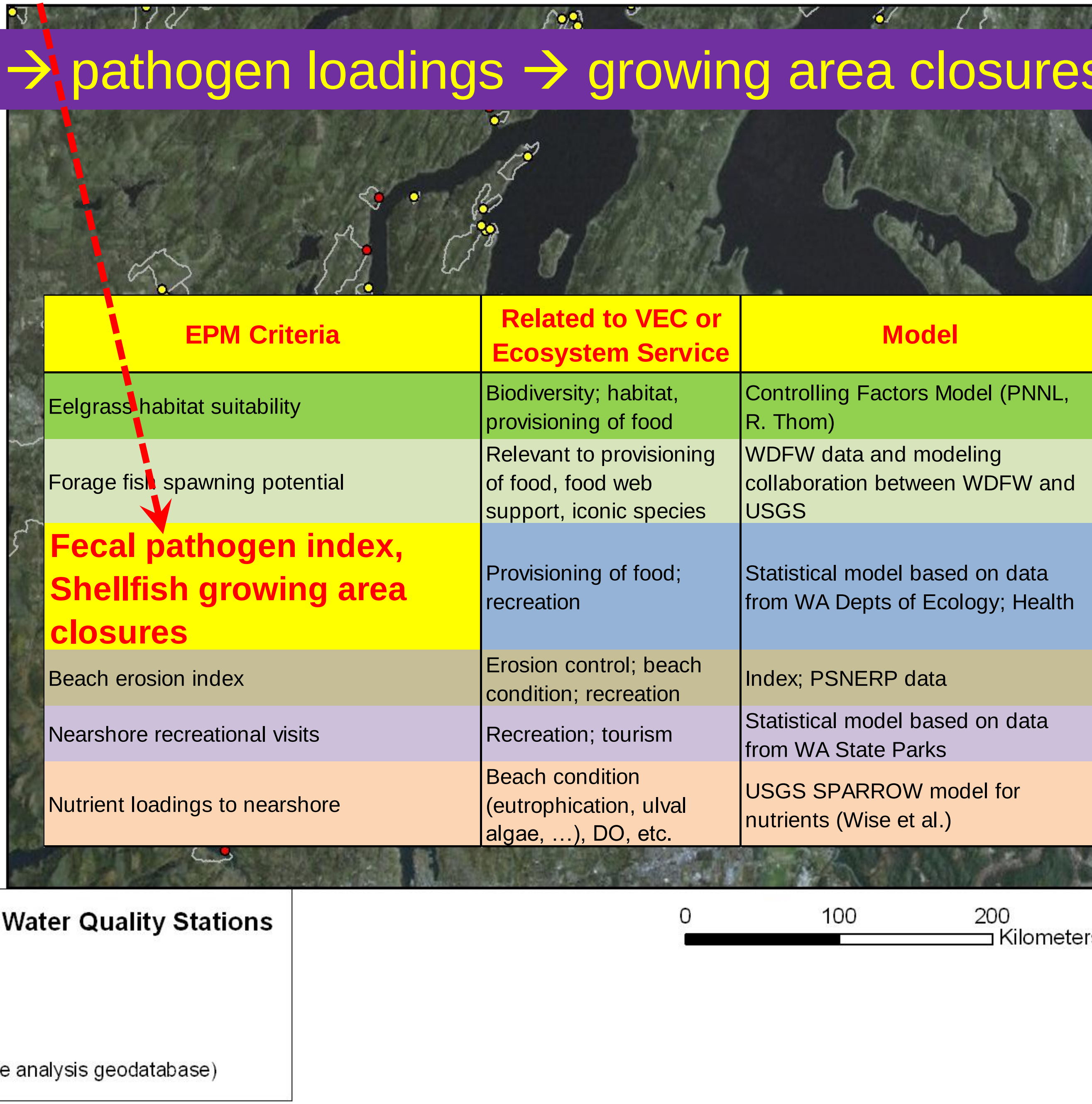


Next steps for nearshore recreational visitation model

- Substitutes
- Weighted population supply
- Detailed park characteristics/amenities
- Env variables: would like to find a signal that varies though scenarios to illustrate the effect of env change on recreational use

Pathogens – shellfish growing areas closures

Land-use → pathogen loadings → growing area closures



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Next steps for pathogen/shellfish closure model:

DRAFT Model of flushing times for South Puget Sound: Contour plot of dye concentrations remaining in the region after approximately 15 months of the dye release. (Washington Department of Ecology)

At Water Quality Stations:

- Flushing times by season, common harvest times
- Temperature
- Salinity

In Drainages:

- Test scales of analysis
- Land use adjacent to streams
- Waste water infrastructure (Daniele Spirandelli, UW Ph.D. candidate)

Further questions: What is potential pathogen exposure to commercial/recreational/tribal shellfish consumers? On a monthly time scale, does increased pathogen risk coincide with higher consumption periods?

Other criteria / models

- Forage fish spawning potential
  - DFW Salmonscape data (simple overlays for now)
    - Working on model with DFW; Krueger, Penttila, others
- Nutrient loading to nearshore
  - USGS SPARROW model
    - Statistical model relating land-use, other sources and sinks, to nutrient concentrations and loadings within stream network; routes loads
- Eelgrass habitat suitability
  - Controlling Factors Model, PNNL, Ron Thom, others
    - Relates local conditions to scored model of habitat suitability

The Beach Erosion Index:

For a given bluff-backed or barrier beach:

The relative potential of a beach to erode due to loss of sediment supply from shoreline armorin

Data Sour

PSNERP C

- **Drift cel**
- **Armorin**
- **Shorefo**

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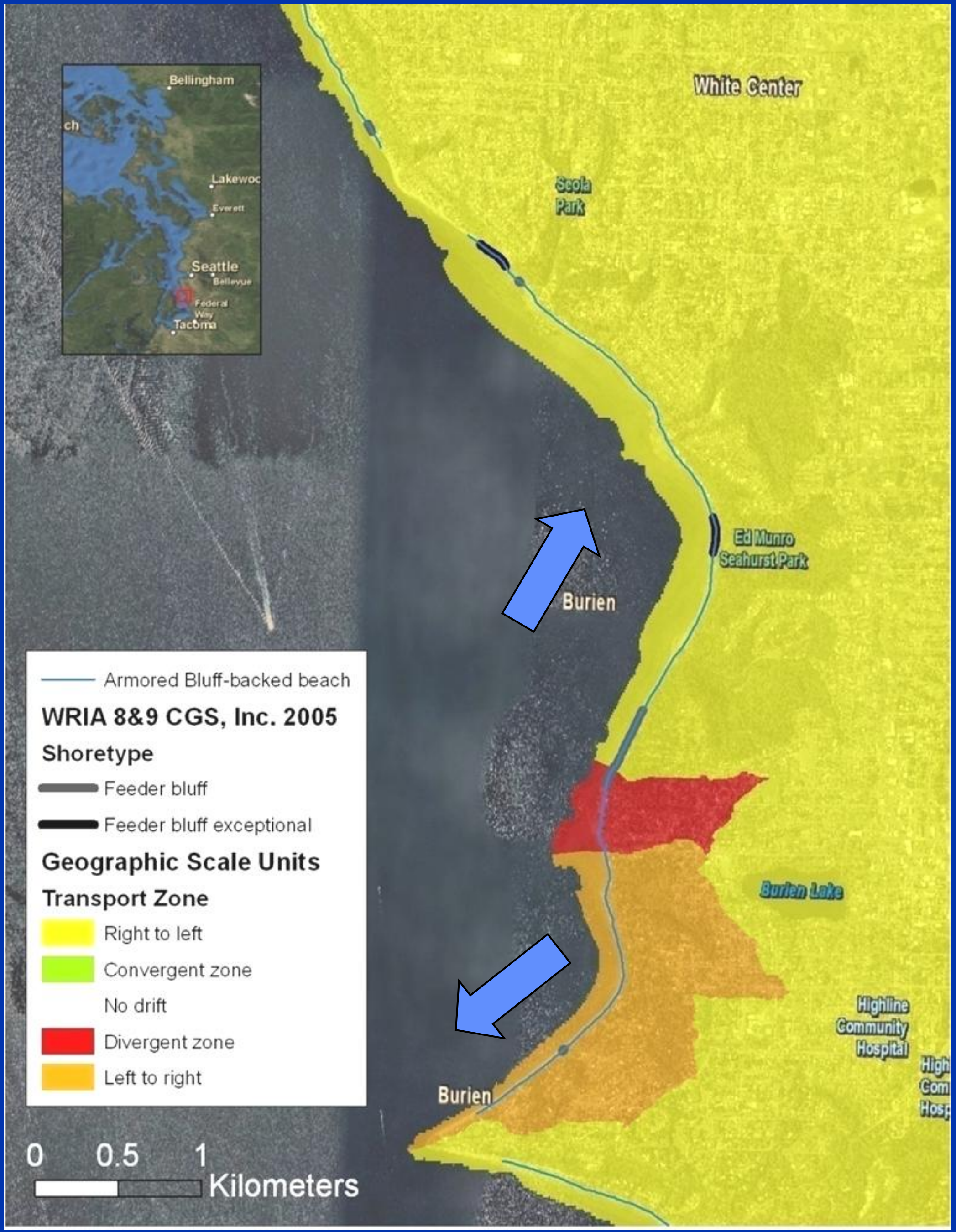


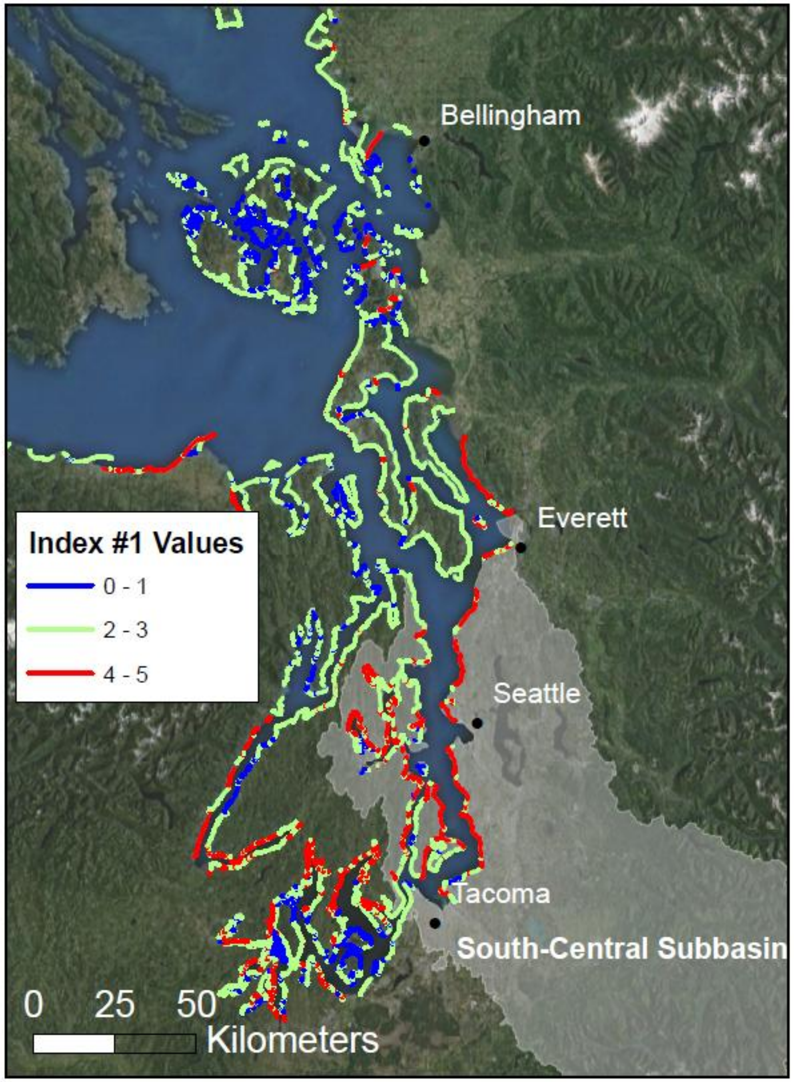
General Concept

How will armoring affect beaches at the armoring site and beaches downdrift of armoring location?

A factor of:

- Fetch distance
- Beach armoring length
- Armor length on bluff-backed beaches located in a beach's divergent zone

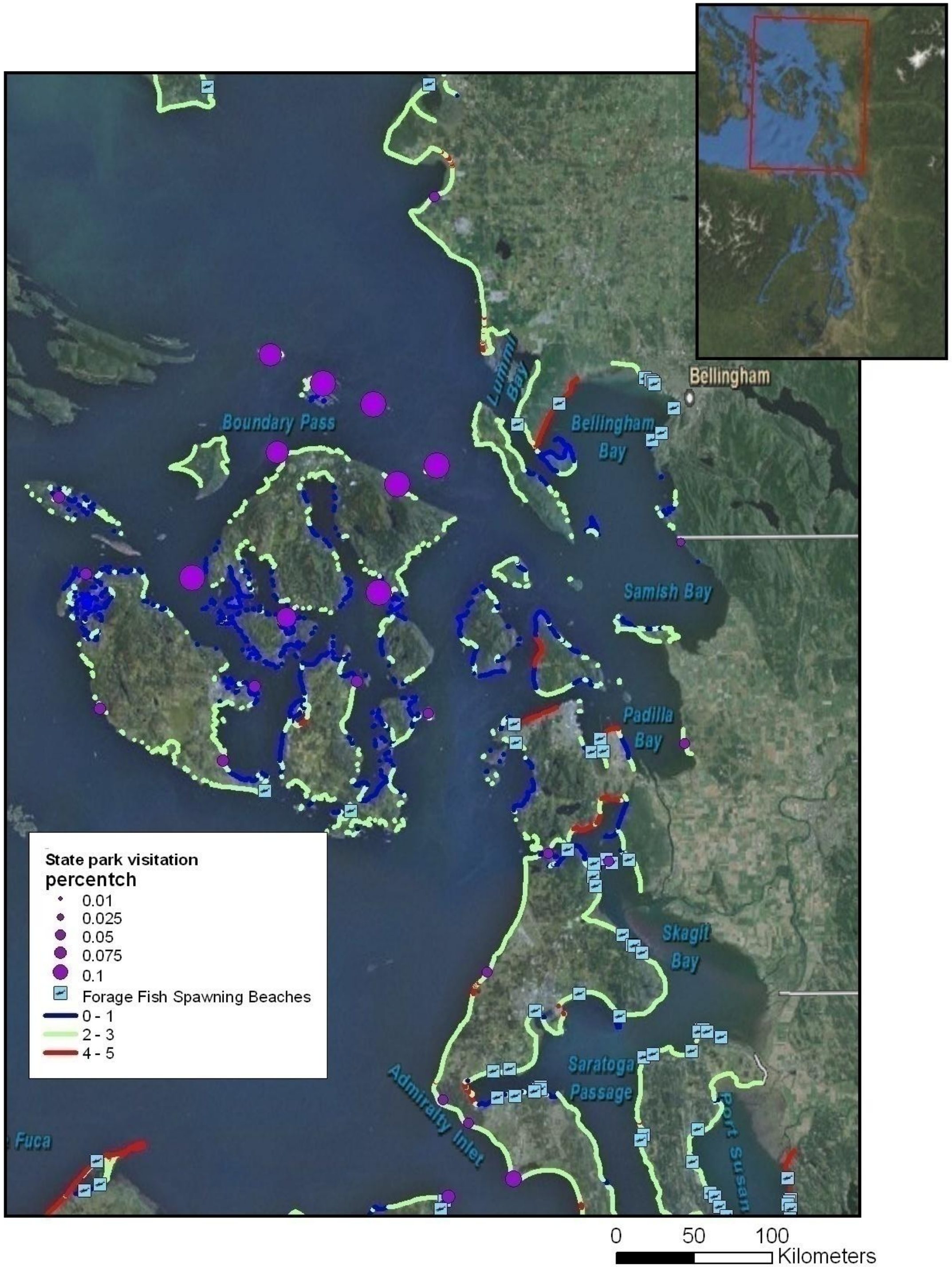
Beach Erosion Index applied to South-Central Puget Sound



Comparing Scenarios for Bainbridge Island

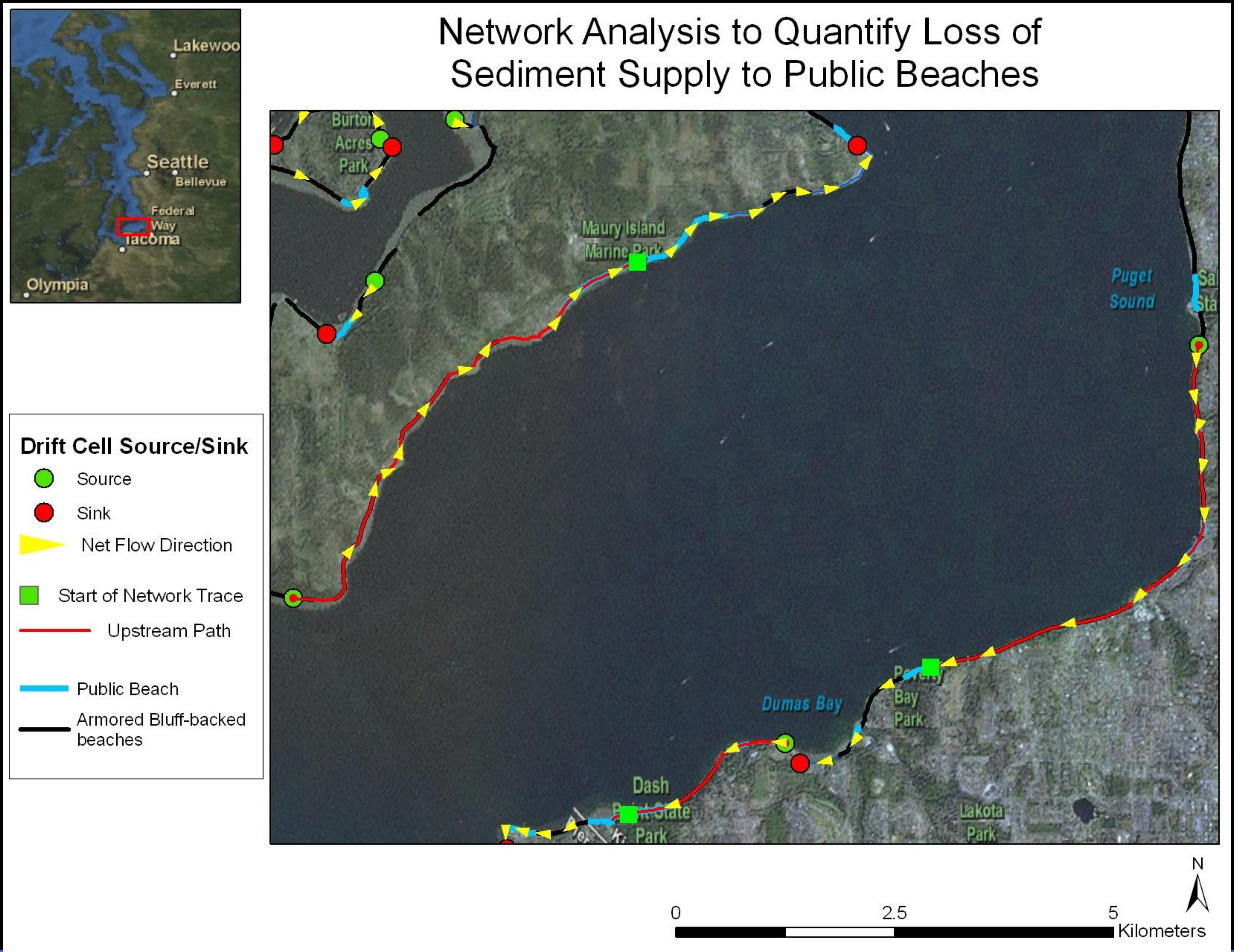
Managed Growth - 2060

Unconstrained Growth - 2060



Overlay of Beach Erosion Index values with Park Visitation Projections and Forage Fish Spawning Locations

Length of updrift armored bluffs calculated with "upstream accumulation" tool



BACK TO THE CONTEXT

Puget Sound alternative futures

Multiagent Decision-making

Select policies and generate land management decision affecting landscape pattern

Landscape Feedbacks

Actors

Decision-makers managing the landscape by selecting policies responsive to their objectives

Scenario Definition

ENVISION

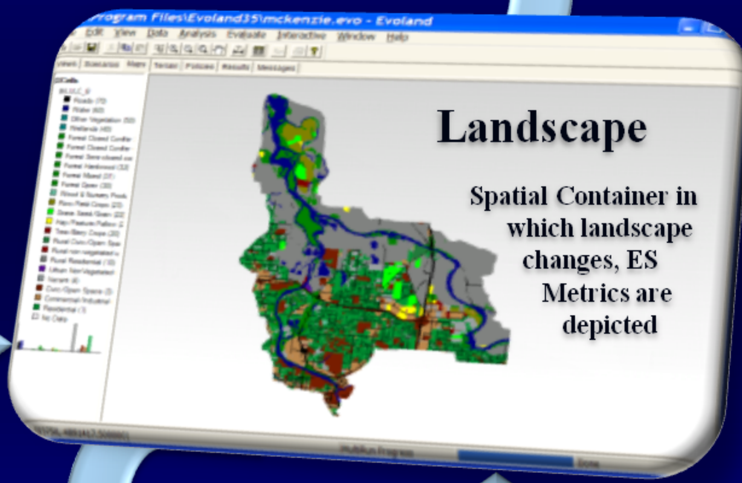
Policies

Fundamental Descriptors of constraints and actions defining land use management decisionmaking

Landscape Evaluation Models

Metrics relevant to changes in regional Human Well-Being

EPM



Autonomous Change Processes

Models of Non-anthropogenic Landscape Change

John Bolte - Oregon State University

Where we would like to go in the next two years …

- Improve scenarios
  - Sea level rise scenarios and impact scenarios
  - Land price changes and feedbacks
- Improve current EPM models
  - Model testing (case studies, workshops)
  - Better use of existing data (e.g., ECY oblique shoreline photos)
  - Longer-term – new data (e.g., lidar, stakeholder surveys)
- Additional EPM criteria/metrics
  - River delta metrics related to agriculture, salmon restoration
  - Relating nearshore habitats to intermediate variables and ultimately human activities

Acknowledgements

Pathogens:

- Mindy Roberts, WDOE
- Skip Albertson, WDOE
- Tim Determan, WDOH
- Greg Coombs, WDOH
- Ashley Scott, WDOH
- Stuart Glasoe, WDOH
- Scott Kellogg, WDOH

Recreational visitation:

- Mike Papenfus, NatCap, Stanford
- Bill Krause, WA St Parks
- Camille Speck, DFG

Beach erosion:

- Guy Gelfenbaum, USGS
- Jim Johannessen, CGS, Inc.
- David Finlayson, USGS
- Hugh Shipman, WDOE
- Scott Campbell, USACE
- Tom Leschine, UW

ENVISION model:

- John Bolte, OSU
- Kellie Vache, OSU

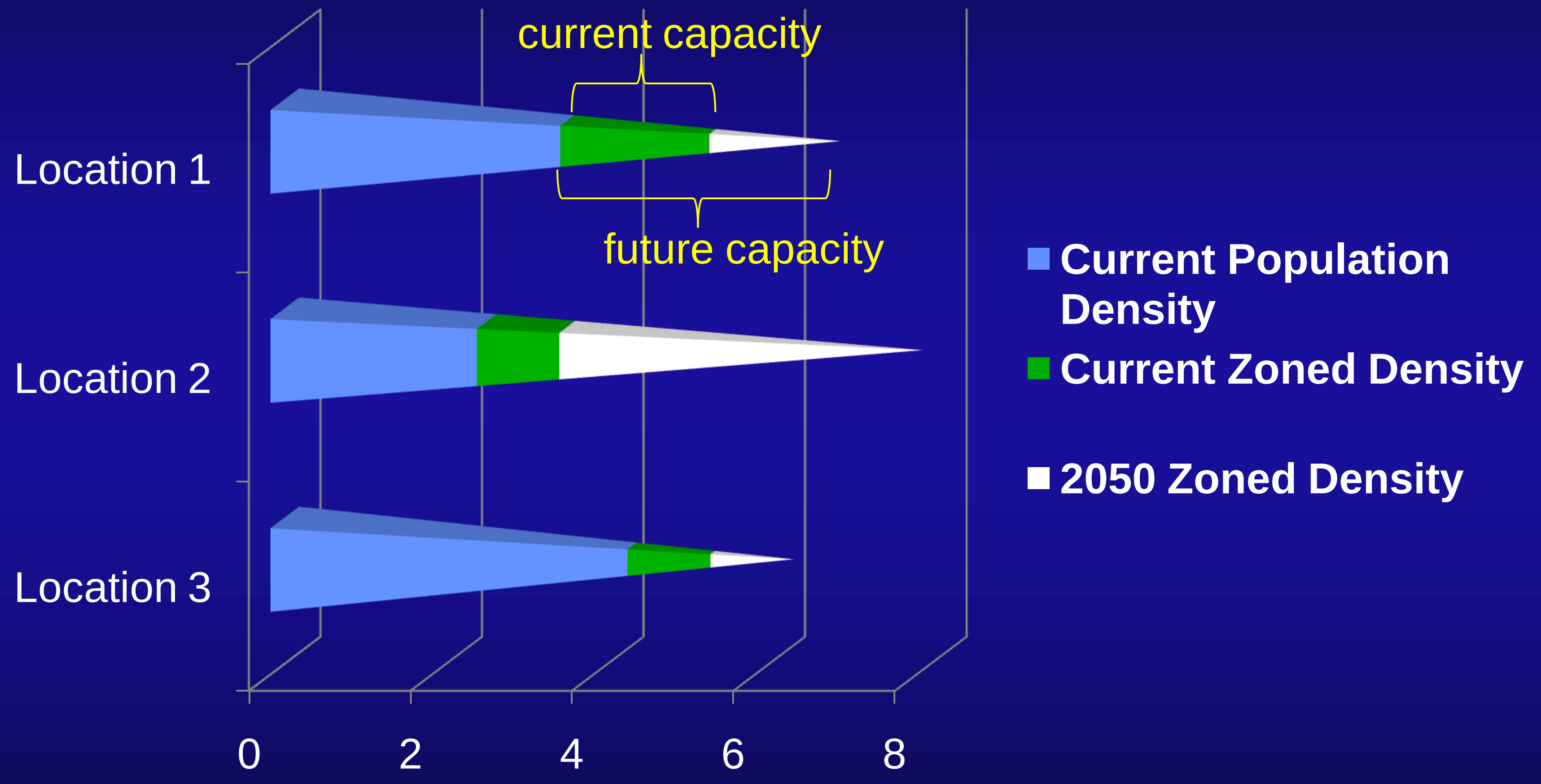
Nutrient loading:

- Dan Wise, USGS
- Hank Johnson, Hydrologist
- Steve Sobieszcyk

Follow-up slides

Scenarios

Placing people on the landscape: capacity



Placing people on the landscape: rules

Conversion of Ag Lands outside UGA
Conversion of Ag Lands inside UGA
Conversion of Forest Lands outside UGA
Conversion of Forest Lands inside UGA
Redevelopment and Infill - Commercial/Industrial
Redevelopment and Infill - Residential
Conversion of Barren Land within UGAs
Conversion of Barren Land outside UGAs
Shoreline Development to Commercial/Residential
Shoreline Infill/Densification of Residential
Wetlands Protection
Restoration of Historic Wetlands
Protection of Herring Spawning/Eelgrass Areas

Barren land conversion inside UGA

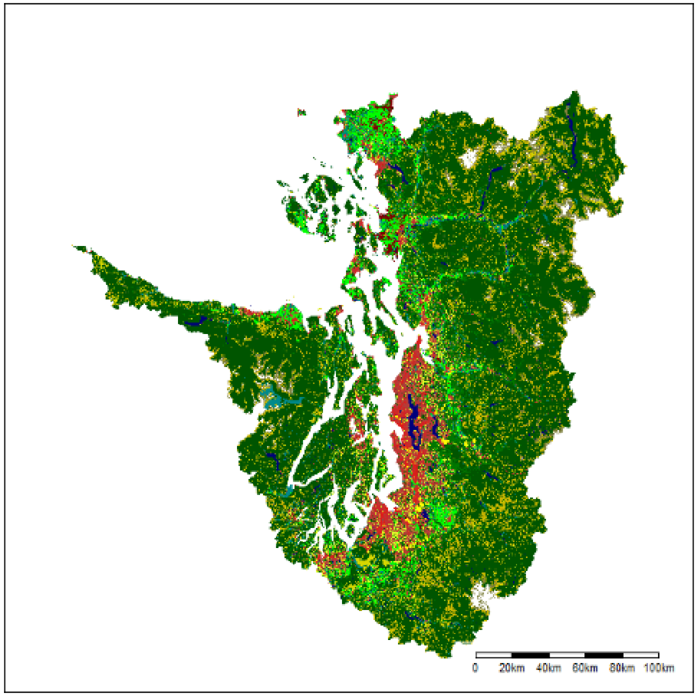
Site Attributes:
Land Use (Fine) is *Barren Land*
and Owner is *Private*
and In Urban Growth Area is *Inside UGA*
and Distance to Coast (m) is *greater than* 1000

Site attributes for rule application

Outcomes:

Possible outcomes

8 Possible Outcomes	
Outcomes	Probability
Development Class=*Suburban-Low* and Land Use (Fine)=*Developed, LowIntensity*	19
Development Class=*Suburban-Med* and Land Use (Fine)=*Developed, Medium Intensity*	7
Development Class=*Suburban-High* and Land Use (Fine)=*Developed, Medium Intensity*	0
Development Class=*Urban-Low* and Land Use (Fine)=*Developed, Medium Intensity*	30
Development Class=*Urban-Med* and Land Use (Fine)=*Developed, Medium Intensity*	17
Development Class=*Park/Open Space* and Land Use (Fine)=*Developed, Open Space*	16
Development Class=*Urban-High* and Land Use (Fine)=*Developed, High Intensity*	10
Development Class=*Commercial* and Land Use (Fine)=*Developed, Medium Intensity*	2



Scores (-3 to 3 scale):

Scoring

Objective: global	
Score	*Condition*
1	Applies Globally
Modifiers	
-2	Conservation Lands is *good/very good*

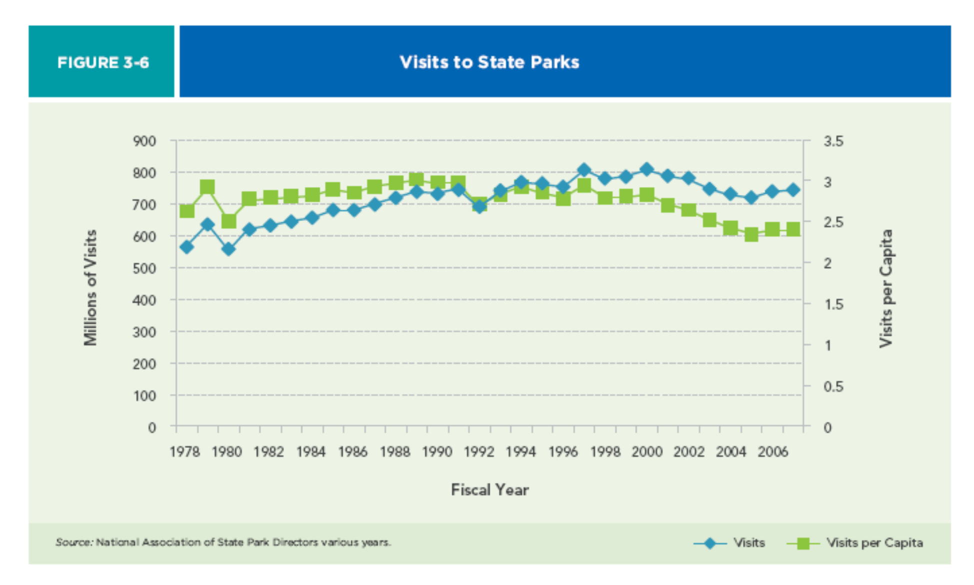
Minimum Persistence: 25
Maximum Persistence: 50
Exclusive: no
Mandatory: no

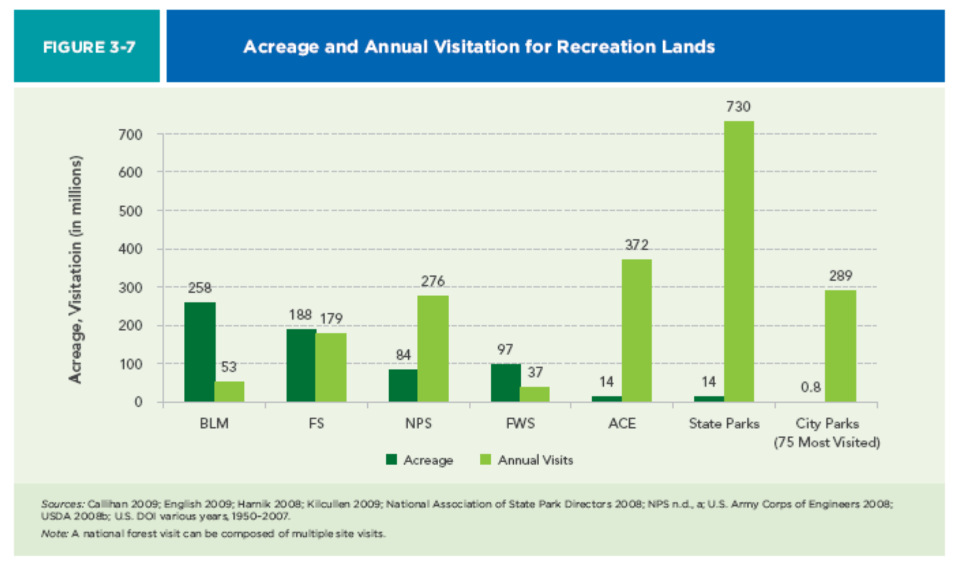
Applies to 263 of 444635 sites (0.06%)

Recreational visits

RFF – State of the Great Outdoors (9/2009)

- Nationally, state parks most likely to provide recreation opportunities
- Even with a small % of land area



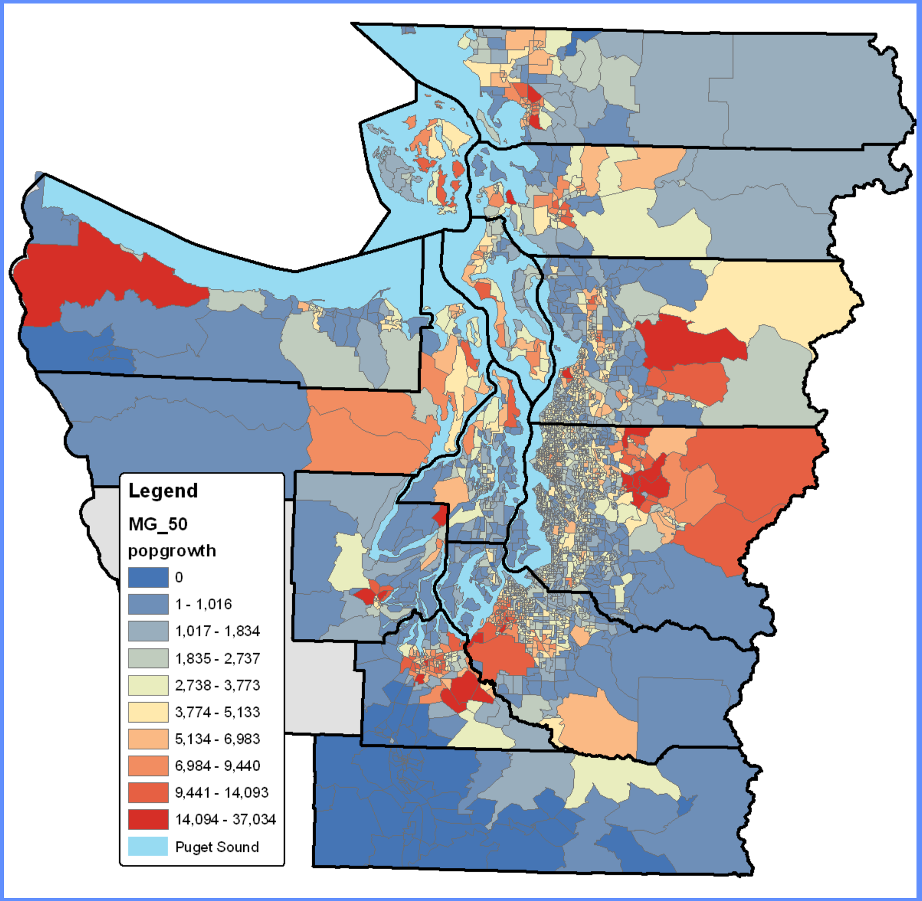


Systematic sample of recreation

- The WA State Parks system tracks visitation
- Spread out across the Sound and vary in access to urban centers and by mode (cars, ferries, pwc)
- n=57 for 2008

In the future?

- How will visitation likely change?
- Envision managed growth scenario in 2050
- Since pop w/in a distance*** can forecast by recalculating in yr50



Vis rate_{50} ~ f(camping, heritage, island, **yr50 population**)

NUTRIENT LOADINGS

Nutrient loadings to Puget Sound

- How will development affect nutrient loadings to puget sound?
- Each year, approximately 11,000 tons of inorganic nitrogen and 2,100 tons of total phosphorus are transported by rivers and streams to Puget Sound and its adjacent waters (1998 numbers, USGS Fact Sheet FS-009-98)
- Nutrient yields are largest from basins with higher percentages of urban and agricultural areas and that receive the highest inputs of nutrients

Assessing Sensitivity to Eutrophication of the Southern Puget Sound Basin

Spatial and Seasonal Perspectives

Bos, J.K., Newton, J.A., Reynolds, R.A., Albertson, S.L.
Washington State Dept. of Ecology, Olympia, WA

Introduction and Approach

Assessment of marine water quality data from the Washington State Dept. of Ecology's long-term Marine Waters Monitoring Program (part of PSAMP) from 1990-1997 shows that many sites in South Puget Sound would be sensitive to nutrient addition or eutrophication. This assessment is based on indicators, including: persistent density stratification; low dissolved oxygen concentrations; high levels of fecal coliform bacteria; high ammonium concentrations; and non-measurable levels of dissolved inorganic nitrogen during the phytoplankton growth season.

Additionally, the South Puget Sound basin has physical characteristics that make it susceptible to eutrophication effects. These features include: shallow bathymetry; slow flushing times; physical stability; numerous inlets with poor circulation; and a large ratio of shoreline to basin. Along with these features, high projected human population growth and subsequent development in the region demand close observation of South Puget Sound water quality variables.

Unfortunately, long-term monitoring data has been collected from 3-5 stations only in the Southern Puget Sound basin, yet a high degree of variation in water quality properties is evident.

In 1998, the Marine Waters Monitoring Group began intensive studies as part of project SPASM (South Puget Sound Area Synthesis Model) to better characterize the spatial and temporal variation of water properties in the South Puget Sound basin. Objectives were: 1) Describe spatial and temporal patterns in water quality variables in South Puget Sound. 2) Identify sites within South Puget Sound that are sensitive to the effects of eutrophication. 3) Assess factors controlling plankton production in this basin. 4) Provide calibration data for the hydrodynamic and water quality models of this basin, currently in development at the Dept. of Ecology (*see Albertson talk and Pelletier poster*).

Cruises occurring seasonally from 1998-2000, along with two cruises in 1994 and 1997, have provided a comprehensive set of data for analysis of nutrient and other water quality dynamics in this region.

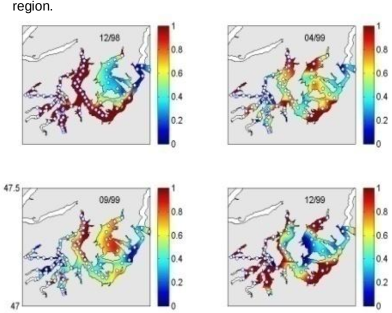


Figure 1. Stratification intensity as estimated by the difference in sigma-t $(\Delta\sigma_t)$ between the surface and bottom of the water column. Higher numbers indicate stronger stratification, requiring more wind or tidal energy to mix the water column.

Density in Southern Puget Sound is largely controlled by salinity gradients. Increased rainfall and riverine input in the winter create areas of stronger stratification. Stratification decreases in the spring as freshwater inputs diminish, but many areas continue to exhibit strong density gradients throughout the year.

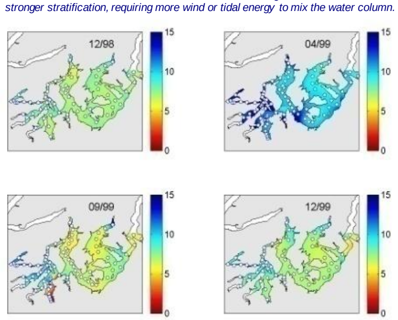
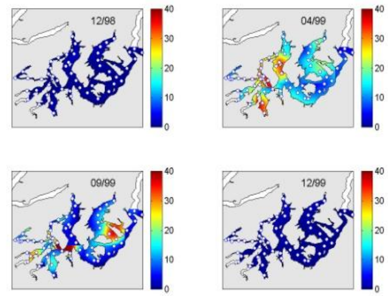


Figure 2. Dissolved oxygen concentration (mg/L) in near bottom waters. Dissolved oxygen levels below 5 mg/L are considered stressful to marine biota health. Levels below 3 mg/L have deleterious effects on marine organisms.

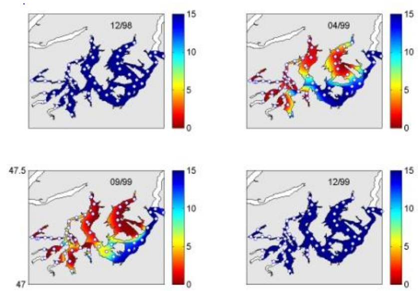
Some areas of South Puget Sound already have low dissolved oxygen concentrations; stratification plays a role. Stratification prevents bottom-water oxygen levels from being replenished by gas exchange and mixing. Stratification also enhances phytoplankton production during the spring and summer, which sinks to the bottom resulting oxygen debt as the material decomposes. In the winter, oxygen levels are generally uniform throughout the water column from strong mixing and lack of photosynthesis. As the phytoplankton growing season progresses, bottom water oxygen levels decrease, nearing depletion or low values in some areas like Budd, Carr, and Case Inlets.

Acknowledgements:
WA State Dept. of Ecology: Kara Nakata, Carol Falkenhayn, John Summers
University of Washington: A Plethora of Student Volunteers!



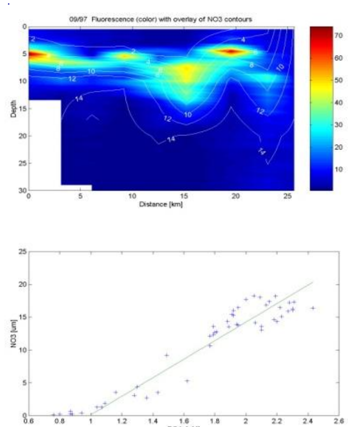
Strong phytoplankton blooms occur, but not consistently in the same places. The blooms appear localized and short-lived, constrained by stratification and nutrient levels. Concentrations of chlorophyll *a* are uniformly low during the winter months due to lack of light. Very high chlorophyll *a* concentrations, indicating blooms, can be found during the spring and summer.

Figure 3. Distribution of surface chlorophyll a concentration (mg m^{-3}). Chl a is used as a measure of phytoplankton biomass.



Surface nitrate can be un-measurable in some areas of South Puget Sound, indicating possible nutrient limitation of phytoplankton production. Dissolved inorganic nitrogen is generally high in Puget Sound waters. Levels may be drawn down during the summer months, in a stratified water column, by phytoplankton population growth. ***These are the water columns that would be susceptible to effects of eutrophication from added nutrients from point and non-point sources.***

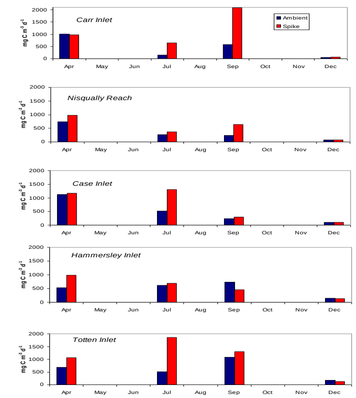
Figure 4. Distribution of surface nitrate concentration (μM). Values below 5 μM are possibly limiting to phytoplankton growth.



Evidence that nitrogen is controlling (i.e. can limit) phytoplankton growth:
1) Nitrogen control of phytoplankton growth is suggested by the strong overlap in chlorophyll with that of nitrate contours during the growing season (top).
2) Further, nitrogen, not phosphate, is indicated as the limiting nutrient in this system, as shown by a typical marine (Redfield) ratio between the elements (~16:1 N:P), with nitrate going to zero when excess phosphate is still found.

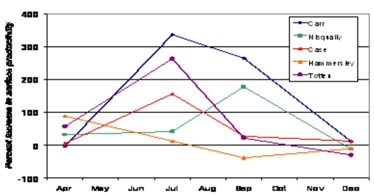
Figure 5. Measurements in Carr Inlet during September 1997. (Top panel): False color plot of the distribution of chlorophyll a fluorescence (relative units) versus distance from the northern head of the inlet, overlaid with contours of nitrate concentration (μM). (Bottom panel): Scatter plot of nitrate vs. phosphate concentrations from discrete water samples. The line represents best-fit regression of the relationship for phosphate concentrations greater than 1 μM.

Landsat Image of the Southern Puget Sound Region 07 July 1991.



Phytoplankton productivity is relatively high and, as predicted from results above, can be enhanced by nutrient addition. An annual integrated production estimate is about 1000 g C m^{-2} y^{-1}. These rates are substantially higher (e.g., 3-5x) than those from many other estuaries like San Francisco Bay or Chesapeake Bay. Nutrient addition experiments resulted in significant increases in productivity; up to 1.5 g C m^{-3} d^{-1} was produced in excess over ambient production from nutrient enhancement.

Figure 6. Seasonal view of primary productivity rates in natural (Ambient) and nutrient-enhanced (Spike) surface seawater samples. The nutrient spike was 30 μM NH_4 and 3 μM PO_4. Data shown are Apr. 99, Jul. 00, Sep. 99 and Dec. 99. The December data were multiplied by 10 in order to be visible.



Nutrient addition can enhance phytoplankton production by as much as 300%, indicating some regions in South Puget Sound are very sensitive to effects from eutrophication. Enhancement was found at all South Puget Sound stations to some extent, but the highest percentage increases occurred in Carr Inlet.

Figure 7. The percent increase in surface primary productivity due to an added nutrient spike for experiments conducted in Apr. 99, Jul. 00, Sep. 99 and Dec. 99.

Conclusions

The following observations clearly indicate that inlets in the South Puget Sound basin are sensitive to effects from eutrophication.

- Stratification of Southern Puget Sound inlets occurs variably throughout the year.
- Dissolved oxygen levels in bottom waters are drawn down during the summer. Levels reach the biological stress level (5 mg/L) in Case and Carr Inlets, and drop to harmful levels (2 mg/L) in Budd Inlet.
- Inlets are well-mixed and replete with nutrients during the winter, but show surface depletion of nitrogenous nutrients during the spring and summer, indicating considerable utilization by phytoplankton.
- Discrete measurements of chlorophyll *a* show concentrations indicative of phytoplankton blooms (15-60 ug/L). These blooms appear concurrently with the depletion of surface nitrate, although the location is random and non-repetitive. The factors causing such transience in these particular blooms are not well-understood from the cruise data.
- Phytoplankton production is limited by nitrogenous nutrients during the growing season. Nutrient addition experiments resulted in a substantially greater rate of primary production (up to 300%), especially in late summer.

Water quality matters concerning eutrophication effects should be focused most strongly on Carr and Case Inlets. Smaller inlets exhibit nutrient sensitivity at various times, but are fairly well-mixed such that strong dissolved oxygen gradients do not appear.

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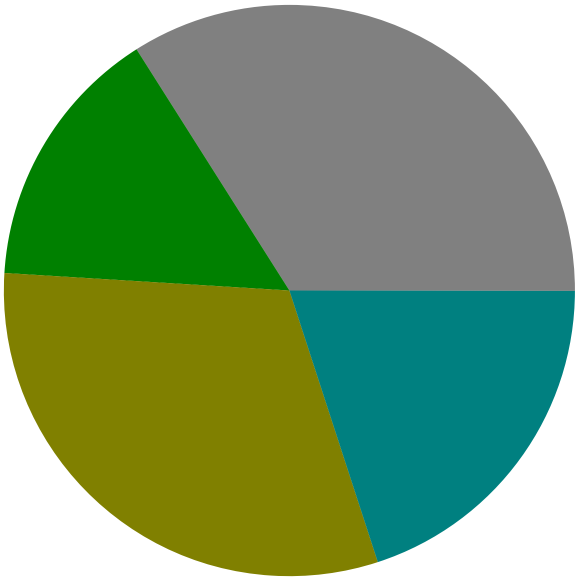
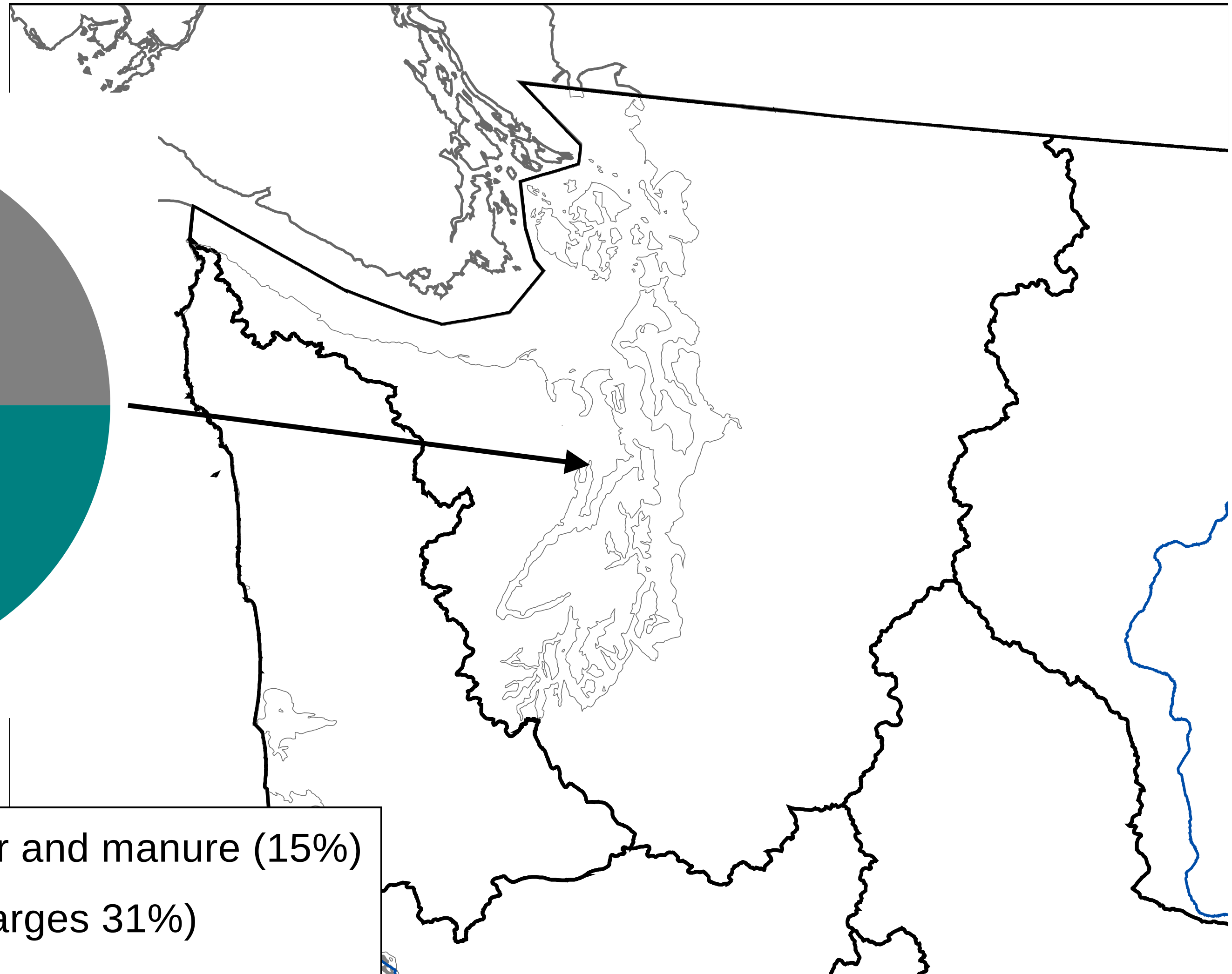
Relating Surface-Water Nutrient Conditions in the Pacific Northwest to Watershed Attributes Using the USGS SPARROW Model

Daniel Wise, Hydrologist
Hank Johnson, Hydrologist
Steve Sobieszcyk
US Geological Survey
Portland, OR

PNW SPARROW TN Results

Delivered to
Puget Sound





- Agricultural fertilizer and manure (15%)
- Point-source discharges 31%)
- Atmospheric deposition (34%)
- Runoff from developed land (20%)

PNW SPARROW Model Calibration (Wise et al.)

- Water-quality data sources
  - USGS
  - EPA STORET (Federal, State, local)
  - Oregon Dept. of Environmental Quality
  - Washington Dept. of Ecology
  - Clean Water Services (metro Portland)
  - City and county public works departments
  - Conservation districts
- Data base of virtually all nutrient and sediment data collected in PNW between 1975 and 2004 (~15,000 sites)

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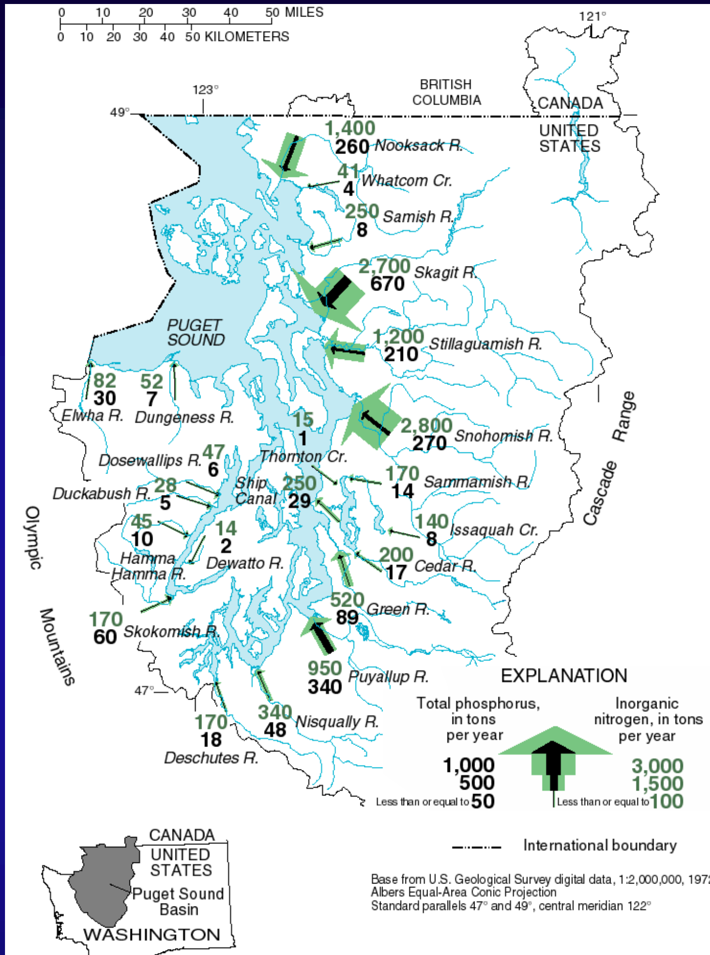
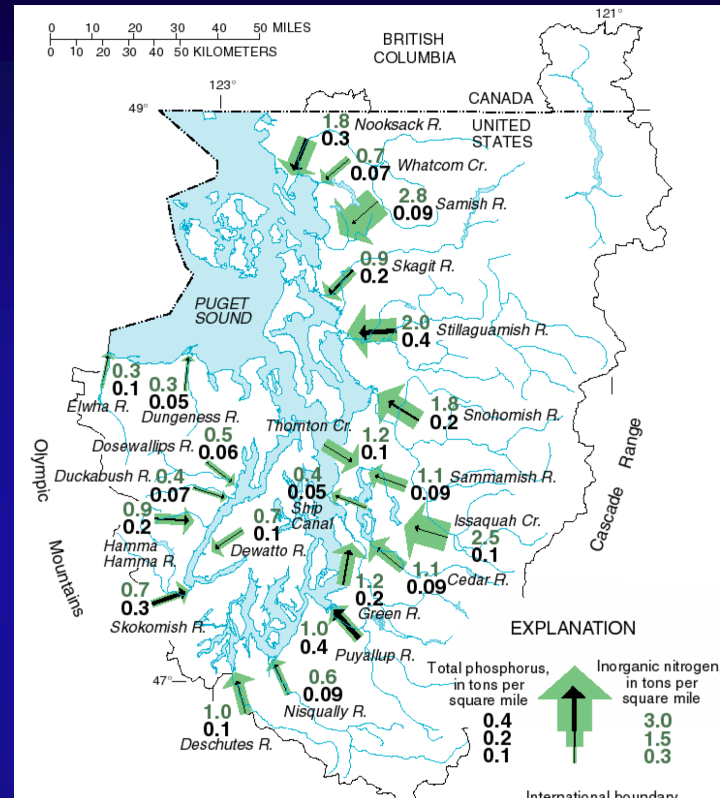
SPARROW implementation for EPM

- **Using PNW calibration for Puget Sound**
- **Implemented directly within ENVISION for evaluating FRAP scenarios**
- **New Puget Sound-specific calibration is being proposed by USGS WA Water Science Center**
- **Issues: agricultural source coefficients biased by eastern WA ag practices, etc.**

Nitrogen loads

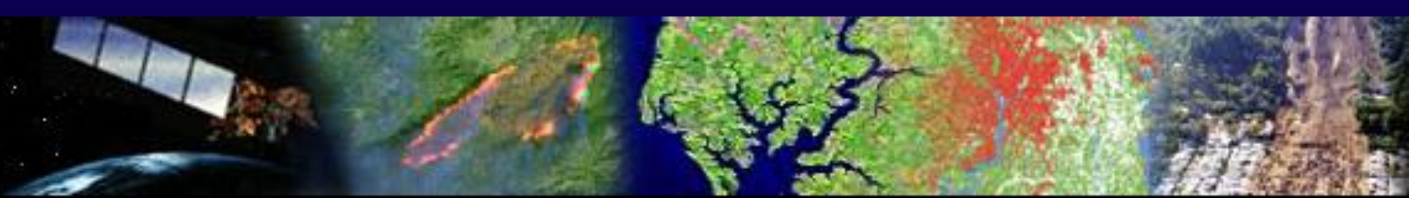


Nitrogen yields



USGS Fact Sheet FS-009-98, Inkpen and Embrey, 1998

USGS

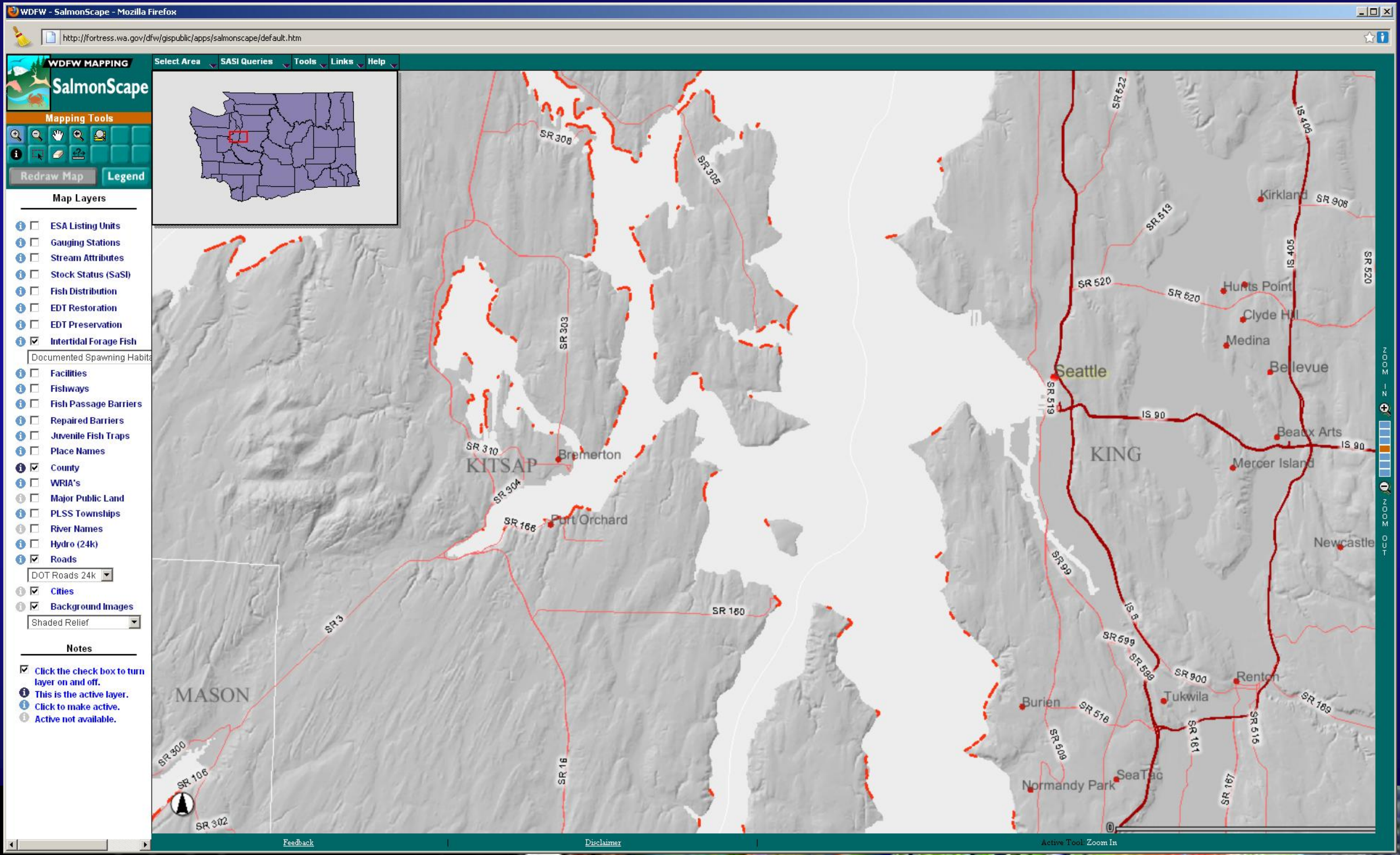


FORAGE FISH SPAWNING POTENTIAL

Forage fish spawning potential

- Held workshop in August:
  - WDFW:
    - Kirk Krueger, Dan Penttila, Ken Pierce
  - USGS:
    - Marty Liedtke, Rick Dinicola, Todd Hawbaker, others

WDFW Salmonscape: Potential and documented forage fish spawing

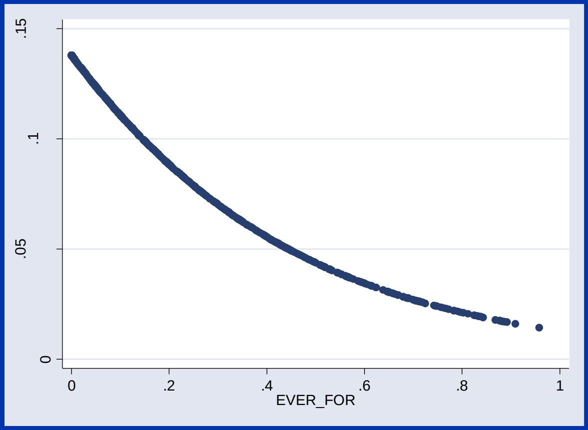


PATHOGEN/SHELLFISH GROWING AREA CLOSURES

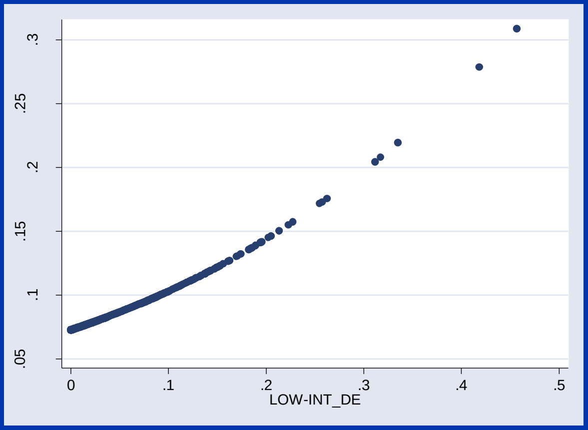
Pathogen model: Probability that FPI >2 (fair or poor) given percent land cover in drainage

Logistic regression | **Number of obs = 747**
LR chi2(3) = 57.08
Prob > chi2 = 0.0000
Log likelihood = -192.25488 | **Pseudo R2 = 0.1293**

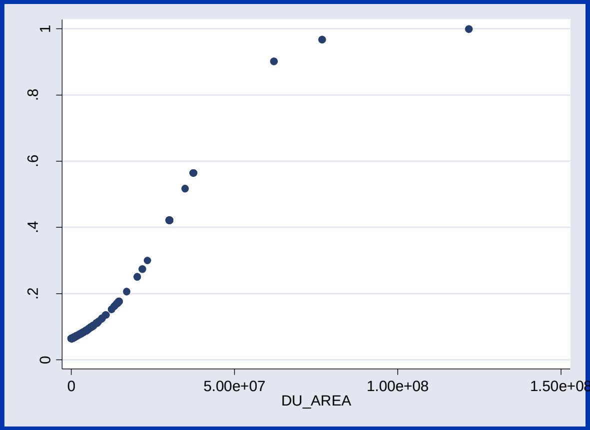
Index2	Coef.	Std. Err.	Z	P>|z|	[95% Conf.	Interval]
du_area	| 0.08	.0144782	5.58	0.000	.0523491	.1091027
ever_for	| -2.41	.7465307	-3.23	0.001	-3.875257	-.9489107
lowint_de	| 4.63	1.935442	2.39	0.017	.8363759	8.42317
_cons	| -2.46	.2421136	-10.15	0.000	-2.930879	-1.981811



Pr(FPI>2) decreases with evergreen forest



Pr(FPI>2) increases with low intensity development



Pr(FPI>2) increases with drainage area

BEACH EROSION INDEX

One version:

PAL: Percent beach length that is armored

PBALDZ: Within divergent zone, percent of bluff-backed beach length that is armored

FD: Fetch distance

Score(PAL) + Score(PBALDZ)*2 + Score(FD)*2

Outcome Goal: Index (1-5) represents the presence or absence of a beach zone that supports specific ecosystem goods and services.

Calculating Potential Loss of Bluff Sediment Supply

Park	Maury Island Marine Park	Poverty Bay Park	Dash Point State Park
Updrift bluff length	6378 m	6291 m	2286 m
Updrift armored bluff length	1342 m	4852 m	433 m
Percent sediment supply loss	21%	77%	19%