Modeling Natural Hydrologic Systems with VELMA (Visualizing Ecosystems for Land Management Assessments)

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Evergreen State College
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Outline

1. What is an ecosystem service?
2. Modeling ecosystem services and tradeoffs for alternative land use decisions
3. Decision support for assisting communities seeking sustainable futures
4. Importance of computer science in environmental decision making

Ecosystem services are the benefits people obtain from natural and managed ecosystems

Four categories:

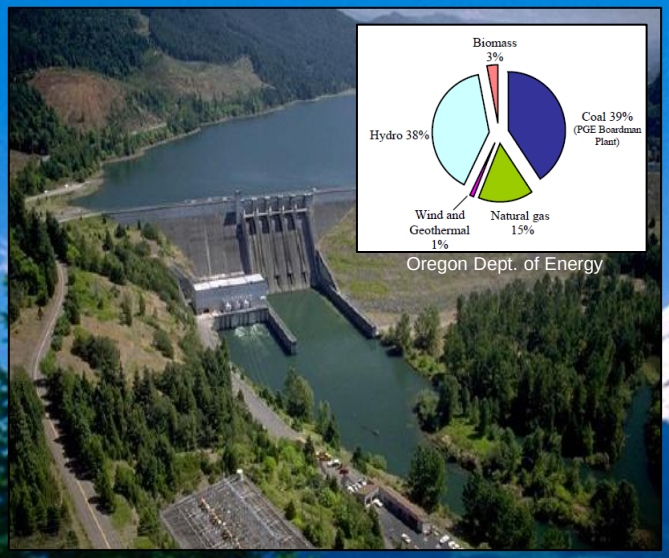
1. ***Provisioning services***, such as production of food, fiber & water
2. ***Regulating services***, such as the control of climate & disease
3. ***Cultural services***, such as spiritual and recreational benefits

4. ***Supporting services***, such as cycling of water & nutrients

Millennium Ecosystem Assessment 2005

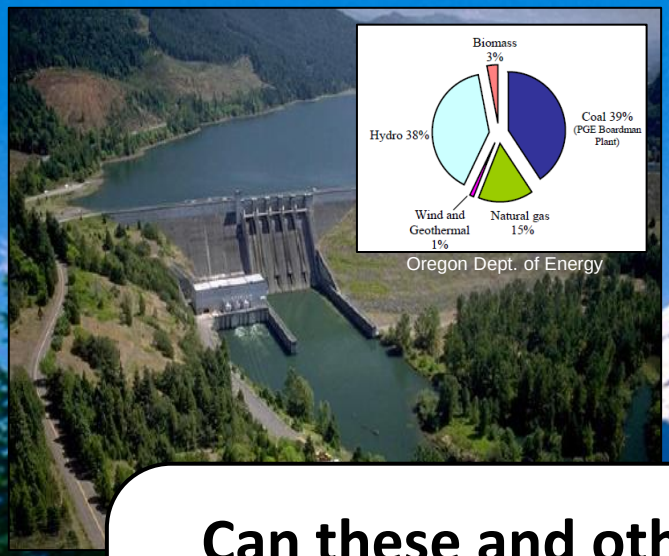
The Pacific Northwest is a region of diverse and highly valued natural resources that provide a variety of ecosystem services vital to society's well-being

U.S. Forest Service



Oregon Dept. of Energy

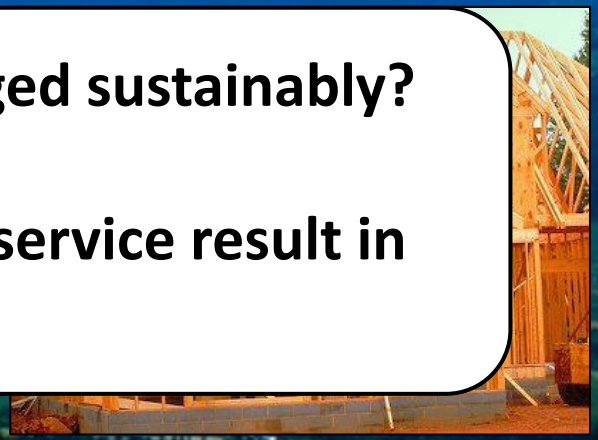

Allison Jones

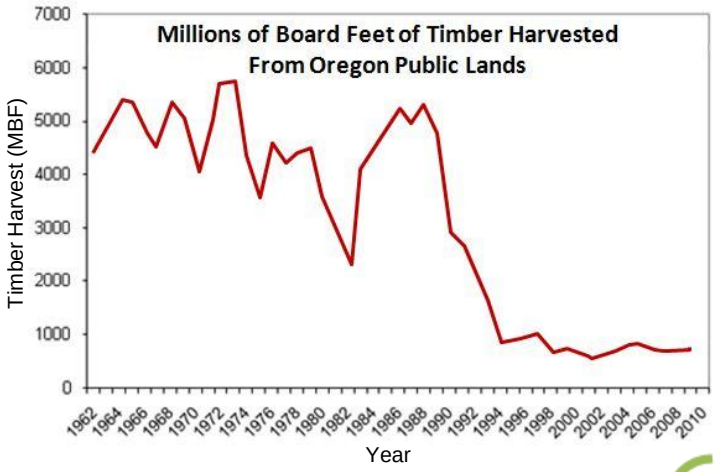


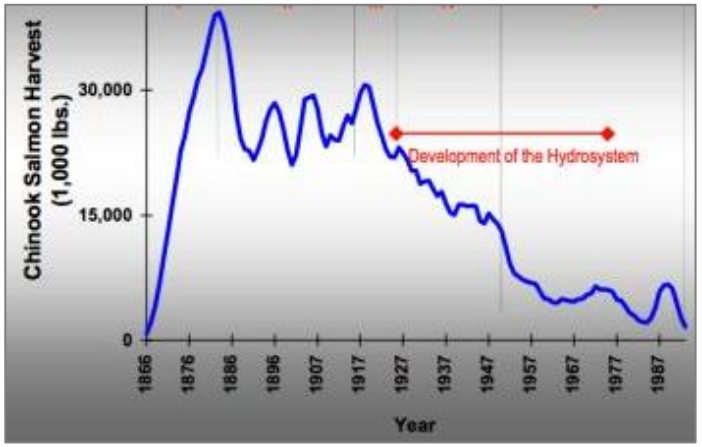
Oregon Dept. of Energy

Can these and other services be managed sustainably?

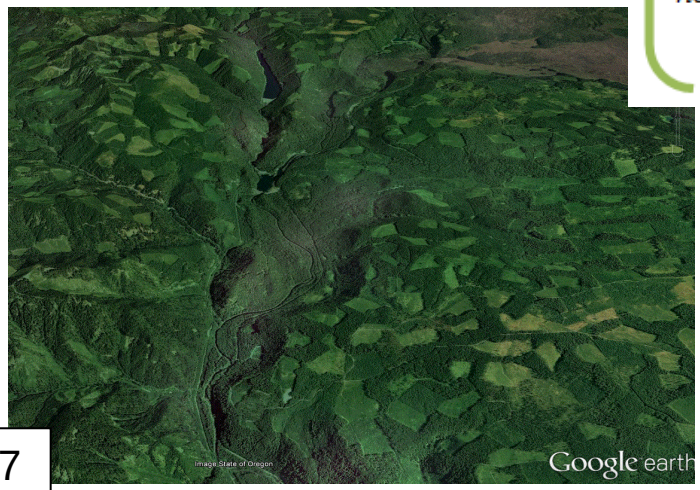
To what extent does emphasizing one service result in trade-offs with others?







"The historical pattern of resource use in the PNW has often been one of boom and bust, with unsustainable management practices leading to severe downturns in major industries, such as the once thriving salmon fishery and forest products industries... Economic and sociological impacts have been particularly damaging to rural communities."



Most ecosystem services are declining globally

Service	Sub-category	Status	Notes
Provisioning Services			
Food	crops	▲	substantial production increase
	livestock	▲	substantial production increase
	capture fisheries	▼	declining production due to overharvest
	aquaculture	▲	substantial production increase
	wild foods	▼	declining production
Fiber	timber	+/–	forest loss in some regions, growth in others
	cotton, hemp, silk	+/–	declining production of some fibers, growth in others
	wood fuel	▼	declining production
Genetic resources		▼	lost through extinction and crop genetic resource loss
Biochemicals, natural medicines, pharmaceuticals		▼	lost through extinction, overharvest
Fresh water		▼	unsustainable use for drinking, industry, and irrigation; amount of hydro energy unchanged, but dams increase ability to use that energy
Regulating Services			
Air quality regulation		▼	decline in ability of atmosphere to cleanse itself
Climate regulation	global	▲	net source of carbon sequestration since mid-century
	regional and local	▼	preponderance of negative impacts
Water regulation		+/–	varies depending on ecosystem change and location
Erosion regulation		▼	increased soil degradation
Water purification and waste treatment		▼	declining water quality
Disease regulation		+/–	varies depending on ecosystem change
Pest regulation		▼	natural control degraded through pesticide use
Pollination		▼[a]	apparent global decline in abundance of pollinators
Natural hazard regulation		▼	loss of natural buffers (wetlands, mangroves)

Source: Millennium Ecosystem Assessment

The value of the world's ecosystem services and natural capital

Robert Costanza*†, Ralph d'Arge‡, Rudolf de Groot§, Stephen Farber‖, Monica Grasso†, Bruce Hannon¶, Karin Limburg#☆, Shahid Naeem**, Robert V. O'Neill††, Jose Paruelo‡‡, Robert G. Raskin§§, Paul Sutton‖‖ & Marjan van den Belt¶¶

NATURE | VOL 387 | 15 MAY 1997

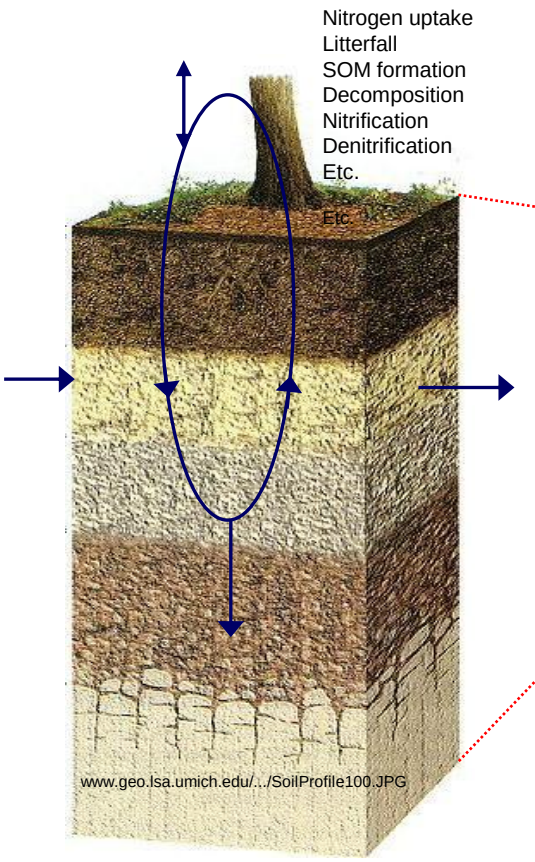
- **The global value of ecosystem services is estimated to be about $33 trillion per year.**
- **Global gross national product is about $18 trillion per year.**

Problem Statement & Research Objective

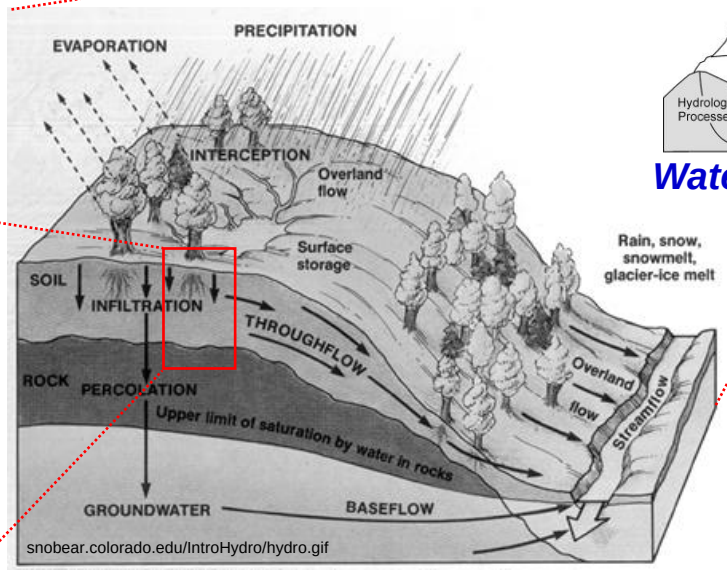
- Communities need comprehensive approaches for meeting present needs without compromising the ability of society and the environment to meet the economic, social and environmental needs of future generations.

- Our goal is to produce & demonstrate decision support tools for quantifying the production and value of ecosystem goods and services for achieving sustainable & healthy communities.

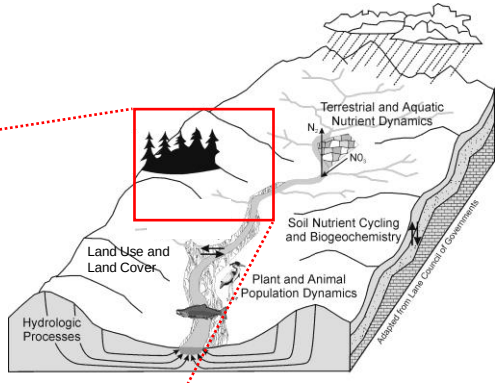
Premise: provisioning services are strongly regulated by hydrological & biogeochemical processes (supporting services) that interact across multiple scales



Plot-scale processes



Hillslope-scale processes

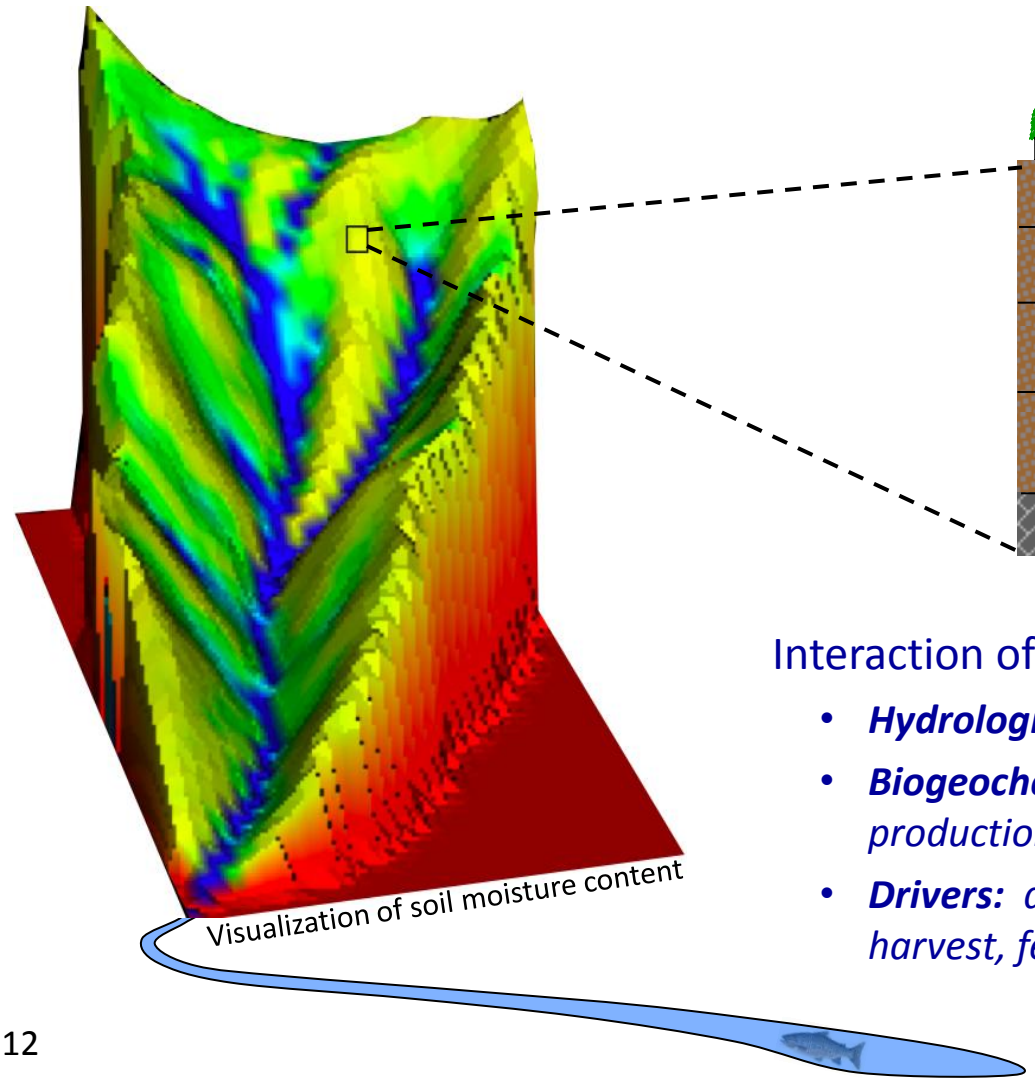


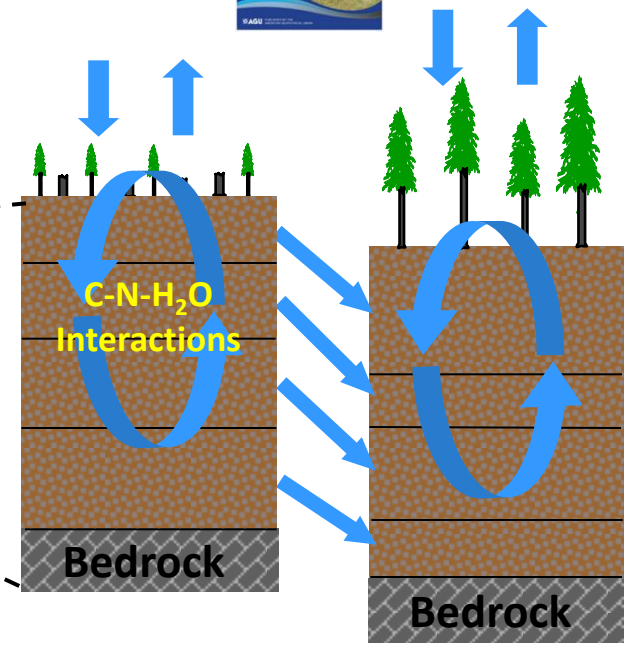
Watershed-scale processes

VELMA Eco-Hydrological Model

Abdelnour, Stieglitz, Pan & McKane, 2011

Abdelnour, McKane, Stieglitz & Pan, 2013





Interaction of hydrological & biogeochemical processes:

- ***Hydrological:*** *streamflow, ET, vertical & lateral flow, …*
- ***Biogeochemical:*** *plant & soil C and N dynamics, production & transport of NH_4, NO_3, DON, DOC, etc.*
- ***Drivers:*** *daily temperature, precip and disturbances (fire, harvest, fertilization…)*

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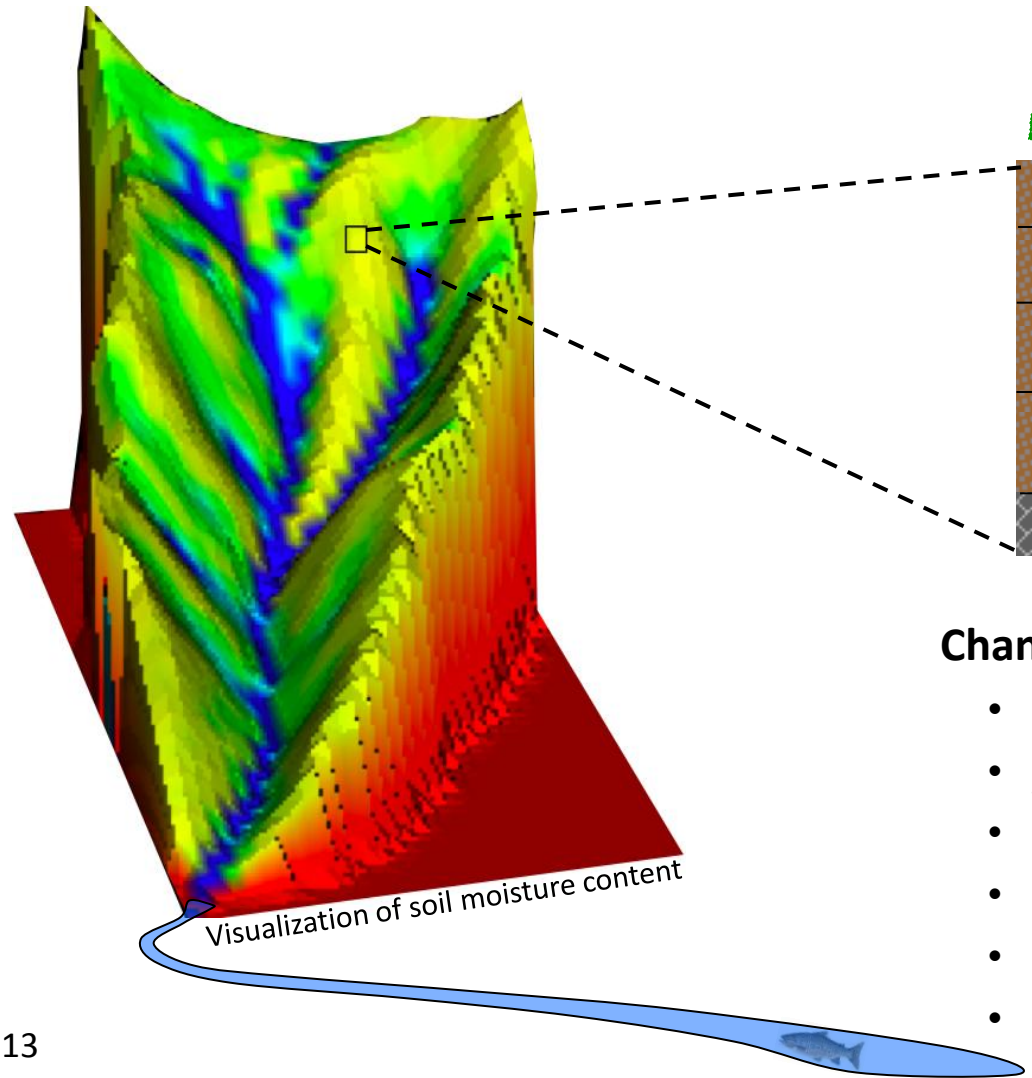
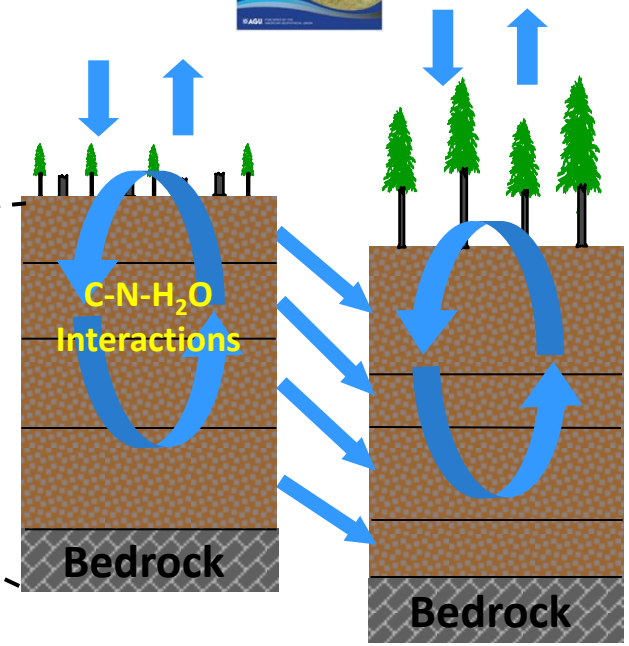




Changes in key ecosystem services:

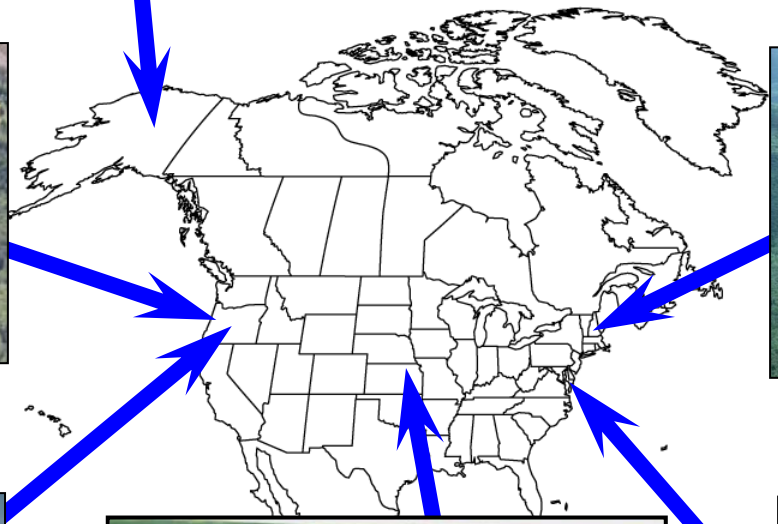
- ***water quality & quantity regulation***
- ***food & fiber production***
- ***greenhouse gas regulation (CO_2, N_2O, NO_x)***
- ***carbon sequestration***
- ***regulation of nitrogen sources & sinks***
- ***biodiversity (links to fish & wildlife models)***

Broad Applicability

Arctic LTER

Hövsgöl LTER, Mongolia

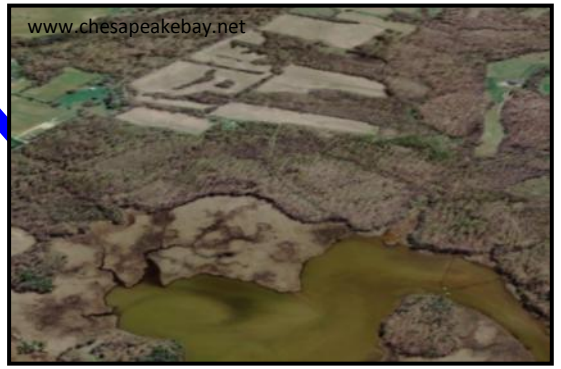
Alsea Watershed



Hubbard Brook LTER

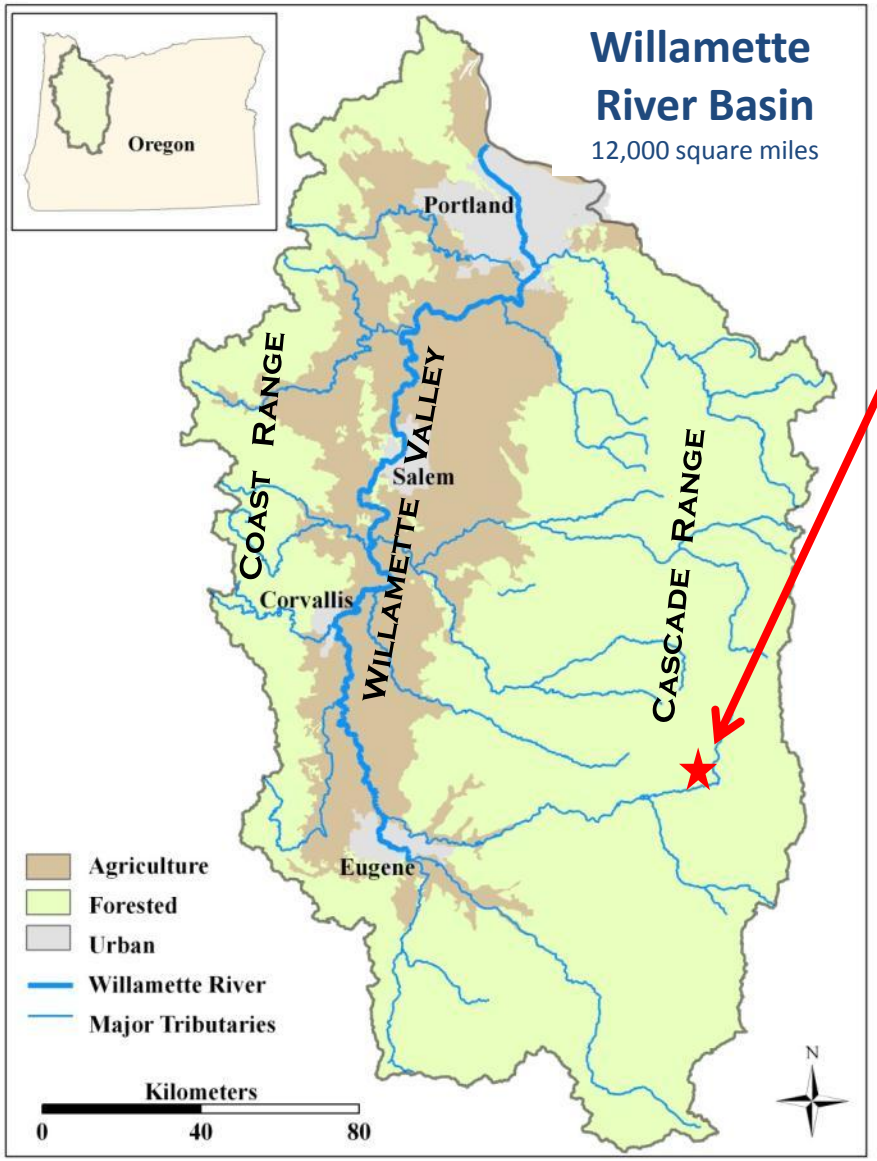
HJ Andrews LTER

Konza Prairie LTER



Chesapeake Bay

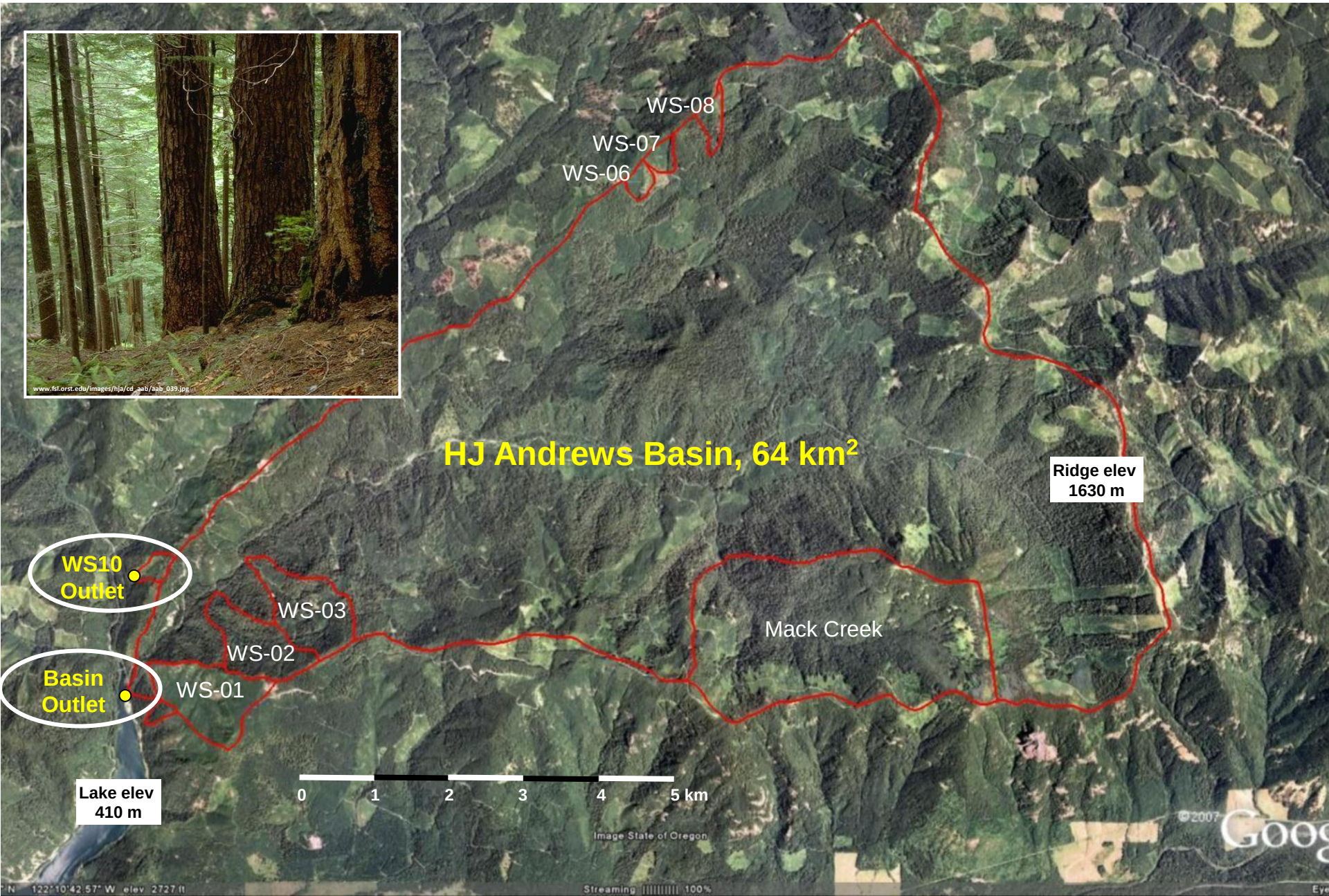
VELMA demonstration of forest harvest effects on multiple ecosystem services



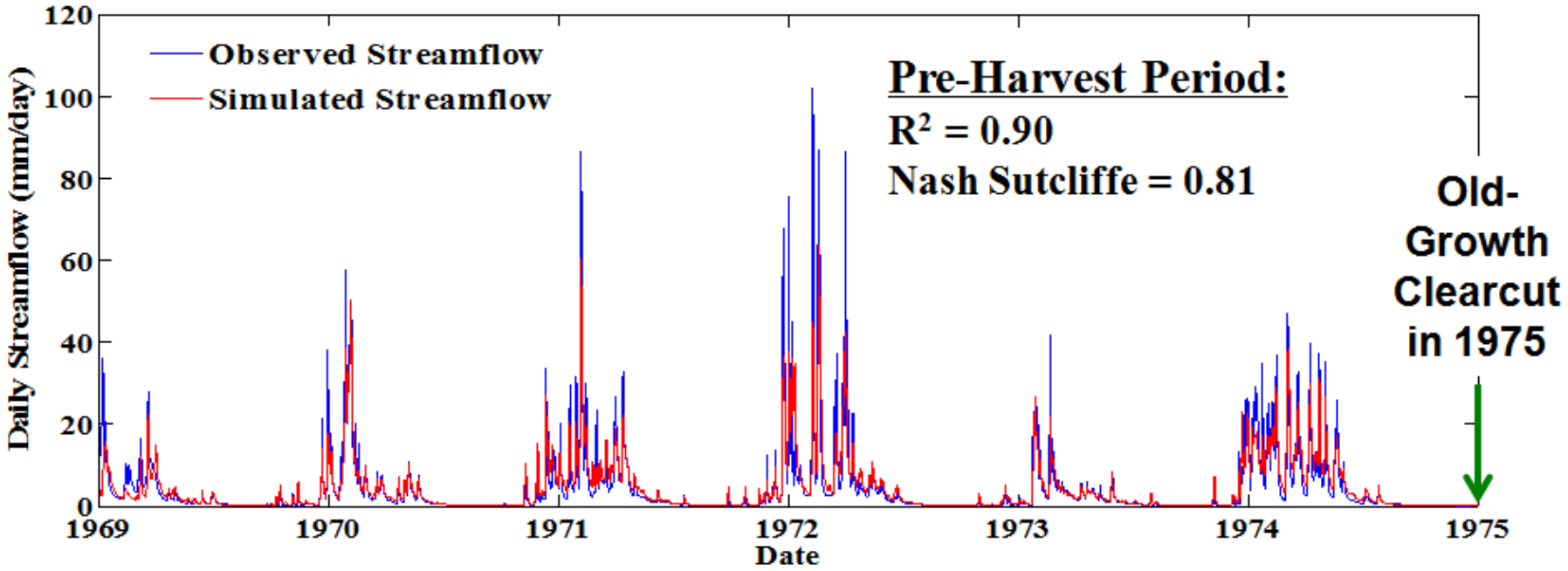
HJ Andrews Long Term Ecological Research (LTER) site

- Long-term monitoring data since 1950s:
  - Climate (temperature, precipitation…)
  - Stream flow & chemistry
  - Forest biomass and productivity
  - Disturbance history
- 40+ years of experimental data describing hydrological & ecological responses to harvest and climate.

HJ Andrews LTER site



WS10 streamflow validation



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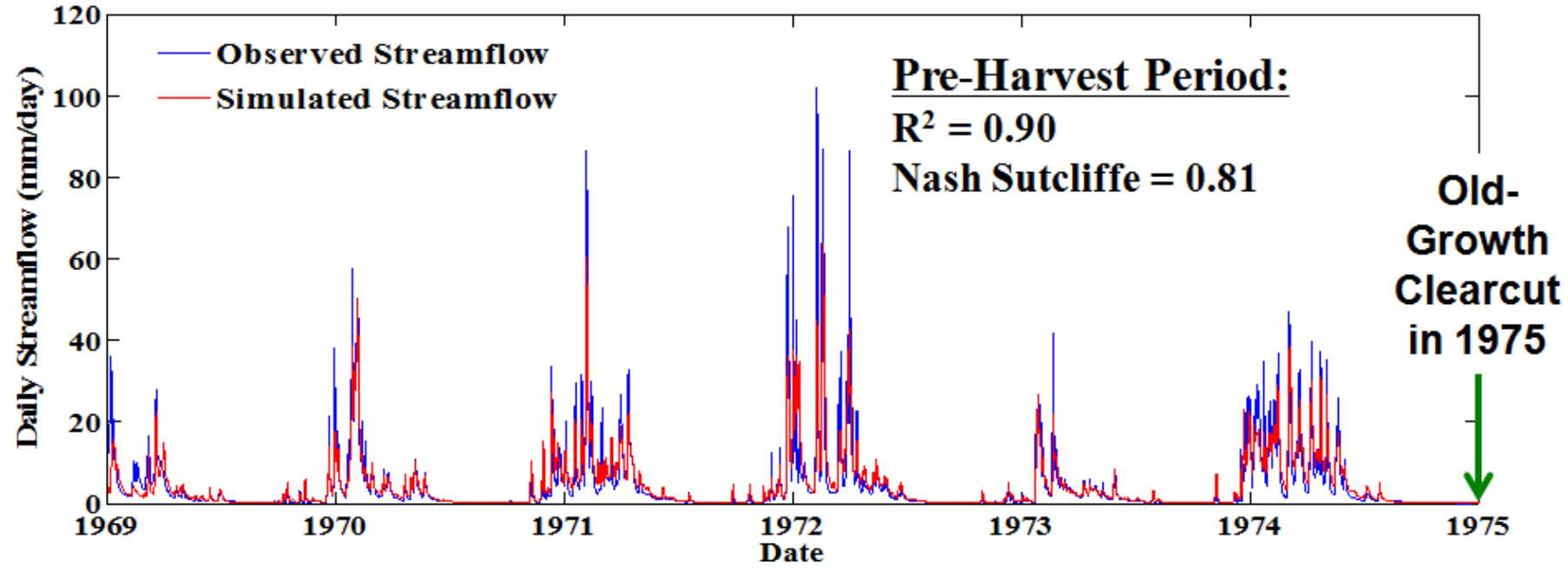
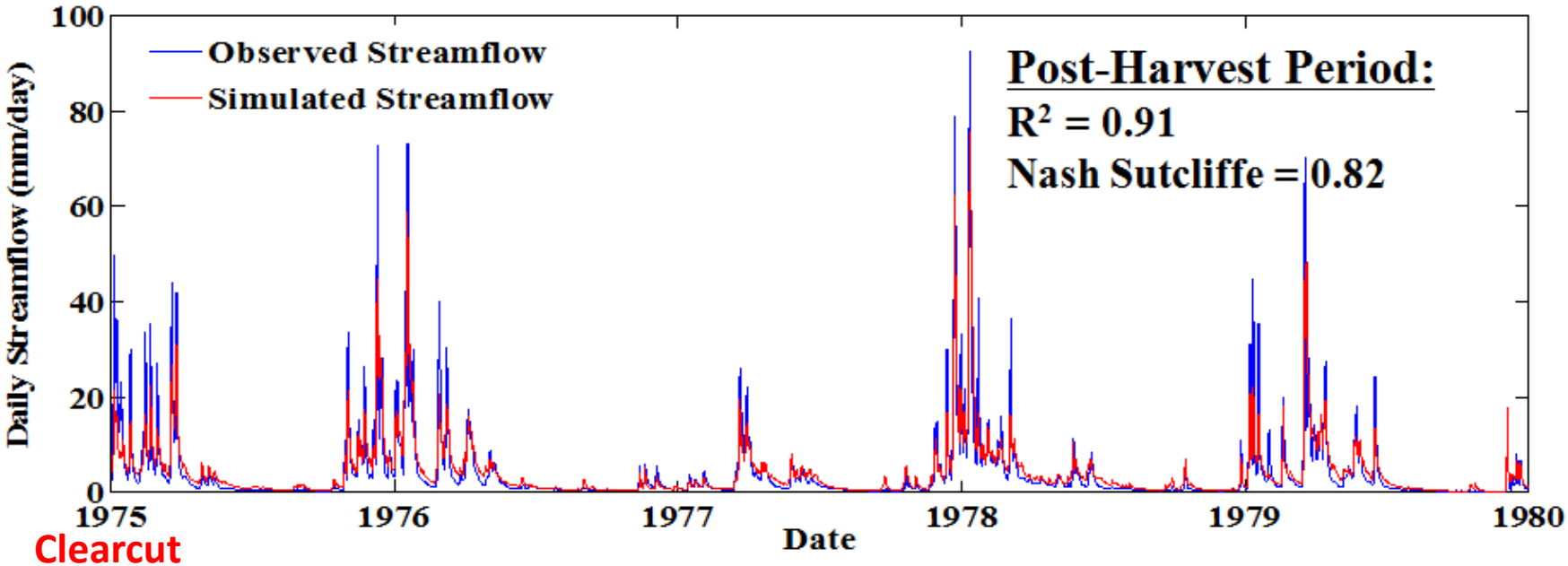
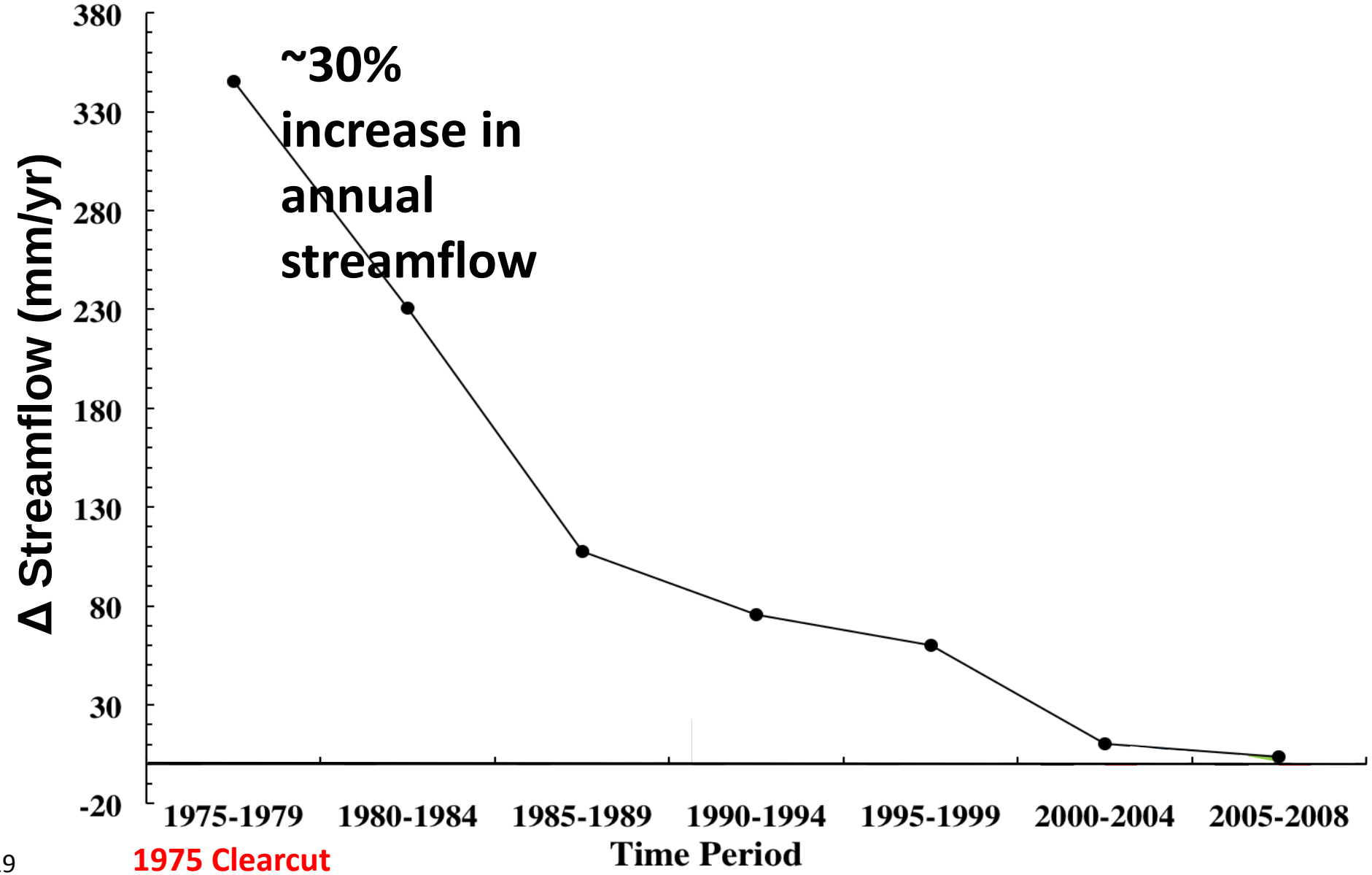


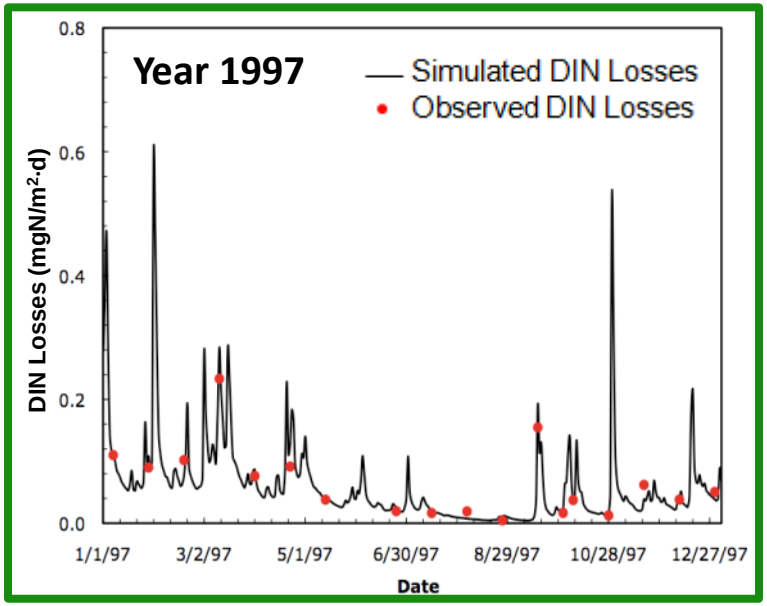


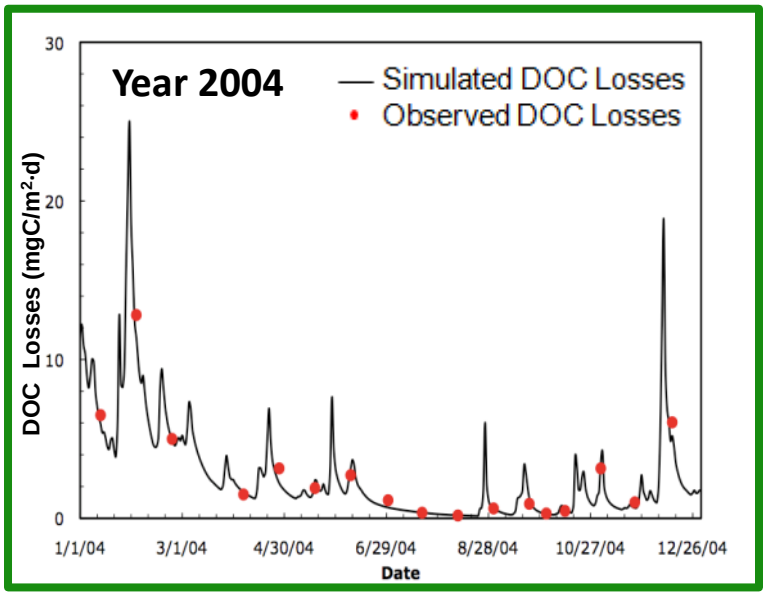
Clearcut

WS10: change in streamflow due to clearcutting



WS10 stream chemistry validation





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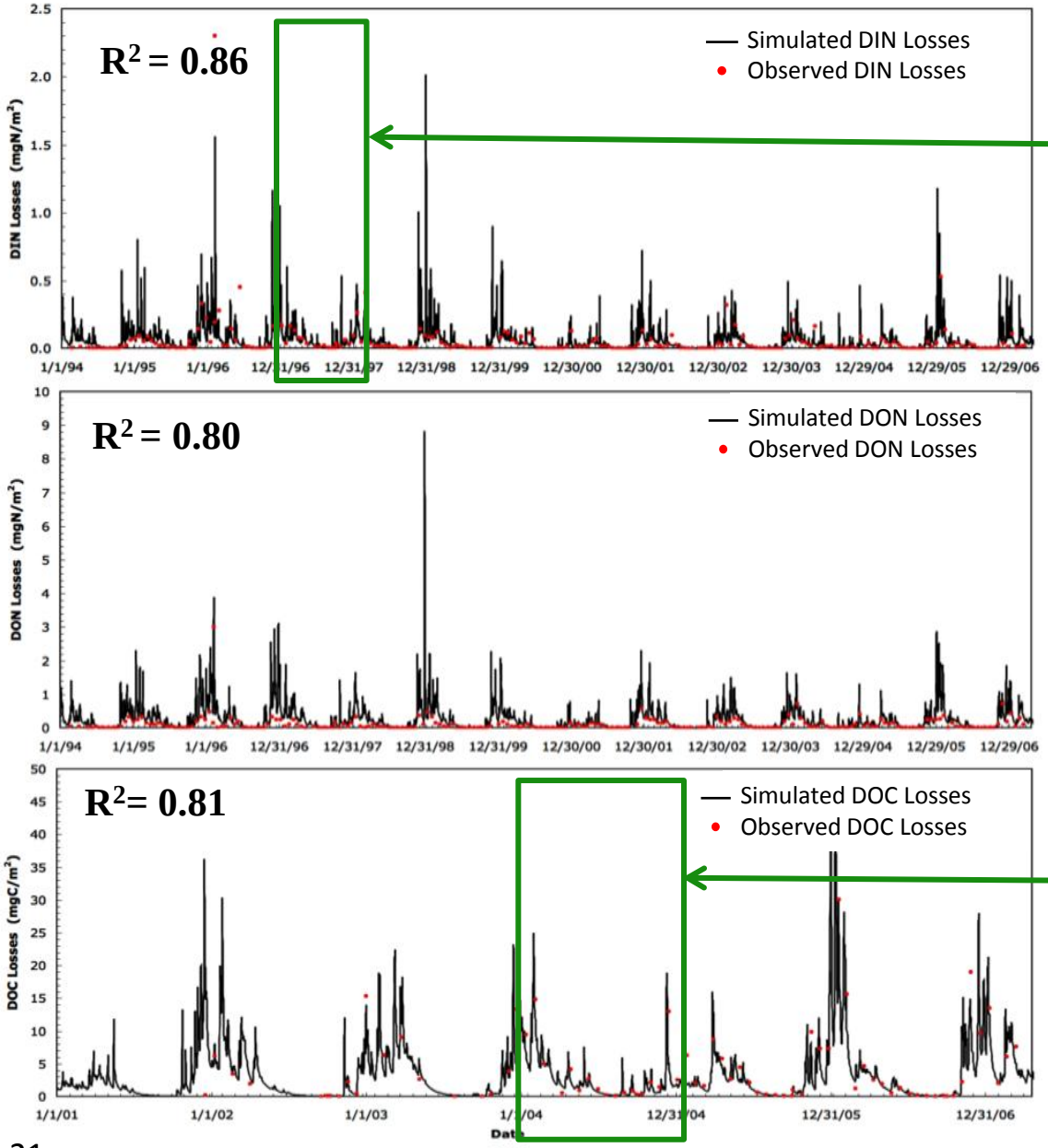
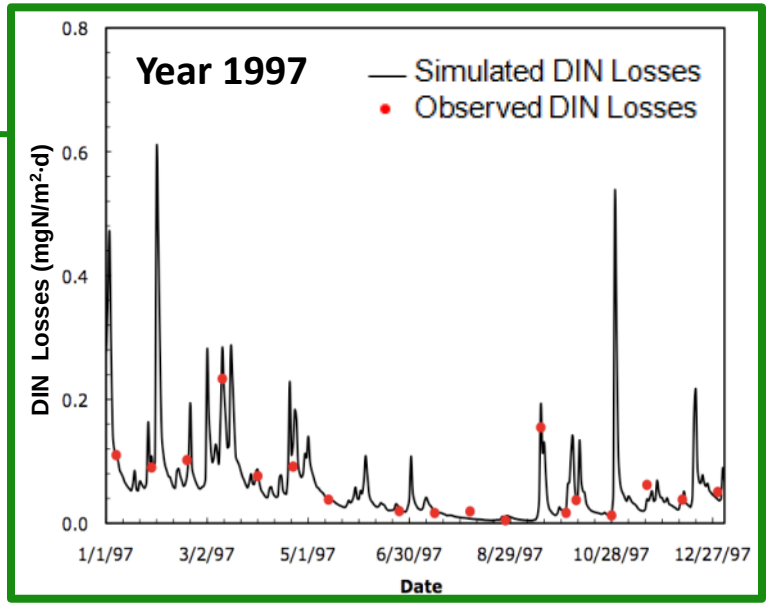
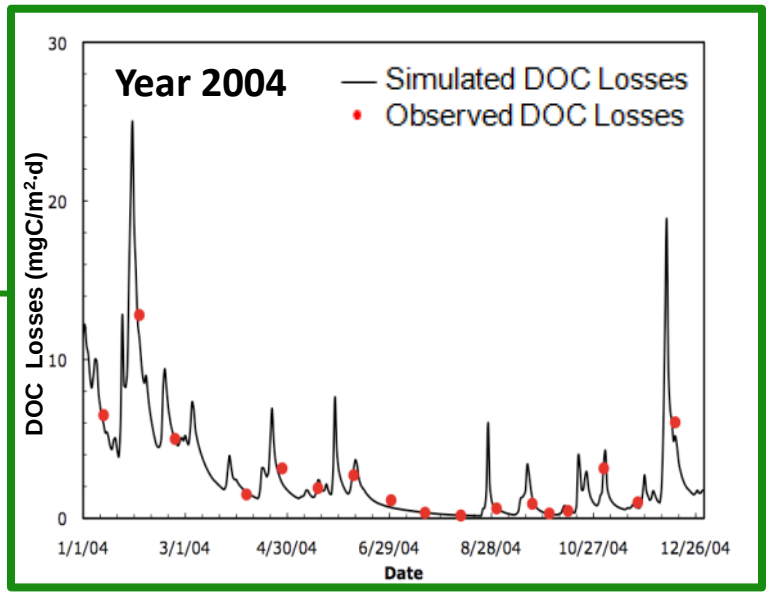
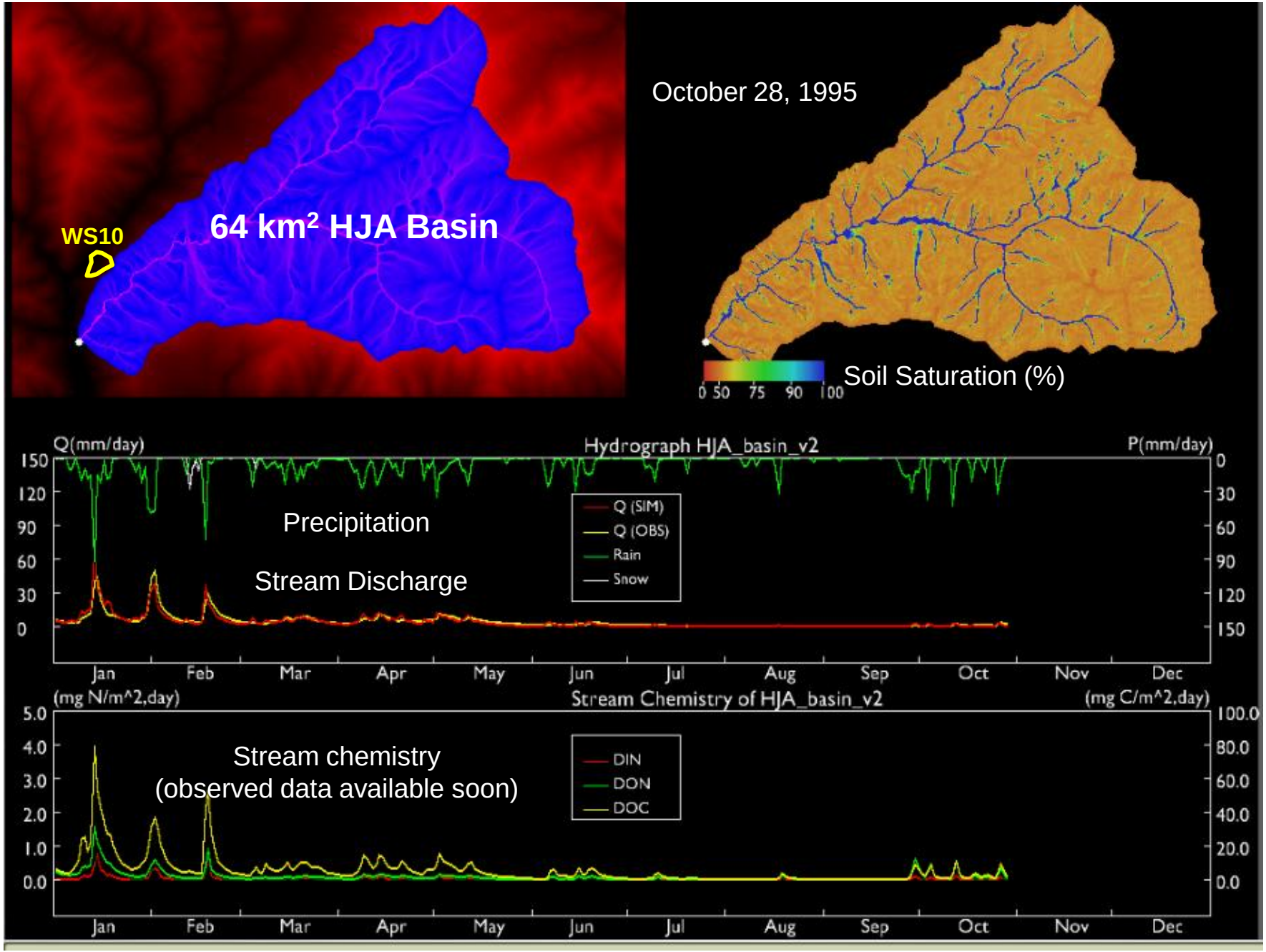


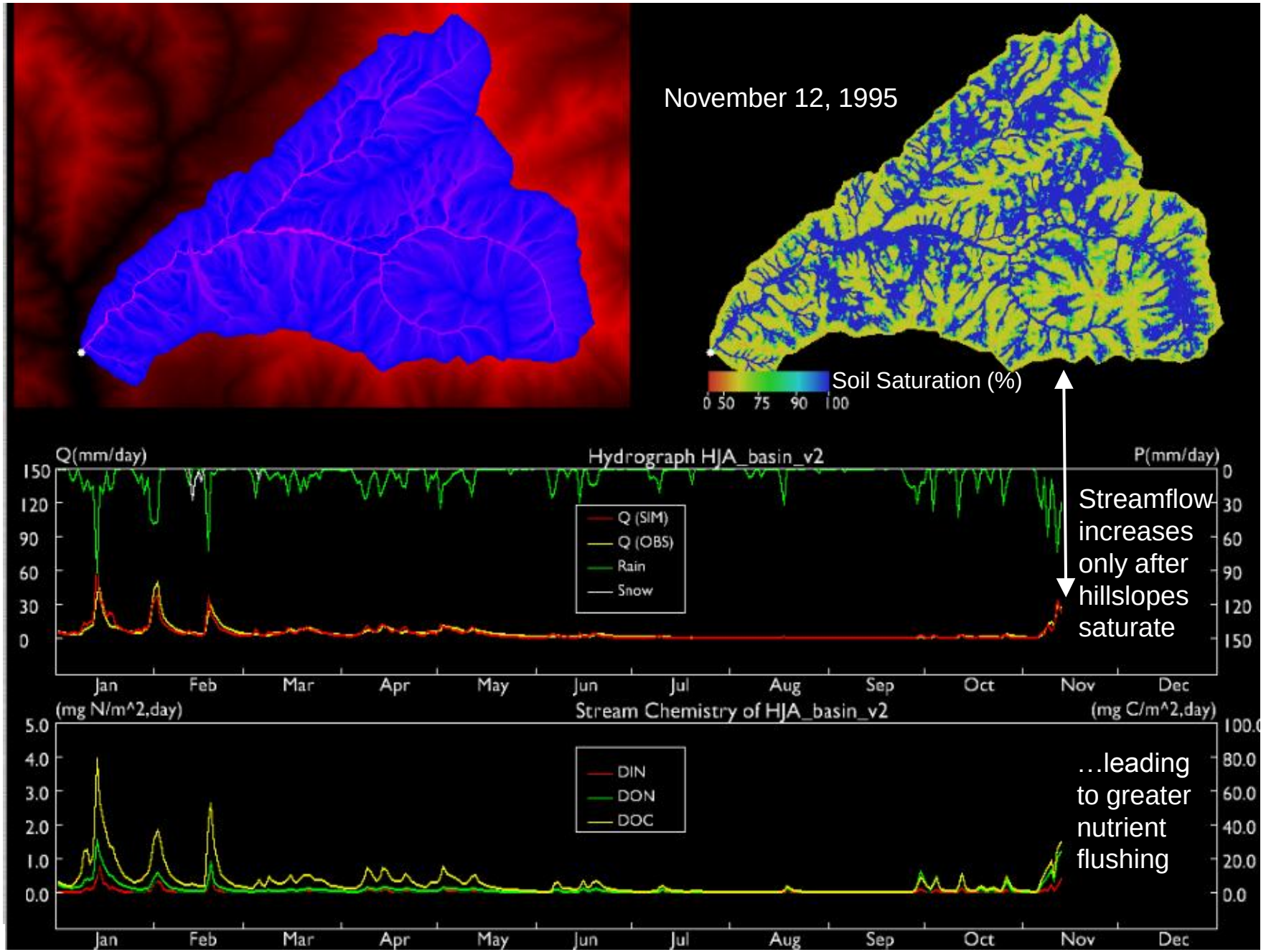




Hydrologic validation across multiple spatial scales



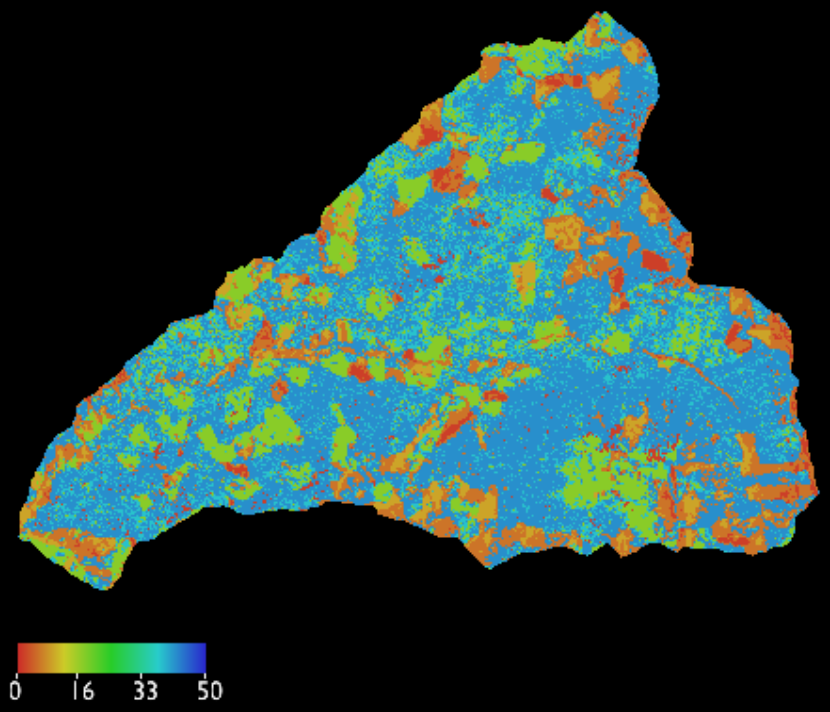
Changes in hillslope connectivity and flushing



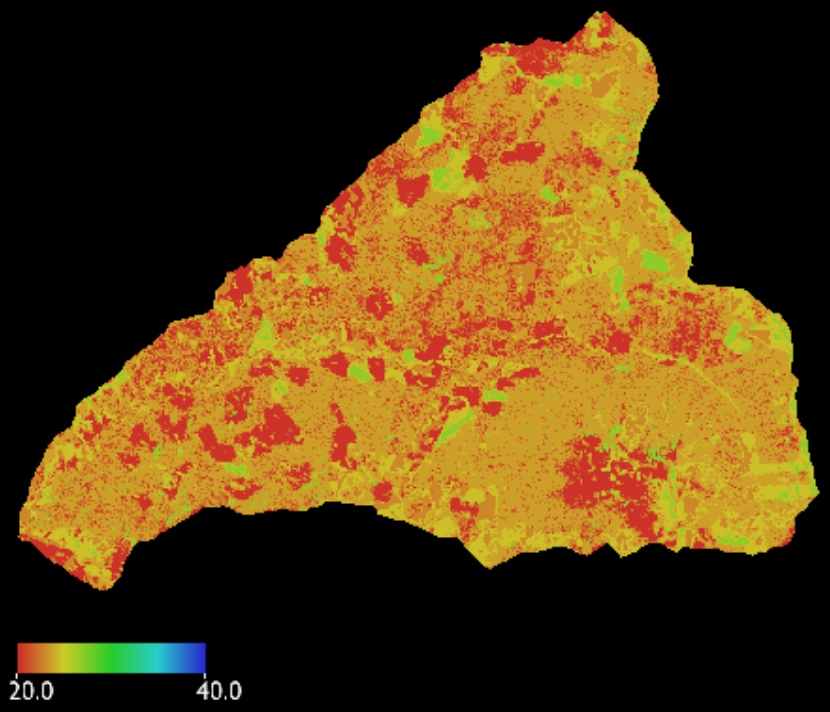
Simulated Carbon Stocks

Present-day land cover, 64 km^2 basin

Plant Carbon (kgC/m^2)



Soil Carbon (kgC/m^2)



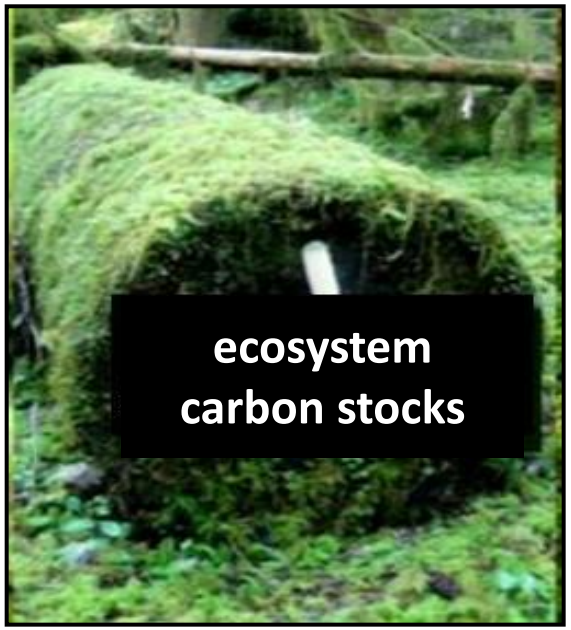
Ecosystem services demo:
three alternative management scenarios for 64 km^2 HJ Andrews Basin

No Harvest
(maintain pre-European old-growth landscape)

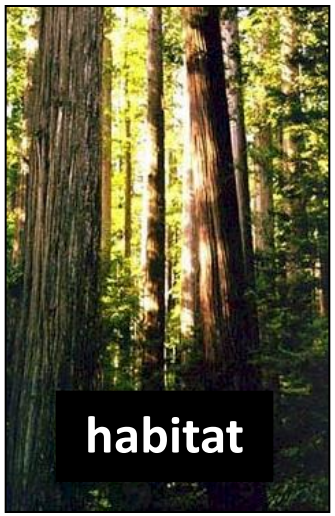
100% Clearcut
(hypothetical)

Present-Day Land Cover
(~45% harvested, 55% old-growth)

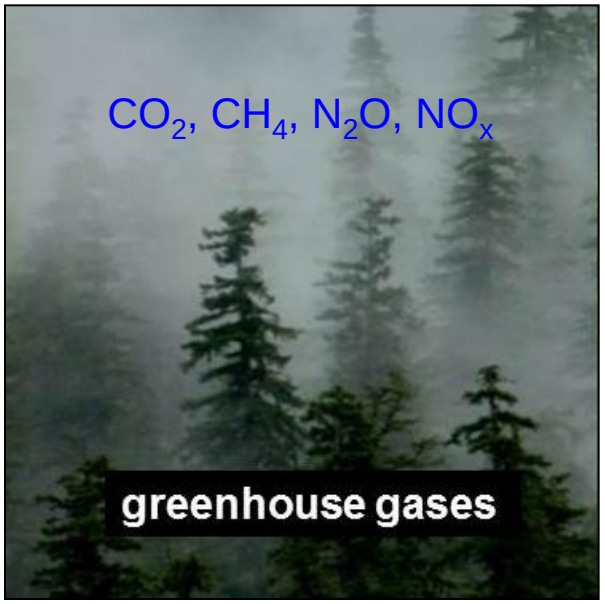
Goal: simulate trade-offs among multiple ecosystem services in response to alternative management decisions



Trade-offs?

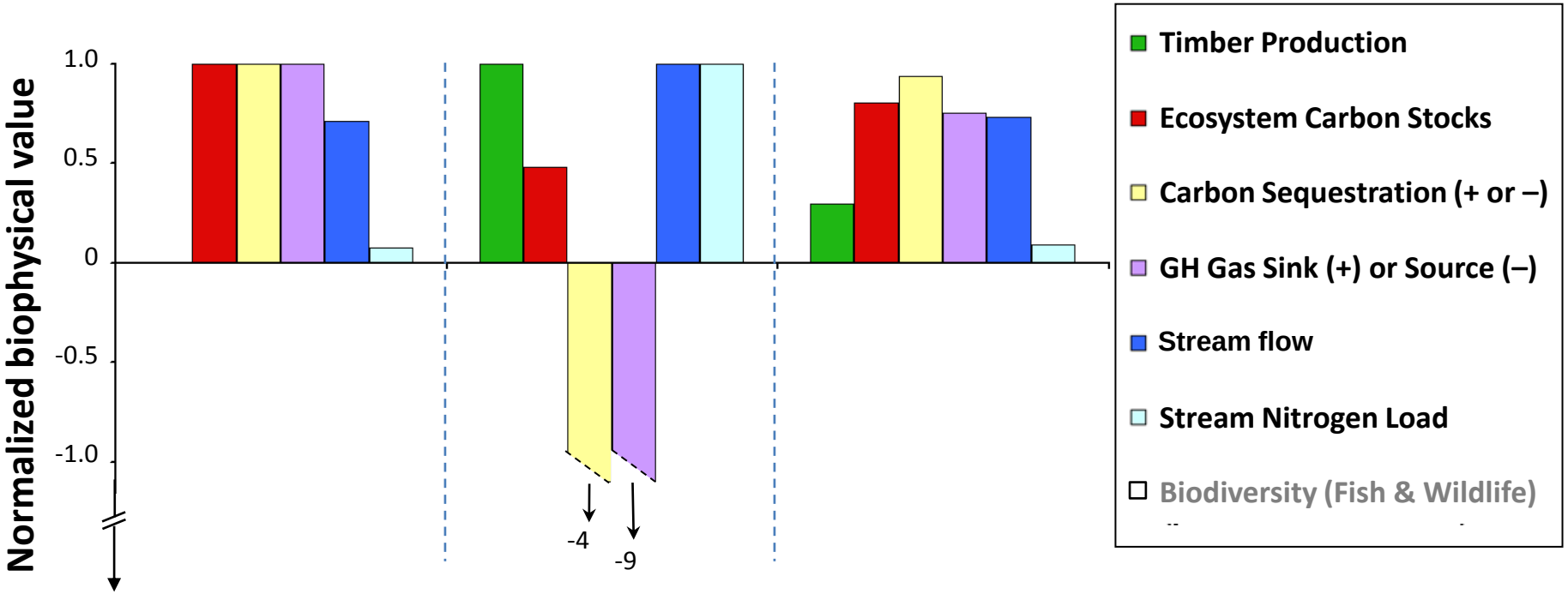


Trade-offs?



Simulated ecosystem service trade-offs for three alternative forest management scenarios

64 km² HJ Andrews Basin



Scenario 1:
No Harvest
(maintain pre-European old-growth landscape)

Scenario 2:
100% Clearcut
(results for 1st five yr after hypothetical cut)

Scenario 3:
Present Land Cover
(45% clear cut, 55% old-growth)

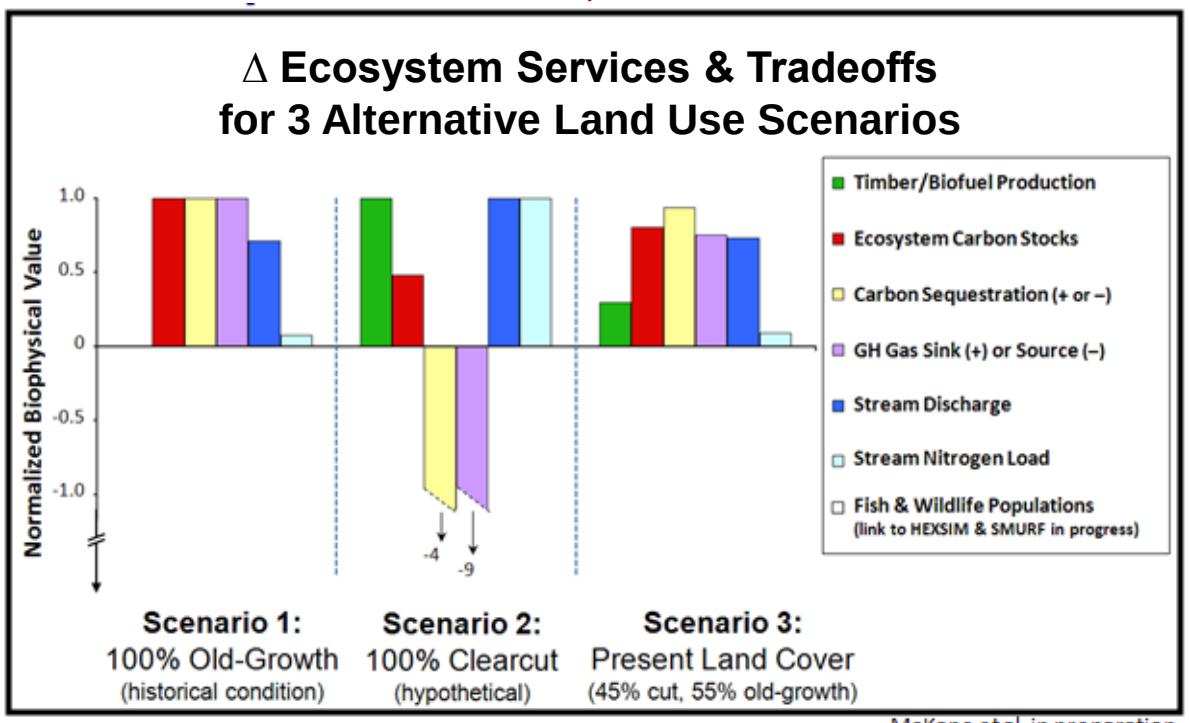
McKane et al. in prep

Incorporate VELMA in decision support framework that can

(1) help land managers & policymakers define alternative future decision scenarios

(2) Identify sustainable land use practices that balance environmental, economic and social criteria

Client-defined Decision Scenarios (land use, climate policies, etc)



McKane et al. in preparation

Benefit Functions

Δ Human Well-Being (environmental, economic and social)

ENVISION Decision Support Tool

http://envision.bioe.orst.edu/

John Bolte, Oregon State University

Actors

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

Landscape Feedbacks

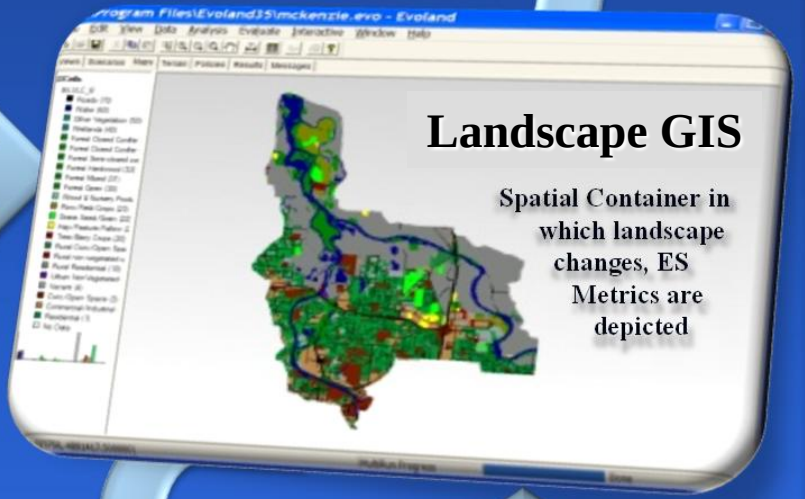
Landscape Production Models

Generating Landscape Metrics Reflecting Ecosystem Service Productions

Scenario Definition

Multiagent Decision-making

Select policies and generate land management decision affecting landscape pattern



Policies

Fundamental Descriptors of constraints and actions defining land use management decisionmaking

Environmental Models:

Ecohydrology, Wildlife, Fish…

Stakeholder Engagement – Early and Often

VELMA Modeling Team

Biogeochemistry:

Bob McKane, EPA

Hydrology:

Marc Stieglitz, Georgia Tech

Alex Abdelnour, Georgia Tech (McKinsey & Company)

Feifei Pan, University of North Texas

Economics:

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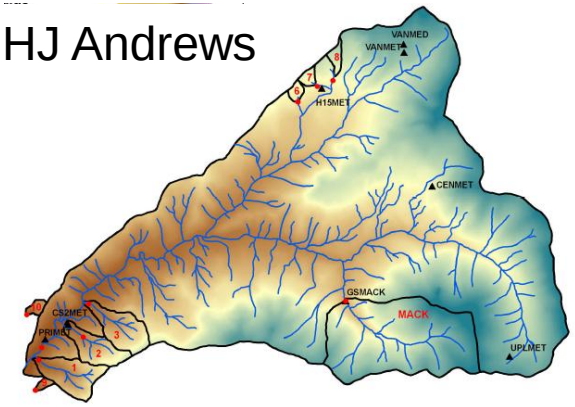
Computer science is essential to state-of-art environmental assessments

1) Computational efficiency

HJ Andrews



- 64 km^2 = 71,000 VELMA pixels (30x30 meter)
- ~100 differential equations solved per pixel per simulated day
- 71,000 X 100 = 7.1 million equations per day
- ~2.6 billion equations per simulated year

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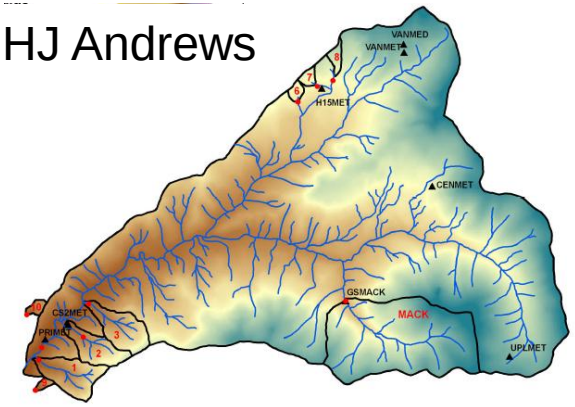

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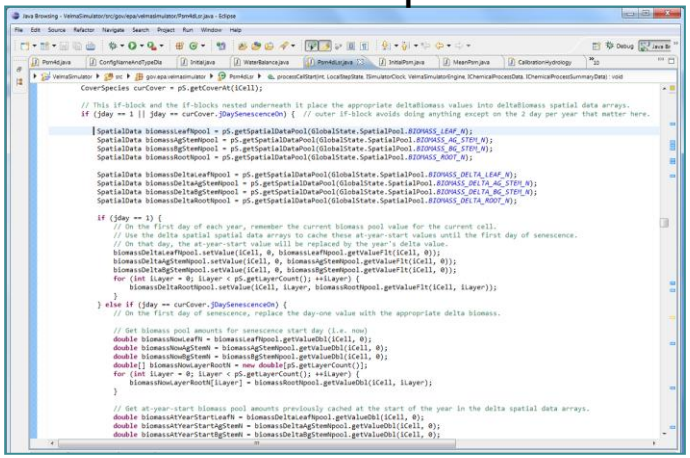
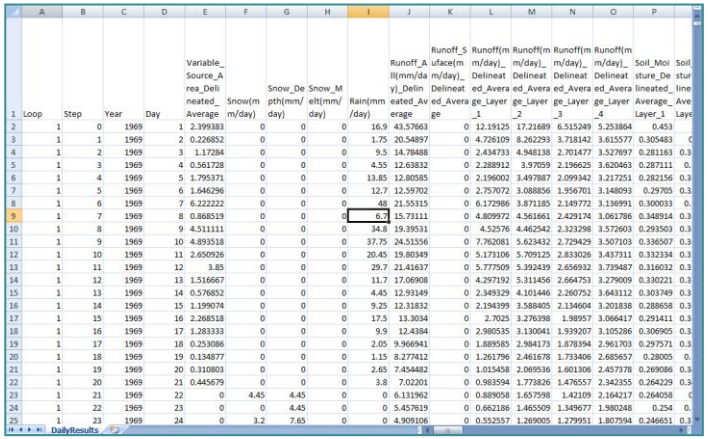
JAVA Eclipse



VELMA requires <1 hour of real time to simulate 1 year for HJ Andrews

Computer science is essential to state-of-art environmental assessments

2) Data visualization



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1	Loop	Step	Year	Day	Variable_Source_Area_Delineated_Average	Snow(mm/day)	Snow_Depth(mm/day)	Snow_Melt(mm/day)	Rain(mm/day)	Runoff_All(mm/day)_Delineated_Average	Runoff_Surface(mm/day)_Delineated_Average	Runoff(mm/day)_Delineated_Average_Layer_1	Runoff(mm/day)_Delineated_Average_Layer_2	Runoff(mm/day)_Delineated_Average_Layer_3	Runoff(mm/day)_Delineated_Average_Layer_4	Soil_Moisture_Delineated_Average_Layer_1	Soil stur line Laye
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3	1	1	1969	2	0.226852	0	0	0	1.75	20.54897	0	4.726109	8.262293	3.718142	3.615577	0.305483	C
4	1	2	1969	3	1.17284	0	0	0	9.5	14.78488	0	2.434733	4.948138	2.701477	3.527697	0.281163	0.3
5	1	3	1969	4	0.561728	0	0	0	4.55	12.63832	0	2.288912	3.97059	2.196625	3.620463	0.287111	0.
6	1	4	1969	5	1.795371	0	0	0	13.85	12.80585	0	2.196002	3.497887	2.099342	3.217251	0.282156	0.3
7	1	5	1969	6	1.646296	0	0	0	12.7	12.59702	0	2.757072	3.088856	1.956701	3.148093	0.29705	0.3
8	1	6	1969	7	6.222222	0	0	0	48	21.55315	0	6.172986	3.871185	2.149772	3.136991	0.300033	0.
9	1	7	1969	8	0.868519	0	0	0	6.7	15.73111	0	4.809972	4.561661	2.429174	3.061786	0.348914	0.3
10	1	8	1969	9	4.511111	0	0	0	34.8	19.39531	0	4.52576	4.462542	2.323298	3.572603	0.293503	0.3
11	1	9	1969	10	4.893518	0	0	0	37.75	24.51556	0	7.762081	5.623432	2.729429	3.507103	0.336507	0.3
12	1	10	1969	11	2.650926	0	0	0	20.45	19.80349	0	5.173106	5.709125	2.833026	3.437311	0.332334	0.3
13	1	11	1969	12	3.85	0	0	0	29.7	21.41637	0	5.777509	5.392439	2.656932	3.739487	0.316032	0.3
14	1	12	1969	13	1.516667	0	0	0	11.7	17.06908	0	4.297192	5.311456	2.664753	3.279009	0.330221	0.3
15	1	13	1969	14	0.576852	0	0	0	4.45	12.93149	0	2.349329	4.101446	2.260752	3.643112	0.303749	0.3
16	1	14	1969	15	1.199074	0	0	0	9.25	12.31832	0	2.194399	3.588405	2.134604	3.201838	0.288658	0.3
17	1	15	1969	16	2.268518	0	0	0	17.5	13.3034	0	2.7025	3.276398	1.98957	3.066417	0.291411	0.3
18	1	16	1969	17	1.283333	0	0	0	9.9	12.4384	0	2.980535	3.130041	1.939207	3.105286	0.306905	0.3
19	1	17	1969	18	0.253086	0	0	0	2.05	9.966941	0	1.889585	2.984173	1.878394	2.961703	0.297571	0.3
20	1	18	1969	19	0.134877	0	0	0	1.15	8.277412	0	1.261796	2.461678	1.733406	2.685657	0.28005	0.
21	1	19	1969	20	0.310803	0	0	0	2.65	7.454482	0	1.015458	2.069536	1.601306	2.457378	0.269086	0.3
22	1	20	1969	21	0.445679	0	0	0	3.8	7.02201	0	0.983594	1.773826	1.476557	2.342355	0.264229	0.3
23	1	21	1969	22	0	4.45	4.45	0	0	6.131962	0	0.889058	1.657598	1.42109	2.164217	0.264058	C
24	1	22	1969	23	0	0	4.45	0	0	5.457619	0	0.662186	1.465509	1.349677	1.980248	0.254	0.
25	1	23	1969	24	0	3.2	7.65	0	0	4.909106	0	0.552557	1.269005	1.279951	1.807594	0.246651	0.3

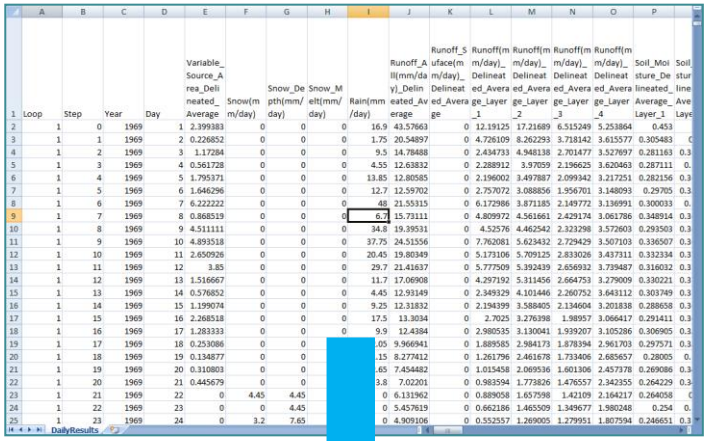
DailyResults

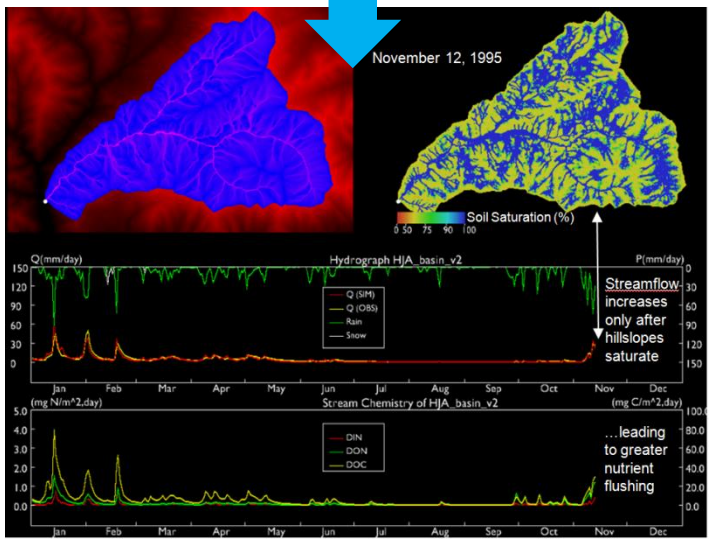
VELMA generates ~1 GB of output for HJ Andrews multi-century simulations...

…very difficult to interpret & communicate results without visualization tools!

Computer science is essential to state-of-art environmental assessments

2) Data visualization





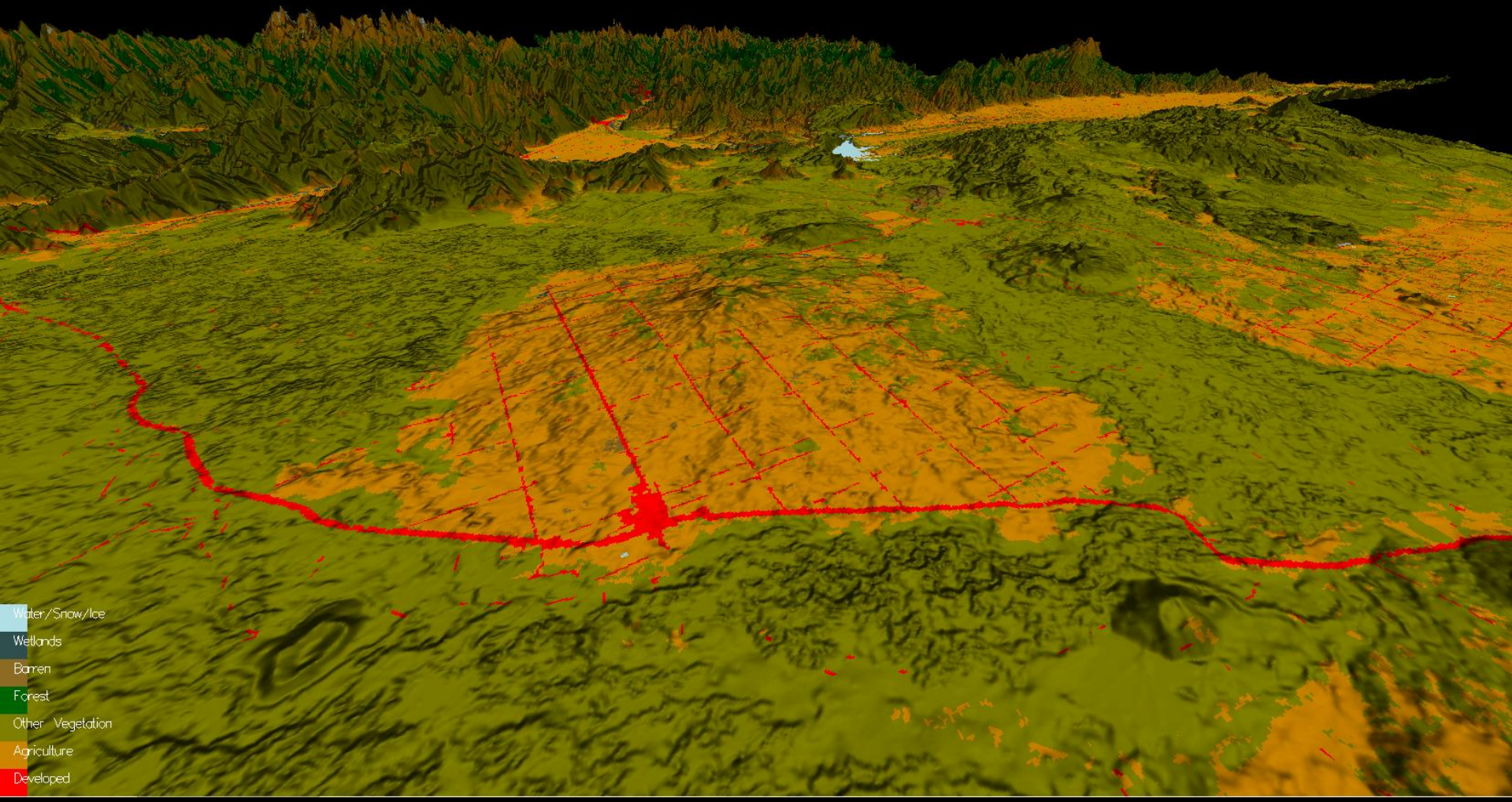
VELMA generates ~1 GB of output for HJ Andrews multi-century simulations

…very difficult to interpret & communicate results without visualization tools!

- Line charts & bar graphs
- 2D spatial-temporal displays (on-the-fly visualization for calibration)
- 3D spatial-temporal displays (e.g., VISTAS post-simulation visualization)

VISTAS visualization software

Dr. Judy Cushing & collaborators




Thanks!