Indicators of water quantity and quality

Lucinda B. Johnson, Dan Breneman, Valerie Brady, Jan Ciborowski, Yakuta Baghat

Sustainable Water Resources Roundtable
Ann Arbor, MI
April 5,6, 2004

Human Activities That Influence Water Quantity and Quality

Activity	**Mechanism**	**Response/Stress**
Water withdrawal (irrigation; drinking water)	⇓ Stream base flow ⇓ Ground water table	⇑ Water temp. (summer) ⇓ Oxygen conc. ⇑ Nutrient conc.
Agricultural field tiles	Disrupts natural hydrology – ⇑ Peak flow & flooding	⇑ Nutrients ⇑ Sediments ⇑ Pesticides ⇓ Nutrient cycling ⇓ Soil infiltration
Impervious surface	Disrupts natural hydrology – ⇑ Peak flow & flooding	⇑ Sediments ⇑ Contaminants ⇓ Nutrient cycling
Forest harvest	Disrupts natural hydrology – ⇑ Peak flow & flooding	⇑ Nutrients ⇑ Sediments ⇑ Pesticides

Impervious surfaces

Pressure

Mechanism

flooding, high runoff, erosion

Sediment running into a stream

Stressor

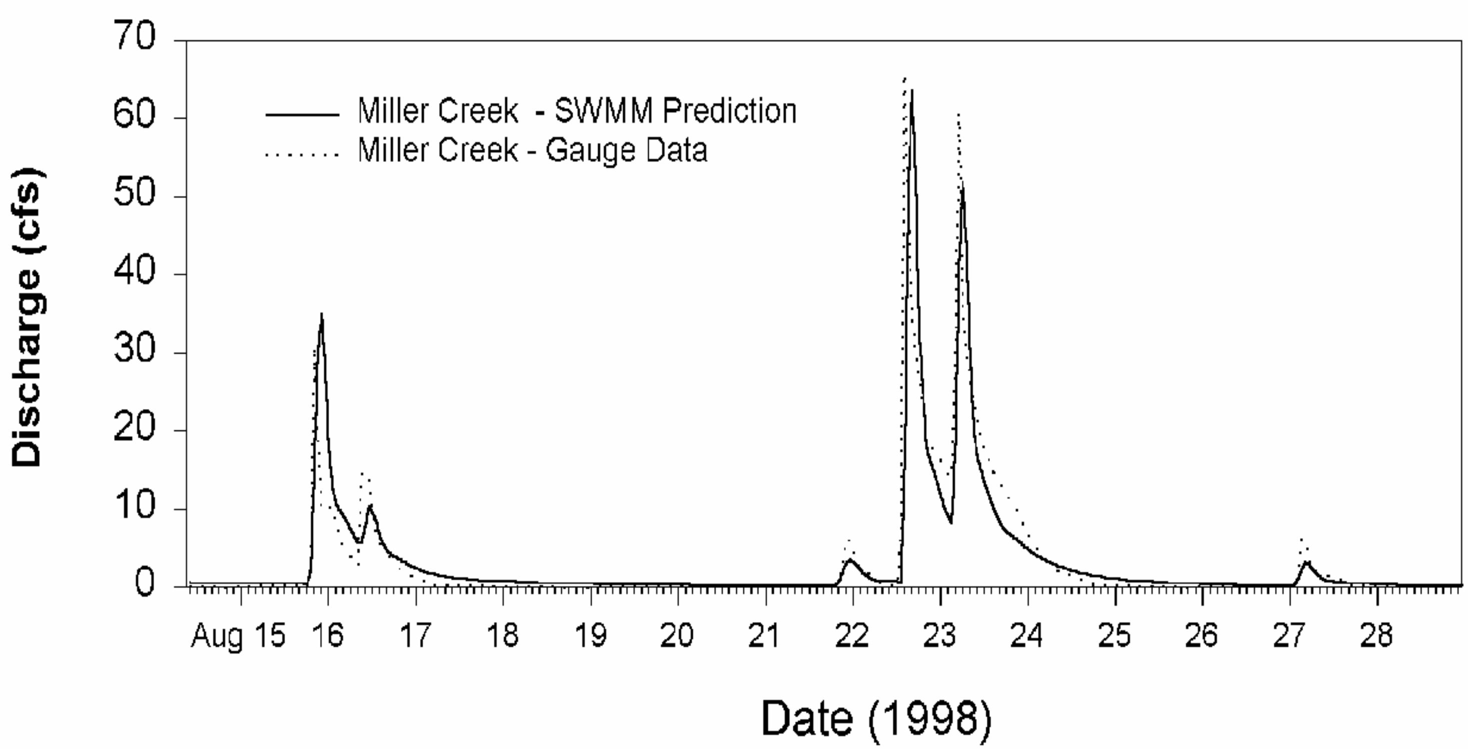
One result: Loss of turbidity-intolerant fish species

Biological Response

Best management practices (BMPs) can mitigate stresses

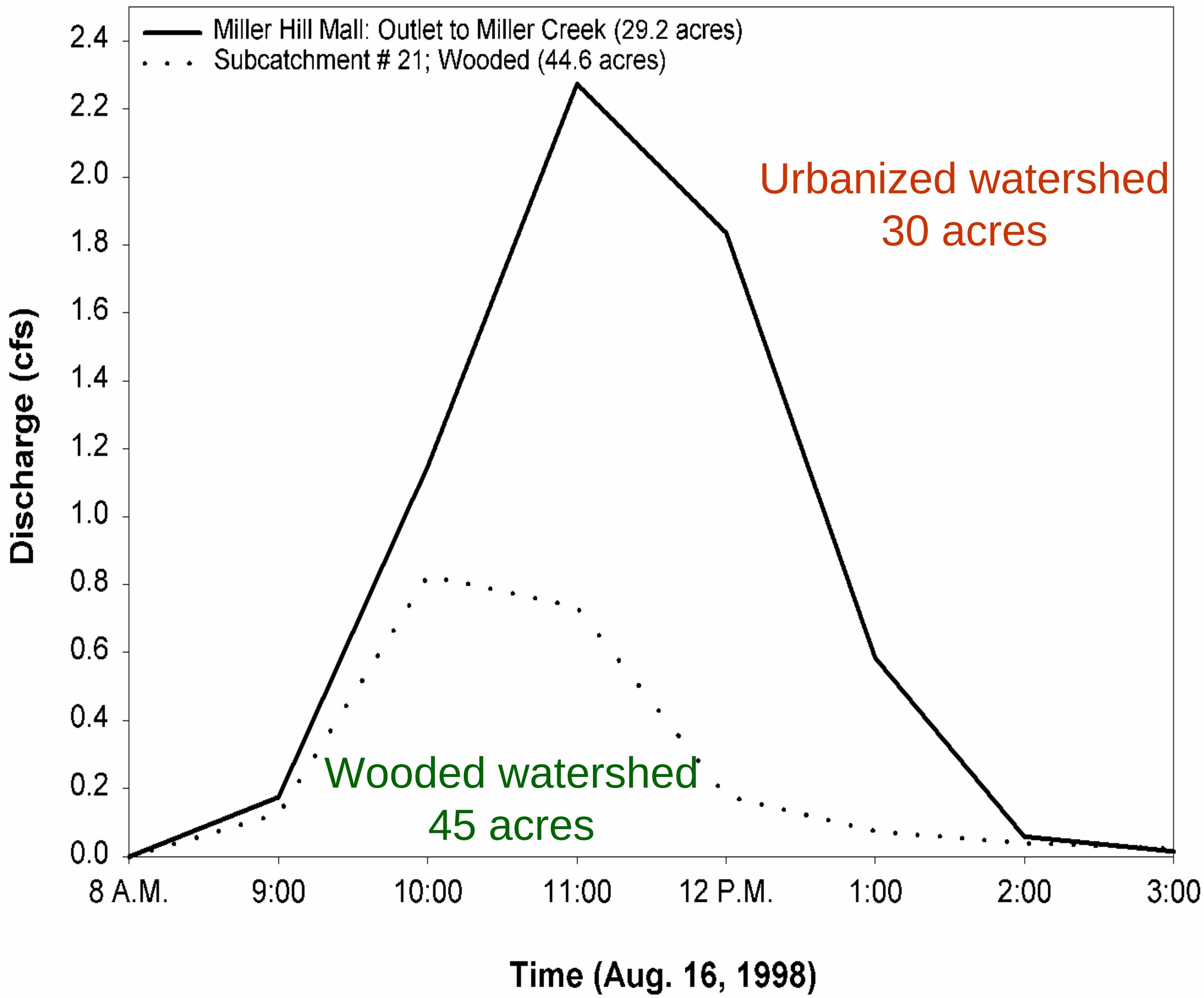
Rain gardens catch water from parking lots and other impervious surfaces. They slow the runoff, which reduces flooding, stream storm peaks, and erosion; and they allow pollutants in the water to settle out before reach streams, lakes and wetlands.

Effects of Impervious Surfaces: Stream Hydrograph



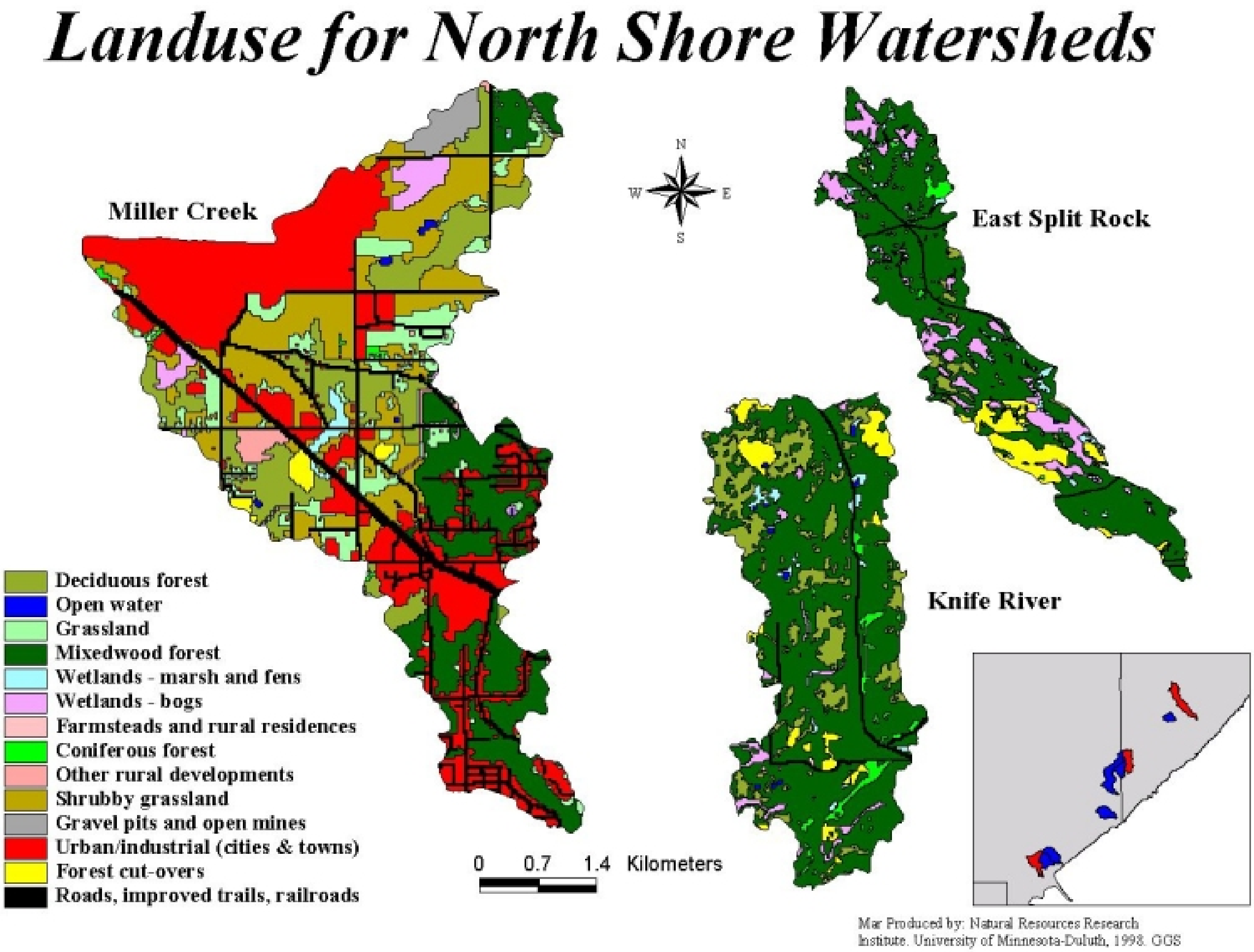
Predicted and observed discharge from middle reach of Miller Creek, a highly urbanized stream in Duluth, MN.

From Schomberg, et al.



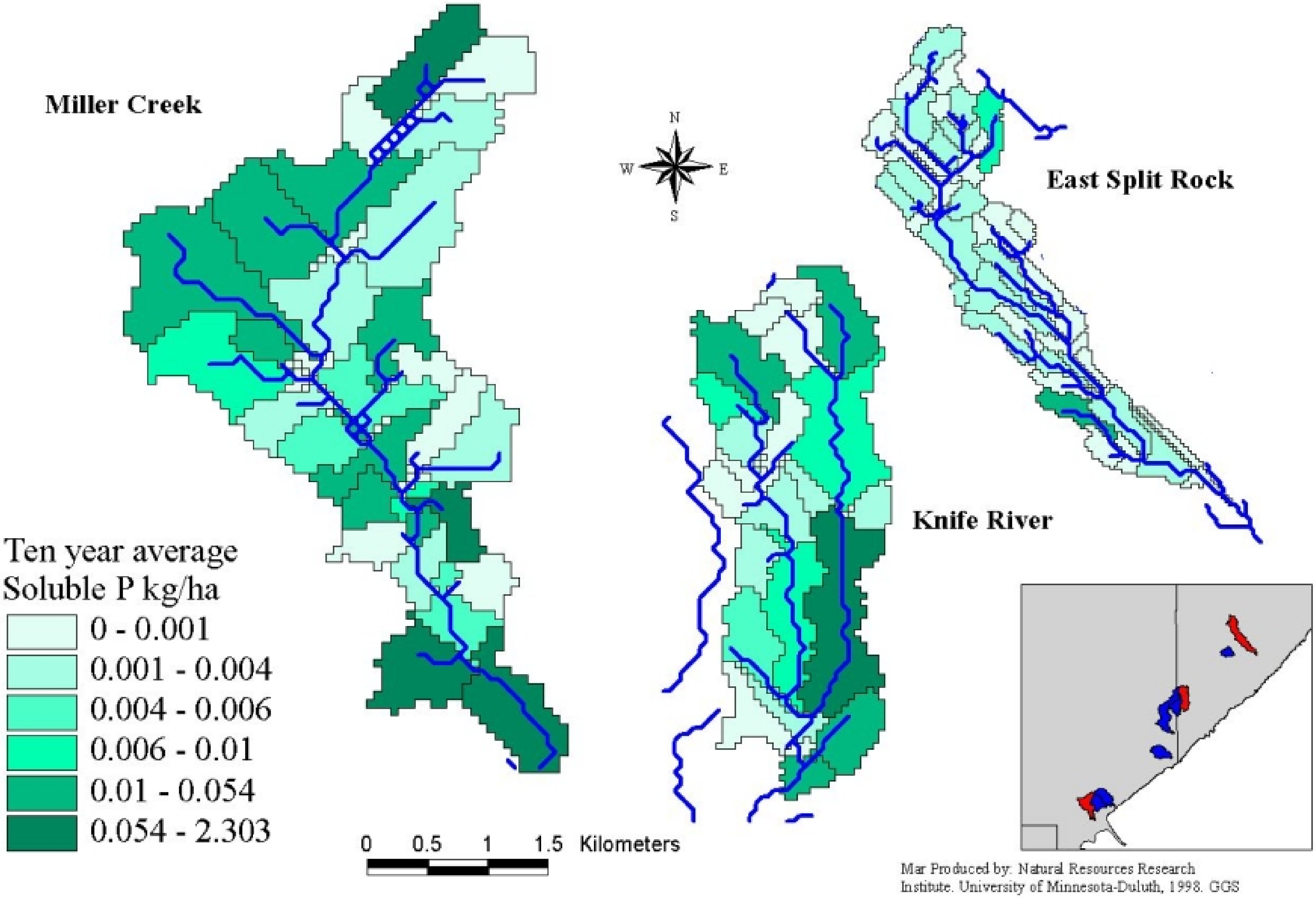
Effects of impervious surface on discharge in Miller Creek, contrasted with a nearby watershed with little urban development

From Schomberg, et al.



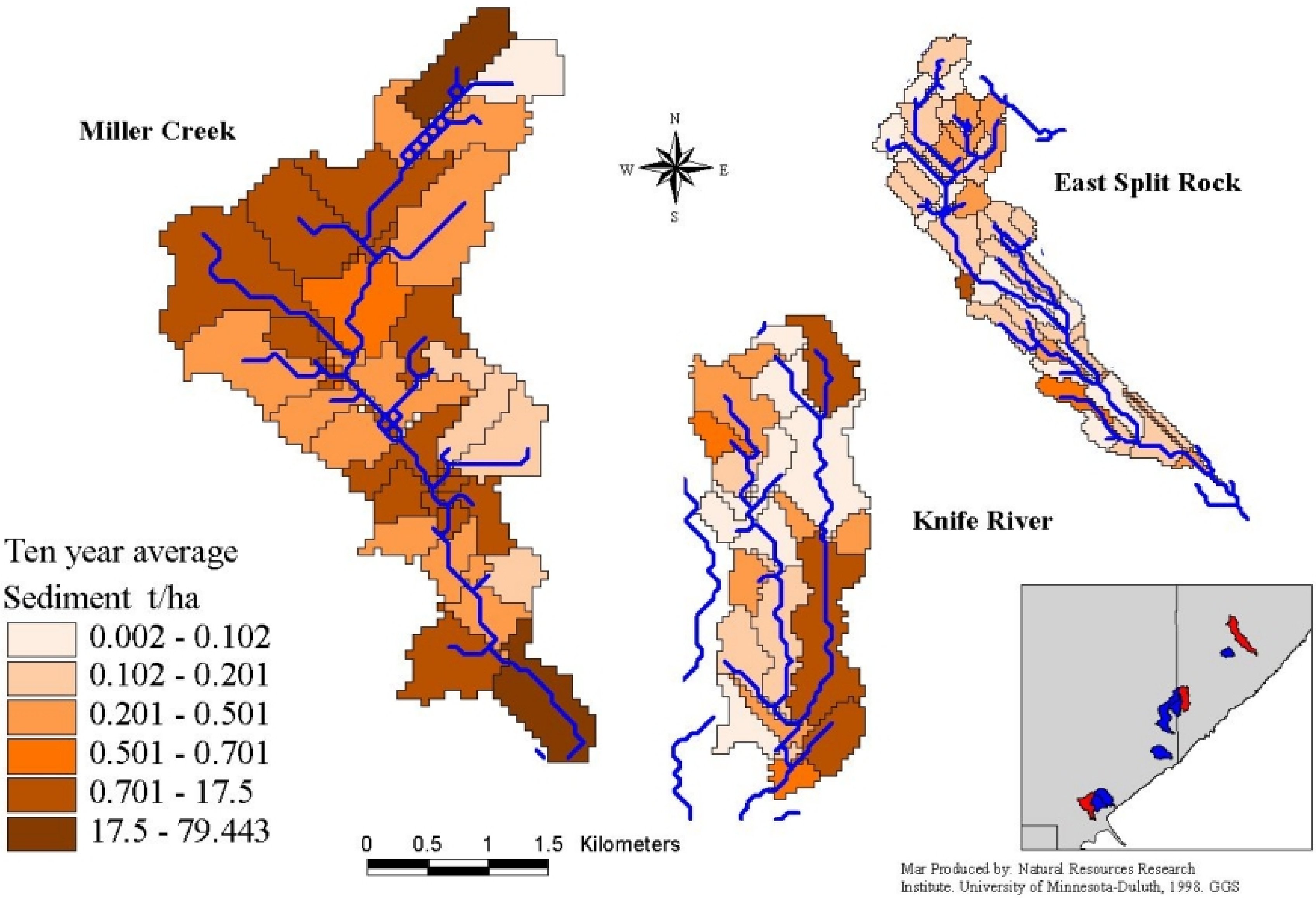
From Schomberg, et al.

Phosphorous for North Shore Watersheds



From Schomberg, et al.

Sediment Yield for North Shore Watersheds

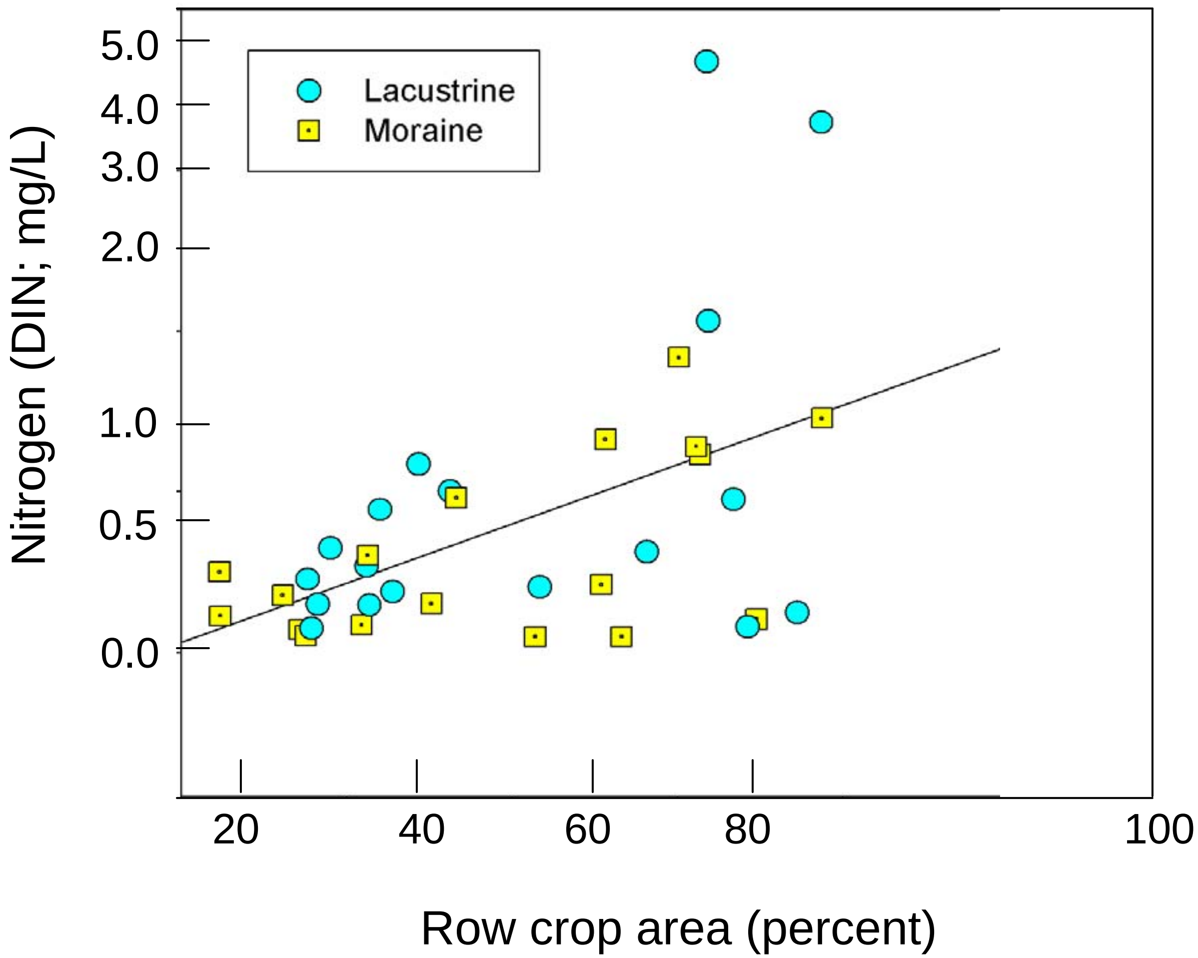


From Schomberg, et al.

Effects of Agriculture:

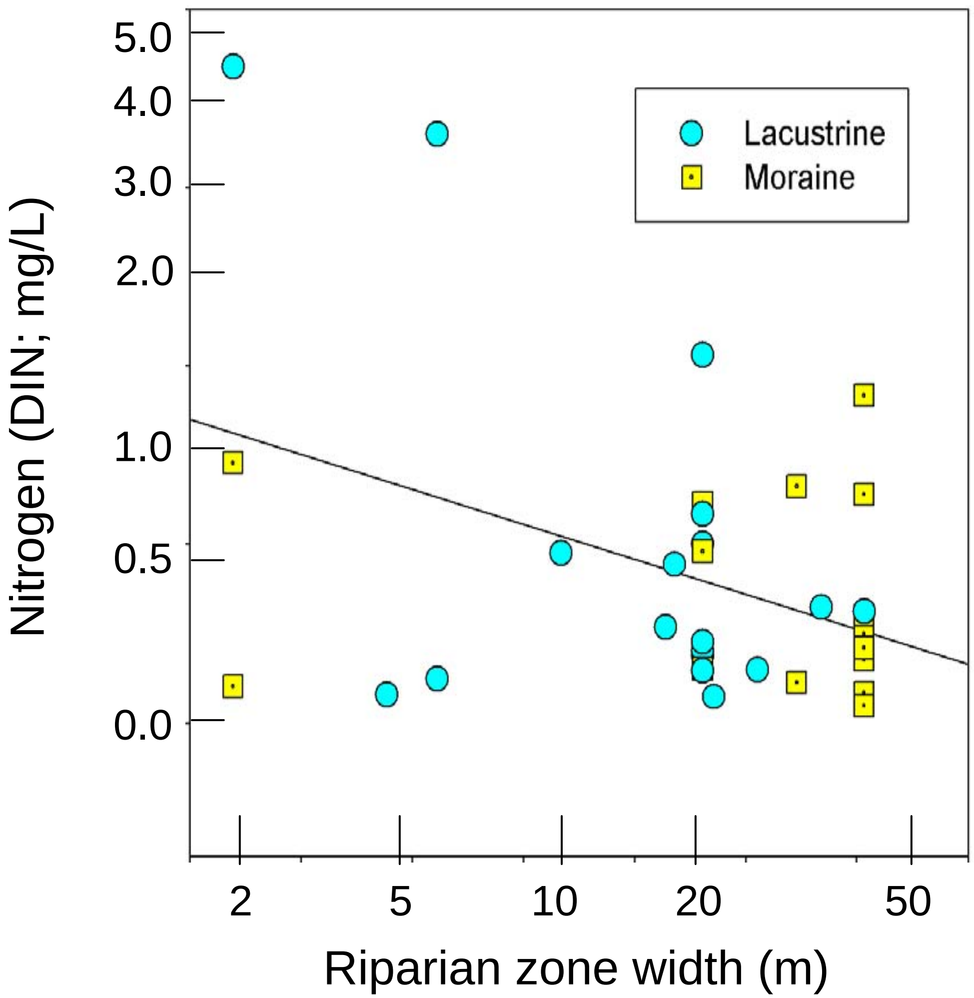
From: USGS

More row crop agriculture leads to more nutrients in streams



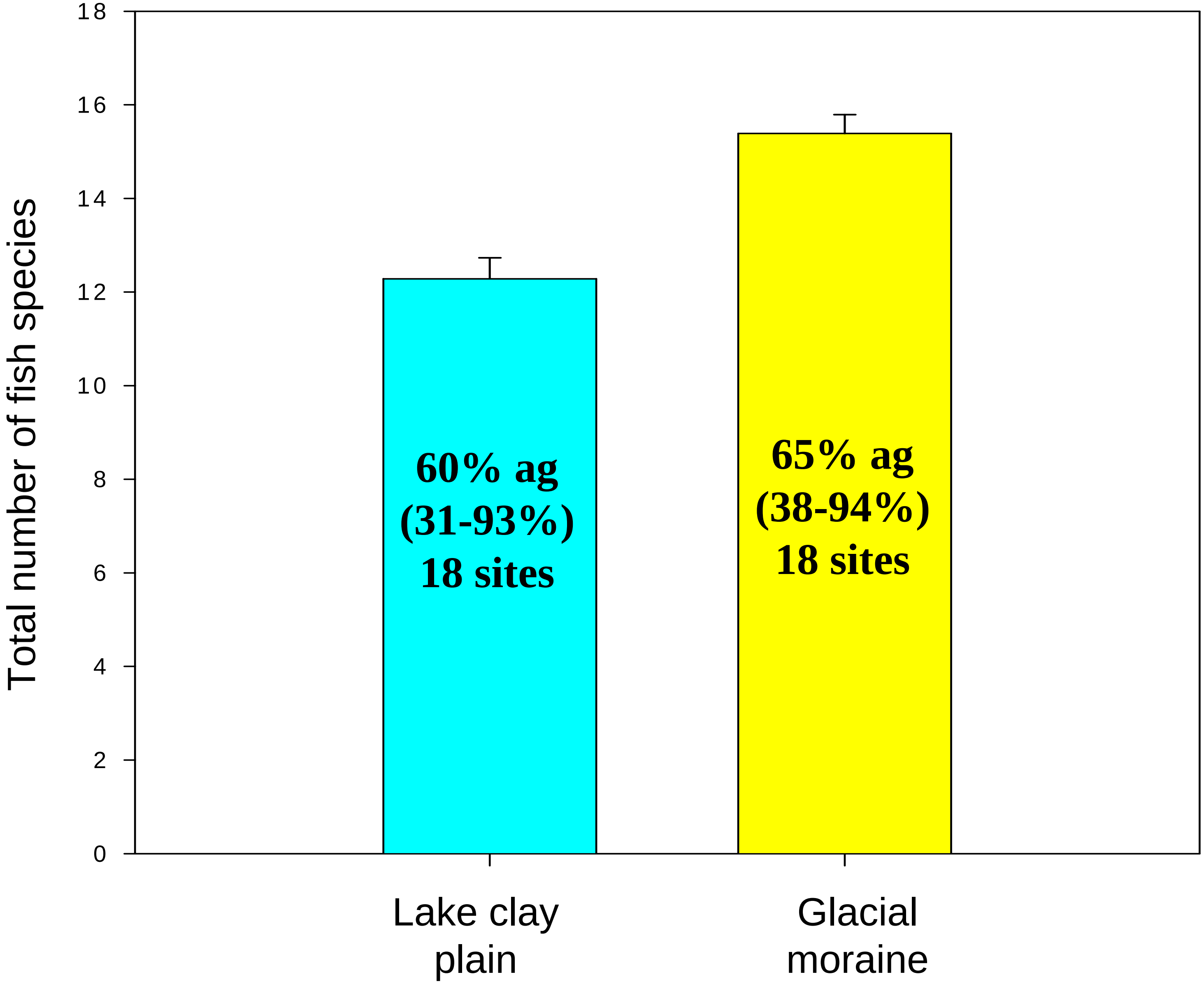
From Johnson et al. 1997

However, undisturbed buffers next to streams reduce the stress



From: Johnson et al. 1997

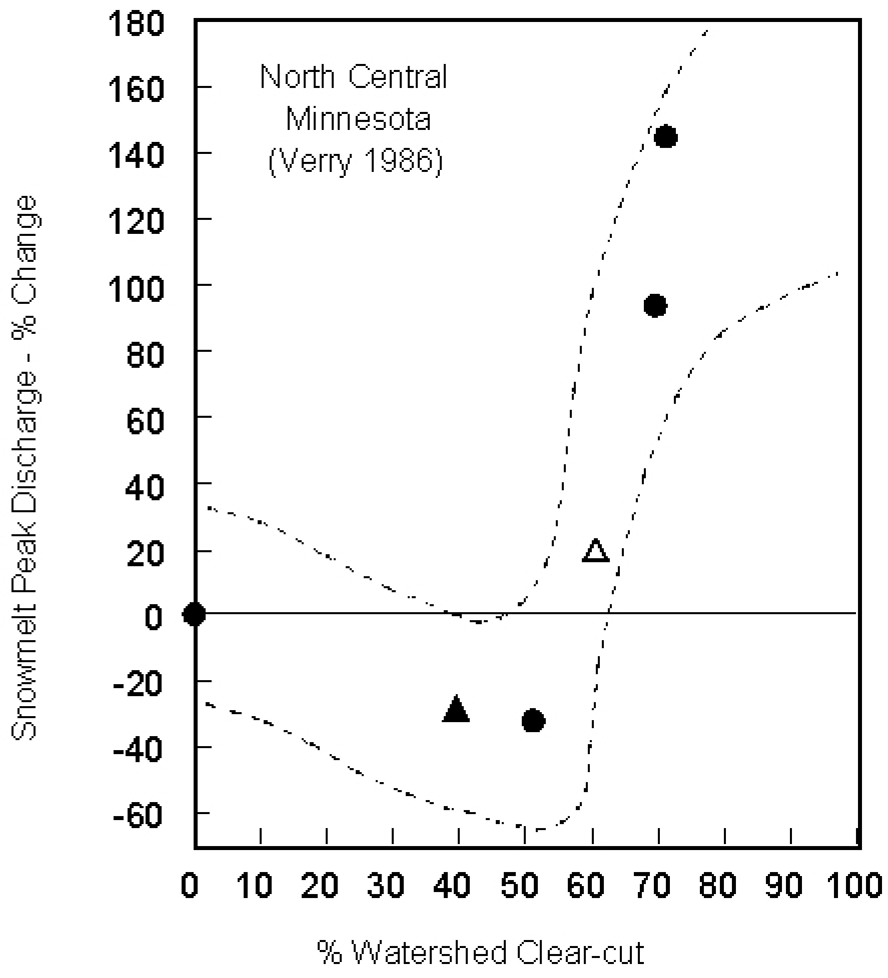
Surficial geology can mediate the effects of human disturbances



From: Johnson et al.

Effects of Forest Harvest:

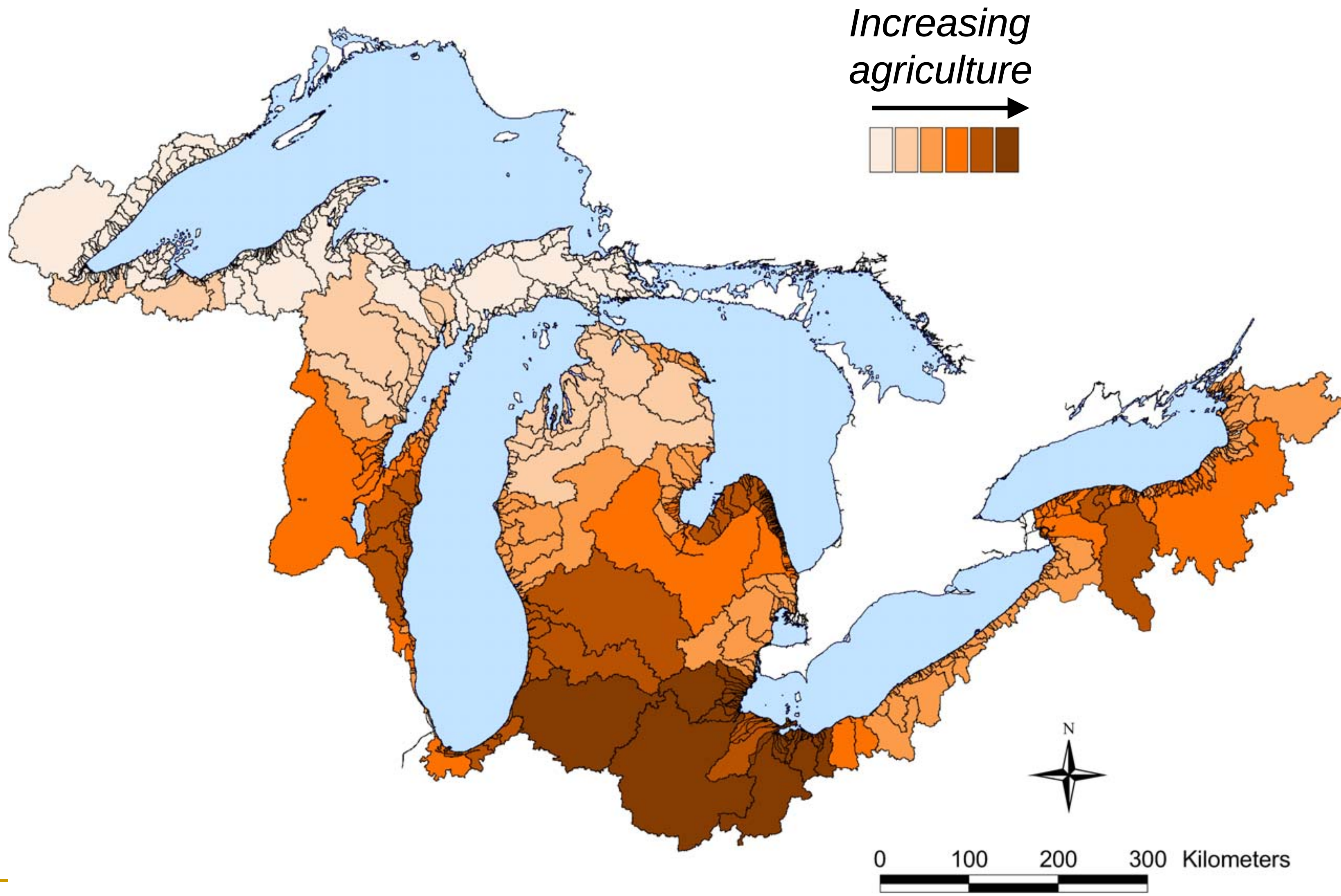
Forest fragmentation threshold

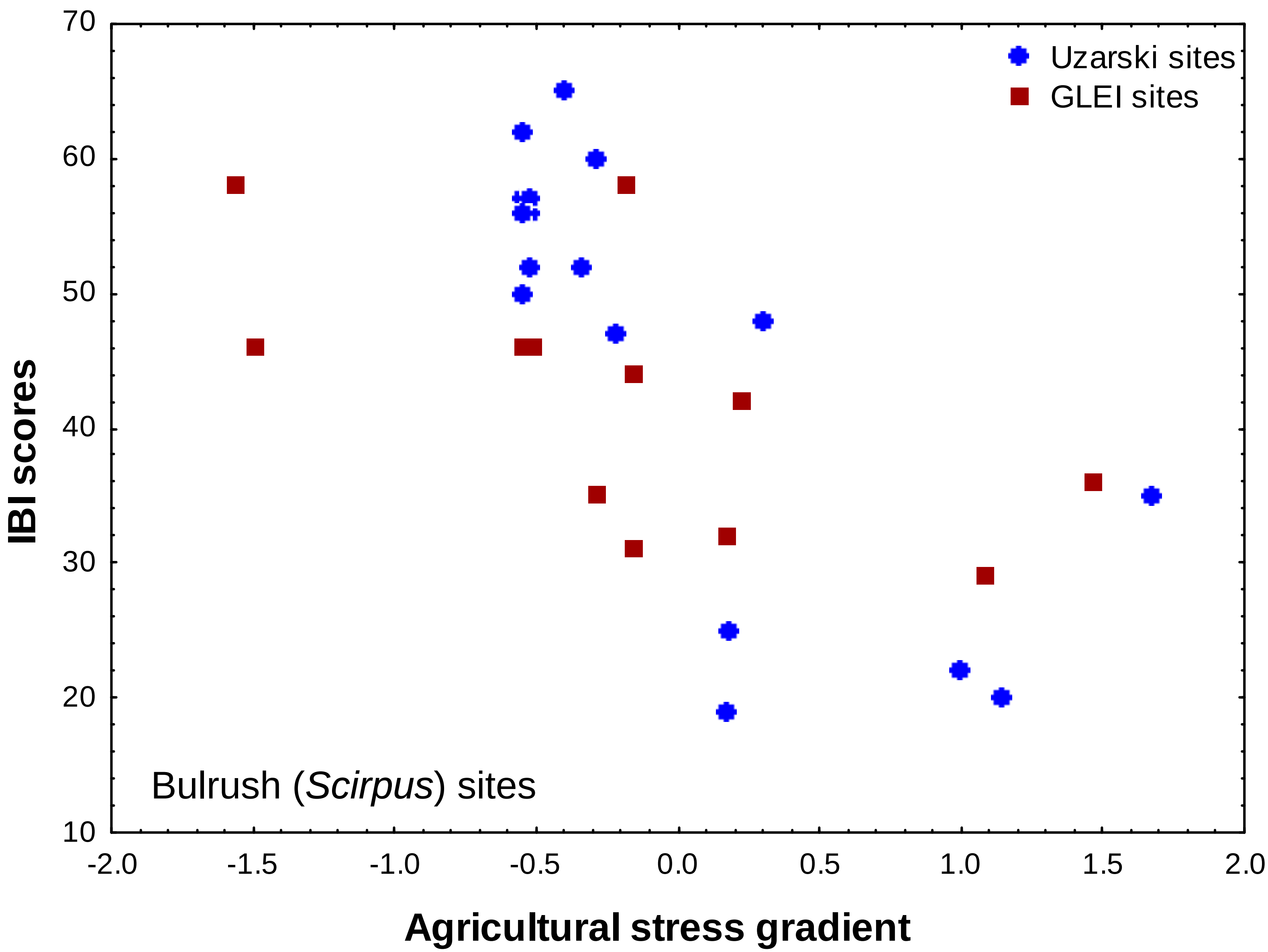


Effects of Water Withdrawal:

Photo credit: Harald Sund

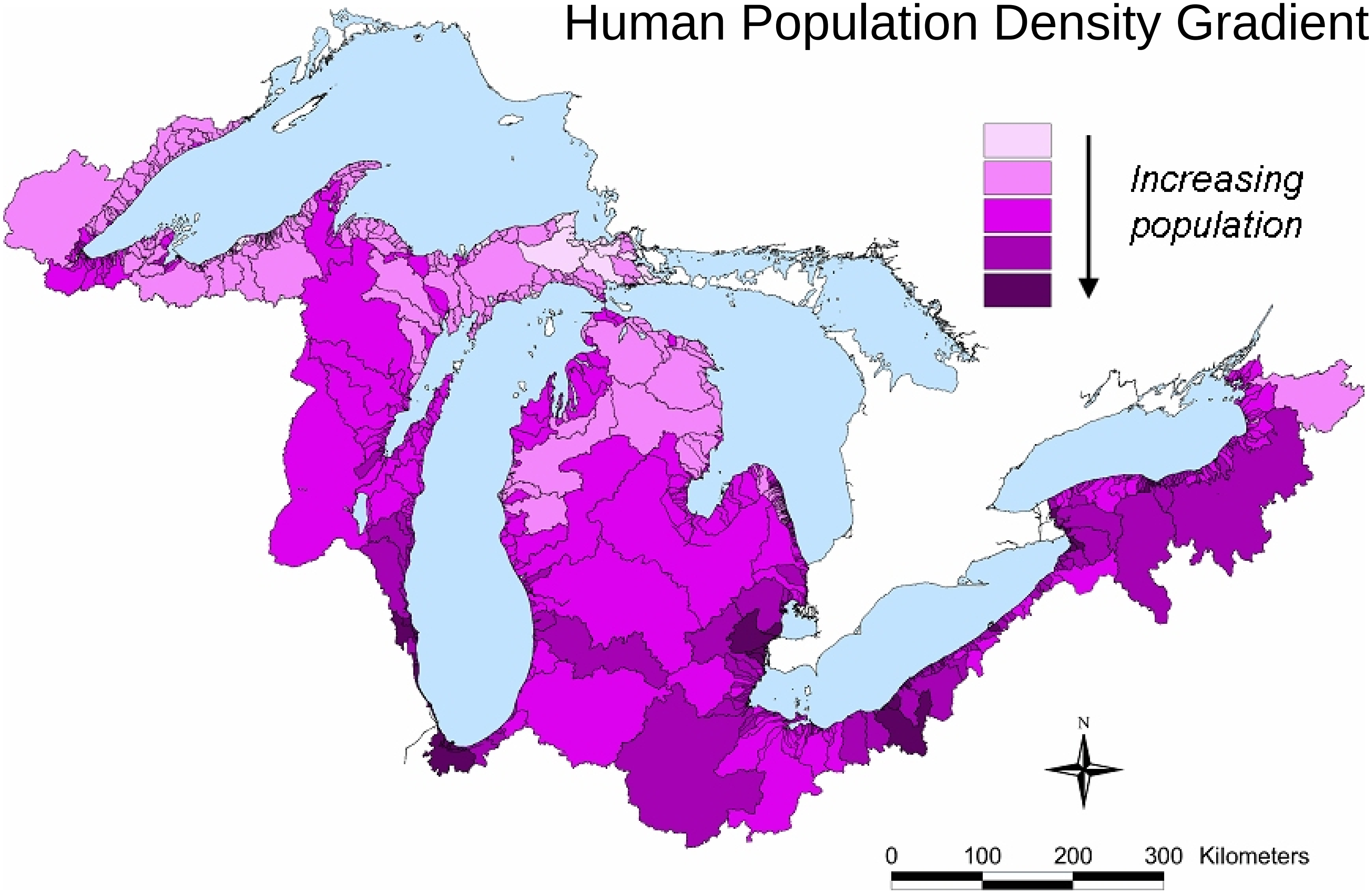
Agriculture Disturbance Gradient 1

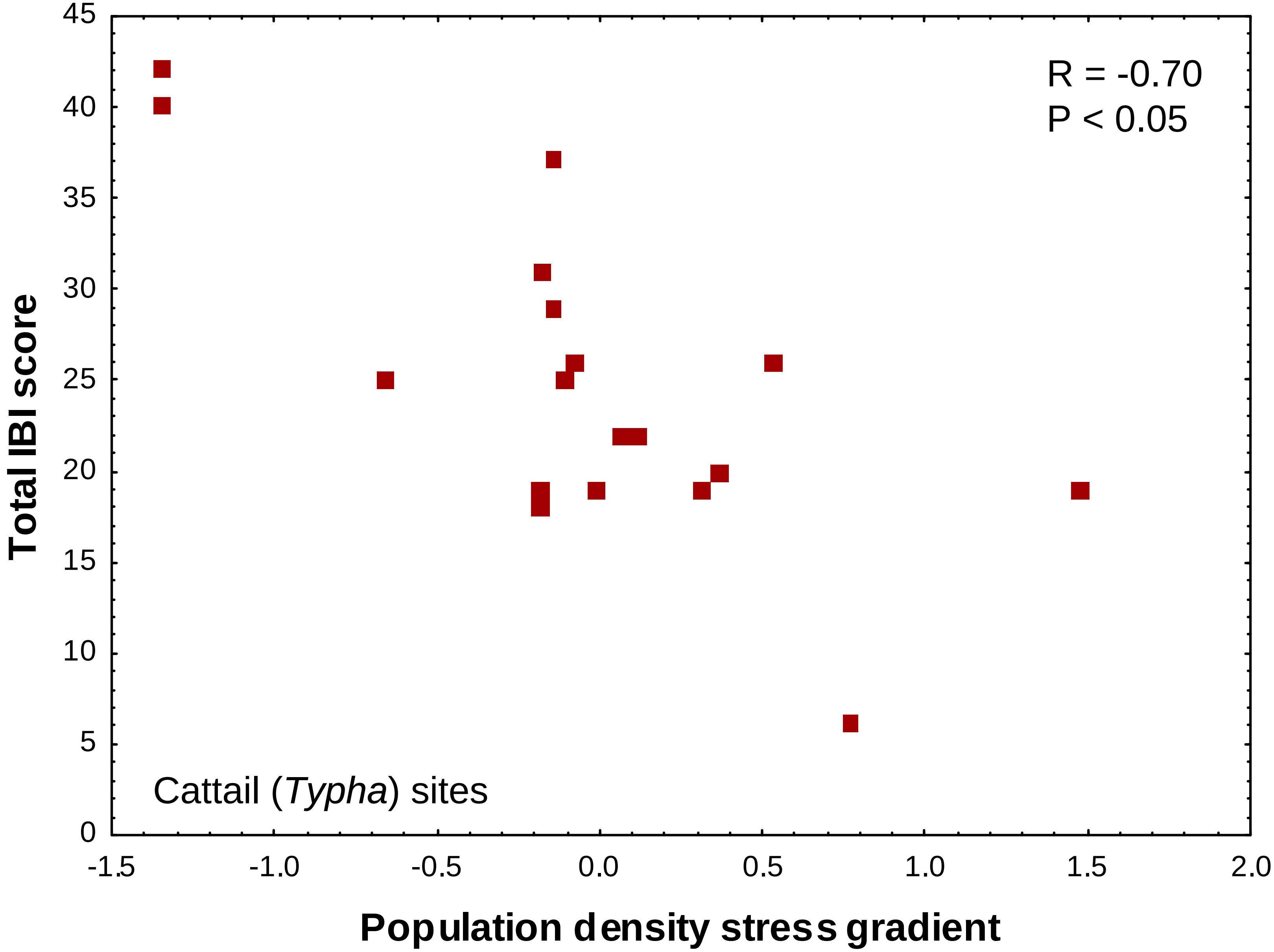




From: Baghat, et al. in preparation.

Human Population Density Gradient 1





From: Baghat, et al. in preparation.

Human Activities That Influence Water Quantity and Quality

Activity	Mechanism	Response	Indicator
Water withdrawal (irrigation; drinking water)	⇓ Stream base flow ⇓ Ground water table	⇑ Water temp. (summer) ⇓ Oxygen conc. ⇑ Nutrient conc.	Water temp. Oxygen conc. Invertebrates Fish
Ag. field tiles	Disrupts natural hydrology – ⇑ Peak flow & flooding	⇑ Nutrients ⇑ Sediments ⇑ Pesticides ⇓ Nutrient cycling ⇓ Soil infiltration	Discharge Wetland water level Invertebrates Fish
Impervious surface	Disrupts natural hydrology – ⇑ Peak flow & flooding	⇑ Sediments ⇑ Contaminants ⇓ Nutrient cycling	Turbidity Nutrients Invertebrates Fish
Forest harvest	Disrupts natural hydrology – ⇑ Peak flow & flooding	⇑ Nutrients ⇑ Sediments ⇑ Pesticides	Turbidity Water temp. Algae, Invertebrates & Fish

Conclusions

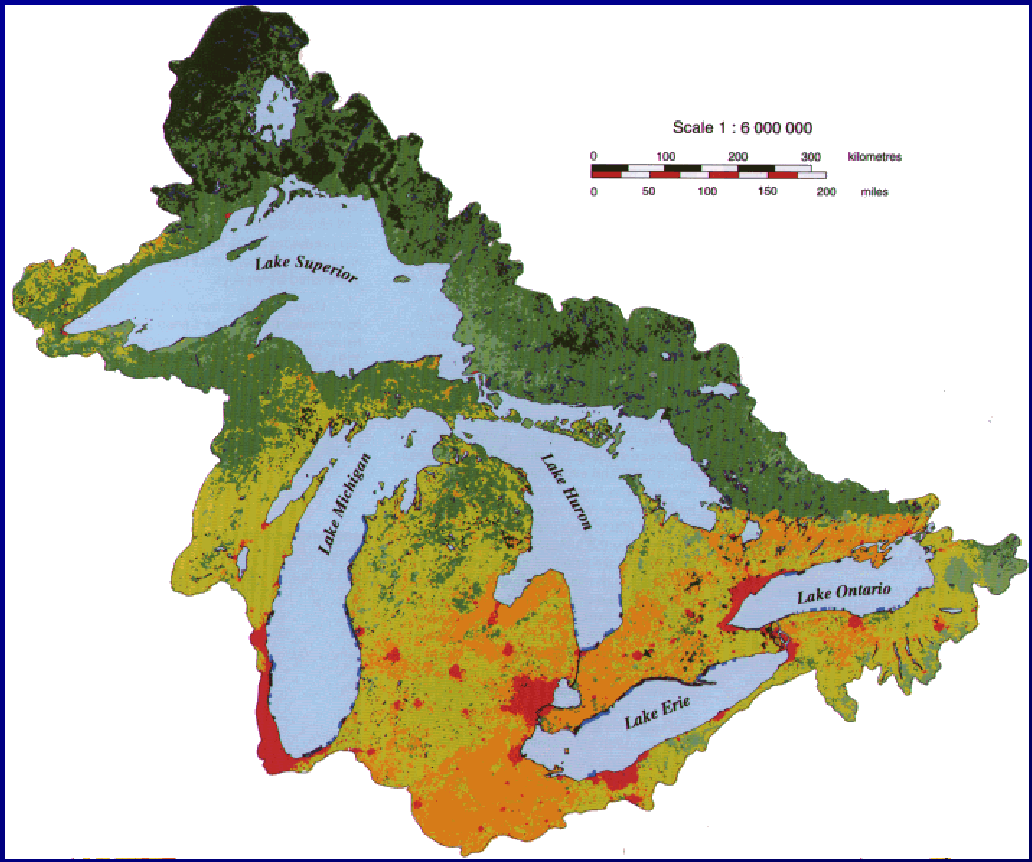
- There are well-documented links between water quality and water quantity issues
- Indicators of water quality, as influenced by human activities that affect water quantity, are:
  - Water temperature, dissolved oxygen, turbidity, nutrients and flow regime
  - Algal, invertebrate and fish communities
- Collaboration with ongoing indicator development efforts is essential for success of the SWRR process

Flow Alteration in Rivers of the Great Lakes

David Allan
School of Natural Resources & Environment
The University of Michigan

Collaborators: L.C. Hinz Jr. N.L. Poff, E. Rutherford,
P. Seelbach, P. Webb, M.J. Wiley
Mapping in cooperation with the Great Lakes Commission
Funded by the Great Lakes Protection Fund

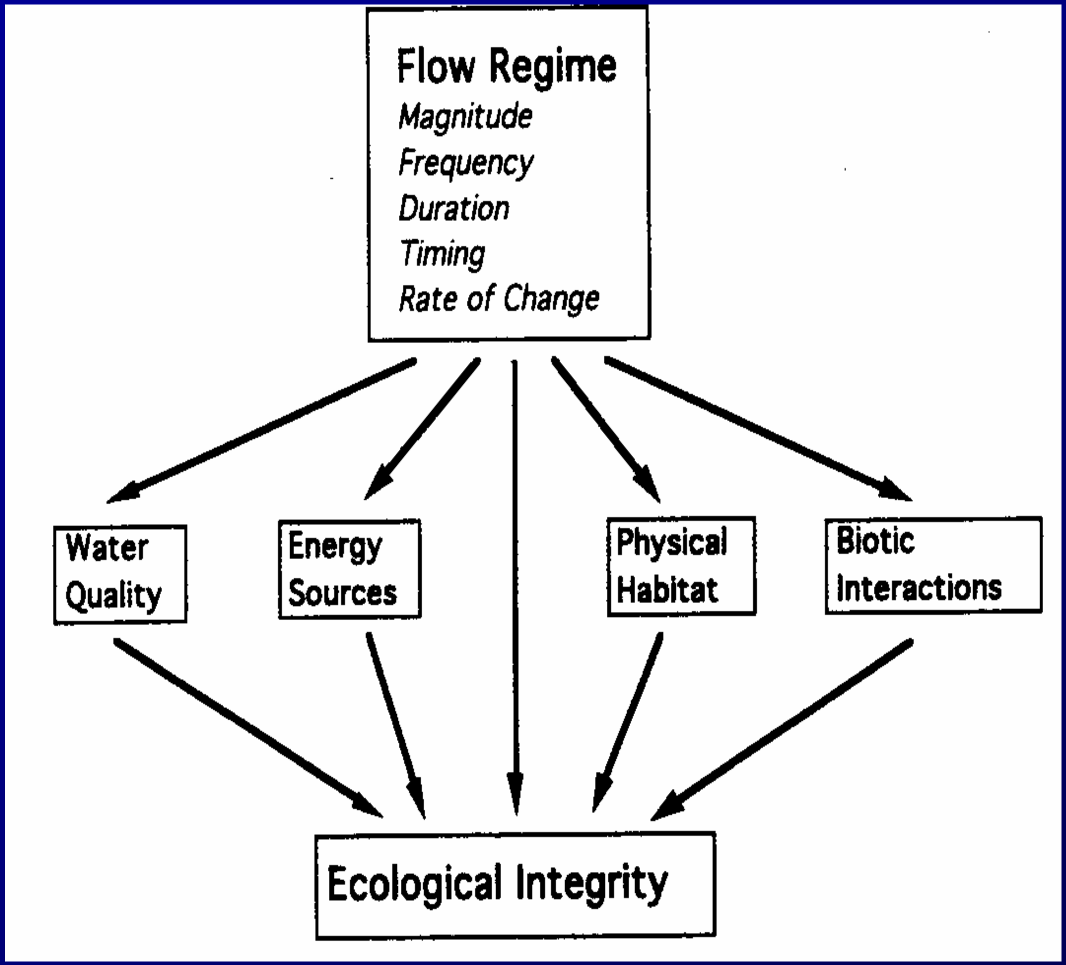
Applying the Flow Regime Concept to the Great Lakes



By developing a hydrogeography of rivers of the Great Lakes basin, we test the robustness of an important organizing concept in stream ecology

KEY TO MAP: Coniferous Forest | Mixed-Wood Forest | Deciduous Forest | Low-Intensity Farming/Pasture | Intensive General Farming | Urban Areas

Flow Regime as a Master Variable



Flow regime is important because it influences stream ecosystems in multiple ways, and its components are accessible to scientific inquiry and to management action

Five Components of Flow Regime

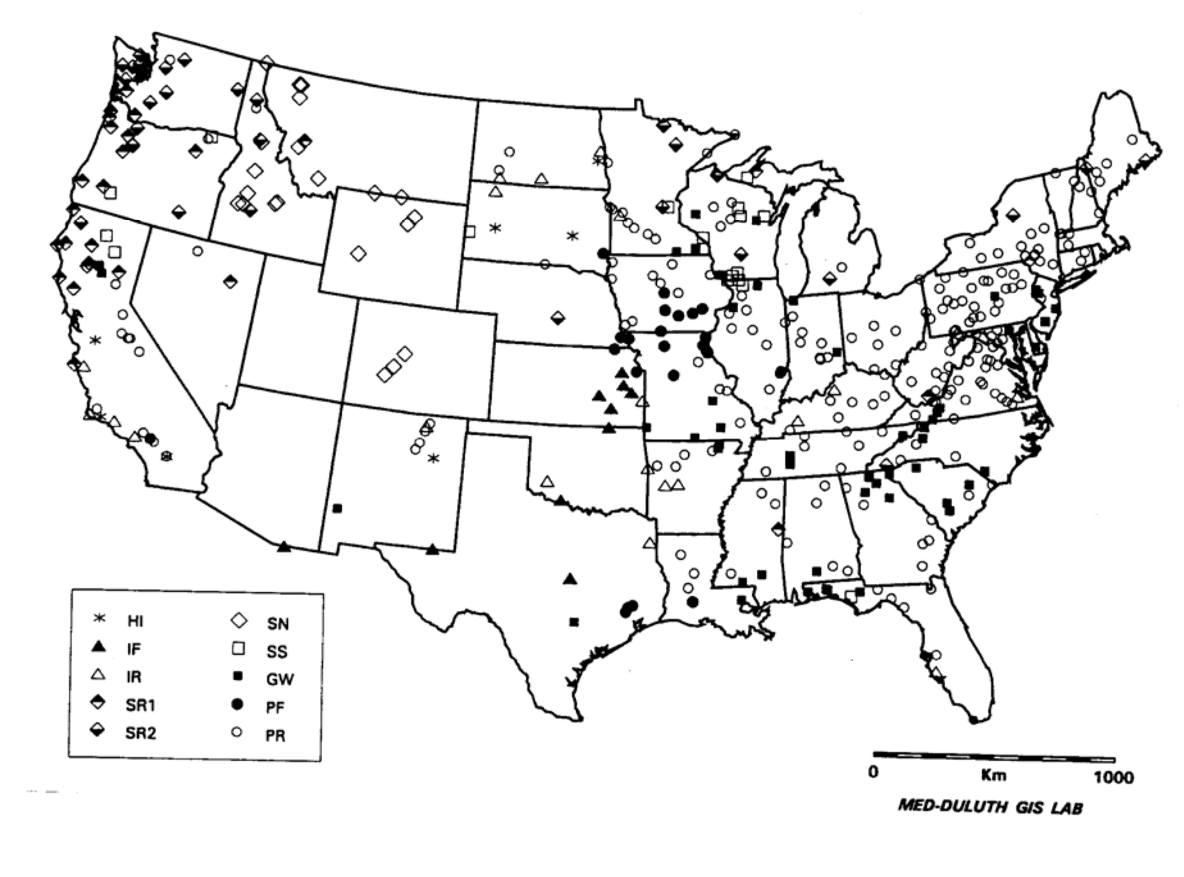
1. **Magnitude of discharge**
   - the amount of water moving past a point, per unit time
2. **Frequency of discharge**
   - how often a flow of a specified magnitude occurs over a specified time interval
3. **Duration**
   - the time period associated with the specified flow condition
4. **Timing** or predictability of flows
   - a measure of the regularity with which they occur
5. **Rate of change**, or flashiness of flow
   - how quickly flow changes

Indicators of Hydrologic Alteration

Brian Richter, TNC

The Flow Regime

Key elements of the flow regime concept include:



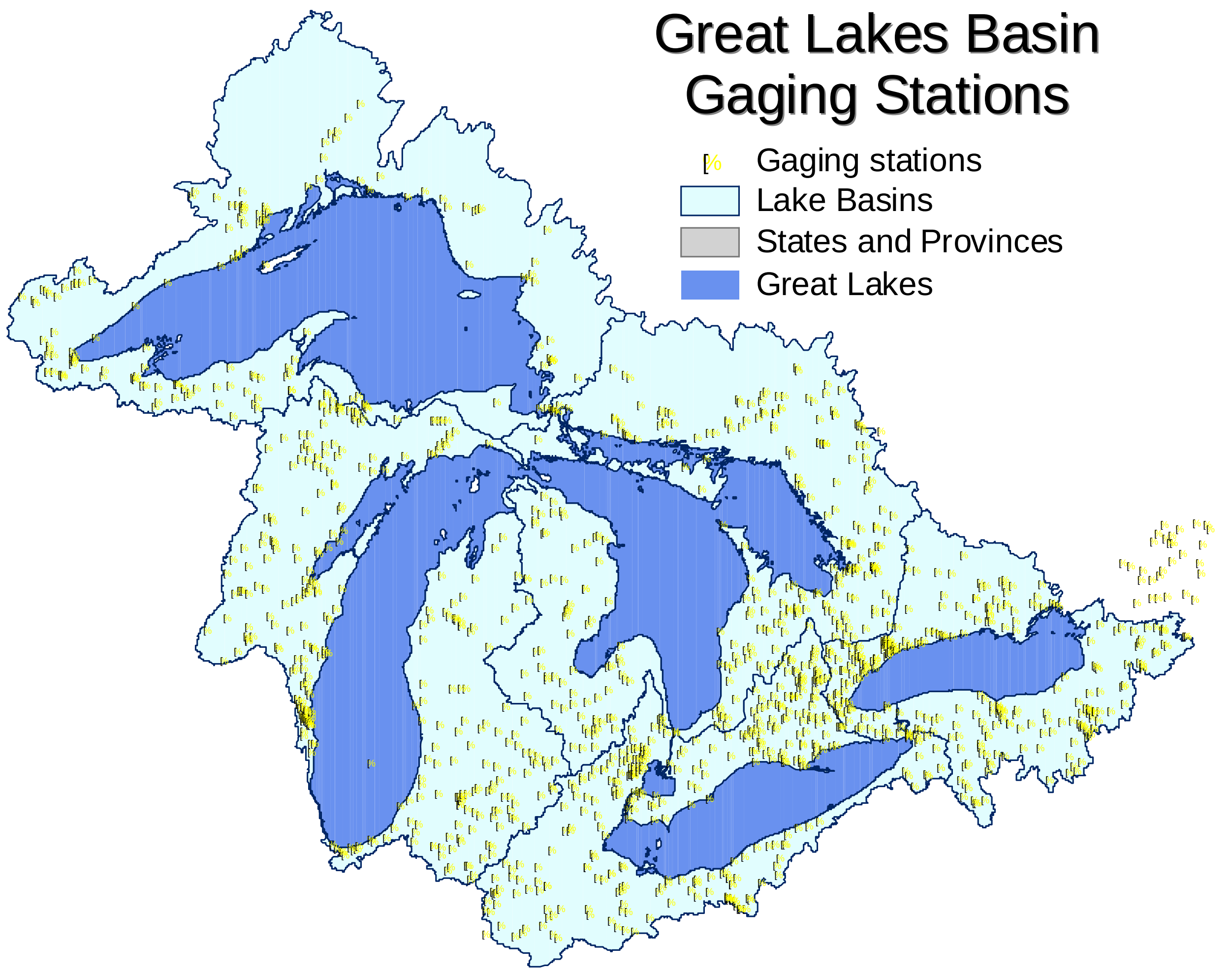
- a hydrogeography can be described
- flow is a "master variable" that affects stream ecosystems in many ways
- key descriptors of flow regime include magnitude, frequency, duration, timing, rate of change

From Poff 1996

Our Questions

- What is meant by flow regime and can we identify flow regimes within rivers of the Great Lakes basin ?
    - Are spatial patterns evident in flow regime that may be indicative of broad geologic and climatic controls ?
- Have human actions discernibly altered flow regimes over the course of the 20^{th} century?
    - What evidence exists of altered flow regimes and what can we infer about human influence ?

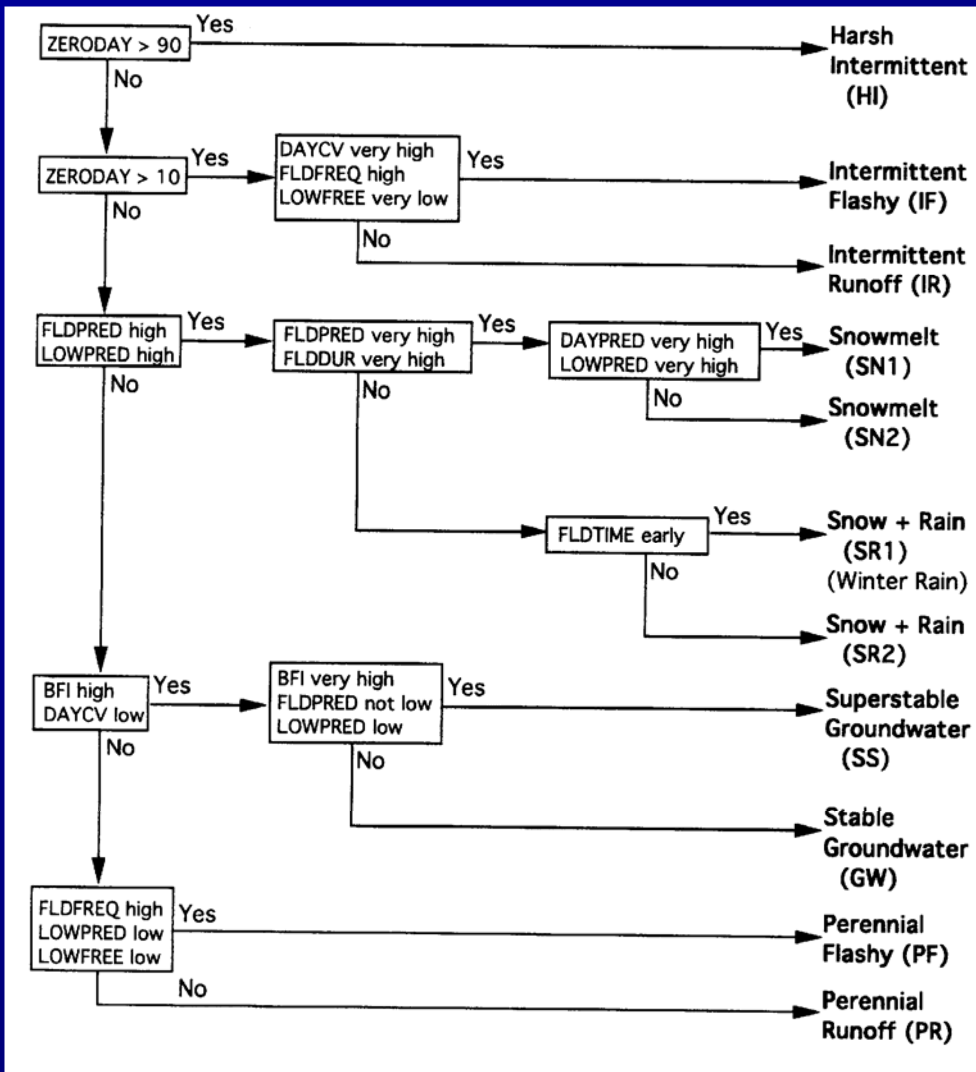
The Database



We selected a total of 425 gages (259 in U.S., 166 in Ontario) to include in our analyses

Gages were excluded due to incomplete records or obvious flow disturbance.

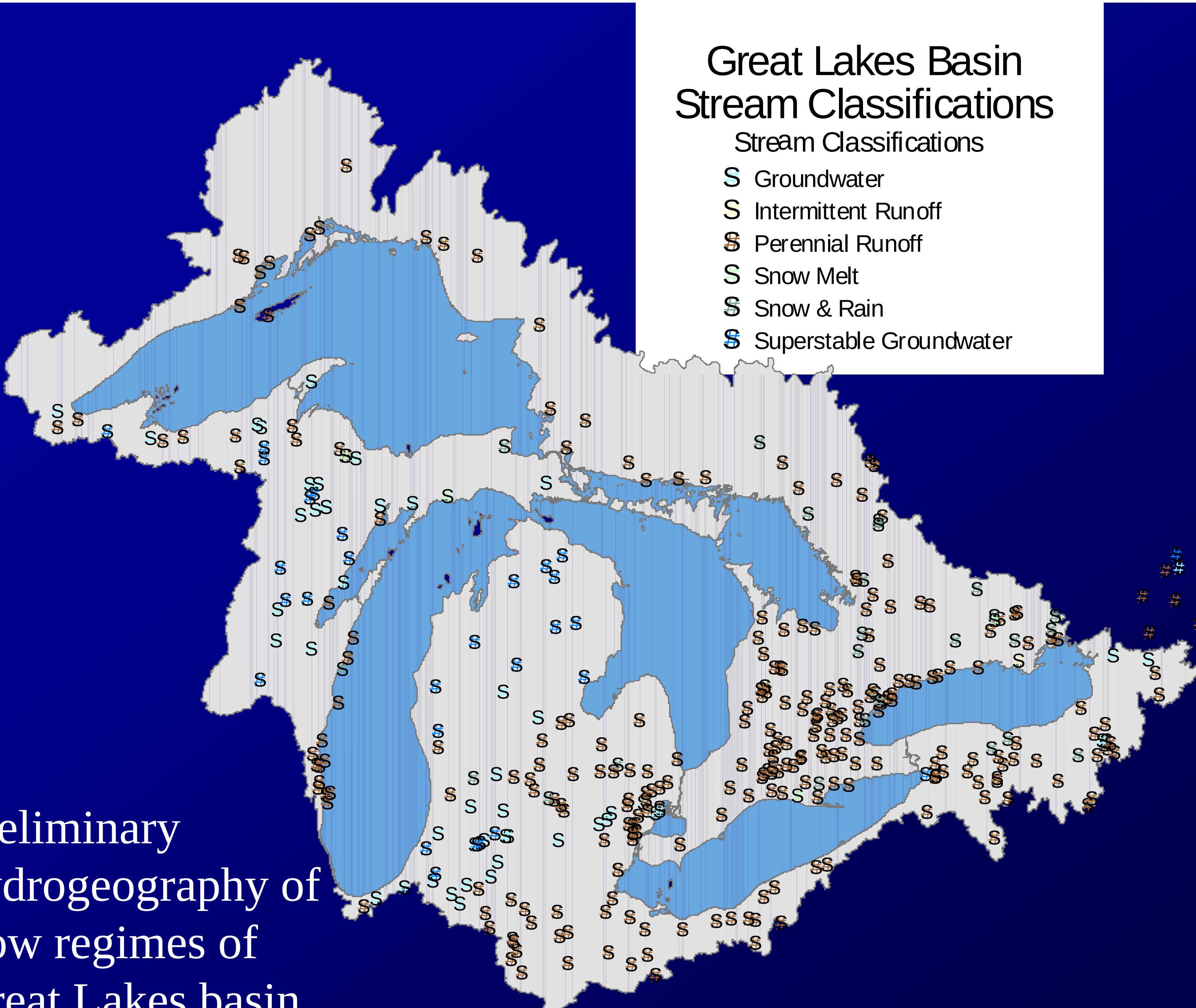
Assigning Streams to Flow Classes



This flow chart of Poff (1996) was used to assign individual streams to his 9 categories.

Six of these categories are represented in the Great Lakes Basin:

Perennial runoff	264 (70%)
Stable groundwater	53 (14%)
Superstable	29 (8%)
Snow + rain	25 (7%)
Snowmelt	4 (1%)
Intermittent runoff	1 (0.3%)



Preliminary hydrogeography of flow regimes of Great Lakes basin

Validity of the Flow Regime Concept

- Our analysis supports the view that flow regimes can be characterized by hydrologic analysis.
- Using less stringent criteria than Poff (1996) we were able to include more gages, and thus achieve a finer-scale mapping.
- A substantial body of literature provides evidence that flow regime influences biological assemblages

Some Key Literature

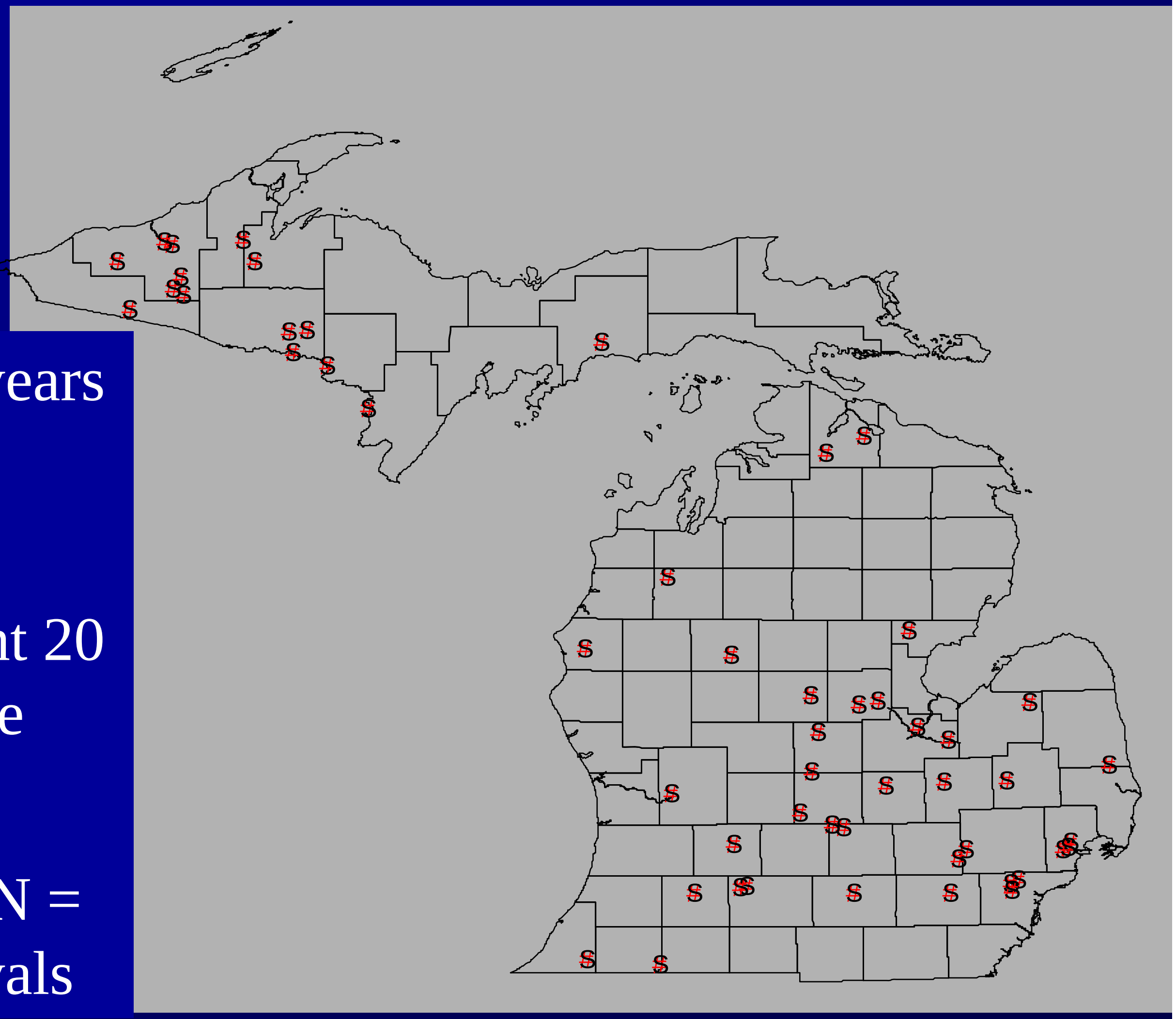
Allan, J.D. et al. 2004. An Assessment of Flows for Rivers of the Great Lakes Basin. Final Report to the Great Lakes Protection Fund, October, 2004. http://www-personal.umich.edu/~dallan/dallan_pubs.html

- Baker D.B., Richards, R.P., Loftus T.T., et al. 2004. A new flashiness index: Characteristics and applications in Midwestern rivers and streams. Journal of the American Water Resources Association 40: 503-522.
- Baron J.S., Poff N.L., Angermeier P.L., Dahm C.N., Gleick P.H., Hairston N.G., Jackson R.B., Johnston C.A., Richter B.D., Steinman A.D. 2002. Meeting ecological and societal needs for freshwater. Ecological Applications 12 (5): 1247-1260
- Poff, N.L. and J.D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76:606-627.
- Poff, N.L. 1996. A hydrogeography of unregulated streams in the United States and an examination of scale-dependence in some hydrologic descriptors. Freshwater Biology 36:71-91.
- Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47:769-784.
- Richards, R.P. 1990. Measures of flow variability and a new flow-based classification of Great lakes tributaries. Journal of Great Lakes Research 16:53-70.

Temporal Change in Flow Regime

- Human actions may alter a river's flow regime
  - Dams and flood storage can regulate river flow, making it more constant
  - Changing land use can alter flow pathways, making river flow more variable
  - Water withdrawals can reduce available runoff
  - Climate change can alter P and ET
- Do long term gage records document temporal changes in hydrologic regime in the Great Lakes Basin?

Flow Regime Changes in Michigan



<u>Early record:</u> earliest 20 years of record, starting before 1950.

<u>Recent record:</u> most recent 20 years of record that include WY1995 or later.

Analysis by paired t-test (N = 53) contrasting time intervals

Changes in Flow Metrics

Magnitude of discharge

Mean daily Q ↑

Water yield ↑

Timing of discharge

Flow predictability ↑

Constancy/predictability ↑

Date of min flow ↓

Frequency of discharge

% floods in 60 days ↑

high pulse events ↑

low pulse events ↓

Duration of discharge

Low pulse duration ↓

Rate of change of discharge

Rise rate ↑

# of reversals ↓

Summary of Temporal Analysis

Compared to early records:

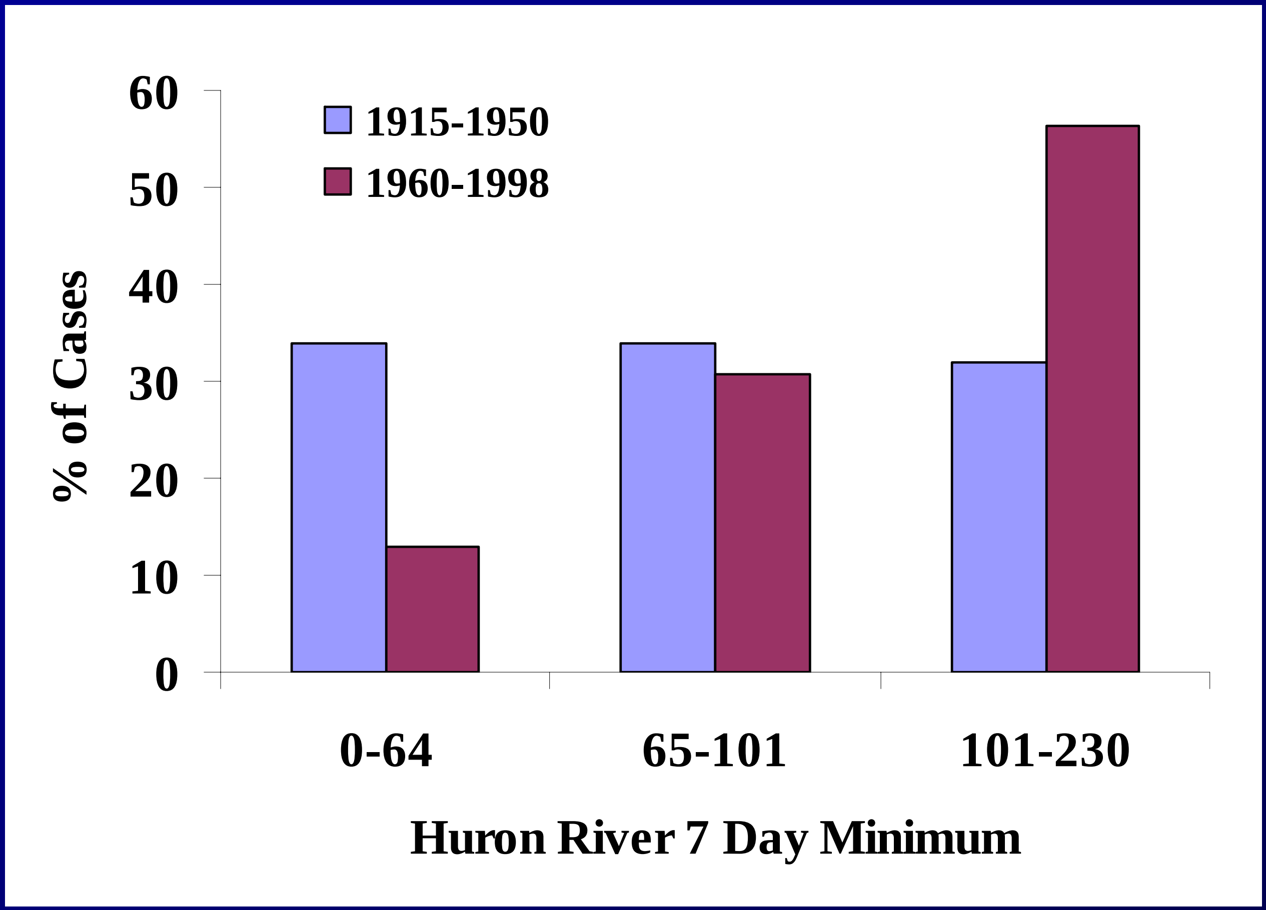
- discharge has increased
- flows exhibit more synchrony, more high flows, and fewer low flow events
- recent flows exhibit shorter duration of low flow events
- flow timing is more predictable, and the date of minimum flow is slightly earlier
- Rate of rise is faster, and reversals are fewer

Another Approach

For a single river….

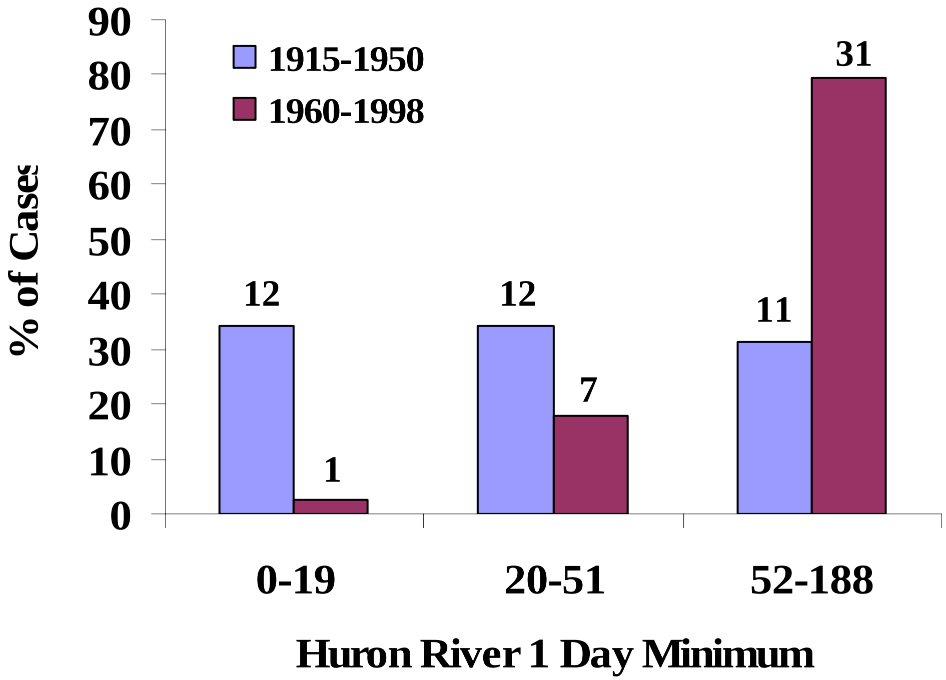
- Characterize flow statistics for a reference period (pre-dam, early decades, etc)
- Trisect range of results into a lower, middle, upper third (so these will be equal)
- Characterize flow statistics for the comparison period (post-dam, late decades)
- Calculate the proportion of those flows that fall in each of the three ranges

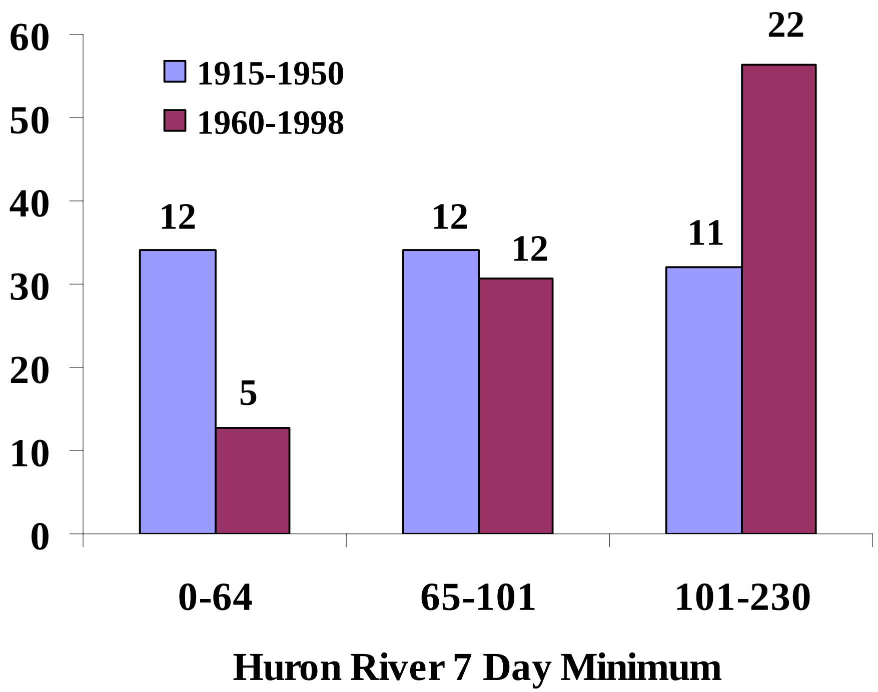
Example



Compared with the earlier (reference) period, fewer minimum flows now fall in the low range, and more fall in the high range

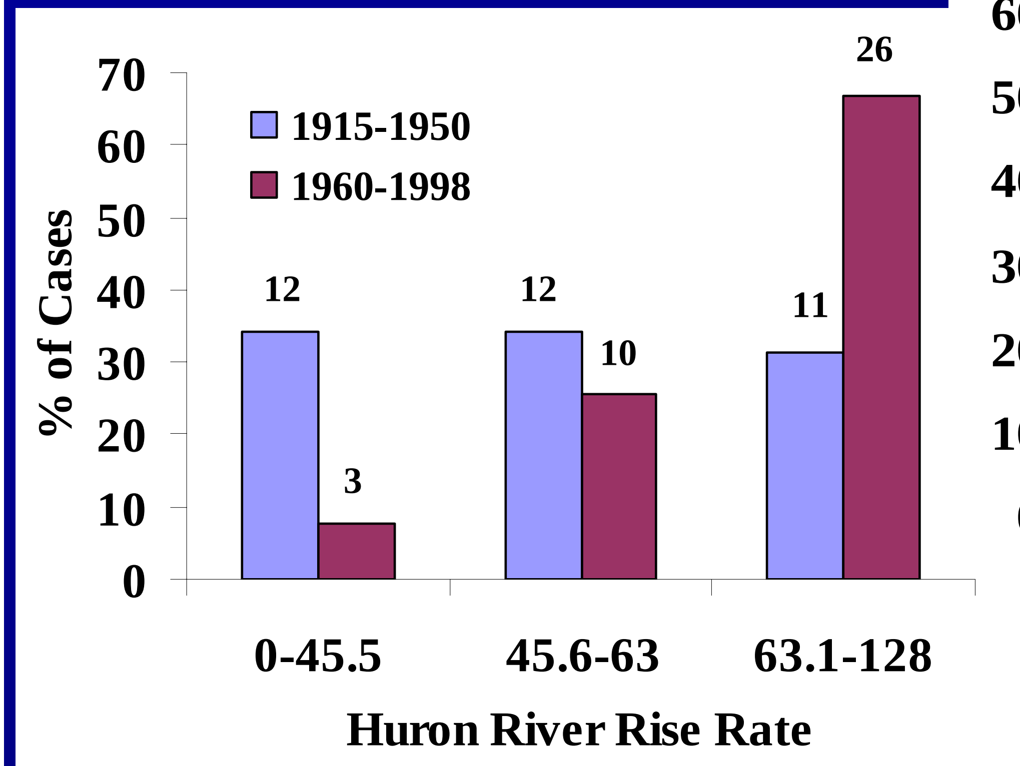
Minimum Flows, Huron River

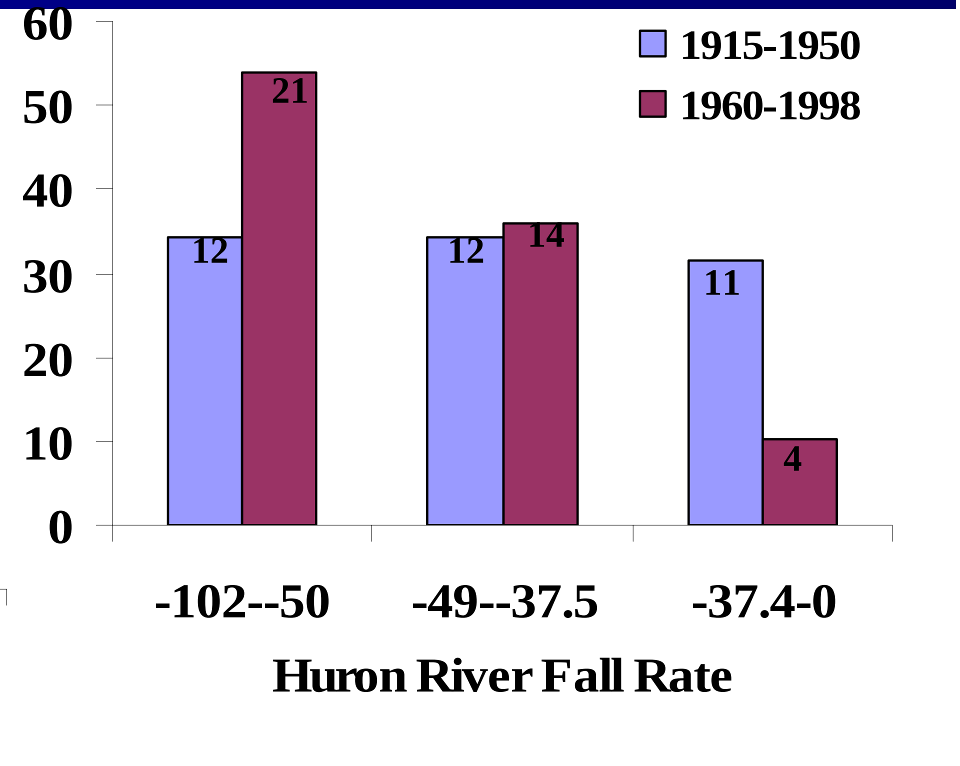




Minimum flows have increased

Rise/Fall Rates, Huron River



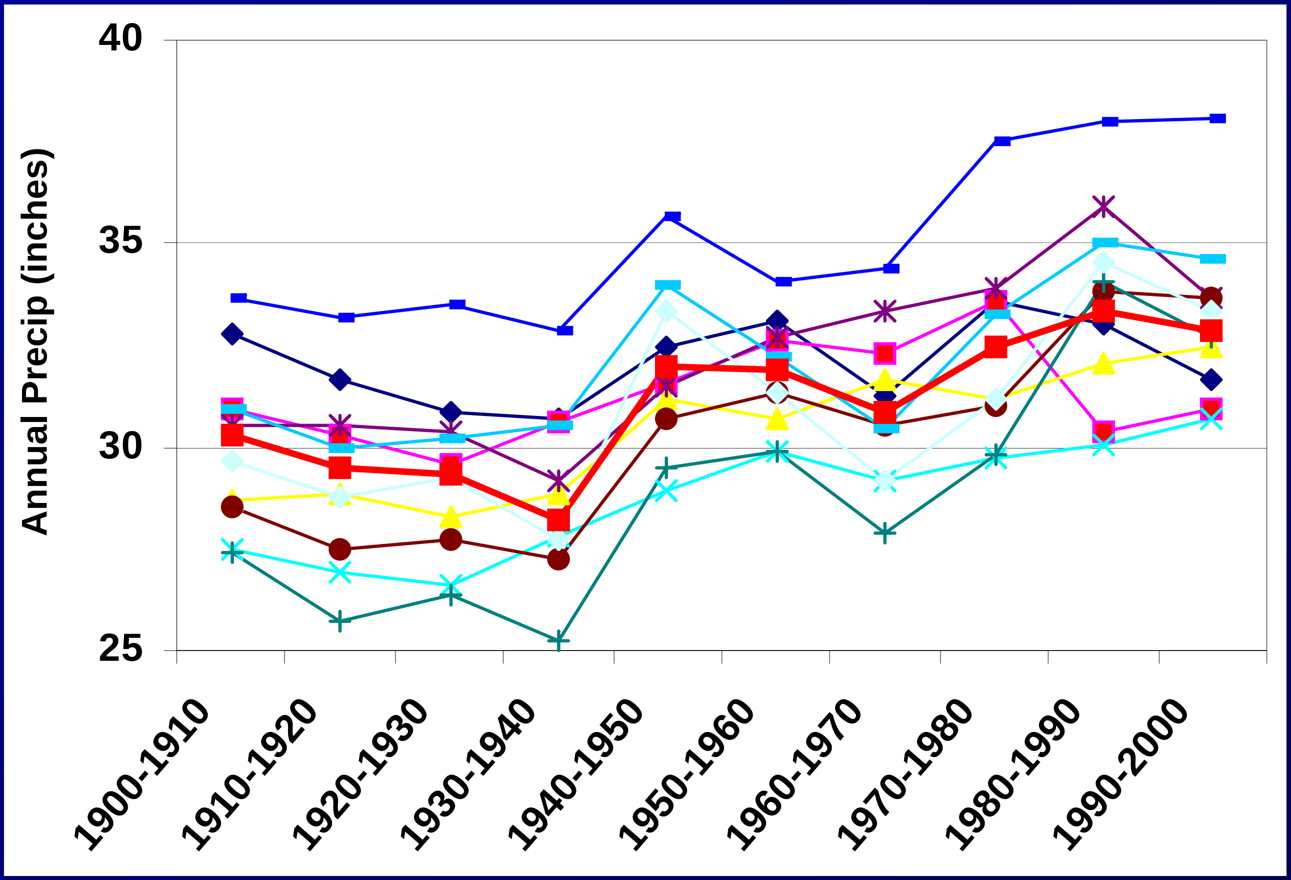


Rise rates are sharply up

Temporal Changes: Summary and Interpretation

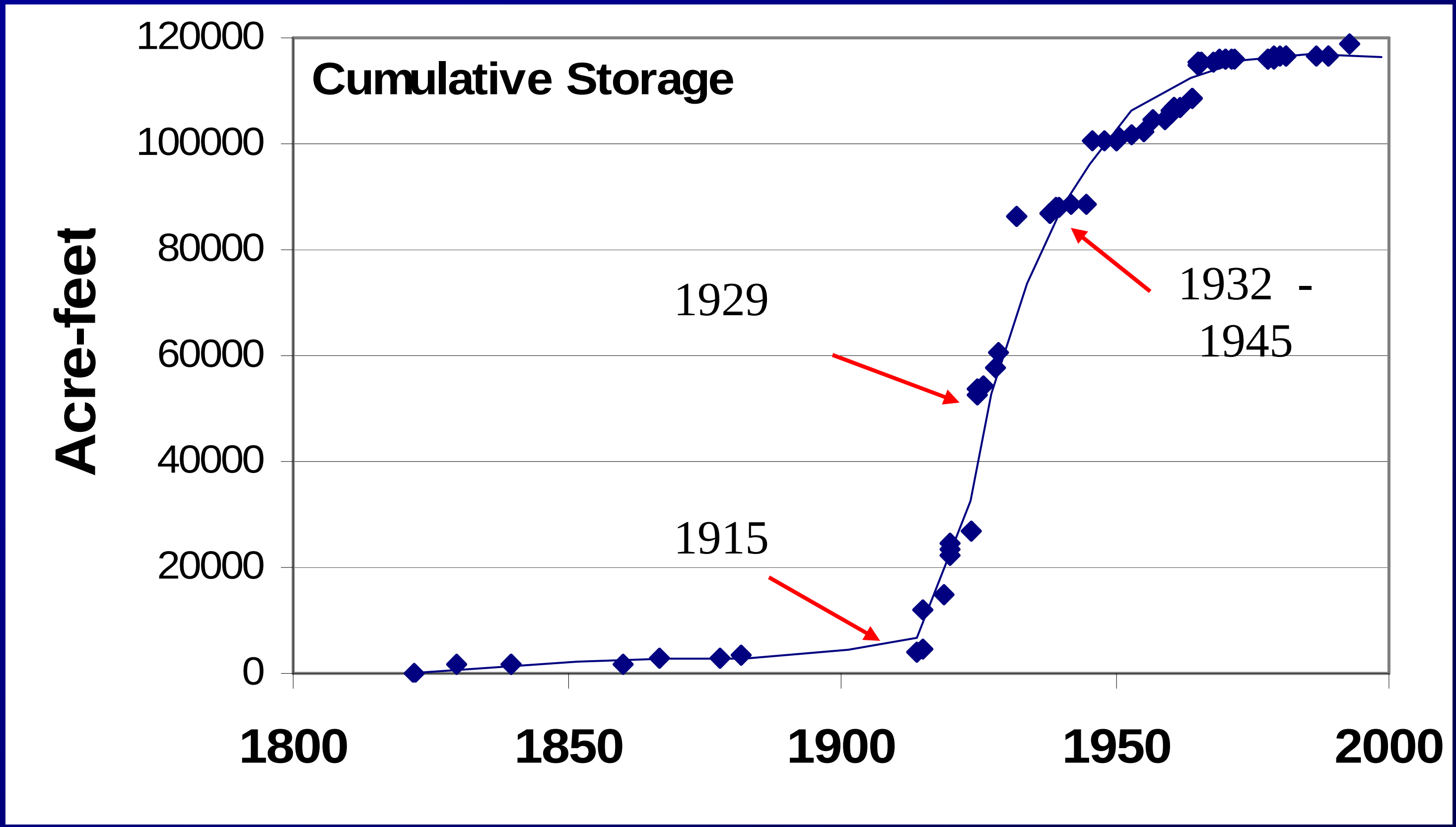
- Low flows have increased
  - Has P increased ? Or (P – ET) ?
- Flows exhibit more synchrony
  - Due to more storage ?
- Faster rates of rise
  - Due to more impervious surface and stormwater conveyance ?

20th C precipitation trends



Annual precipitation for ten regions of Michigan, averaged by decade. Bold red line is the average for all regions.

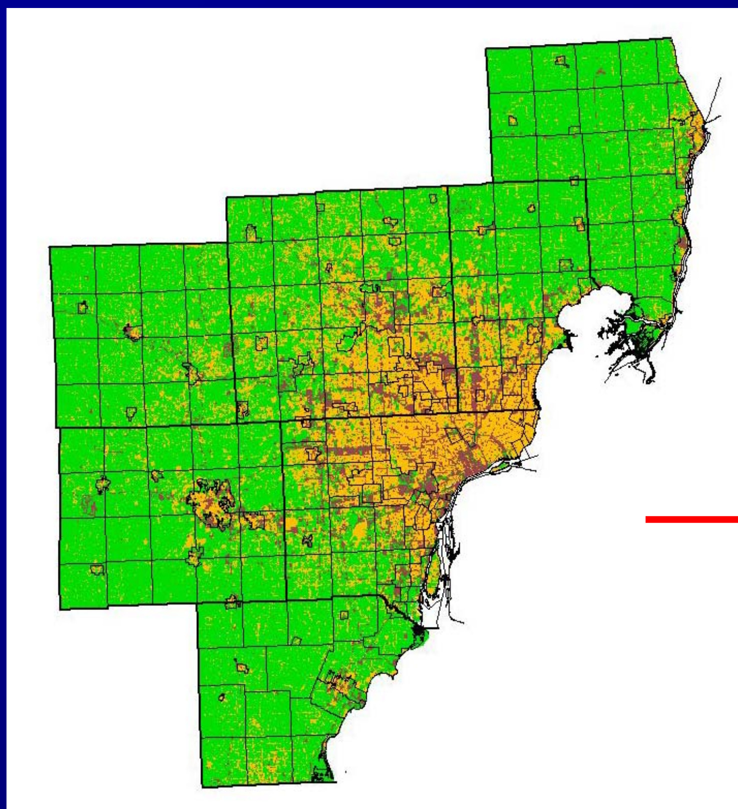
20th C Storage Trends



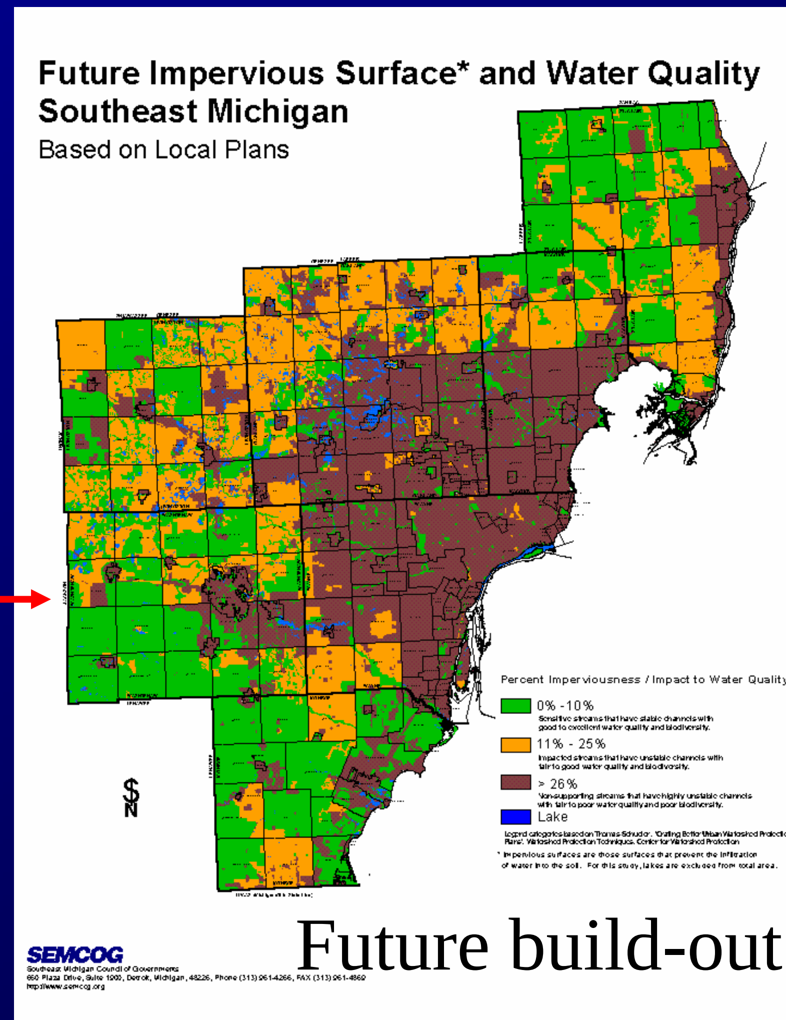
Total storage capacity of all impoundments on the Huron River is now about 26% of total annual water discharge

20^{th} C Impervious Surface Trends

Thanks to Amy Mangus and SEMCOG



1995



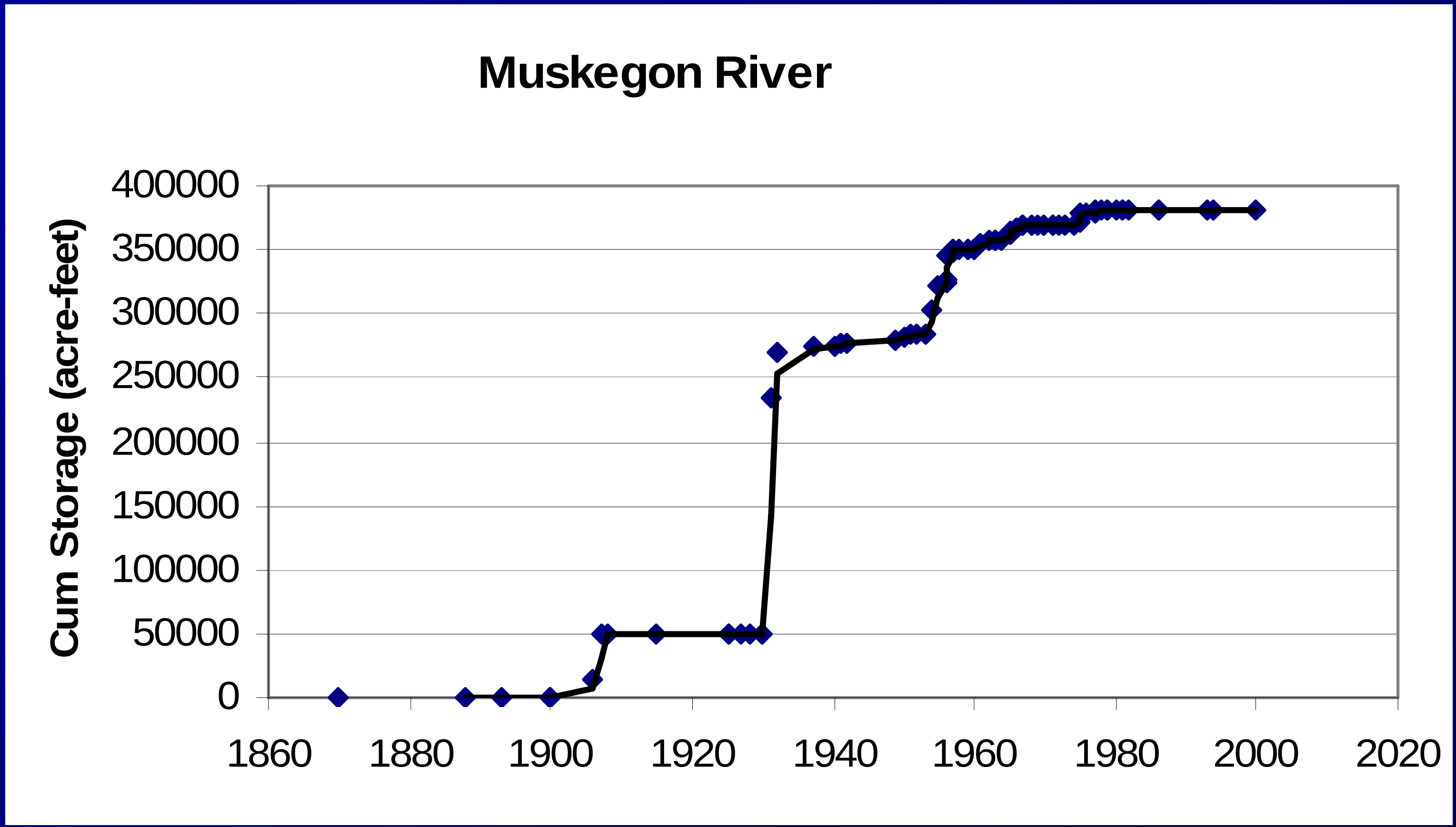
Future build-out

Acknowledgements

- Martha Carlson, Sarah Greene and Jennifer Mackay for assistance in acquiring and analyzing data.
- Stuart Eddy and the Great Lakes Commission for GIS and graphics assistance.
- Jim Diana, Ed Rutherford, Paul Seelbach, Paul Webb and Mike Wiley for helpful advice.

Funding for this project was provided by the Great Lakes Protection Fund.

20th C Storage Trends



What Role Do Ecological Indicators Play in Ensuring Sustainable Water Resources?

Brian H. Hill
US Environmental Protection Agency
Mid-Continent Ecology Division
Duluth, Minnesota

What we expect from indicators of sustainability—

- useful for describing baseline and current conditions

- measure of the effectiveness of management actions and policies

- forecast future changes.

McCool and Stankey (2004)

Ecological Indicators—

Prophet or Private Eye?

"…indicators must provide information relevant to specific assessment questions, which are developed to focus monitoring data on environmental management issues."

Evaluation Guidelines for Ecological Indicators
EPA/620/R-99/005 (May 2000)

Key Elements of Ecosystem Indicators—

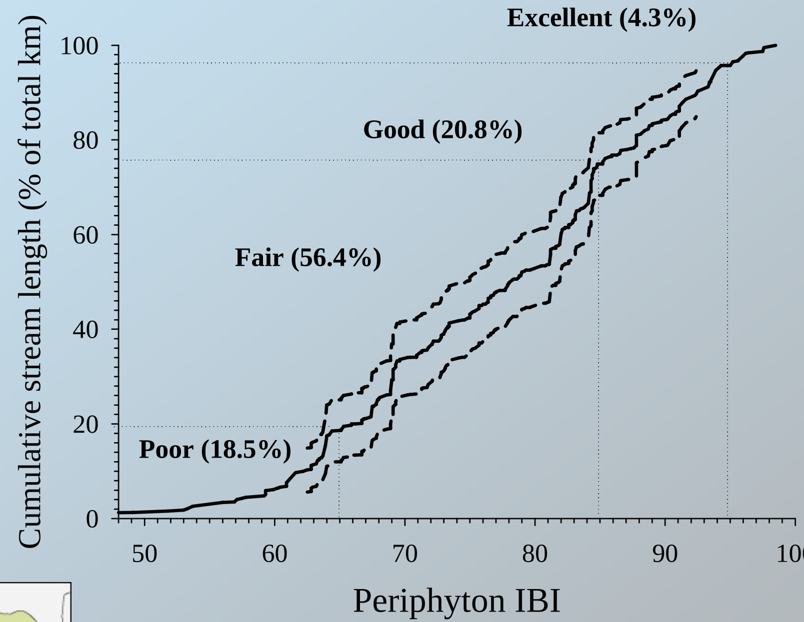
- ecosystem structure
  - species richness
  - species diversity
  - biomass
  - food web connectivity
- ecosystem function
  - energy flow
  - biogeochemical cycling
- diagnostics
  - stressor-response
- stability
  - resistance
  - resilience

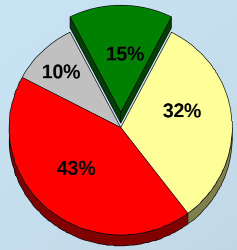
GUINDON

"The ecosystem collapsed again! Frogs! We need Frogs!"

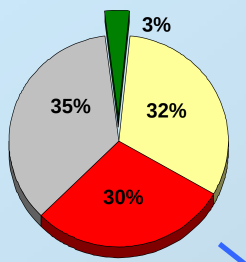
Ecological indicators tell us about— ecosystem structure

Algae tell us...

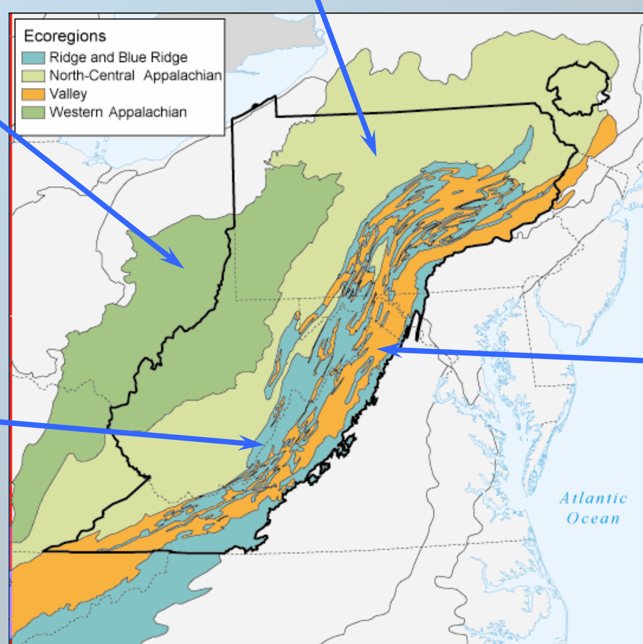


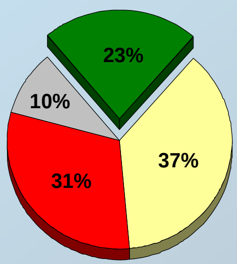


North Central Appalachians

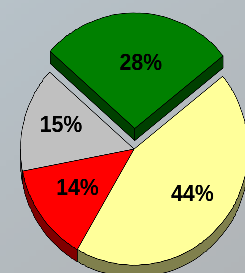


Western Appalachians





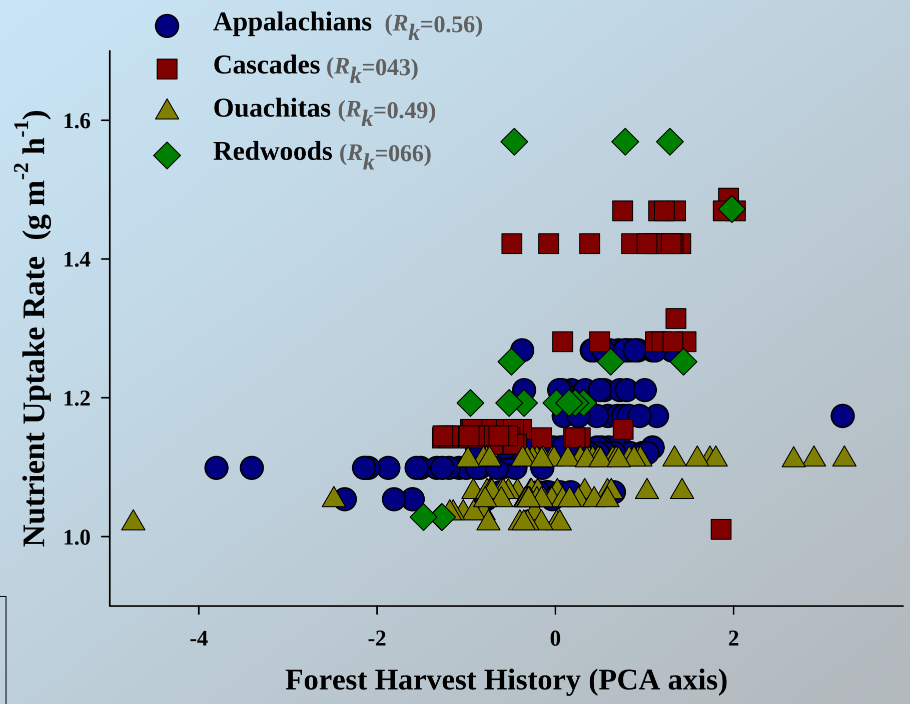
Valleys

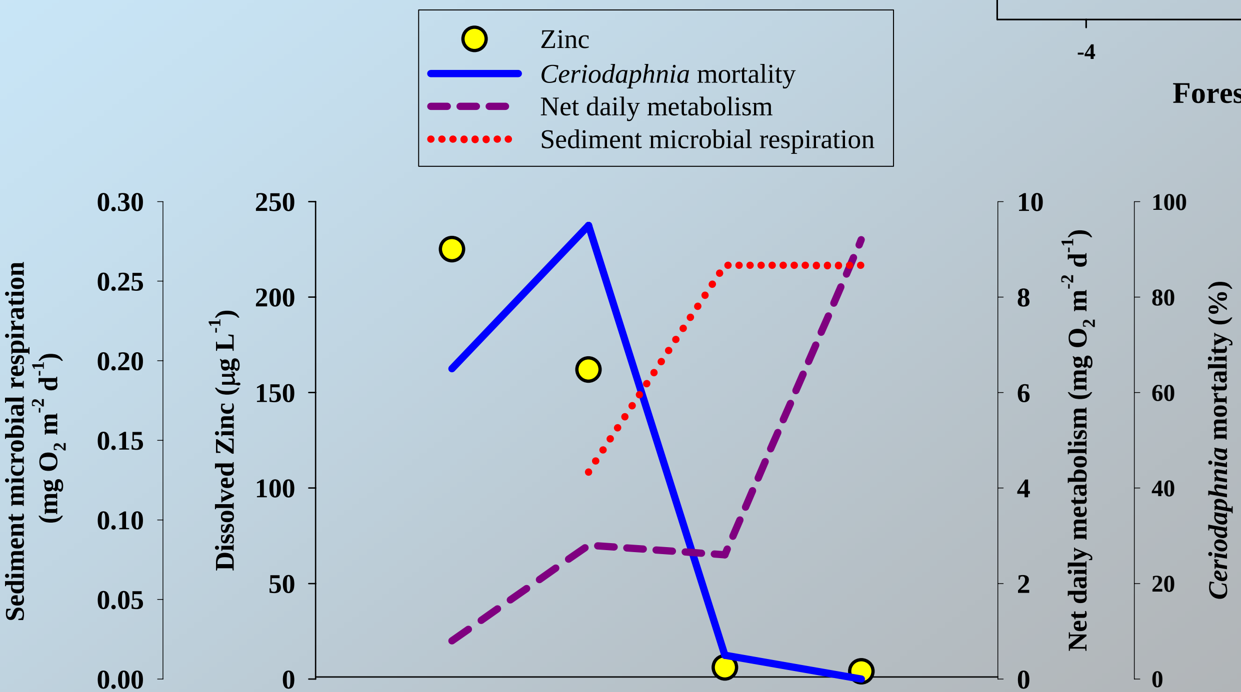


Ridge and Blue Ridge

Fish tell us...

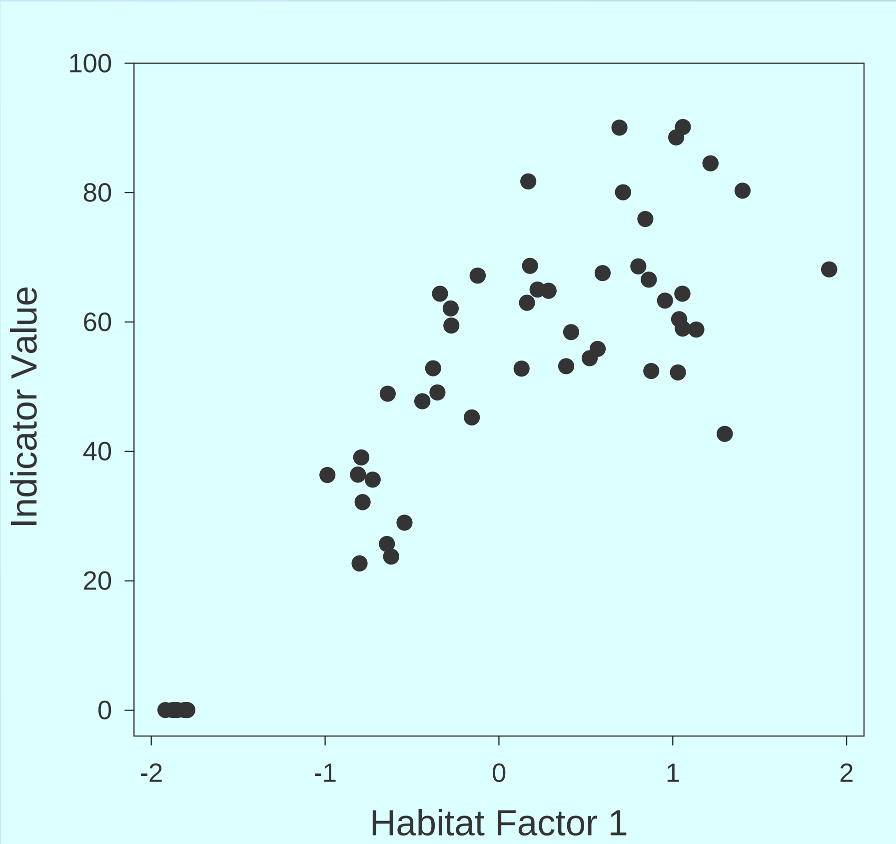
Ecological indicators tell us about—ecosystem function

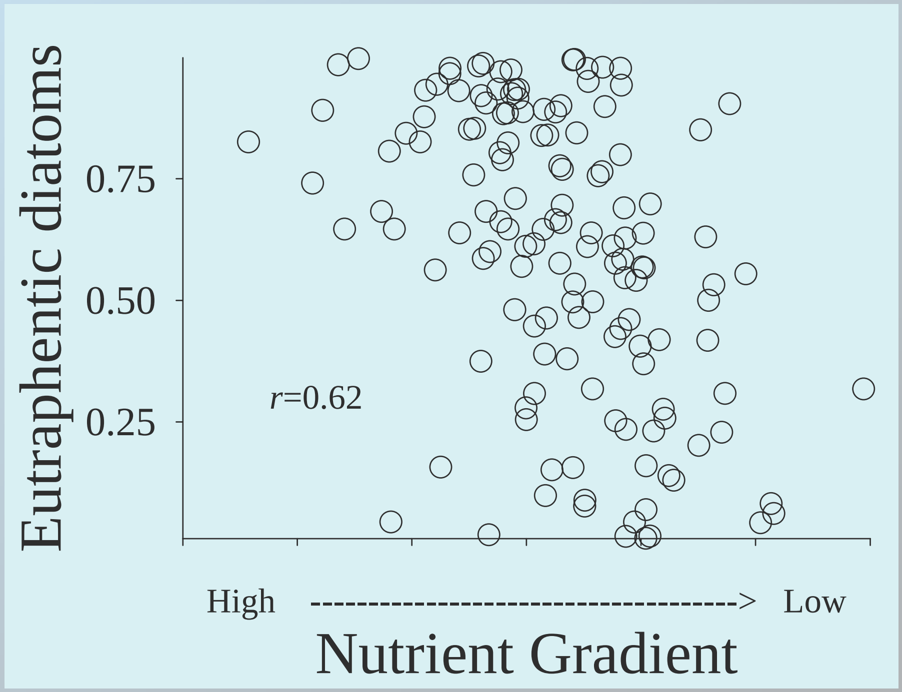




Ecological indicators – diagnose causes of impairment

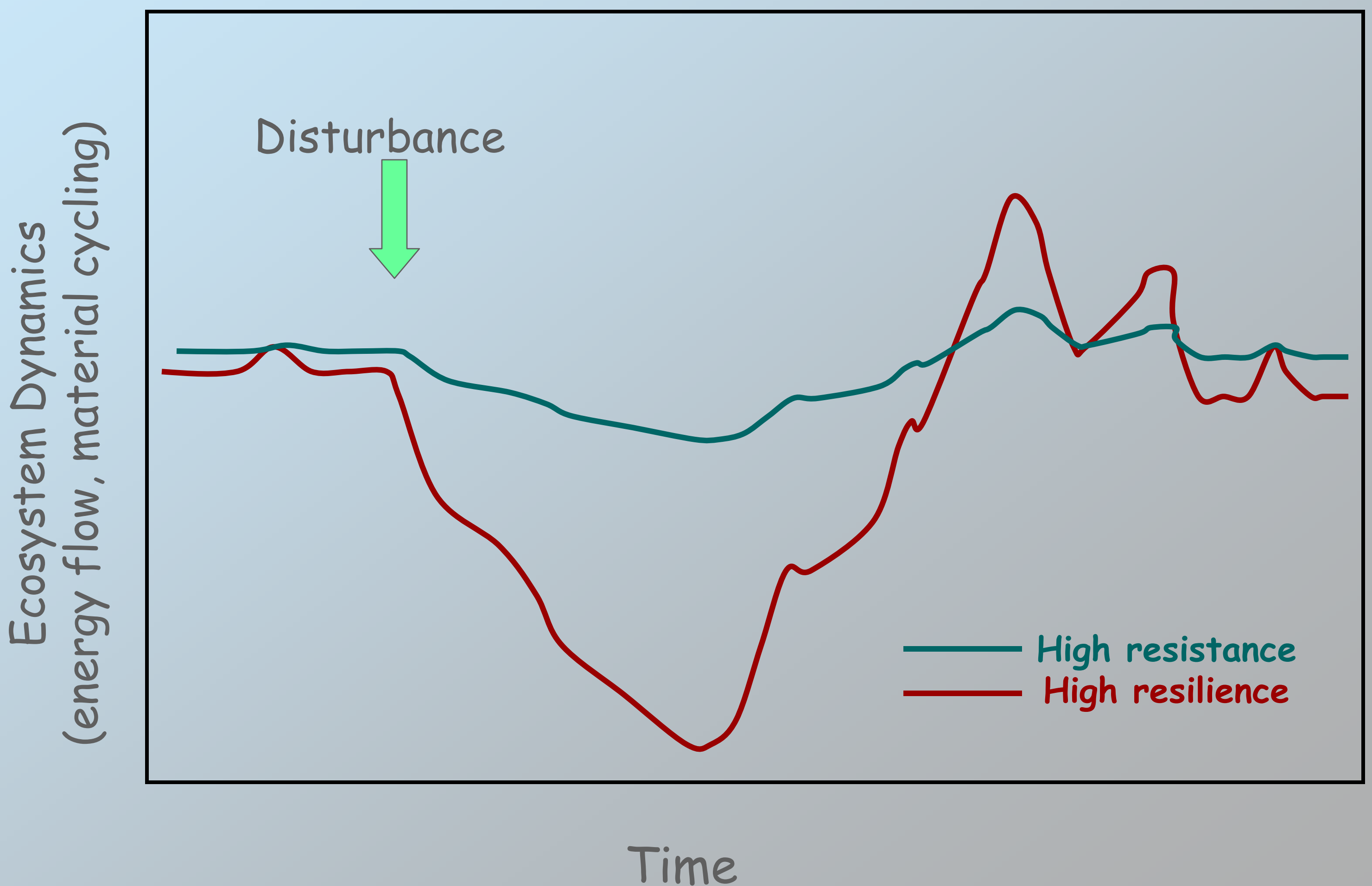
Fish IBI Response to Habitat Gradient

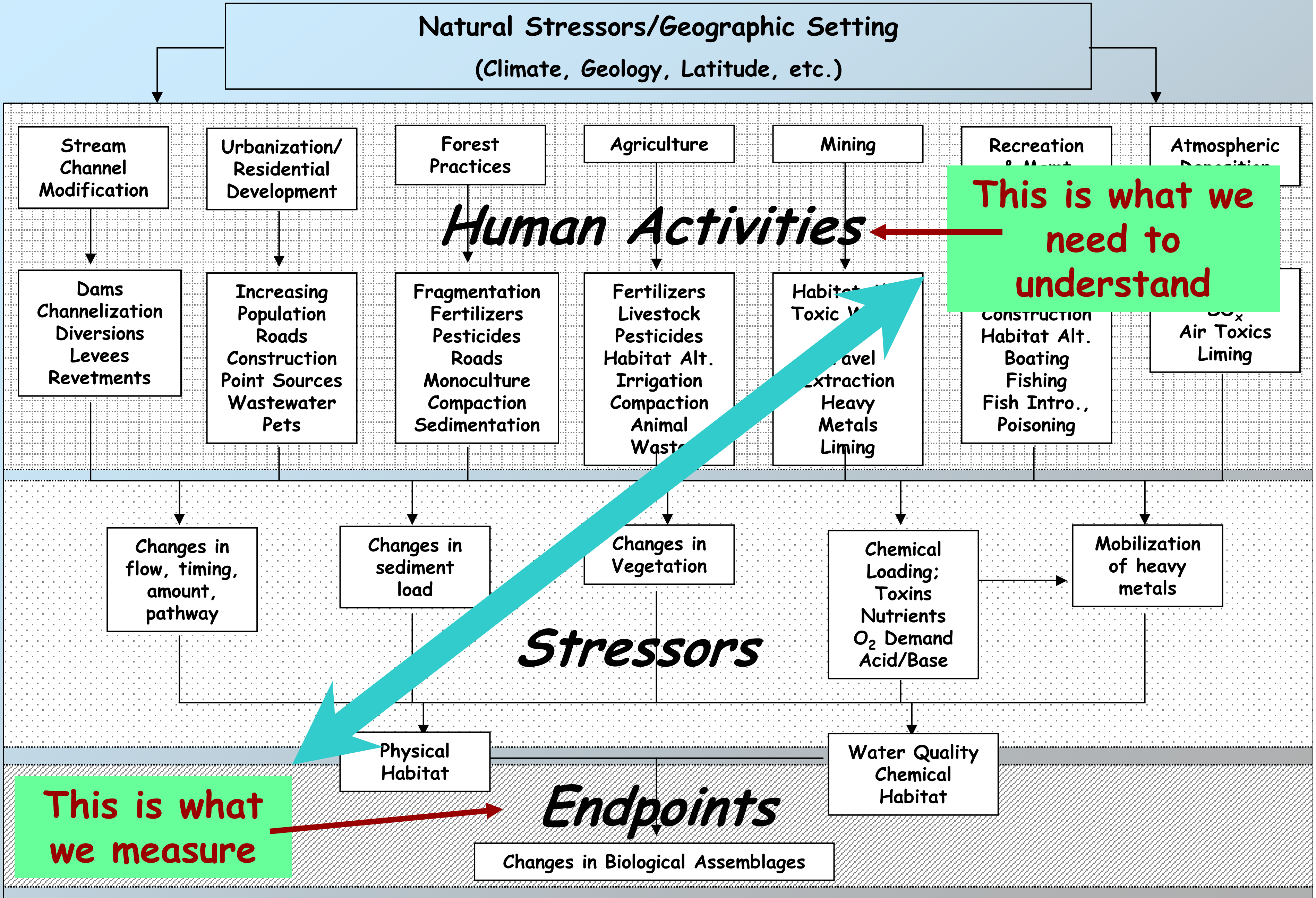




Diatom Response to Nutrient Gradient

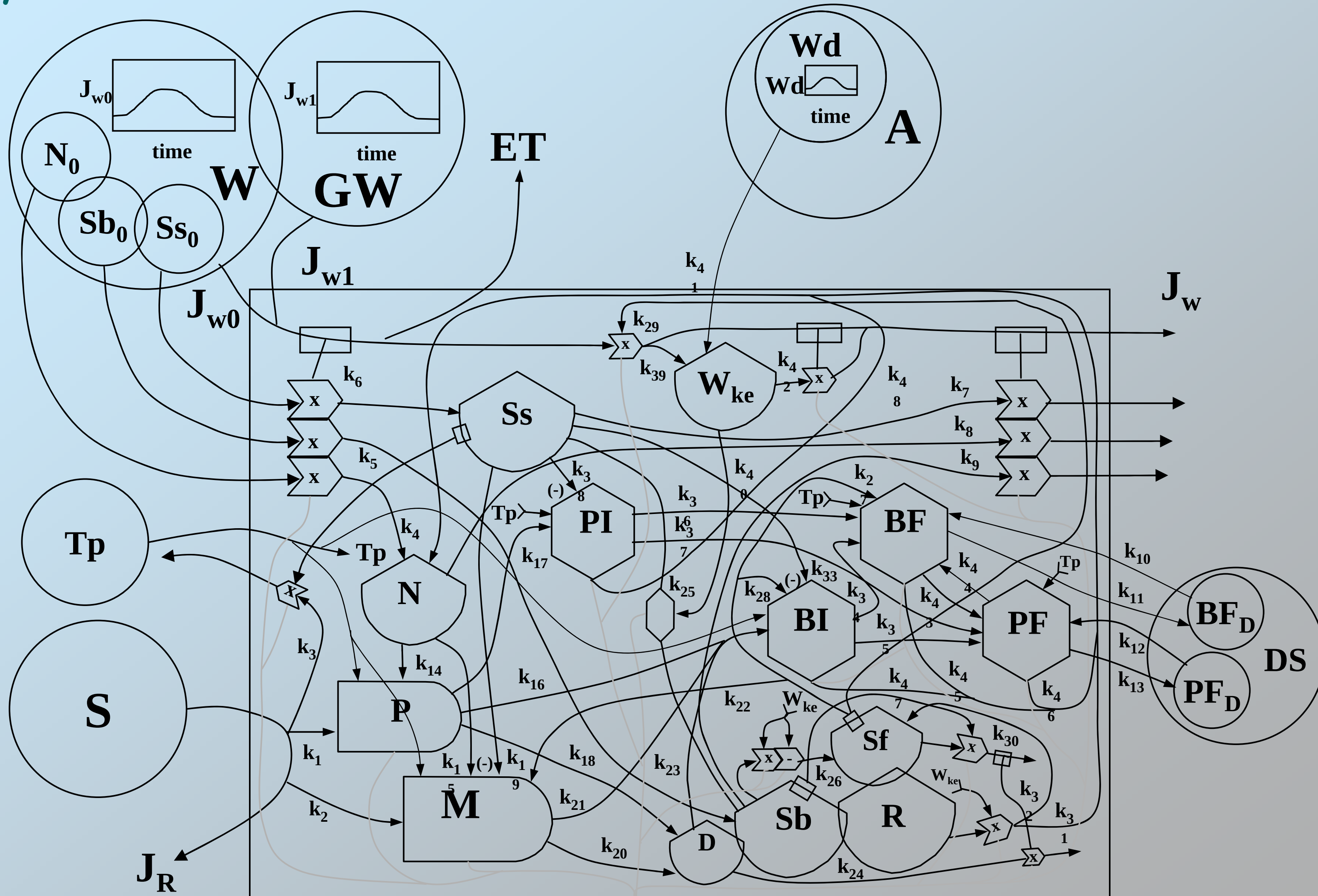
Ecological indicators tell us about—ecosystem stability





R. Jan Stevenson (from Bryce et al. 1999)

What ecologist tell non-ecologists about ecosystems...



...but, the fact is we can measure all of these components and their interactions

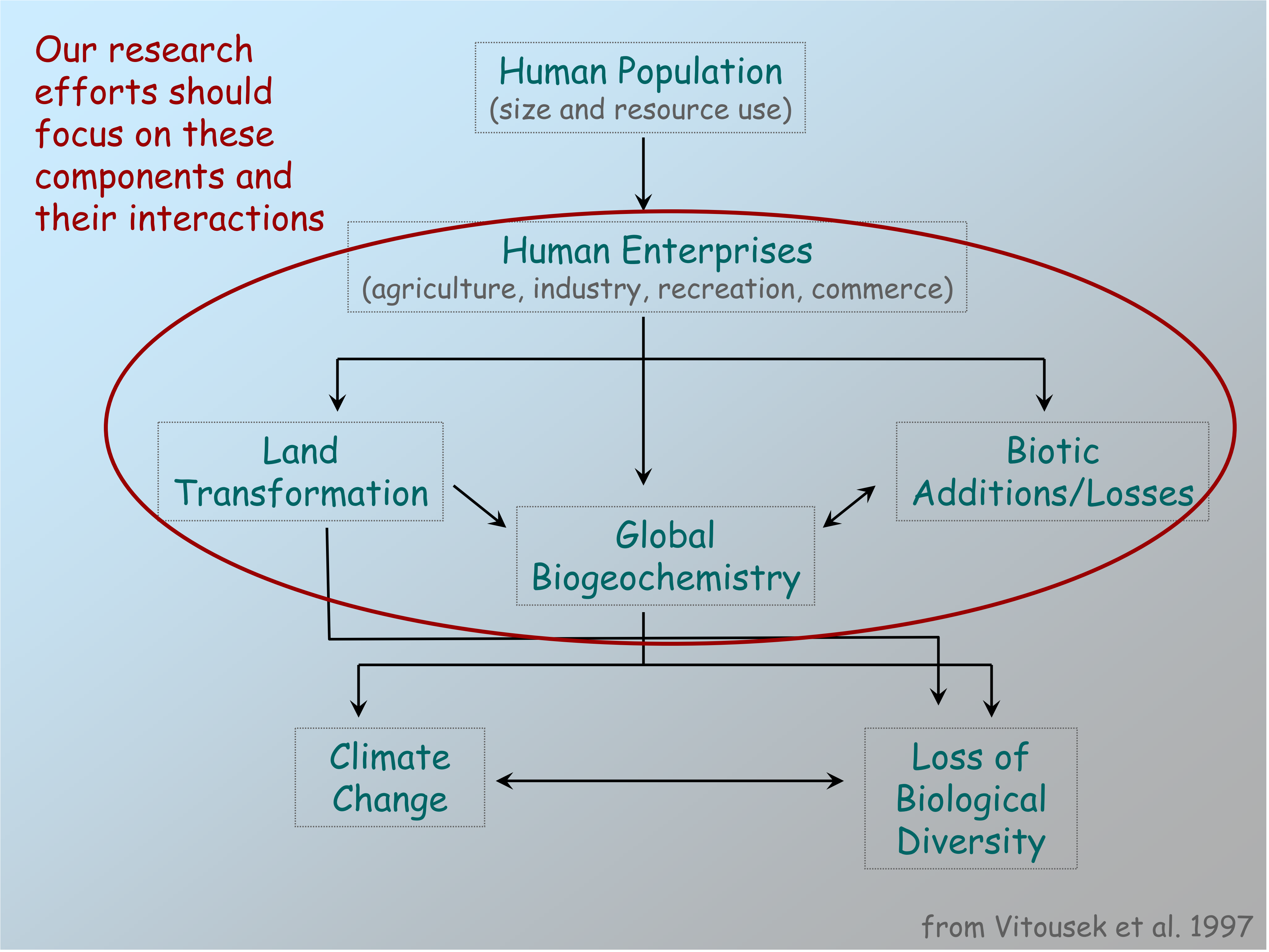
Our current views of ecosystems, by themselves, will not help promote sustainability because...

- Indicators of condition for surface waters, while good for what they do, are only measures of the symptoms, not the problem

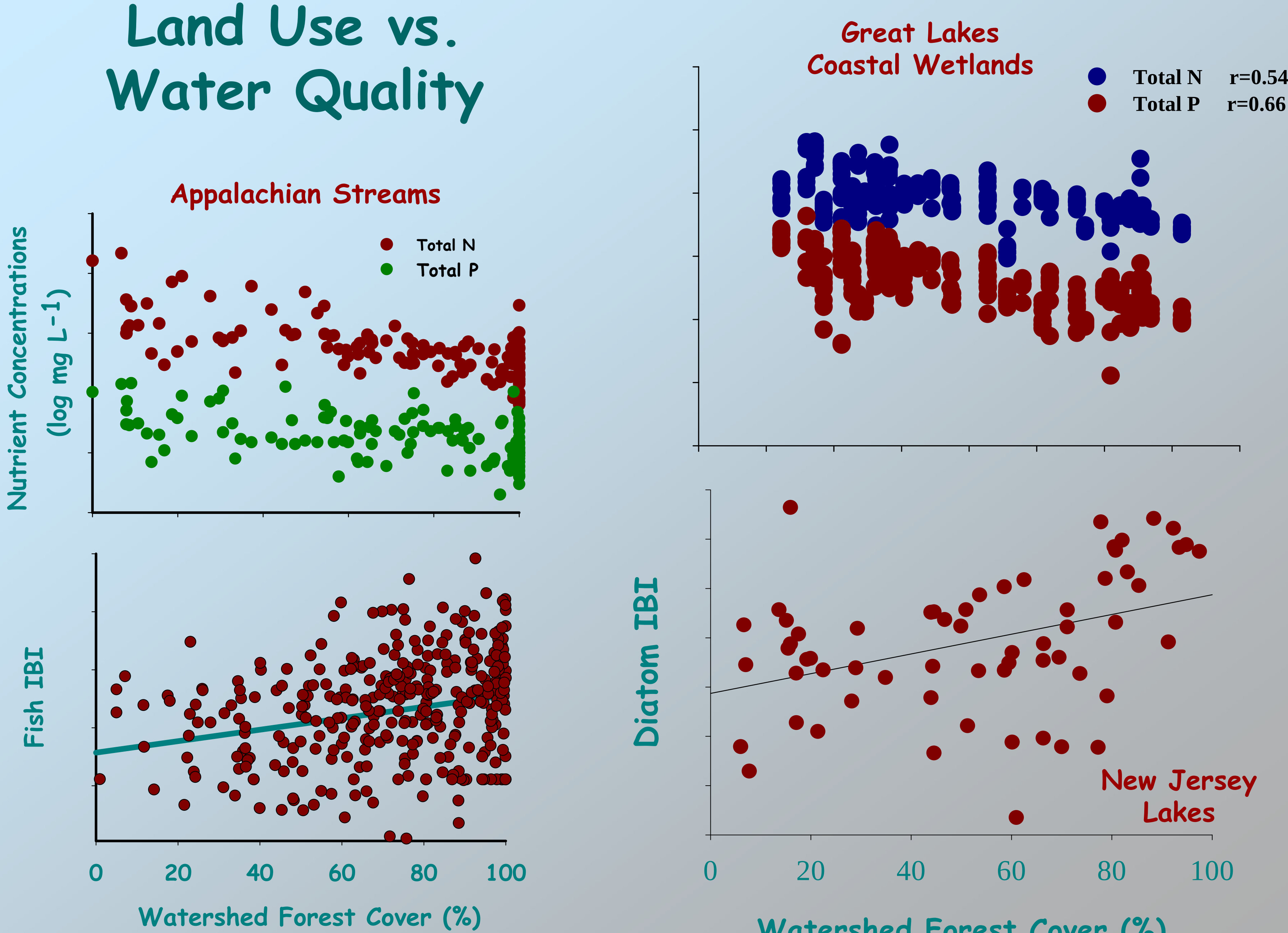
- Indicators are generally limited to the spatio-temporal scale of measurement, and are difficult to extrapolate to the appropriate scales

- Sustainability is a system level property that includes not only the determinants of surface waters but also how the system may change in the future

...indicators of sustainable surface waters may not be a realistic goal!


Our research efforts should focus on these components and their interactions
Human Population
(size and resource use)
Human Enterprises
(agriculture, industry, recreation, commerce)
Land Transformation
Global Biogeochemistry
Biotic Additions/Losses
Climate Change
Loss of Biological Diversity
from Vitousek et al. 1997

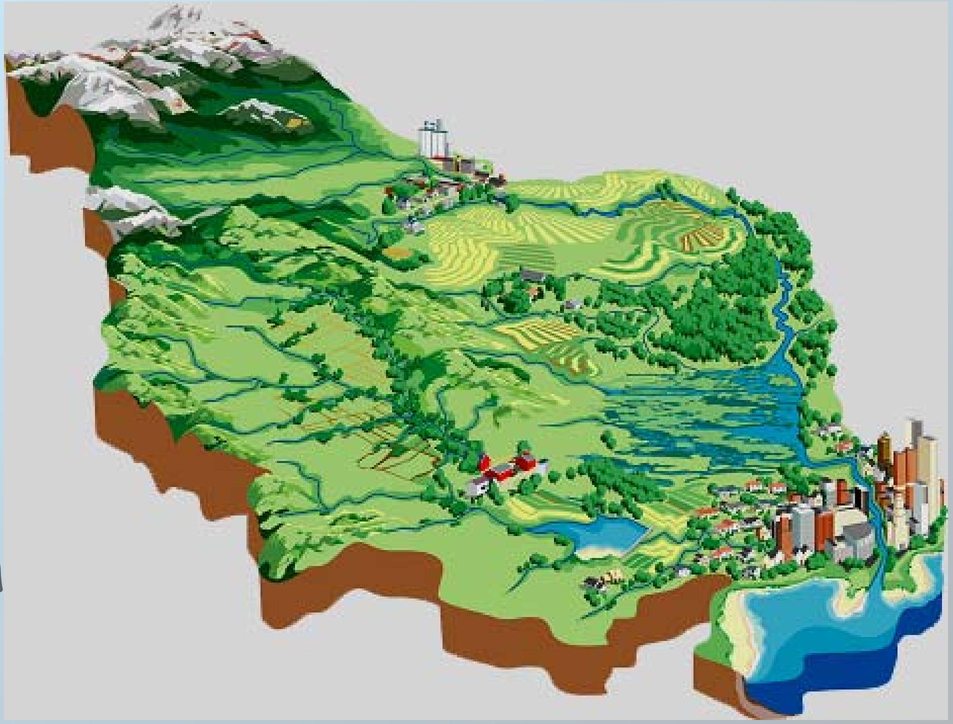
Land Use vs. Water Quality



"If the public were told how much harm ensues from unwise land-use, it would mend its ways. This was my credo, and I still think it is a fairly accurate definition of what is called conservation education. Behind this deceptively simple logic lie three unspoken but important assumptions: 1) that the public is listening, or can be made to listen; 2) that the public responds, or can be made to respond, to fear of harm; 3) that ways can be mended without any important change in the public itself. None of these assumptions is, in my opinion, valid."

Aldo Leopold (1949)
A Sand County Almanac

How do we get the public to respond?



1. **Education**
   a) K-12 programs
   b) post-secondary
   c) community outreach

2. **Engagement**
   a) inclusion of all stakeholders
   b) respect for all perspectives

3. **Empowerment**
   a) consensus management plans
   b) adoption by general public
   c) enforcement at stakeholder level

Research Needs

- indicators linking aquatic resources to their watersheds
- indicators of ecosystem functions and stability
- indicators that inform and engage stakeholders
- models capable of predicting futures with less than perfect information

From www.salmonnation.com

"Whole watershed land use in the 1950s was the best predictor of present-day diversity, whereas riparian and watershed land use in the 1990s were comparatively poor indicators."

Harding et al, 1998

As land goes so goes man

Ding Darling, 1962

"Once upon a time I agreed with Eric Chivian and the Center for Health and the Global Environment that people will protect the natural environment when they realize its importance to their health and to the health and lives of their children. Now I am not so sure. It's not that I don't want to believe that; it's just that I read the news and connect the dots..."

Bill Moyers (2004)
on receiving the Global
Environment Citizen Award

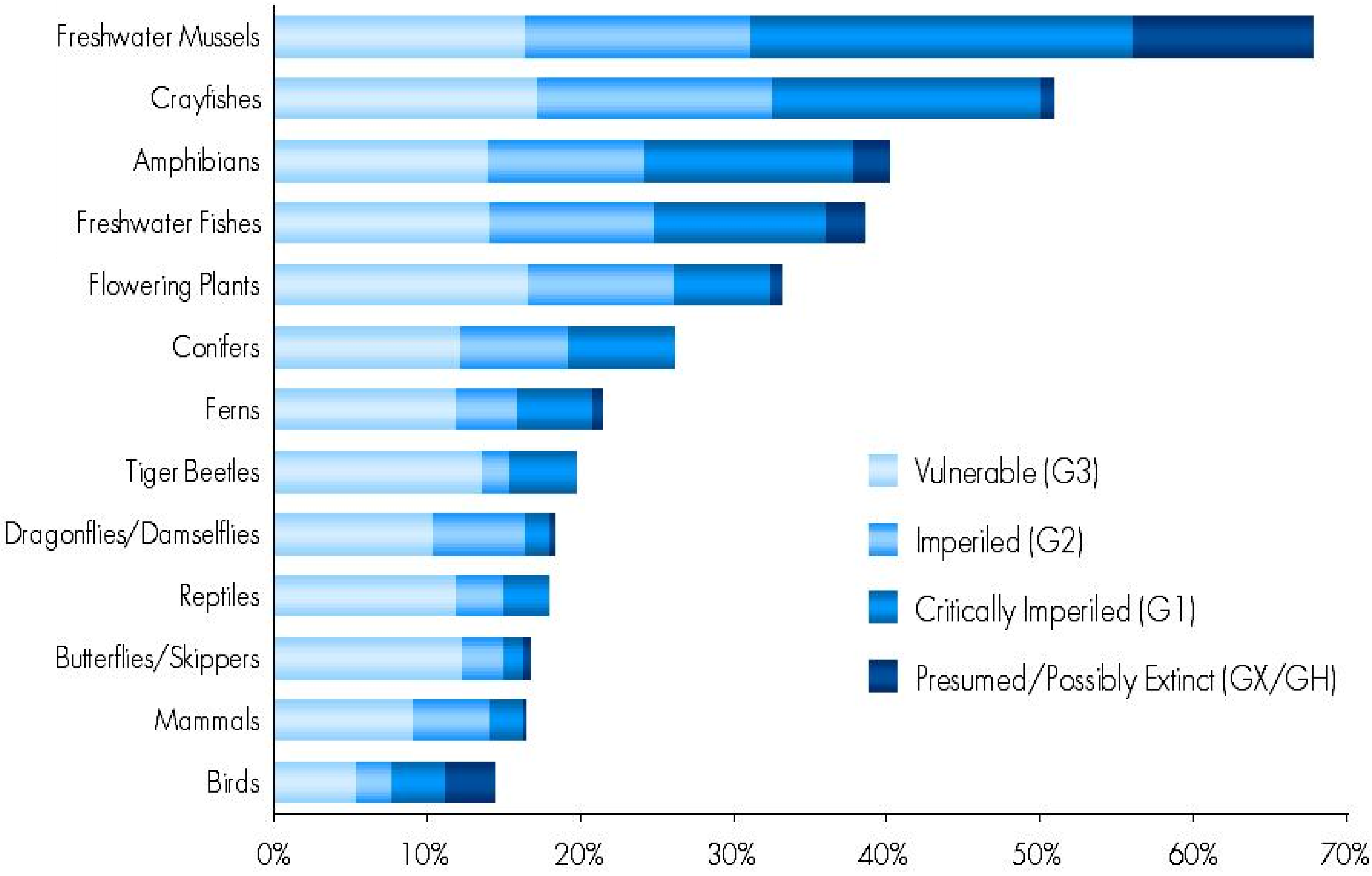
Ecologically Sustainable Water Management

Andy Warner

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

www.nature.org awarner@tnc.org www.freshwaters.org

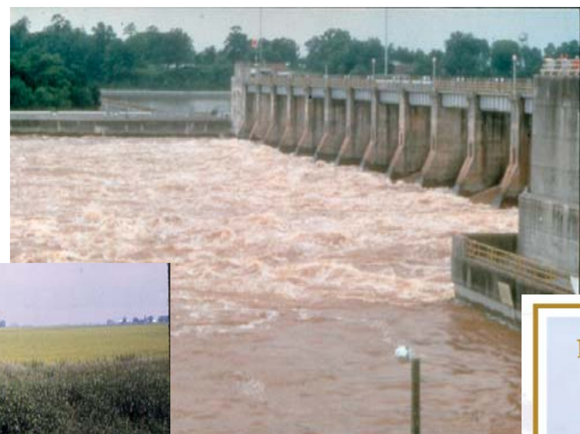
Proportion of U.S. Species at Risk

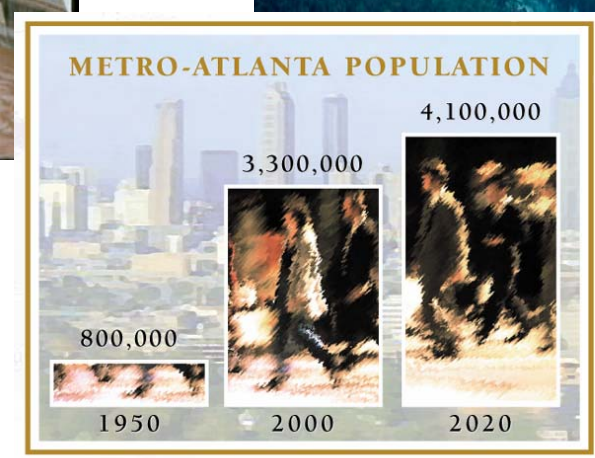


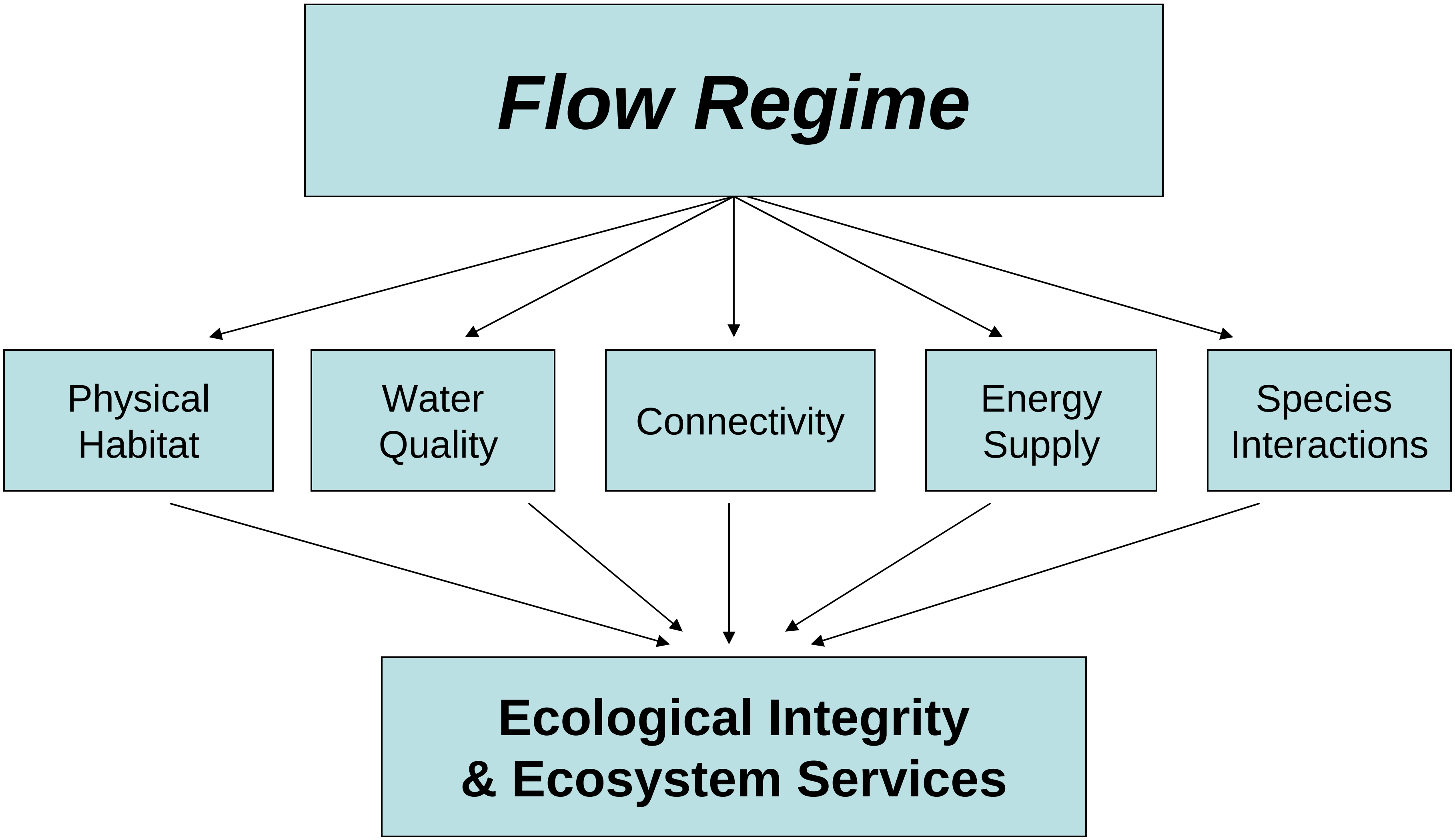
Freshwater Ecosystems

Causes of Species Loss…

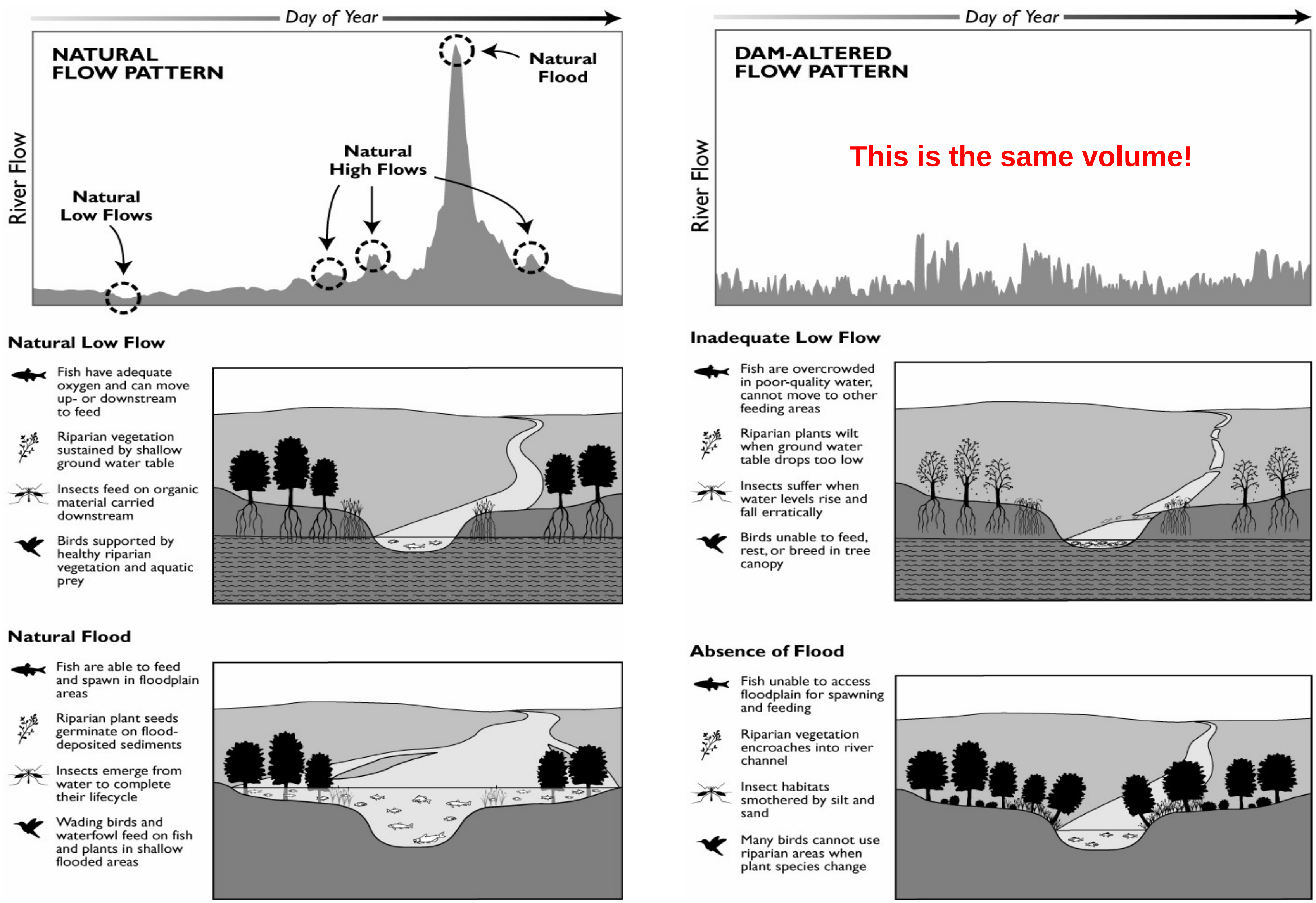
- Water Quality Degradation
- **Changes in Natural Flows**






Flow Regime
Physical Habitat
Water Quality
Connectivity
Energy Supply
Species Interactions
Ecological Integrity & Ecosystem Services

It’s Not Just a Matter of Water Volume…



Environmental Flows

The flow of water in a natural river or lake that sustains healthy ecosystems and the goods and services that humans derive from them.

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Environmental Flows

The goal is *not* to create optimal conditions for all species all of the time;

⇙ we want to create adequate conditions for all native species *enough* of the time.

Environmental Flows

<u>Defining and Implementing</u>

- Flow Restoration Database (global, 400+)
- Recommended process for defining ecosystem flows
- Sustainable Rivers Project...

www.freshwaters.org

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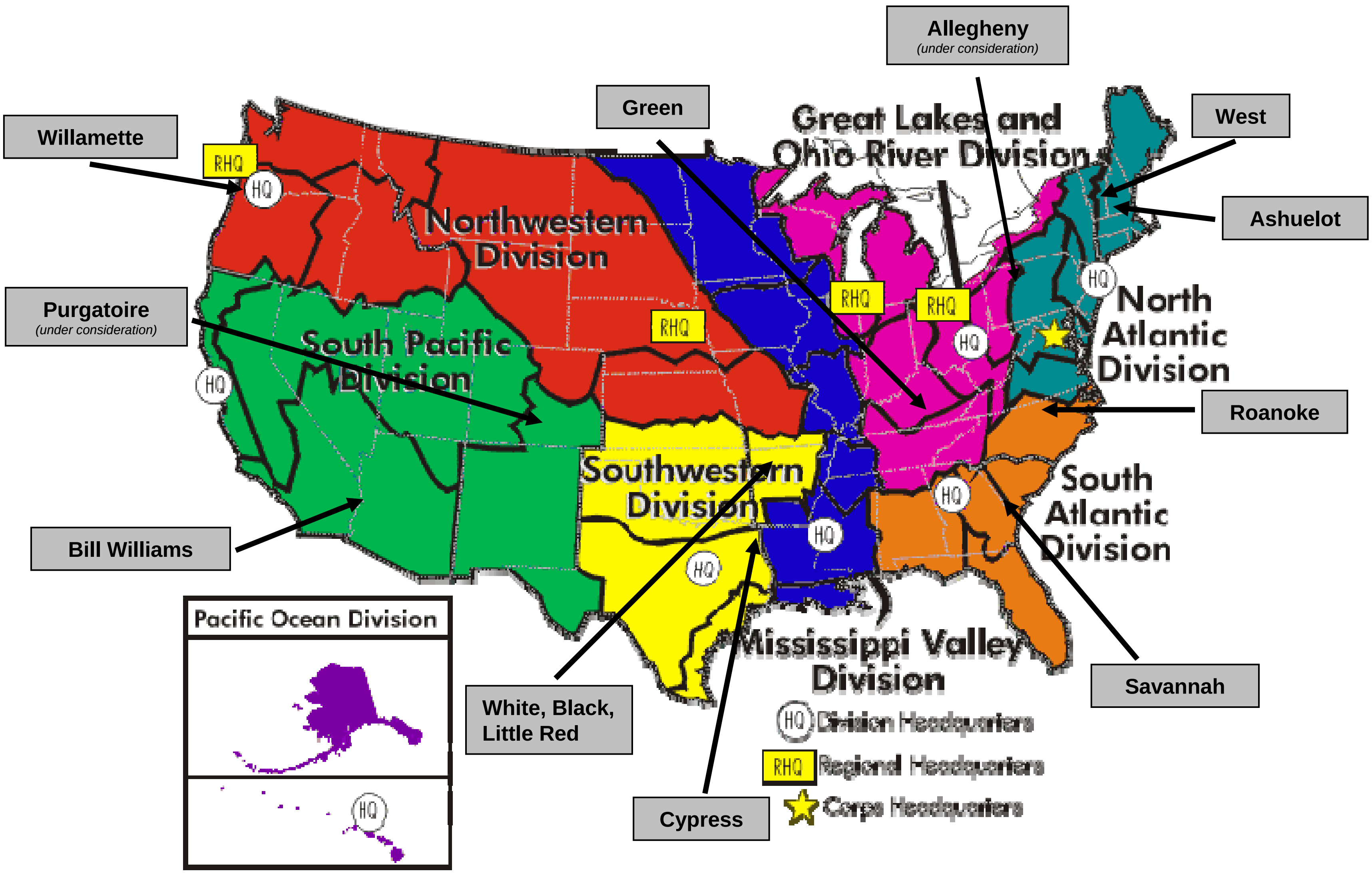
Sustainable Rivers Project

Current Sites



Ecologically Sustainable Water Management
What's Missing in the U.S.?

- Clear management goals for our rivers that explicitly recognize ecological needs for water quantity and flow

- State/federal program designed to achieve these goals
  - ***Permitting processes that are 1) ecologically protective; 2) supportive of long-term economic development; and, 3) balanced in sharing responsibility***

- **Systematic and efficient process for setting limits of hydrologic alteration across multiple rivers (e.g., state-wide)**

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Limits of Hydrologic Alteration Method

LOHA is a Method founded upon three basic concepts:

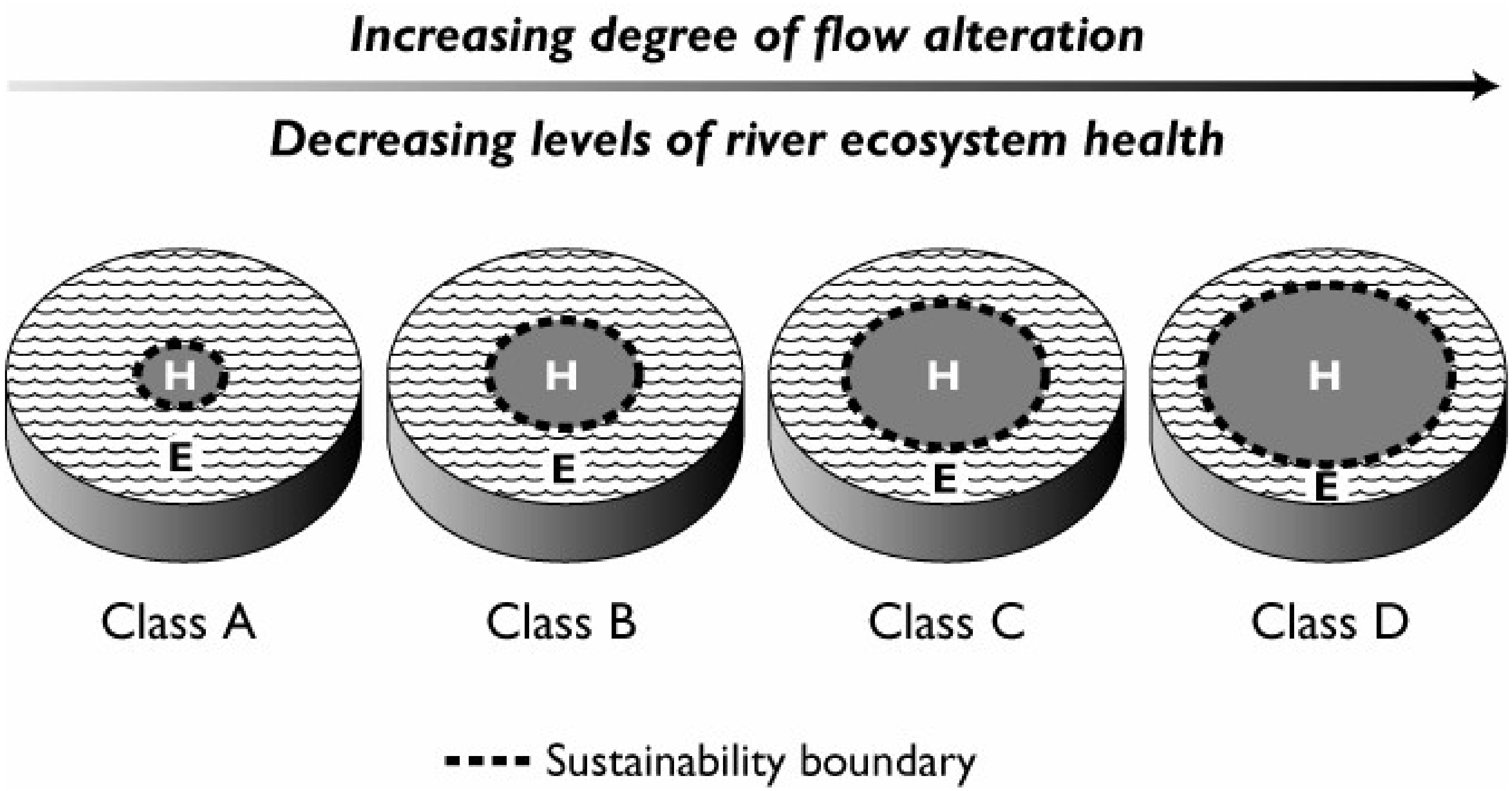
- Environmental flow recommendations should be based on long-term ecosystem health, rather than limited components such as fish species
  (e.g., Arthington *et a*l. 1992; Richter *et al*. 1997; Poff *et al*. 1997; Dyson *et al*. 2003; Annear *et al*. 2004)

- Ecosystem health is best supported by the natural flow regime, and departures from natural flows will result in ecosystem degradation
  (e.g., Arthington *et al*. 1992; Poff *et al.* 1997; Richter *et al*. 2003; Bunn and Arthington 2003; Annear *et al*. 2004)

- The health of rivers can be described as spanning a spectrum of degradation such as "excellent" to "poor"
  (e.g., Petts 1996; King *et al*. 2004; Richter and Postel 2003; USEPA 2004)

  - **These river health classes can be used as a basis for goal-setting and applied to defining environmental flows for all rivers in a state**

Ecological Goal Setting



From: "Rivers for Life: Managing Water for People and Nature"

by Sandra Postel and Brian Richter (Island Press 2003)

LOHA Method: General Steps

- **Set Goals: Assign Rivers a Desired Ecological Condition (Class)**
  Set health goals for rivers or river segments (much like state water quality classification)
- **Assess Compliance with Hydrologic Criteria**
  Specific criteria are dependent upon the river's Class and allow compliance to be assessed
- **Design Protection Strategies for Rivers Meeting Criteria**
  Analogous to water quality anti-degradation policies; facilitates review of new permit applications
- **Design Restoration Strategies for Rivers Out of Compliance**
  Analogous to TMDLs; facilitates watershed- and market-based approaches for streamflow restoration

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LOHA Template: Relate ecological condition classes to natural and altered flows

↙ *these parallel the biological condition classes for aquatic ecosystems in the U.S. (EPA, 2004)*

Ecological Condition Class	**Description of Biological Condition**	**Limits of Hydrologic Alteration (*hypothetical example*)**
1	*Natural or native condition*	Extreme low flow duration: < 5% Monthly low flow magnitudes: <10% High-flow pulse frequency: <10% Small flood magnitude: <10% Large flood magnitude: <15%
2	*Minimal changes in the structure of the biotic community and minimal changes in ecosystem function*	Extreme low flow duration: < 5% Monthly low flow magnitudes: <10% High-flow pulse frequency: <15% Small flood magnitude: <20% Large flood magnitude: <25%
3	*Evident changes in structure of the biotic community and minimal changes in ecosystem function*	Extreme low flow duration: < 10% Monthly low flow magnitudes: <15% High-flow pulse frequency: <20% Small flood magnitude: <25% Large flood magnitude: <25%
4	*Moderate changes in the structure of the biotic community and minimal changes in ecosystem function*	Extreme low flow duration: < 15% Monthly low flow magnitudes: <20% High-flow pulse frequency: <30% Small flood magnitude: <40% Large flood magnitude: <40%
5	*Major changes in structure of the biotic community and moderate changes in ecosystem function.*	Extreme low flow duration: < 20% Monthly low flow magnitudes: <25% High-flow pulse frequency: <50% Small flood magnitude: <50% Large flood magnitude: <50%
6	*Severe changes in structure of the biotic community and major loss of ecosystem function*	Extreme low flow duration: > 20% Monthly low flow magnitudes: >25% High-flow pulse frequency: >50% Small flood magnitude: >50% Large flood magnitude: >50%

Ecologically Sustainable Water Management

Technical Tasks and Research Needs

- Select the river categorization system most appropriate for a state

  modest effort: existing state/national examples

- Identify the flow parameters that can best represent the health of a river

  moderate effort: representativeness v.s. manageable number

- Establish thresholds between river health classes Increase the resolution at which we can define thresholds between river classes

  large effort: increase the certainty and resolution between river classes

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