US EPA ARCHIVE DOCUMENT

Forecasting Changes in Wetland-Associated Ecosystem Services Associated with Climatic and Land-Cover Change in the Susquehanna River Basin, USA

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[4] Department of Meteorology
[5] Department of Agricultural Economics and Rural Sociology

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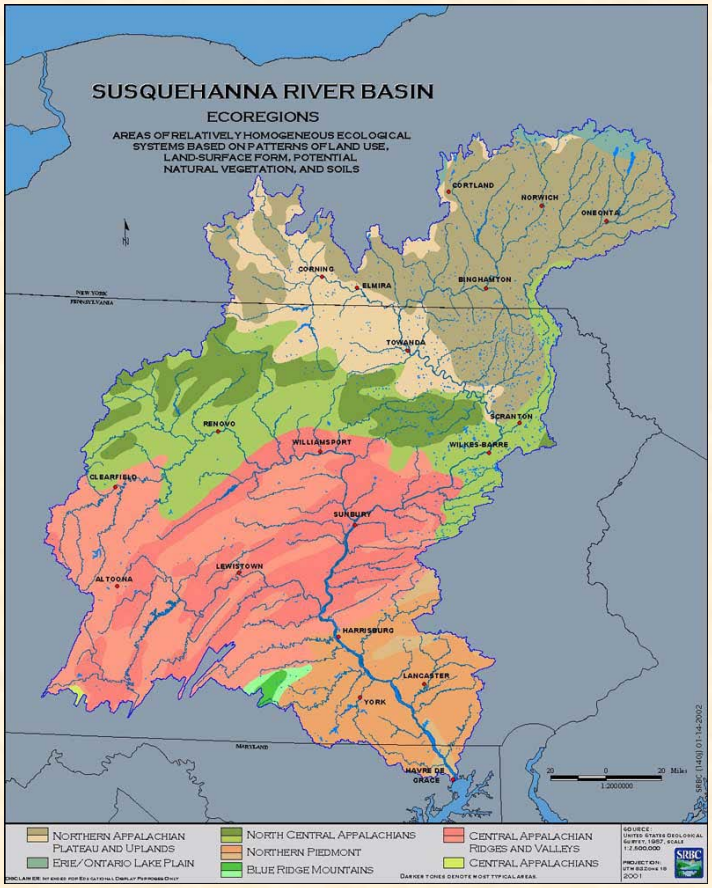
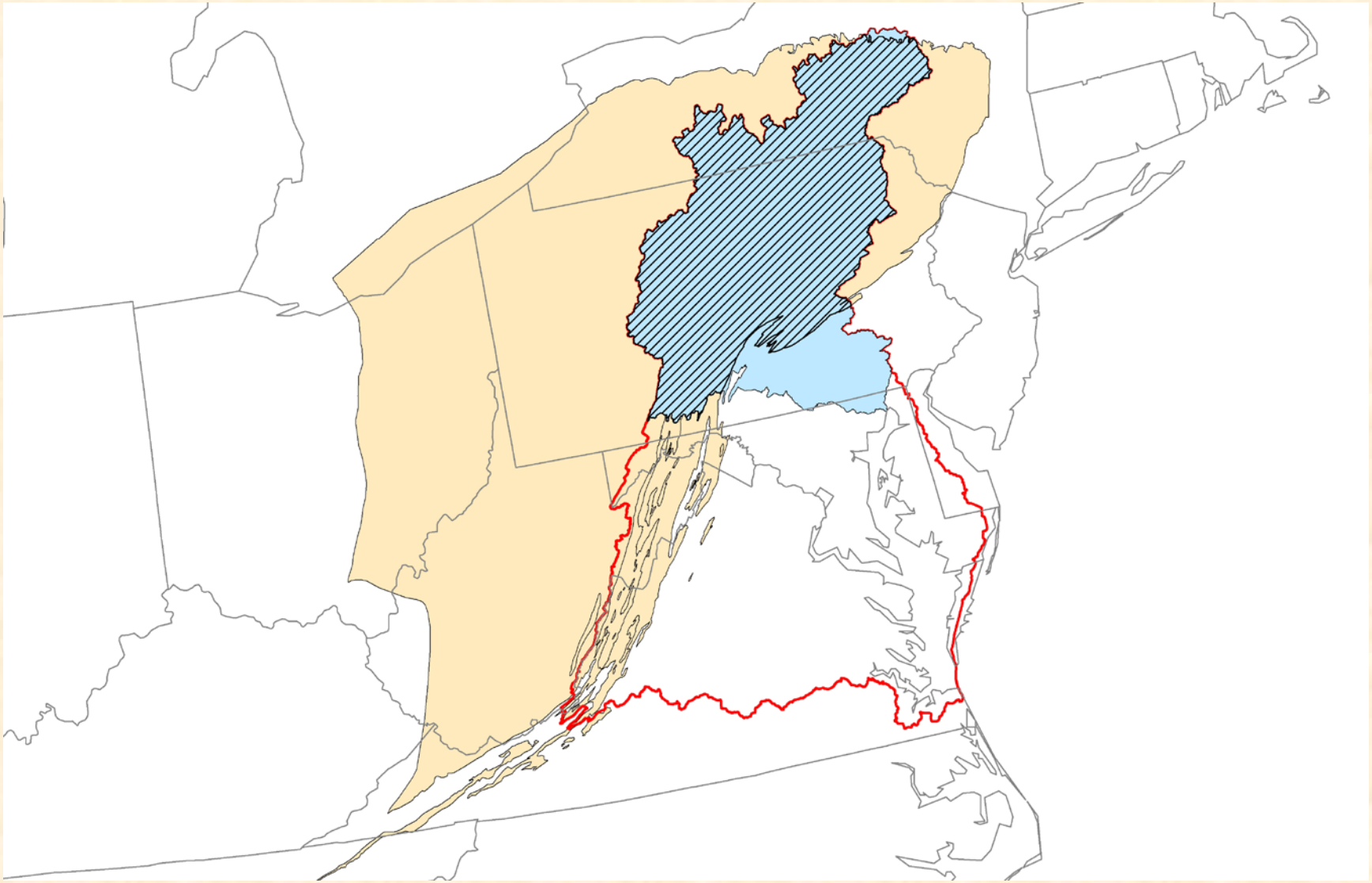
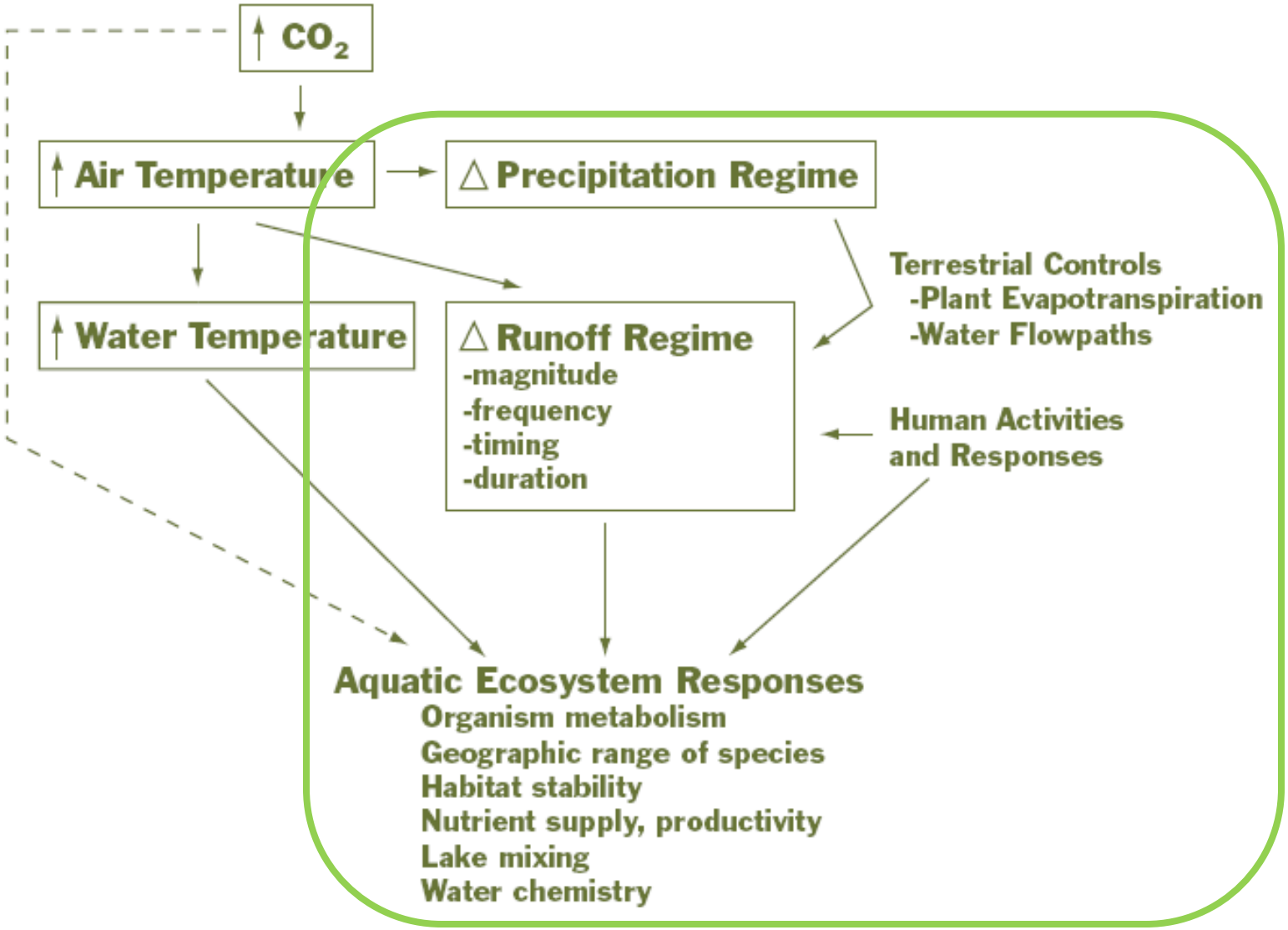

SUSQUEHANNA RIVER BASIN
ECOREGIONS
AREAS OF RELATIVELY HOMOGENEOUS ECOLOGICAL SYSTEMS BASED ON PATTERNS OF LAND USE, LAND-SURFACE FORM, POTENTIAL NATURAL VEGETATION, AND SOILS
CORTLAND
NORWICH
ONEONTA
CORNING
ELMIRA
BINGHAMTON
TOWANDA
RENOVO
WILLIAMSPORT
SCRANTON
WILKES-BARRE
CLEARFIELD
SUNBURY
LEWISTOWN
ALTOONA
HARRISBURG
LANCASTER
YORK
HAVRE DE GRACE
NEW YORK
PENNSYLVANIA
MARYLAND
20 0 20 Miles
1:2000000
NORTHERN APPALACHIAN PLATEAU AND UPLANDS
ERIE/ONTARIO LAKE PLAIN
NORTH CENTRAL APPALACHIANS
NORTHERN PIEDMONT
BLUE RIDGE MOUNTAINS
CENTRAL APPALACHIAN RIDGES AND VALLEYS
CENTRAL APPALACHIANS
DARKER TONES DENOTE MOST TYPICAL AREAS
SOURCE: UNITED STATES GEOLOGICAL SURVEY, 1967, SCALE 1:2,500,000
PROJECTION: UTM ZONE 18 2001
SRBC

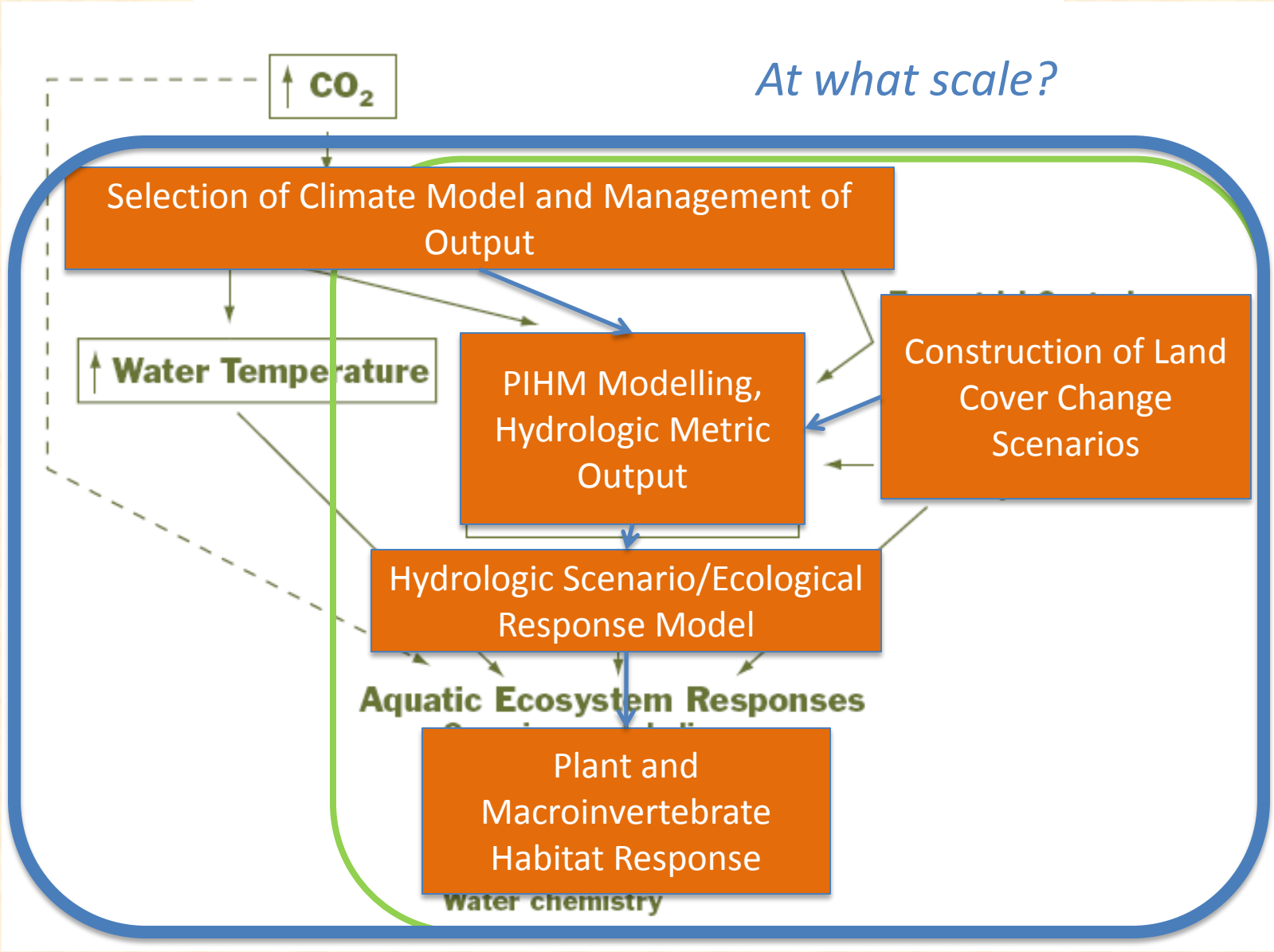


CO_2, Climate, and Ecological Processes



Poff et al 2005

CO_2, Climate, and Ecological Processes

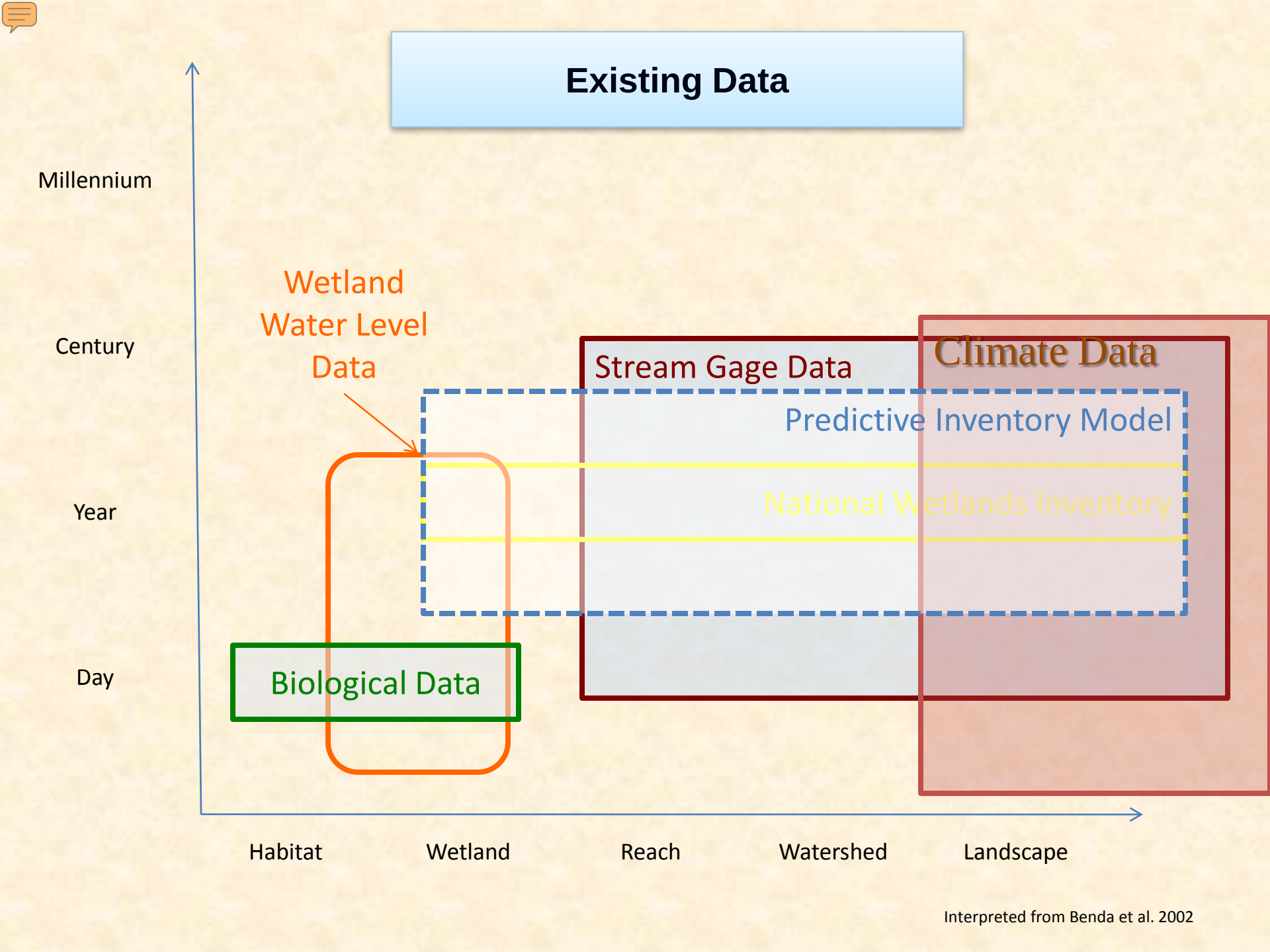


Poff et al 2005

When one has finished building one's house, one suddenly realizes that in the process one has learned something that one really needed to know in the worst way - before one began.

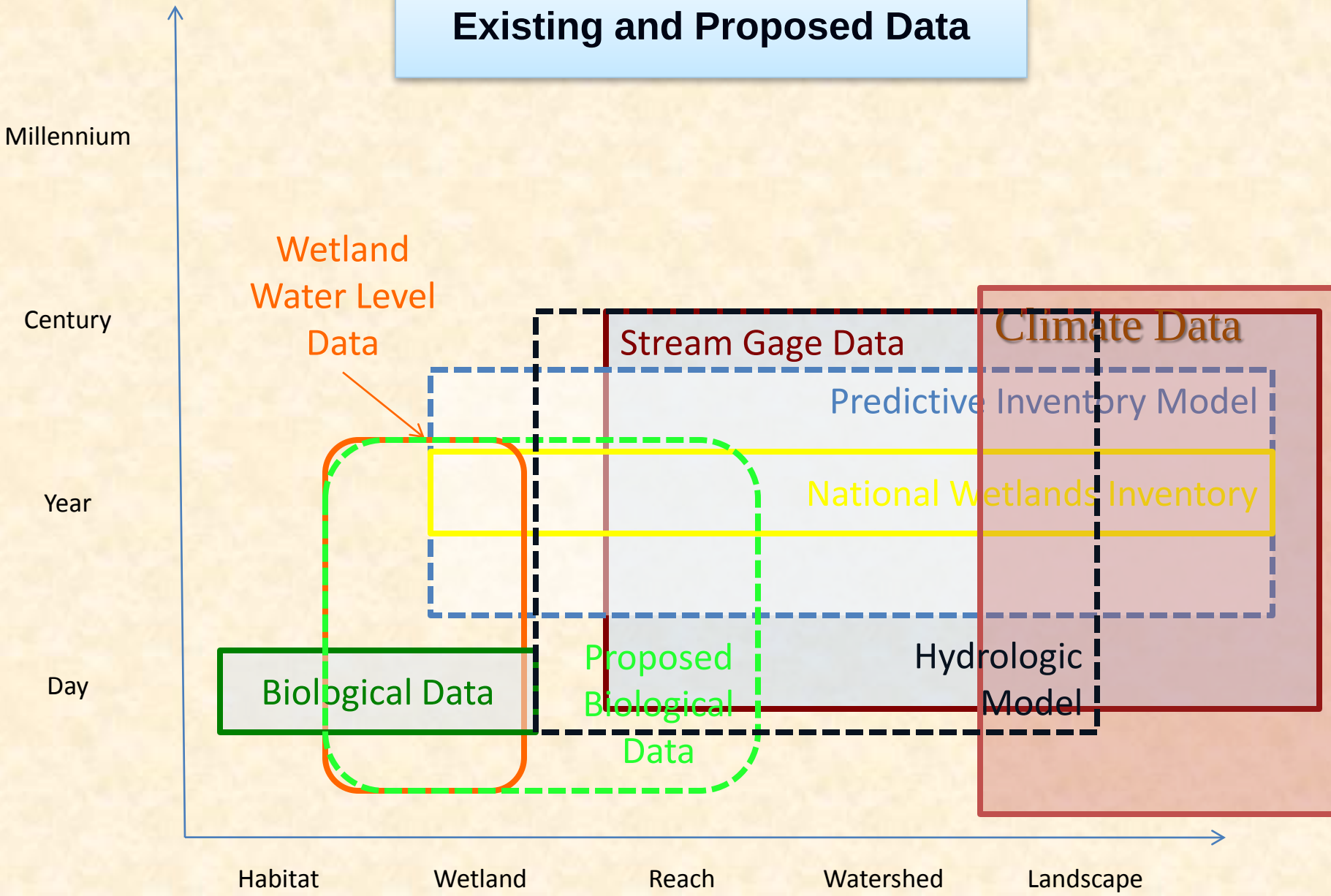
Friedrich Nietzsche

Existing Data

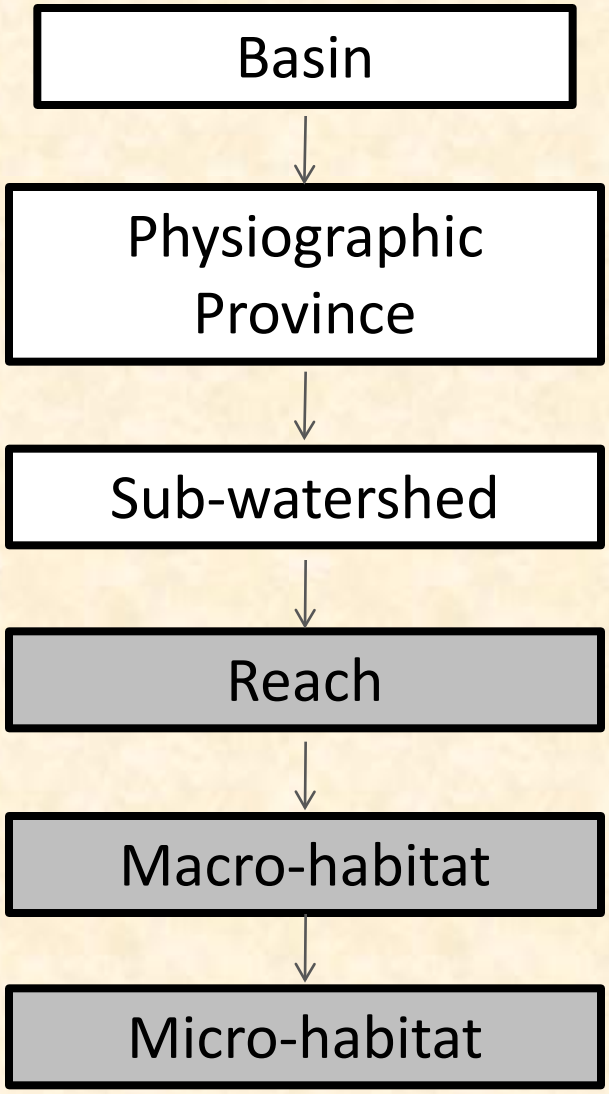


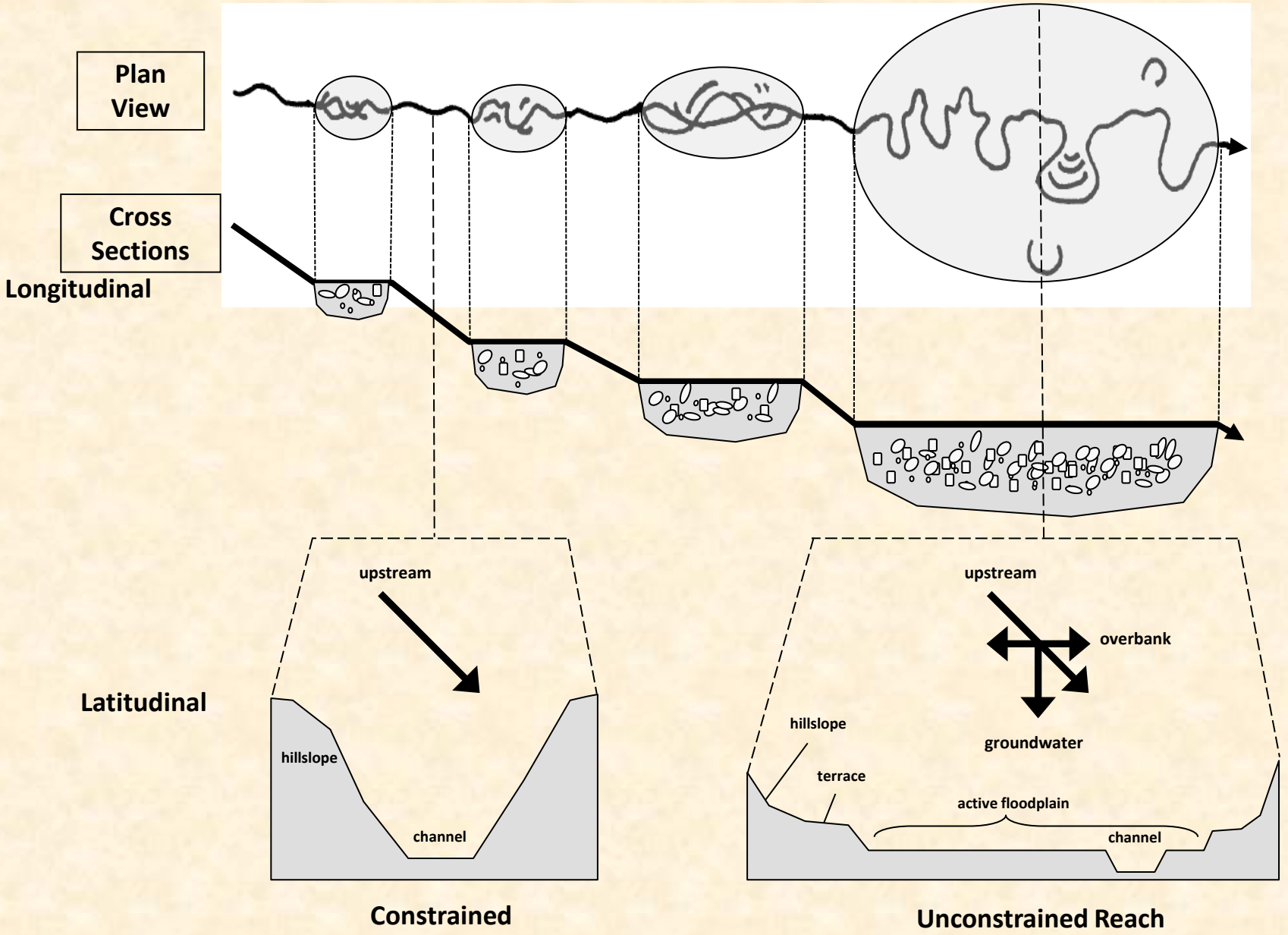
Interpreted from Benda et al. 2002

Existing and Proposed Data



Interpreted from Benda et al. 2002

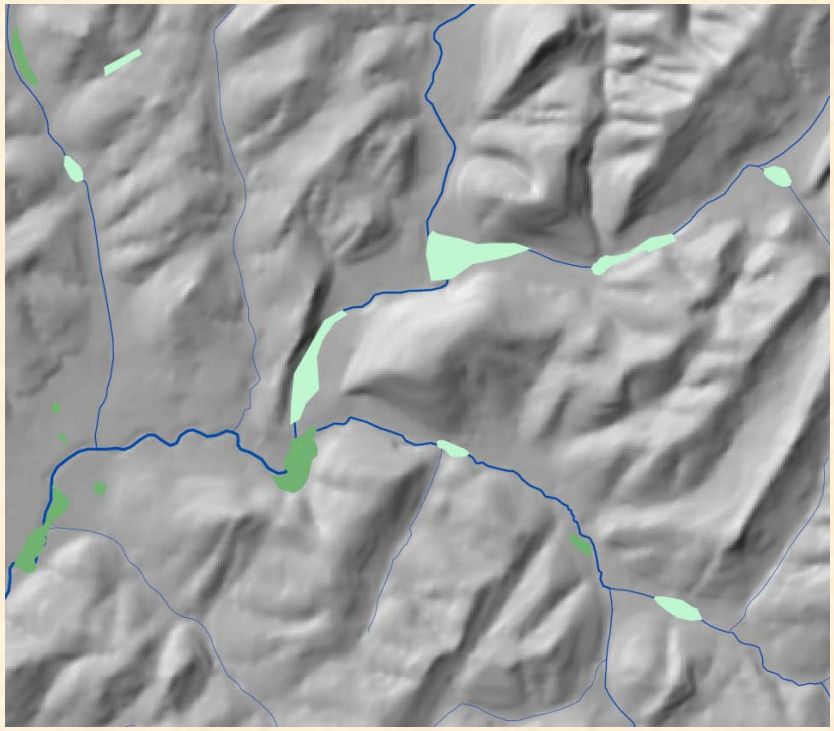

Basin
Physiographic Province
Sub-watershed
Reach
Macro-habitat
Micro-habitat

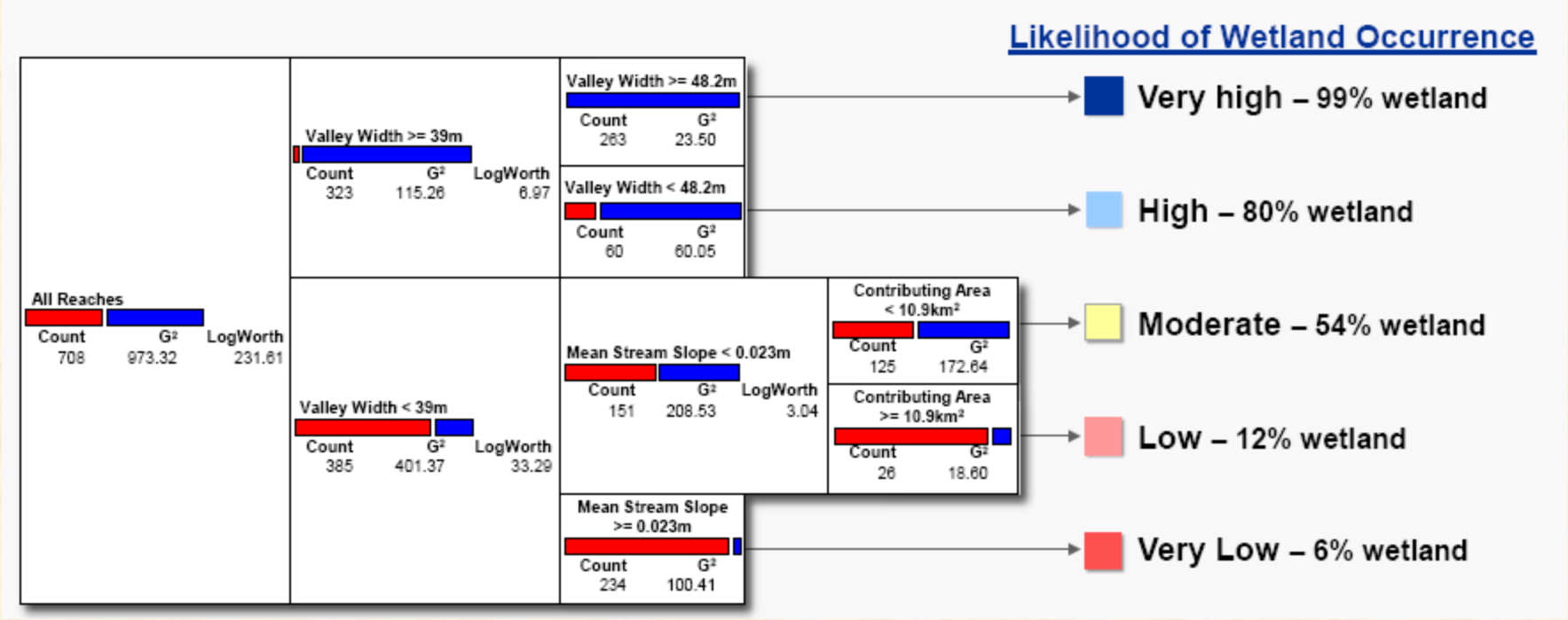


Sensu Ward et. al 2002

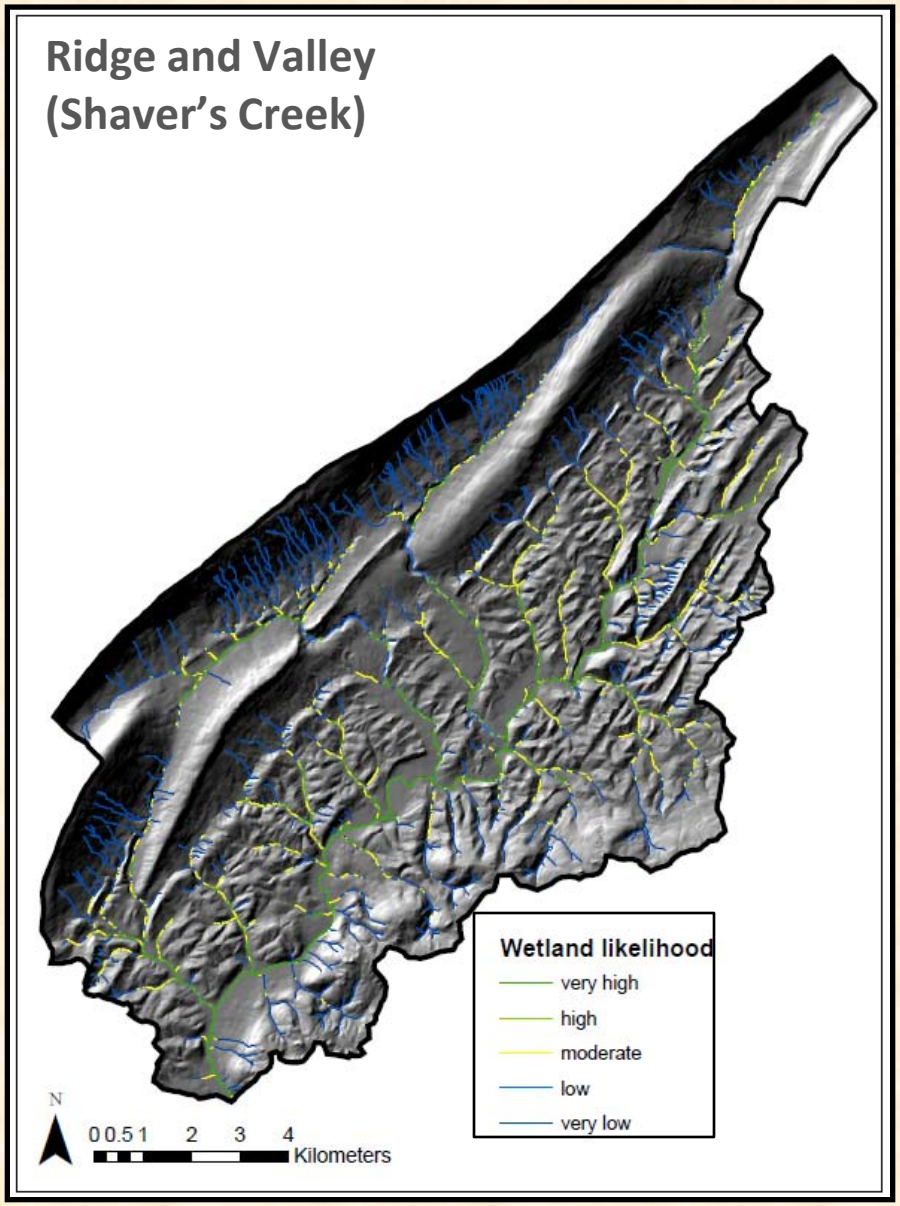
Reach Characterization

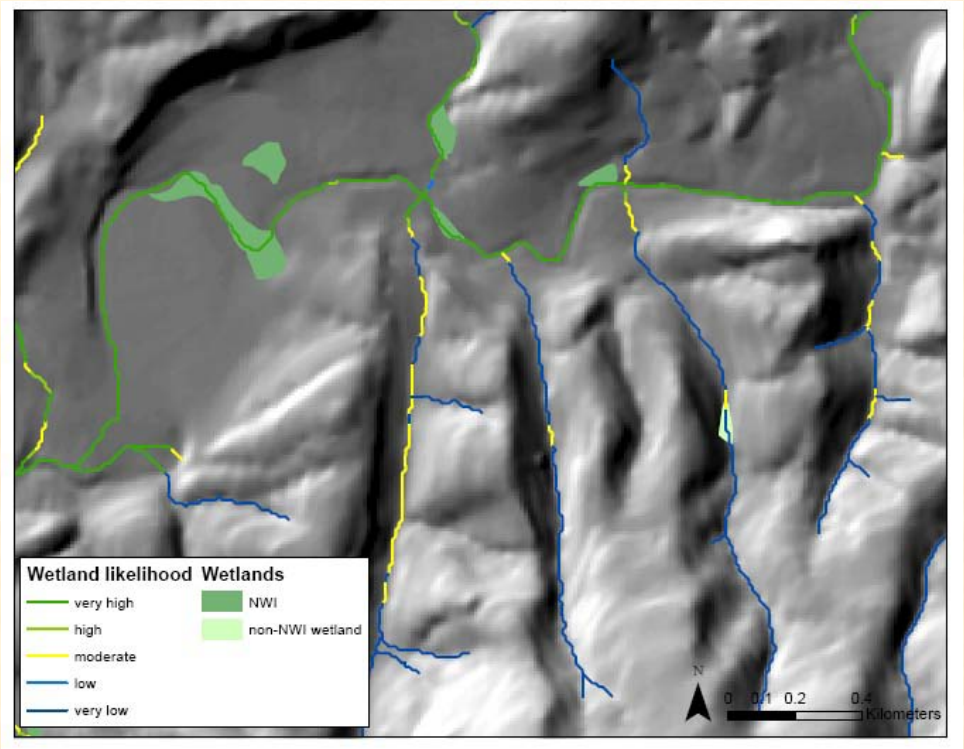
- Response variables: known locations of wetlands
  - non-open water National Wetlands Inventory (n=40)
  - Field identified wetlands (n=30)
  - Non-wetland reaches (n=35)
- Predictor variables: Topographic indices characterizing each reach derived from 10-m DEM using NetTrace (Miller 2003)
  - valley width
  - mean stream slope
  - contributing area
  - specific stream power
  - valley width index



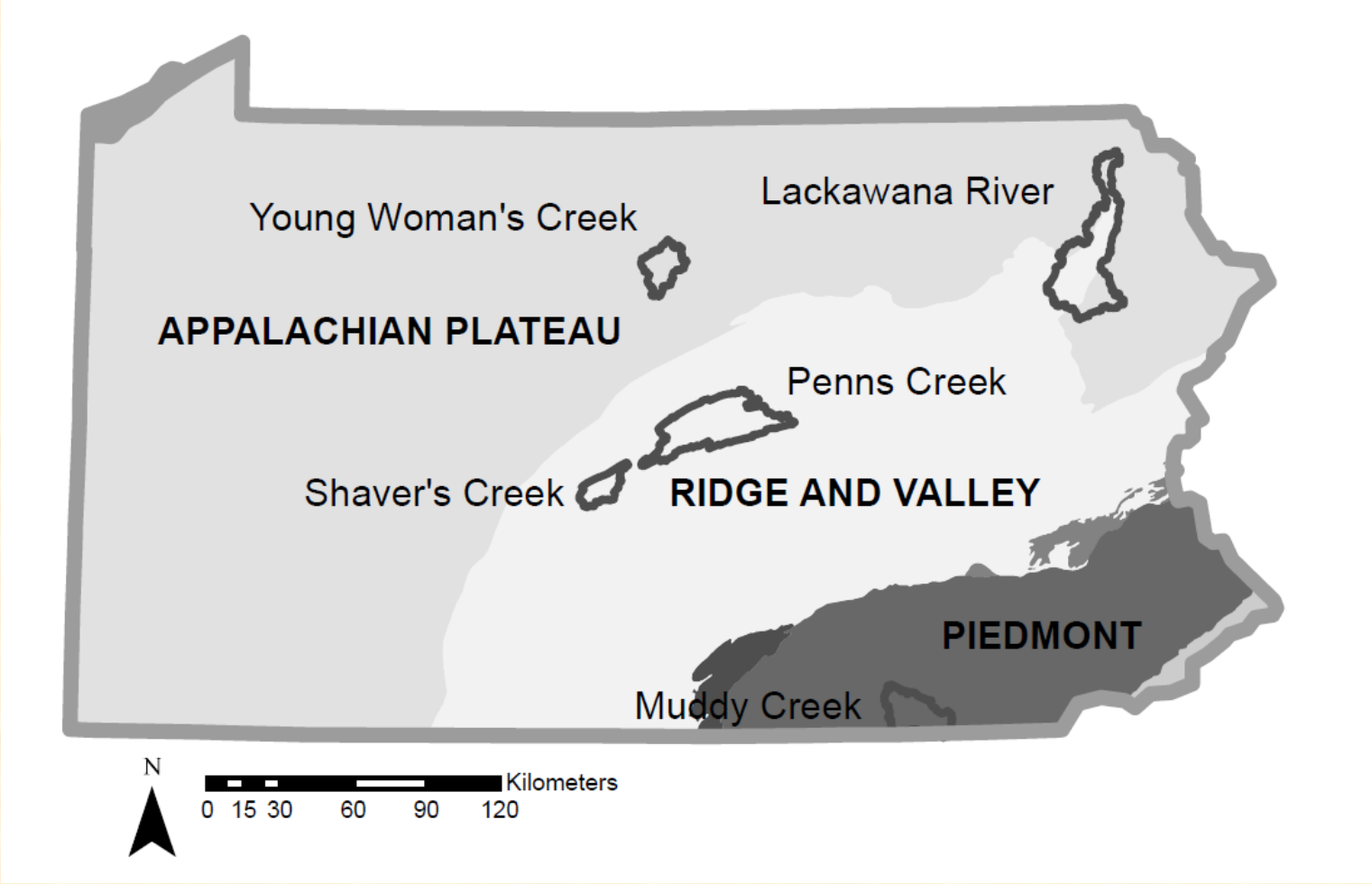


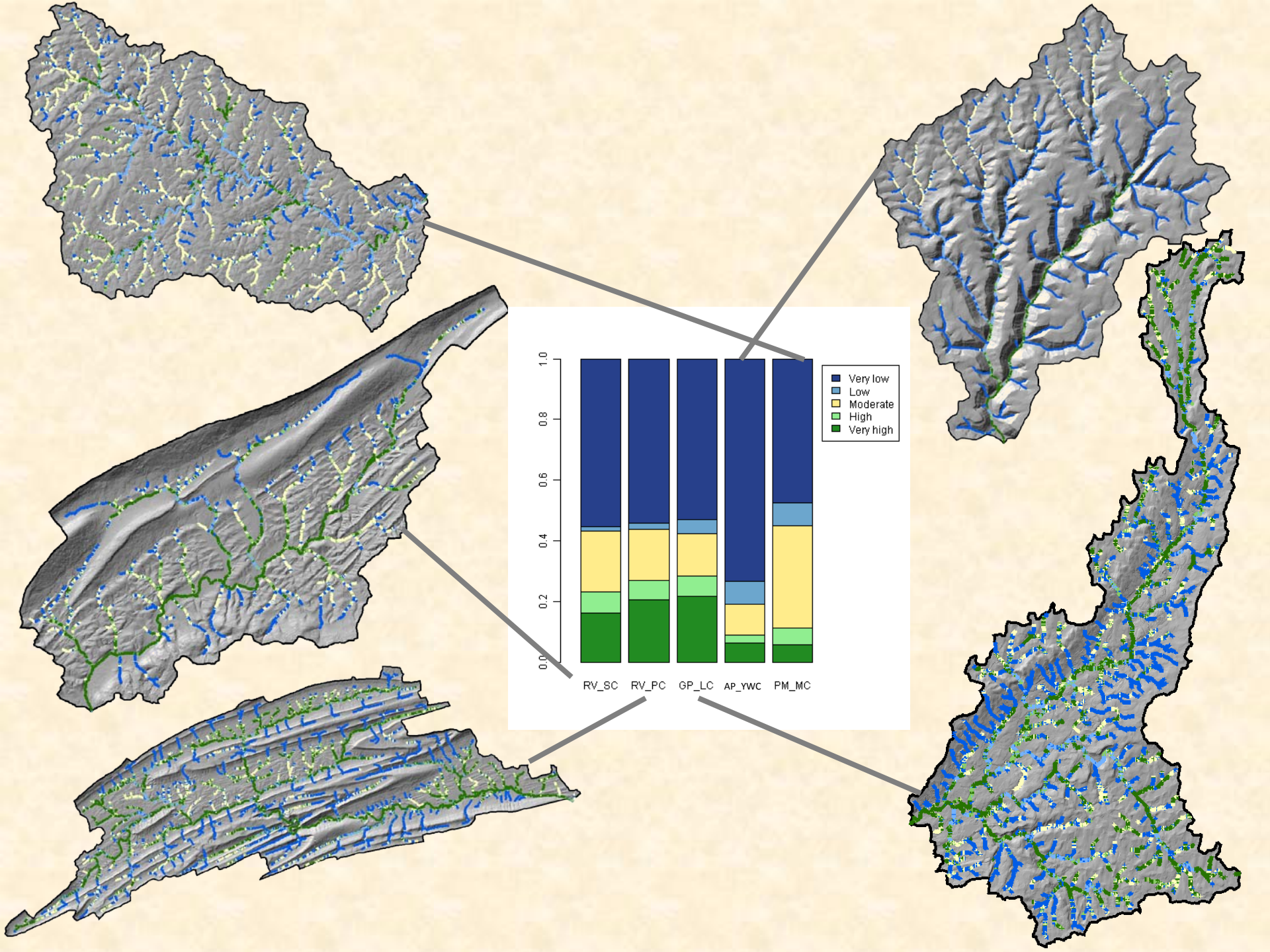
Unconstrained	**Very high** highly laterally unconstrained
Unconstrained	**High** laterally unconstrained
Unconstrained	**Moderate** smaller streams, less laterally or longitudinally constrained for size
Constrained	**Low** larger streams, constrained longitudinally and somewhat laterally
Constrained	**Very low** highly constrained both laterally and longitudinally


Ridge and Valley
(Shaver's Creek)
Wetland likelihood
very high
high
moderate
low
very low
N
0 0.5 1 2 3 4
Kilometers

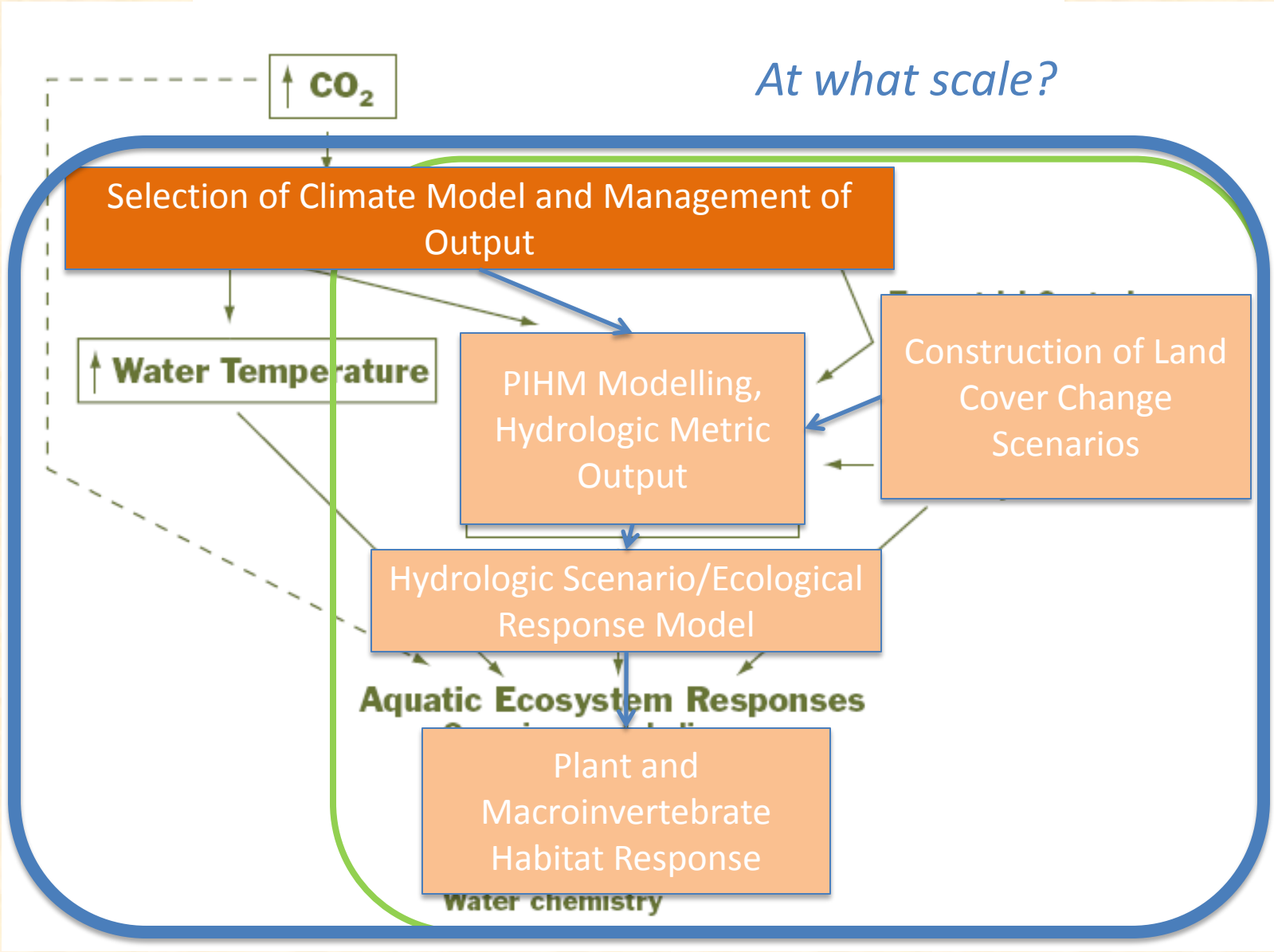

Wetland likelihood
very high
high
moderate
low
very low
Wetlands
NWI
non-NWI wetland
N
0 0.1 0.2 0.4
Kilometers

Study Sub-watersheds

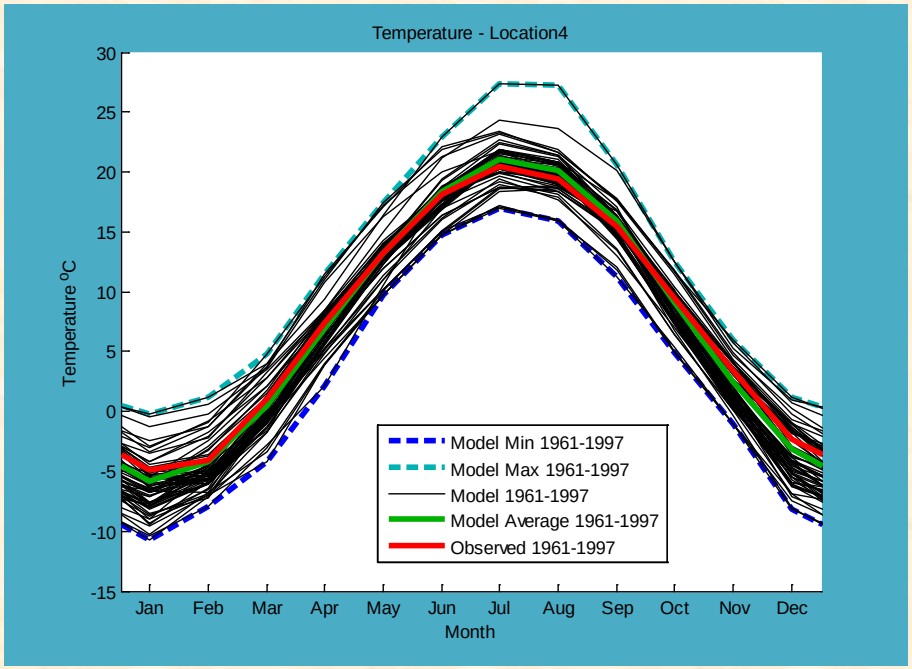


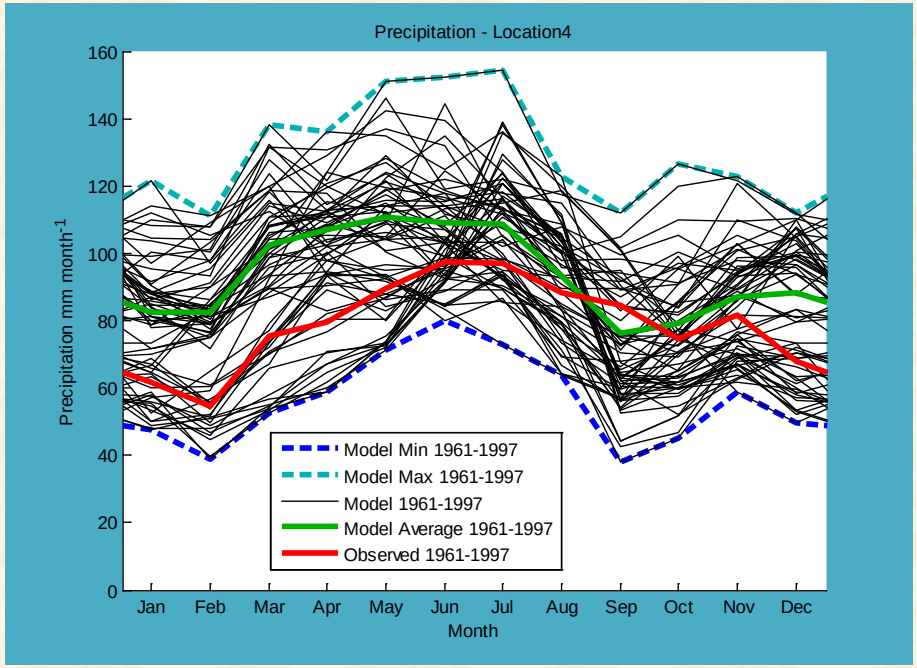

0.0
0.2
0.4
0.6
0.8
1.0
RV_SC
RV_PC
GP_LC
AP_YWC
PM_MC
Very low
Low
Moderate
High
Very high

CO_2, Climate, and Ecological Processes



Poff et al 2005





Selection of Climate Model and Management of Output

Metrics for Model Selection

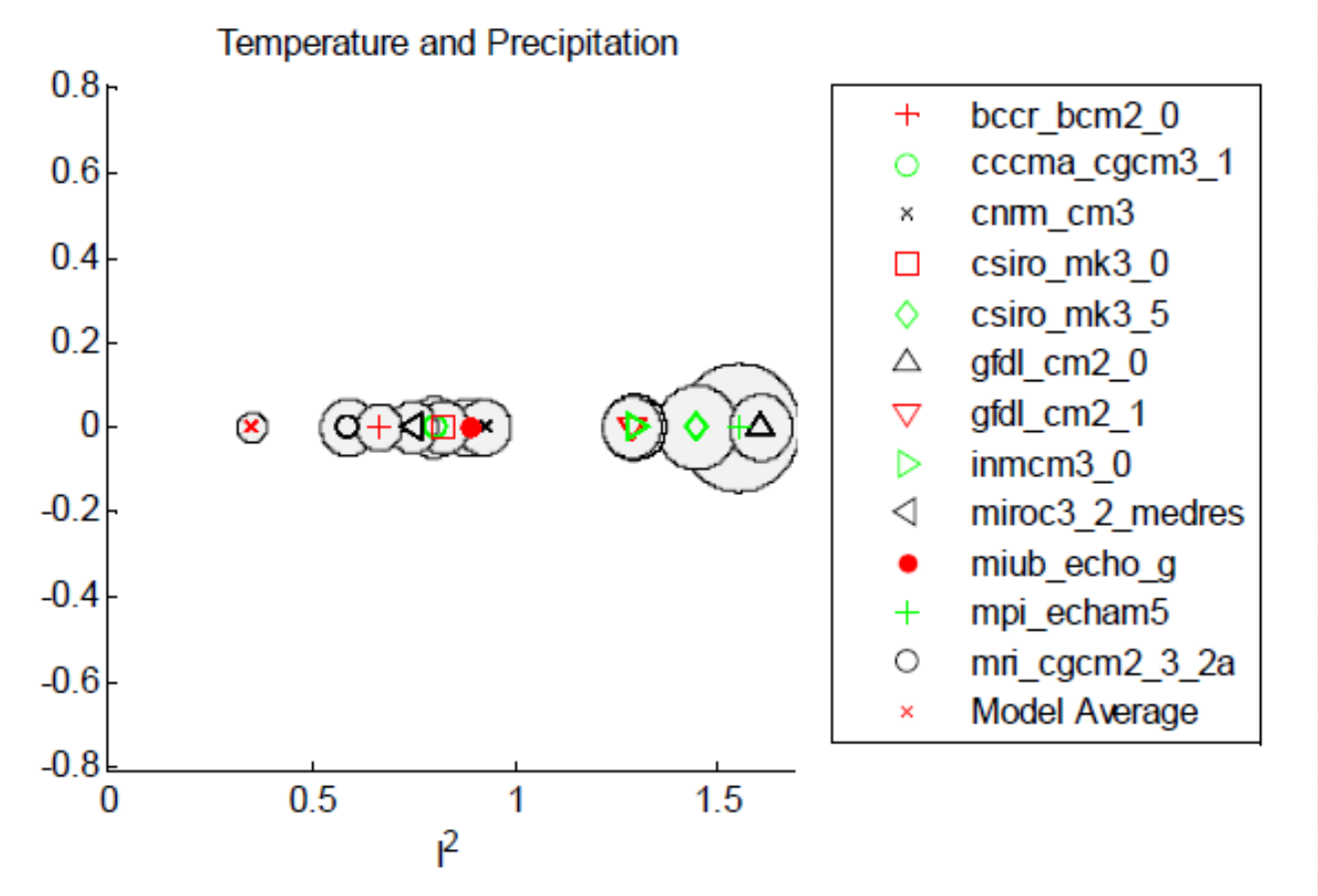
- Annual cycle of mean temperature
- Annual cycle of mean precipitation
- Annual cycle of interannual temperature variability (standard deviation)
- Annual cycle of interannual precipitation variability (standard deviation)
- Mean annual cycle of intramonthly temperature variability (std. dev.)
- Mean annual cycle of intramonthly precipitation variability (std. dev.)
- Mean annual cycle of the maximum number of consecutive dry days within a month
- Mean annual cycle of the maximum 5-day precipitation total within a month
- Mean annual cycle of precipitation intensity (total monthly precipitation divided by the number of wet days*)
- Mean annual cycle of the number of days with precipitation exceeding 10 mm

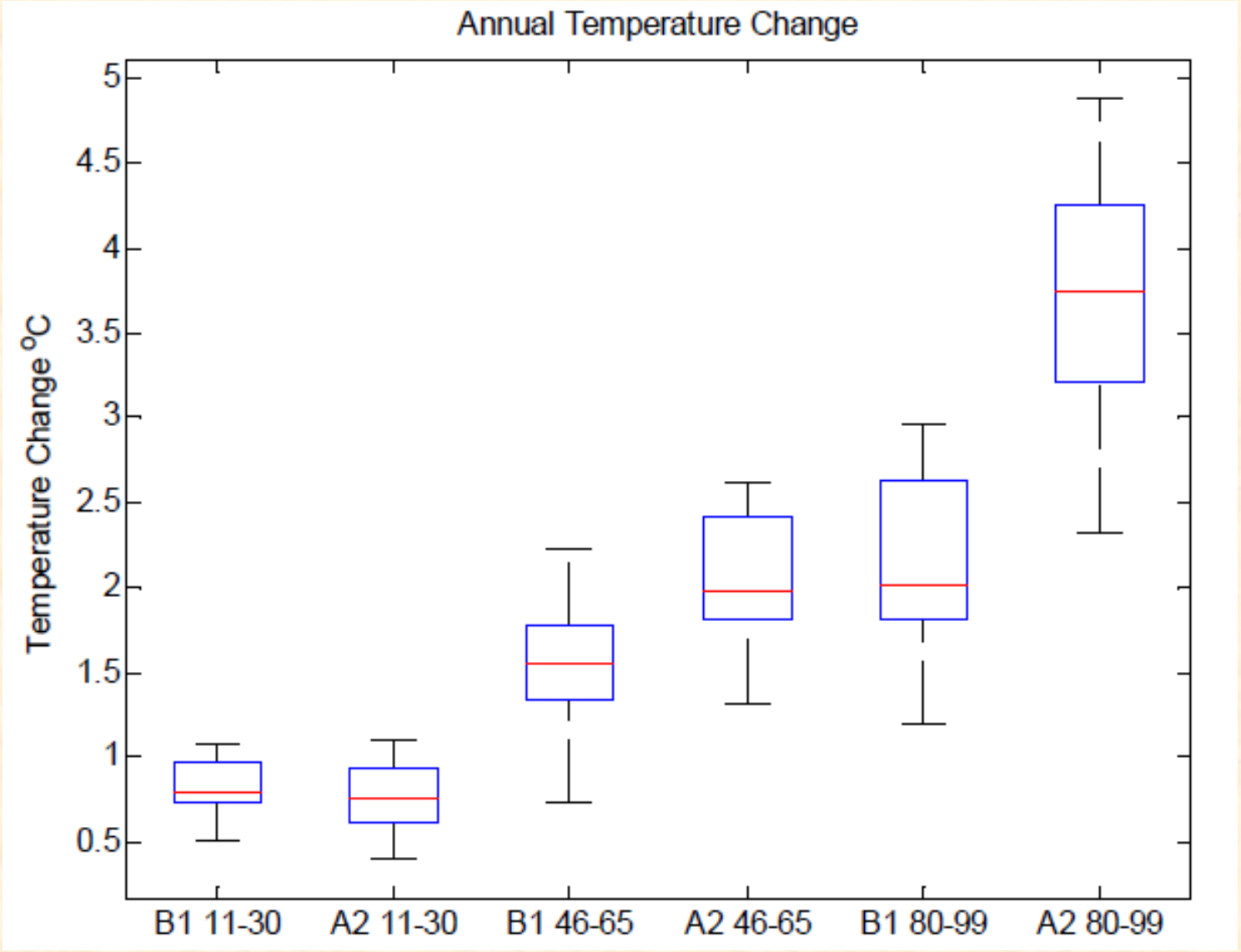
*A wet day is considered to be a day in which precipitation exceeds 1 mm.

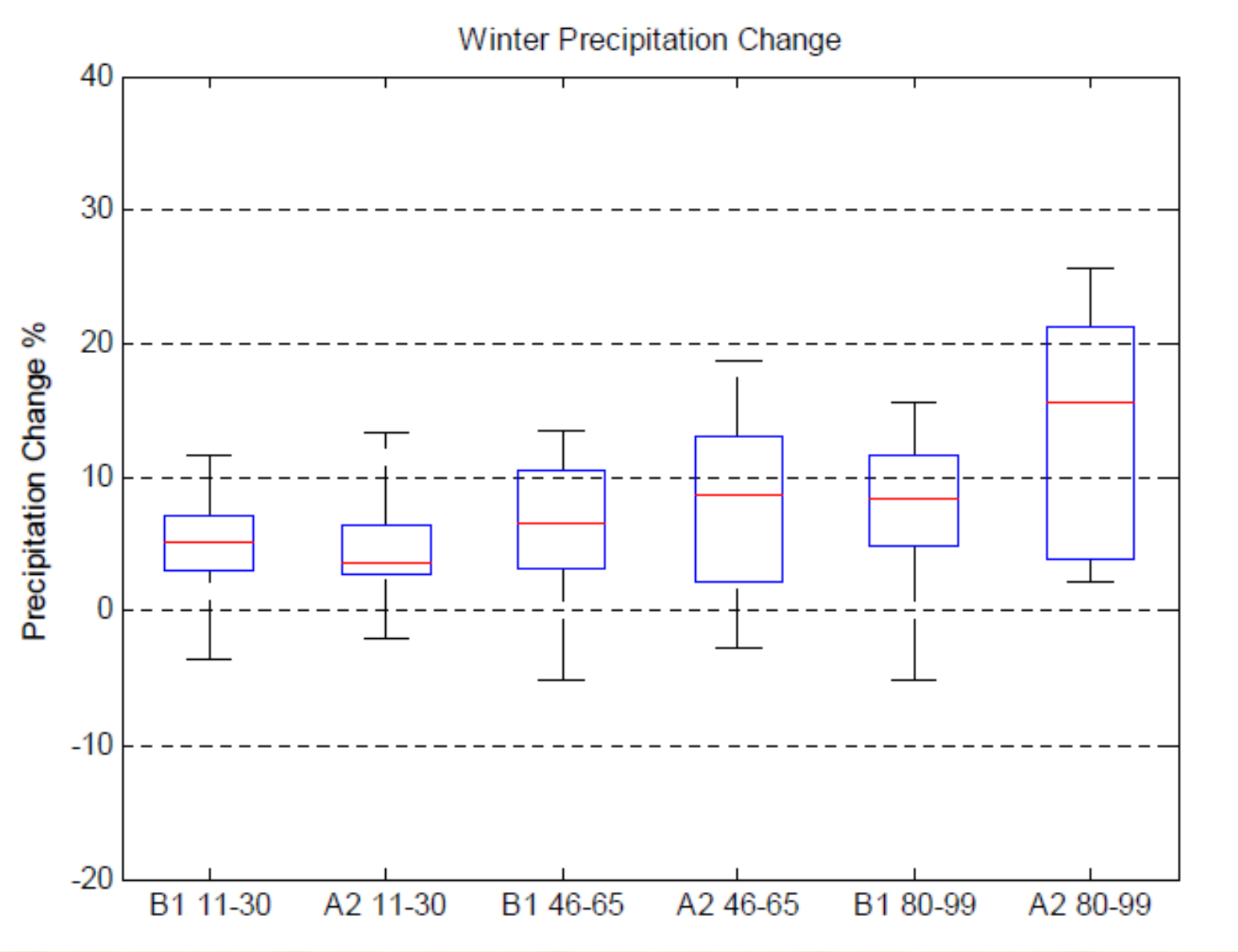
Selection of Climate Model and Management of Output

Multi-metric index for model evaluation

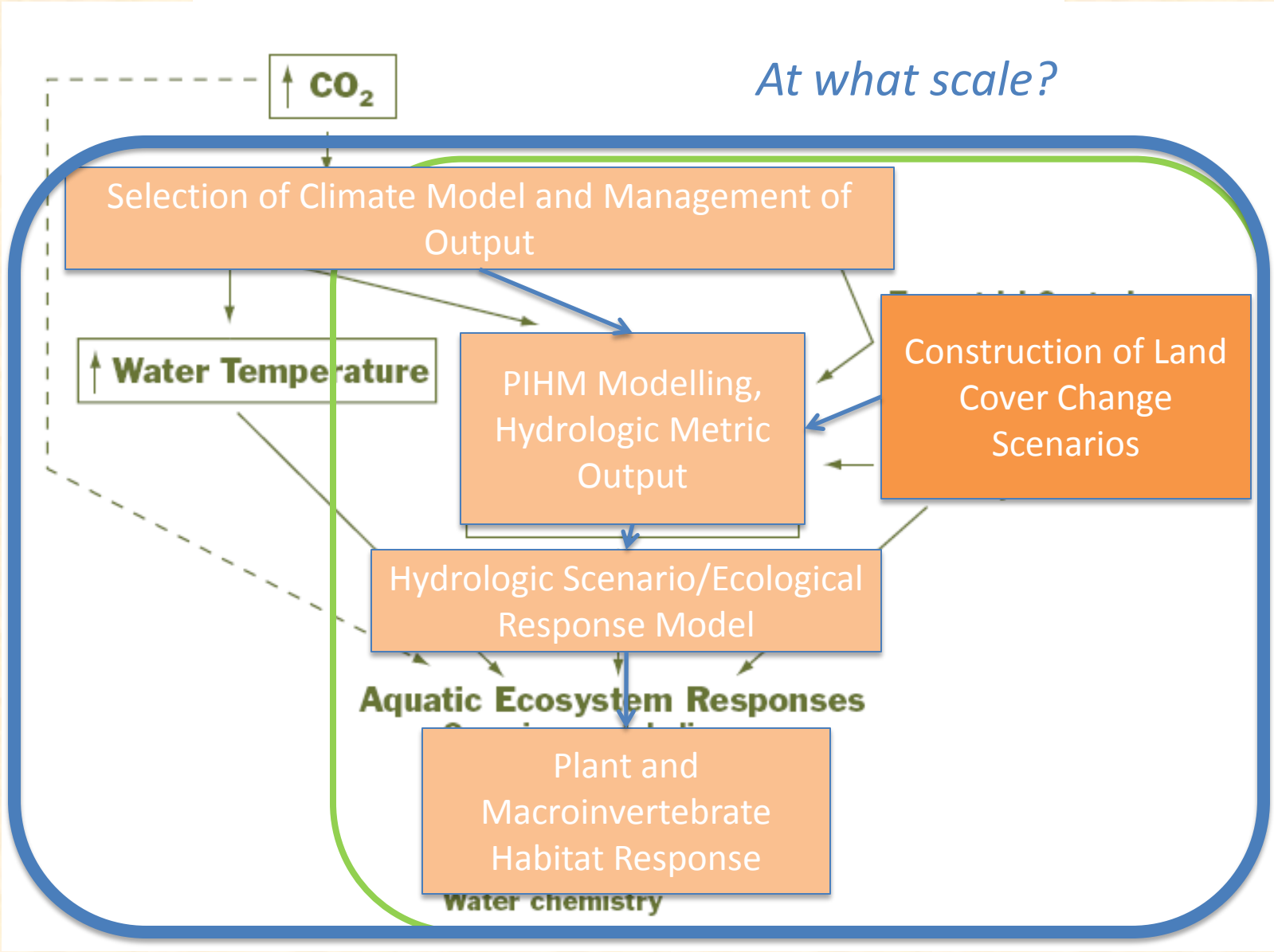
[approach of Reichler and Kim (2008)]




Annual Temperature Change
Temperature Change °C
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
B1 11-30
A2 11-30
B1 46-65
A2 46-65
B1 80-99
A2 80-99


Winter Precipitation Change
Precipitation Change %
40
30
20
10
0
-10
-20
B1 11-30
A2 11-30
B1 46-65
A2 46-65
B1 80-99
A2 80-99

CO_2, Climate, and Ecological Processes



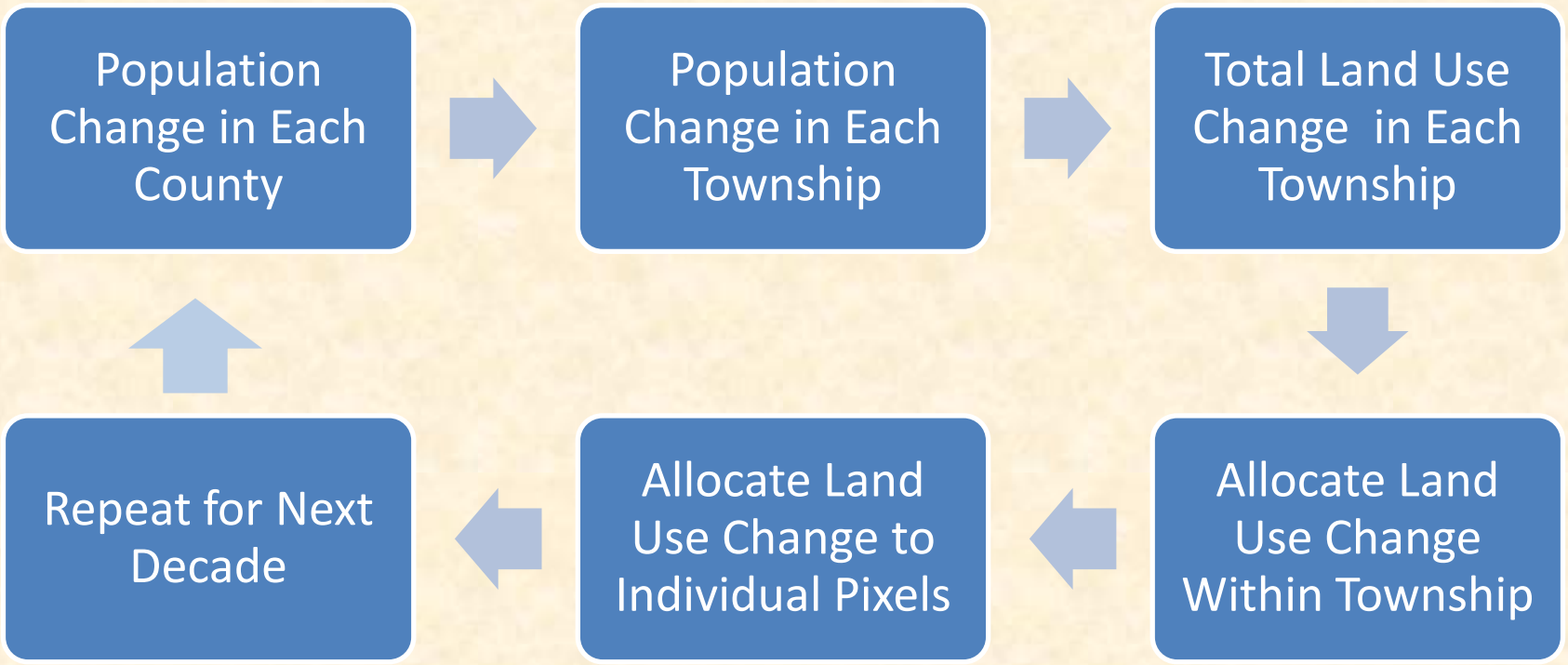
At what scale?

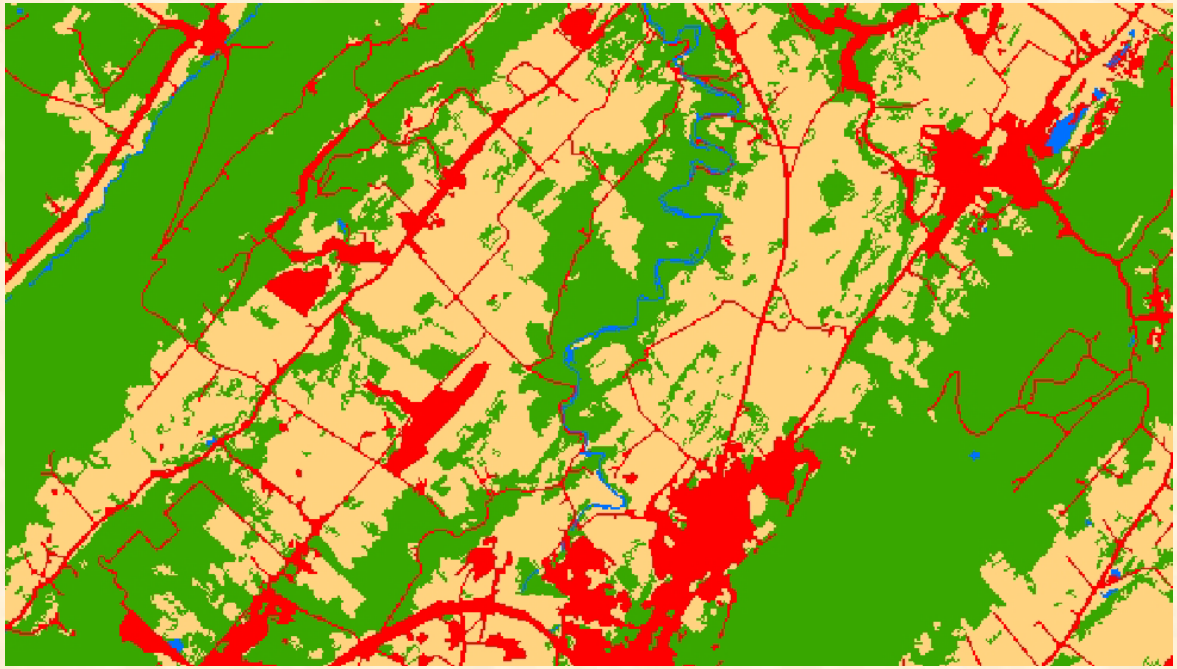
Poff et al 2005

Projecting a Future Land Use Scenario

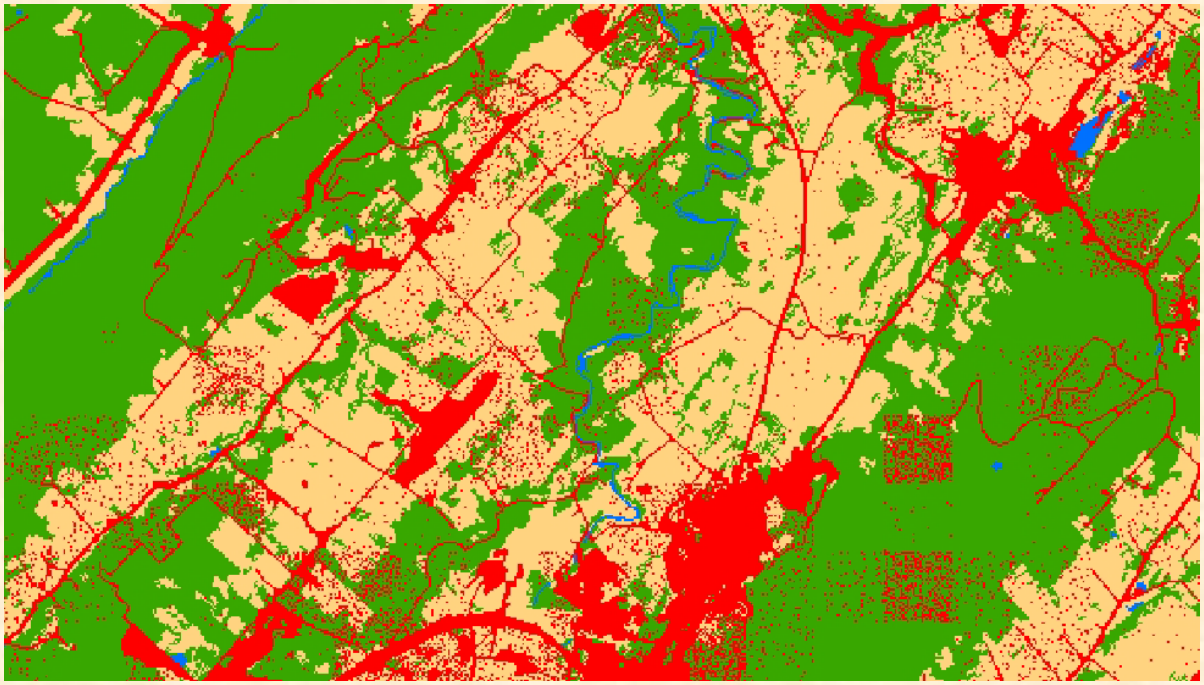
- Objective: Create a map of land use in 2050 for each study basin
  - Start with 2001 NLCD
  - Project total land use change in each basin
  - Allocate land use change within the basin to areas where it is more likely to occur
  - Distribute change on the landscape in a plausible way, matching observed patchiness
  - Models calibrated using observed population and land use change from 1990/1992 to 2000/2001

Multilevel Model





2001



2050

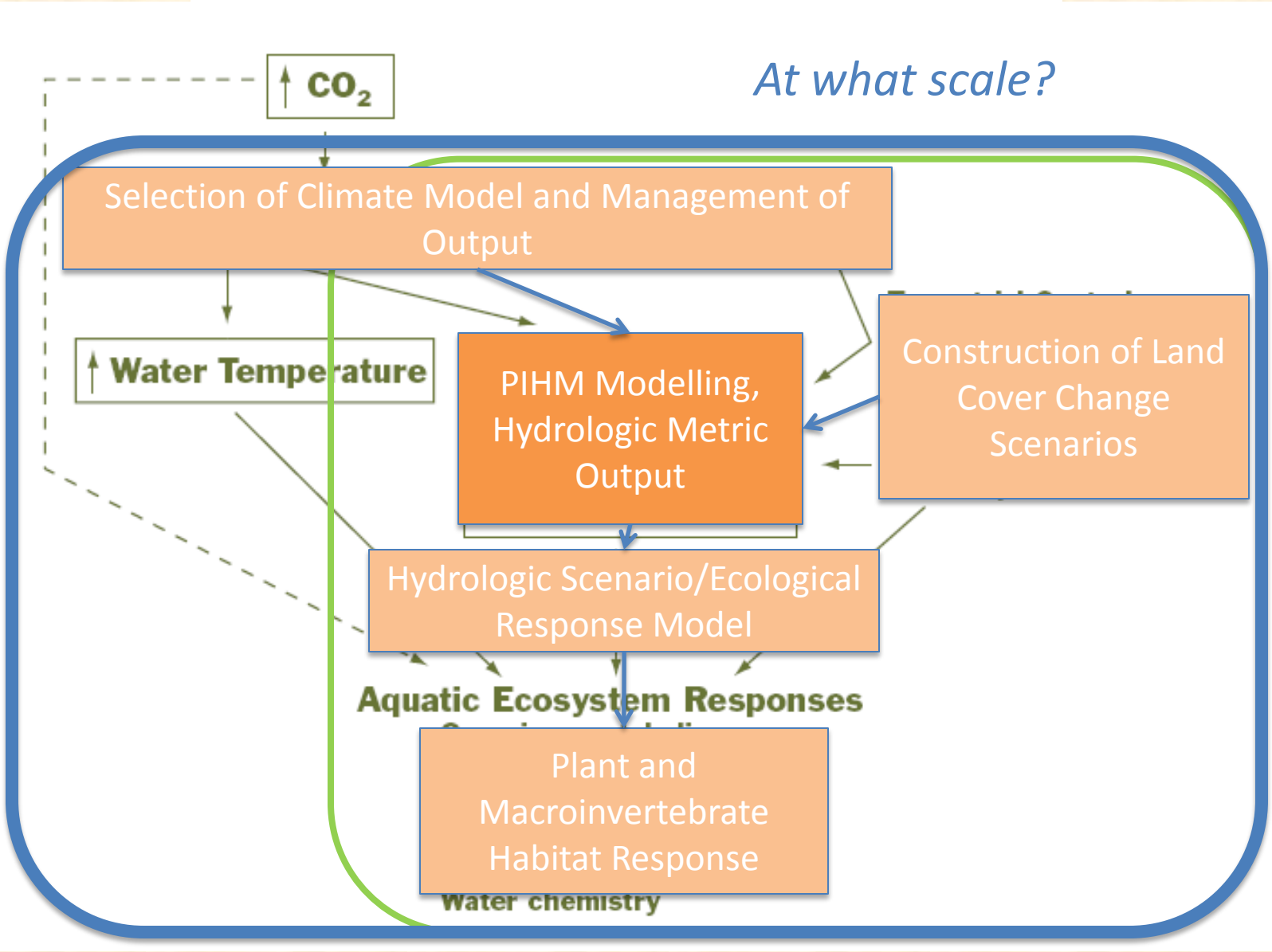
Land Cover Change

Basin Name	1992 %Developed	2001 %Developed	2050 %Developed	2001-2050 % Increase in Developed
Shaver Creek	4.8	4.8	5.7	18.8
Little Conestoga	39.8	41.4	48.9	18.2
Spruce Creek	5.5	5.6	8.0	42.3

Construction of Land Cover Change Scenarios

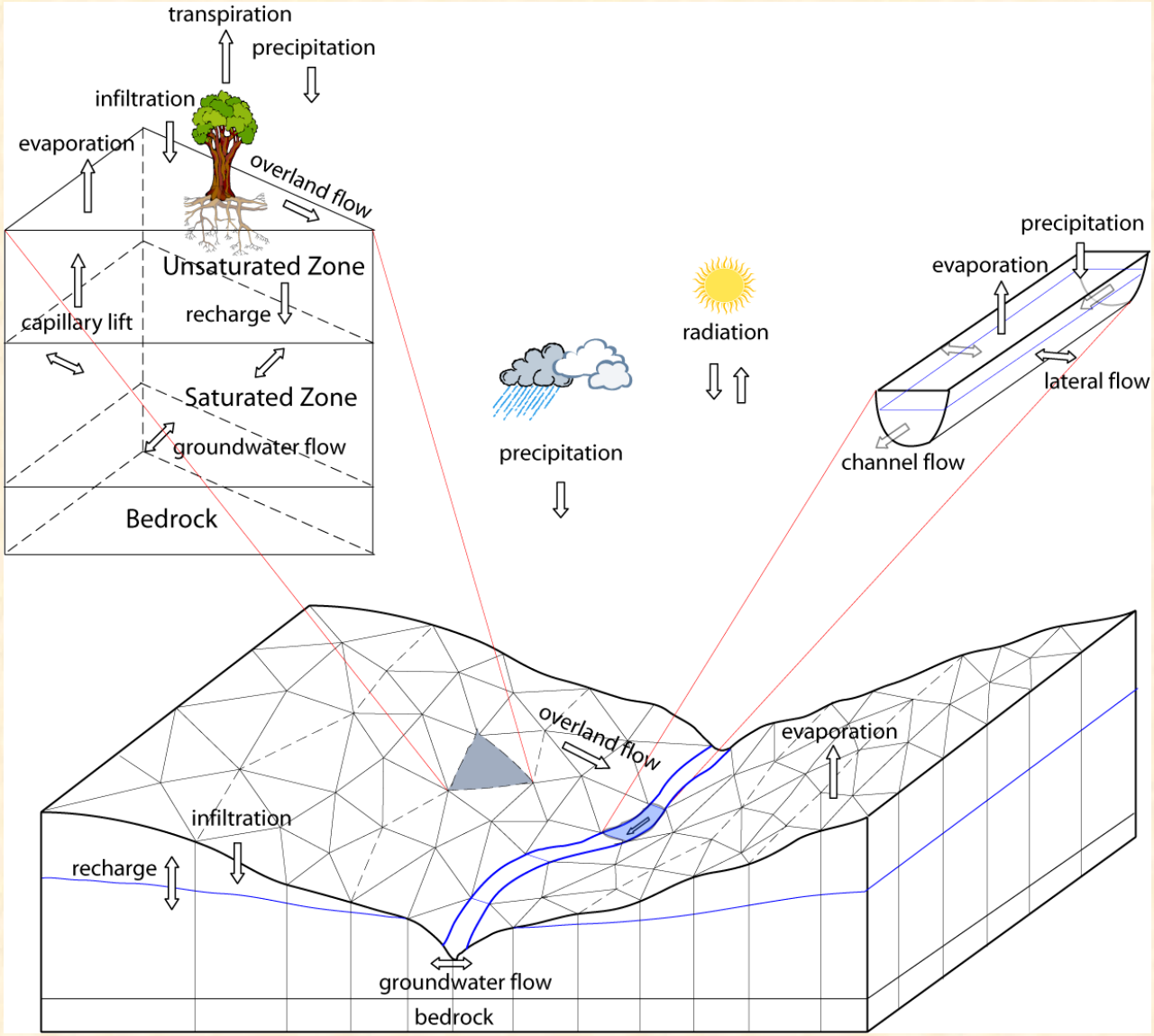
CO_2, Climate, and Ecological Processes

At what scale?



Poff et al 2005

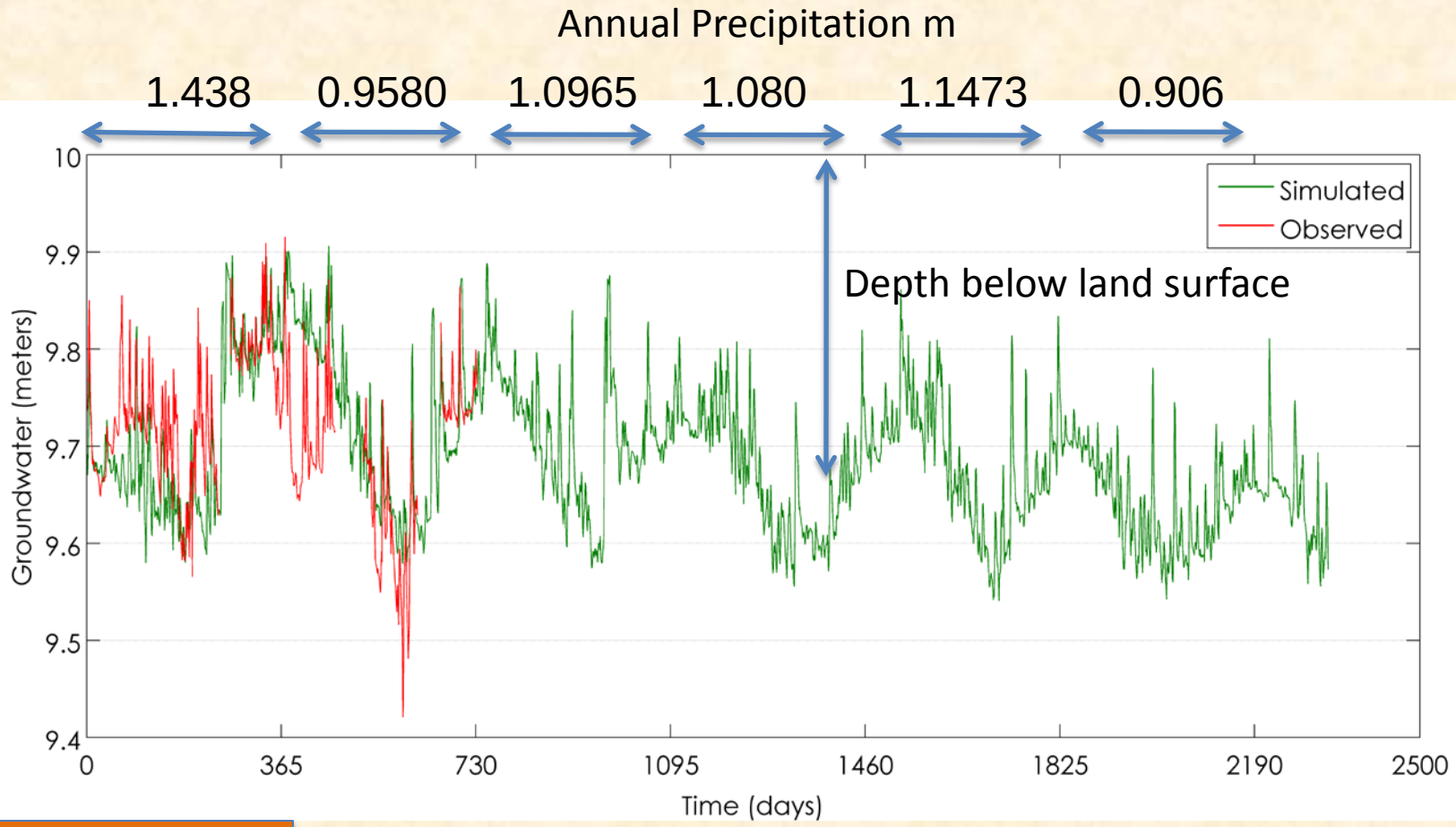
Penn State Integrated Hydrologic Model (PIHM)



PIHM Modelling, Hydrologic Metric Output

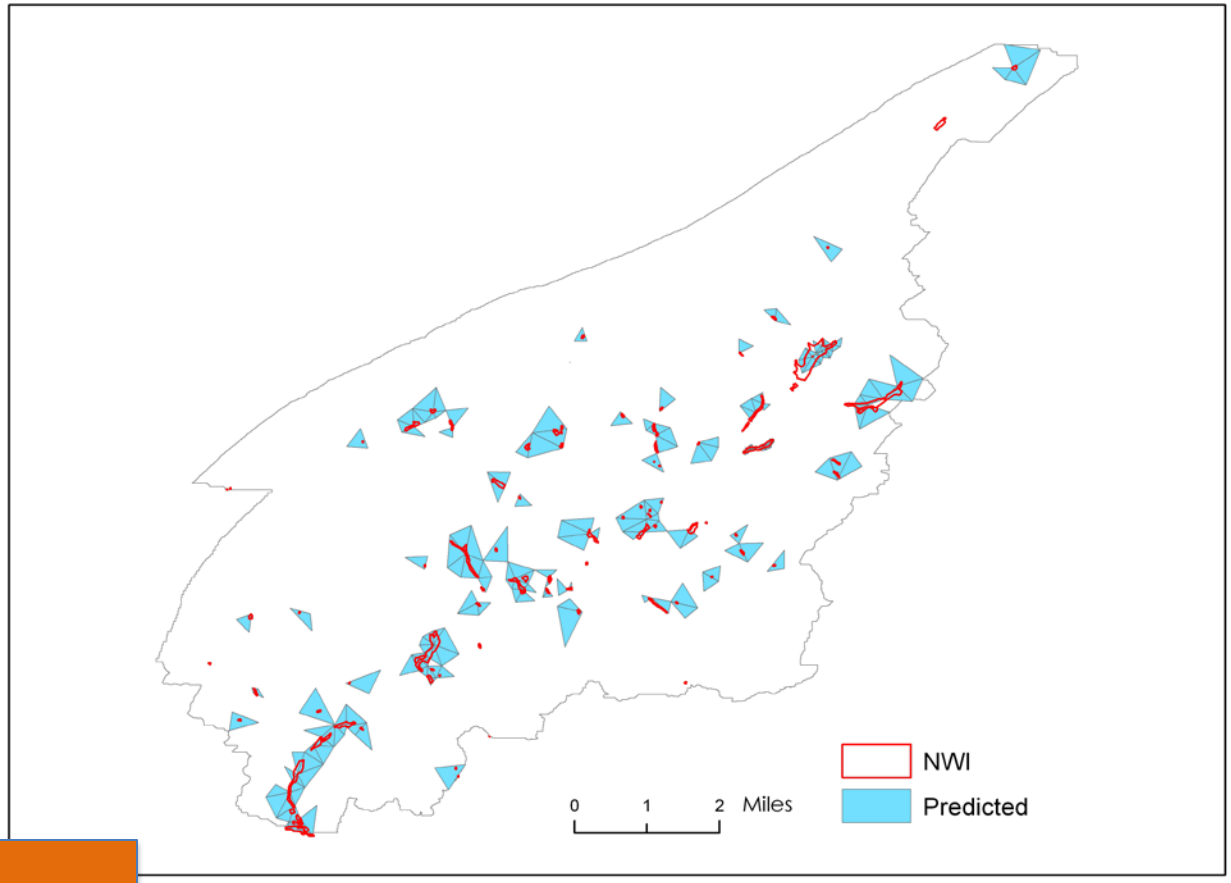
Qu and Duffy 2007

Observed and Simulated, 2004-2009



PIHM Modelling, Hydrologic Metric Output

Predicted vs. NWI, 30 cm rule

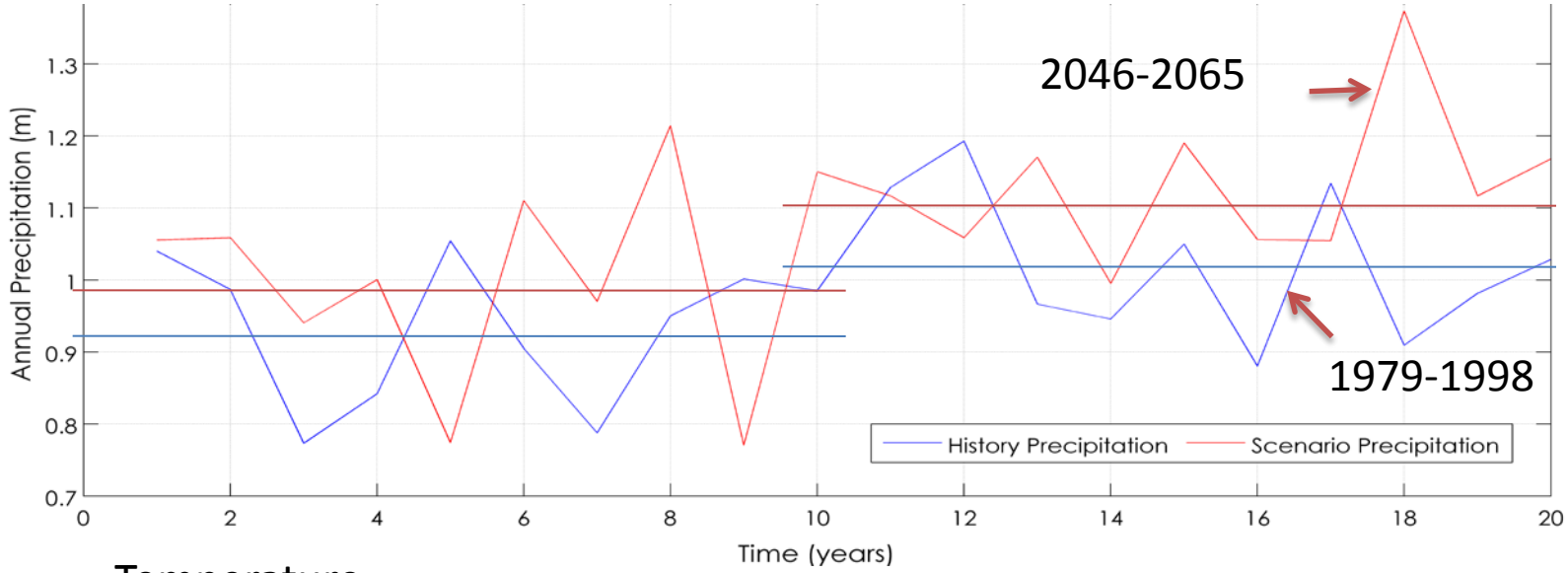


PIHM Modelling, Hydrologic Metric Output

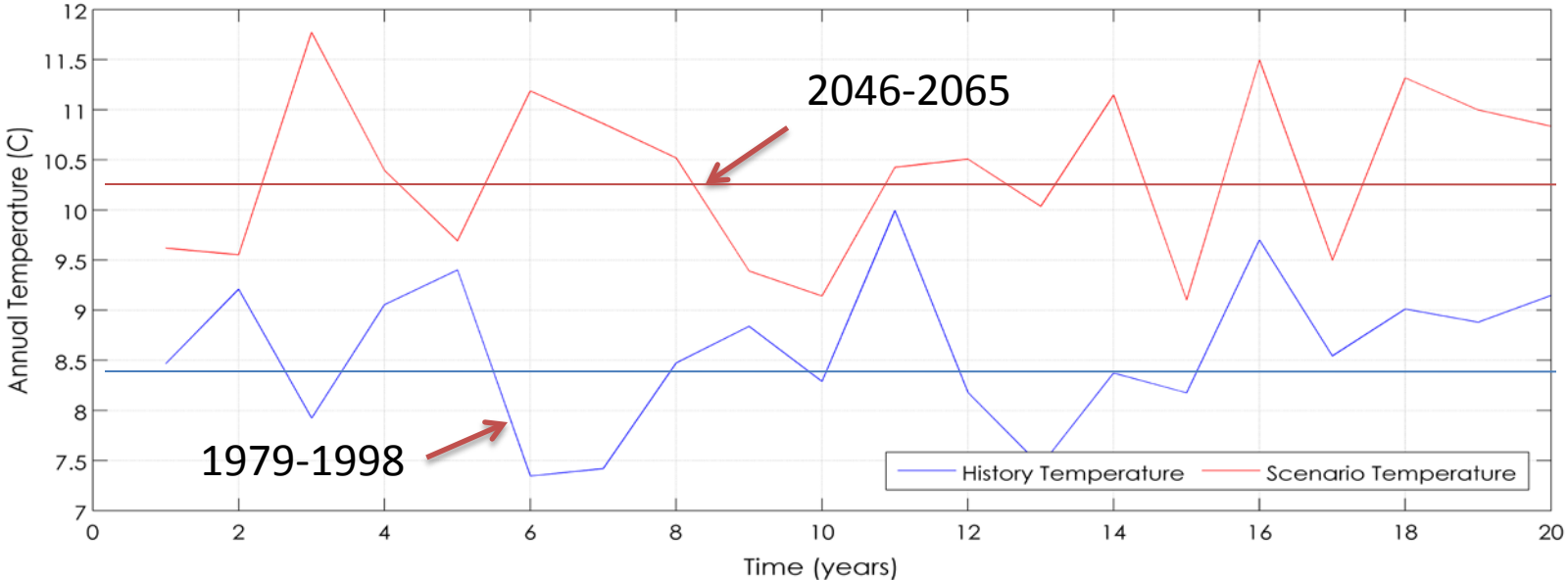
Ray Najjar Gopal Bhatt

IPCC FORCING

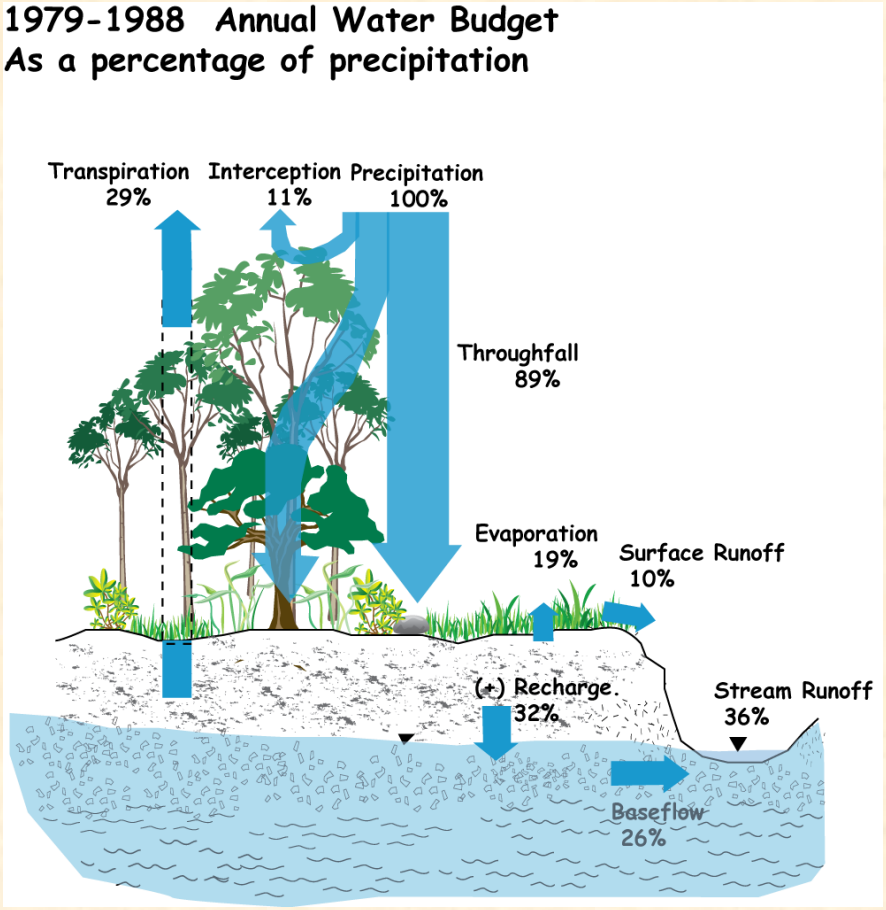
Precipitation

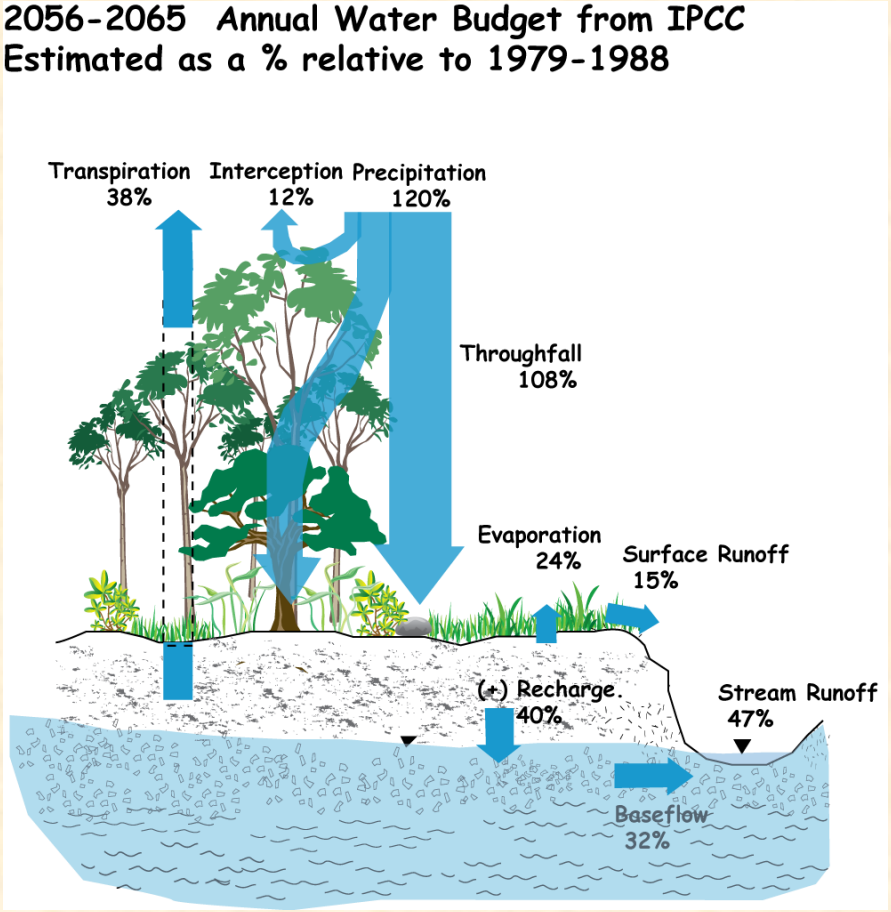


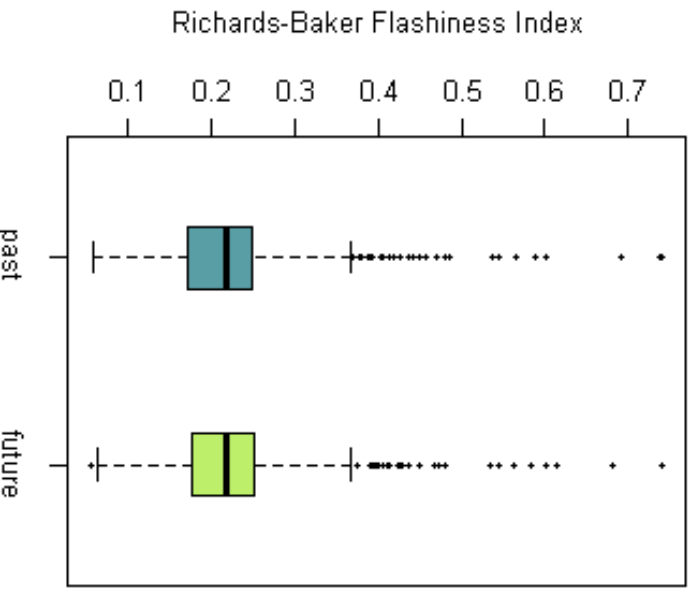
Temperature

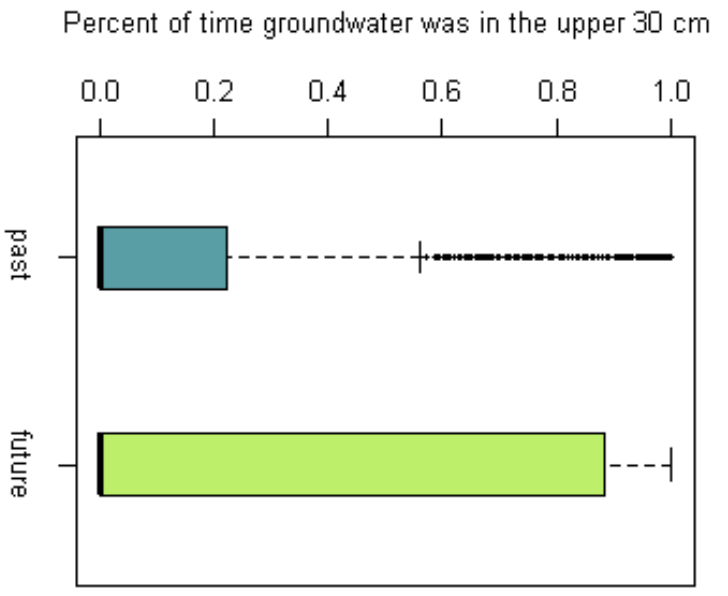


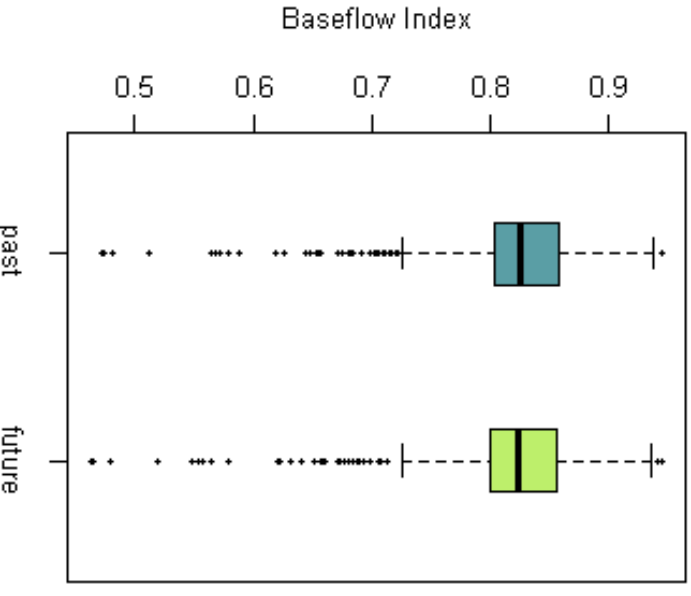
Water Budget Comparison

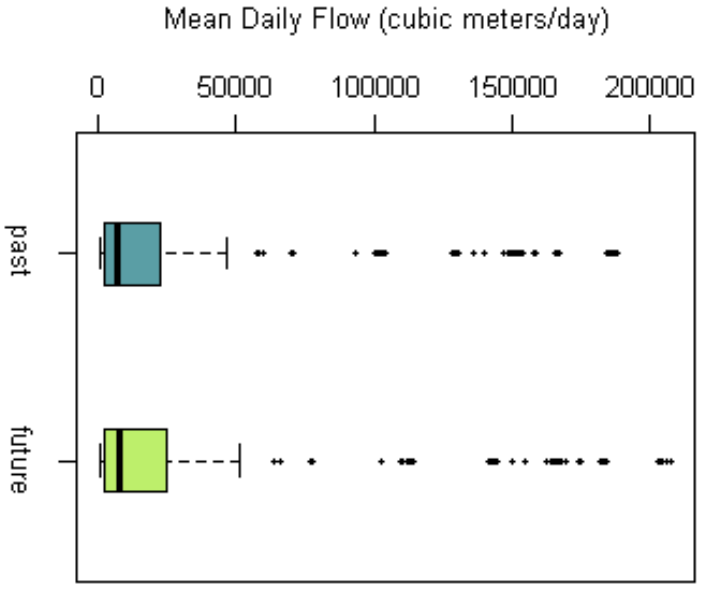




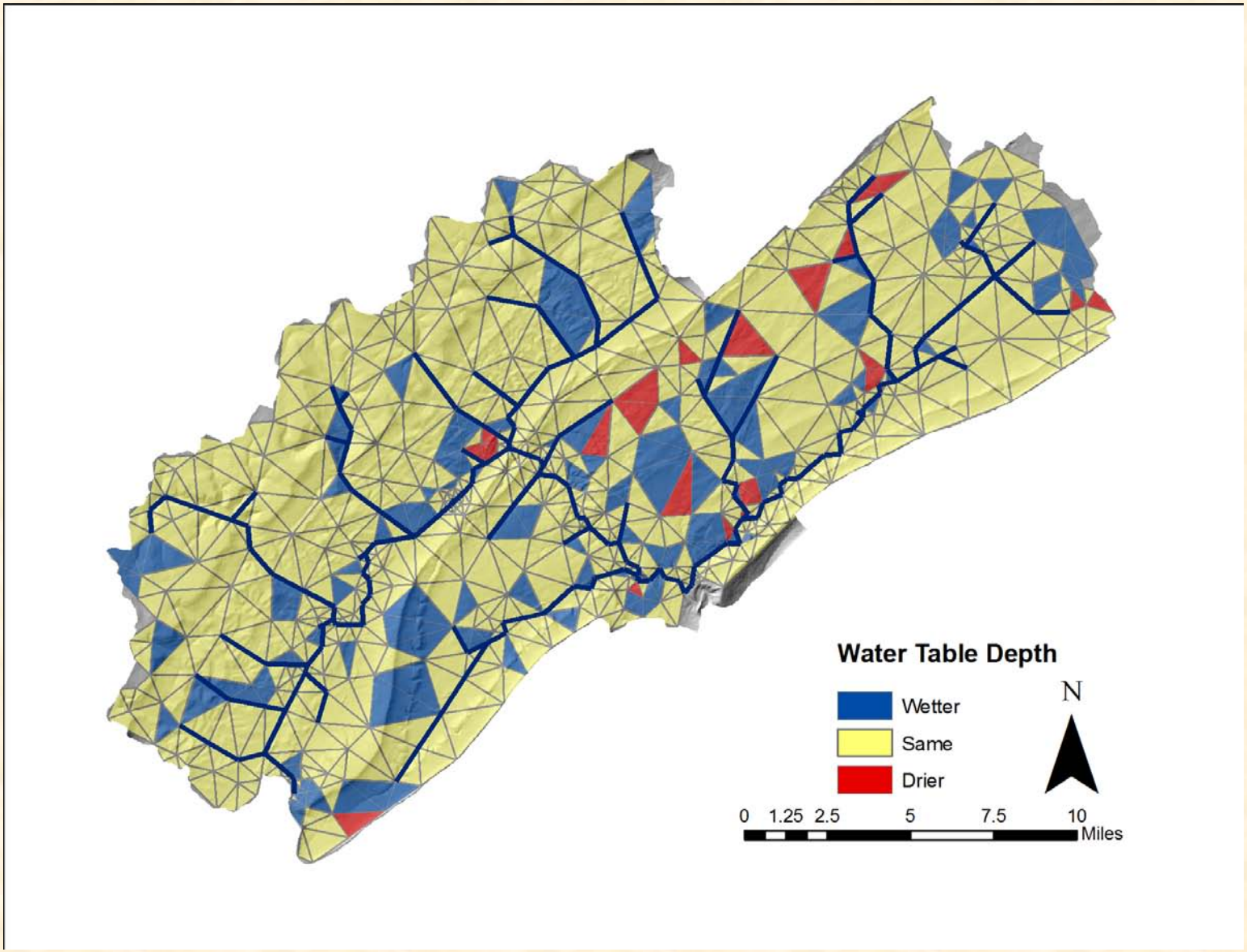

Richards-Baker Flashiness Index
0.1
0.2
0.3
0.4
0.5
0.6
0.7
past
future

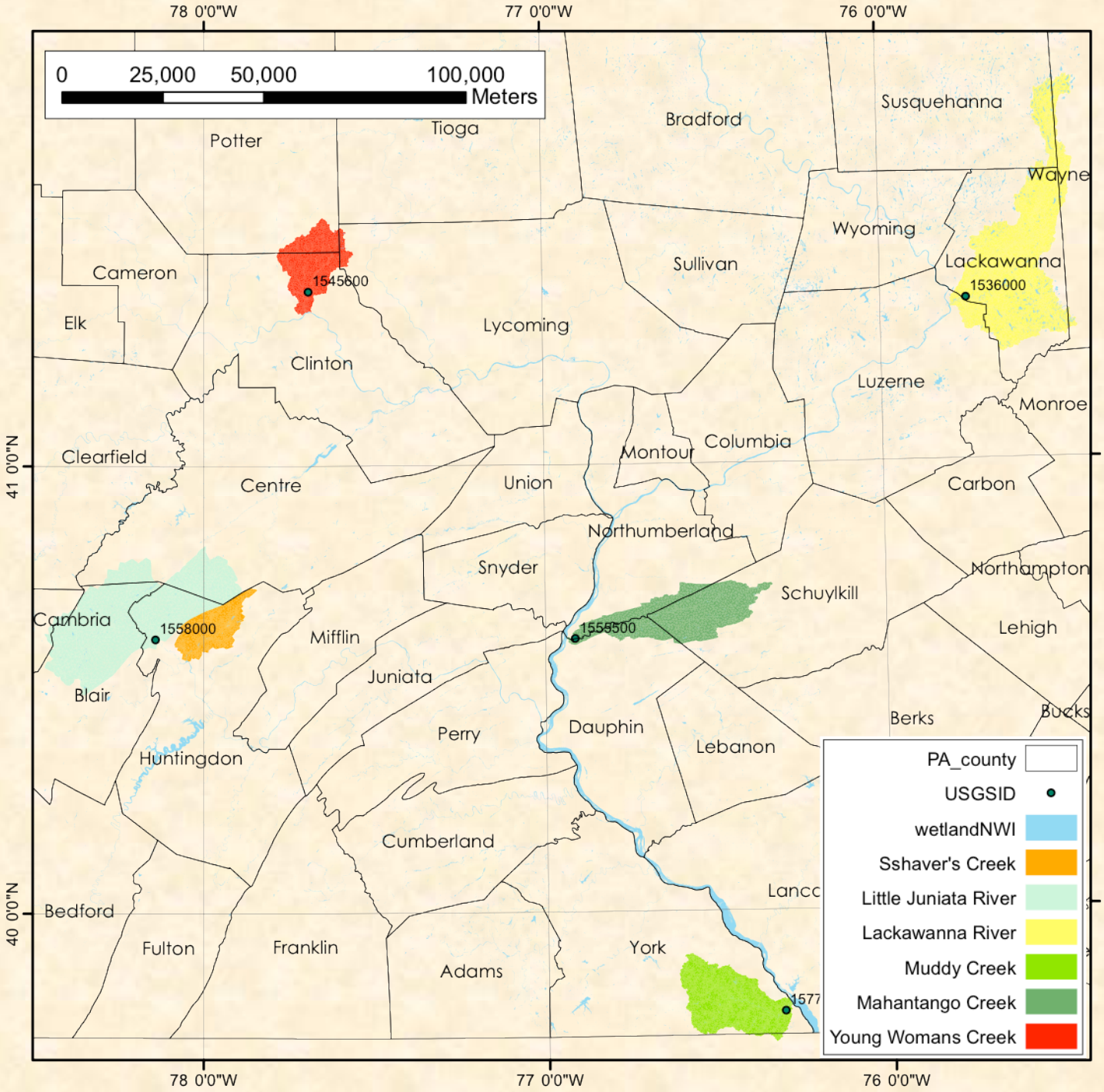

Percent of time groundwater was in the upper 30 cm
0.0
0.2
0.4
0.6
0.8
1.0
past
future


Baseflow Index
0.5
0.6
0.7
0.8
0.9
past
future


Mean Daily Flow (cubic meters/day)
0
50000
100000
150000
200000
past
future

Spatially Heterogeneous




78 0'0"W
77 0'0"W
76 0'0"W
41 0'0"N
40 0'0"N
0 25,000 50,000 100,000
Meters
Potter
Tioga
Bradford
Susquehanna
Wayne
Wyoming
Sullivan
Lackawanna
1536000
Cameron
1545600
Elk
Lycoming
Clinton
Luzerne
Monroe
Clearfield
Centre
Union
Montour
Columbia
Carbon
Northumberland
Snyder
Northampton
Schuylkill
Cambria
1558000
1555500
Mifflin
Juniata
Lehigh
Blair
Berks
Bucks
Perry
Dauphin
Lebanon
Huntingdon
Cumberland
Lancc
Bedford
Fulton
Franklin
Adams
York
1577
PA_county
USGSID
wetlandNWI
Sshaver's Creek
Little Juniata River
Lackawanna River
Muddy Creek
Mahantango Creek
Young Womans Creek

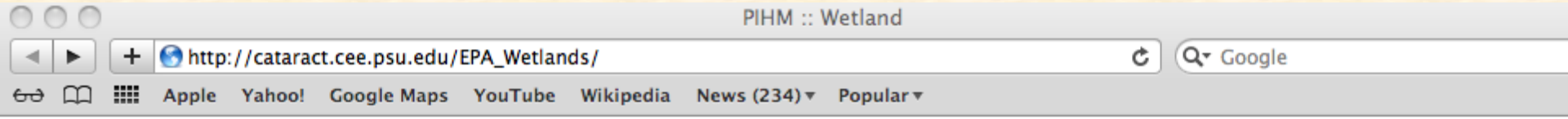
OVERVIEW

The Penn State Integrated Hydrologic Model (PIHM) is a multiprocess, multi-scale hydrologic model where the major hydrological processes are fully coupled using the semi-discrete finite volume method. The model itself is "tightly-coupled" with PIHMgis, an open-source Geographical Information System designed for PIHM. The PIHMgis provides the interface to PIHM, access to the digital data sets (terrain, forcing and parameters) and tools necessary to drive the model, as well as a collection of GIS-based pre- and post-processing tools. Collectively the system is referred to as the Penn State Integrated Hydrologic Modeling System. The modeling system has been written in C/C++, while the GIS interface is supported by Qt. The Penn State Hydrologic Modeling System is open source software, freely available for download at this site along with installation and user guides.

It is our intention to begin a debate on the role of "Community Models" in the hydrologic sciences. Our research is a response to recent trends in US funding for "Observatory Science" that have emerged at NSF over the last few years, namely, the NSF-funded CUAHSI program (Consortium of Universities for Advanicing Hydrologic Sciences).

PIHM represents our strategy for the synthesis of multi-state, multiscale distributed hydrologic models using the integral representation of the underlying physical process equations and state variables. Our interest is in devising a concise representation of watershed and/or river basin hydrodynamics, which allows interactions among major physical processes operating simultaneously, but with the flexibility to add or eliminate states/processes/constitutive relations depending on the objective of the numerical experiment or purpose of the scientific or operational application.

Products for Public Use



GIS, PIHMgis Project, PIHM Data-Model and Simulation Outputs for Wetlands Response to Climate Change Study

6 Directories, and 6 files

name	type	size	last modified
LackawannaRiver	<DIR>		
LittleJuniataRiver	<DIR>		
MahantangoCreek	<DIR>		
MuddyCreek	<DIR>		
ShaverCreek	<DIR>		
YoungWomansCreek	<DIR>		
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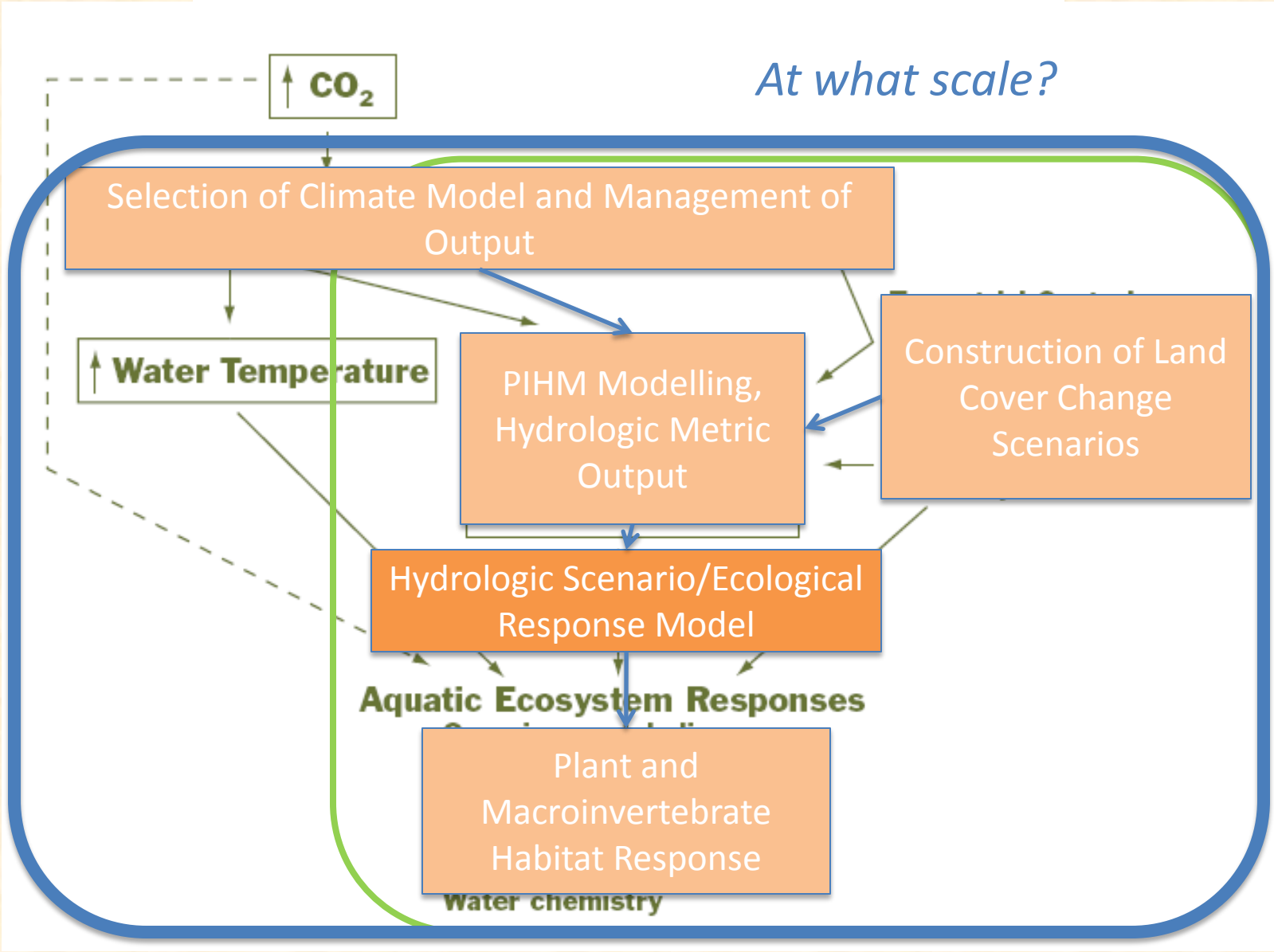
_Wetland_Study_Sites.pdf	pdf	6.64mb	08/30/11 12:08
meteo.dat.readme.pdf	pdf	69.76kb	09/08/11 12:58
Rivershape.pdf	pdf	89.55kb	09/08/11 03:08
Watershedaverage.readme.pdf	pdf	25.37kb	09/13/11 03:07
watershedsinfo.dat	dat	564bytes	09/13/11 02:46

CO_2, Climate, and Ecological Processes



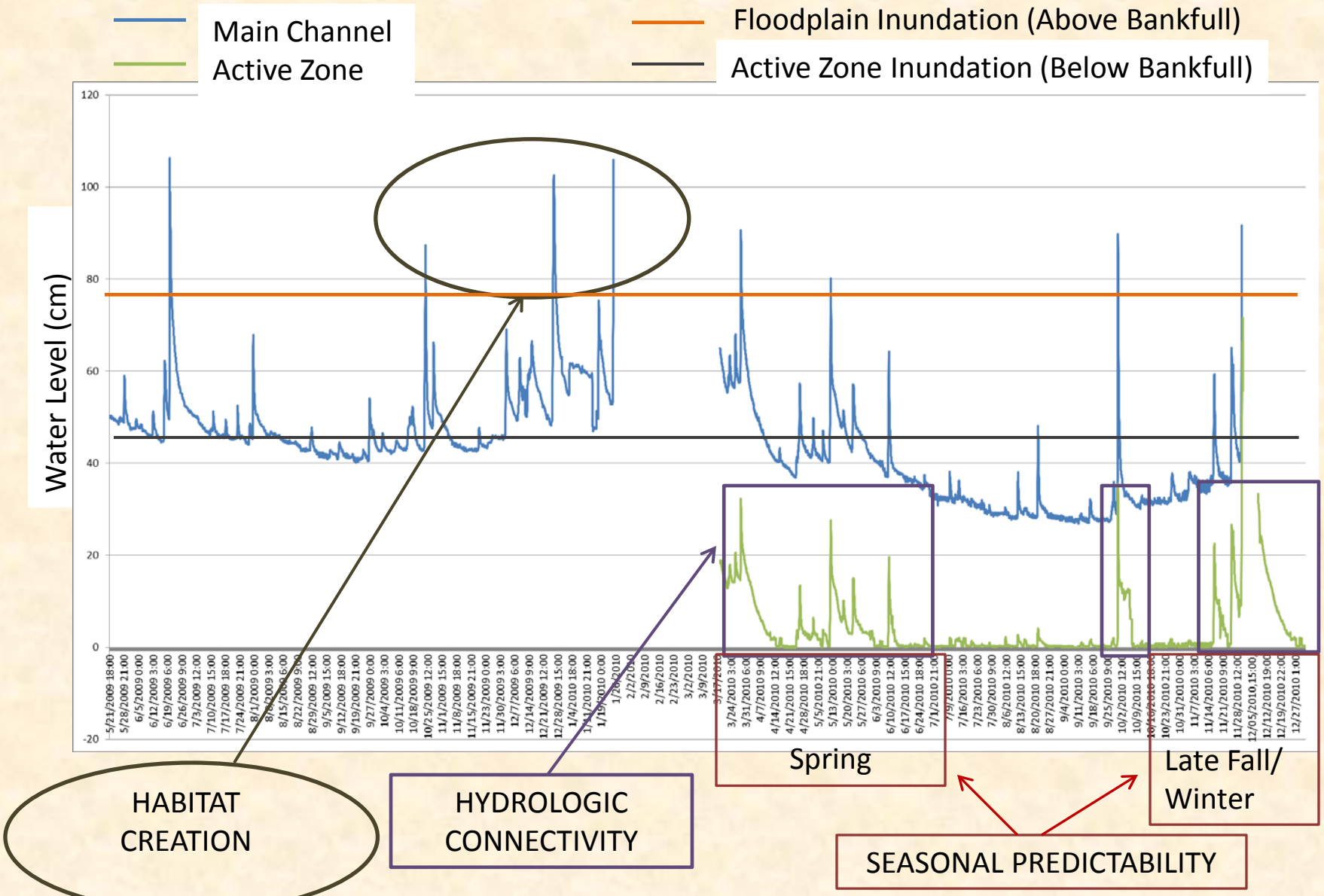
At what scale?

Poff et al 2005

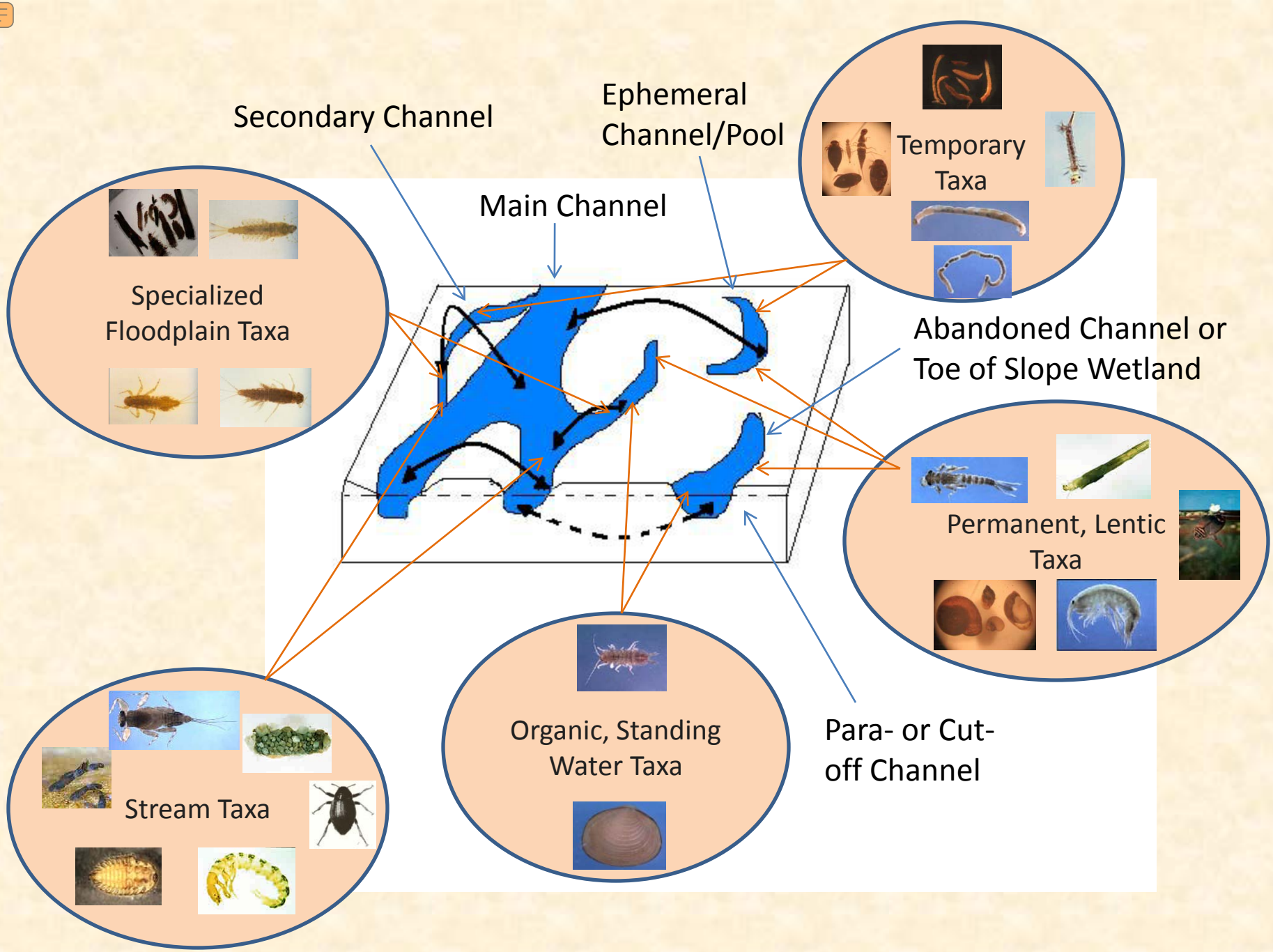
Building a Translator

- Predicting changes in wetland ecosystem function to climate change
  - Riverine wetlands provide habitat for aquatic plants and macroinvertebrates; habitat structured by hydrologic processes
- Changing precipitation and temperature patterns
  - Loss of low magnitude (below bankfull) flood events and groundwater recharge during ecologically critical seasons
- Land use a surrogate
  - Stream channels cutoff from adjacent floodplains and wetlands (incision/excessive sedimentation)
  - Loss of connection during below bankfull flood events
  - Wetlands experience spatial and temporal changes in groundwater levels

Hydrologic Scenario/Ecological Response Model



MONITORING PERIOD: 5/21/09 – 12/30/10

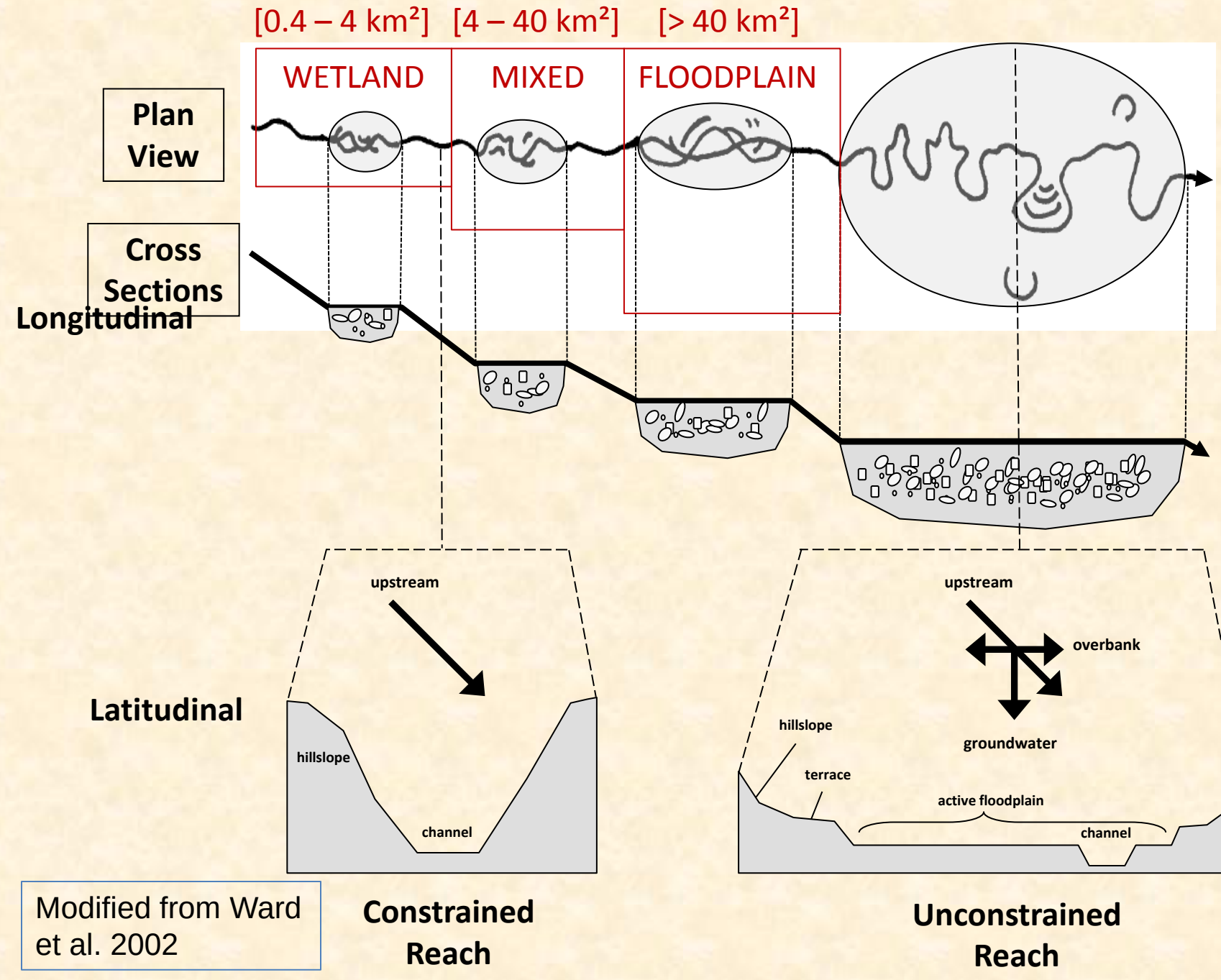

Secondary Channel
Ephemeral Channel/Pool
Main Channel
Temporary Taxa
Specialized Floodplain Taxa
Abandoned Channel or Toe of Slope Wetland
Permanent, Lentic Taxa
Organic, Standing Water Taxa
Para- or Cut-off Channel
Stream Taxa

RIVERINE BIODIVERSITY IS HIGHLY DEPENDENT ON THE FLOW REGIME, WHICH DETERMINES THE PHYSICAL HABITAT IN WHICH SPECIES RESIDE.

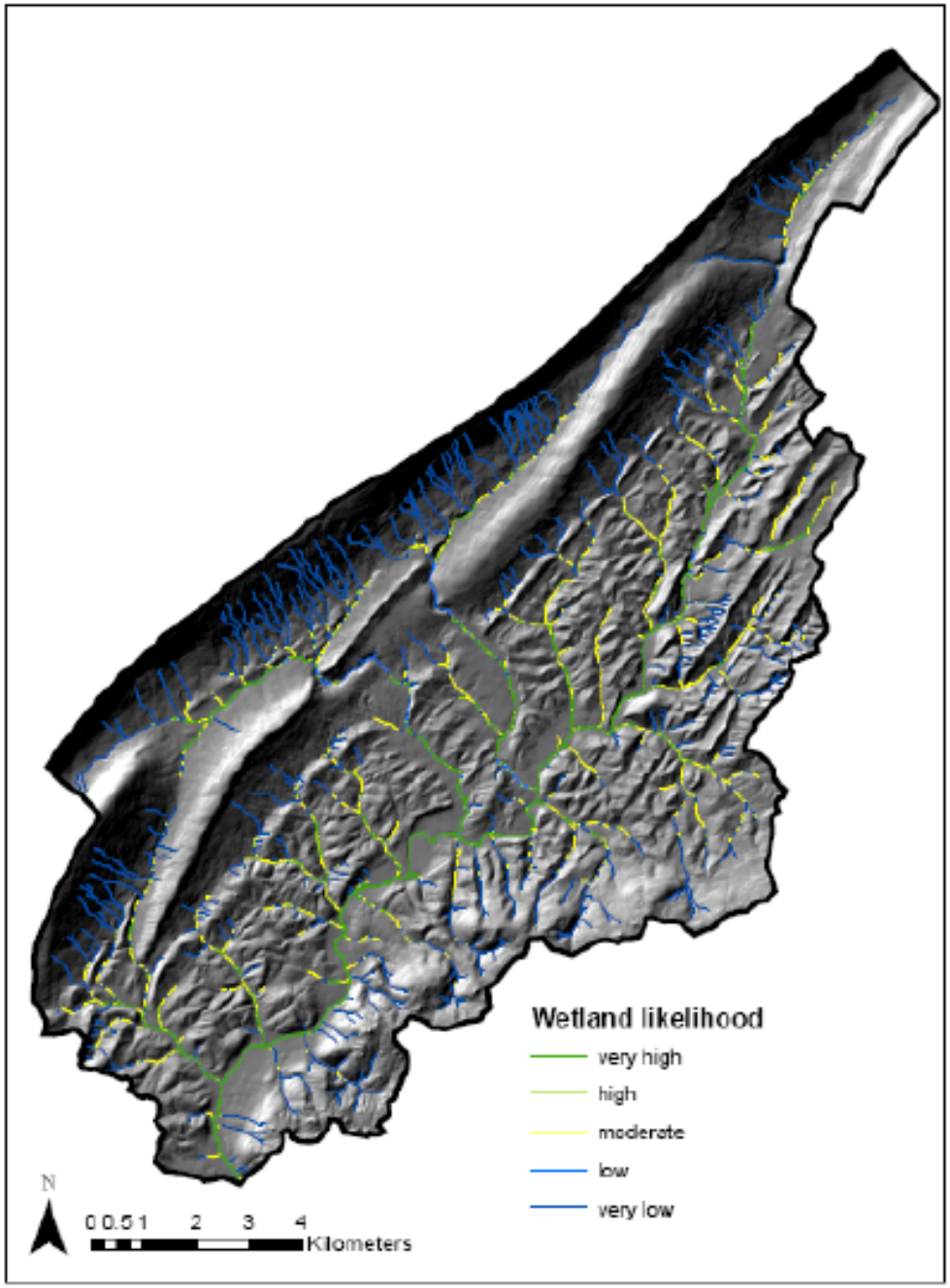
HYDROLOGICAL PROCESS
(ECOLOGICAL FUNCTION)

AQUATIC HABITAT
(STRUCTURAL DIVERSITY)

BIOLOGICAL DIVERSITY
(MACROINVERTEBRATE RICHNESS)

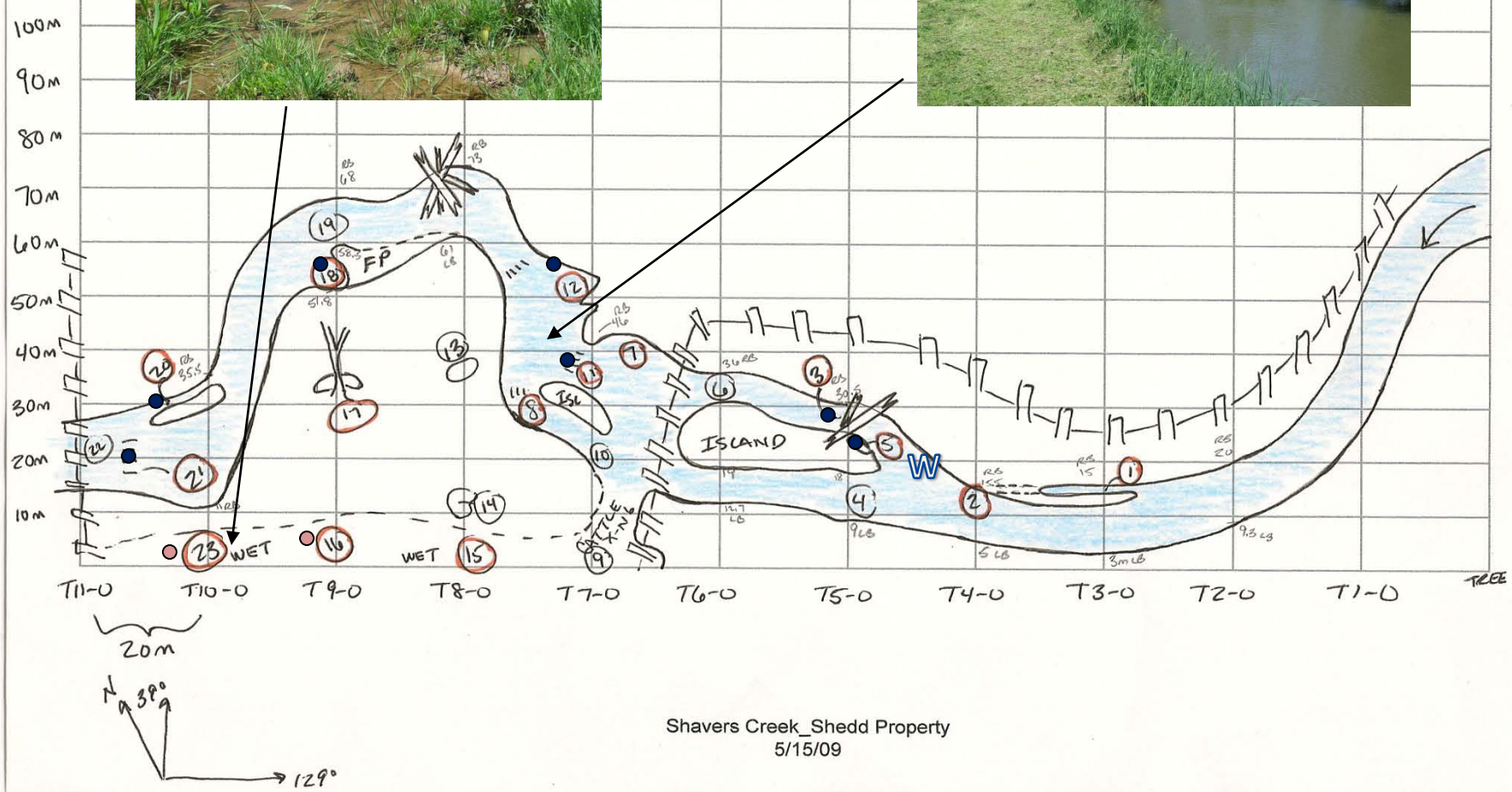


Modified from Ward et al. 2002


Wetland likelihood
very high
high
moderate
low
very low
N
0 0.5 1 2 3 4
Kilometers

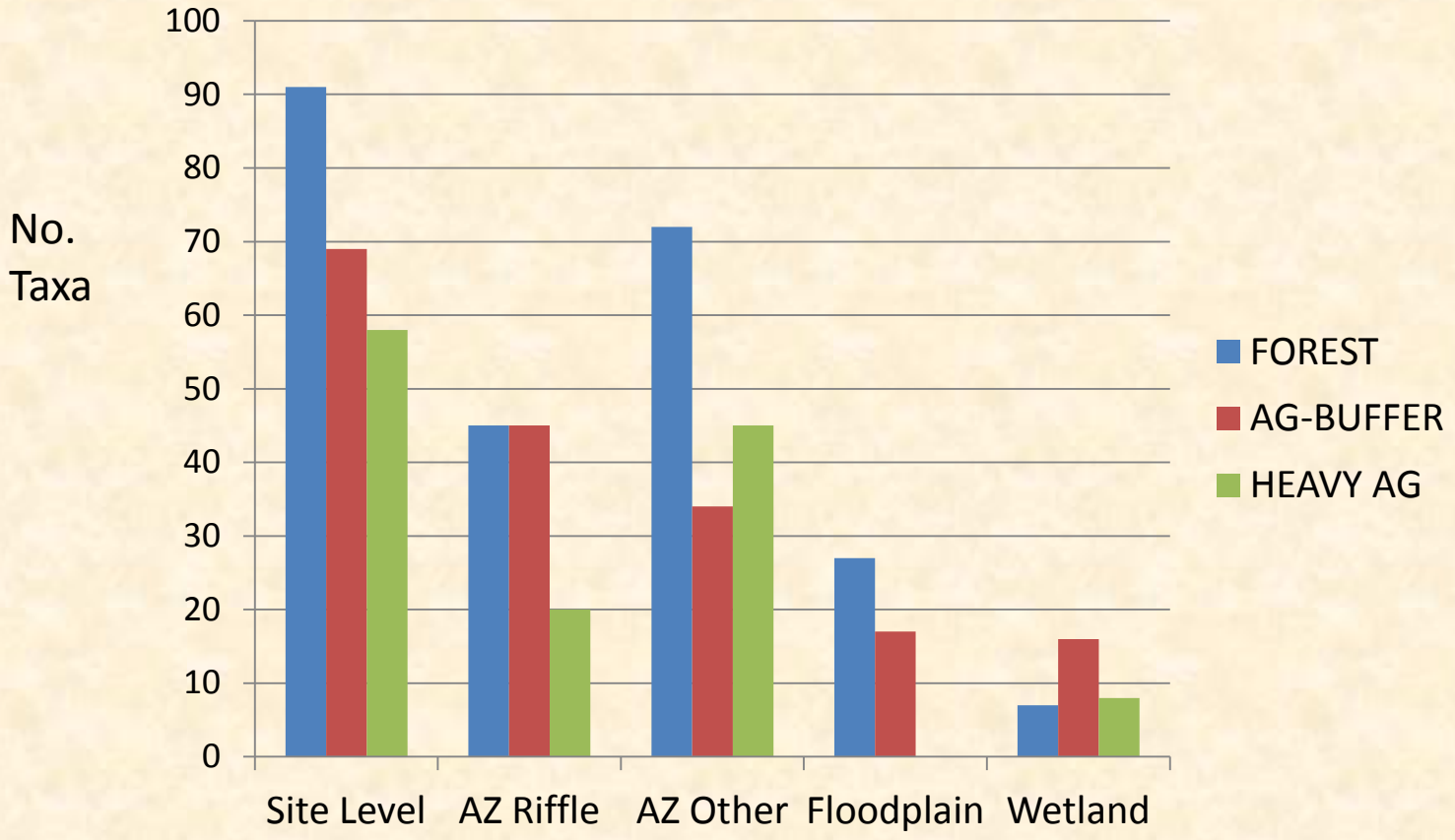
(a.)

Bald Eagle Creek
5/21/09



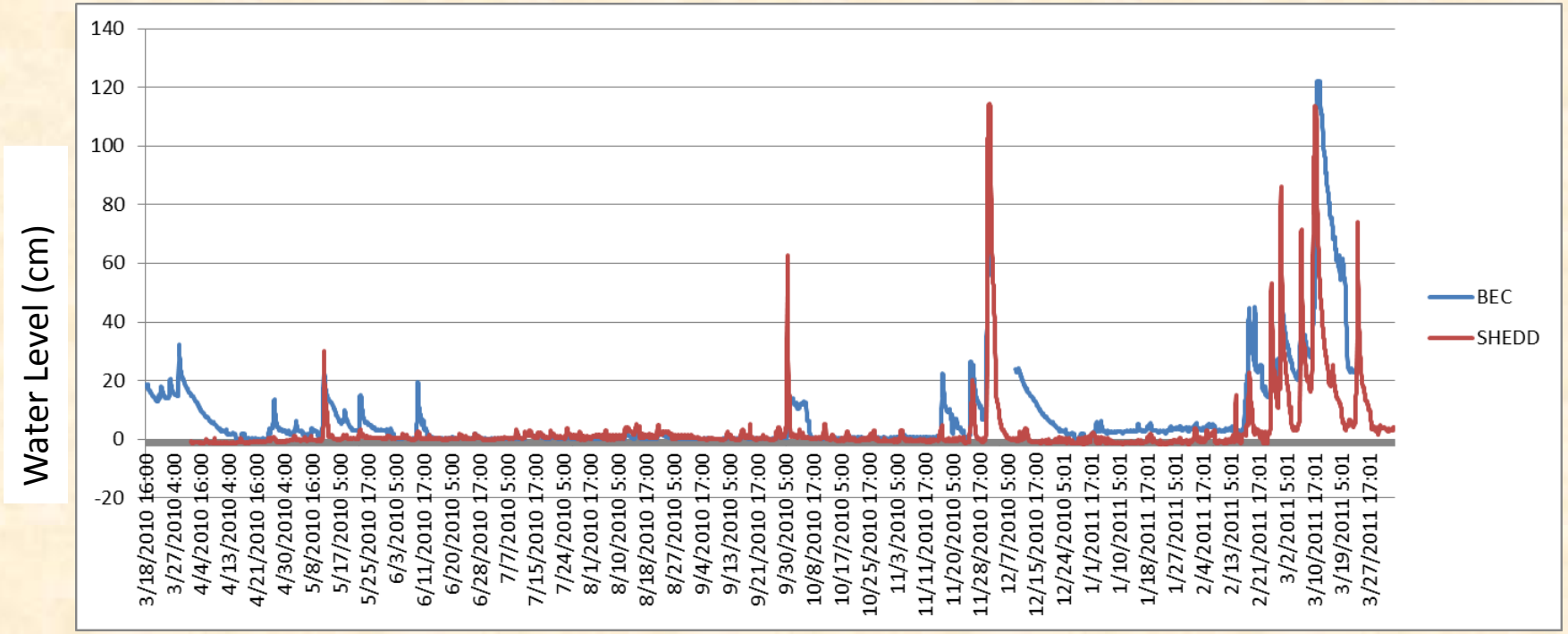
Shavers Creek_Shedd Property
5/15/09

Macroinvertebrate Diversity

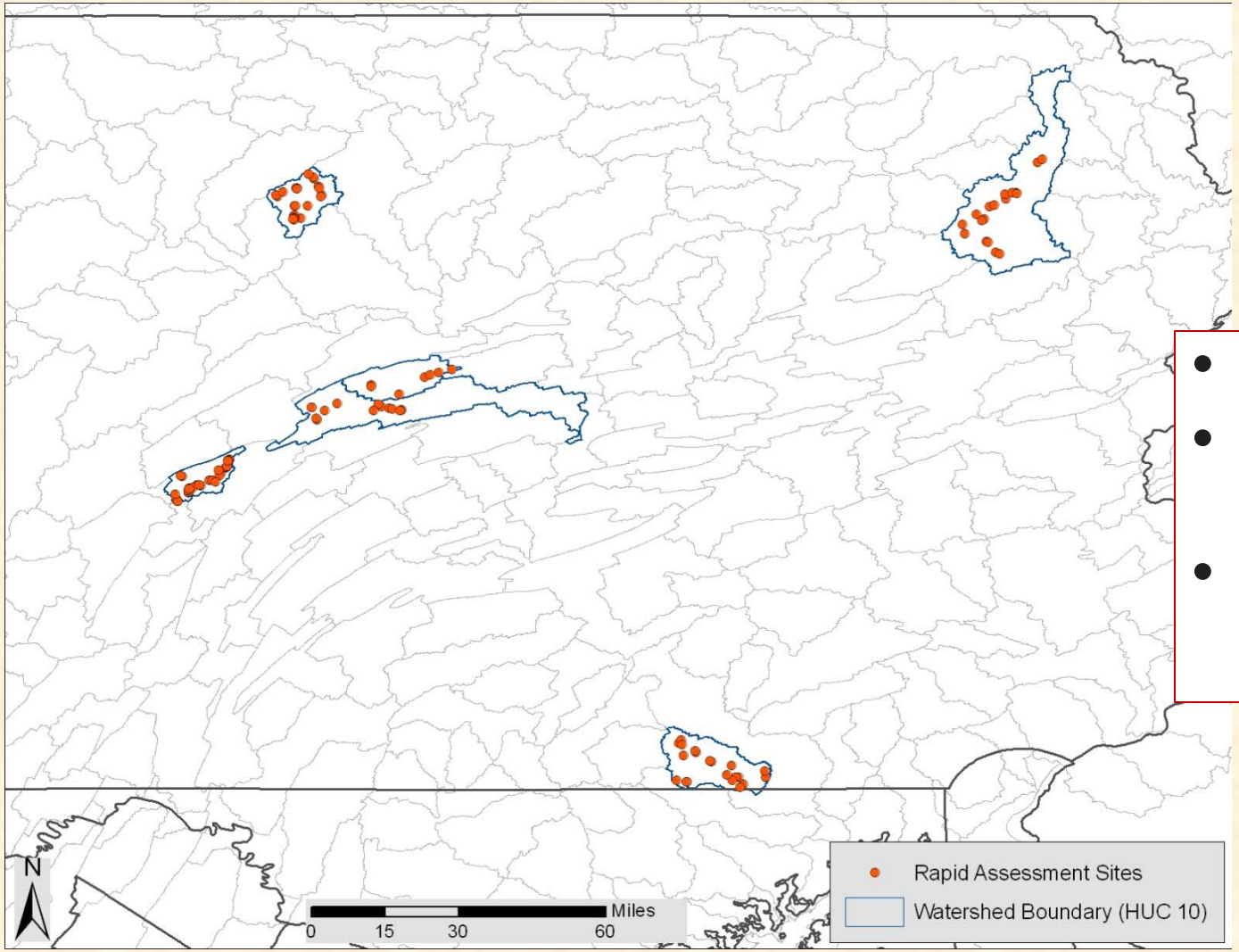


HYDROLOGY

3/18/2010 – 3/27/2011



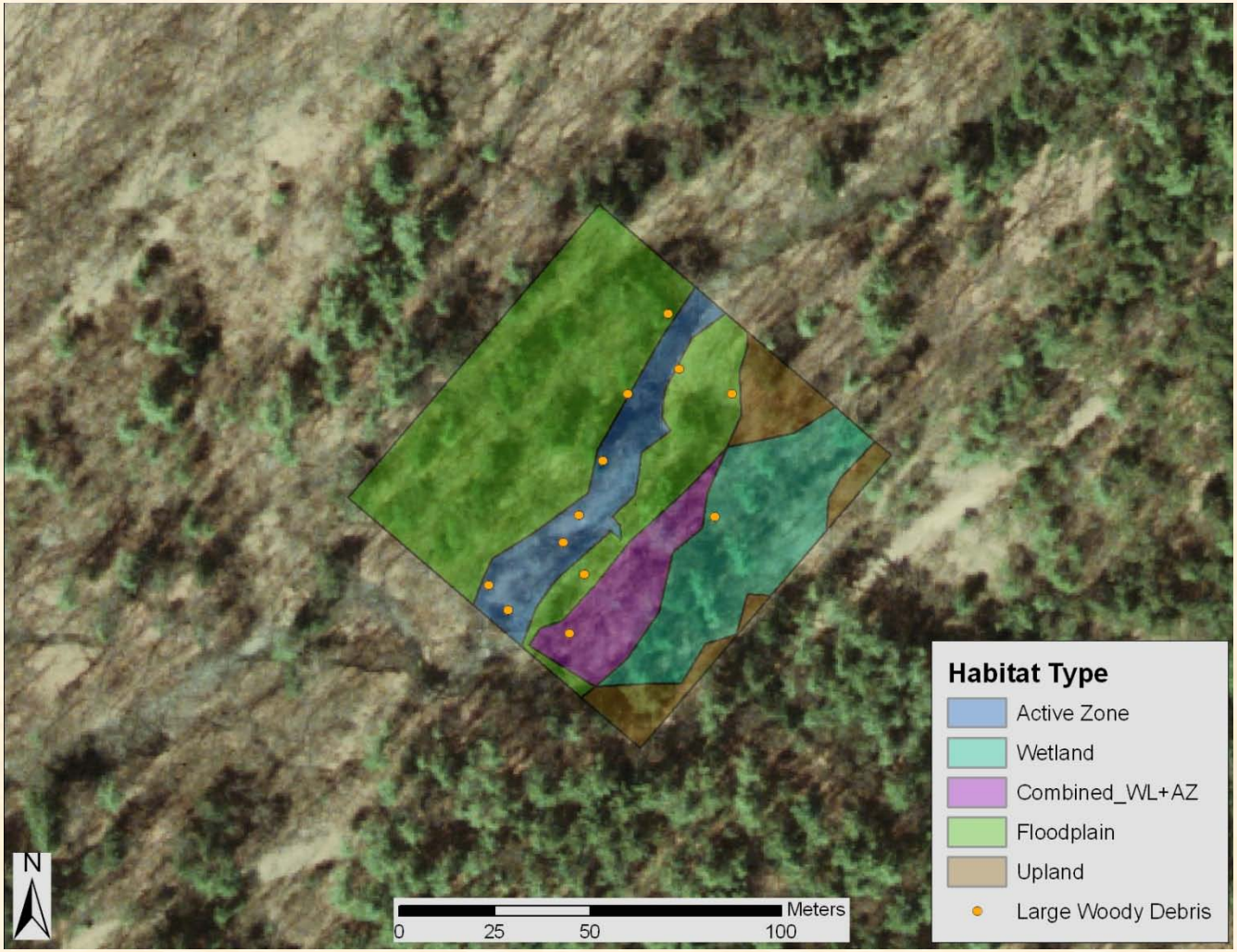
RIVERINE RAPID ASSESSMENT



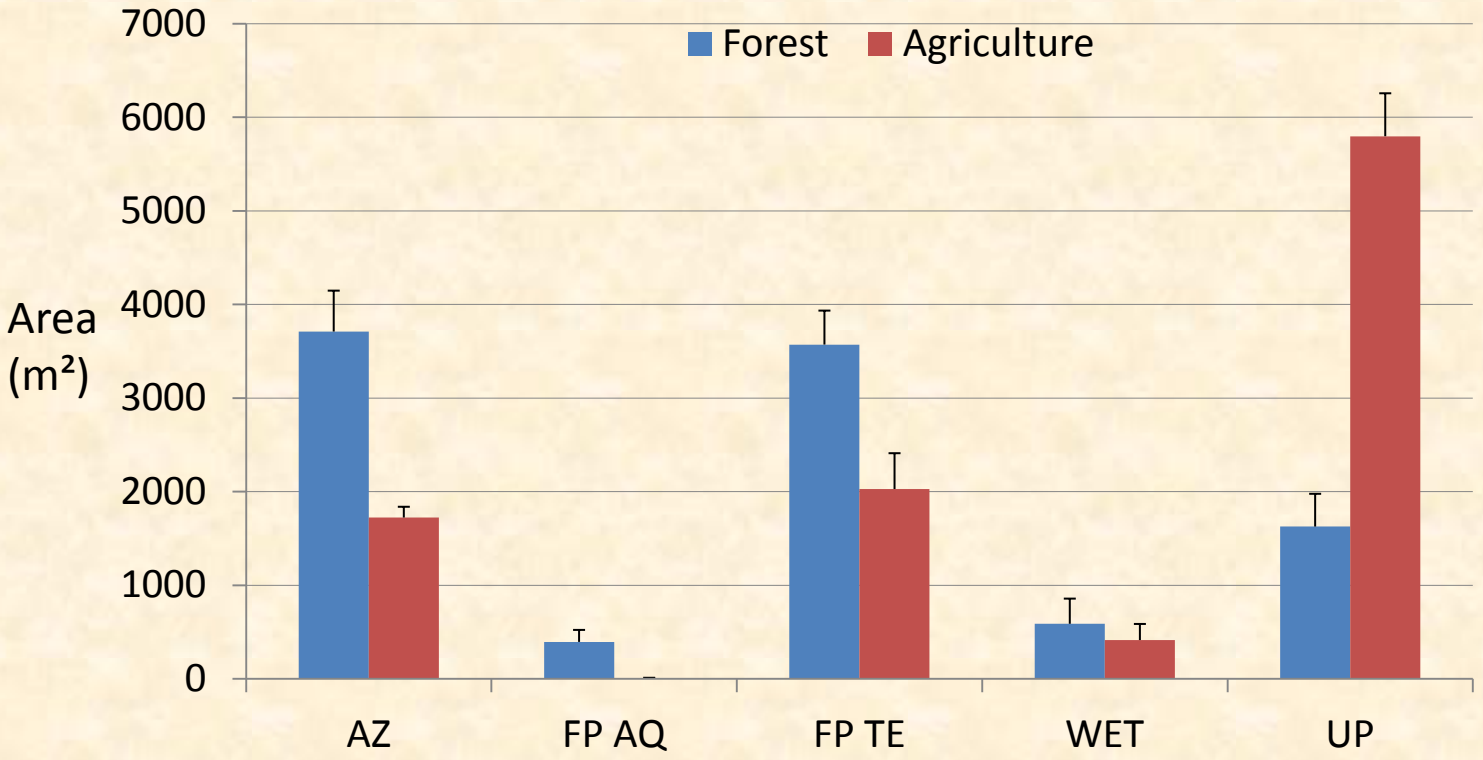
- Habitat Area
- Habitat Complexity
- Habitat Condition

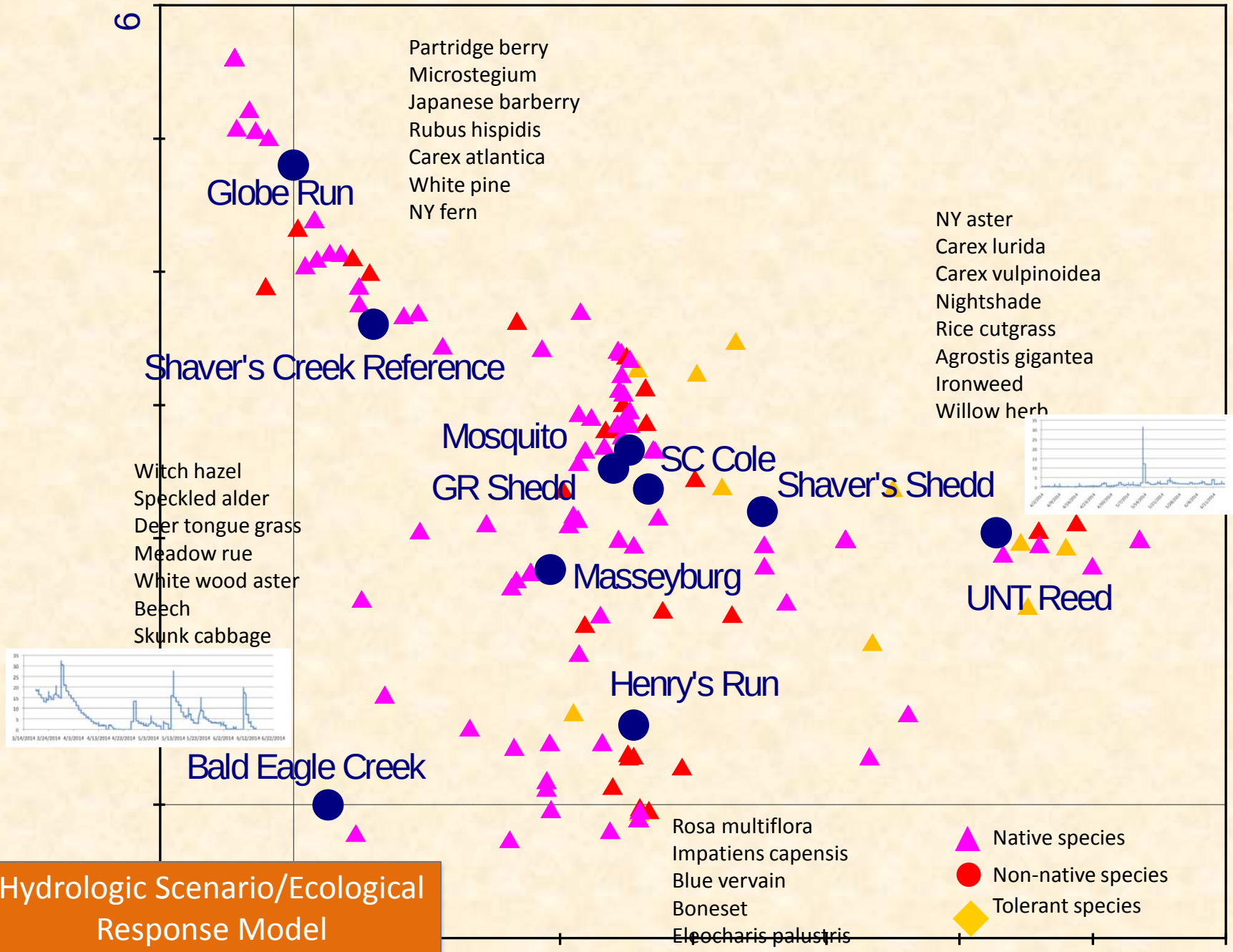
HABITAT AREA: Floodplain Forested Site

HABITAT AREA: Mixed Forested Site



RESULTS: FLOODPLAIN HABITAT AREA





Hydrologic Scenario/Ecological Response Model

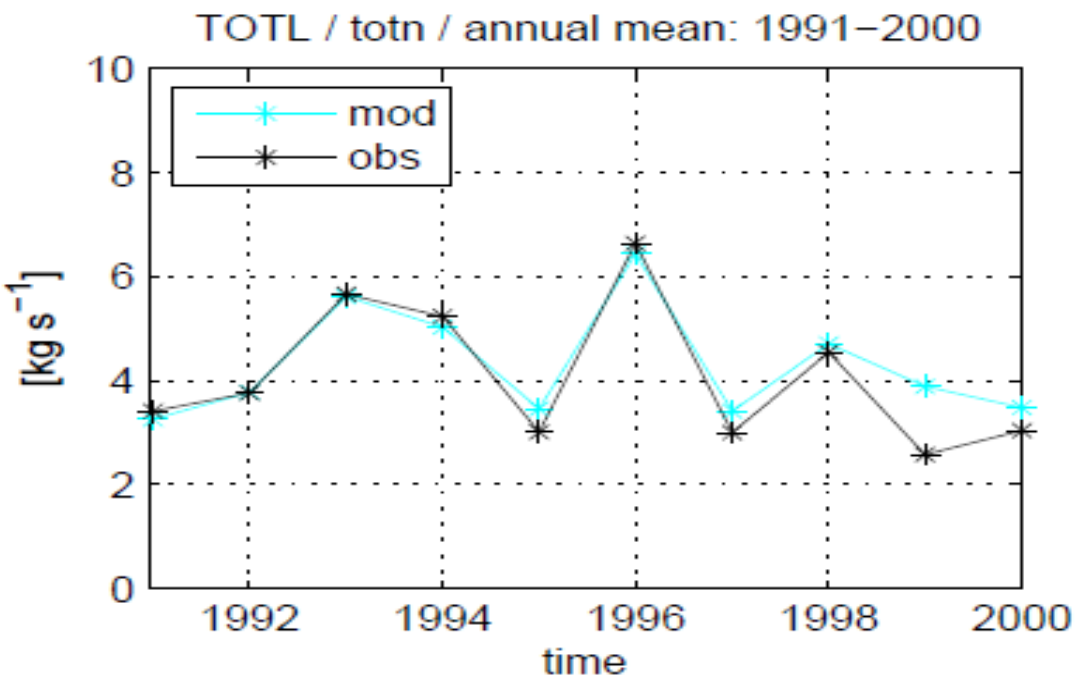
MAGNITUDE OF MONTHLY CONDITIONS	MAGNITUDE & DURATION OF ANNUAL EXTREME CONDITIONS	FREQUENCY & DURATION OF ABOVE AND BELOW BANKFULL PULSES*	RATE & FREQUENCY OF WATER CONDITION CHANGES
Mean monthly values	Annual minima 1-day means	Number of flood (above bankfull) pulses/year	Means of all positive differences between consecutive daily means
Mean value for each 3-mo season (J-M, A-J, J-S, O-N)	Annual maxima 1-day means	Number of active zone (below bankfull) pulses/year	Means of all negative differences between consecutive daily values
Mean annual flow	Annual minima 3-day means	Number of flood pulses/3 mo. Season	No. of rises
	Annual maxima 3-day means	Number of active zone pulses/3 mo. Season	No. of falls
	Annual minima 7-day means	Mean duration of flood pulses within each year	
	Annual maxima 7-day means	Mean duration of active zone pulses within each year	
	Annual minima 30-day means	Mean duration of flood pulses within each 3 mo. season	
	Annual maxima 30-day means	Mean duration of active zone pulses within each 3 mo. season	
	Annual minima 90-day means		
	Annual maxima 90-day means		
	December minimum value		

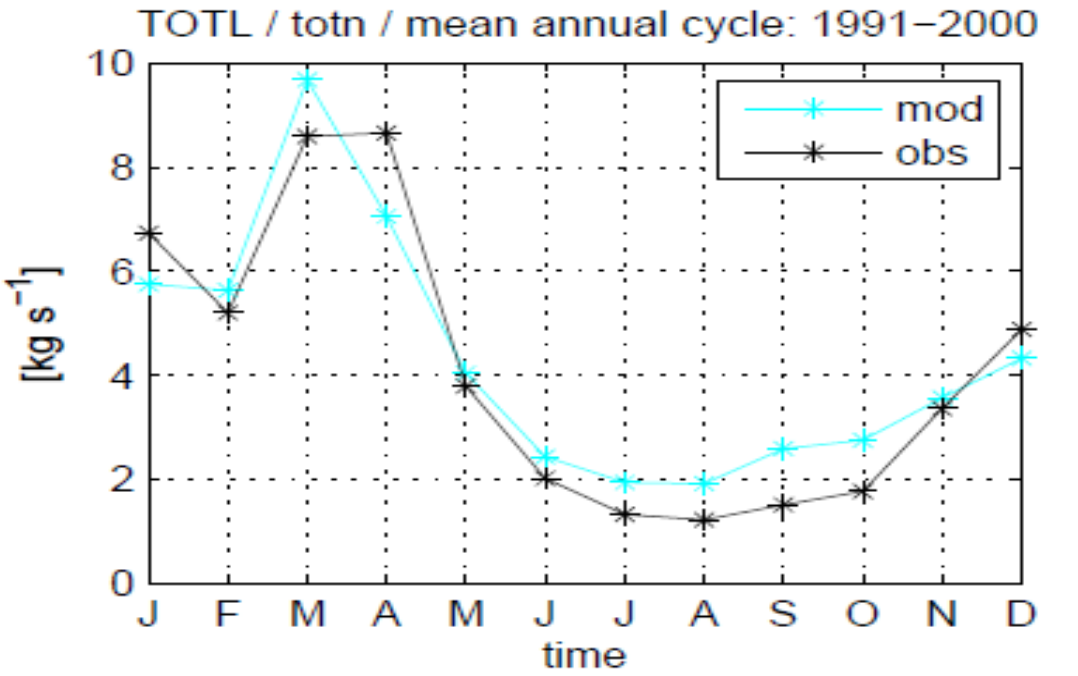
Hydrologic Scenario/Ecological Response Model

Future?

- Wetter, with probable expansion of wetland area
- Habitat may be simpler, lower diversity
- Spatially variable within watersheds; variable within reach types; variable across ecoregions
- Currently evaluating hydrologic metrics for predictive capability; events are important
- Mechanistic understanding of habitat creation/maintenance processes

Model evaluation: N loading

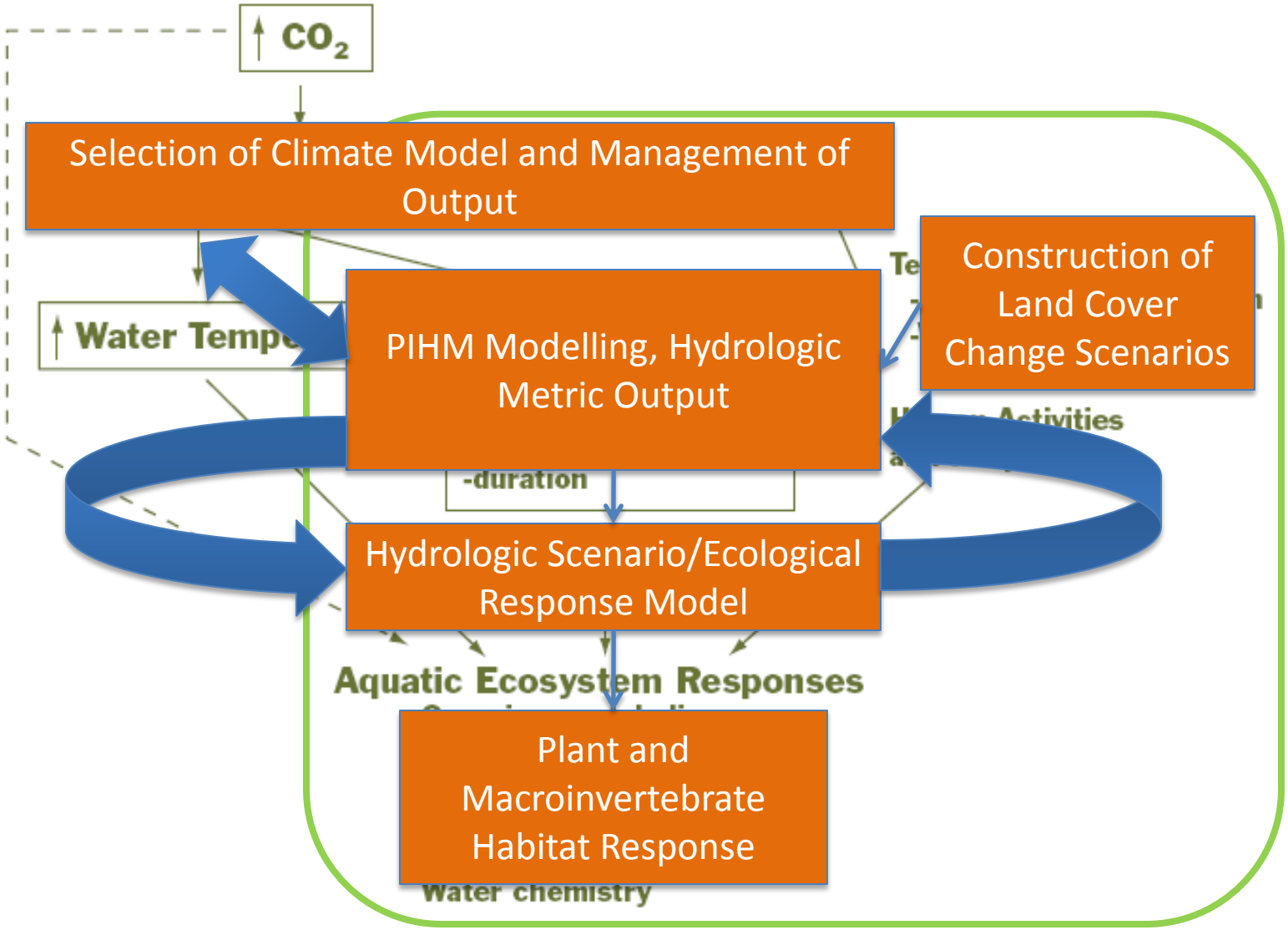




When one has finished building one's house, one suddenly realizes that in the process one has learned something that one really needed to know in the worst way - before one began.

Friedrich Nietzsche

CO_2, Climate, and Ecological Processes



Poff et al 2005

House-Building Hints

- Spatially-explicit results are highly uncertain
- Scales of prediction are matched with scales of management and vulnerability
- Process is meaningful, tools are useful
- Web-sharing of results and tools is difficult