# Sensitivity of Water Yield Response to Changes in Forest Cover and Climate in the U.S.

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NC State University

and many other collaborators…..

# Outline

- Forests and water supply under a changing climate:
  - How much change in water supply should we expect?
  - How much impacts of forest adaptation measures on water?
- Water Supply Stress Index model (WaSSI-CB)
- Model applications in the U.S.
  - Sensitivity of water supply to forest cover and climate change
  - Impacts of 4 climate change scenarios on water yield

# Progress Made

LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
FORESTRY DIVISION,
*Washington, D. C., November 1, 1892.*

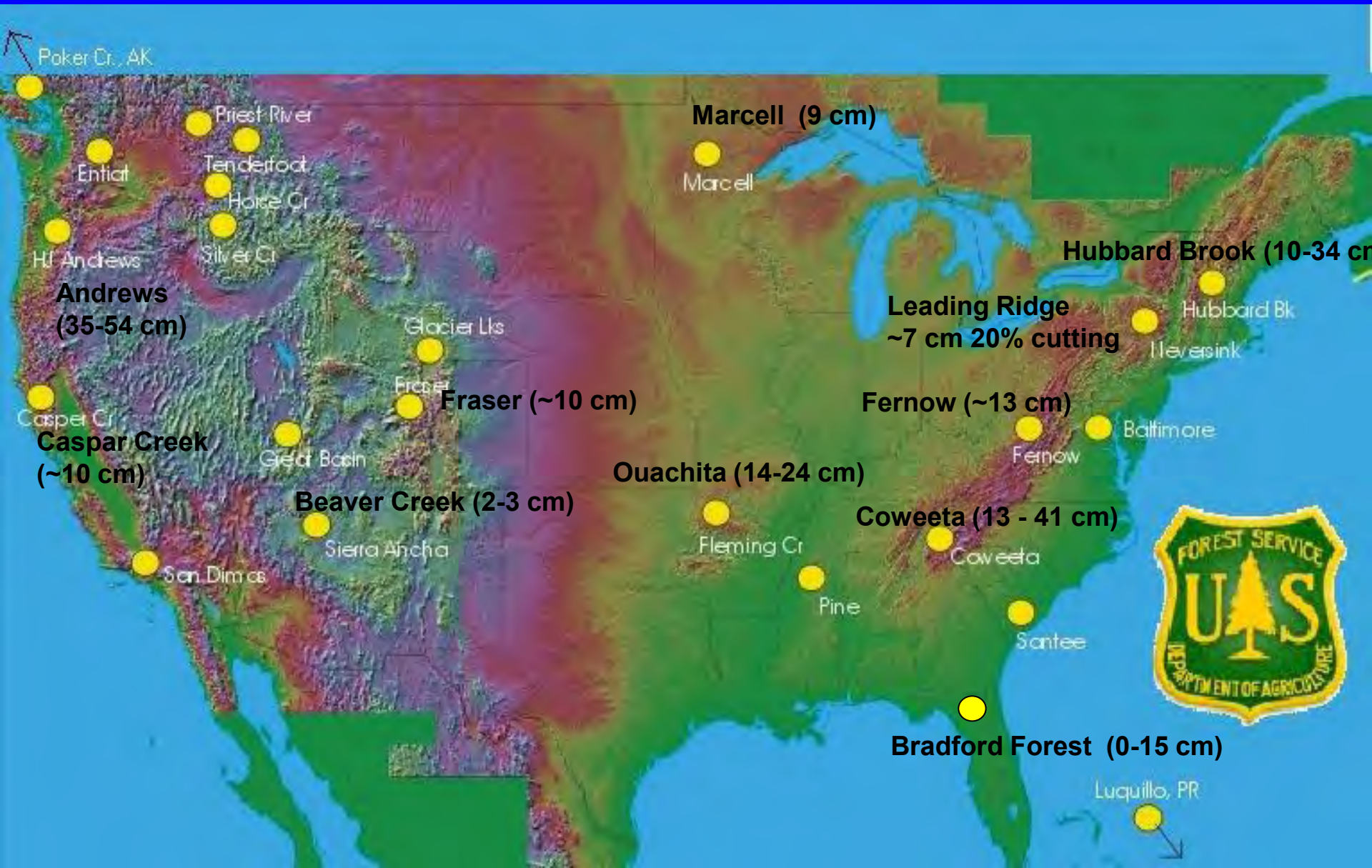
SIR: I have the honor to submit herewith for publication a review of the meteorological observations which have been made, mostly in foreign countries, for the purpose of determining whether and to what extent forests influence climate, together with a discussion of the manner in which forests affect the water conditions of the earth and other matter elucidating the question of forest influences in general.

Respectfully,

B. E. FERNOW,
*Chief of Division.*

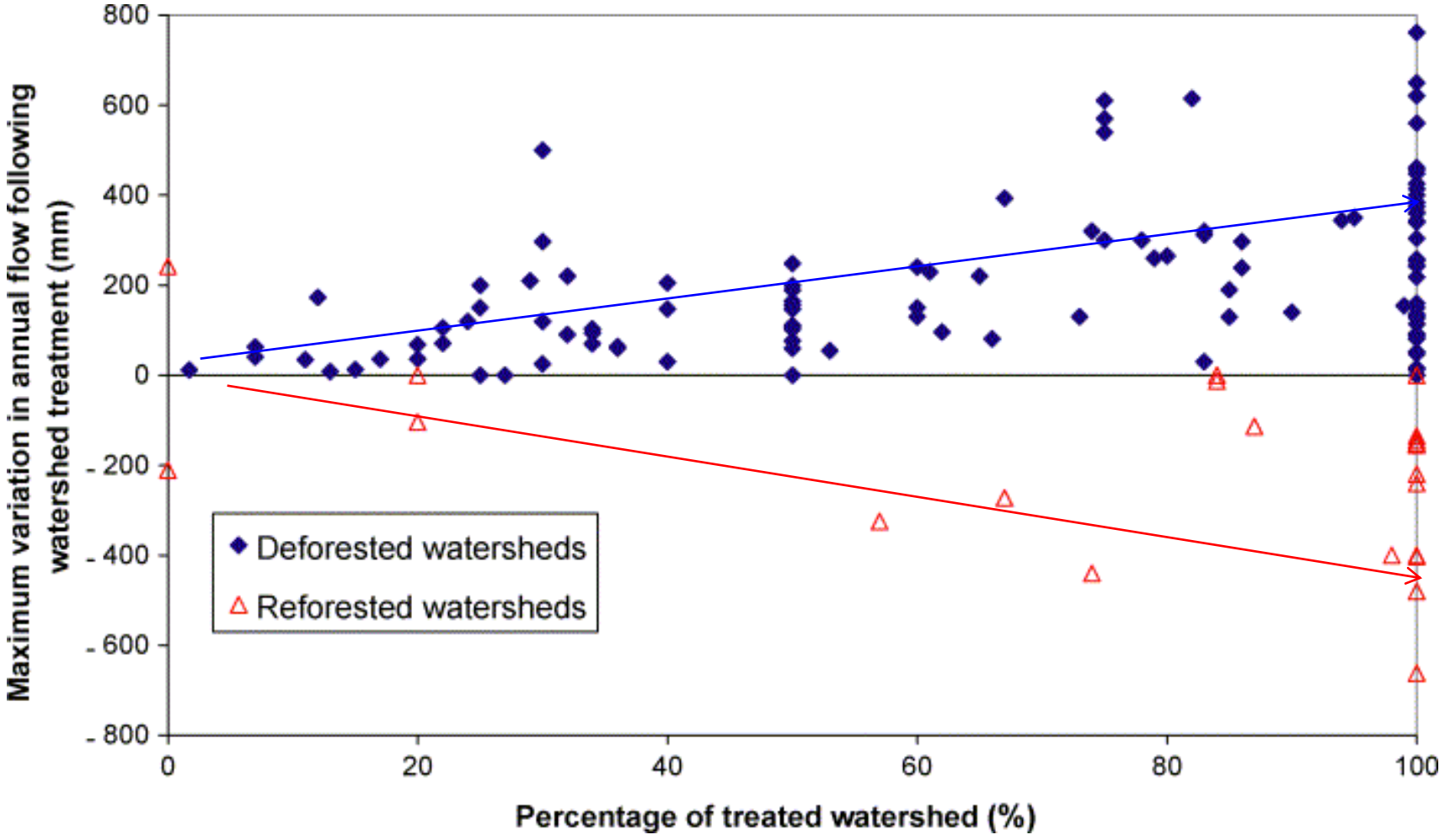
HON. J. M. RUSK,
*Secretary of Agriculture.*

# First Year Annual Water Yield Responses to Forest Removal in the U.S.A.

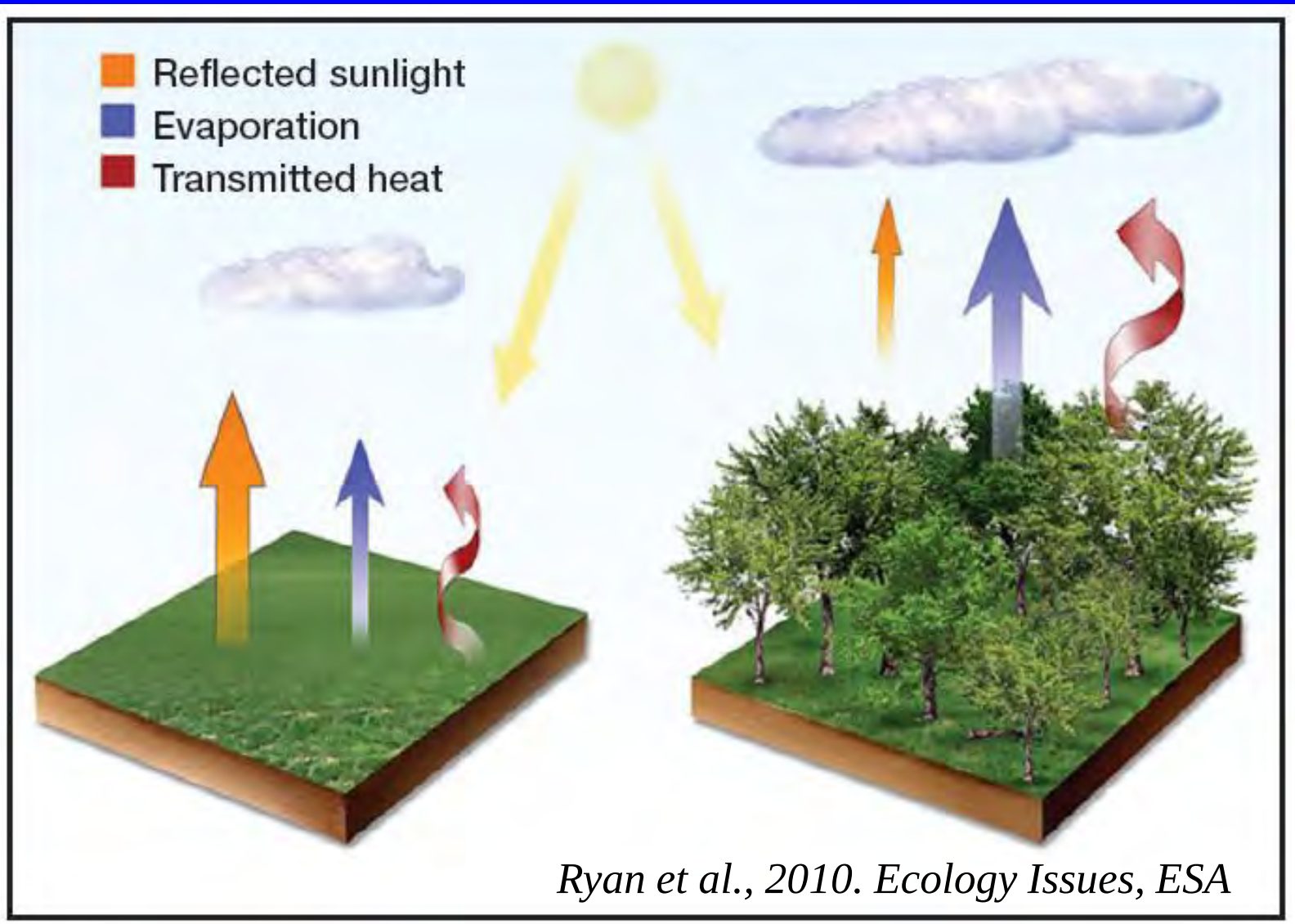


# Streamflow Flow Response to Watershed Manipulation

(*Andreassian, Journal of Hydrology 2004 (291):1-27)*

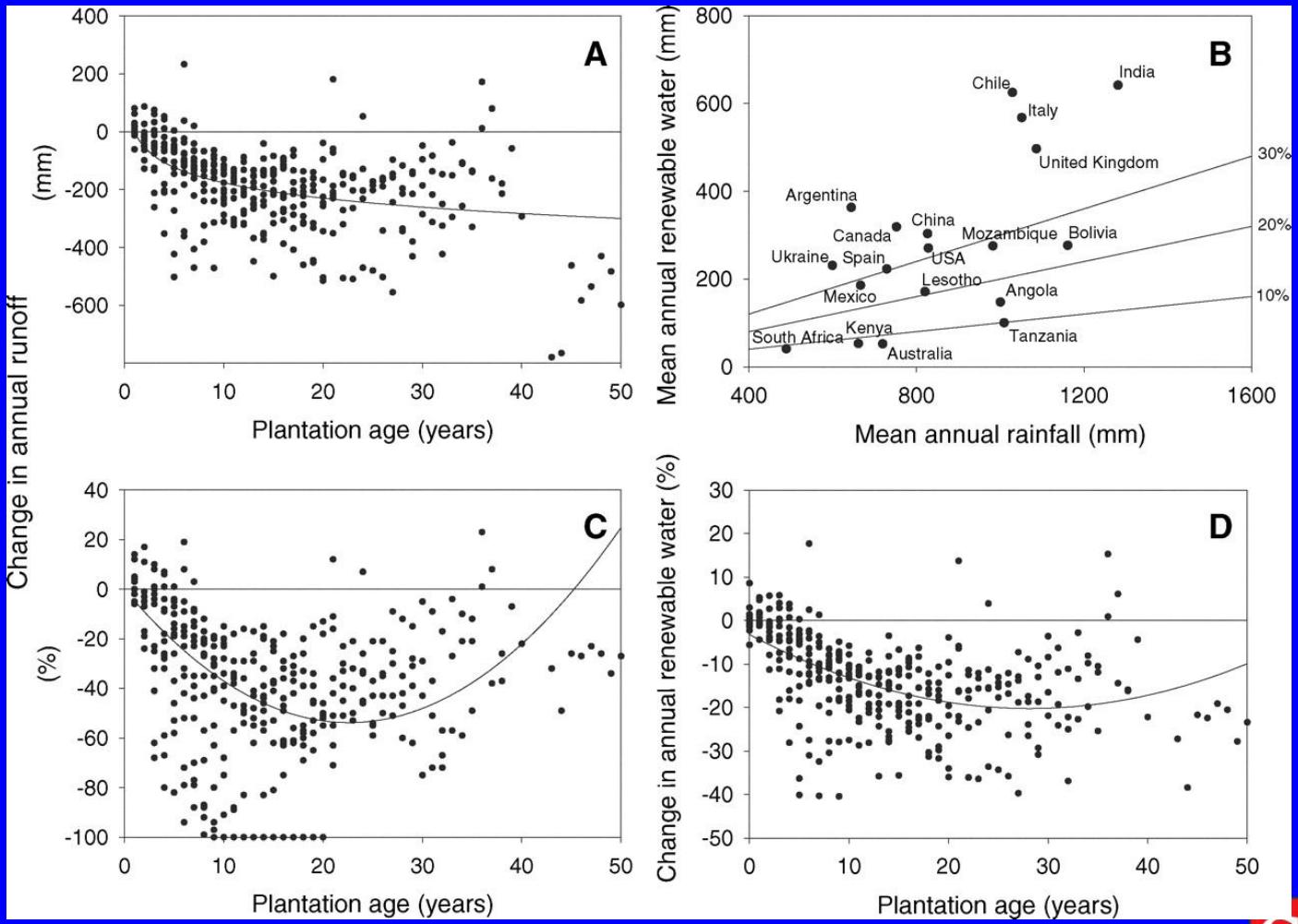


# More trees, more warming?

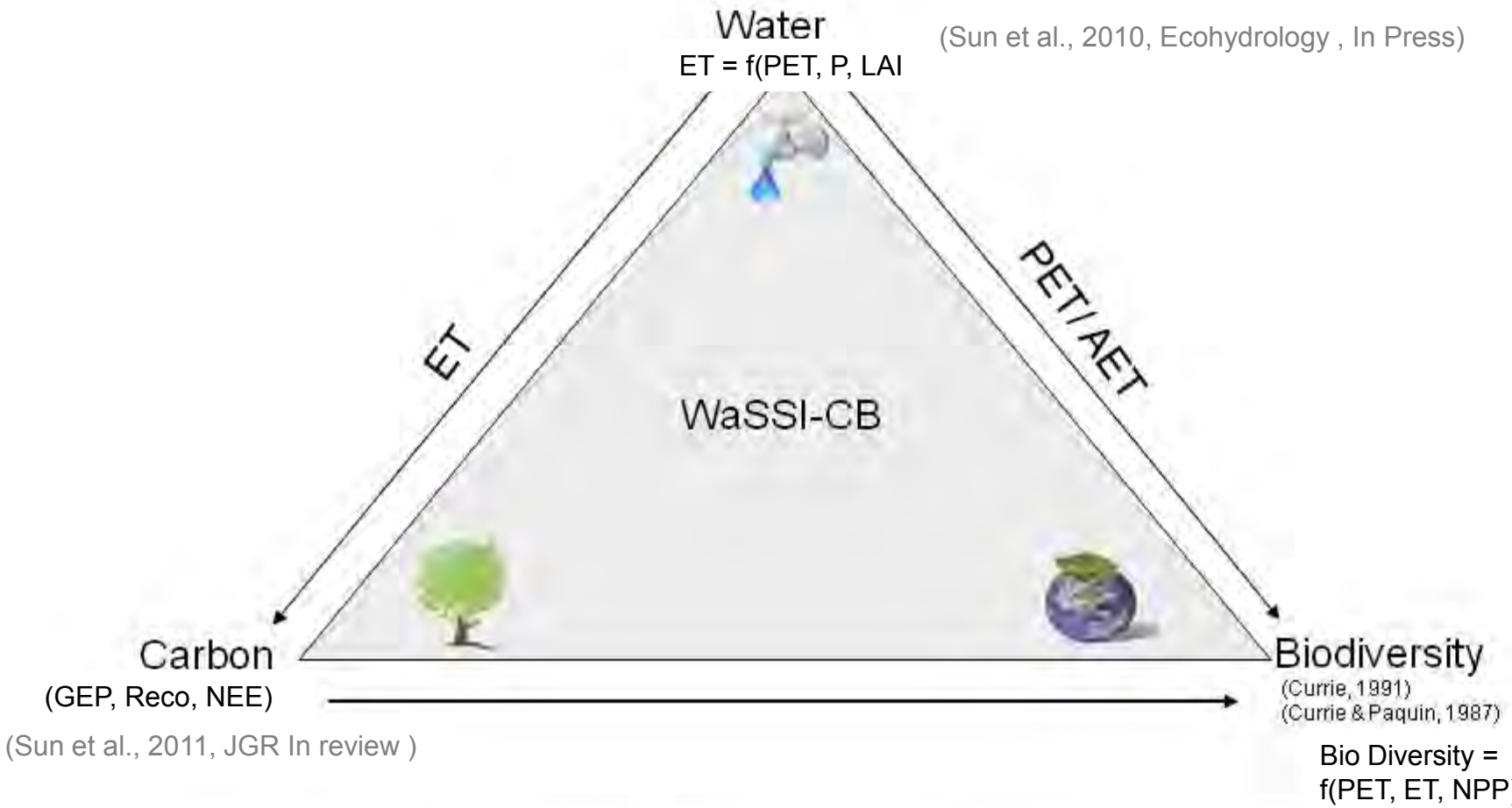



*Ryan et al., 2010. Ecology Issues, ESA*

# Tradeoffs between Water and Carbon Sequestration
## *(Jackson et al, 2005 Science)*




Published by AAAS



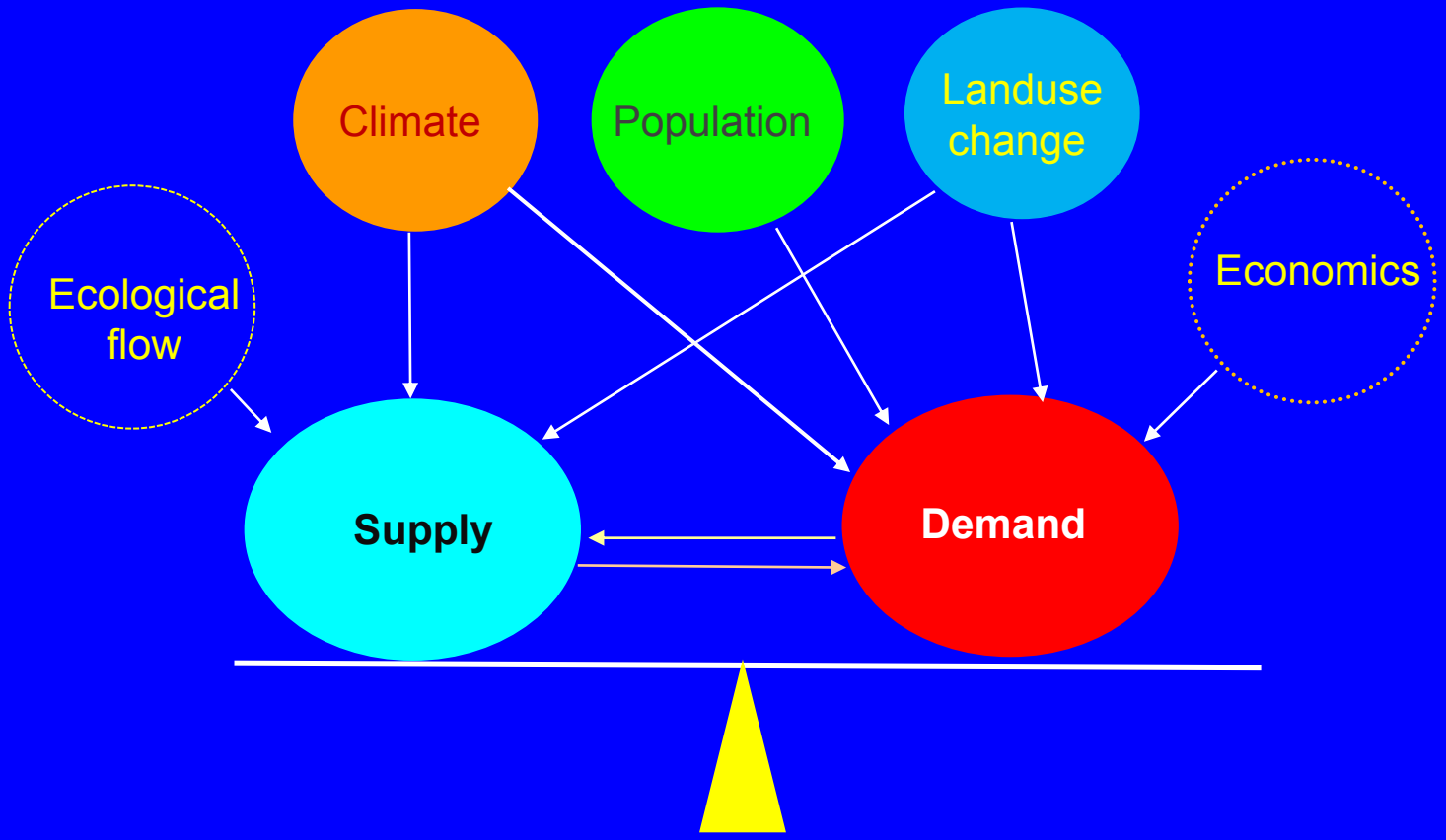

# WaSSI-CB Modeling Framework

**(McNulty *et al*., 2010)**

SGCP

# Water

## Multiple Stressor Effects on Supply and Demand



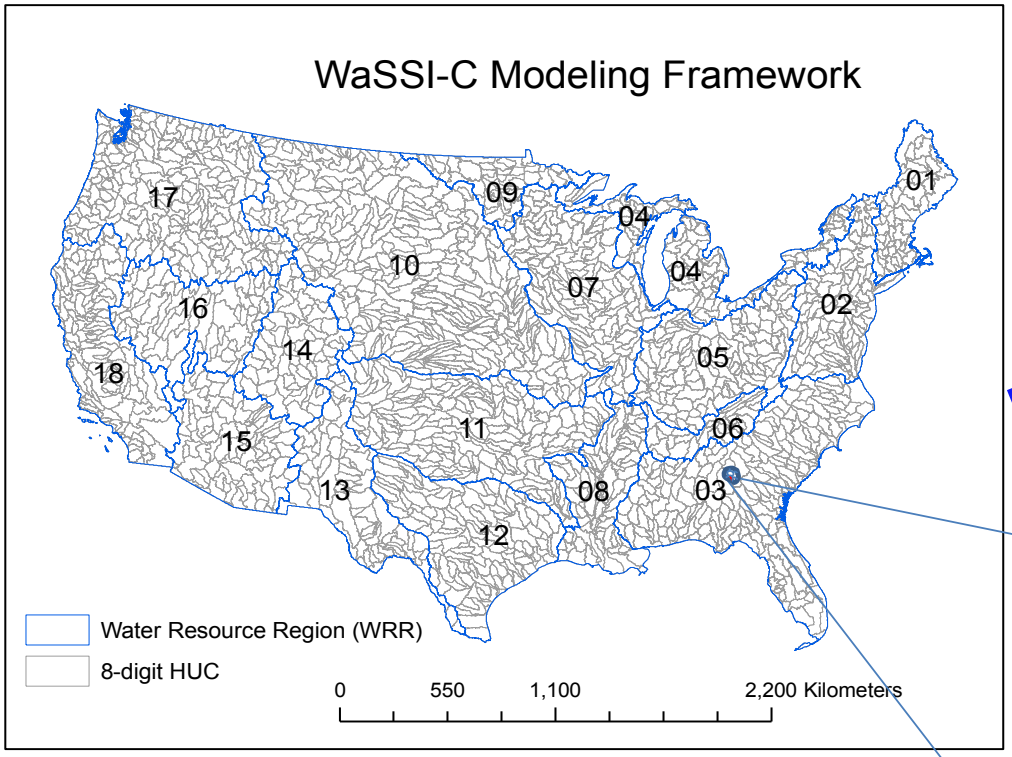

*(Sun et al. JAWRA, 2008 44(5):1073-1075)*

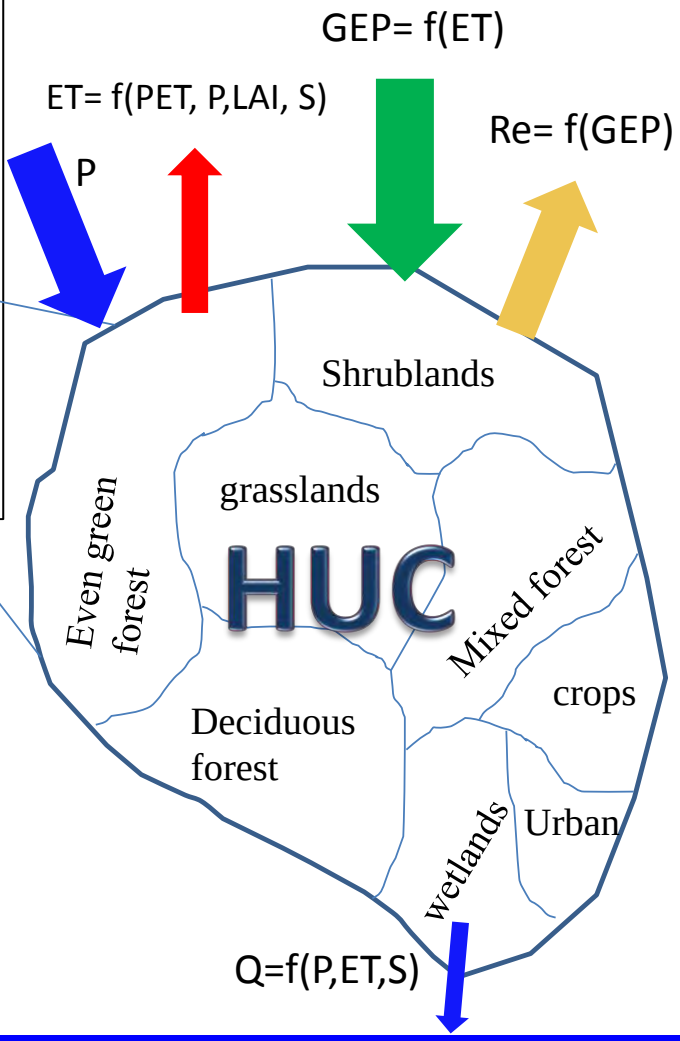
# Water

## Water Supply Stress Index

$$\mathrm{WaSSI} = \frac{\text{Water Demand}}{\text{Water Supply}}$$

***(Sun et al. JAWRA, 2008 44(5):1073-1075)***



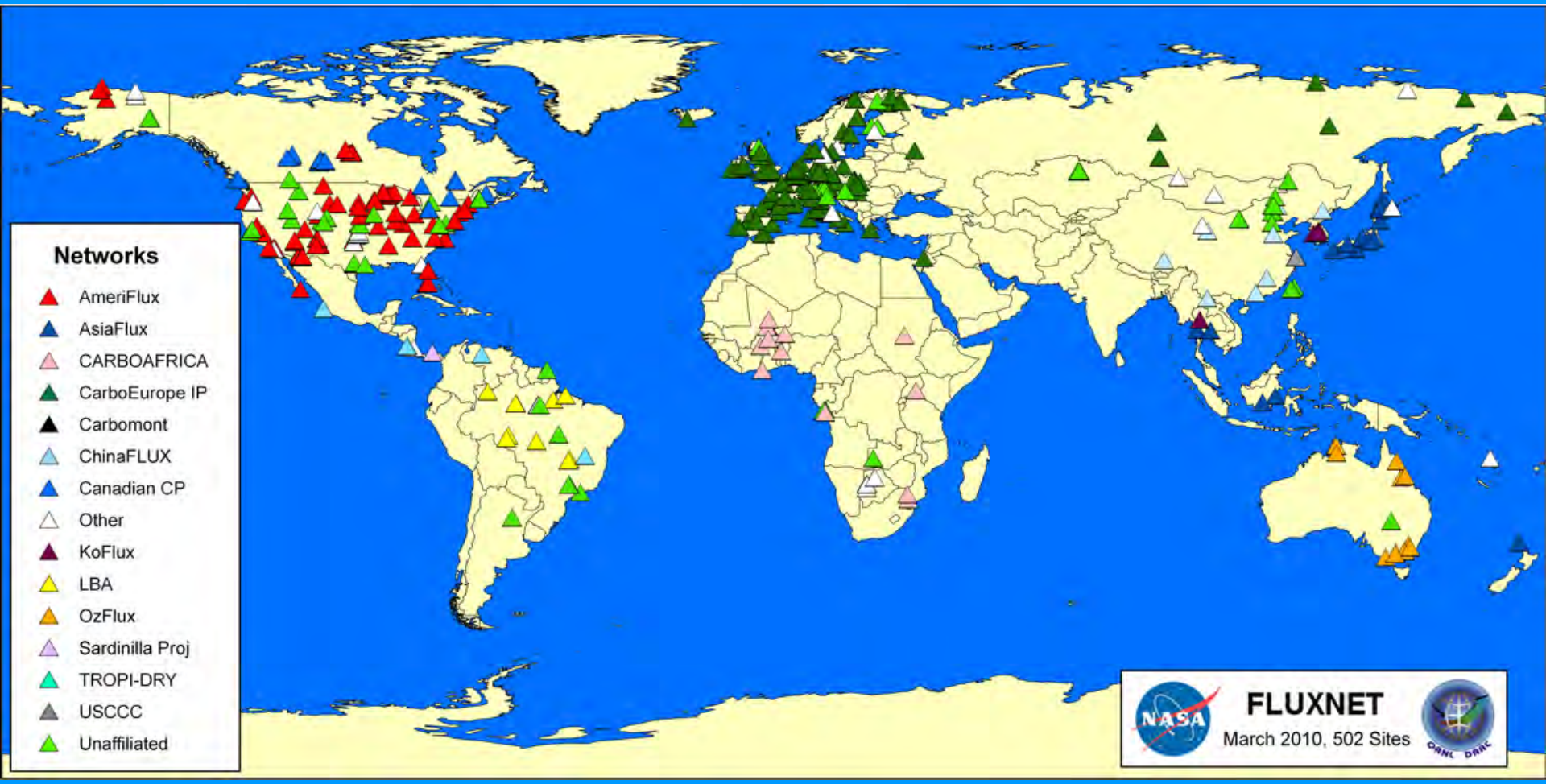

Water balance

$\Delta S = P - Q - ET$

Carbon balance

$NEE = -(GEP - Re)$

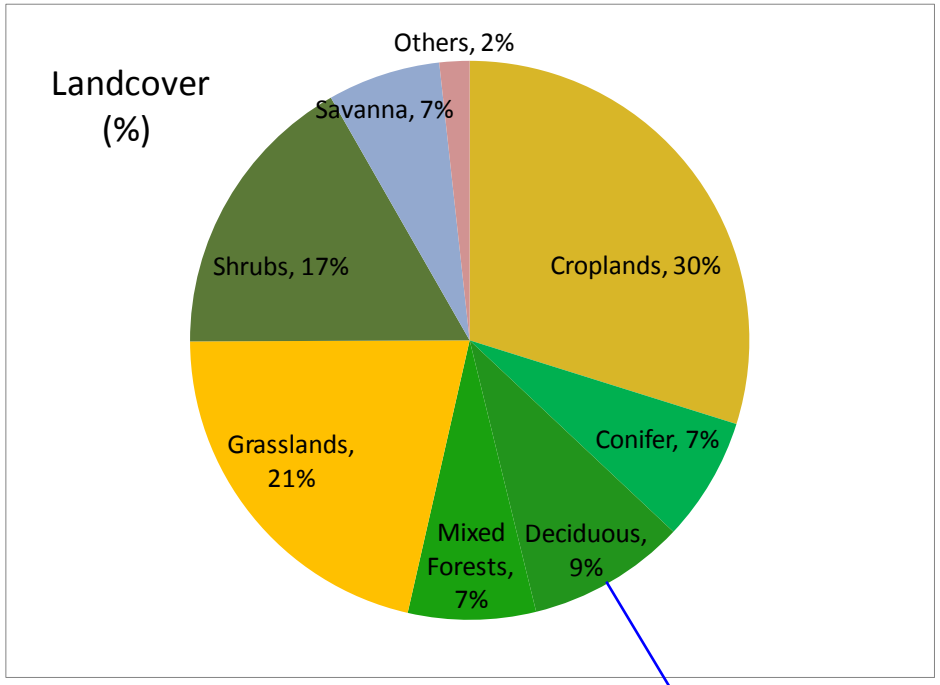
# FLUXNET


Networks
AmeriFlux
AsiaFlux
CARBOAFRICA
CarboEurope IP
Carbomont
ChinaFLUX
Canadian CP
Other
KoFlux
LBA
OzFlux
Sardinilla Proj
TROPI-DRY
USCCC
Unaffiliated
NASA
FLUXNET
March 2010, 502 Sites
ORNL DAAC

# Model Applications

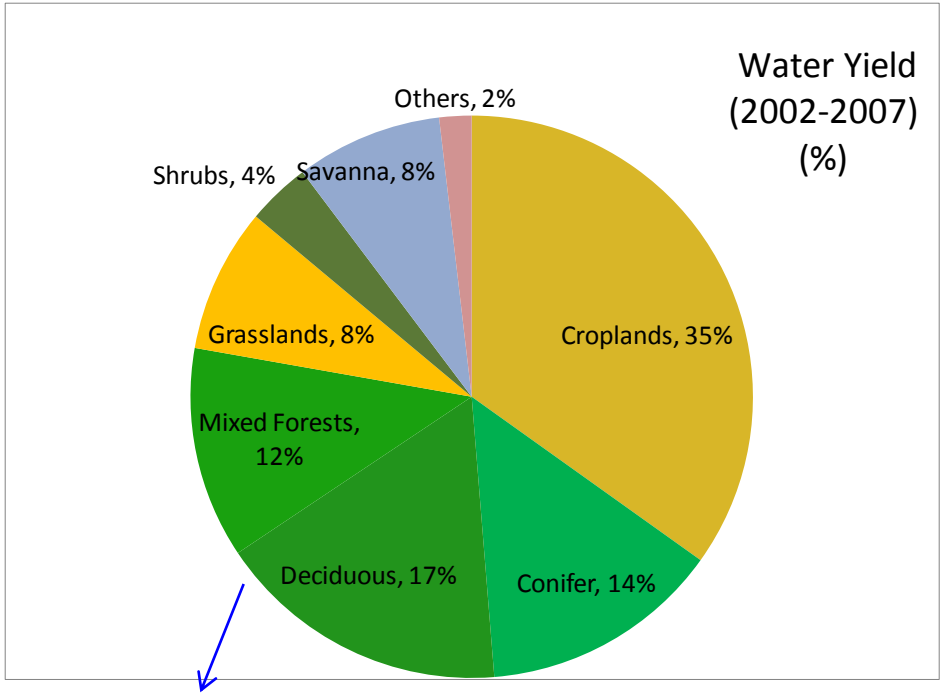
- A national picture across 2100 watersheds
- Sensitivity of possible management options and climate change
- Likely consequences under four future climate scenarios as predicted by Four Global Circulation Models in 2050

# Land Cover (%)



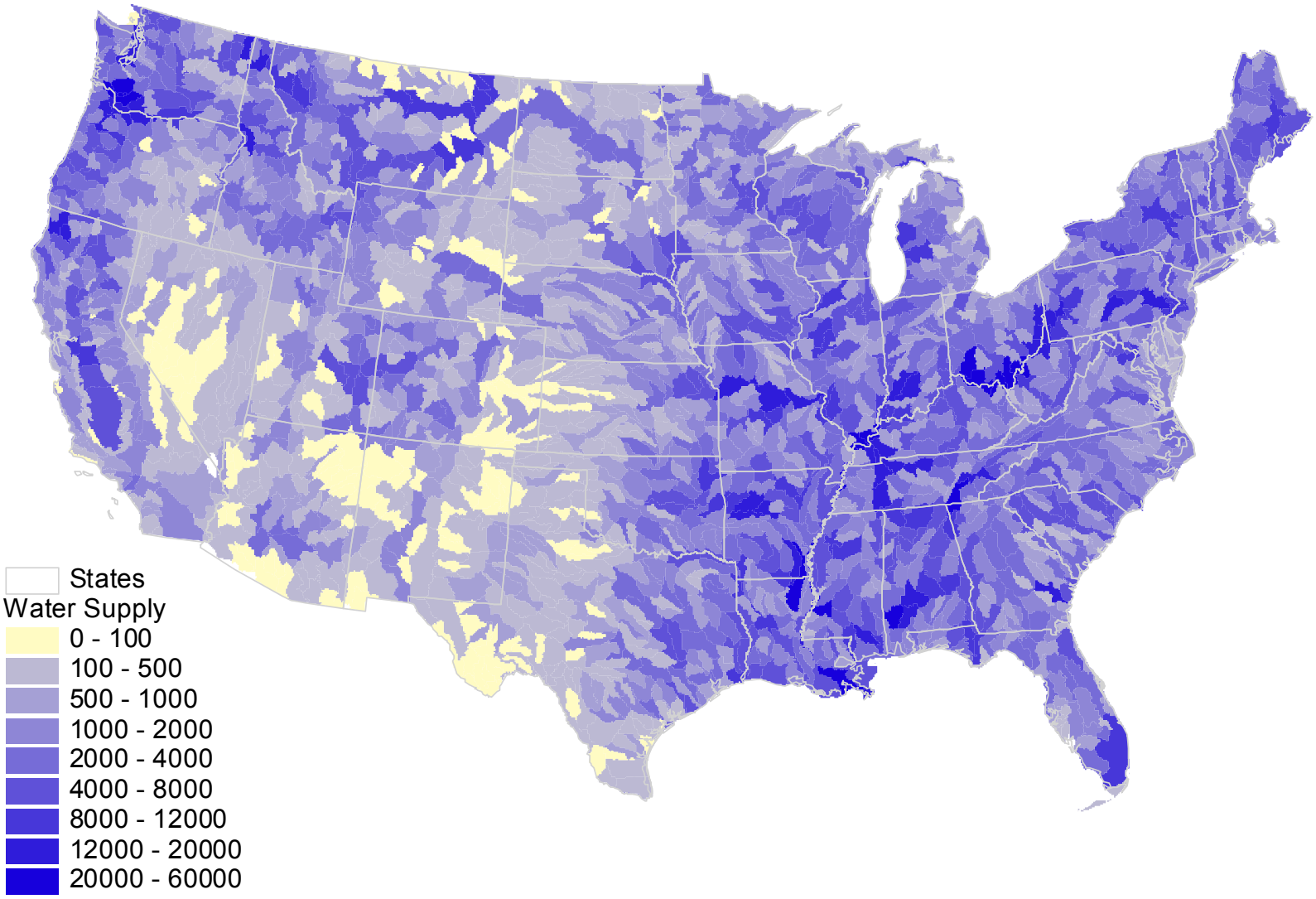

23%

# Water Yield (%)

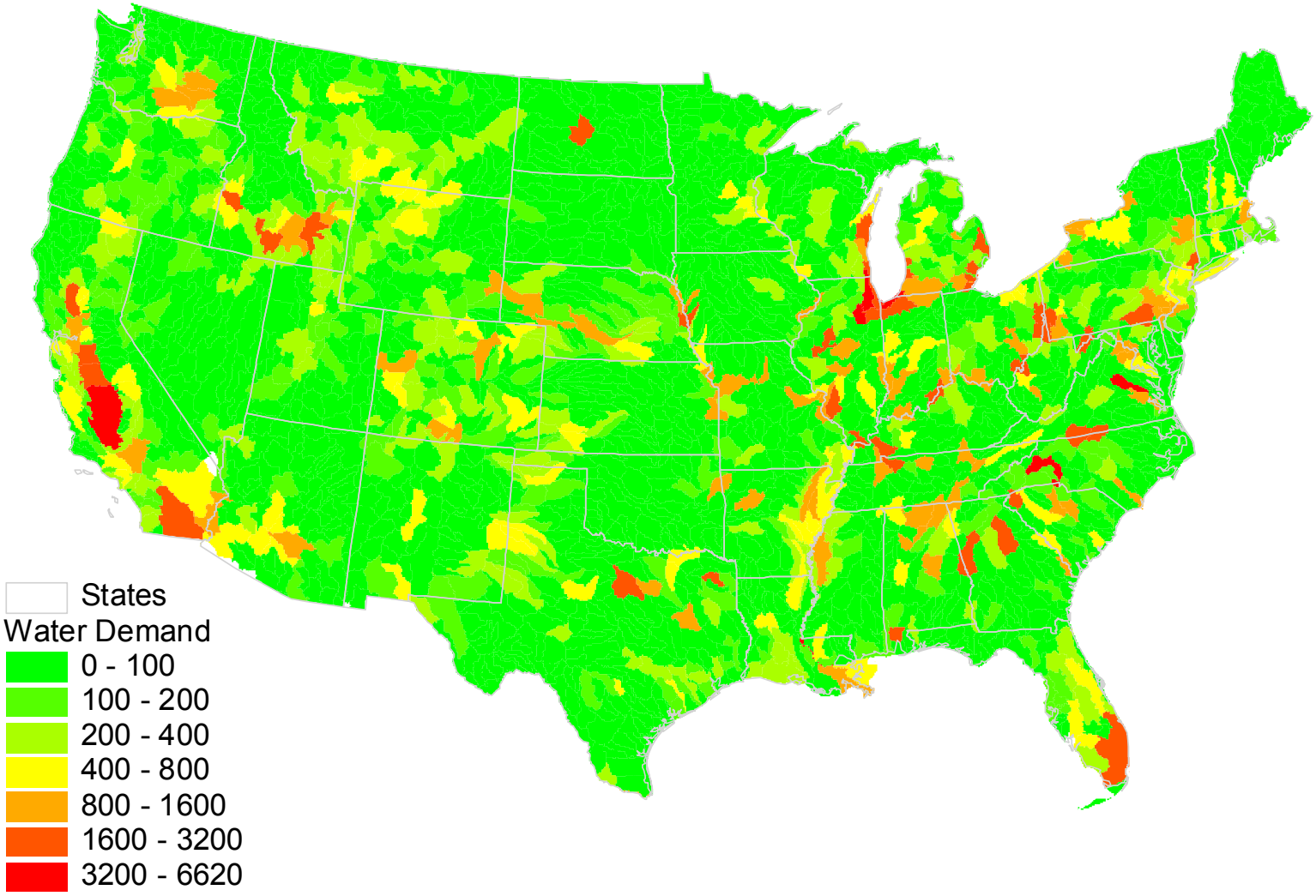



43%

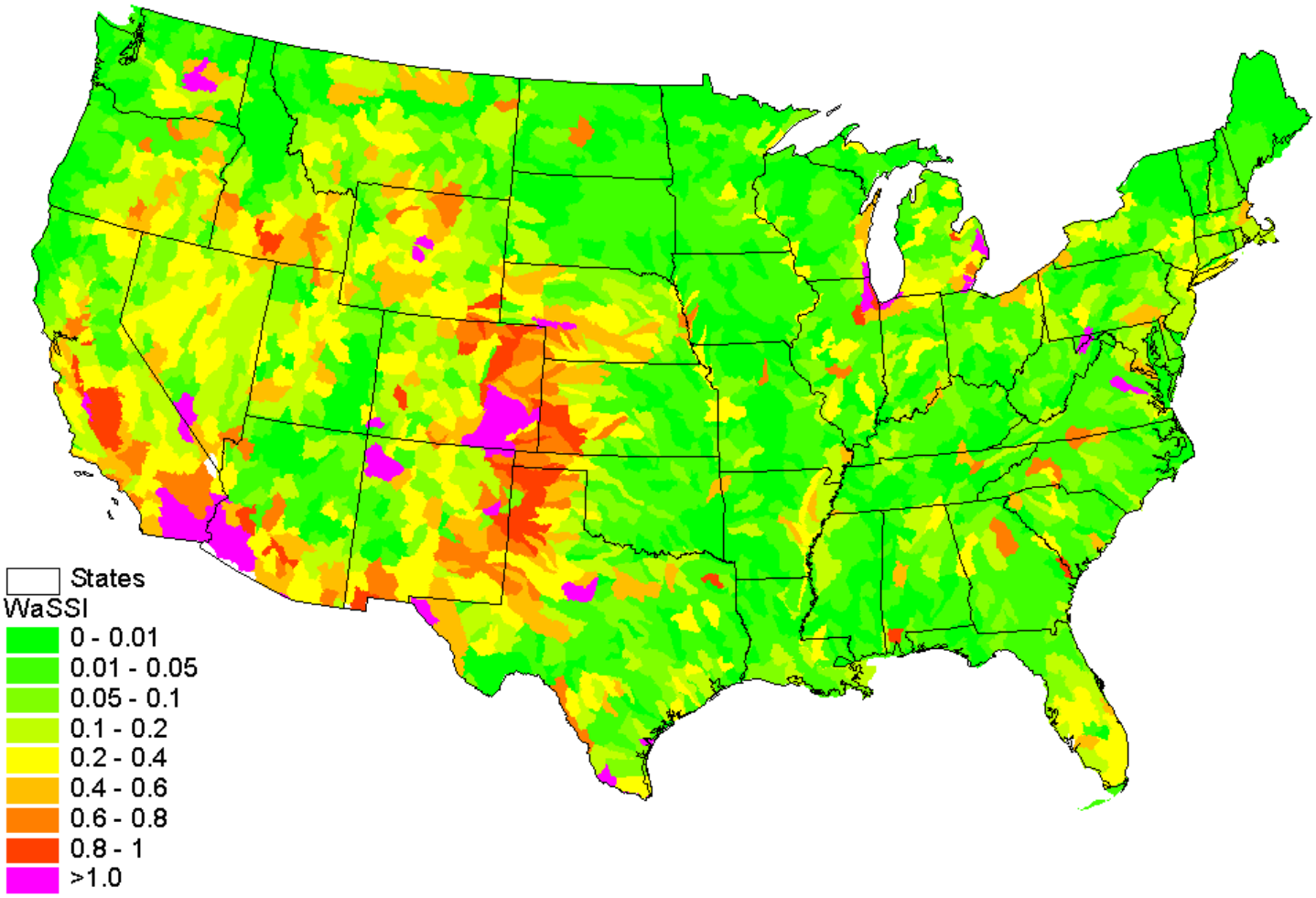
# Current Water Supply (MGD)



# Current Water Demand (MGD)



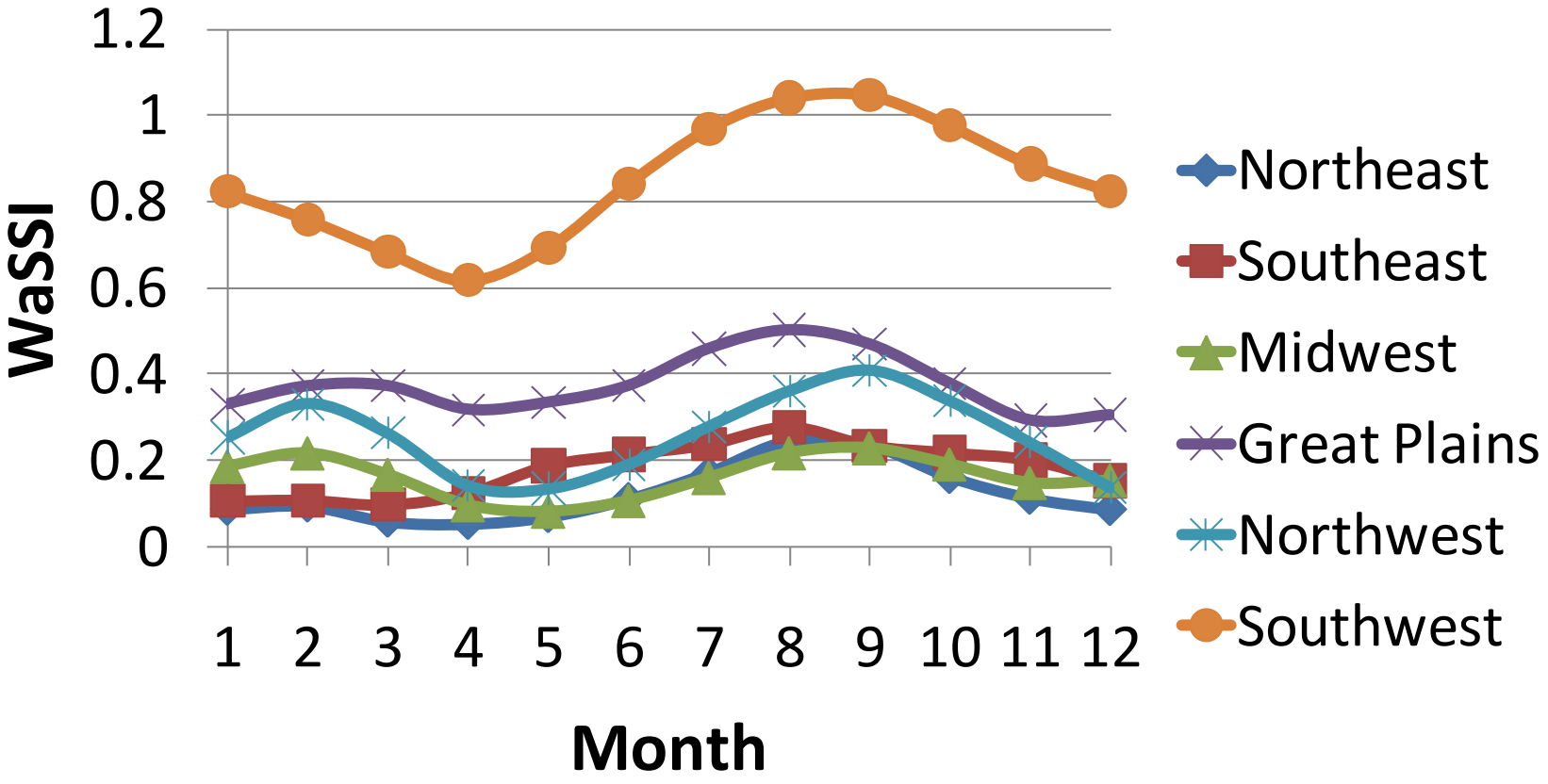
# Water Demand / Water Supply (WaSSI) (1974-1993)




(Sun *et al*., 2010 JGR in review)

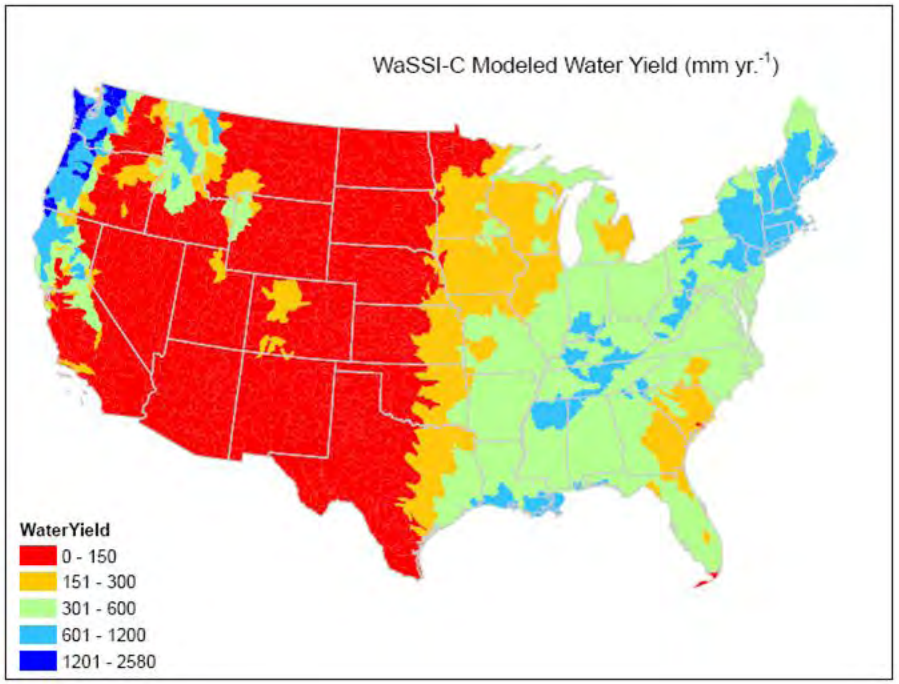
# Example Output

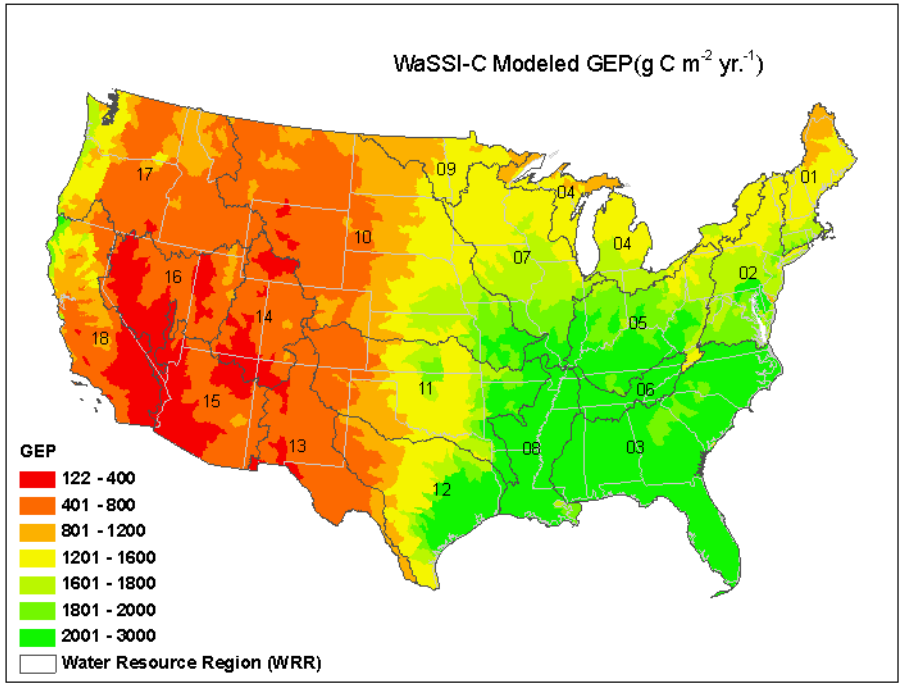
## 1996 – 2005 Mean Monthly WaSSI



# Water Yield

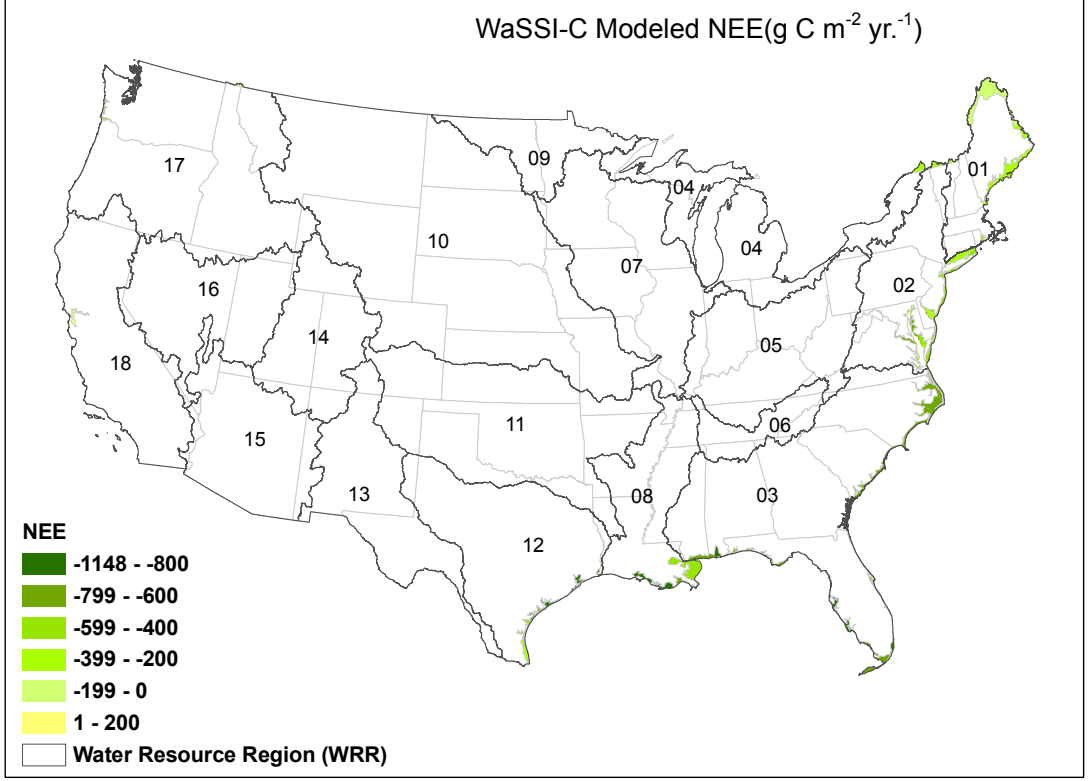
# Ecosystem Productivity



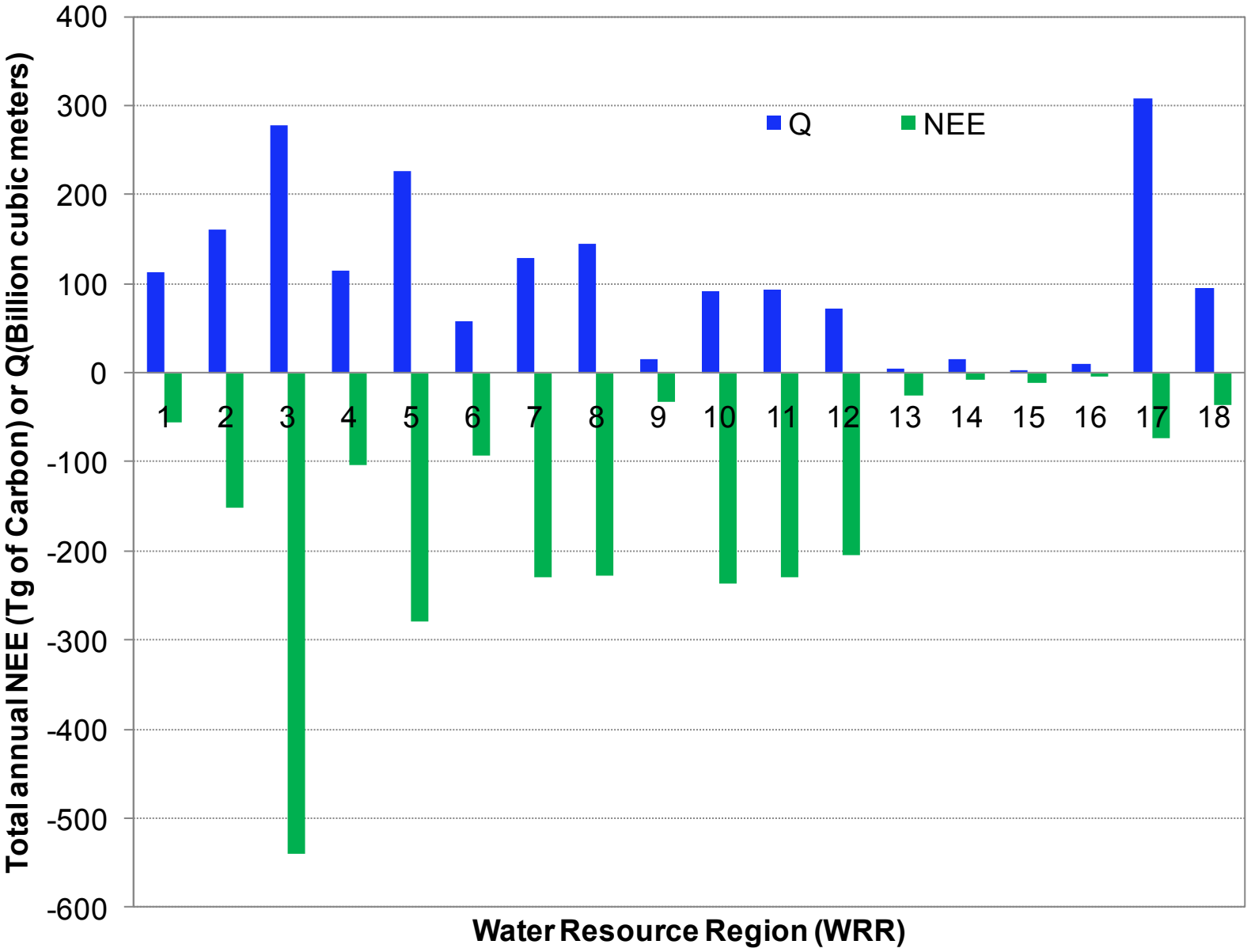




(Sun *et al*., 2010 JGR in review)

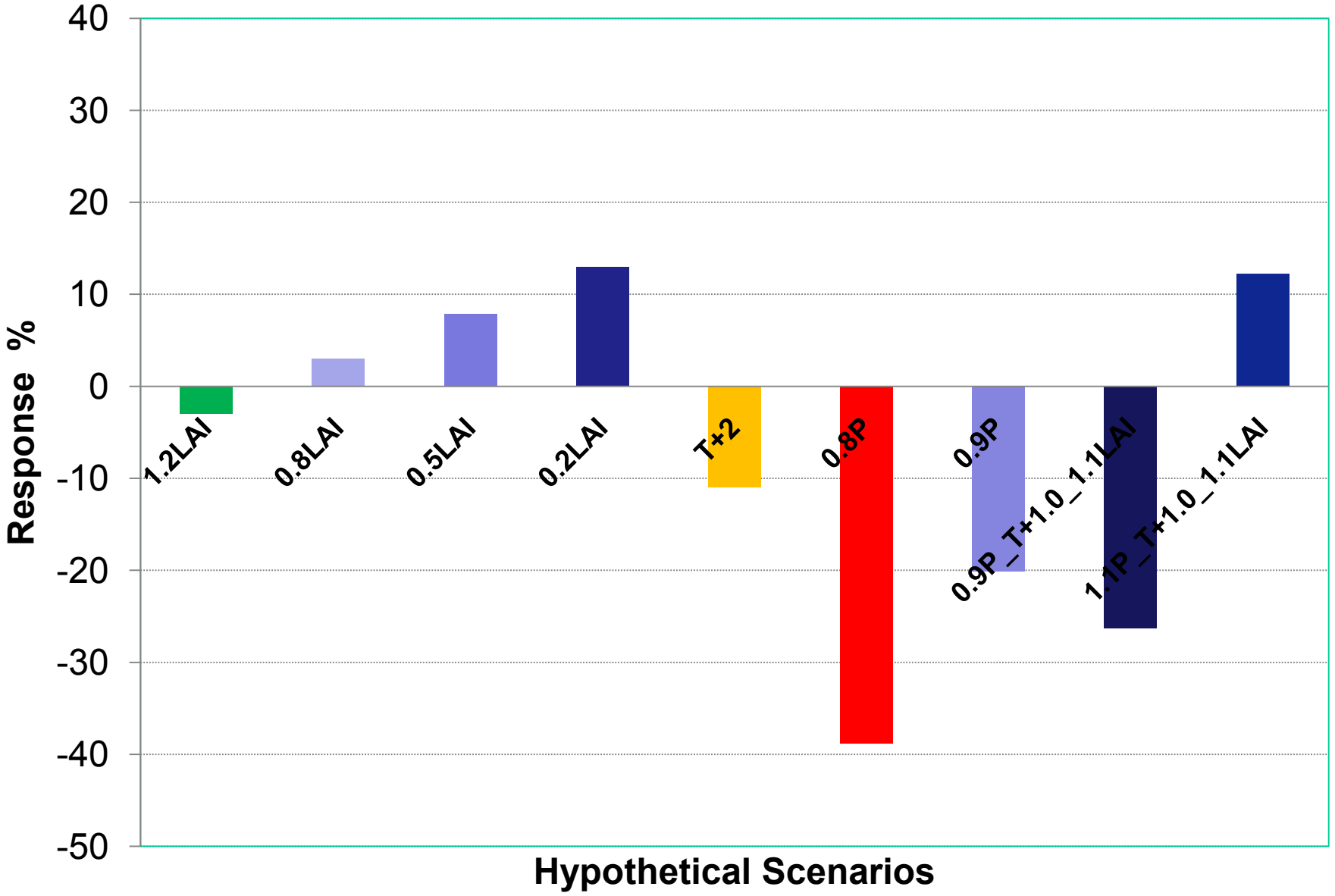
# Net Ecosystem Exchange (NEE)

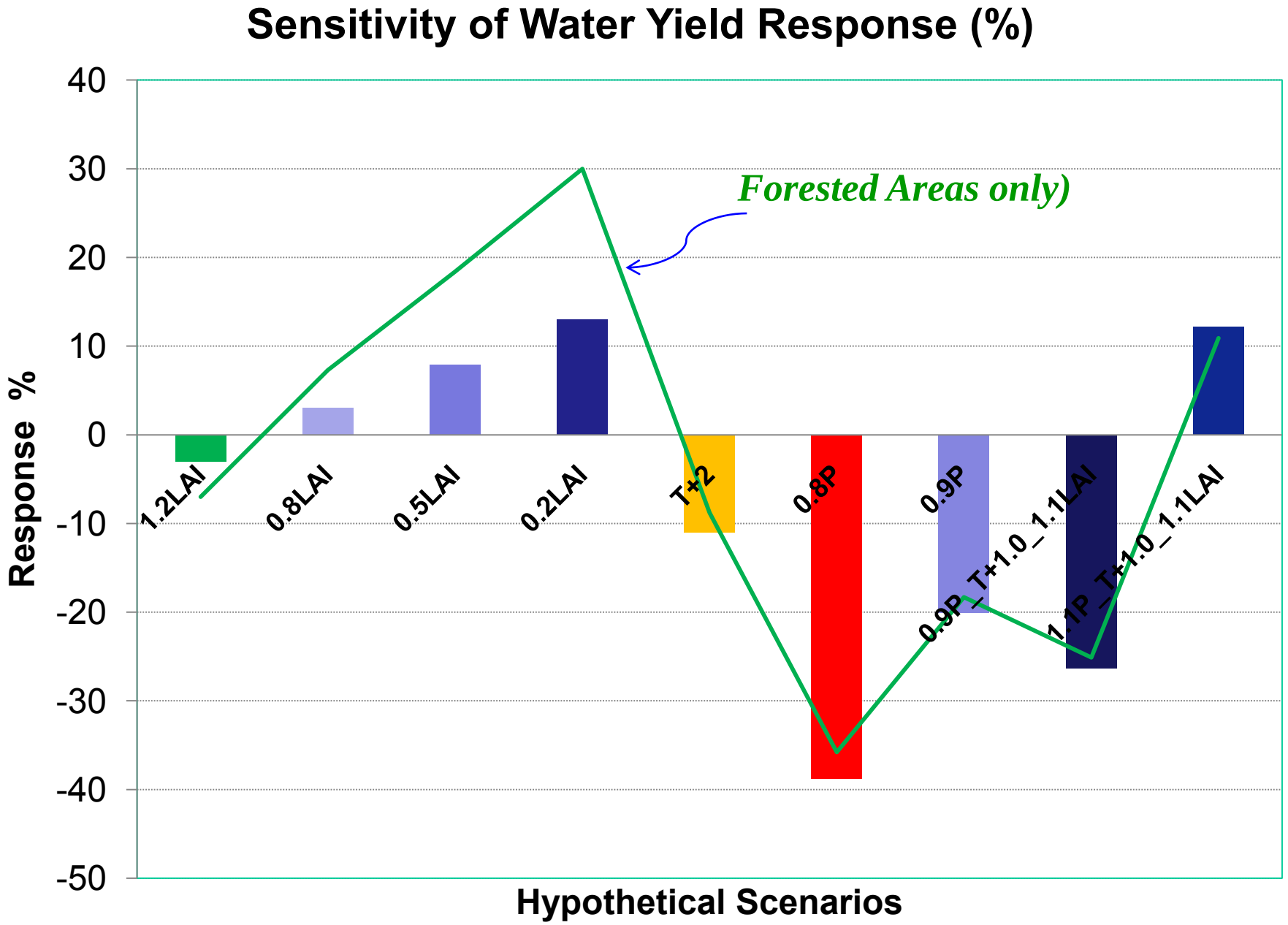


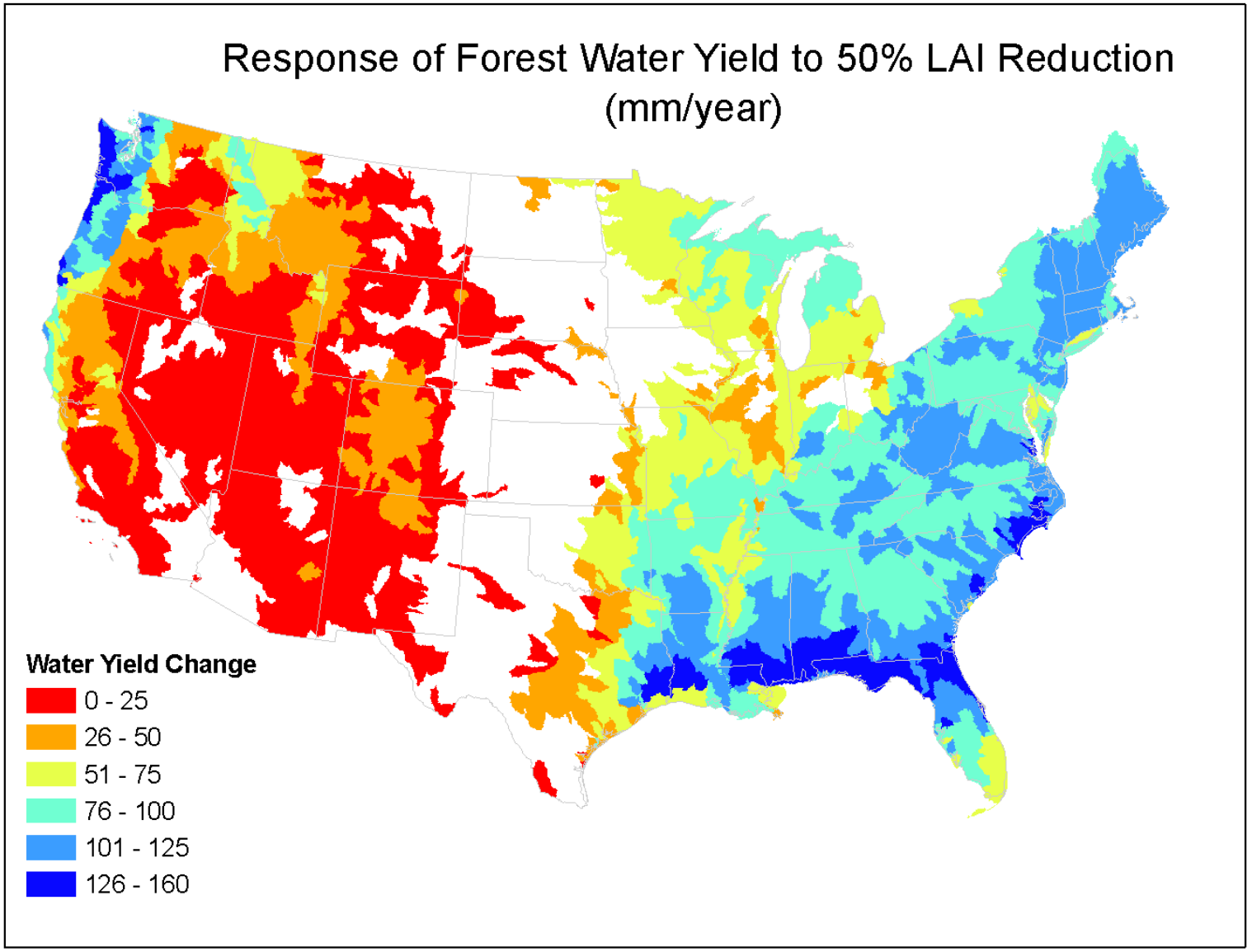

(Sun *et al.*, 2010 JGR in review)


400
300
200
100
0
-100
-200
-300
-400
-500
-600
Q
NEE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Total annual NEE (Tg of Carbon) or Q(Billion cubic meters)
Water Resource Region (WRR)

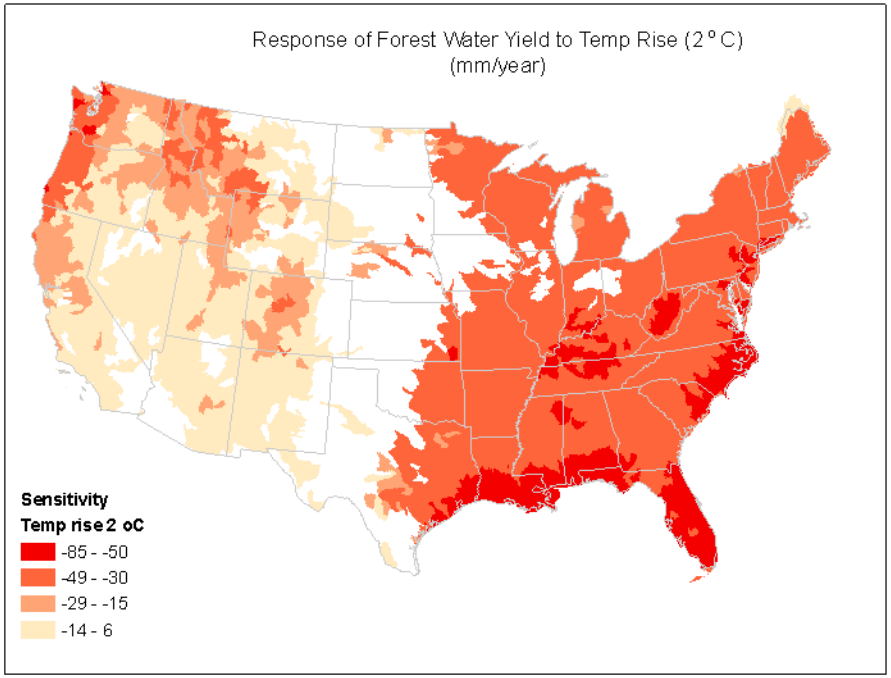
# Sensitivity of Forest Water Yield to Forest Cover or Climate Change

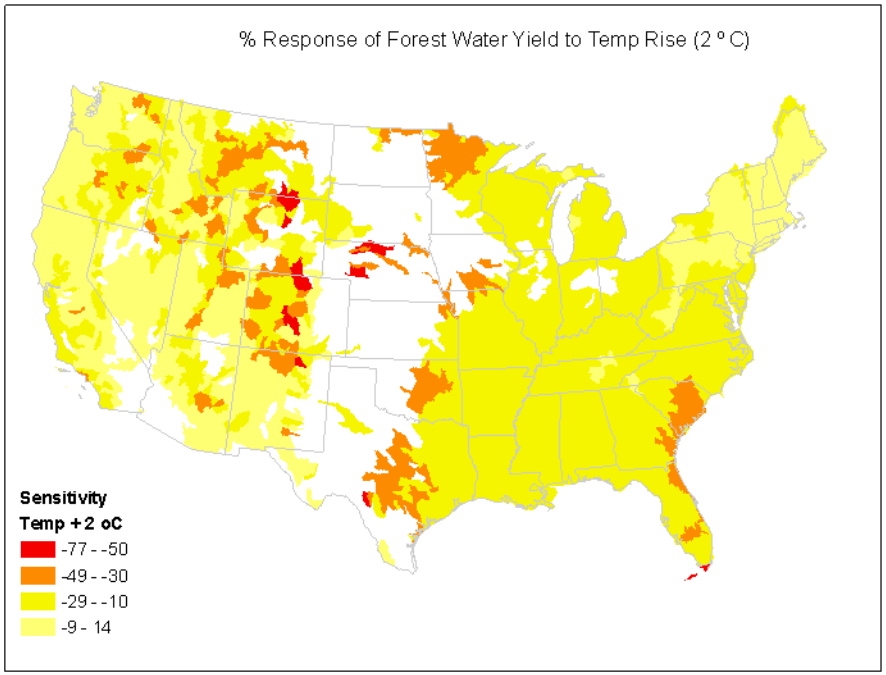

Sensitivity of Water Yield Response (%)
Response %
40
30
20
10
0
-10
-20
-30
-40
-50
1.2LAI
0.8LAI
0.5LAI
0.2LAI
T+2
0.8P
0.9P
0.9P_T+1.0_1.1LAI
1.1P_T+1.0_1.1LAI
Hypothetical Scenarios


Sensitivity of Water Yield Response (%)
Response %
40
30
20
10
0
-10
-20
-30
-40
-50
Forested Areas only)
1.2LAI
0.8LAI
0.5LAI
0.2LAI
T+2
0.8P
0.9P
0.9P_T+1.0_1.1LAI
1.1P_T+1.0_1.1LAI
Hypothetical Scenarios


Response of Forest Water Yield to 50% LAI Reduction
(mm/year)
Water Yield Change
0 - 25
26 - 50
51 - 75
76 - 100
101 - 125
126 - 160

# Temp + 2 ºC

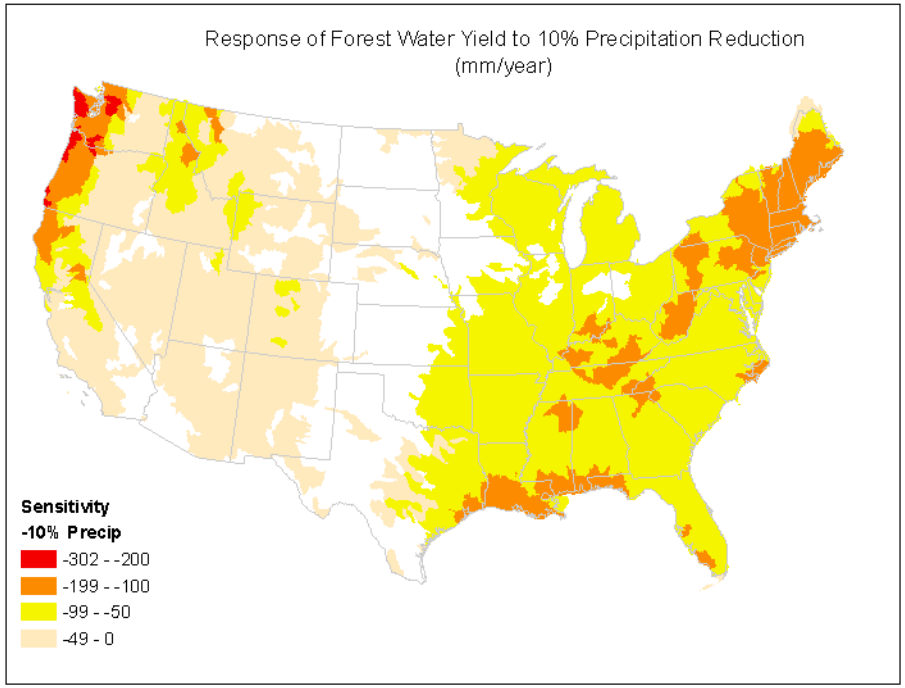


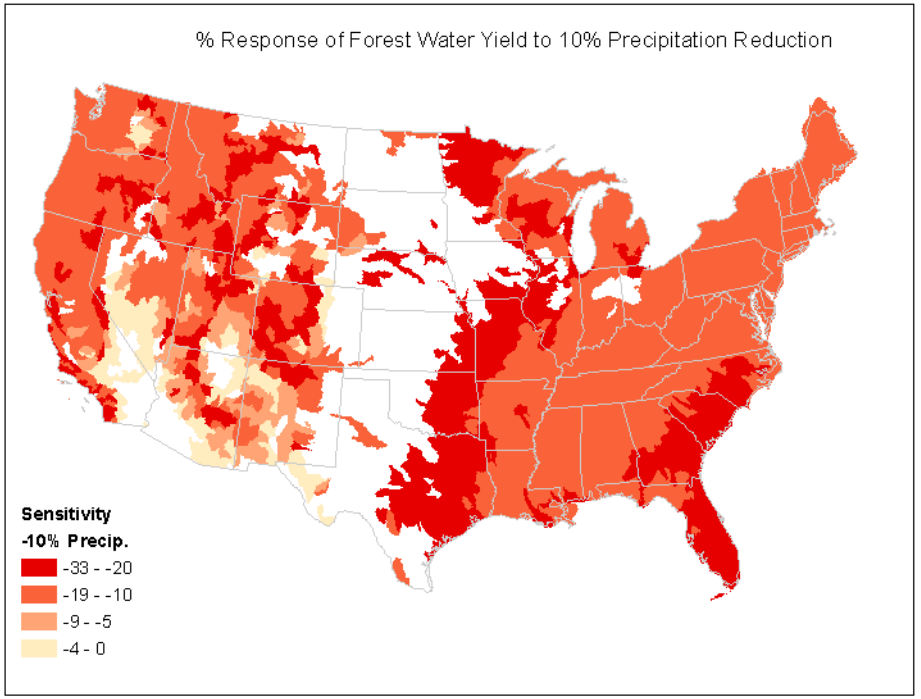




**mm/yr.**

**%**

# Precip -10%




**mm/yr.**

**%**

# Sensitivity of Water Yield to Climate and Reforestation

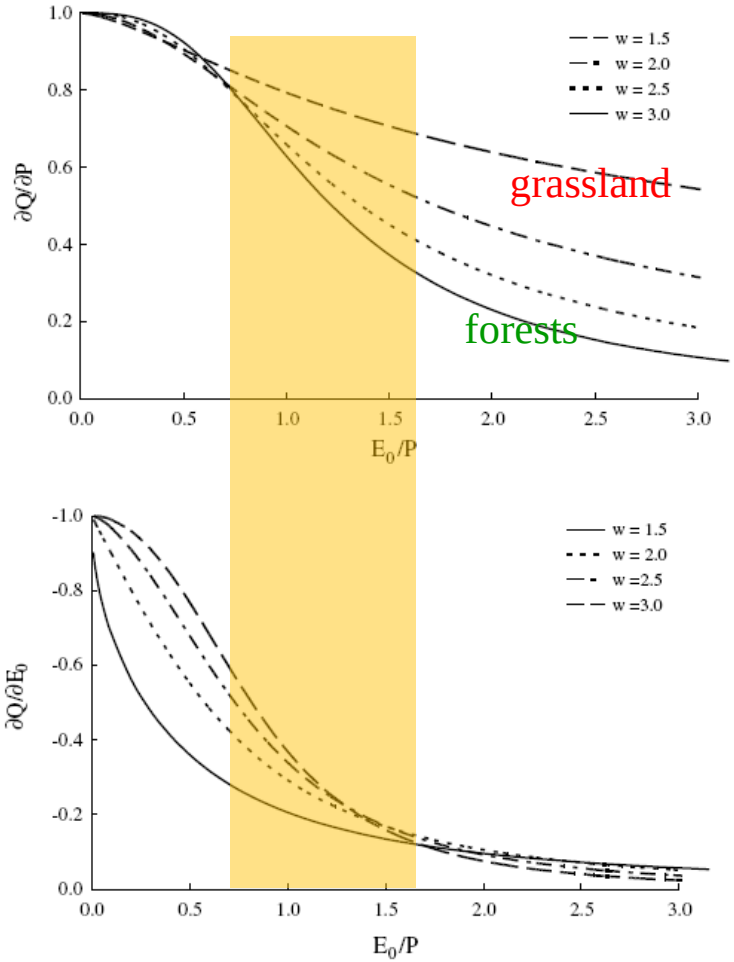



**Figure 6** Runoff sensitivity to precipitation ($\partial Q/\partial P$) and potential evapotranspiration ($\partial Q/\partial E_0$) in different climatic zones as expressed as the index of dryness ($E_0/P$), where the parameter $w$ represents the integrated effects of catchment characteristics such as vegetation cover, soil properties, and catchment topography.

**Precipitation**

**Potential ET (Air Temperature)**

*Ma et al., Journal of Hydrology, 352, 2008*

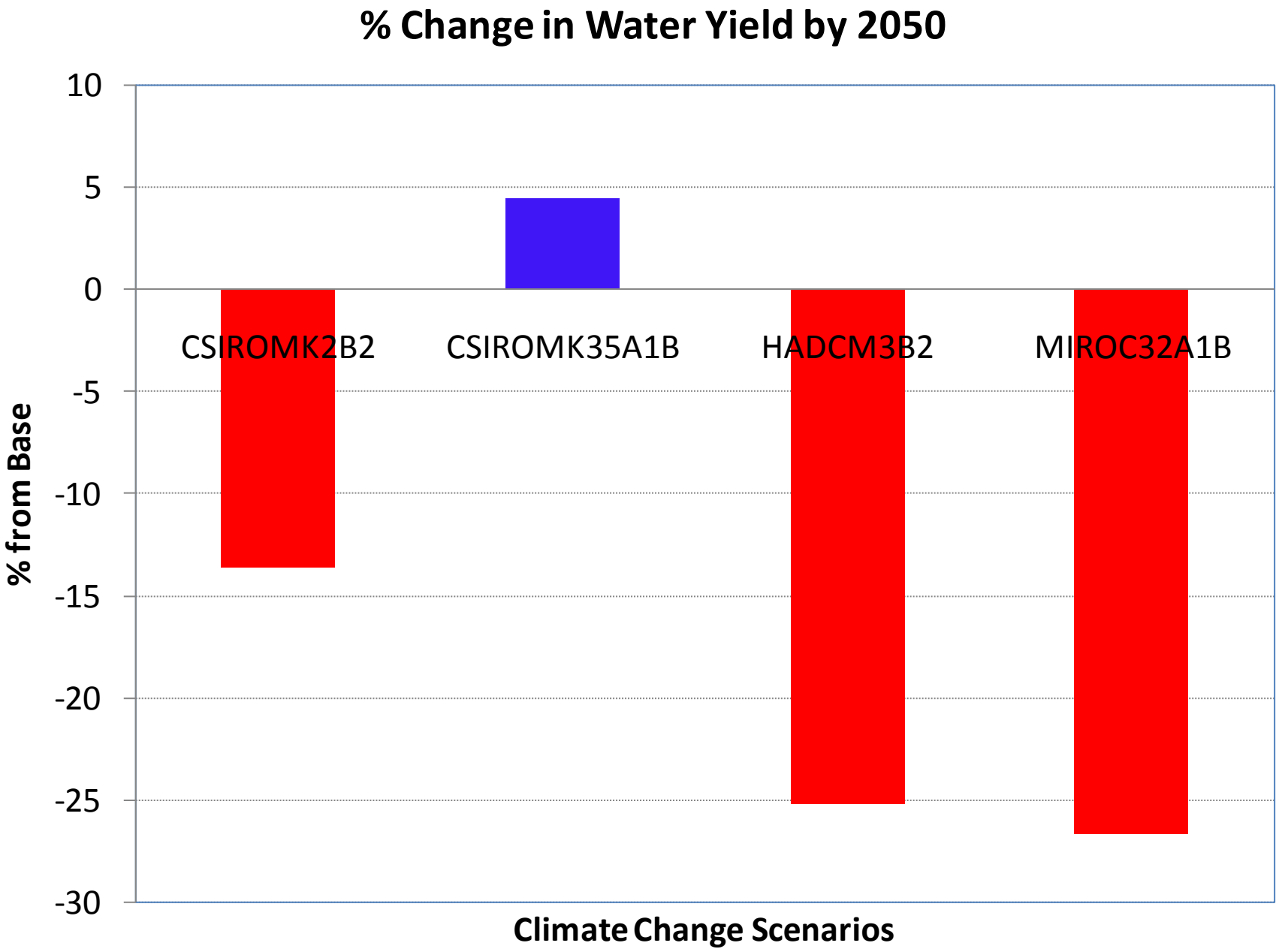
# Impacts of climate change in 2050 under four scenarios:

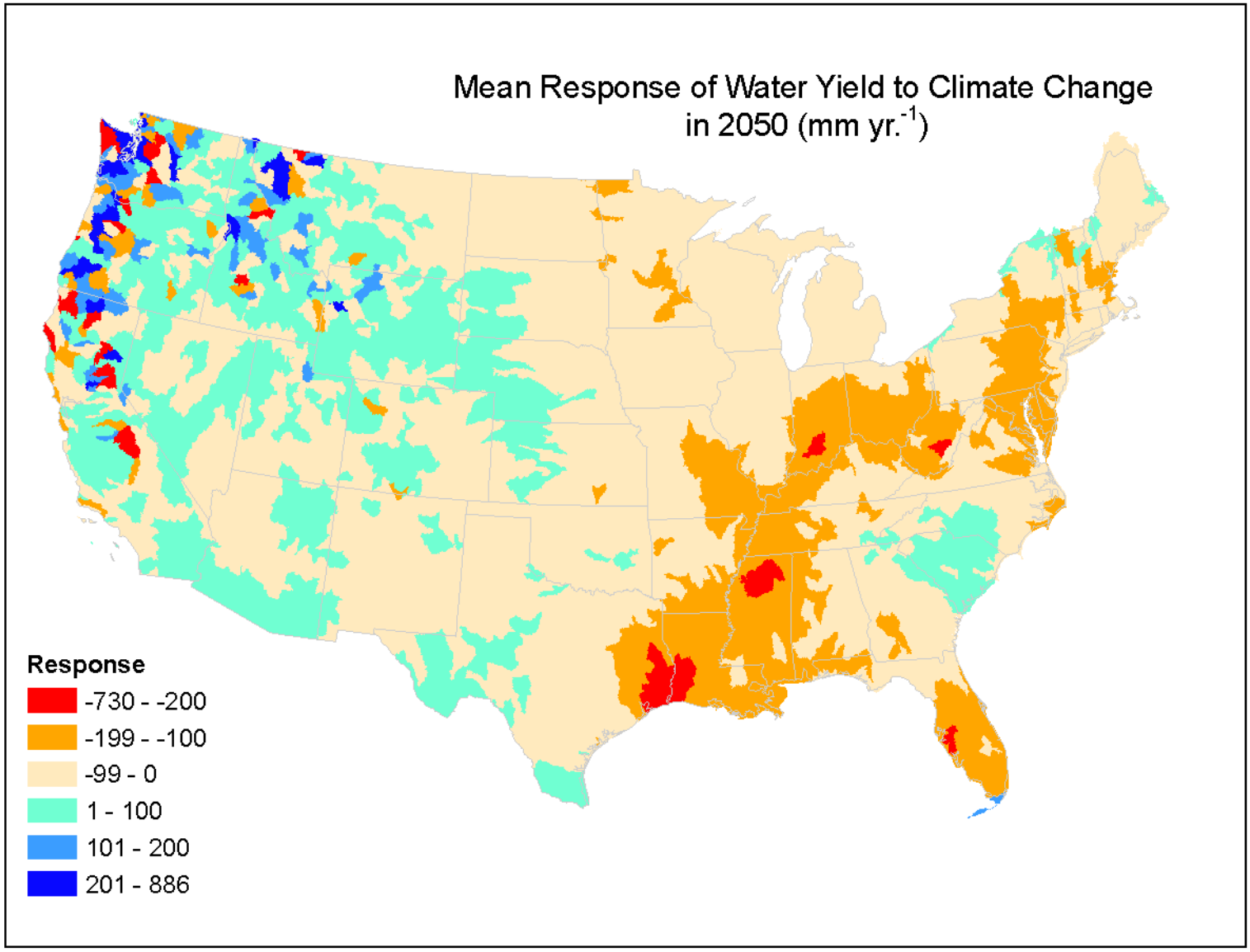
1. CSIROMK2B2, Similar Precip. & Warmer (14% higher PET)

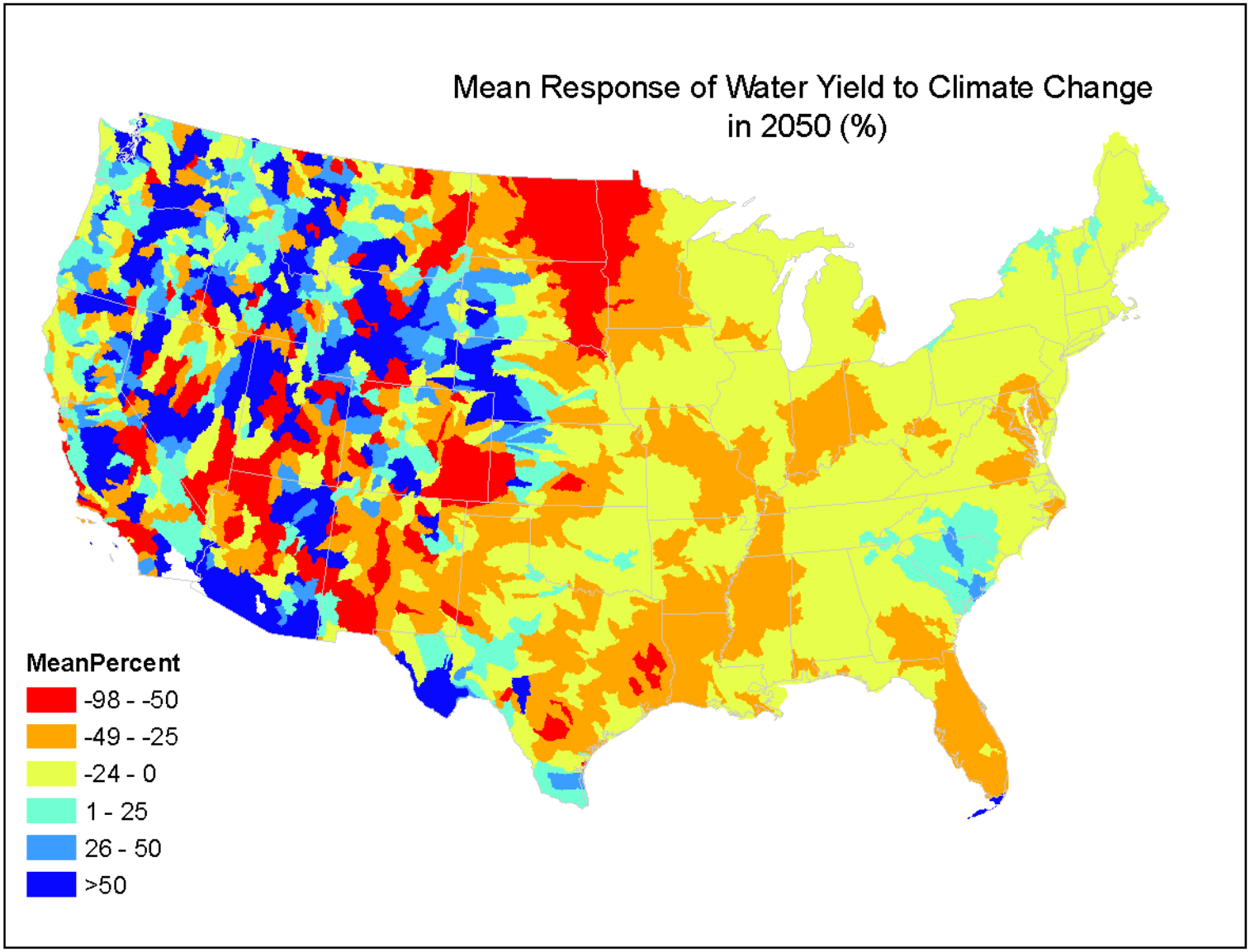
2. CSIROMK35A1B, Wetter (5% higher) & Warmer (11% higher PET)

3. HadCM3B2, Drier (-7%) & Warmer (15% higher PET)

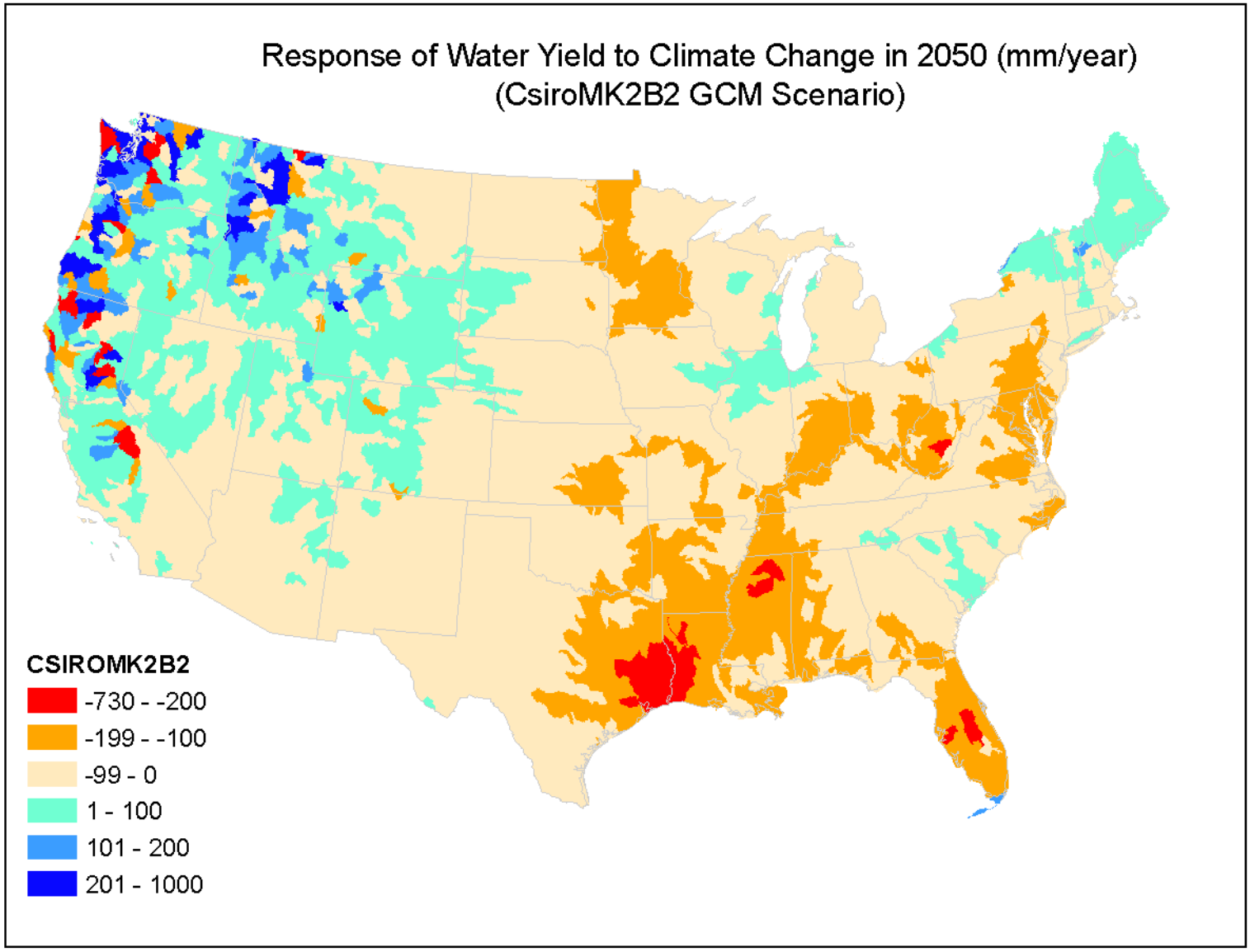
4. MIROC32A1B, Drier (-8%) & Hotter (19% higher PET)


% Change in Water Yield by 2050
10
5
0
-5
-10
-15
-20
-25
-30
% from Base
CSIROMK2B2
CSIROMK35A1B
HADCM3B2
MIROC32A1B
Climate Change Scenarios

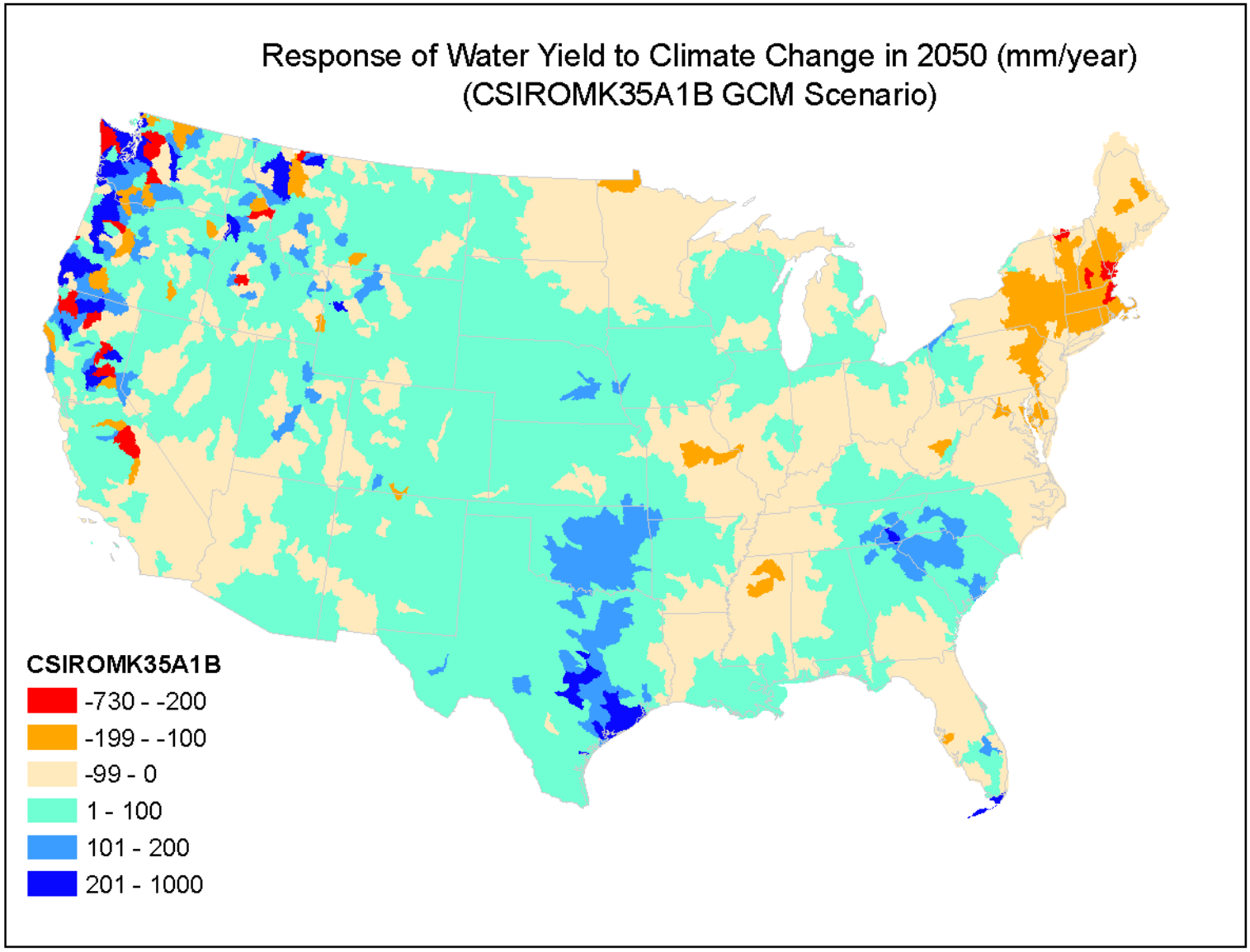

Mean Response of Water Yield to Climate Change in 2050 (mm yr.-1)
Response
-730 - -200
-199 - -100
-99 - 0
1 - 100
101 - 200
201 - 886


Mean Response of Water Yield to Climate Change in 2050 (%)
MeanPercent
-98 - -50
-49 - -25
-24 - 0
1 - 25
26 - 50
>50

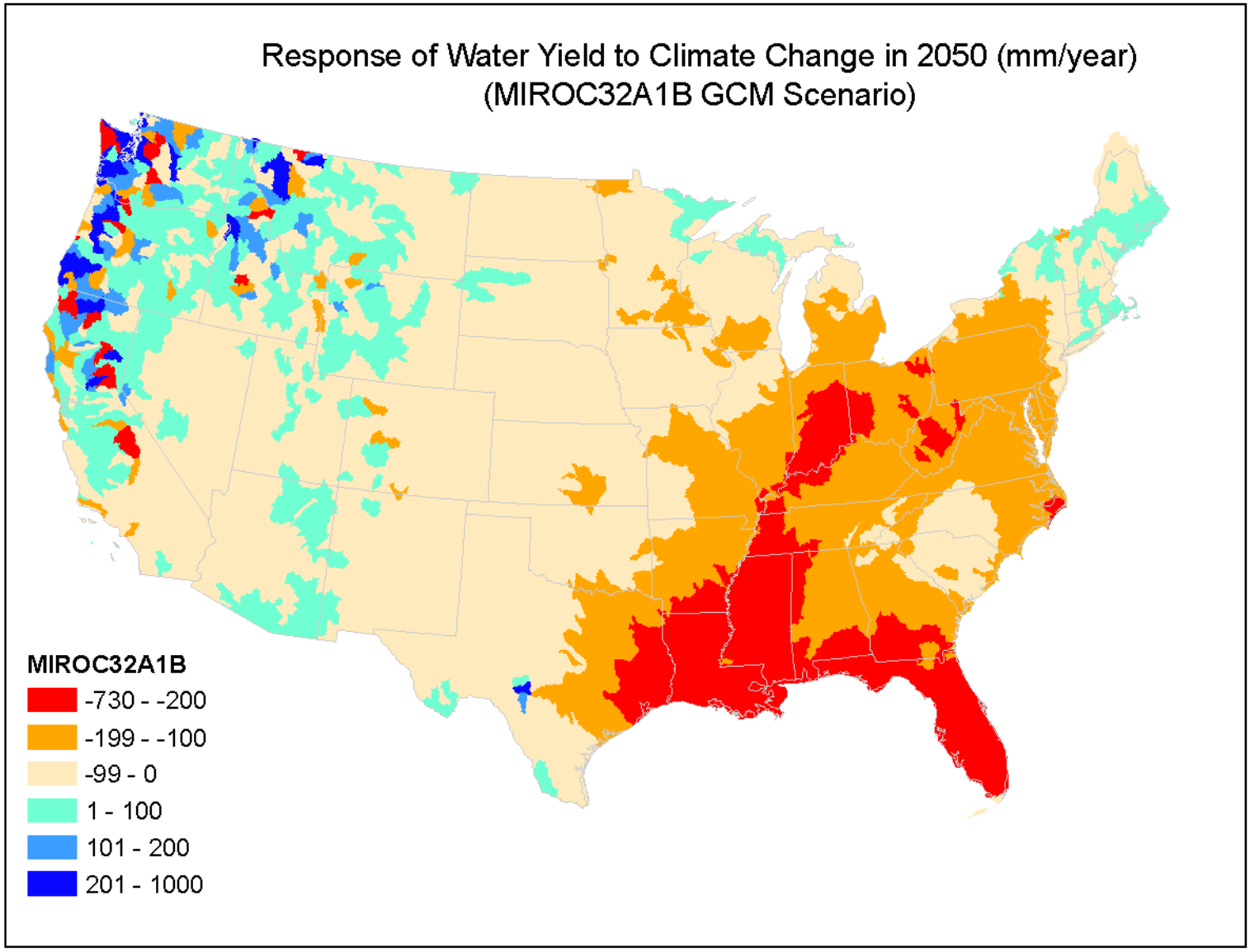
# Similar Precip. & Warmer (14% higher PET)



# Wetter (5% higher) & Warmer (11% higher PET)



# Drier (-8%) & Hotter (19% higher PET)



# Summary

1. 23% of forest lands provides 43% of water yield (2 Trillion $m^3$) in the conterminous United States.

2. Water yield response (% of baseline flow) to forest management is most sensitive in dry areas and SE coastal areas where PET is close to Precip.

3. Water supply can be substantially affected by climate change, especially precipitation patterns, which are difficult to predict.

4. Forest management options for climate change adaptation may have significant impacts on local water supply in some regions (Size and magnitude of vegetation change matter).