Regional Carbon Sequestration and Climate Change:

Its all about Water

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Science Presentation
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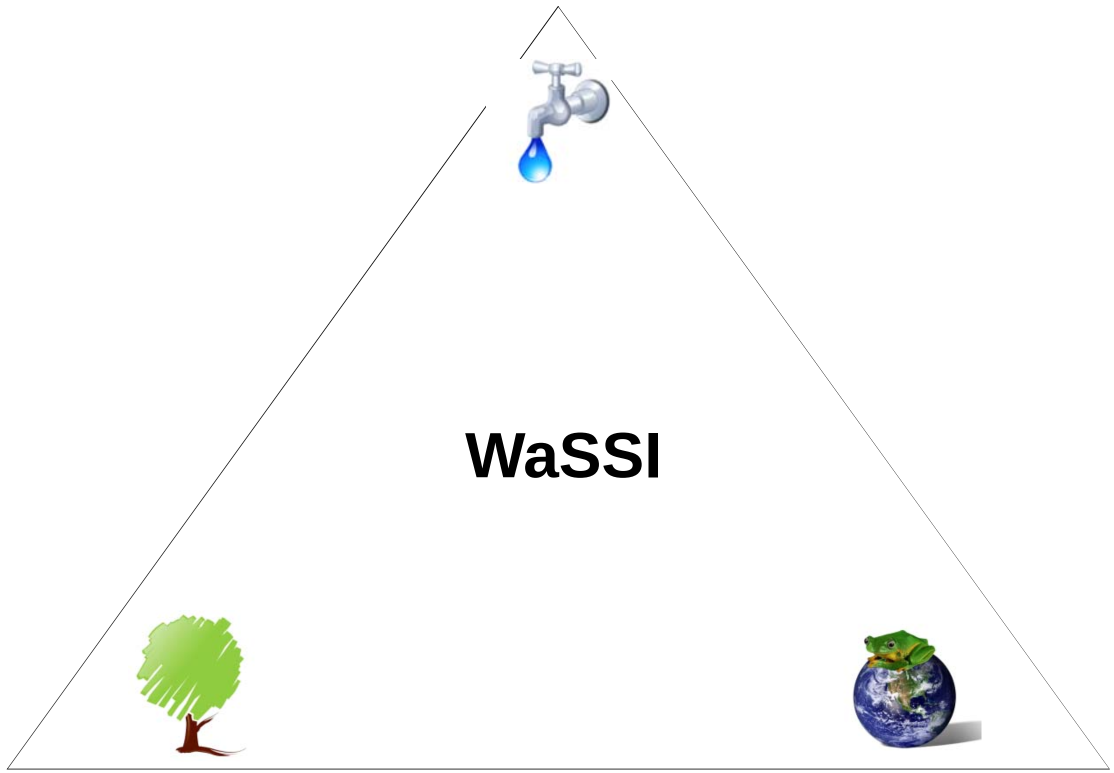
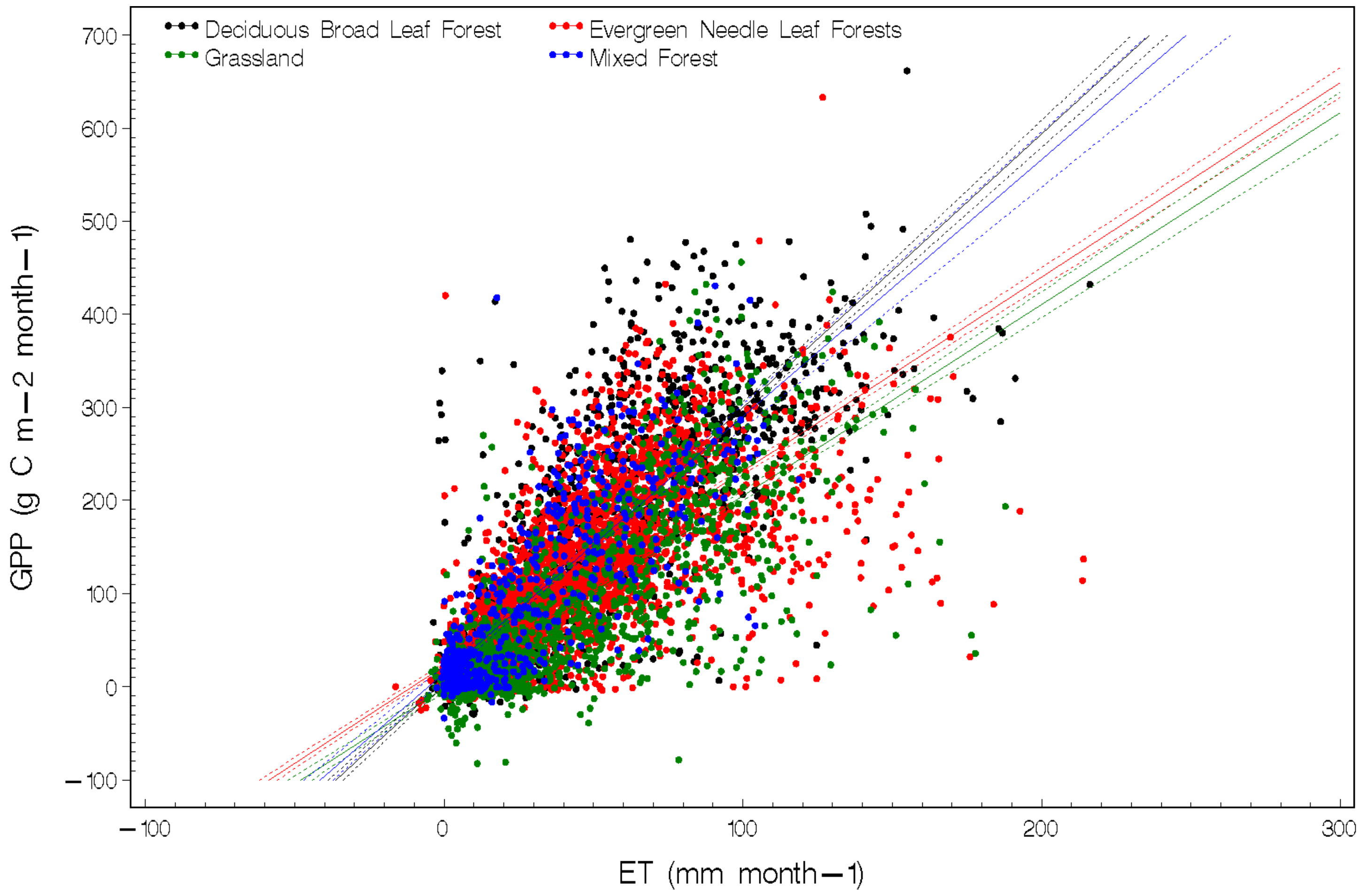
USDA United States Department of Agriculture National Institute of Food and Agriculture

WaSSI Ecosystem Model



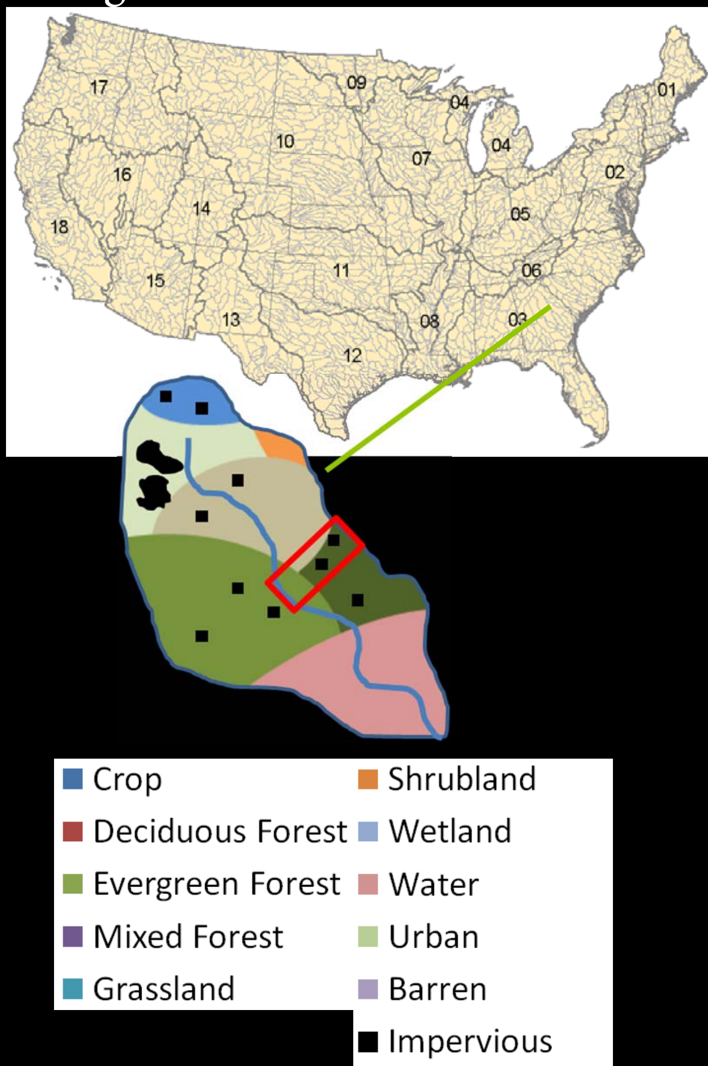
Carbon & Water Relationships



FLUXNET DATA)

Watershed and Land Cover Based

8-digit HUC Watersheds of the U.S.



Water

ET=f(PET, PPT, LAI, SM)

Sun et al., Ecohydrology,2011

Carbon

NEE=f(ET)

Sun et al., JGR, 2011

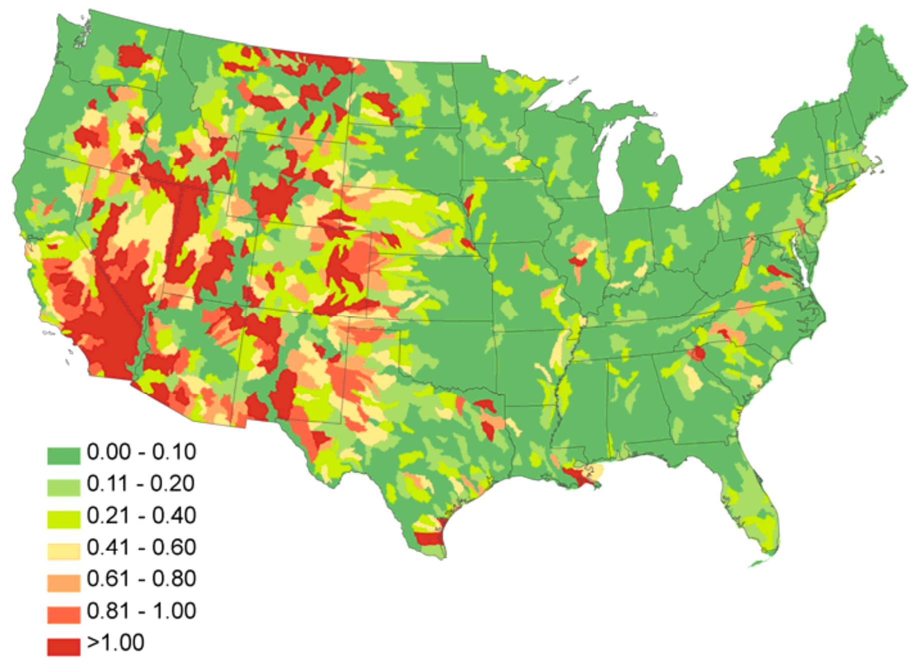
Water Supply Stress Index (WaSSI)

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

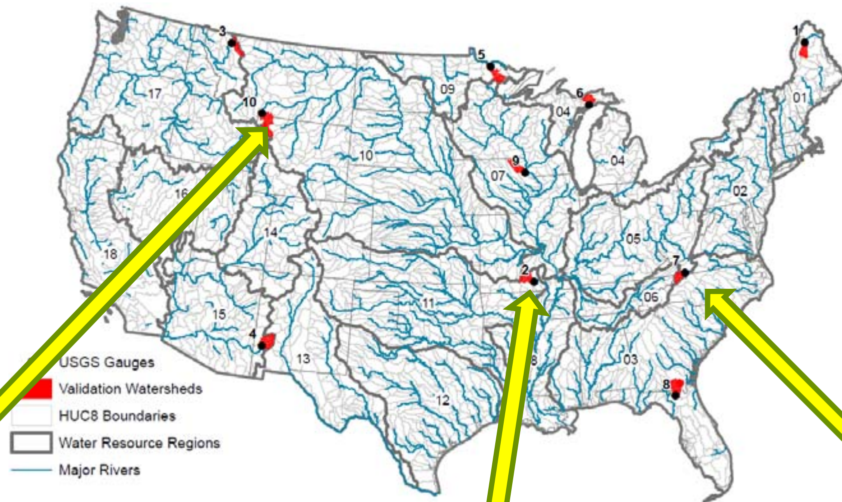
<u>Sectors</u>

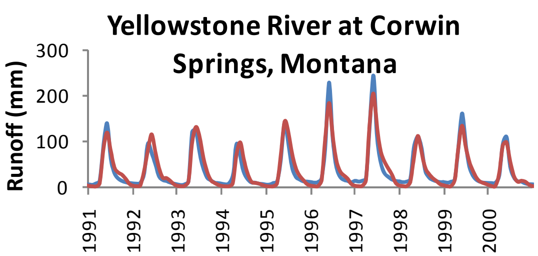
1. Domestic
2. Industrial
3. Irrigation
4. Thermopower
5. Mining
6. Livestock
7. Public Supply
8. Aquaculture

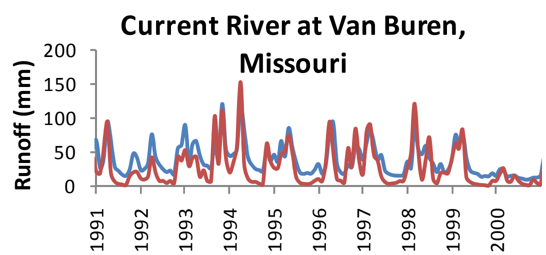
1981-2000 WaSSI

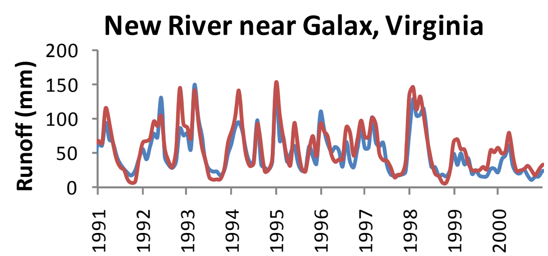


Continental scale validation (~850 km^2)





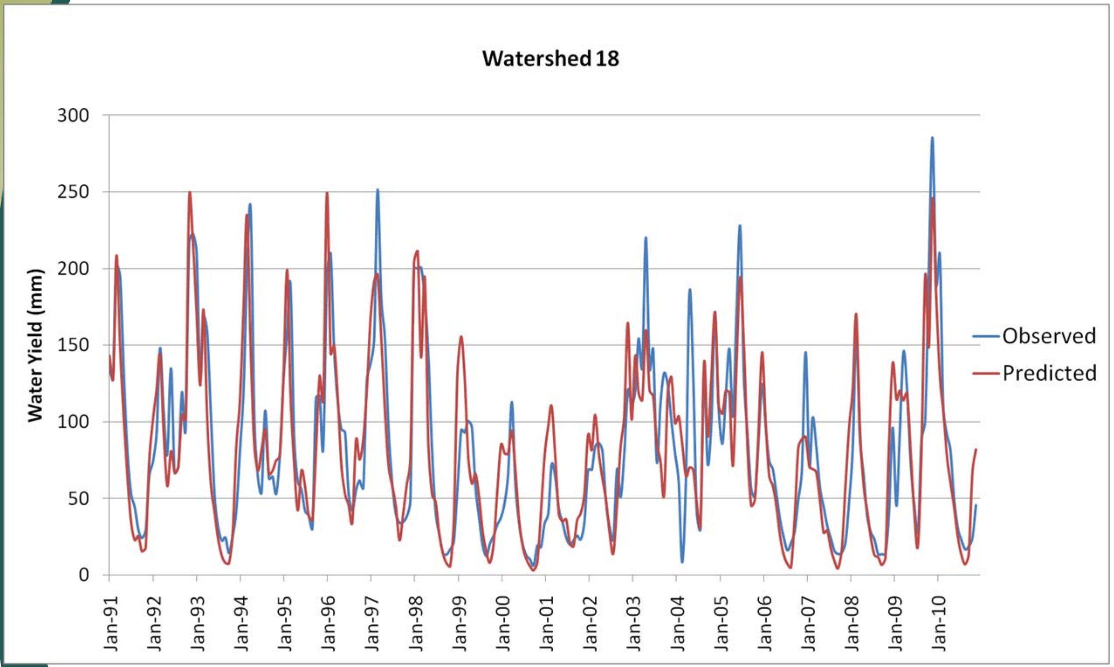


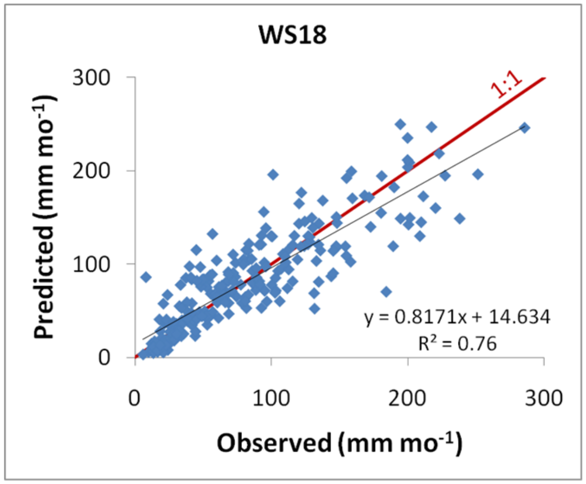


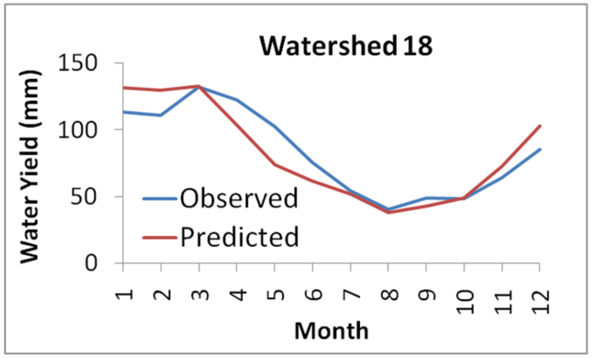
Caldwell et al., HESS, 2012

Fine-scale validation (~0.1 km^2)

Watershed 18, Coweeta, NC







Mean Annual Bias: -6.6 mm (-0.7%)

Monthly NSE: 0.75

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, G00J05, doi:10.1029/2010JG001573, 2011

Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model

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[1] We developed a water-centric monthly scale simulation model (WaSSI-C) by integrating empirical water and carbon flux measurements from the FLUXNET network and an existing water supply and demand accounting model (WaSSI). The WaSSI-C model was evaluated with basin-scale evapotranspiration (ET), gross ecosystem productivity (GEP), and net ecosystem exchange (NEE) estimates by multiple independent methods across 2103 eight-digit Hydrologic Unit Code watersheds in the conterminous United States from 2001 to 2006. Our results indicate that WaSSI-C captured the spatial and temporal variability and the effects of large droughts on key ecosystem fluxes. Our modeled mean (±standard deviation in space) ET (556 ± 228 mm yr^{-1}) compared well to Moderate Resolution Imaging Spectroradiometer (MODIS) based (527 ± 251 mm yr^{-1}) and watershed water balance based ET (571 ± 242 mm yr^{-1}). Our mean annual GEP estimates (1362 ± 688 g C m^{-2} yr^{-1}) compared well ($R^2 = 0.83$) to estimates (1194 ± 649 g C m^{-2} yr^{-1}) by eddy flux-based EC-MOD model, but both methods led significantly higher (25–30%) values than the standard MODIS product (904 ± 467 g C m^{-2} yr^{-1}). Among the 18 water resource regions, the southeast ranked the highest in terms of its water yield and carbon sequestration capacity. When all ecosystems were considered, the mean NEE (−353 ± 298 g C m^{-2} yr^{-1}) predicted by this study was 60% higher than EC-MOD's estimate (−220 ± 225 g C m^{-2} yr^{-1}) in absolute magnitude, suggesting overall high uncertainty in quantifying NEE at a large scale. Our water-centric model offers a new tool for examining the trade-offs between regional water and carbon resources under a changing environment.

Citation: Sun, G., et al. (2011), Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model, *J. Geophys. Res.*, *116*, G00J05, doi:10.1029/2010JG001573.

1. Introduction

[2] Evapotranspiration (ET), water yield, gross ecosystem productivity (GEP), net primary productivity (NPP), ecosystem respiration (Re), and net ecosystem exchange (NEE) (i.e., NEE = -NEP, where NEP is net ecosystem productivity) are the key ecosystem functions [*Xiao et al.*, 2008, 2010; *Beer et al.*, 2010; *Jung et al.*, 2010; *Tian et al.*, 2010; *Xiao et al.*, 2010] that directly affect many ecosystem services, including providing stable and high quality water, moderating climate, sequestering atmospheric carbon dioxide, and protecting biodiversity. Understanding the tightly coupled water and carbon cycles is critical to evaluating regional and global biogeochemical cycles under a changing climate [*Law et al.*, 2002; *Nemani et al.*, 2003; *Beer et al.*, 2007, 2010]. Quantifying water and carbon balances at regional and continental scales is essential for land managers and policy makers to develop sound mitigation and adaptation strategies in response to global change.

[3] Although it is well known in ecology that water is a major control to plant growth and productivity [*Chapin et al.*, 2004; *Noormets et al.*, 2008; *Domec et al.*, 2009], water and carbon have long been treated as two separated entities. Many existing ecosystem models have some forms of coupling between carbon and water, mostly related to the effects of soil moisture on photosynthesis process. However, these models have rarely been validated with both carbon and water flux measurements [*Hanson et al.*, 2004; *Noormets et al.*, 2006; *Domec et al.*, 2010; *Tian et al.*, 2010]. Similarly, the hydrologic community has long ignored the feedbacks

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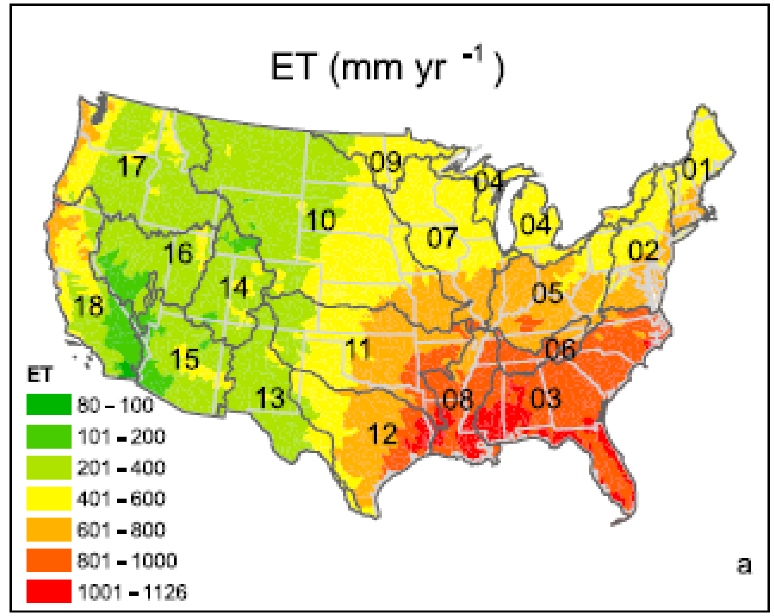
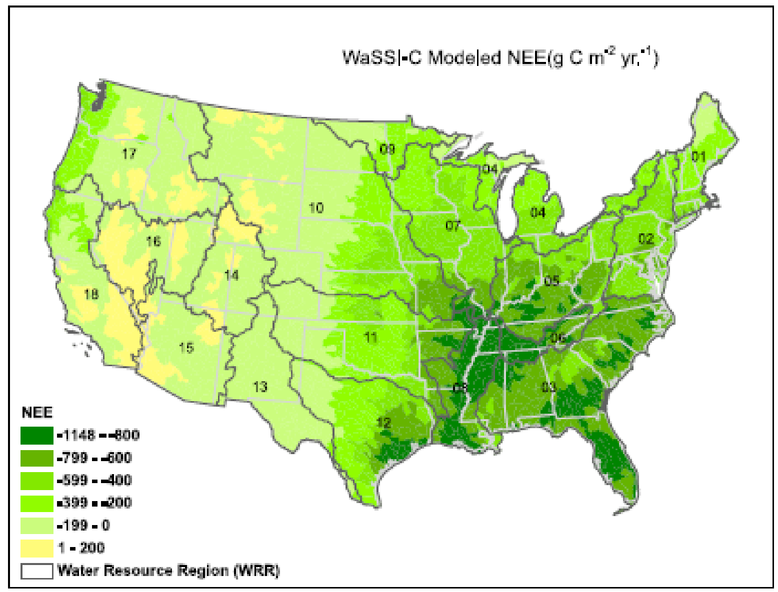
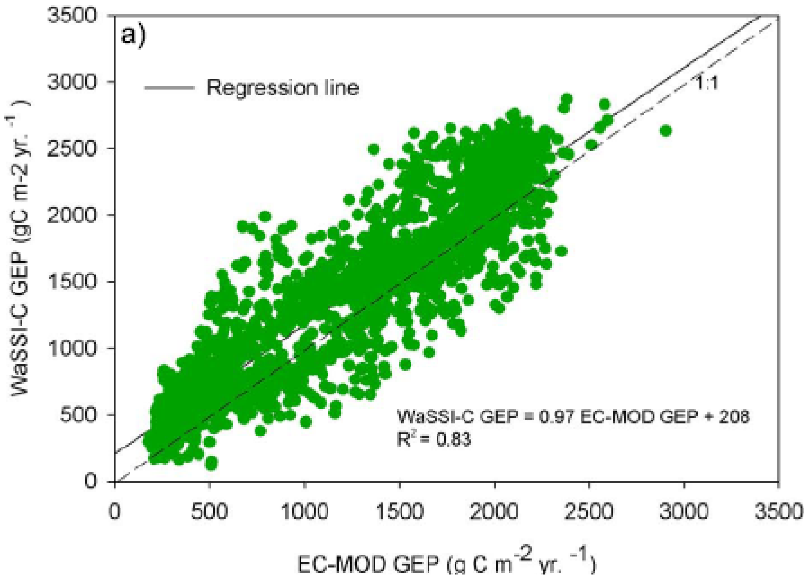
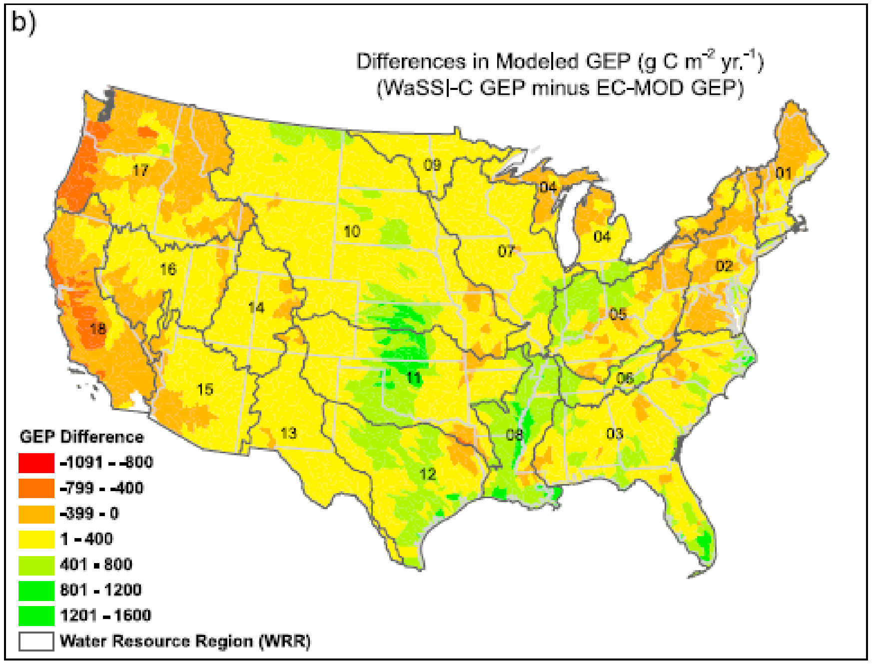




Carbon Validation





Sun et al., JGR,2011

Oh Goody! A New Research Tool!

Given that WaSSI appears to be reproducing reality fairly well, what can we do with the model?

WaSSI Research Questions

How will changes in air temperature impact southeastern US ecosystem water use, forest growth and carbon sequestration?

How will changes in precipitation impact southeastern
US ecosystem water use, forest growth and carbon sequestration?

How will air temperature and precipitation interact to impact southeastern US ecosystem water use, forest growth and carbon sequestration?

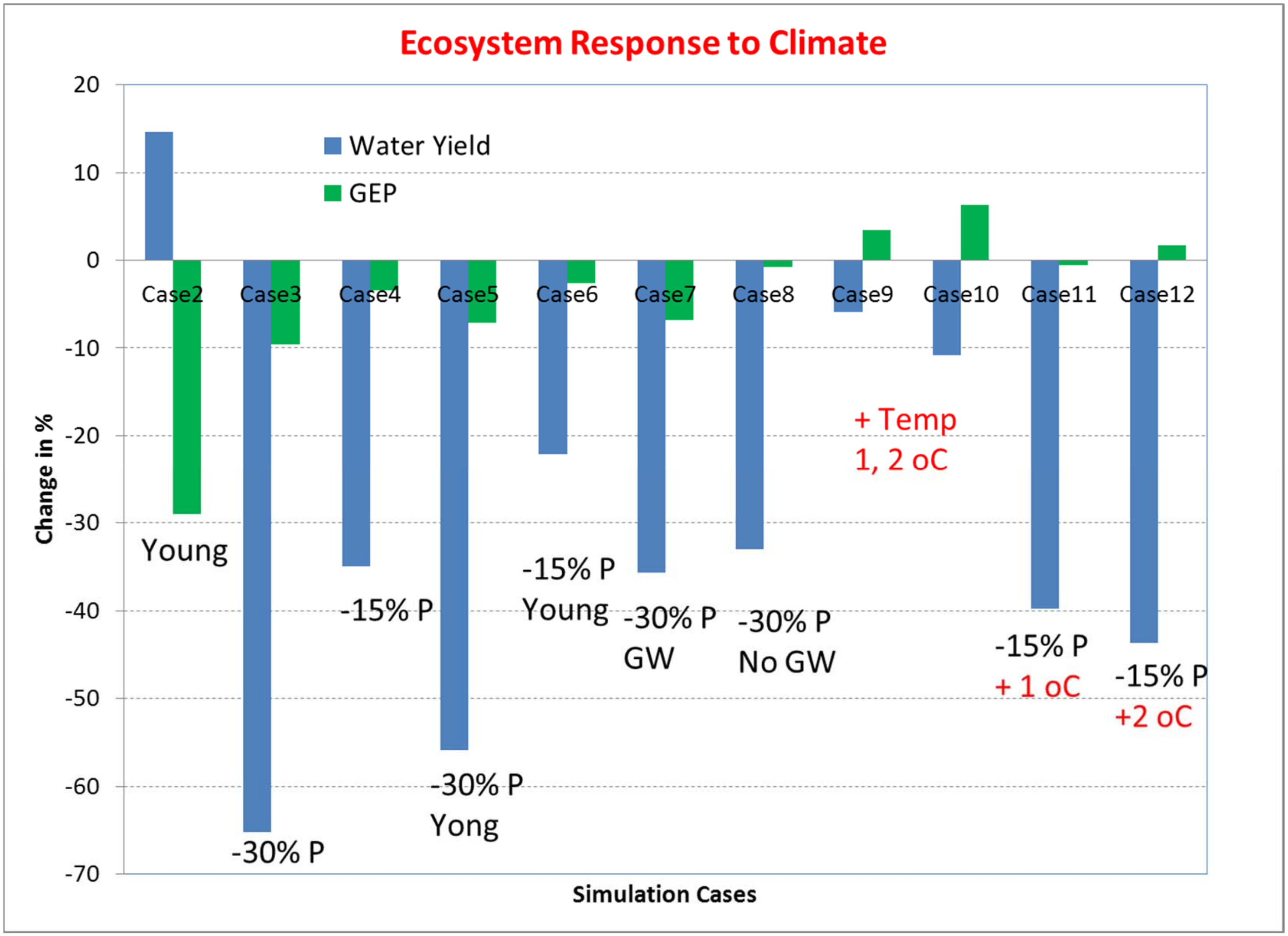
WaSSI Research Questions (cont.)

- How will forest age impact southeastern US ecosystem water use, forest growth and carbon sequestration?

- How will all of these factors change over space and time?

Scenarios

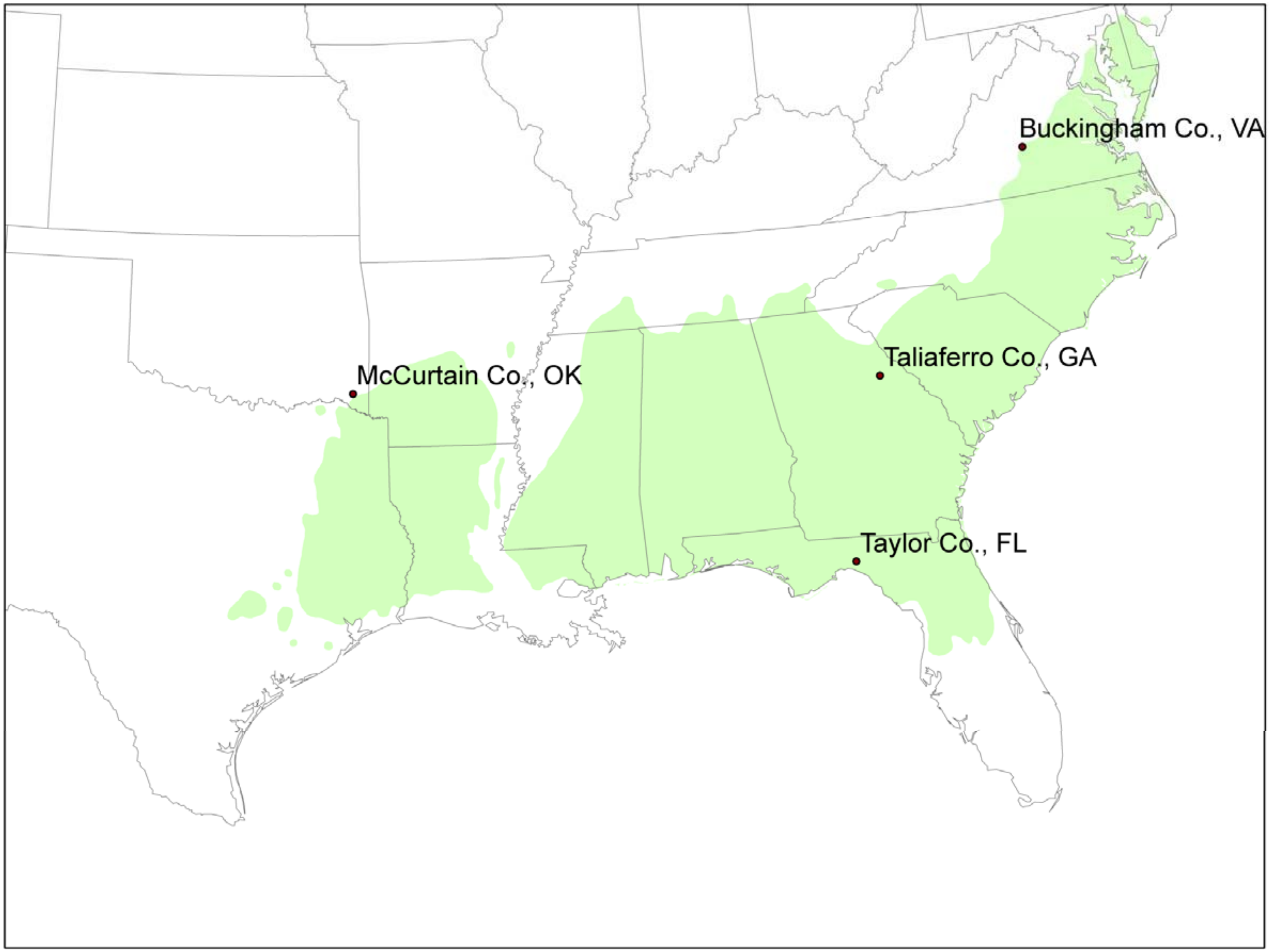
Scenario	Description
1	17 YO Loblolly Pine
2	7 YO Loblolly Pine
3	17 YO Loblolly, 30% PPT reduction all months
4	17 YO Loblolly, 15% PPT reduction all months
5	7 YO Loblolly, 30% PPT reduction all months
6	7 YO Loblolly, 15% PPT reduction all months
7	17 YO Loblolly, 30% PPT reduction growing season (months 4-10)
8	17 YO Loblolly, 30% PPT reduction dormant season (months 11-3)
9	17 YO Loblolly, 1 degree TEMP increase all months
10	17 YO Loblolly, 2 degree TEMP increase all months
11	17 YO Loblolly, 15% PPT reduction, 1 degree TEMP increase all months
12	17 YO Loblolly, 15% PPT reduction, 2 degree TEMP increase all months



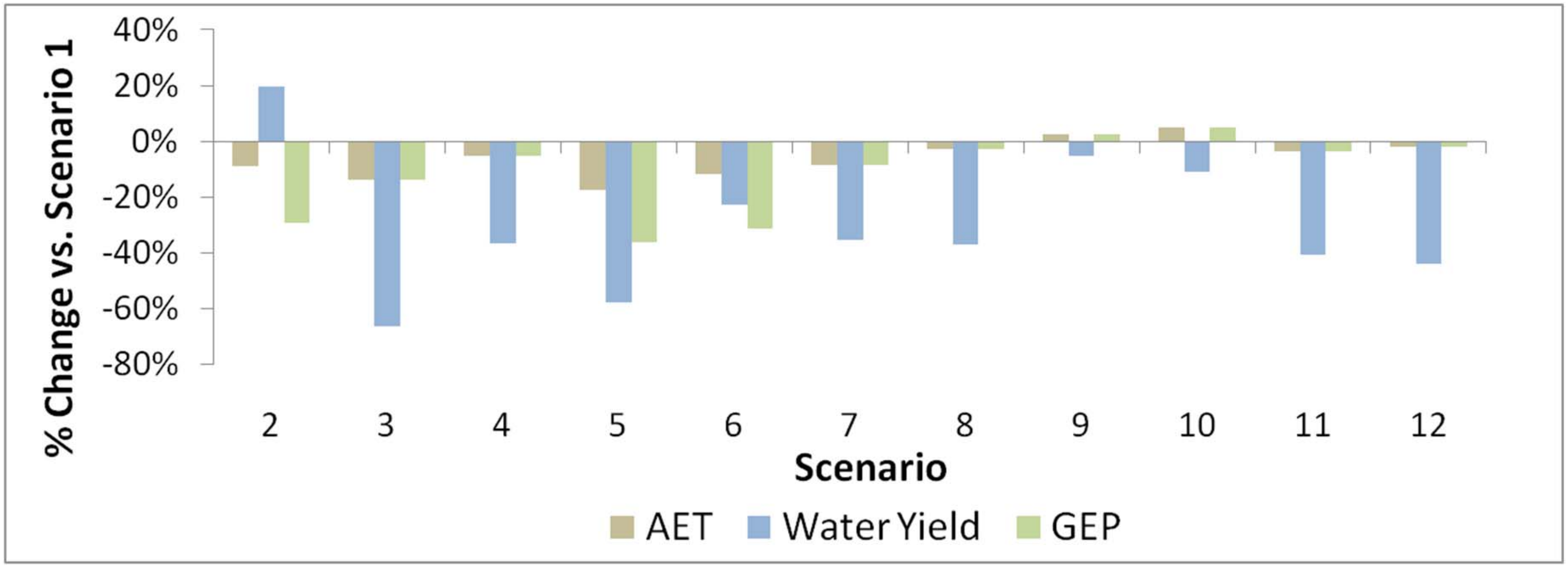
Ecosystem Response to Climate
Water Yield
GEP
20
10
0
-10
-20
-30
-40
-50
-60
-70
Change in %
Case2
Case3
Case4
Case5
Case6
Case7
Case8
Case9
Case10
Case11
Case12
Simulation Cases
Young
-30% P
-15% P
-30% P
Yong
-15% P
Young
-30% P
GW
-30% P
No GW
+ Temp
1, 2 oC
-15% P
+ 1 oC
-15% P
+2 oC

PINEMAP Tier III Sites

-



Tier III Site: Taliaferro Co., GA



Baseline 17 yr. Loblolly Pine

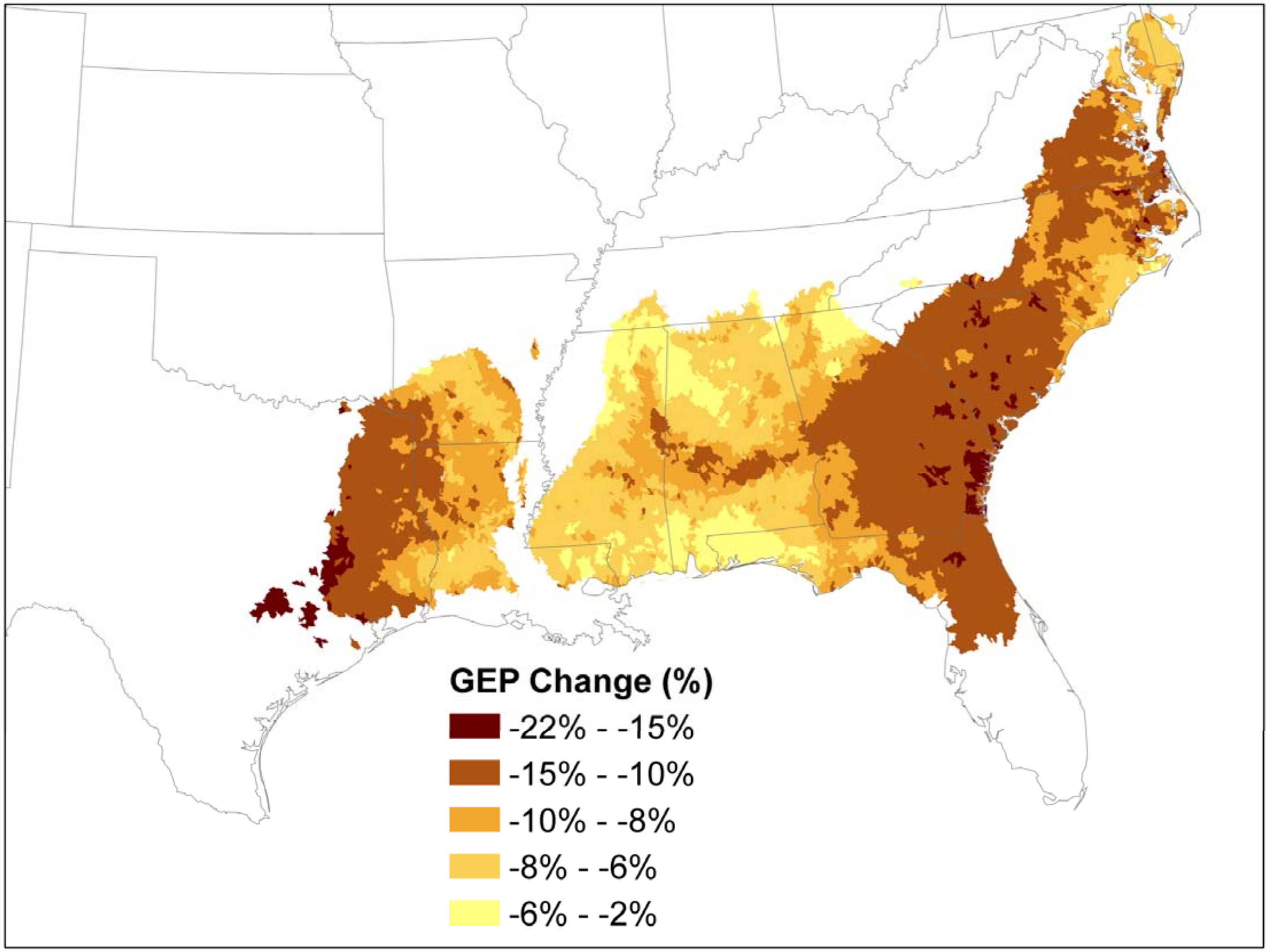
PPT = 1149 mm/yr
AET = 792 mm/yr
Water Yield = 355 mm/yr
GEP = 2012 gC/m2/yr

Scenario	Description
1	17 YO Loblolly Pine
2	7 YO Loblolly Pine
3	17 YO Loblolly, 30% PPT reduction all months
4	17 YO Loblolly, 15% PPT reduction all months
5	7 YO Loblolly, 30% PPT reduction all months
6	7 YO Loblolly, 15% PPT reduction all months
7	17 YO Loblolly, 30% PPT reduction growing season (months 4-10)
8	17 YO Loblolly, 30% PPT reduction dormant season (months 11-3)
9	17 YO Loblolly, 1 degree TEMP increase all months
10	17 YO Loblolly, 2 degree TEMP increase all months
11	17 YO Loblolly, 15% PPT reduction, 1 degree TEMP increase all months
12	17 YO Loblolly, 15% PPT reduction, 2 degree TEMP increase all months

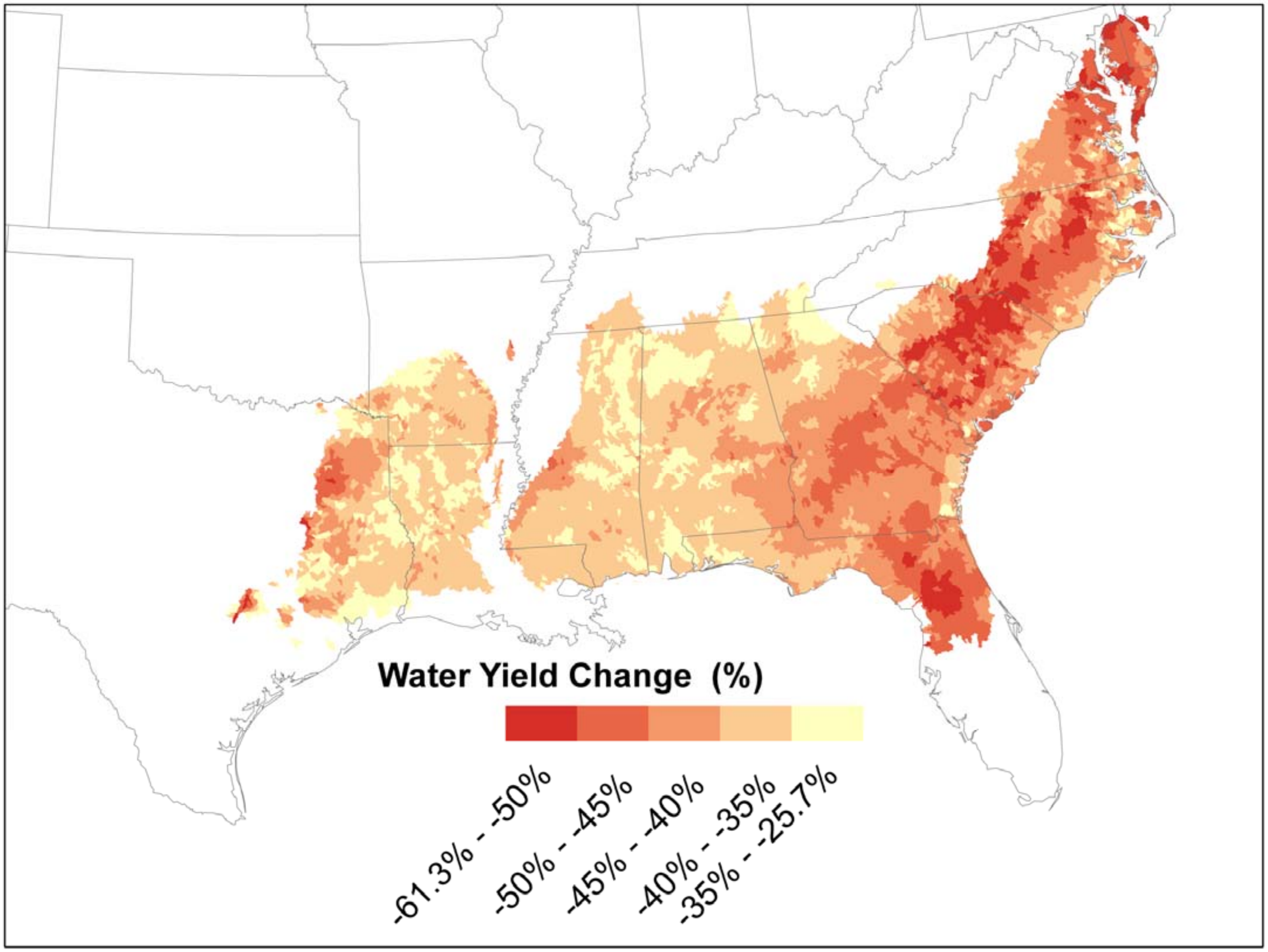
-30% Precipitation Reduction

	VA site	FL site	GA site	OK site
PPT change (%)	-30%	-30%	-30%	-30%
AET change (%)	-12%	-10%	-14%	-10%
Water Yield change (%)	-63%	-65%	-66%	-65%
GEP change (%)	-12%	-10%	-14%	-10%

-30% Precipitation Reduction



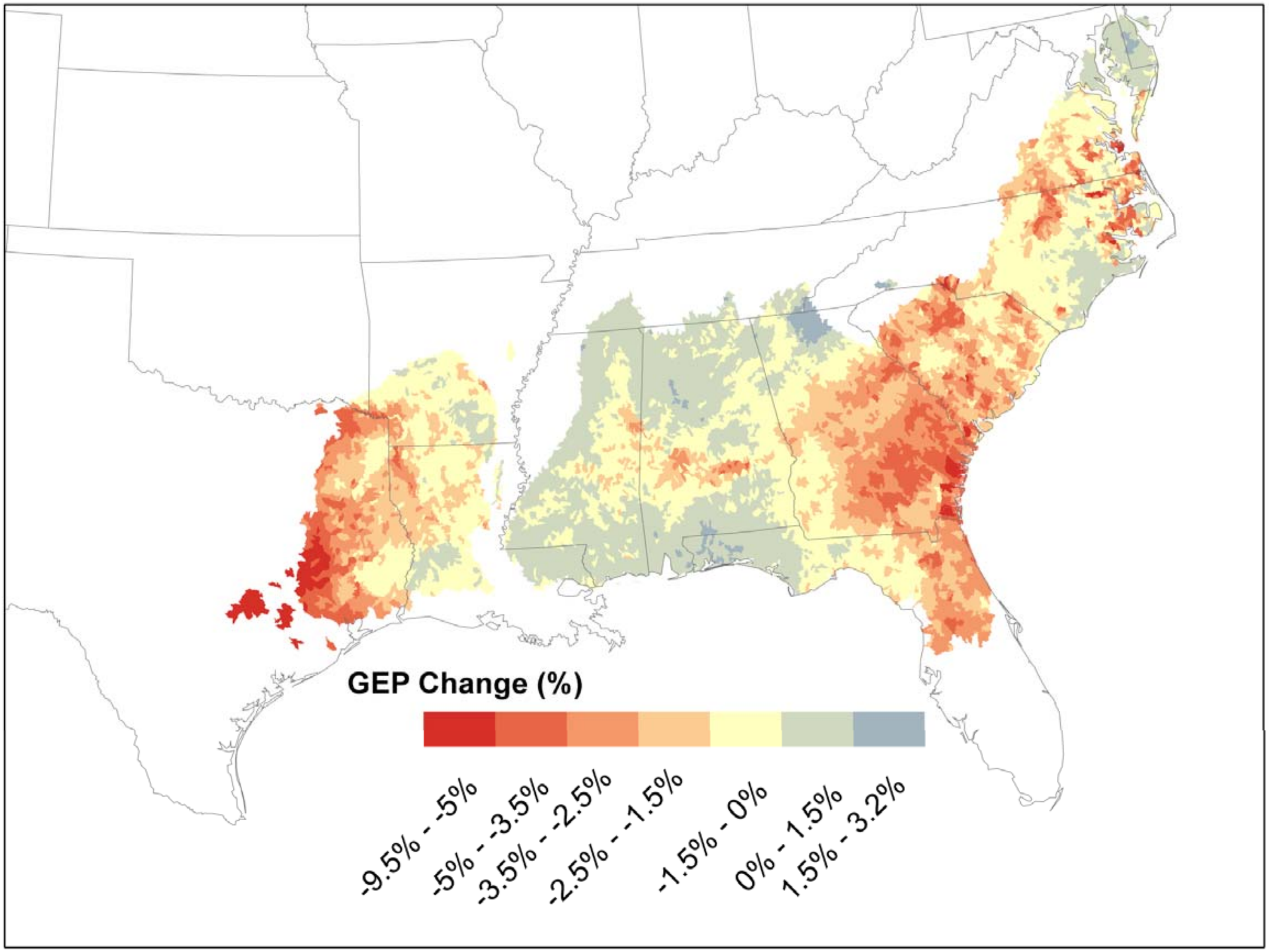
-30% Precipitation Reduction



-15% Precipitation + 1 Degree C

	VA site	FL site	GA site	OK site
PPT change (%)	-15%	-15%	-15%	-15%
AET change (%)	-3%	-1%	-3%	0%
Water Yield change (%)	-37%	-40%	-41%	-40%
GEP change (%)	-2%	-1%	-3%	-1%

-15% Precipitation + 1 Degree C



Take Home Messages

- 15% reduction in precipitation could cause large reductions in stream flow, but not productivity
- 30% reductions in precipitation could have minimal impacts on productivity in areas where precipitation is high, but will have large impacts in drier areas
- Similar impacts on older vs. young pines.
- Rise in air temp (1-2 degree C) increases productivity
- Water availability is key to productivity