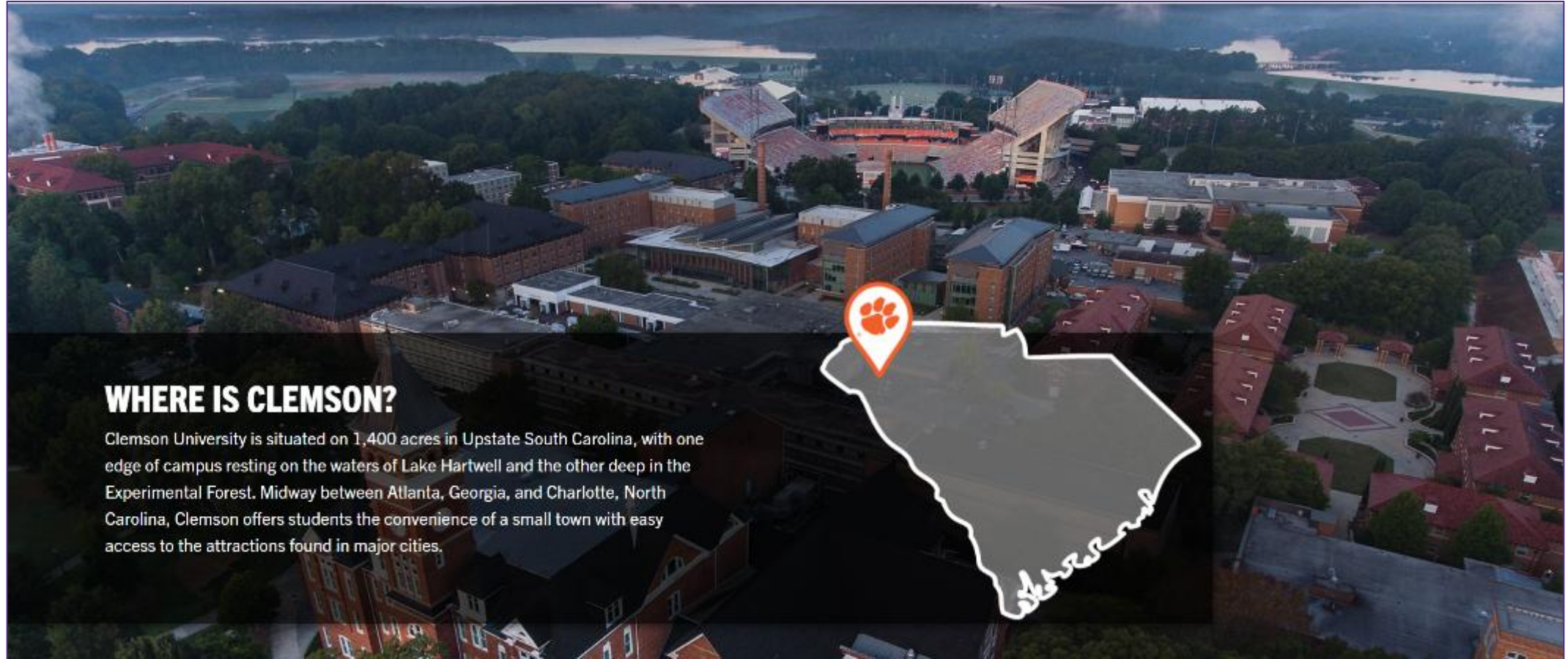


Designing Watersheds for Integrated Development (DWID): Optimizing Land Use for Water Quality and Economic Sustainability

Puneet Dwivedi, Ph.D.
Professor and Hilliard Endowed Chair in
Environmental Sustainability, Department of
Forestry and Environmental Conservation,
Clemson University, Clemson, South Carolina

The 30th Annual International Consortium on Applied
Bioeconomy Research Conference 2026
Ravello, Italy || July 10, 2026





WHERE IS CLEMSON?

Clemson University is situated on 1,400 acres in Upstate South Carolina, with one edge of campus resting on the waters of Lake Hartwell and the other deep in the Experimental Forest. Midway between Atlanta, Georgia, and Charlotte, North Carolina, Clemson offers students the convenience of a small town with easy access to the attractions found in major cities.

Current Lab

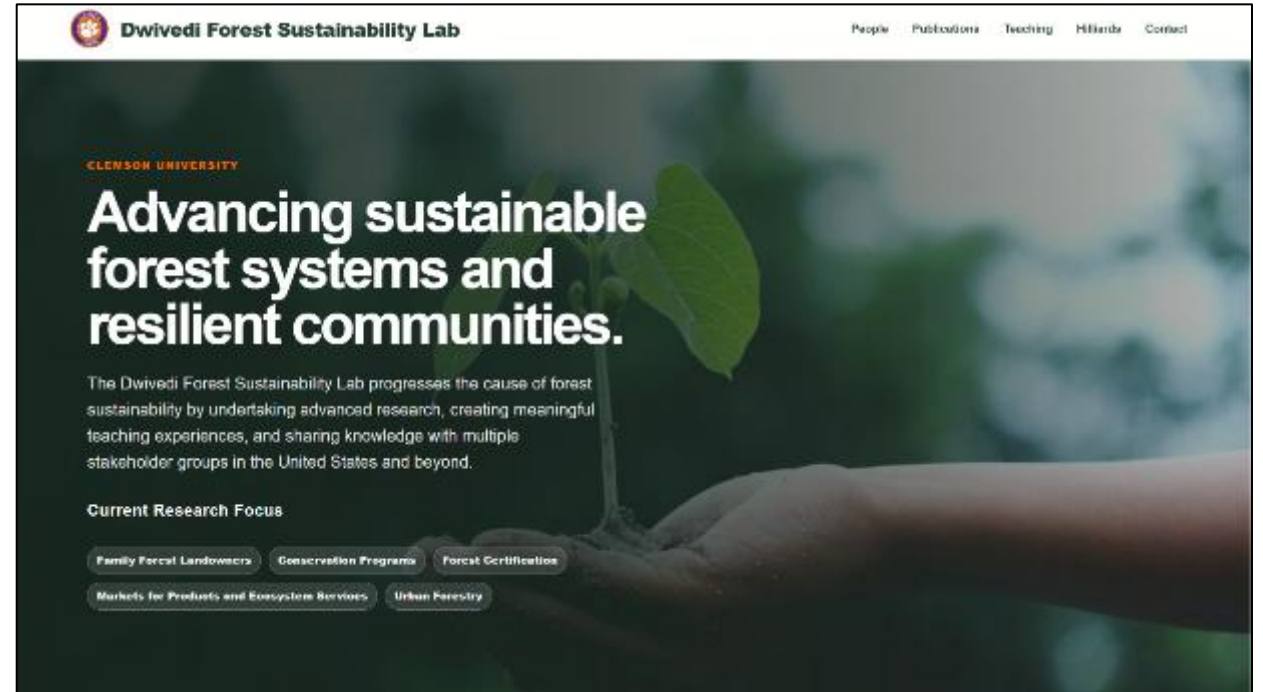
Four M.S. Students
Bandhan, Probir, Khagendra, & Lydia

Eleven Ph.D. students
Ben, **Onyinye**, Sabya, Lalita, Shakir, Rajesh,
Ignatius, Kaustav, Vaine, Reinhard, & Naveen

One incoming (fall 2026) M.S. student
Anna Maria

Three postdocs
Ashok, Rakhi Goswami, TBA

Total 20 people (fall 2026)



<https://www.dfslx.org/>

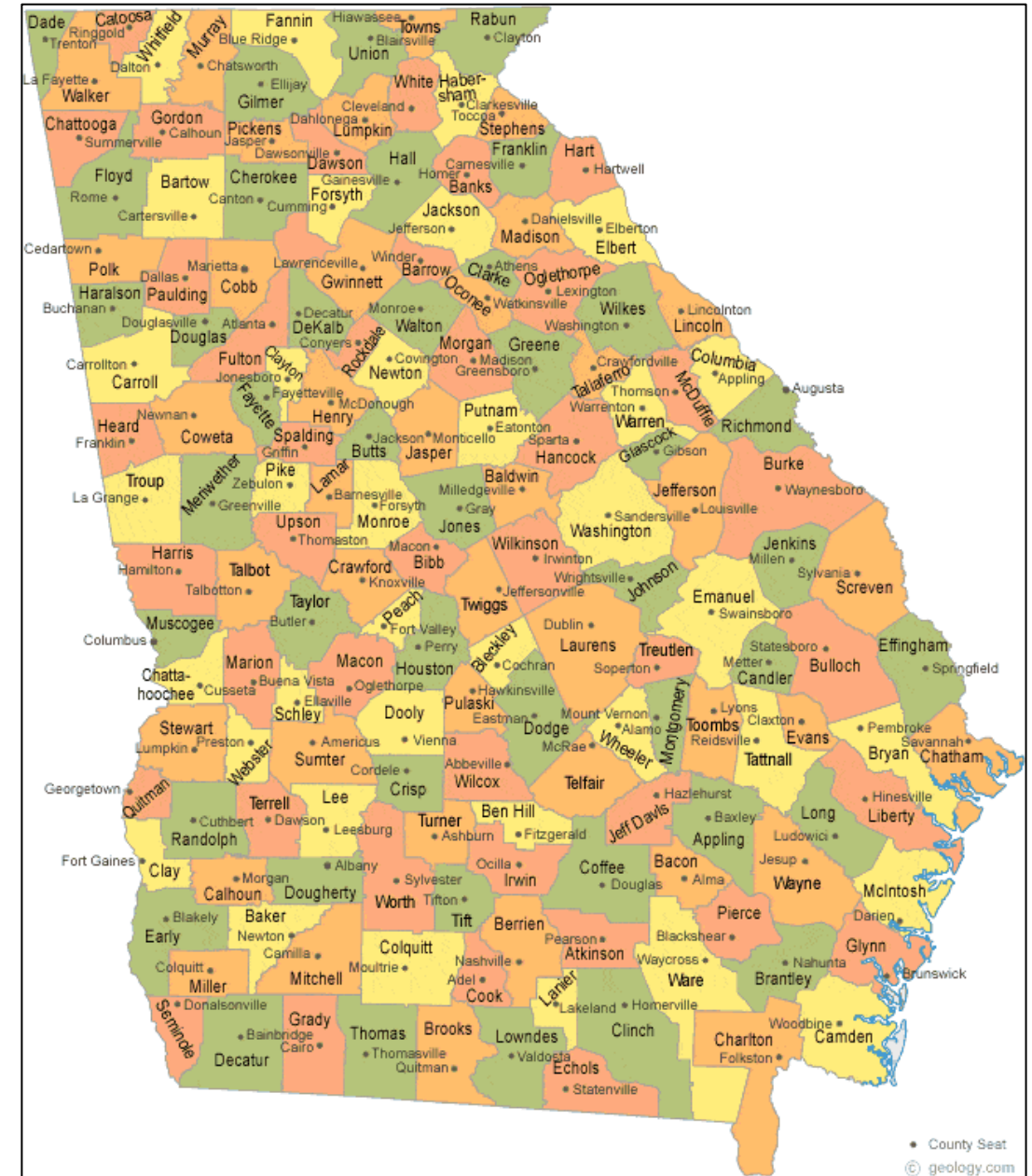
The Study Area

Part of the original 13 colonies

Founded in 1732

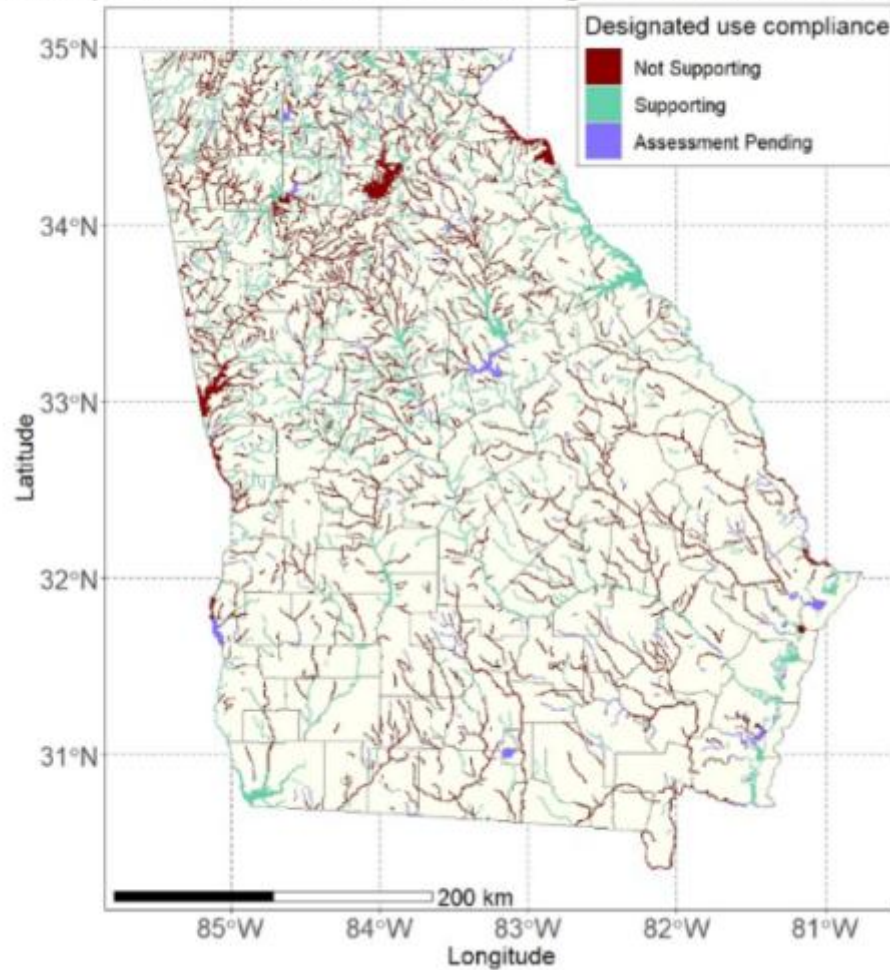
Statehood: January 2, 1788

The largest state east of the Mississippi River
(37 million acres)

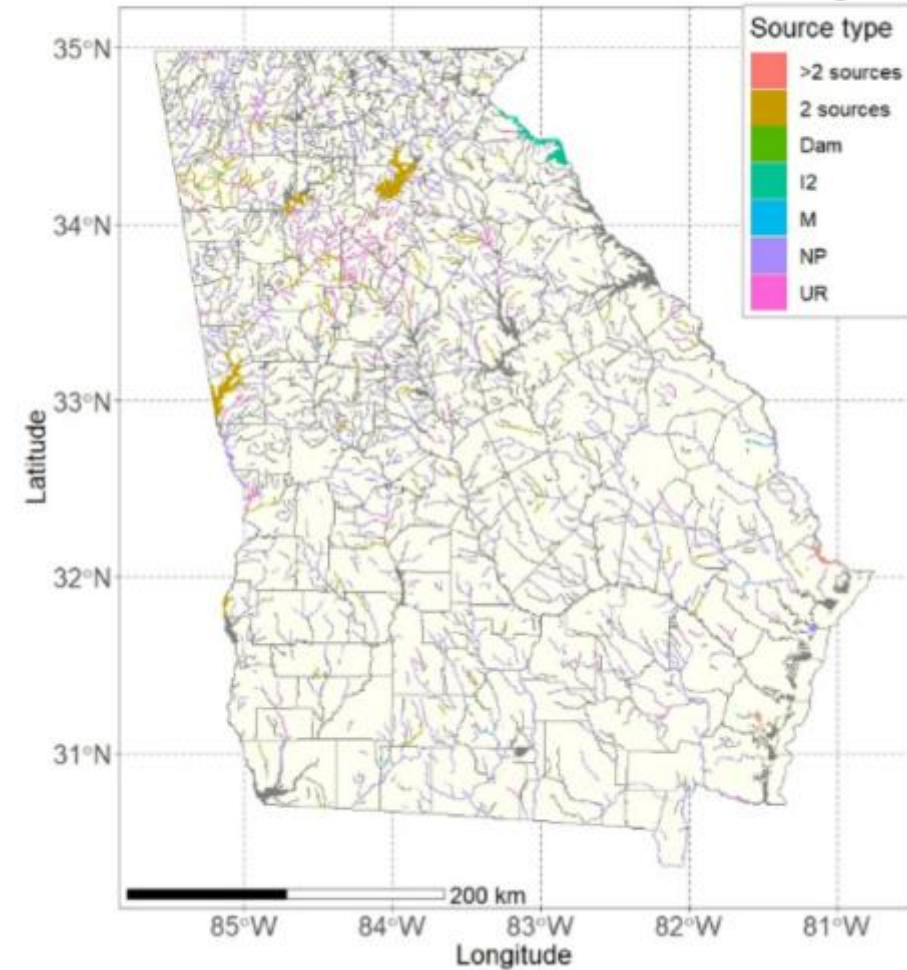


Water Quality in Georgia

a. Compliance status for water designated use in Georgia



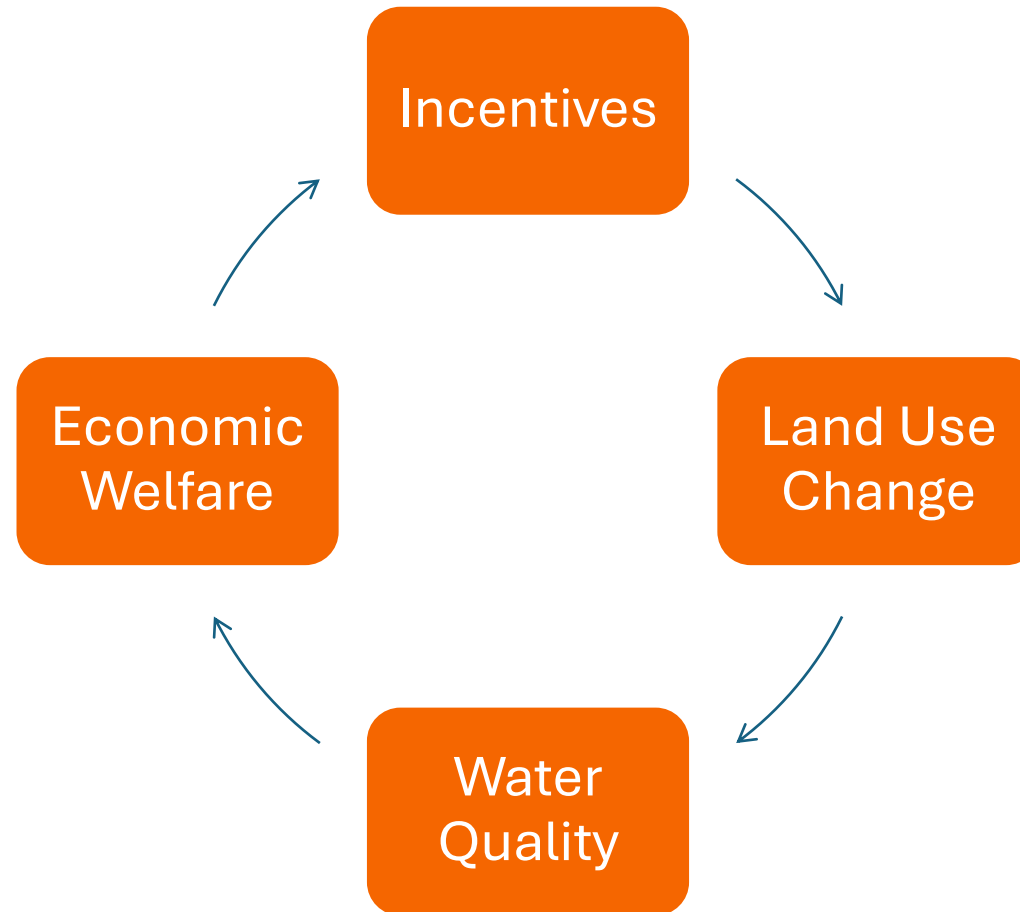
b. Pollution sources for water bodies in Georgia



Possible Solution



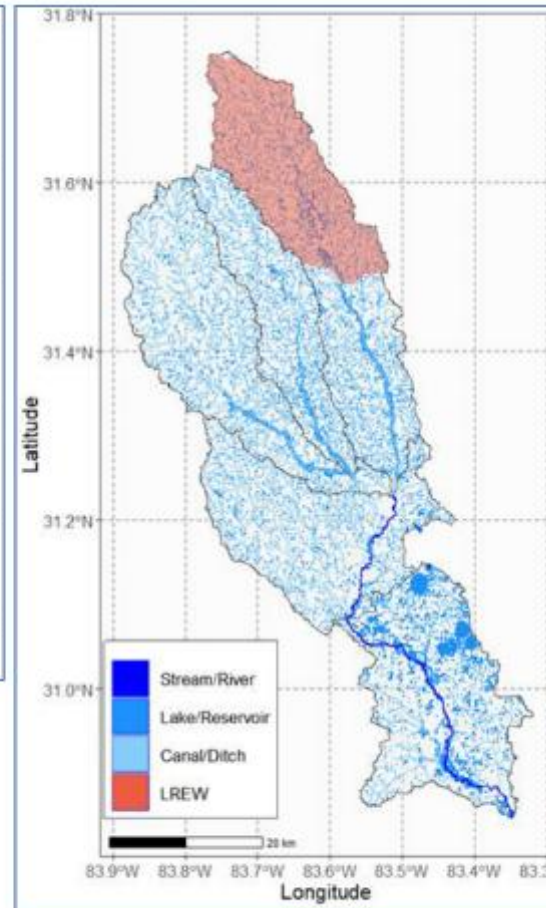
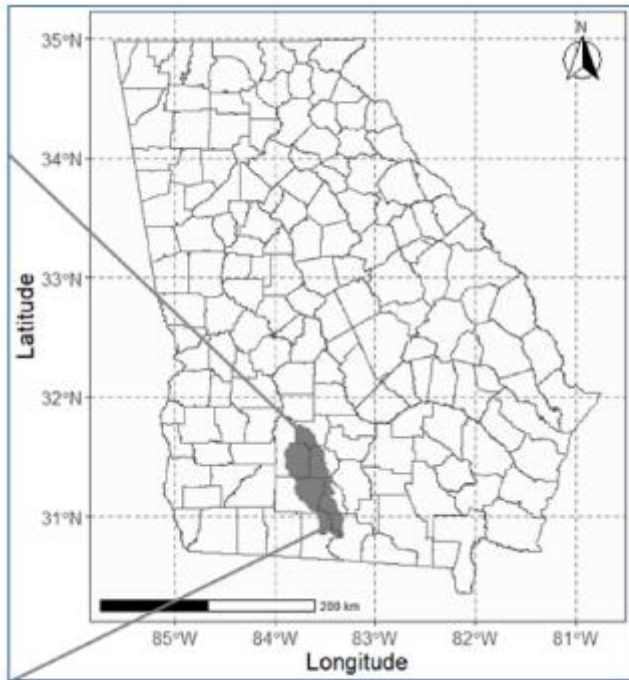
Economic and Environmental Tradeoffs



Goal of the Study

Modeling the economic and environmental tradeoffs related to potential water quality improvement in light of land use changes over space and time in Georgia.

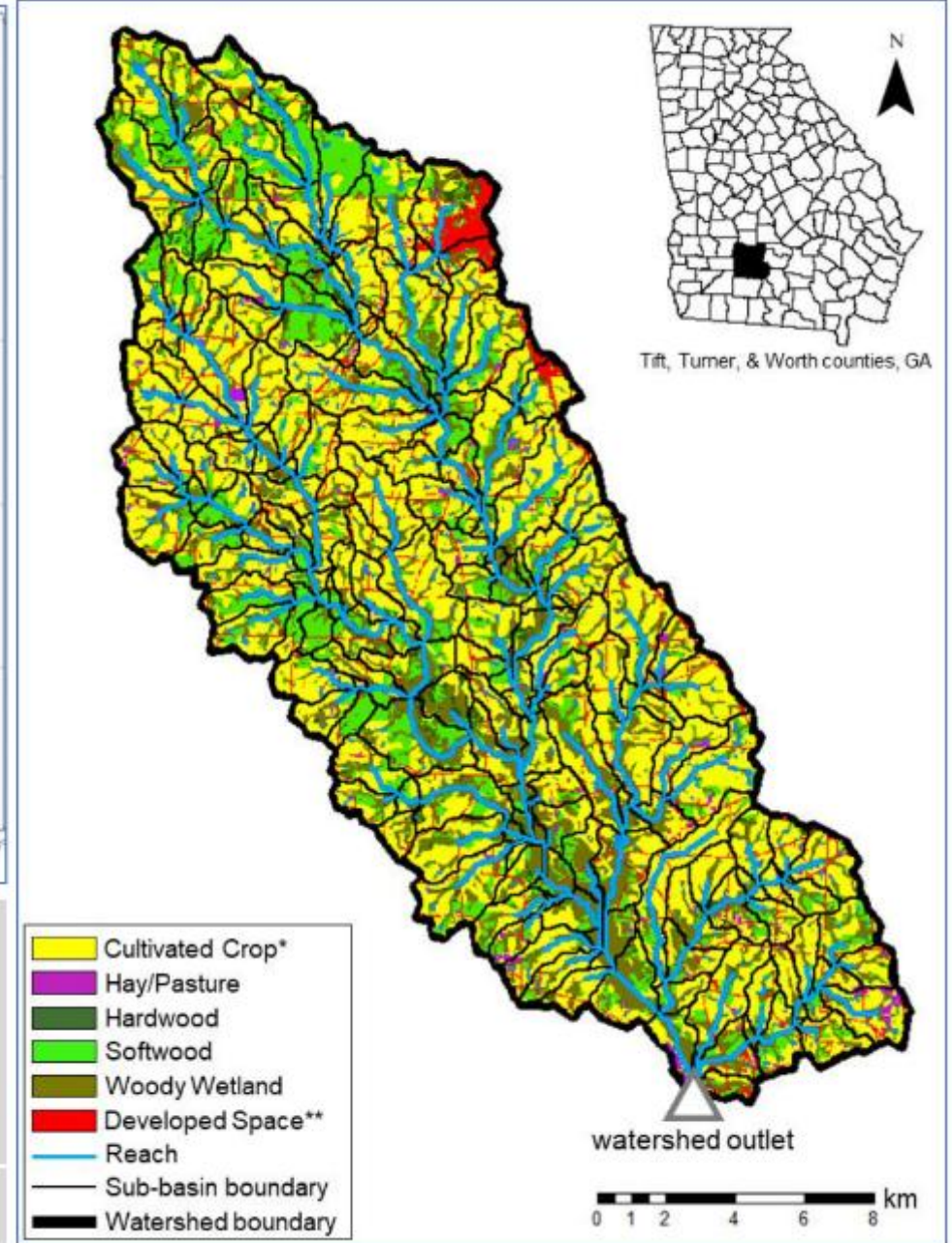
Study Area



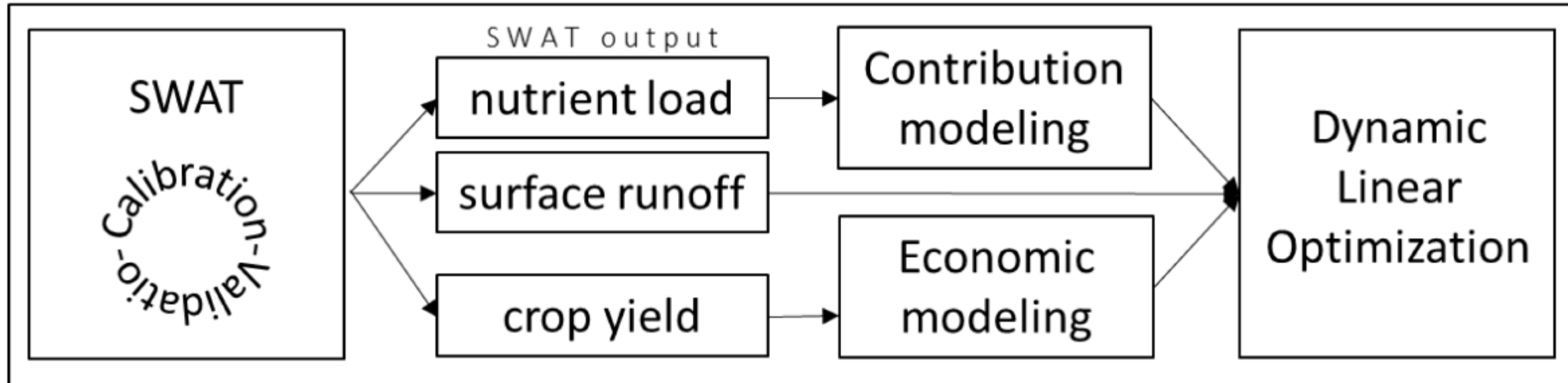
Land Use: About 51% row crops (primarily peanut, corn, and cotton), 16% evergreen forest, 2% deciduous forest, and 1% hay. Other notable categories include woody wetland (22%), which largely occur on the borders of the stream network and urban space (6%), mostly confined to a small northeast corner.

Period: 1997 - 2005

Area: 82,533.2 acres



Framework: Designing Watershed for Integrated Development (DWID)



SWAT Modeling (Key Assumptions)

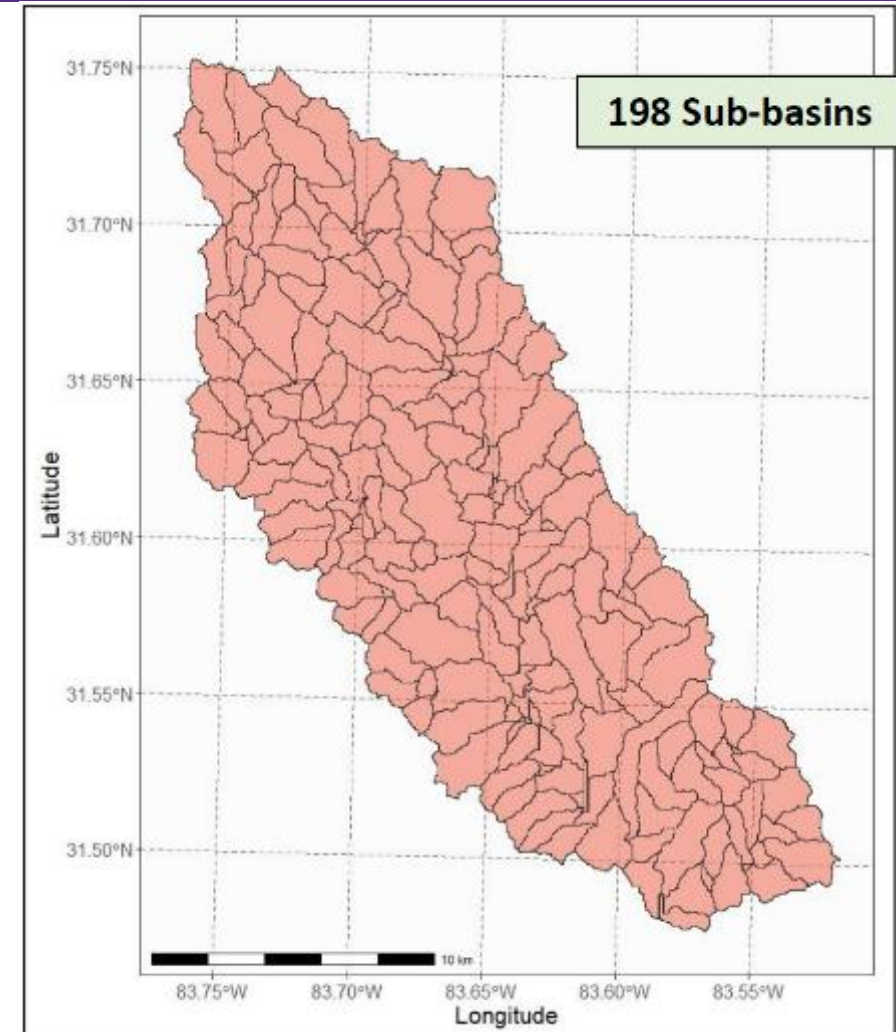
Hydrological Response Units (HRUs): 1272

Cotton-Corn-Peanut Rotation

Model Initialization (1993 –1996)

Model Calibration (1997 –2001)

Model Validation (2002 –2003)



Economic Modeling

The screenshot shows the USDA National Agricultural Statistics Service website. The header includes the USDA logo and navigation links. A large banner for the 2022 Census of Agriculture is prominent, with the text "RESPOND NOW". Below the banner, there are sections for "Today's Reports" and "Find Data and Reports by:", which includes a map of the United States and a "COMPLETE YOUR SURVEY ONLINE" button.

The screenshot shows the University of Georgia Extension website. The header includes the University of Georgia logo and navigation links. A large banner for "Stories of Extension" is prominent, with the text "Science in service of humanity and the environment is the core of Extension. And that's what inspired Almanac, our latest collection of stories, which you can now experience digitally." Below the banner, there are sections for "Explore Topic Areas" and "Discover Almanac".

The screenshot shows the TimberMart-South website. The header includes the TimberMart-South logo and navigation links. A large banner for "TimberMart-South is Hiring" is prominent, with the text "We serve our clients by reporting accurate timber and timberland market data, as well as by providing analysis on current and historic trends and events." Below the banner, there are sections for "TimberMart-South is now hiring a News Editor/Research Professional" and "We are looking for someone with writing, editing, and/or journalism experience with excellent proofreading skills, strong interpersonal skills, and knowledge of software applications to edit and write TimberMart-South's Market News Quarterly." The footer includes the contact information "If interested, please email resume and cover letter to tmart@timbermart-south.com."

Dynamic Linear Optimization Model

Objective Function (Maximize)
Net Present Value Over Time

Subject to
Land Availability Constraints
Land Balance Constraints
Water Quality Constraints

Scenarios

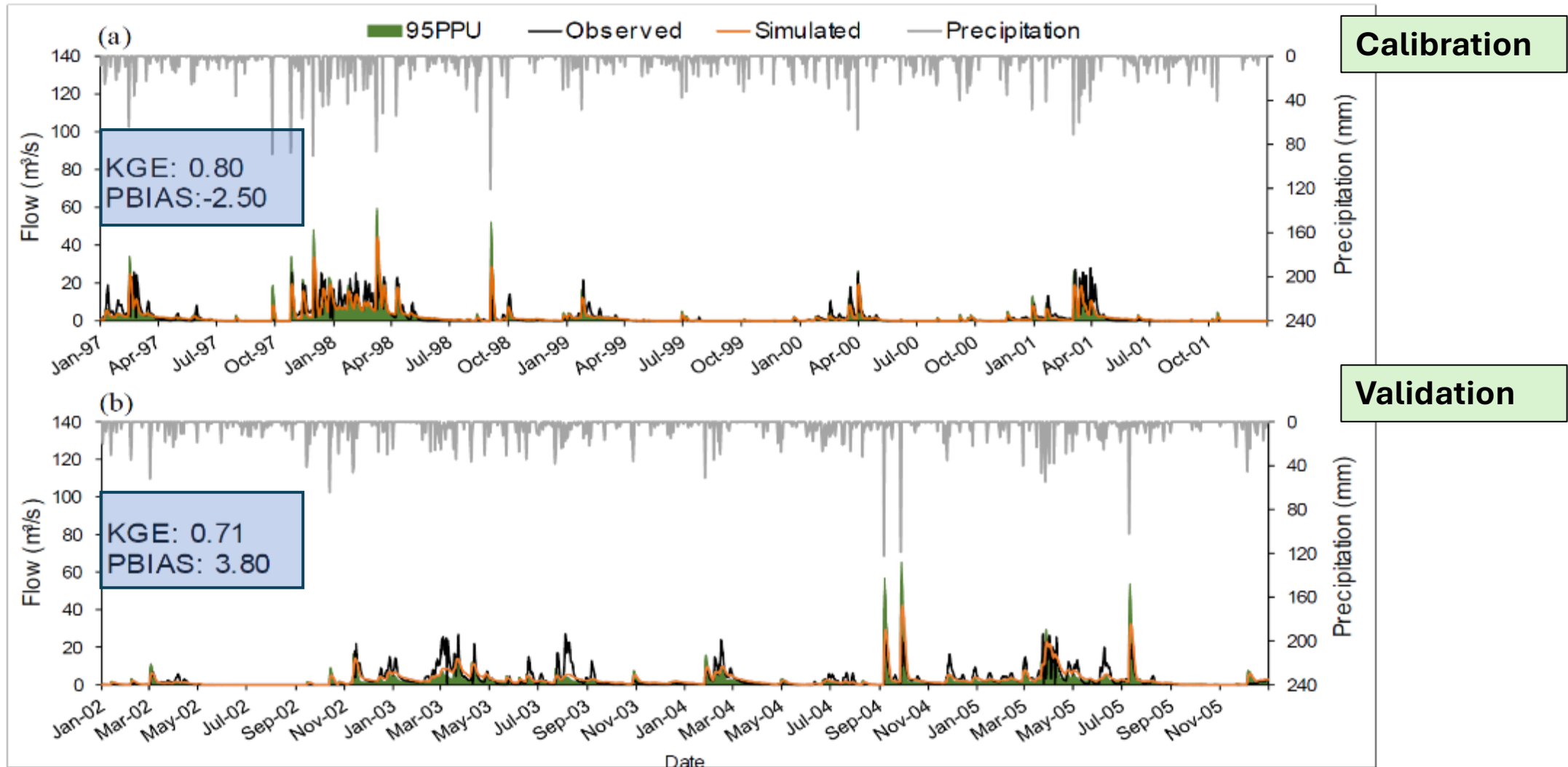
NO ₃ -N	Percent decline	P	Percent decline	NO ₃ -N & P	Percent decline*
N1	48.00	P1	14.75	NP1	48.00, 14.75
N2	52.00	P2	15.25	NP2	49.16, 15.08
N3	56.00	P3	15.75	NP3	50.33, 15.42
N4	60.00	P4	16.25	NP4	51.50, 15.75
N5	64.00	P5	16.75	NP5	52.66, 16.08
N6	68.00	P6	17.25	NP6	53.82, 16.42
N7	72.00	P7	17.75	NP7	54.99, 16.75

Twenty-two scenarios are devised in total including a common Base scenario (defined by limits for NO₃-N and P constraints that remain constant over time). Percentage declines for each of the three categories (NO₃-N, P, and NO₃-N & P) were devised based on equal intervals, starting with the percentage triggering an initial change in profits and ending with a percentage representing the maximum threshold permitted by the model.

Results

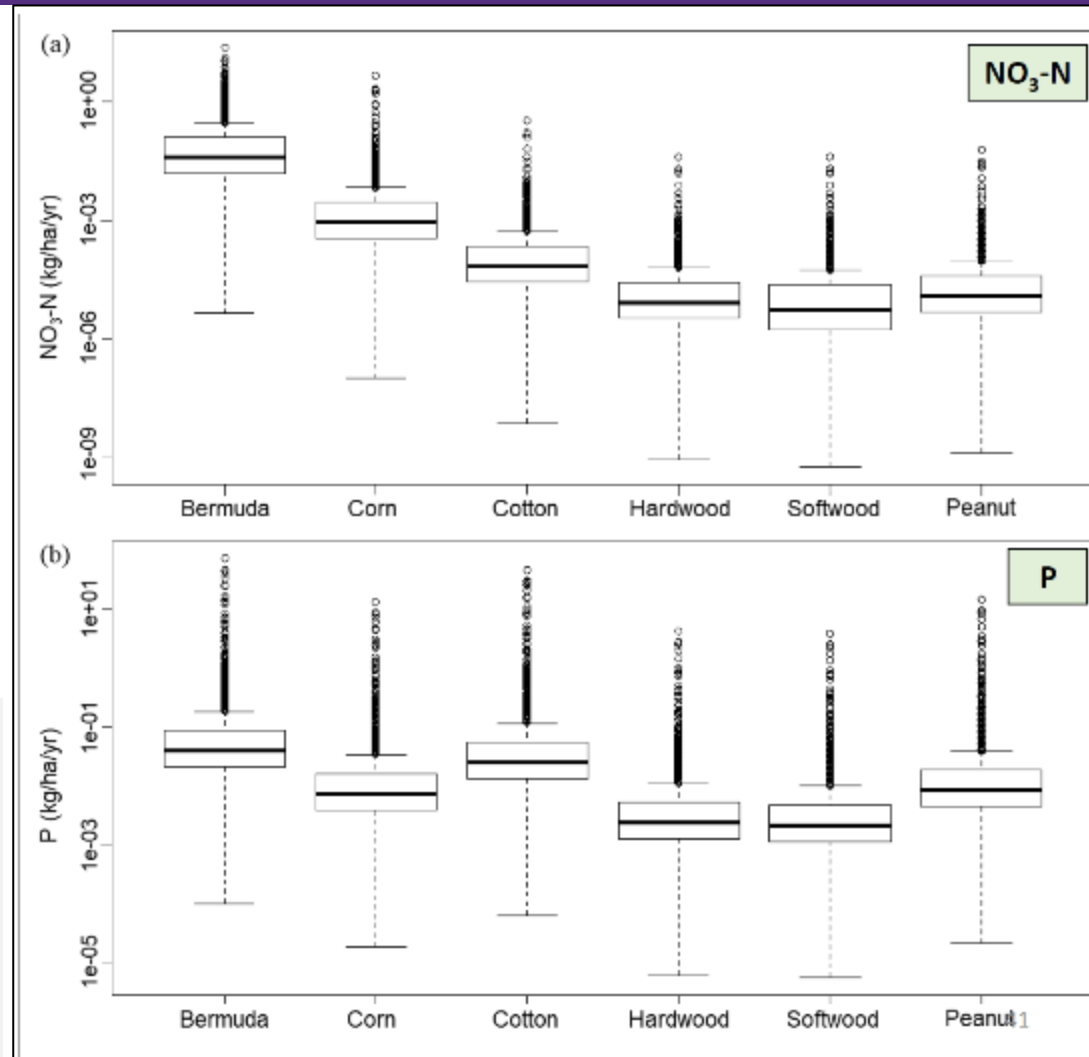


SWAT Modeling

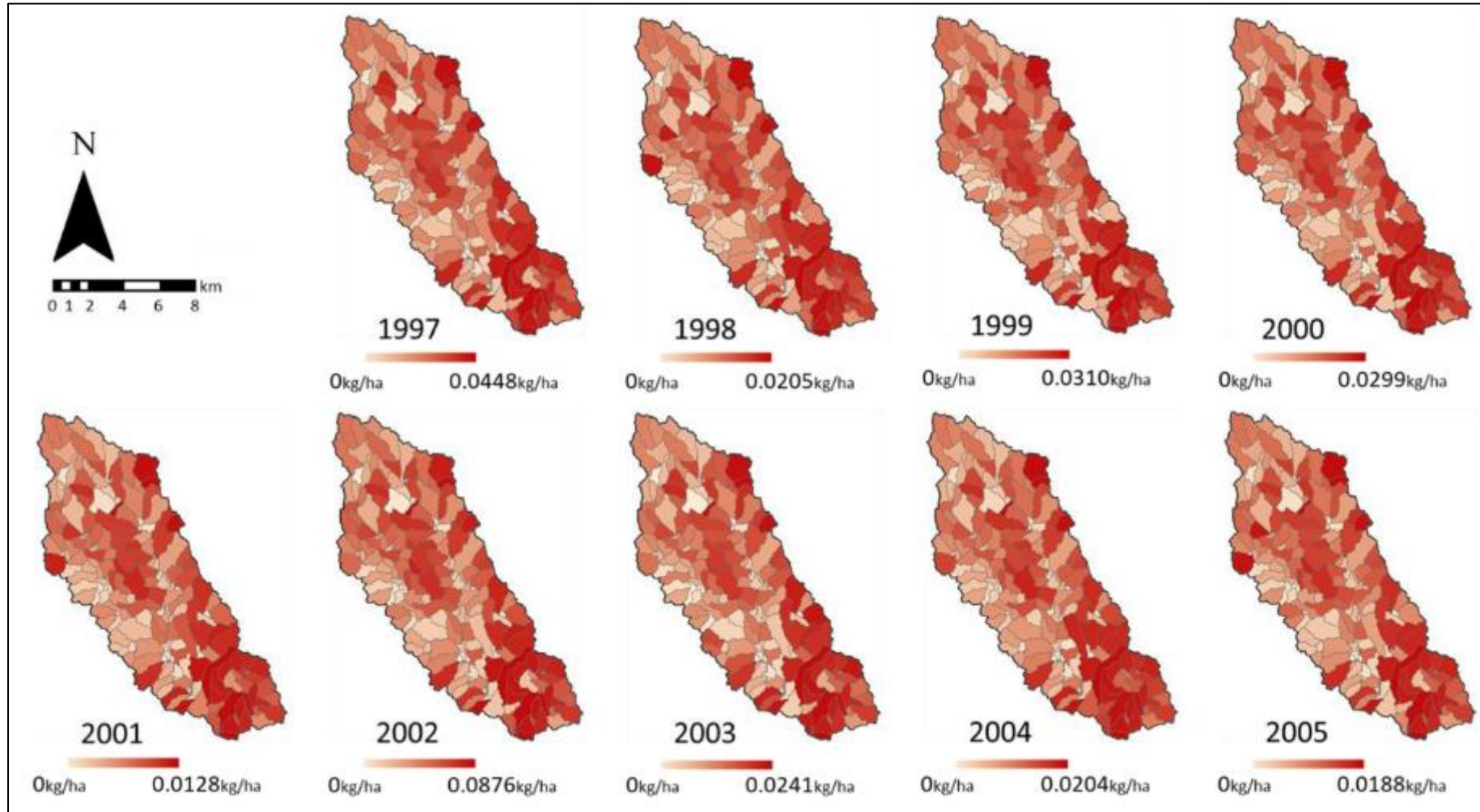


SWAT Modeling

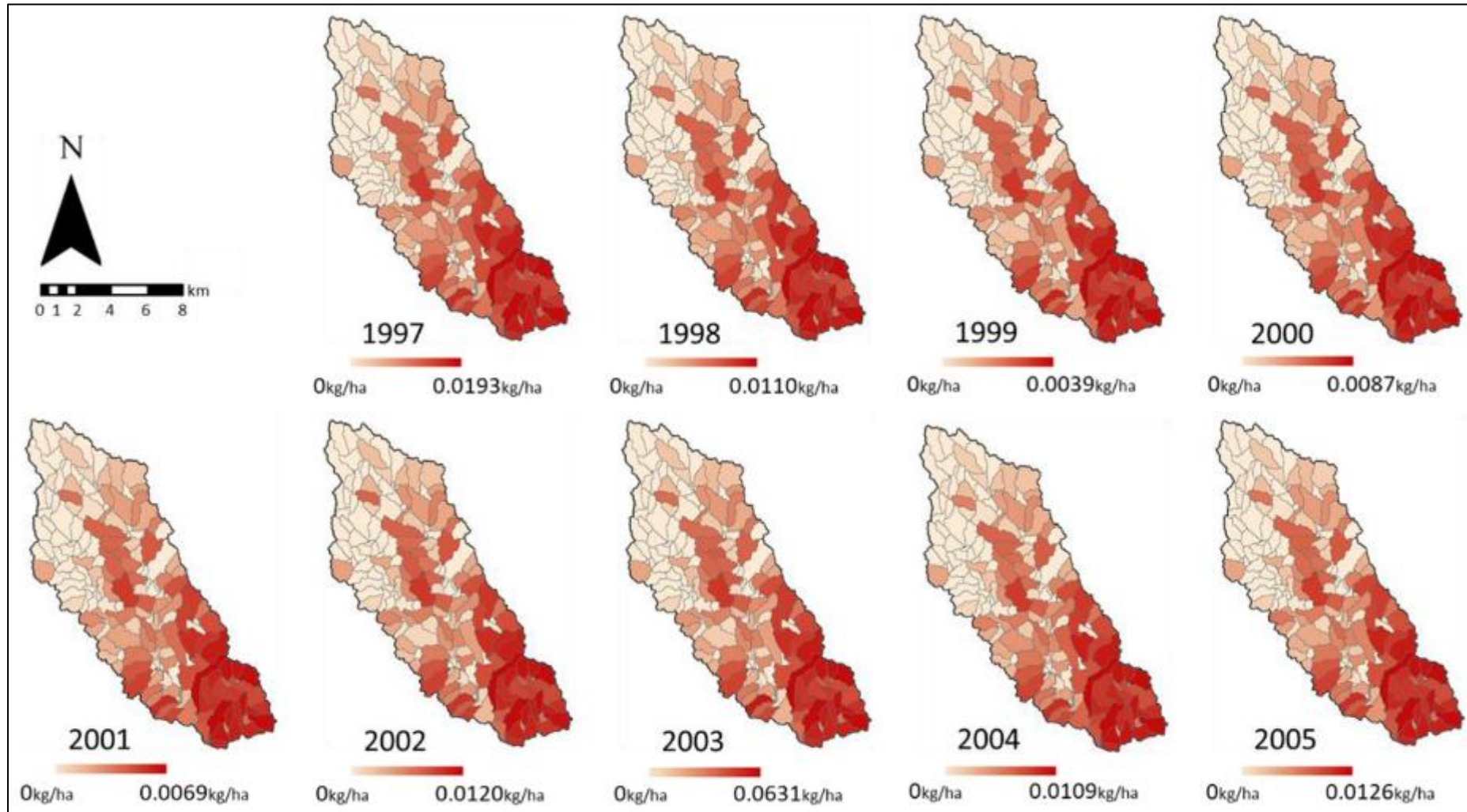
Points reflect HRU-level data and depict the average load over the nine years considered, 1997 to 2005.



Contribution Modeling



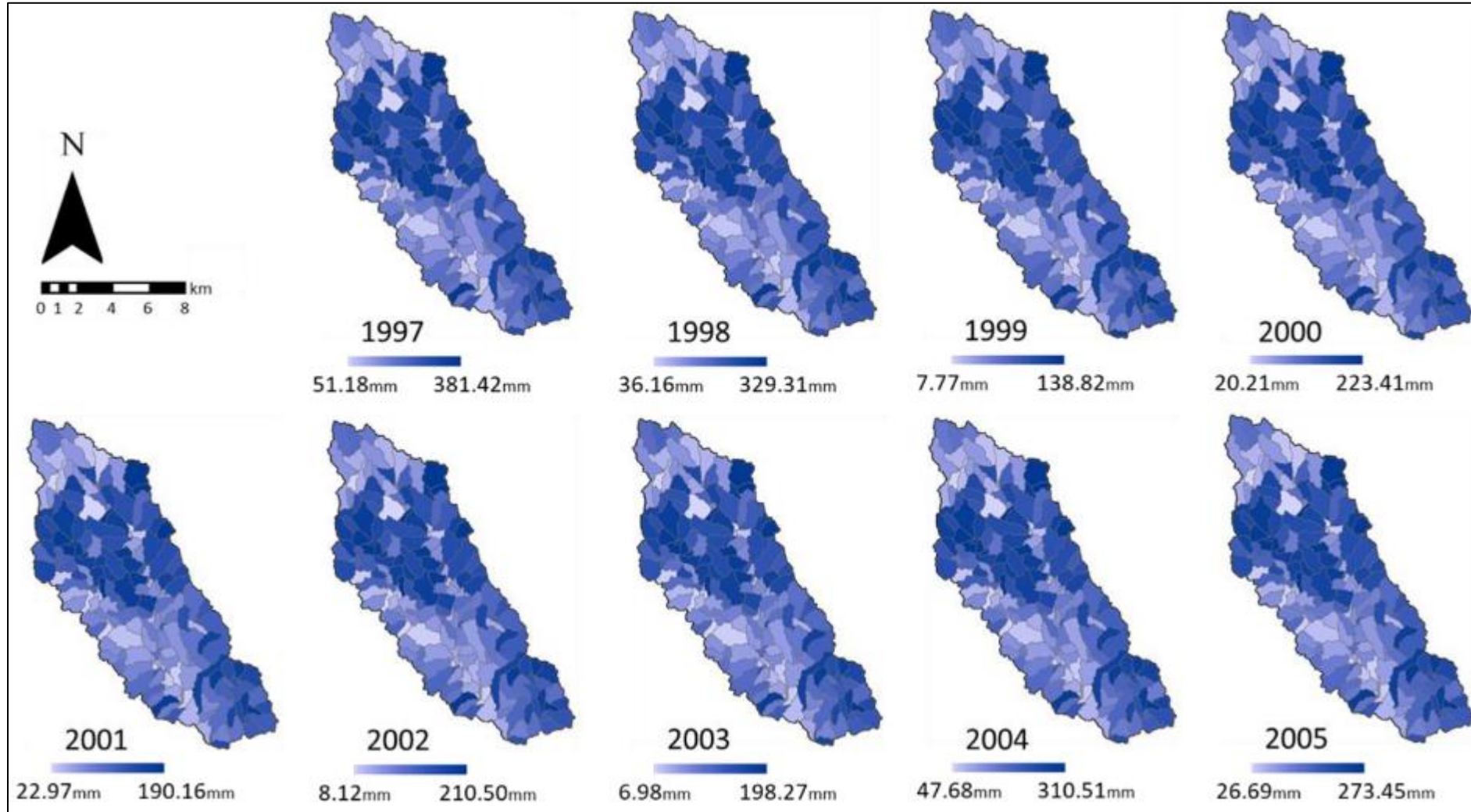
Contribution Modeling



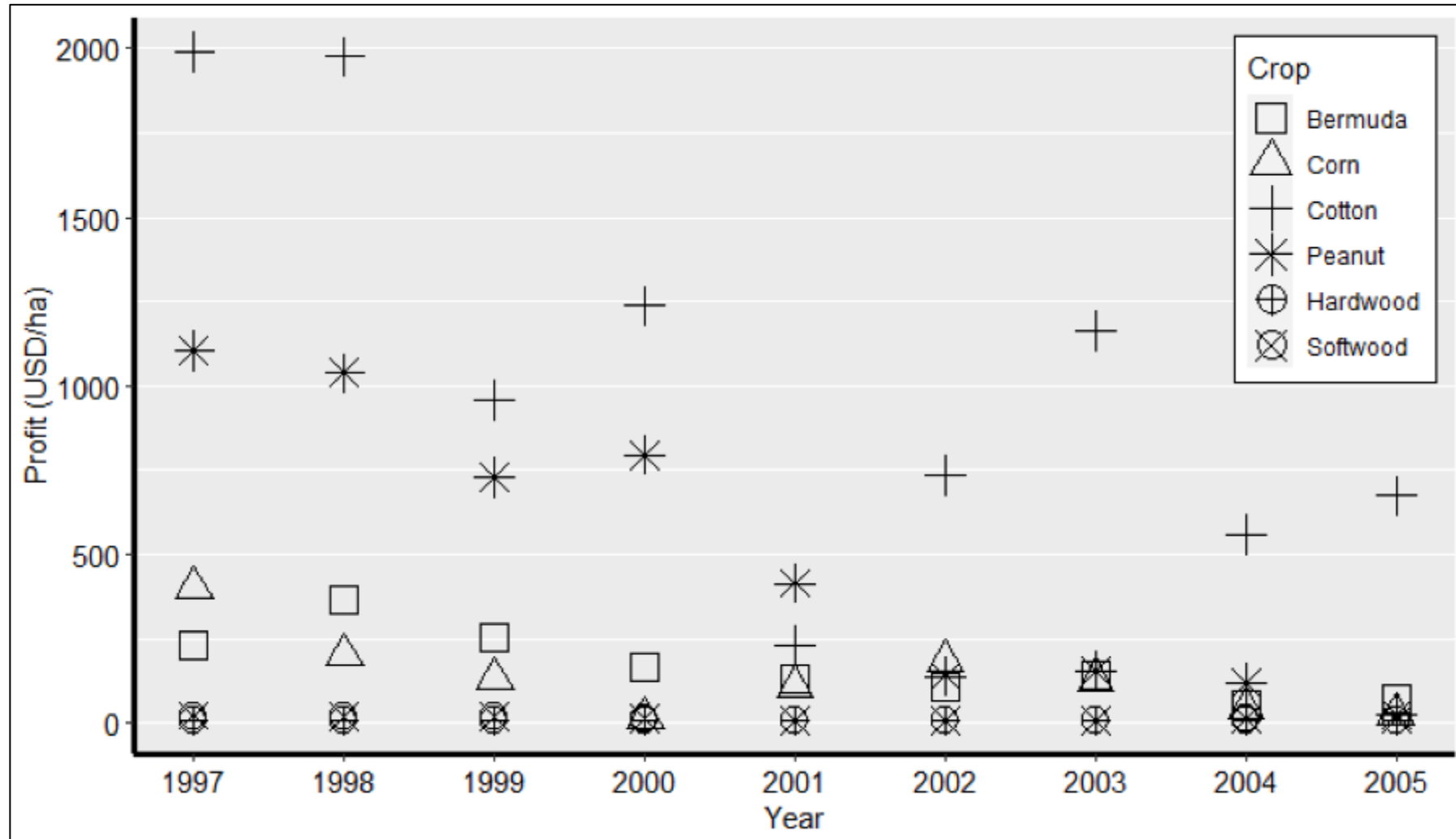
P Load

Contribution Modeling

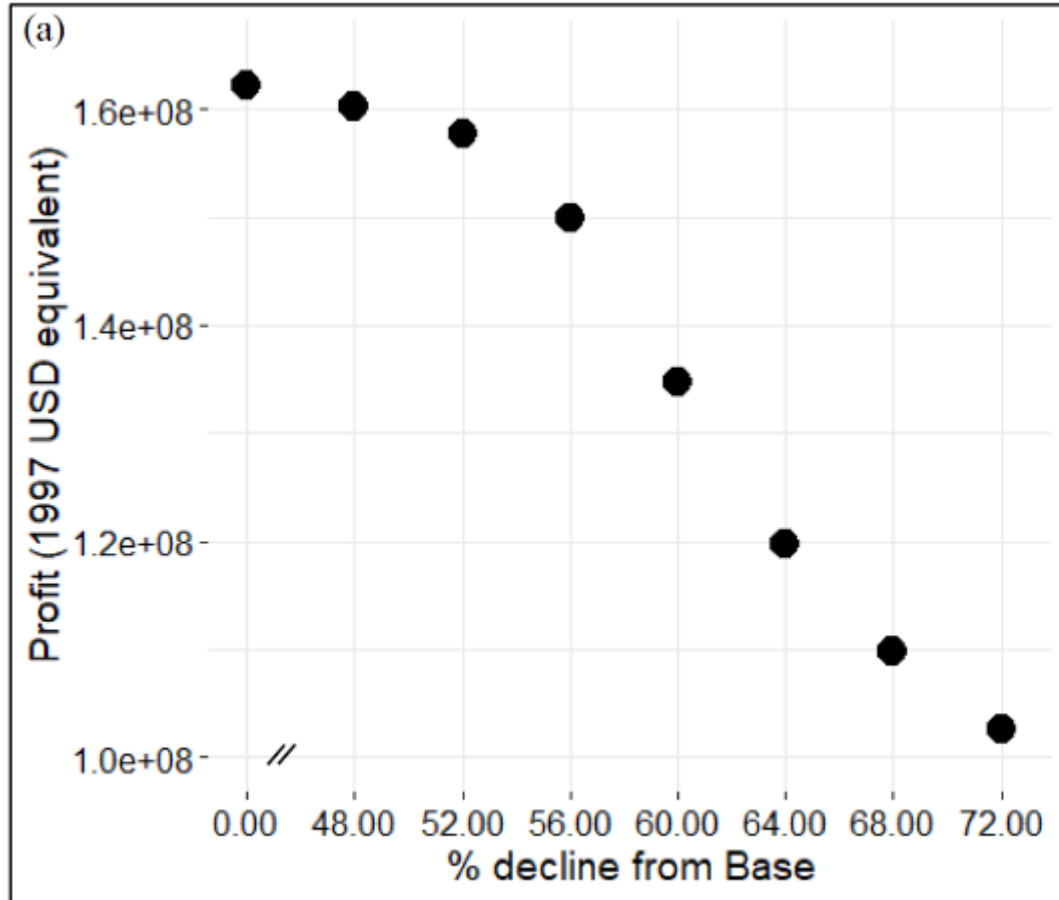
Surface Runoff



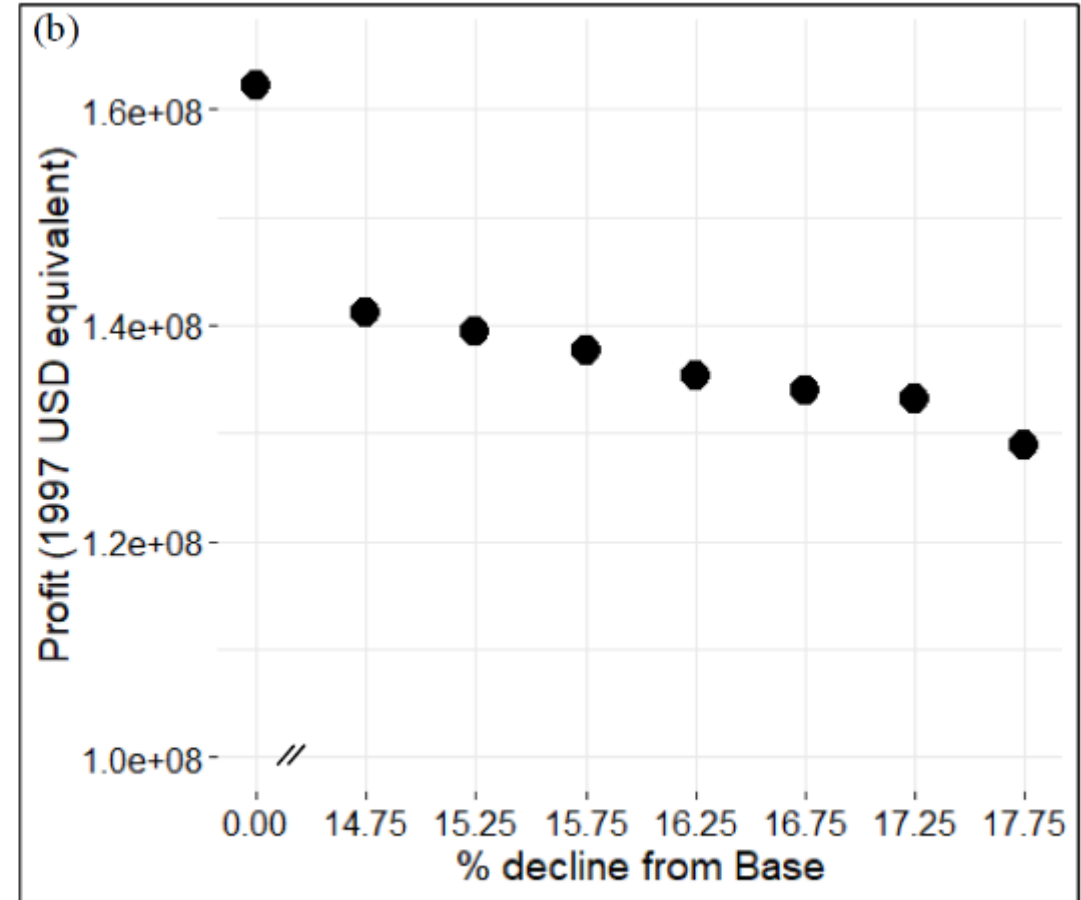
Economic Modeling



Economic and Environmental Tradeoffs

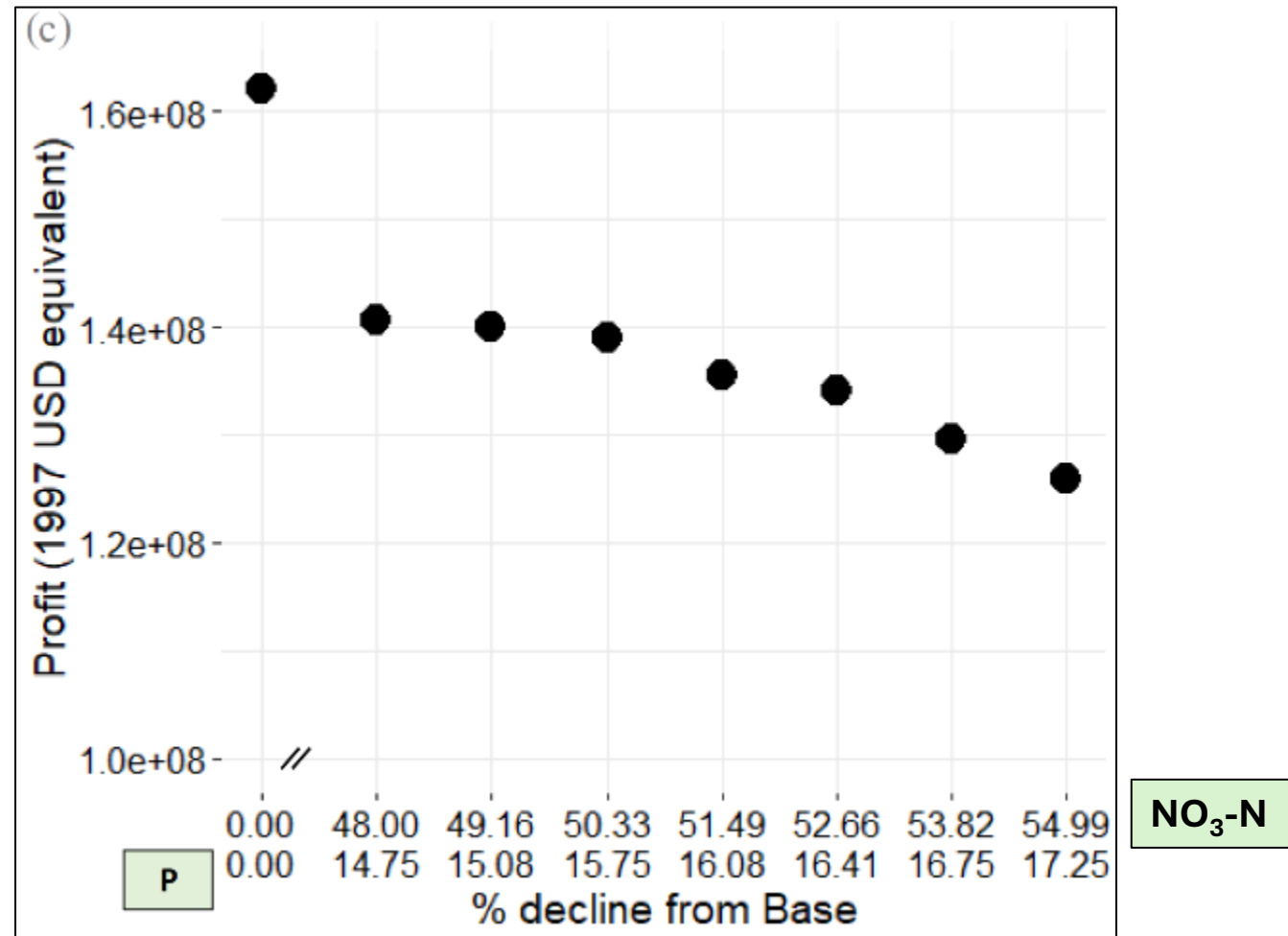


NO₃-N

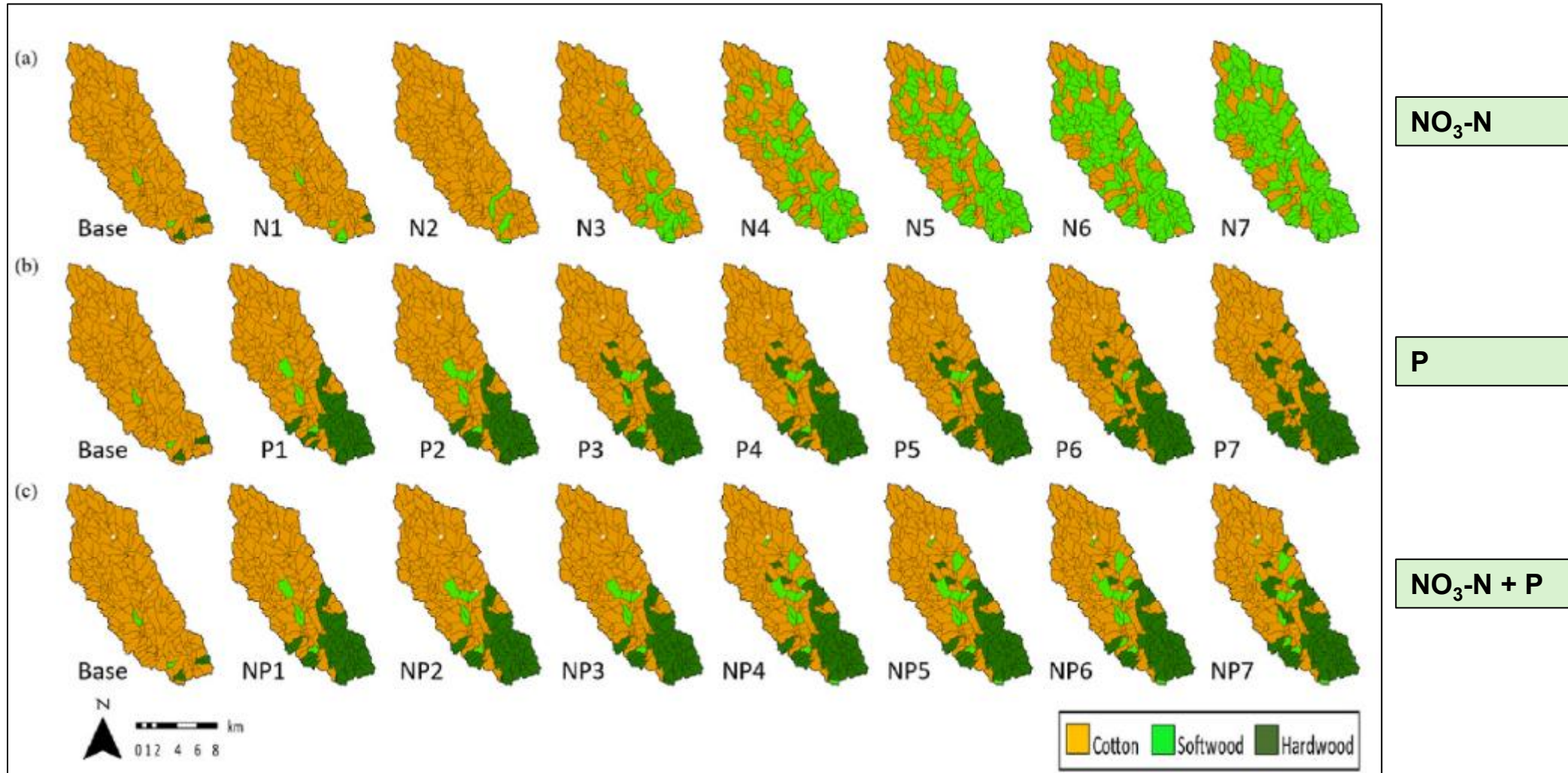


P

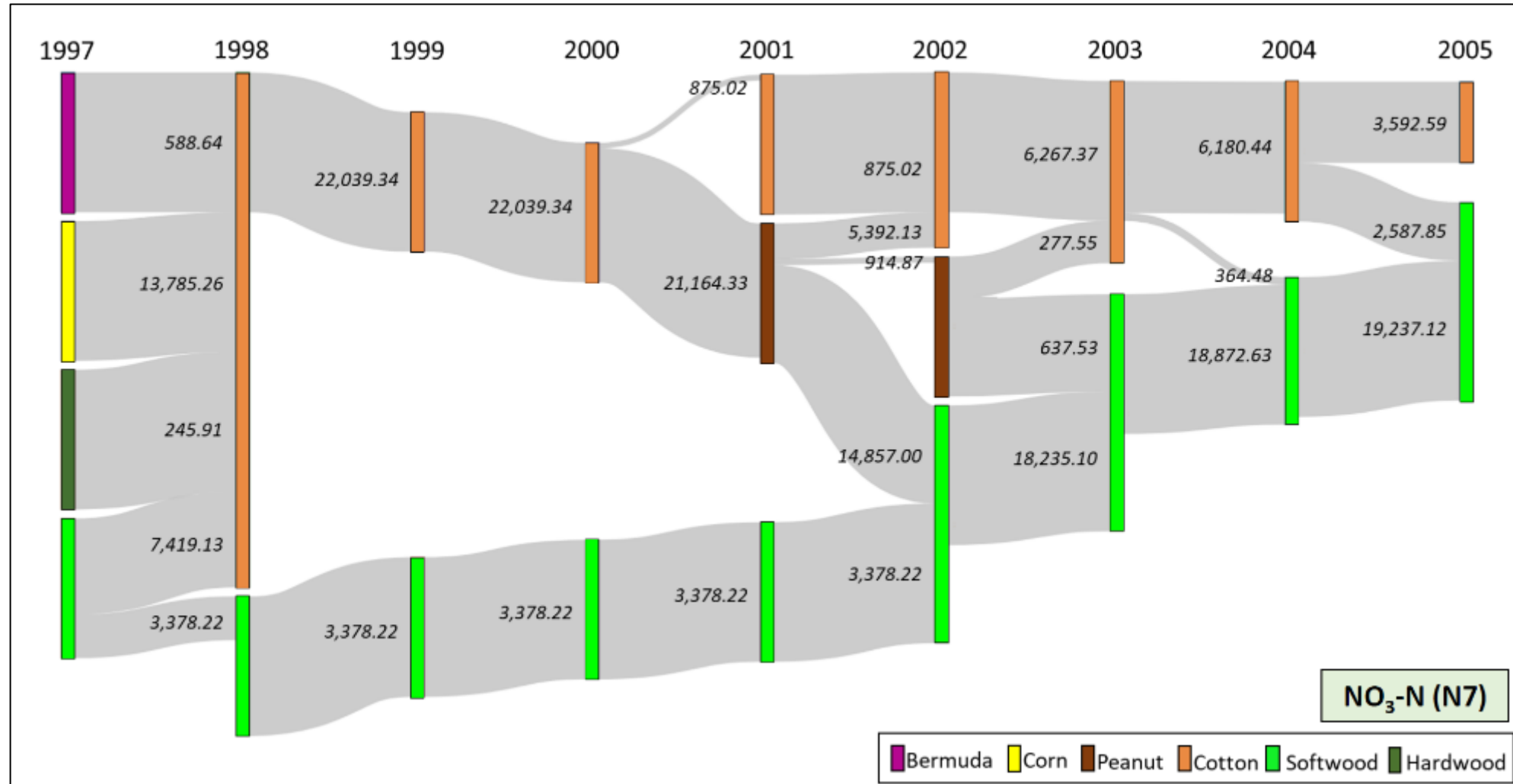
Economic and Environmental Tradeoffs



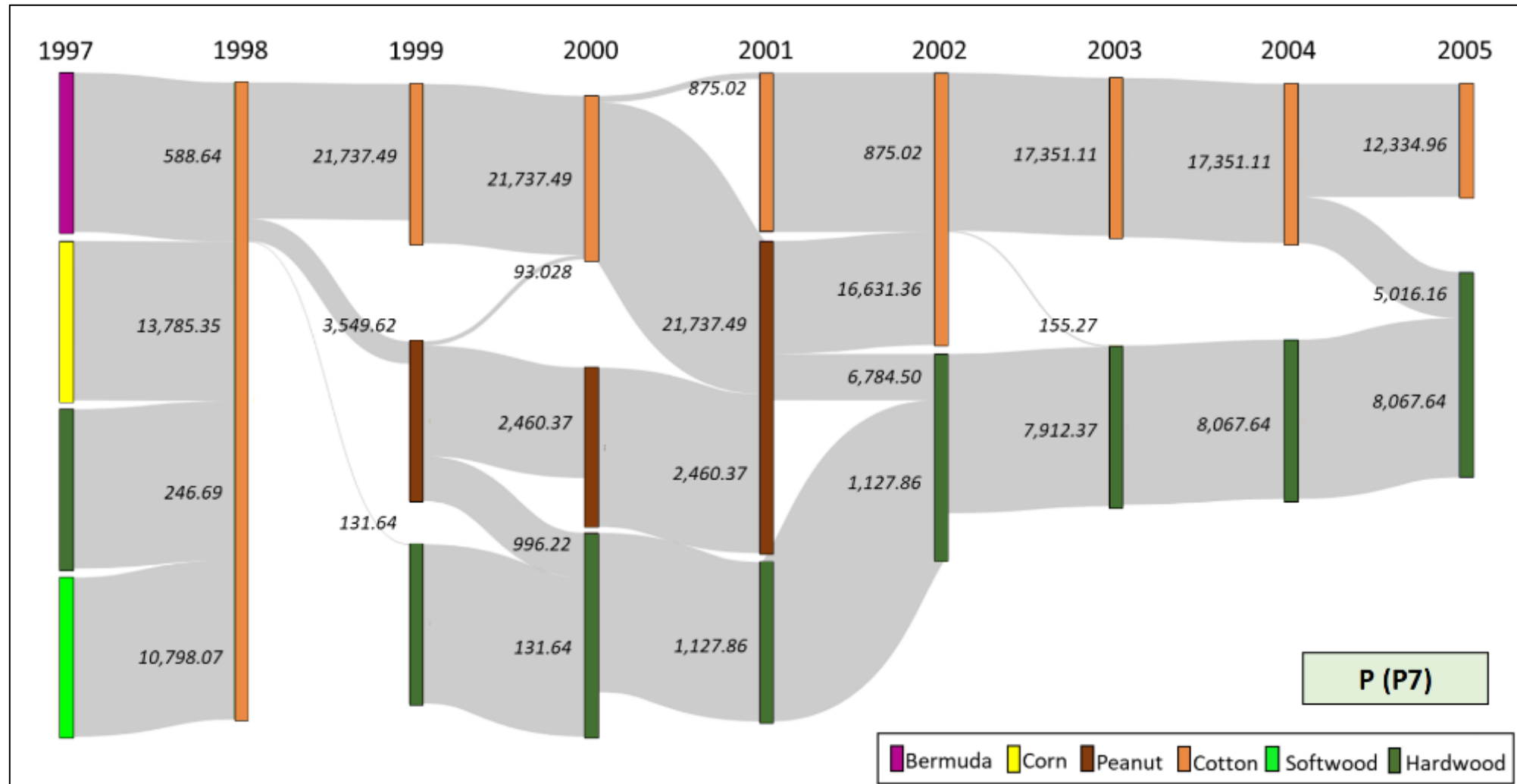
Projected Land Use Change



Projected Land Use Change



Projected Land Use Change



Publication

Water Resources and Economics 41 (2023) 100209

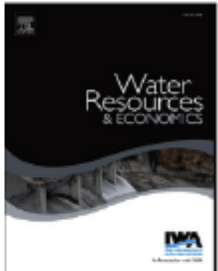


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journal homepage: www.elsevier.com/locate/wre



Designing Watersheds for Integrated Development (DWID):
Combining hydrological and economic modeling for optimizing
land use change to meet water quality regulations

Ranjit Bawa^{a,d,*}, Puneet Dwivedi^a, Nahal Hoghooghi^b, Latif Kalin^c, Yu-Kai Huang^a



Non-Stochastic DWID Model

Stochastic DWID Model

How confident do we want to be in meeting the phosphorus water quality standard, keeping in mind the variability of phosphorus loadings from each sub-basin for each land use type in the presence of yield variability?

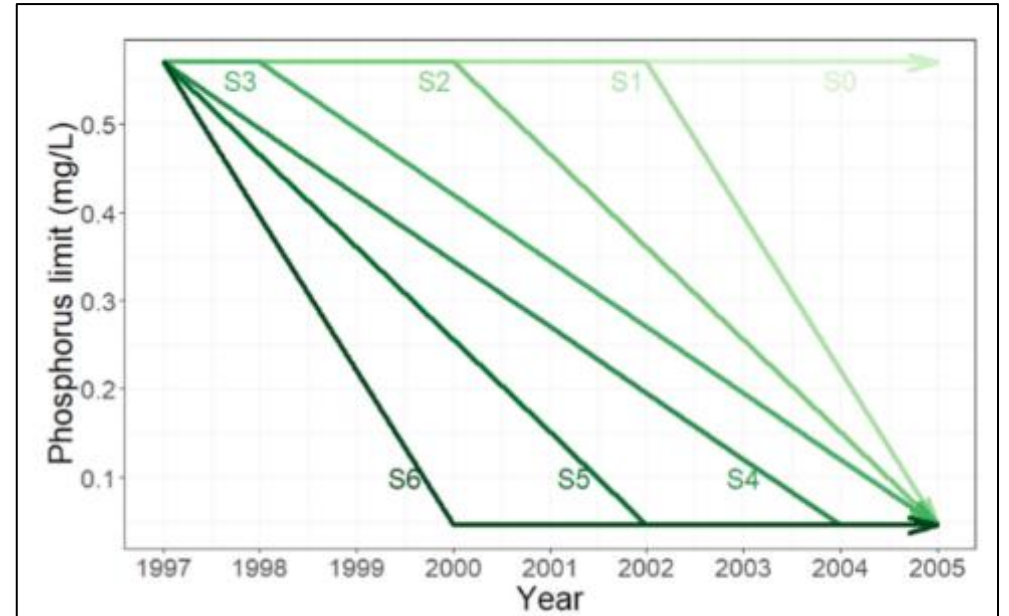
Chance Constraint Approach

Stochastic DWID Model

Scenario descriptions for phosphorus concentration limits.

Scenario	Description
S0	No regulation.
S1	Start to reduce the TP concentration limit in the 5th year and linearly decrease to the USEPA standard.
S2	Start to reduce the TP concentration limit in the 3rd year and linearly decrease to the USEPA standard.
S3	Start to reduce the TP concentration limit in the 1st year and linearly decrease to the USEPA standard.
S4	Linearly decrease the TP concentration limit to the USEPA standard within 7 years.
S5	Linearly decrease the TP concentration limit to the USEPA standard within 5 years.
S6	Linearly decrease the TP concentration limit to the USEPA standard within 3 years.

50% Confidence Level (Deterministic)

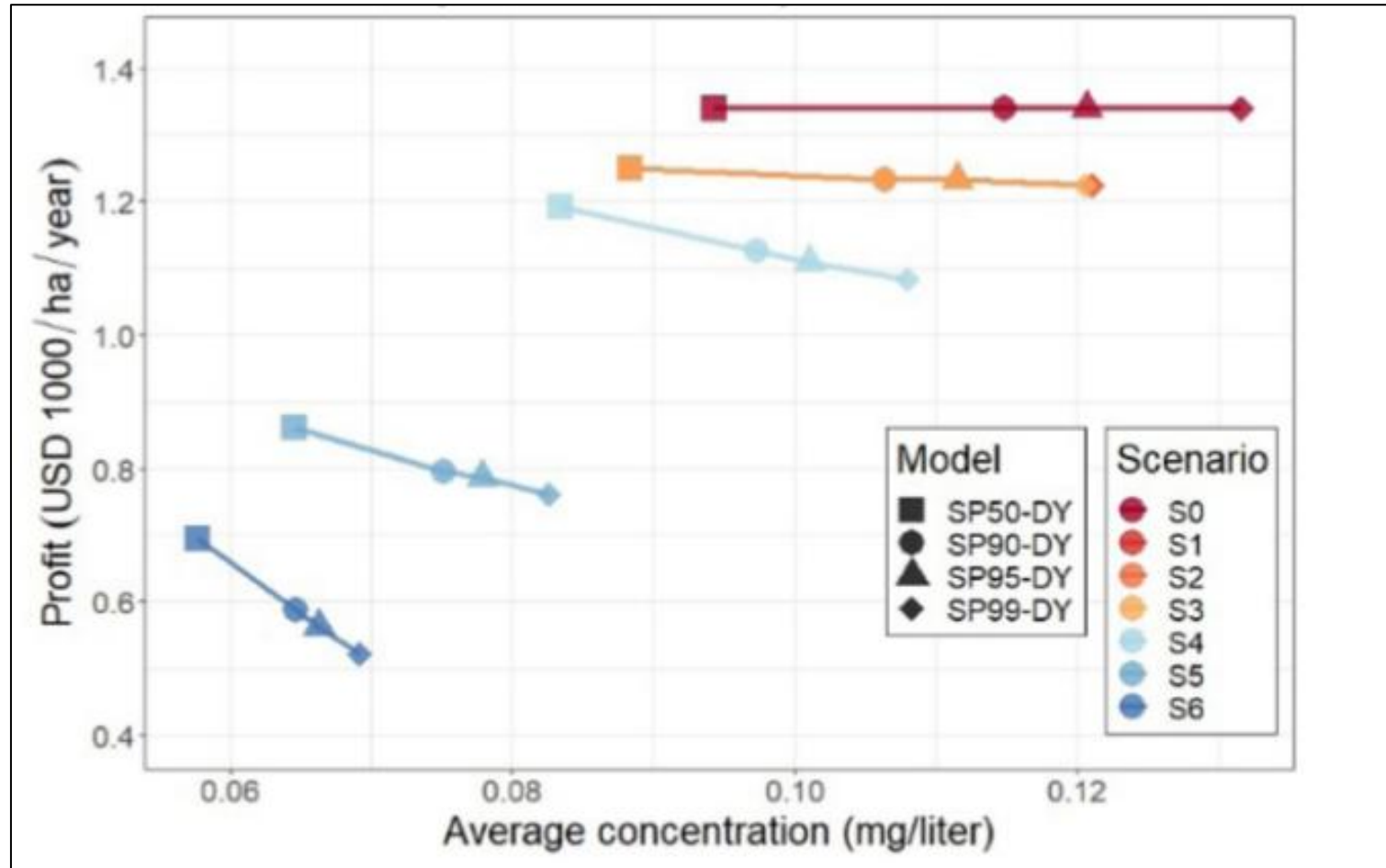


90% Confidence Level (Stochastic)

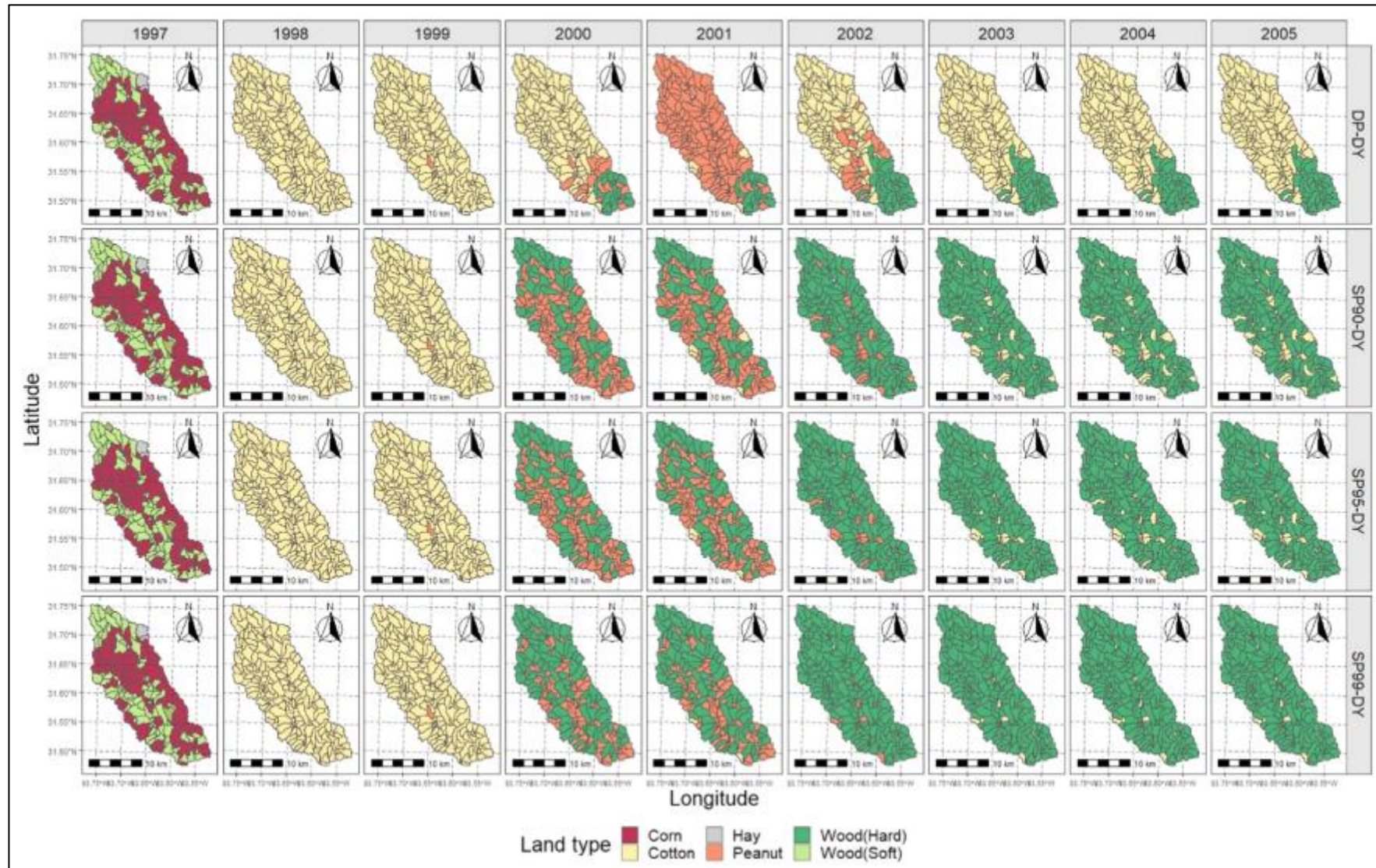
95% Confidence Level (Stochastic)

99% Confidence Level (Stochastic)

Stochastic DWID Model



Stochastic DWID Model



Publication

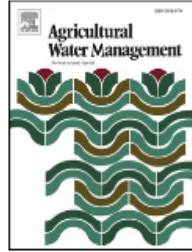
Agricultural Water Management 271 (2022) 107799

Contents lists available at [ScienceDirect](#)

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Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat



Designing Watersheds for Integrated Development (DWID): A stochastic dynamic optimization approach for understanding expected land use changes to meet potential water quality regulations



[Yu-Kai Huang](#)^{a,*}, [Ranjit Bawa](#)^a, [Jeffrey Mullen](#)^b, [Nahal Hoghooghi](#)^c, [Latif Kalin](#)^d,
[Puneet Dwivedi](#)^a

Stochastic DWID Model

DWID Modeling Approach

Advantages

- Tradeoff analysis for optimal policy designs
- Spatial targeting (better utilization of money and time)
- Signifies the role of forestry in meeting water quality expectations
- Highly customizable & applicable to watersheds at the global level

Disadvantages

- Time Intensive

Final thought...

Better watershed policy needs both physical routing and economic response, and, most importantly, uncertainty belongs in the decision-making framework.

Social dimensions are critical.



Thanks!

Puneet Dwivedi, Ph.D.

Professor | Glenn '65 and Heather Hilliard Endowed Chair in Environmental Sustainability

Clemson University | Department of Forestry and Environmental Conservation

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