Resilience to Extreme Events in Social Ecological Systems of the Lake Champlain Basin

(Basin Resilience to Extreme Events, BREE)

BREE IAM Status and Development Plans

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BREE Overarching Research Question

What are properties within the Lake Champlain Basin that drive hydrologic and nutrient responses to extreme events, and what are strategies for increasing resilience to protect water quality in the social ecological system?

WORKING HYPOTHESIS

The structure and state of systems can either dampen or amplify the cascading impacts of extreme events as their effects flow through the Social Ecological System of the Basin

FOCAL EXTREME EVENTS

- We define “extreme events” as “meteorological phenomena such as high temperature and precipitation with consequent events that are system responses, such as floods or droughts (Field et al. 2012)”.

- Following specific extreme events are being investigated by the BREE team in the hydro-meteorological context of the Lake Champlain Basin:

  (1) heavy and persistent precipitation and resulting floods;

  (2) intra-annual and inter-annual droughts;

  (3) heat waves;

  (4) cold snaps; and

  (5) extreme changes in the distribution of precipitation form (snow to rain).

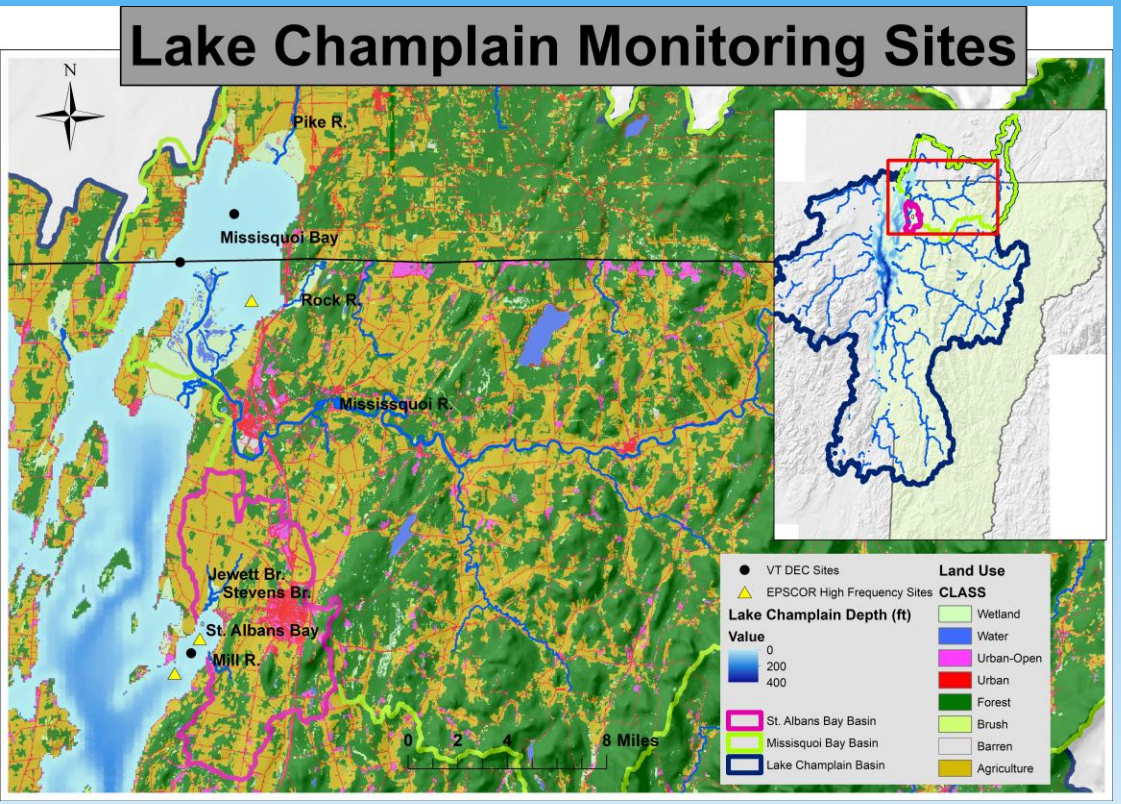
BREE
Basin Resilience to Extreme Events
in the Lake Champlain Basin

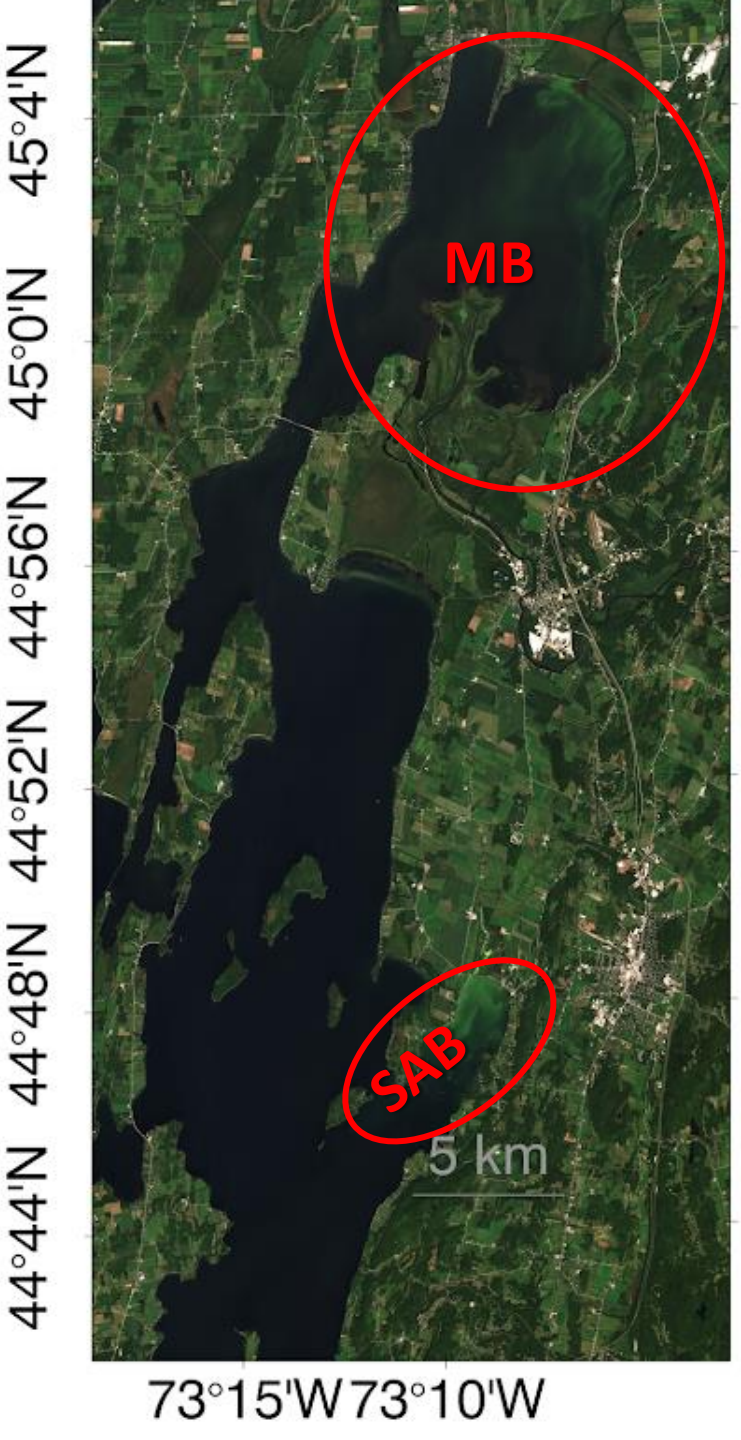
IAM Research Question: What strategies for resilience can be implemented to manage the risk from extreme events and what are the trade-offs for prioritizing public sector investments?

Extreme hydro-climatic event

Risk from change of state in the bay: mesotrophic to eutrophic

IAM Focal SES: Missisquoi & St. Albans





Shallow eutrophic systems that differ in terrestrial and open water connectivity

Adaptive Management Approach to Identify Resilient Strategies

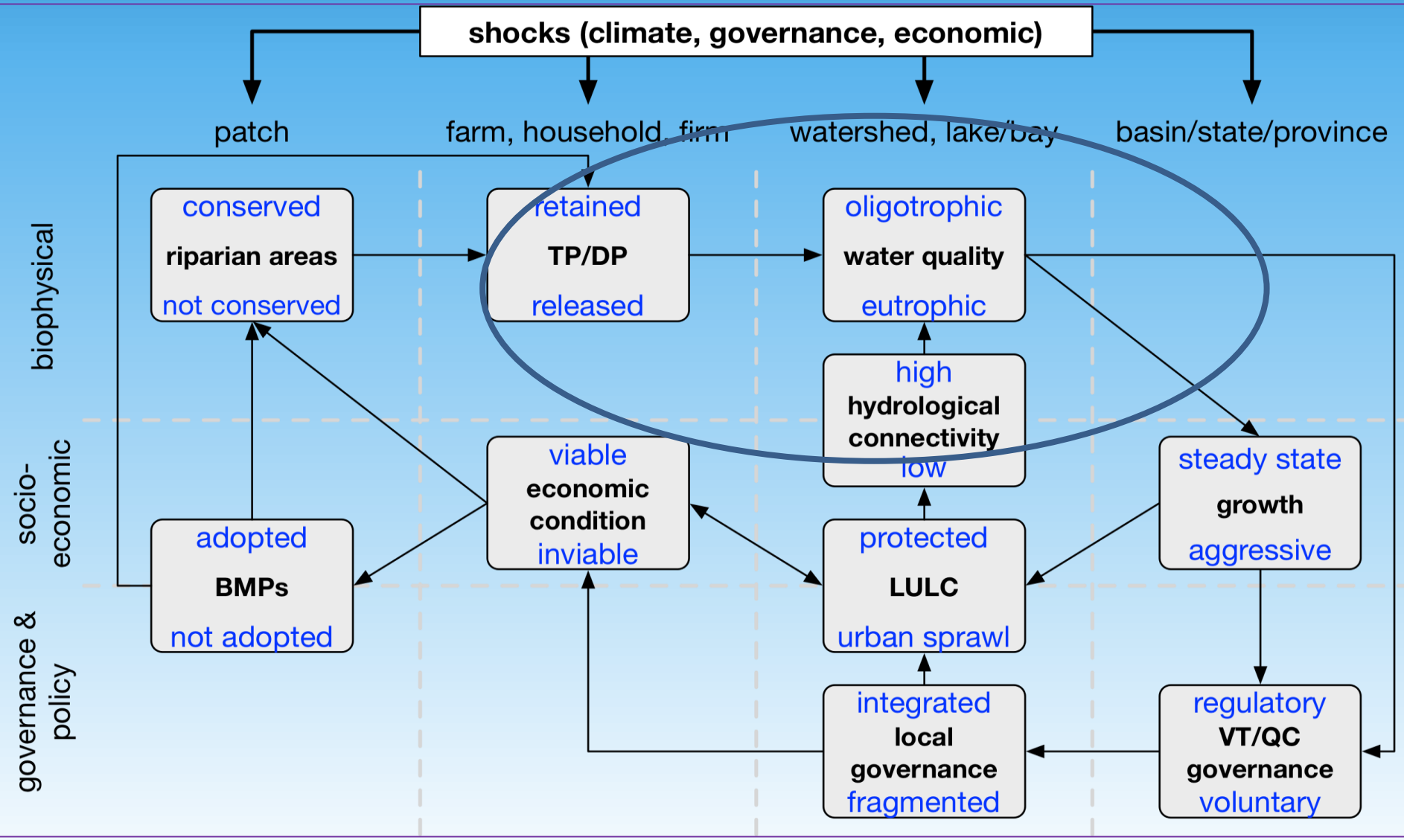
BREE IAM Policy & Technical Advisory Committee (PTAC) consensus on two definitions of resilience:

1: "The Lake Champlain Basin system should maintain critical functions after an event without significant post-event inputs" [Ex-Secretary, Agency of Agriculture]

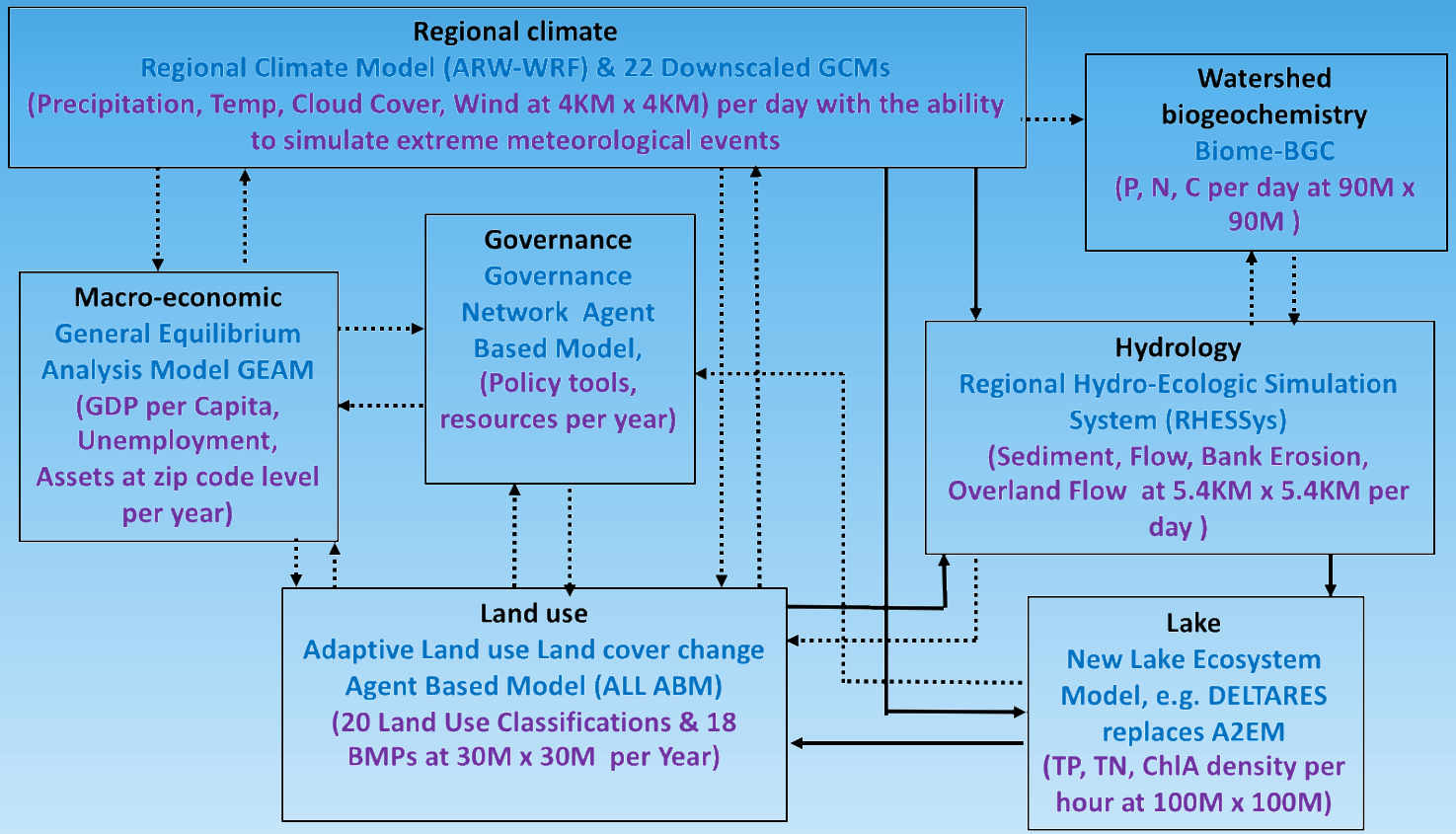
2: Ability to provide for public safety and property for as many people as possible affordably [Town Manager, St. Albans]

Identification of resilient strategies thus requires shared understanding BY ALL STAKEHHOLDERS of "desirable" alternate states in focal SES that maintain critical functions and maximize public interest

Hypothesized alternate states in the focal SES



BREE IAM V1.0: A modular, multi-scalar approach to test SES behavior in a computational IAM



Feedforward IAM can explore "baseline" SES behavior under various extreme event scenarios. Feedbacks and couplings will enable comparisons

→ Integration is enabled in BREE IAM

⇢ Integration is being tested/planned in BREE IAM

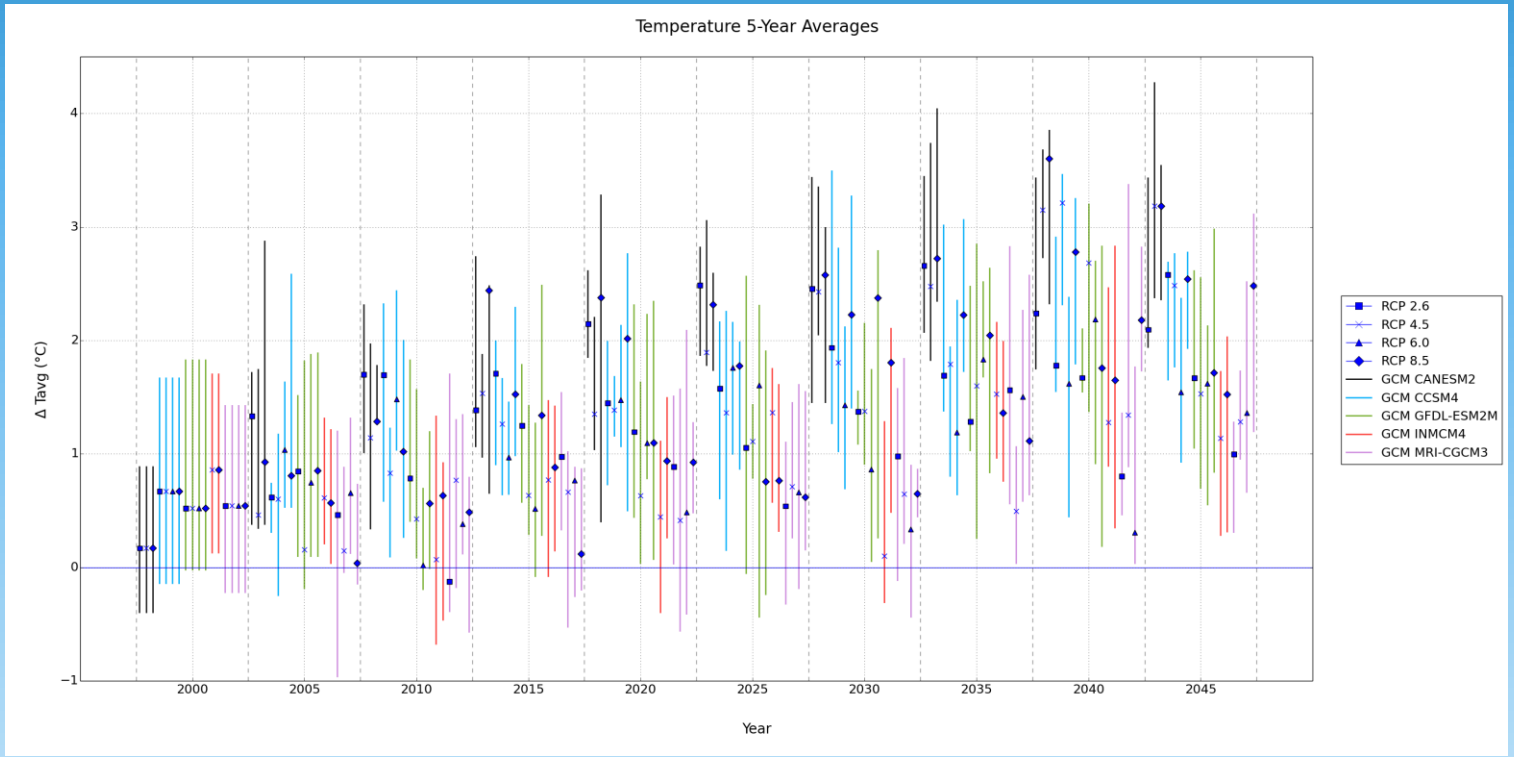
Papers in development from the current IAM configuration

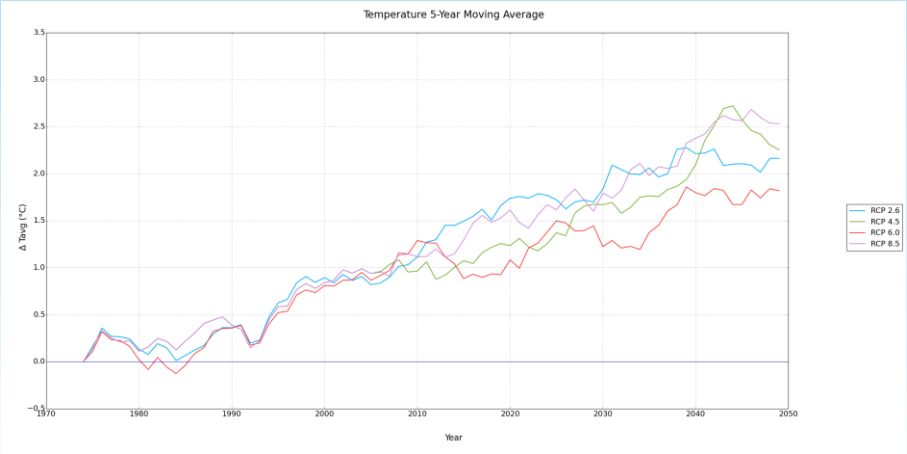
1. **Feedforward IAM mid-century projections under different climatic and P reduction scenarios**
2. Feedforward IAM end of century projections under different climatic and land use scenarios
3. Feedforward IAM P loading: quadratic vs weighted vs threshold based regressions
4. Feedforward IAM: Sensitivity of HABs to changing variance in temperature and precipitation
5. Feedforward IAM: Farmer BMP adoption and P load reductions
6. Feedback-enabled IAM scenarios

"Ensemble Method" of Scenario Settings Used for Cascading IAM Version 1.1 Missisquoi Runs, 2000-2050

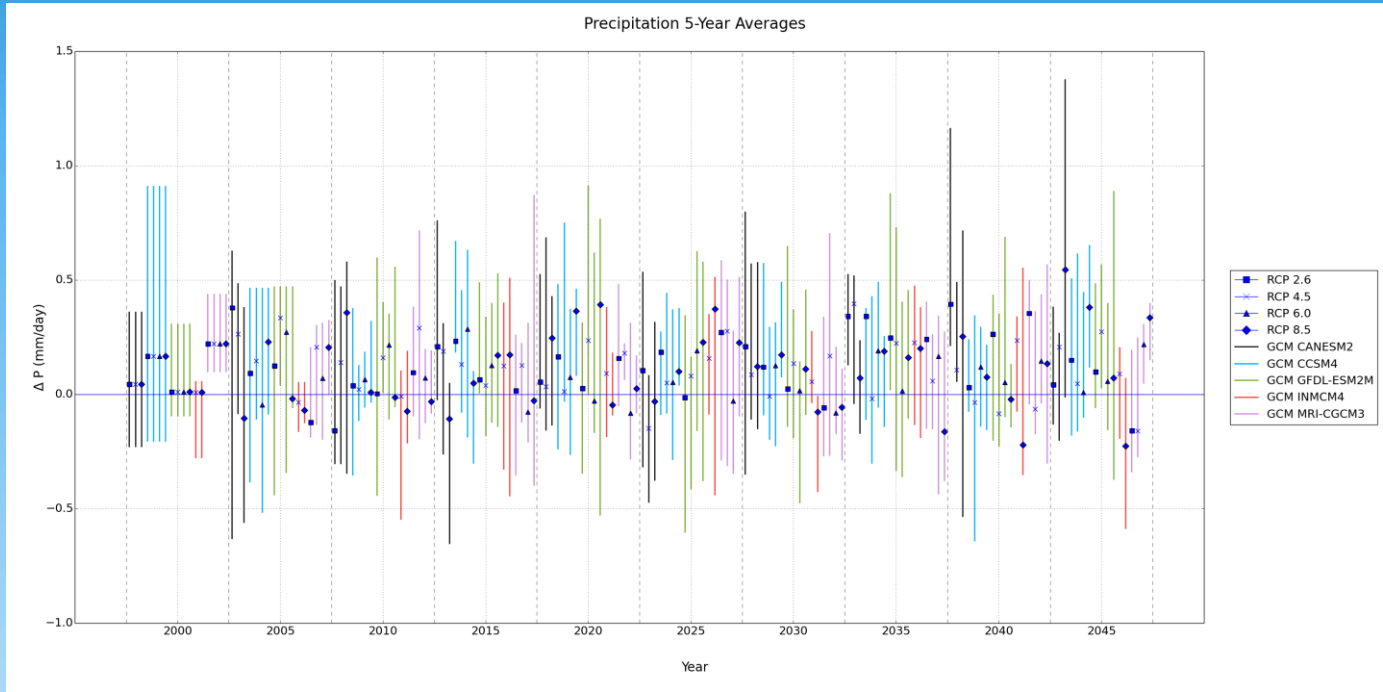
- **Four Climate Scenarios**: RCP 2.6, RCP 4.5; RCP 6.0 and RCP 8.5
  - Ensemble of five GCMs that are among the best to reproduce late 20th centruy North-Eastern US climatic conditions identified by Thibeault, J.M. and Seth, A., 2015. **Toward the credibility of Northeast United States summer precipitation projections in CMIP5 and NARCCAP simulations**. *Journal of Geophysical Research: Atmospheres*, *120*(19).
- **LULCC ABM Scenario**: Business As Usual
- **Hypothetical TP reduction scenarios for BAU LULCC ABM**
  - 100% TP reduction from 2016-2050 scenario (ex-Secretary Ag scenario)
  - 90%, 85%, 80%, **60%**...0% TP reduction scenario runs
- **Remaining settings are similar to IAM Version 1.0** (e.g. no additional changes in model settings and calibration as reported in Zia et al. 2016)

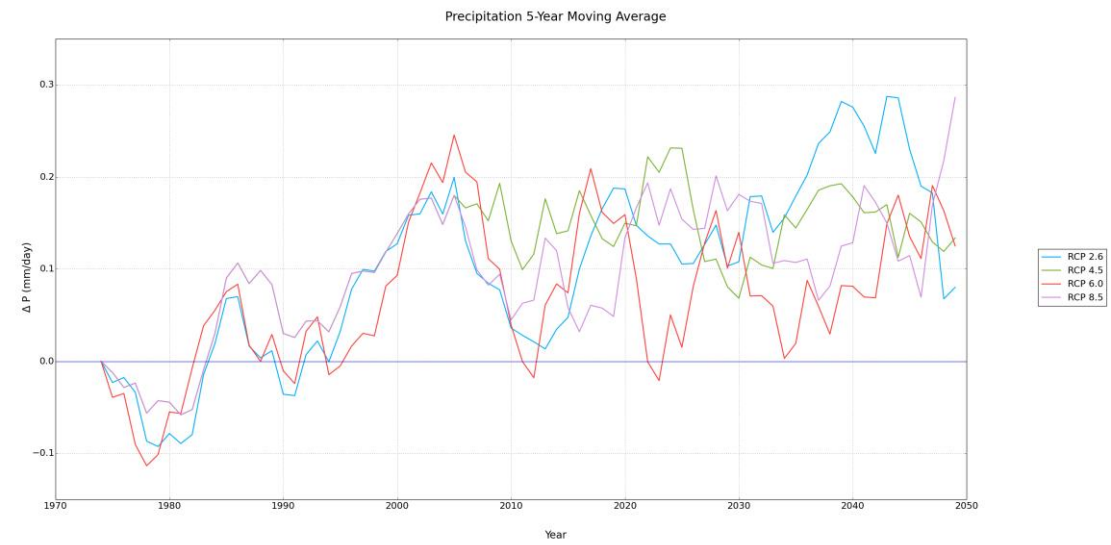
GCM Ensemble Projections, 2000-2050



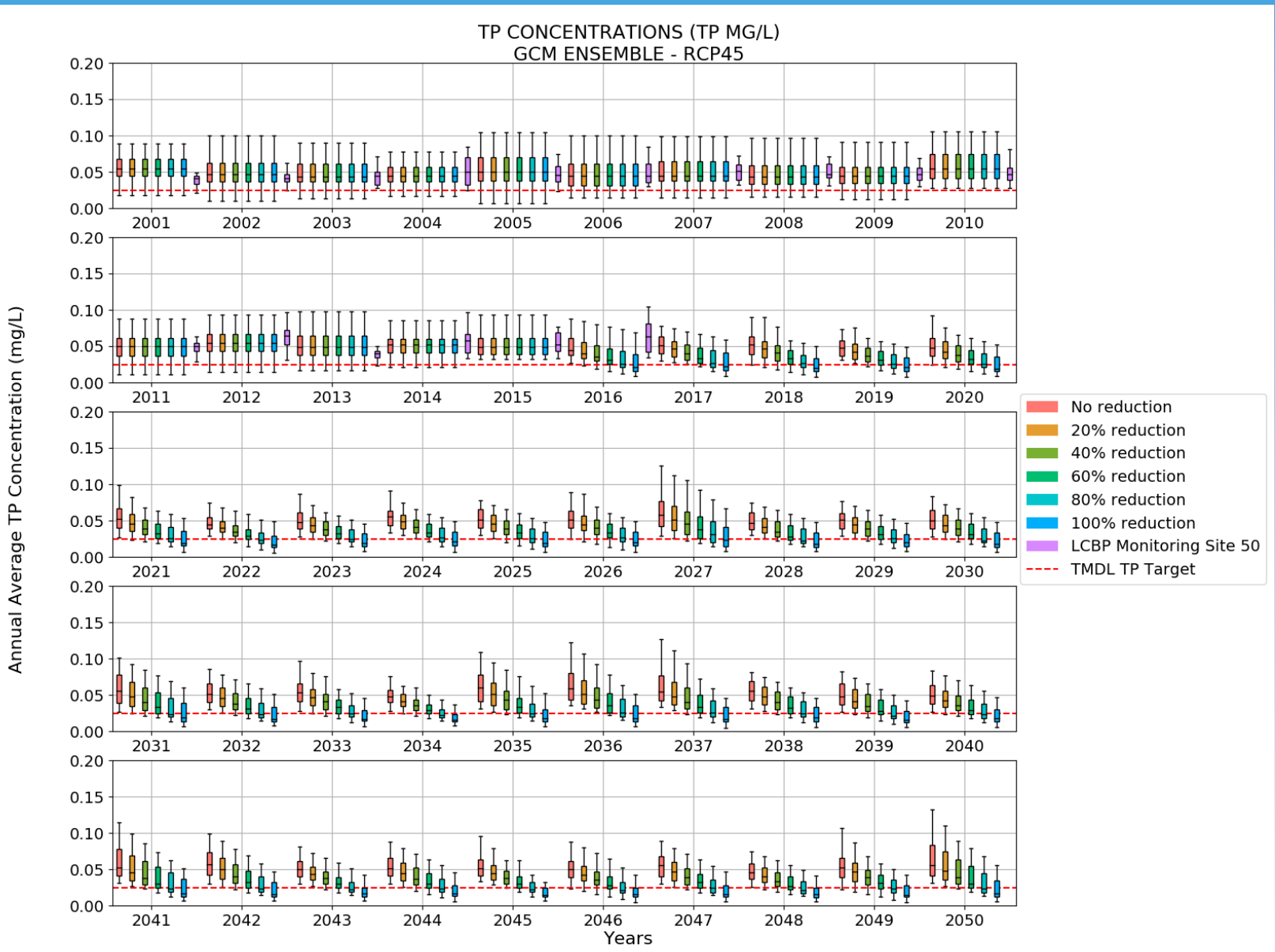


GCM Ensemble Projections, 2000-2050

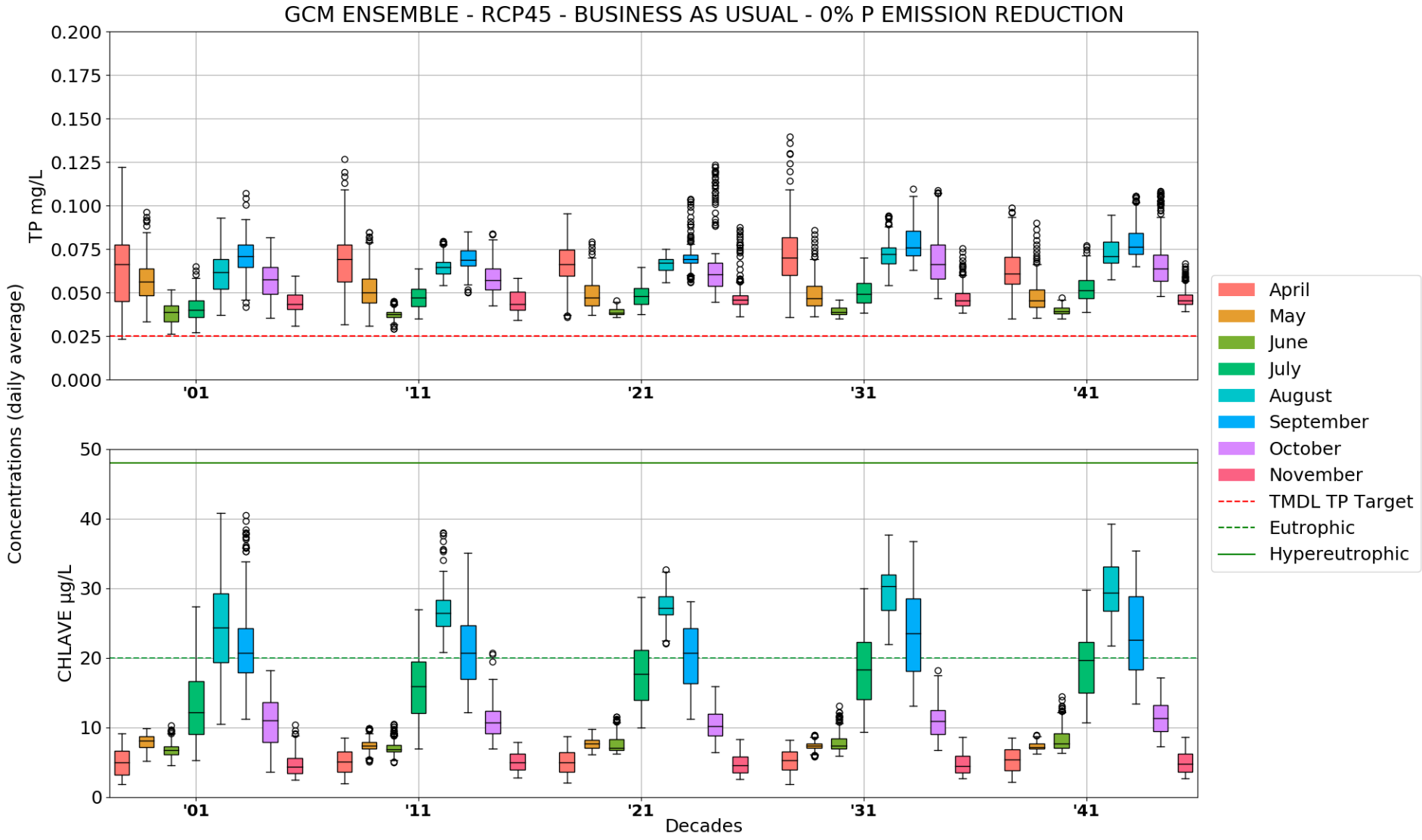




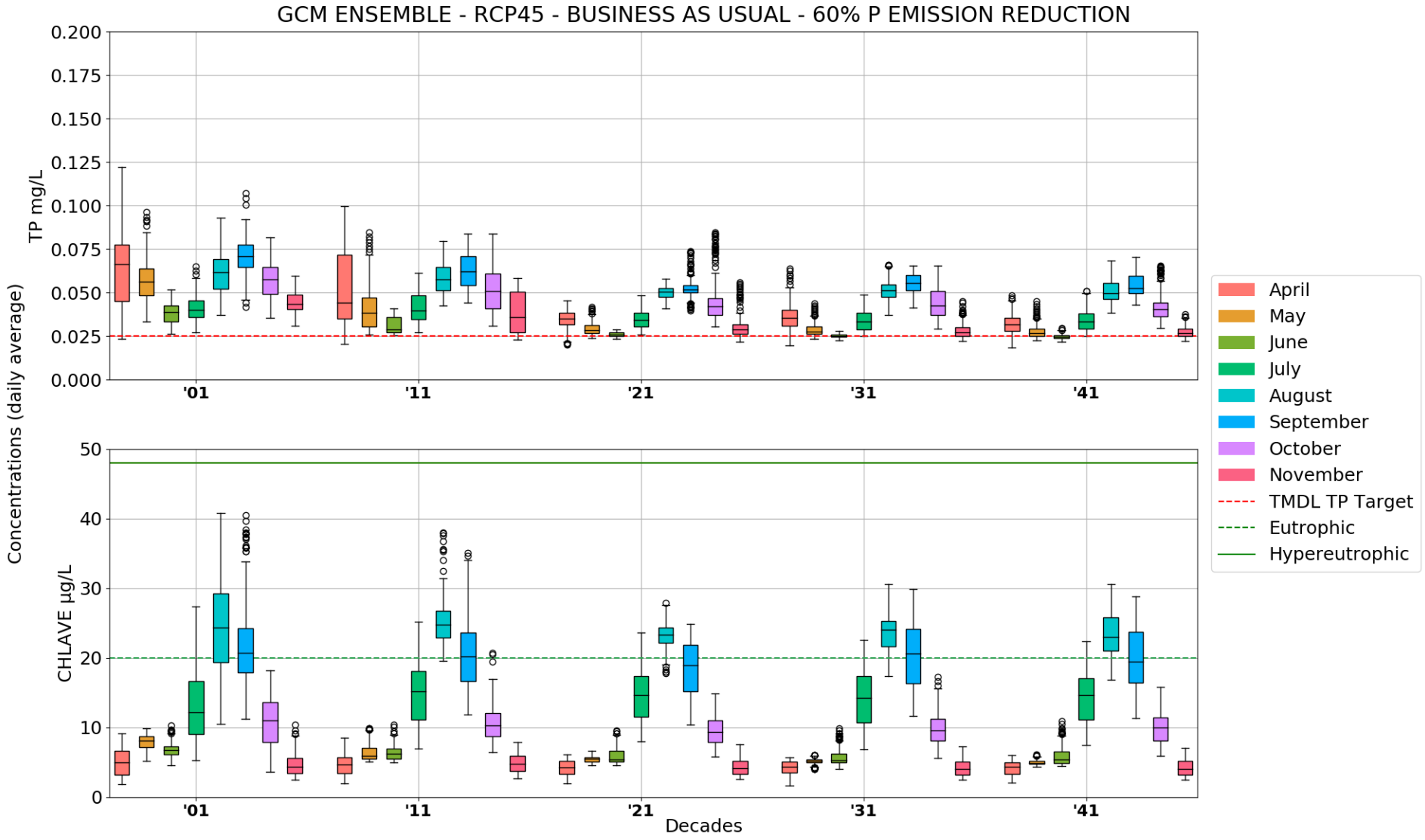
IAM projected TP concentrations for Missisquoi Bay site #50 under GCC stabilization RCP45 scenario for 0%, 20%, 40%, 60%, 80% and 100% TP loading reductions, compared with TMDL target of 0.025mg/L



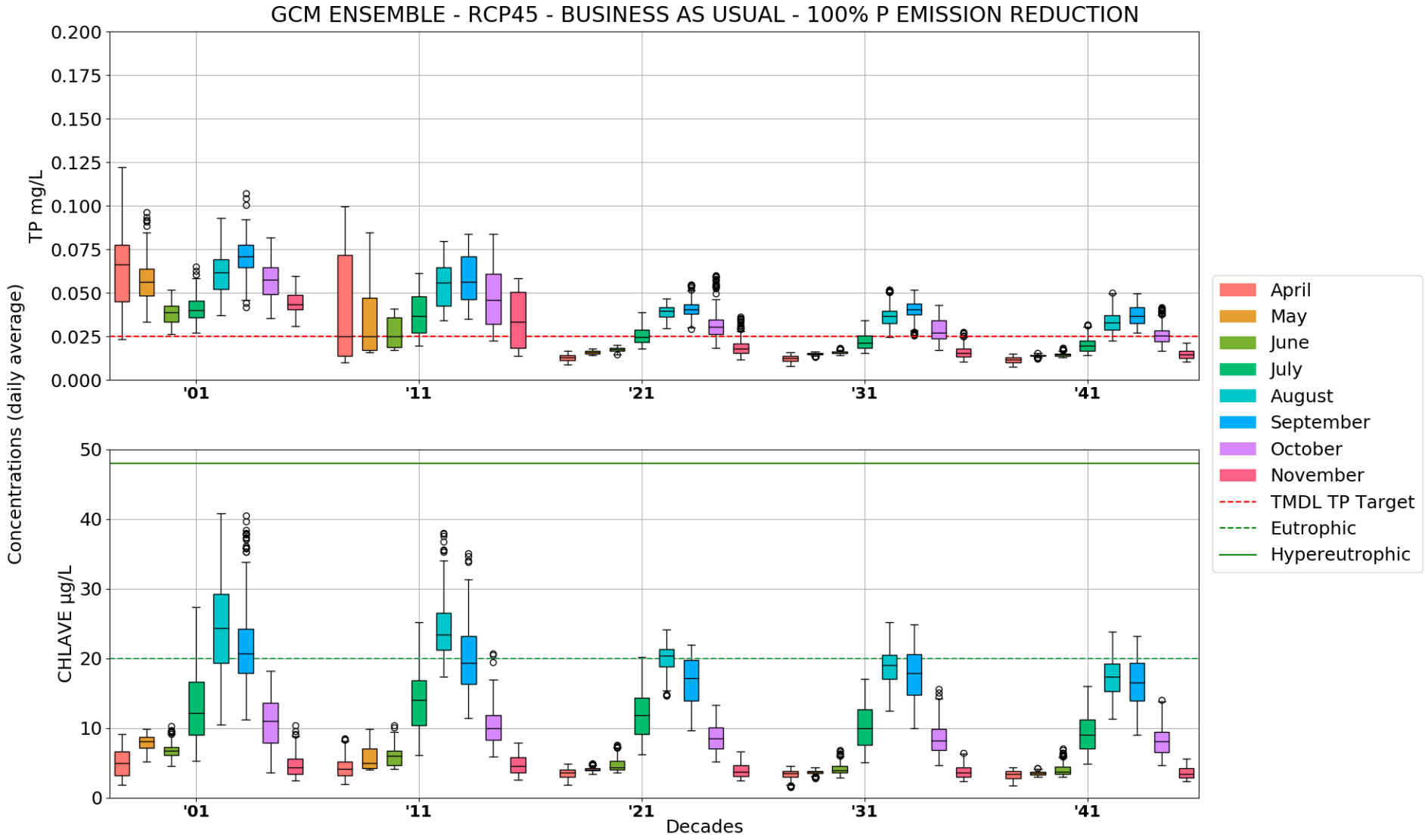
Projected TP and CHLA concentrations averaged for April through November for five decades (2000-2050) under GCC stabilization RCP4.5 scenario for **0% TP load** reductions



Projected TP and CHLA concentrations averaged for April through November for five decades (2000-2050) under GCC stabilization RCP4.5 scenario for **60% TP load** reductions

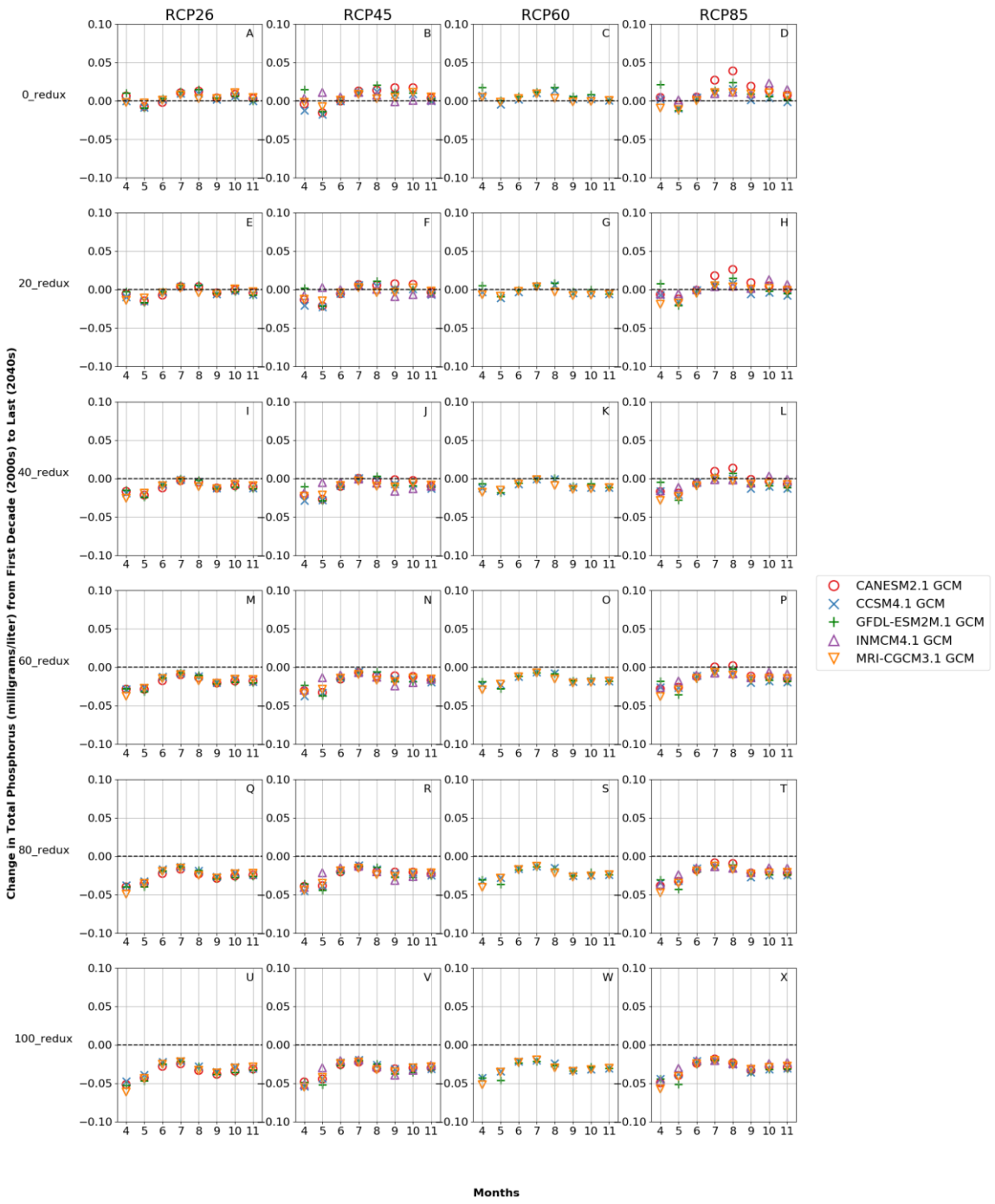


Projected TP and CHLA concentrations averaged for April through November for five decades (2000-2050) under GCC stabilization RCP4.5 scenario for **100% TP load** reductions



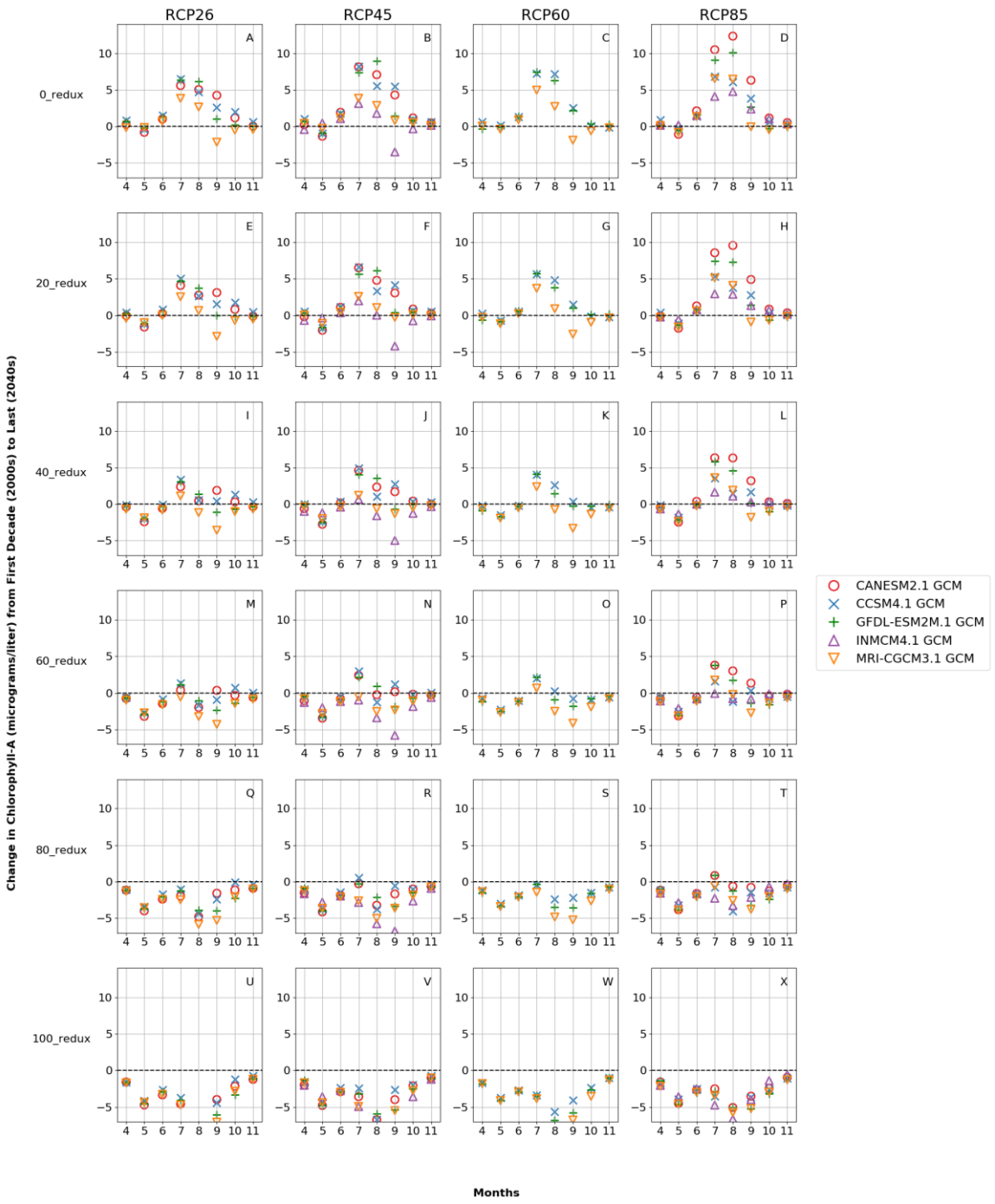
Projected changes in TP mg/L from the baseline first decade 2000s to mid-century 2040s under four GCC scenarios for 0% to 100% TP load reduction scenarios under BAU land use scenario

Relative sensitivity of TP to GCC vs TP loading reduction scenario is being estimated

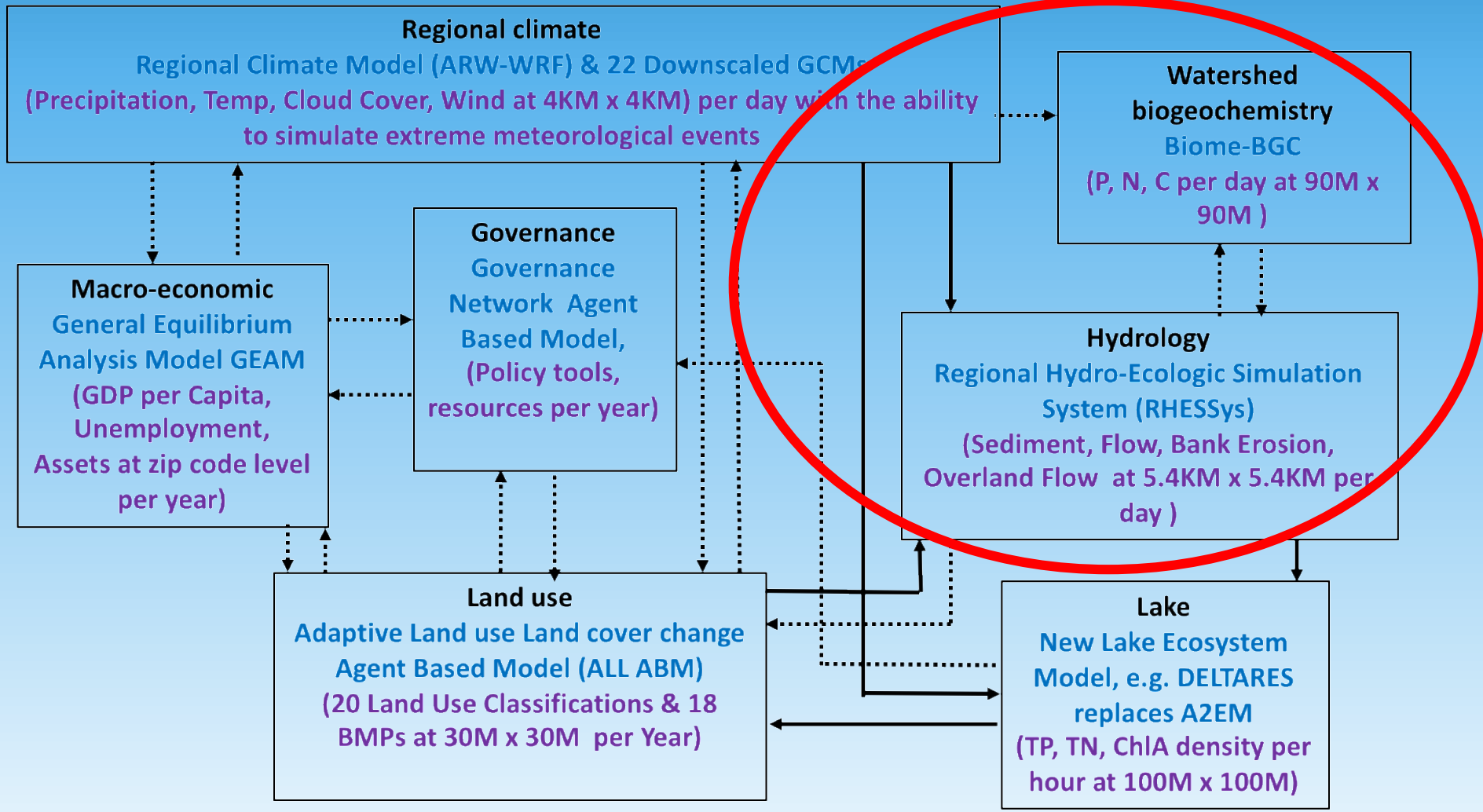


Projected changes in ChlA mg/L from the baseline first decade 2000s to mid-century 2040s under four GCC scenarios for 0% to 100% TP load reduction scenarios under BAU land use scenario

Relative sensitivity of ChlA to GCC vs TP loading reduction scenario is being estimated



BREE IAM DEVELOPMENT PLAN: INTEGRATION OF RHESSys WITH BIOME-BGC



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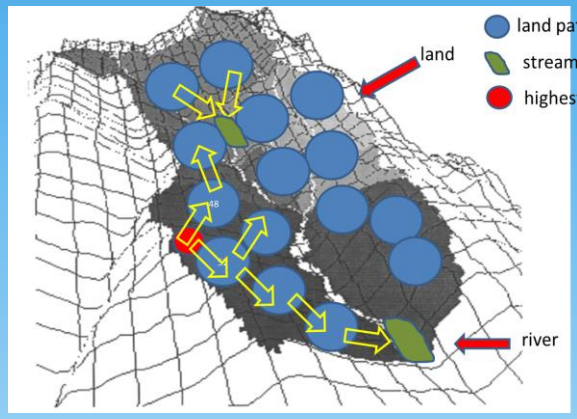
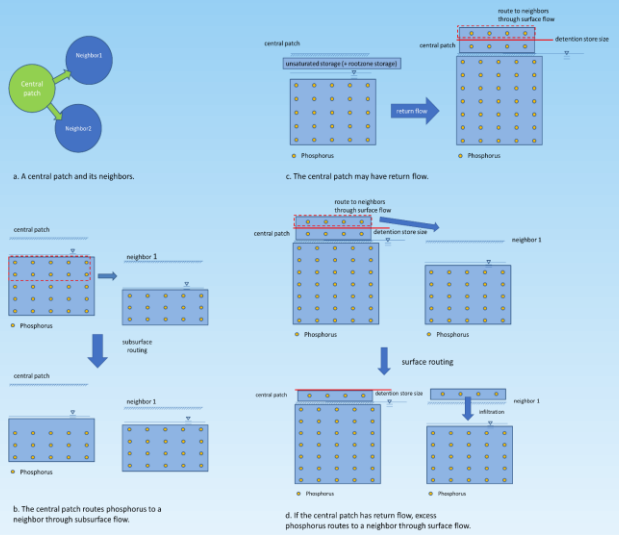
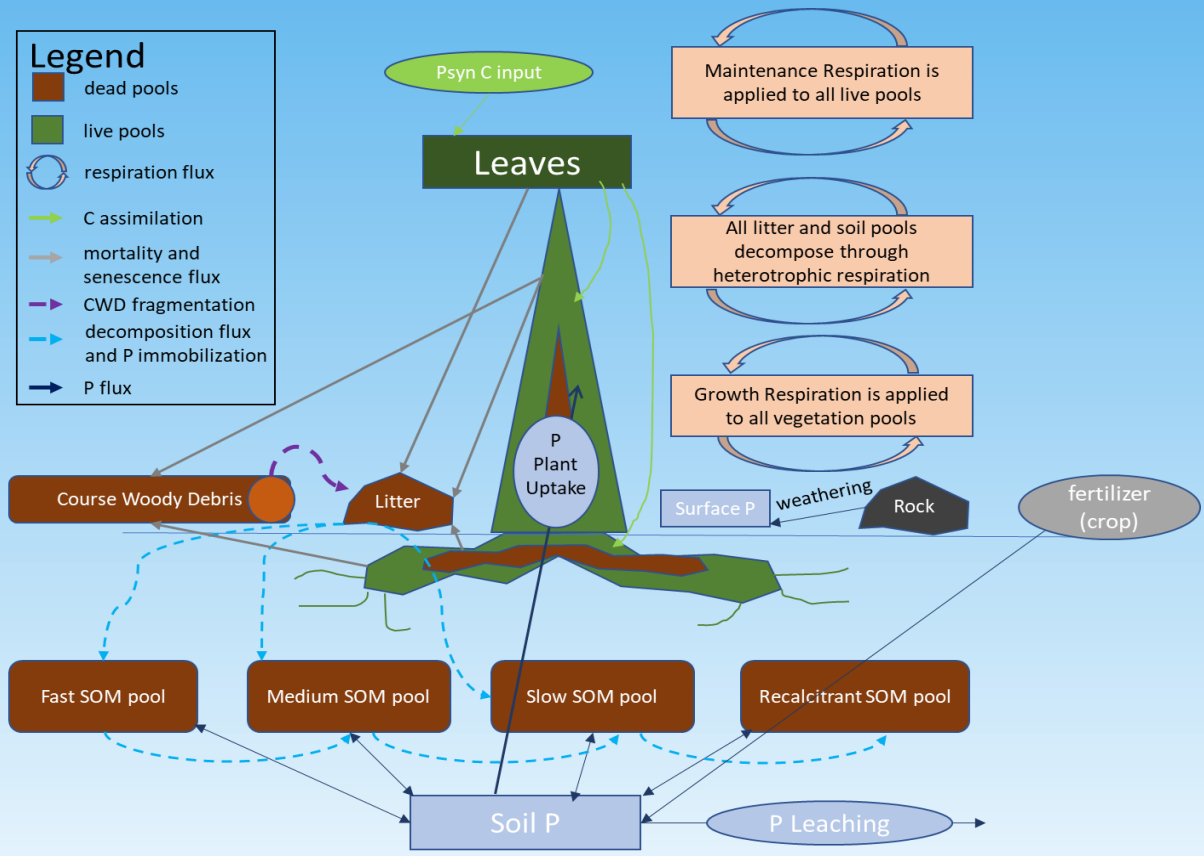
RHESSys-P development framework: Shang et al.



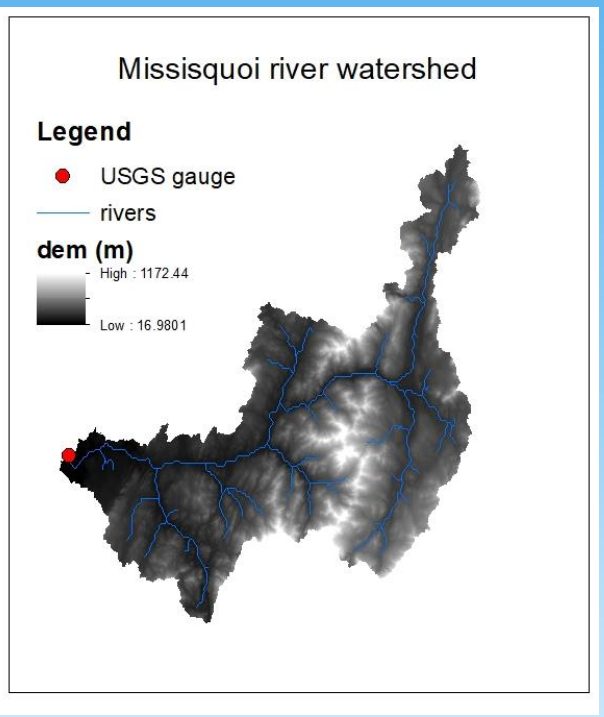


Explicit routing scheme for RHESSys-P

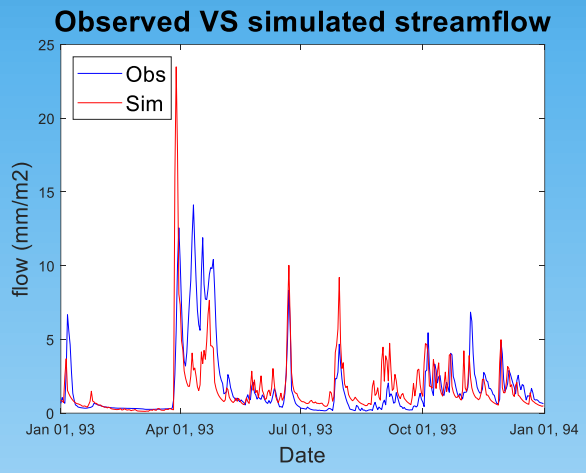


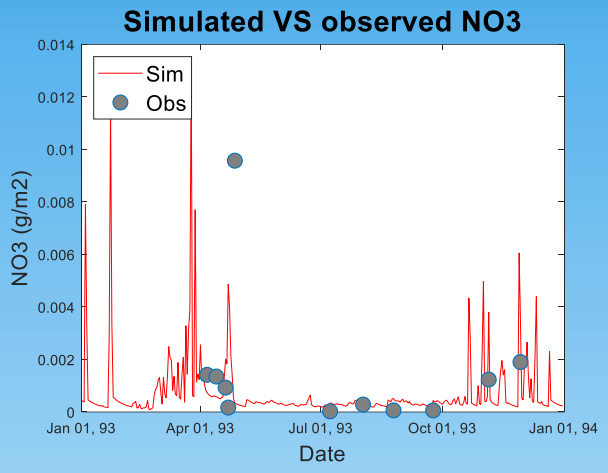
Phosphorus pools and fluxes in RHESSys-P

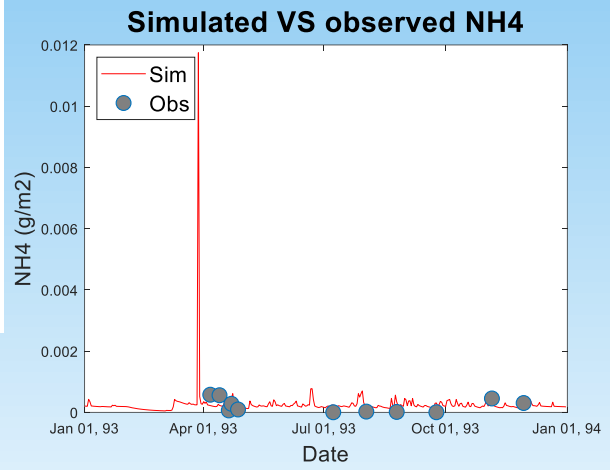
Preliminary RHESSys-P Calibration Results

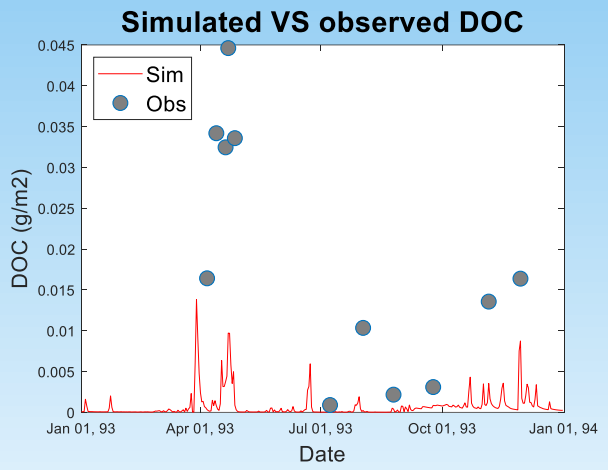


Missisquoi river watershed and USGS gauge









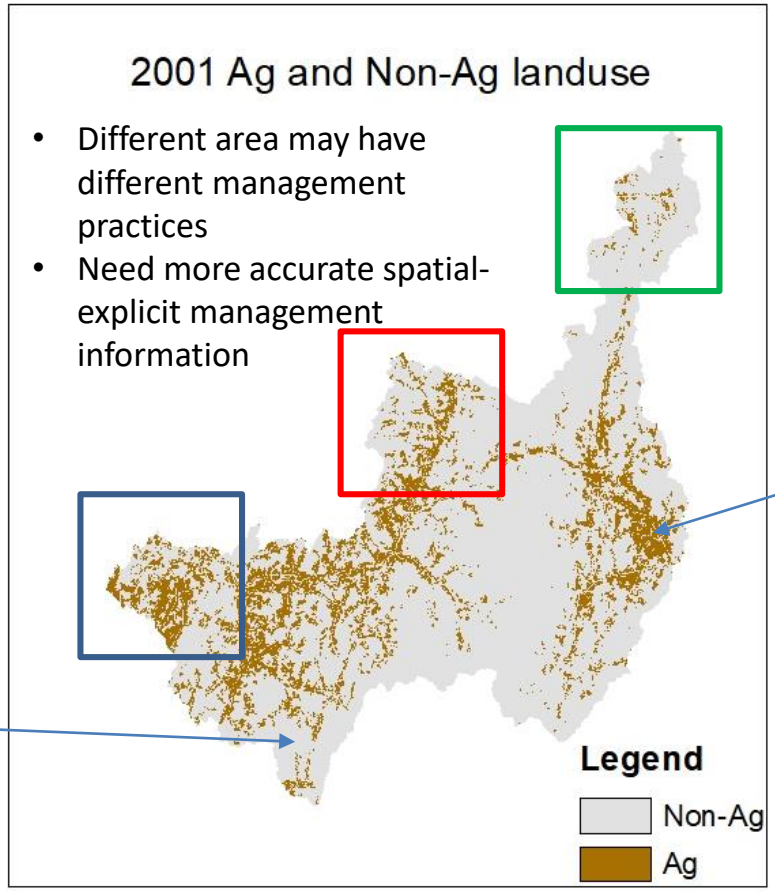
Preliminary calibration results of streamflow, NO3, NH4 and DOC for the year 1993

Agriculture Land Management Data Gap

Scheme
- Fertilizer (DIP)
- Fertilizer (DOP)
- Harvest date
- …

Scheme 0

For Non-Ag



For Agriculture land, currently, assume the same practice for all agriculture land

Scheme 1

DIP

Date	Amount
1991/5/20	3 (g/m2)
1992/5/20	3 (g/m2)

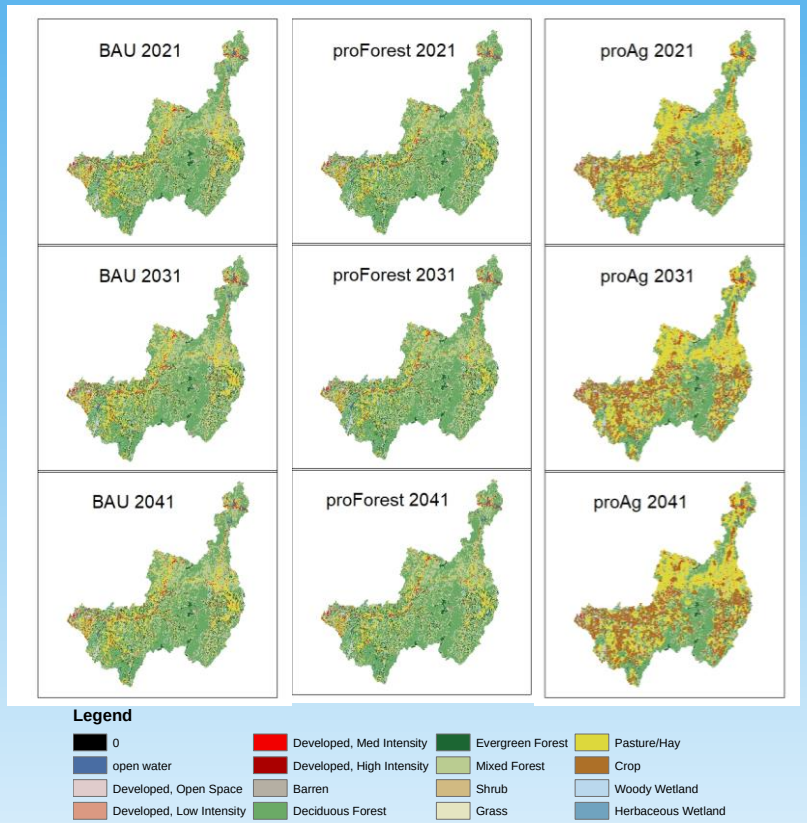
DOP

Date	Amount
1991/5/20	1 (g/m2)
1992/5/20	1 (g/m2)

Harvest

Date
1991/9/20
1992/9/20

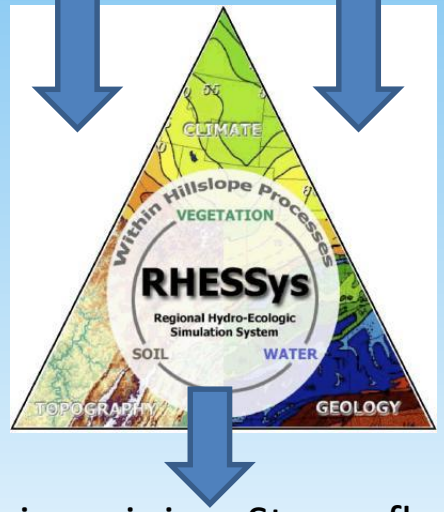
Climate change and LUCC impacts on Missisquoi river watershed being estimated under the new RHESSys-P model

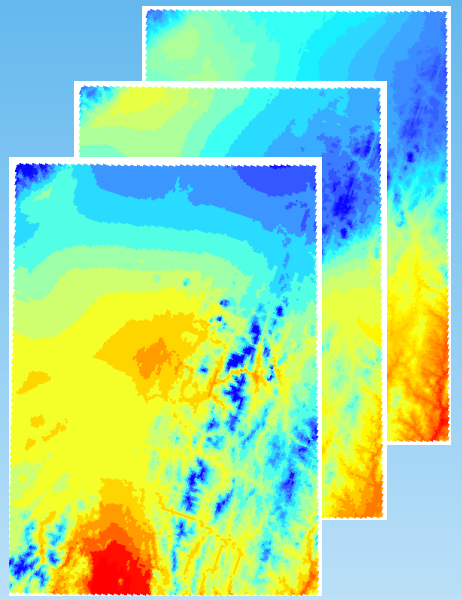


Landuse change for Business As Usual, proAg and proForest scenarios

Future Landuse

Future climate

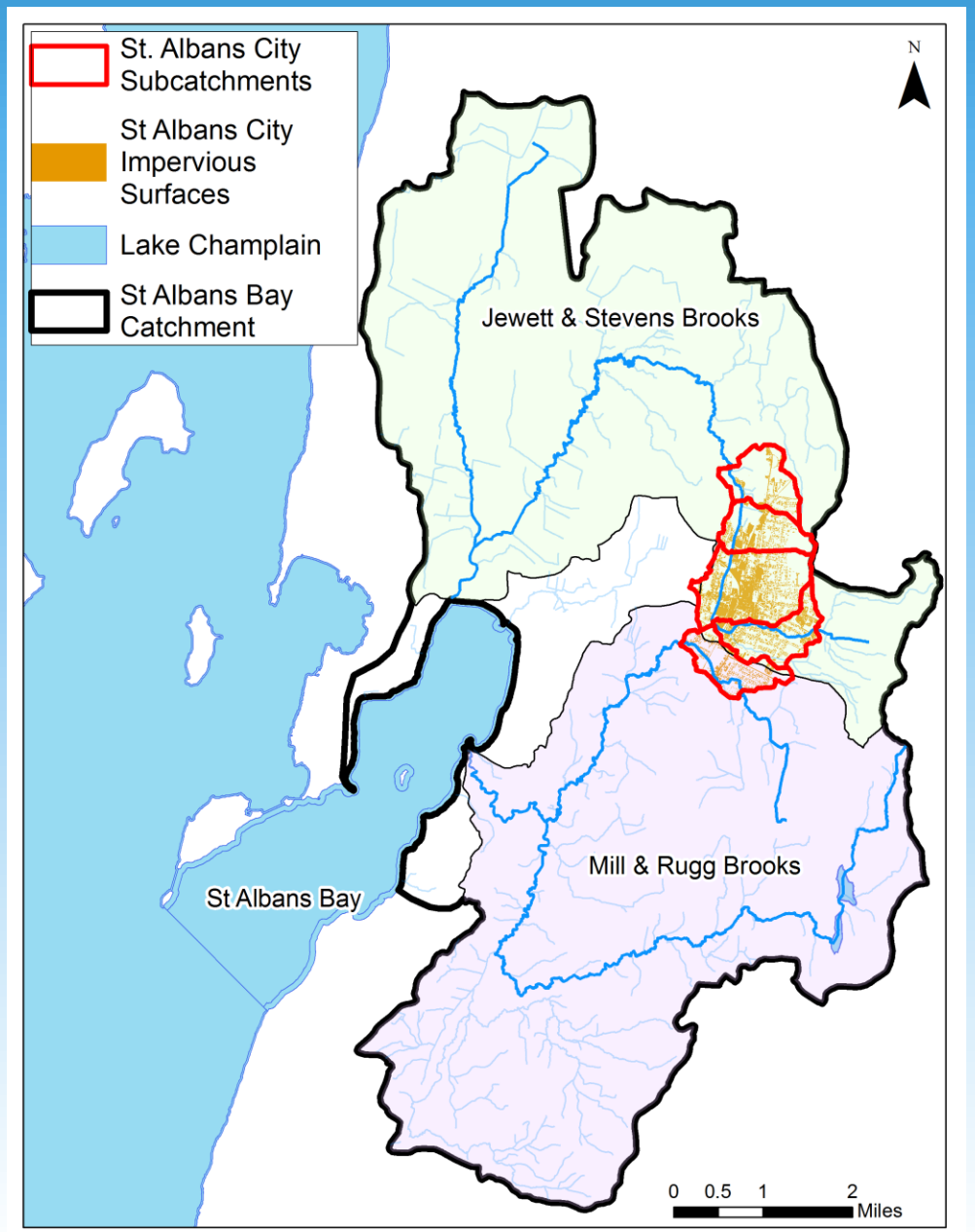




GCM downscaled climate data

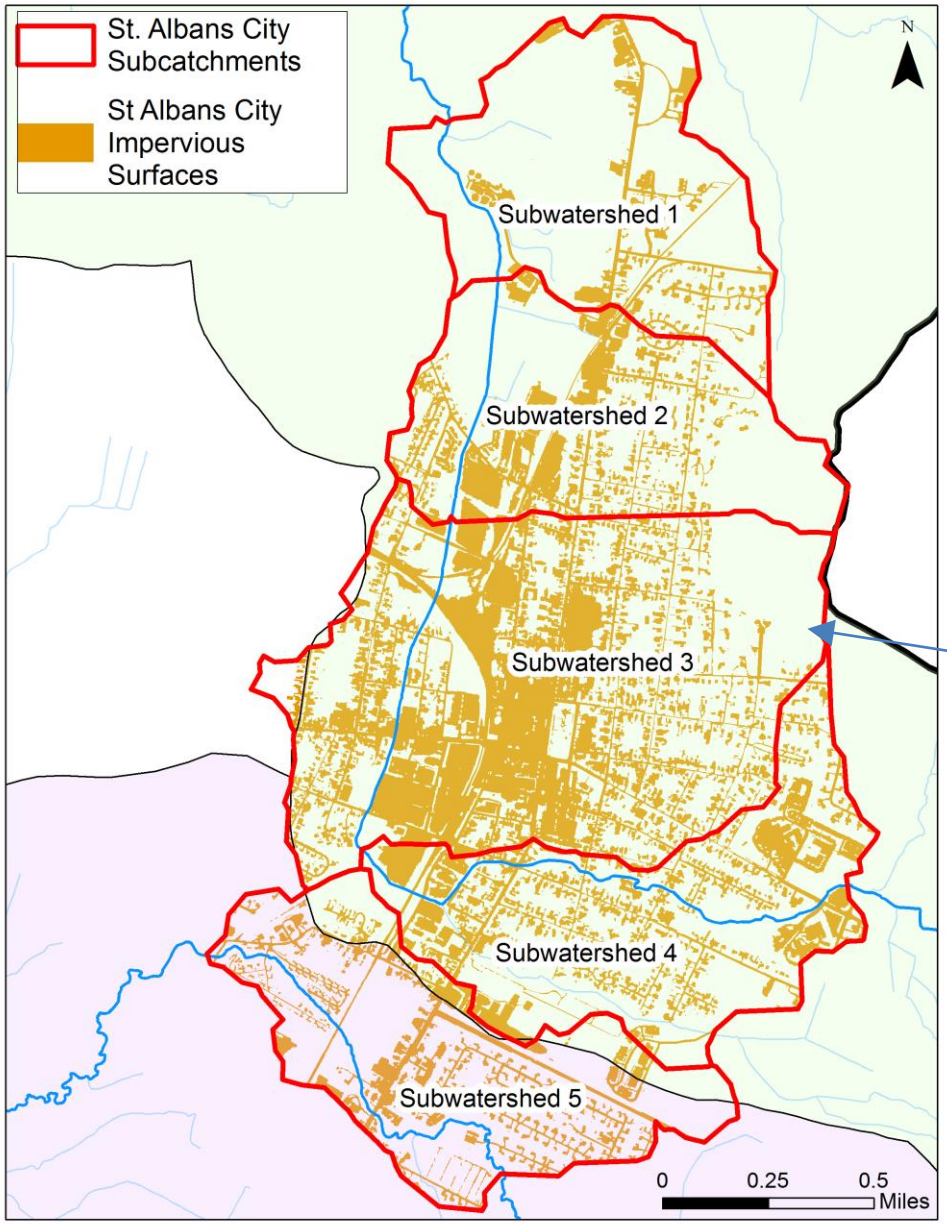
Missisquoi river Streamflow and nutrients

RHESSys-SWMM Integration for St. Albans SES



Enhance the hydrological model to include representation of urban stormwater infrastructure: SWMM model linked with Rhessys

RHESSys-SWMM Integration



Spatial stormwater infrastructure data for stormwater (SWMM) model (pipe diameters, slopes, junctions, inlets, etc).

BREE IAM DEVELOPMENT PLAN: INTEGRATION OF RHESSys WITH LAKE MODELS

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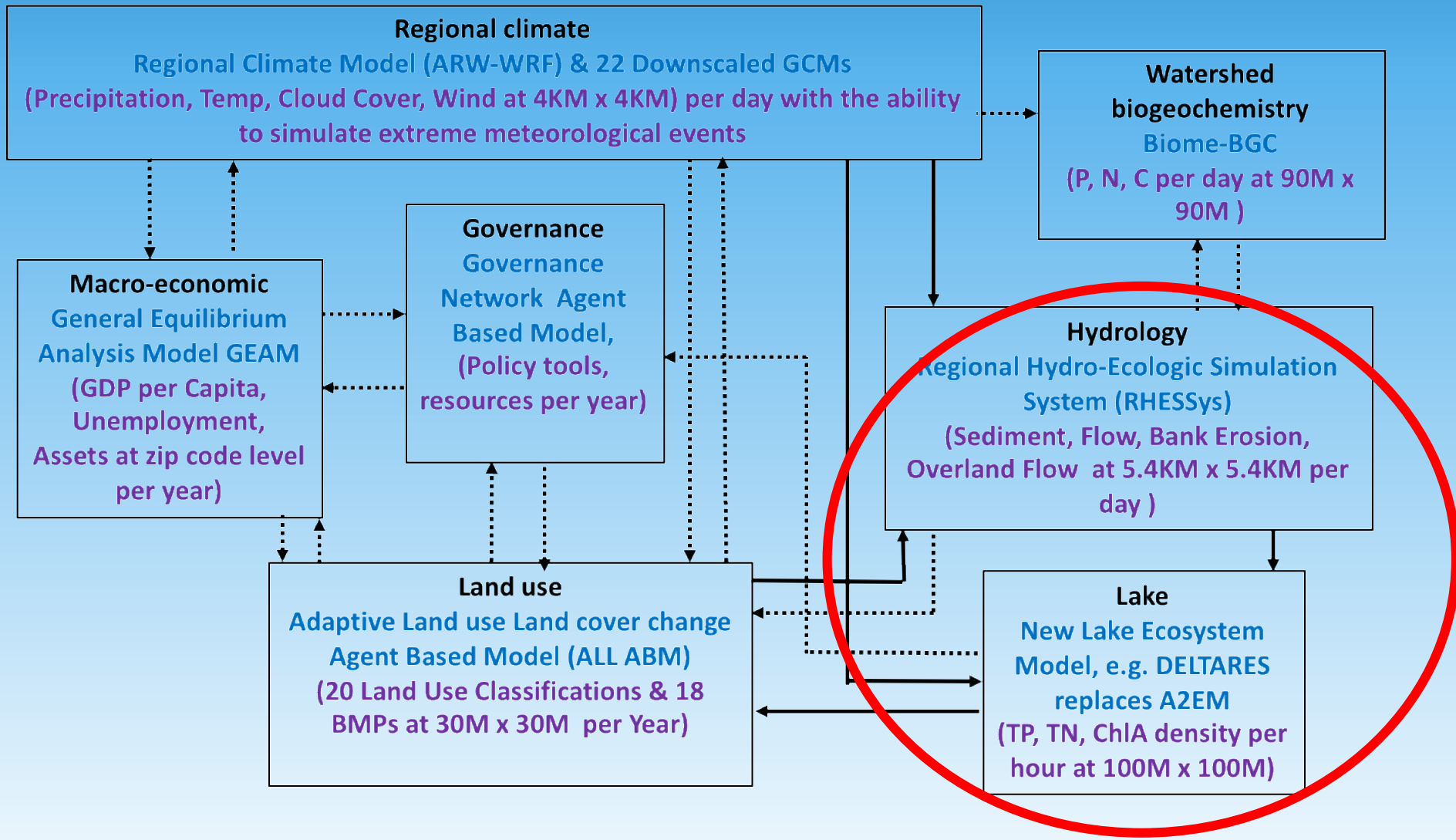
in the Lake Champlain Basin



→ Integration is enabled in BREE IAM

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New Hydrodynamic Deltares Model Flexible Mesh Grid and Initial Output

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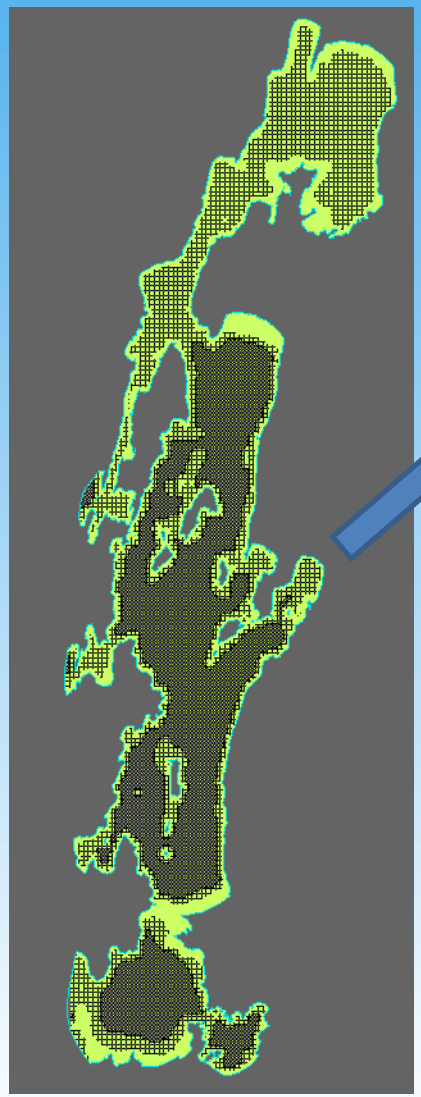
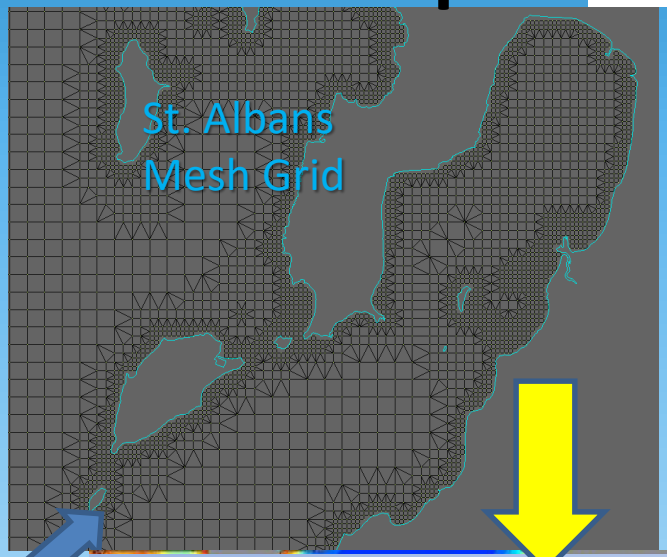
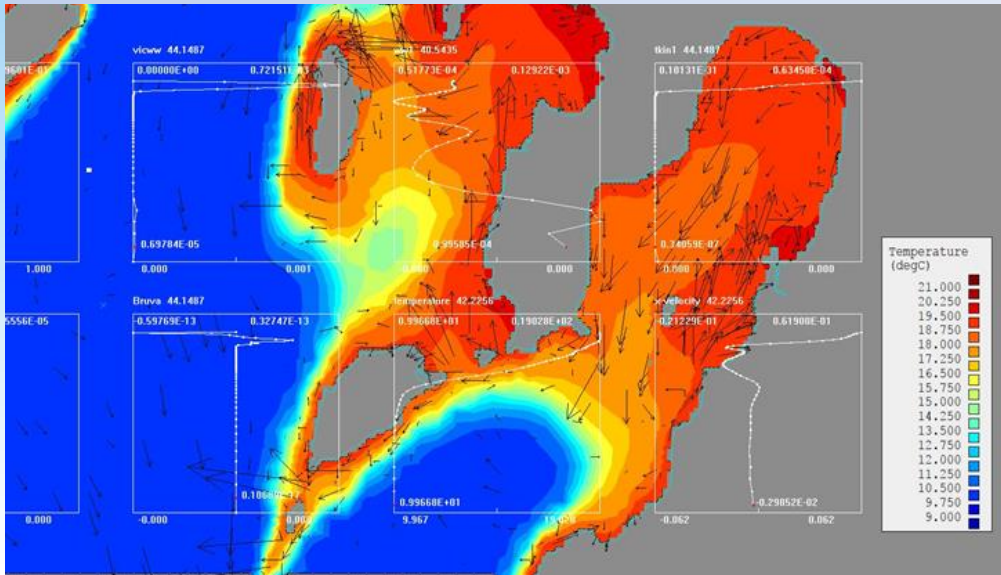




Coupling with Deltares's own DELWAQ or another open source model like CAEDYM, PCLake expected in 2018-19

Example Temp. and Velocity Output for St. Albans Bay Study Site



Inland Sea Early Temperature Calibration Results

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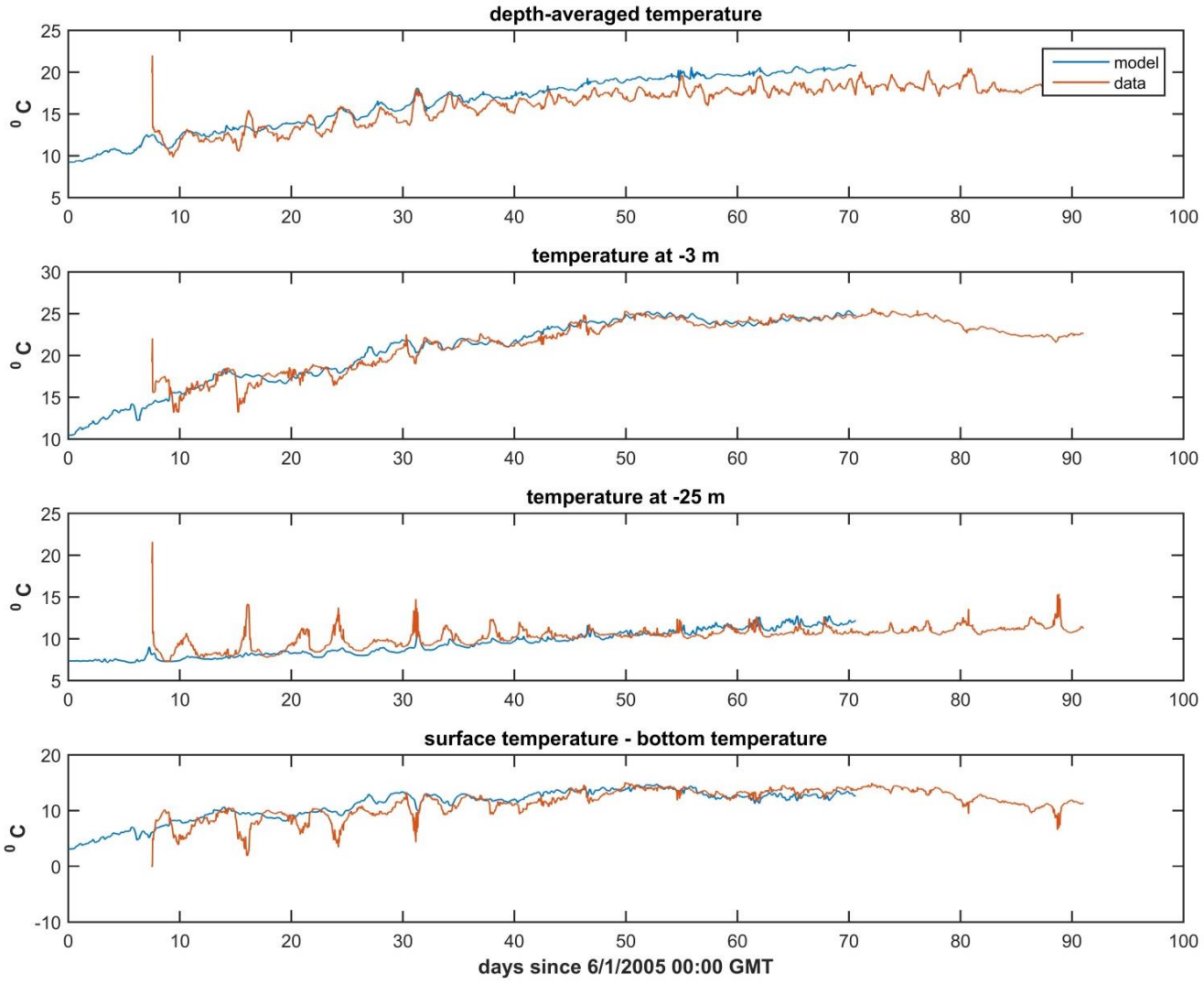
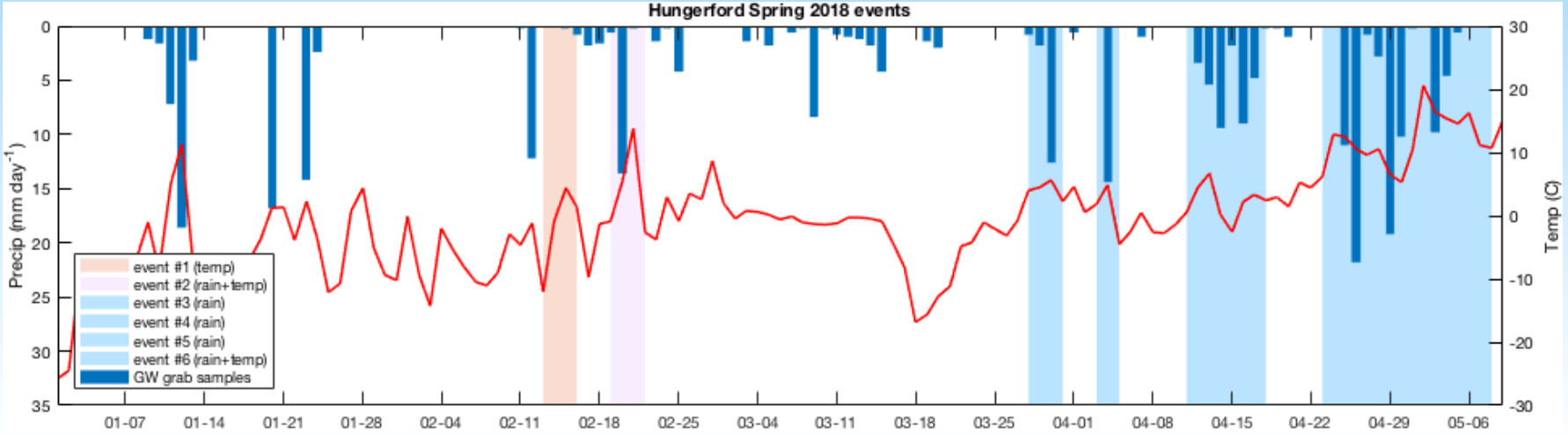


Erin Seybold

Postdoctoral Associate

BREE Ecology Team

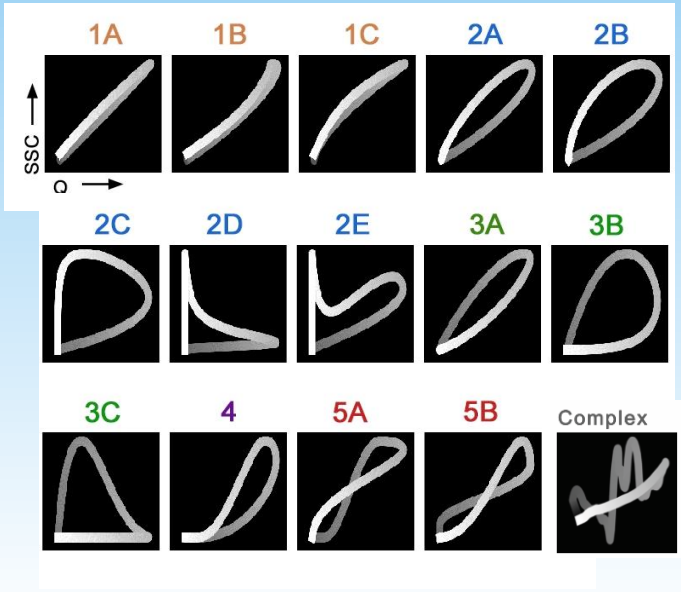
How do changes in snowmelt affect nutrient loading to Lake Champlain?

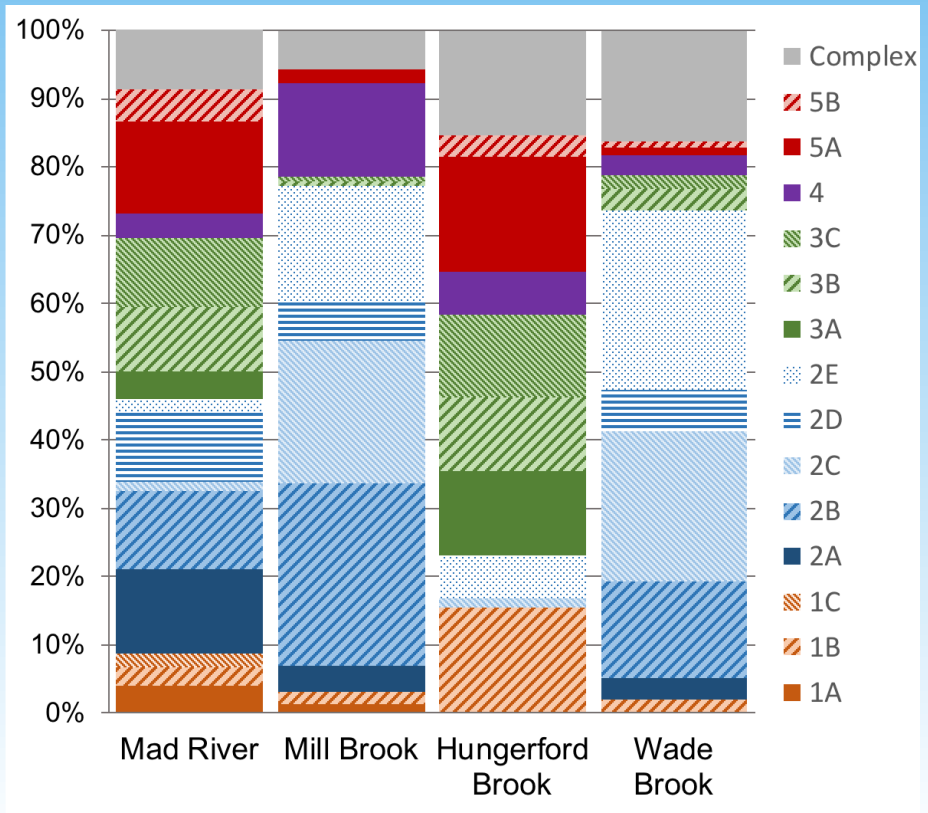


Applying Deep Learning to Hydrological Events

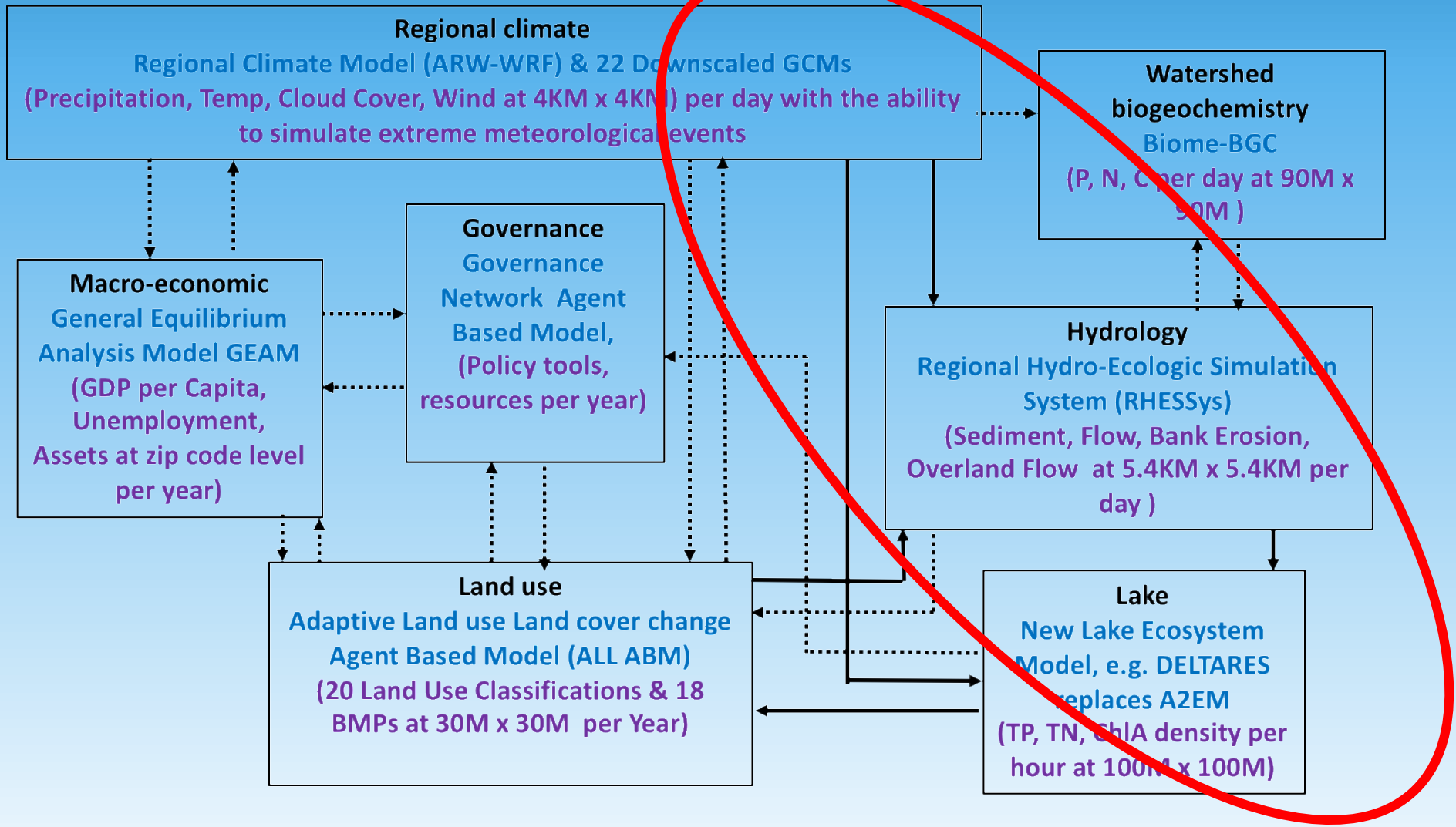
- *Can we use deep learning and a "library" of hydrological event types to characterize sources of sediment and nutrients from high- frequency sensor data?*

Dr. Scott Hamshaw





BREE IAM DEVELOPMENT PLAN: EXTREME EVENTS IN WATERSHEDS AND BAYS



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Climate Team Objectives

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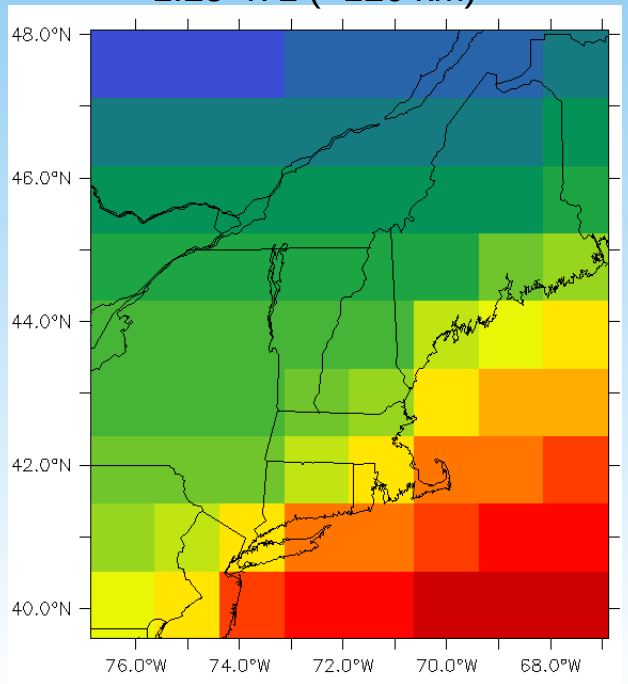
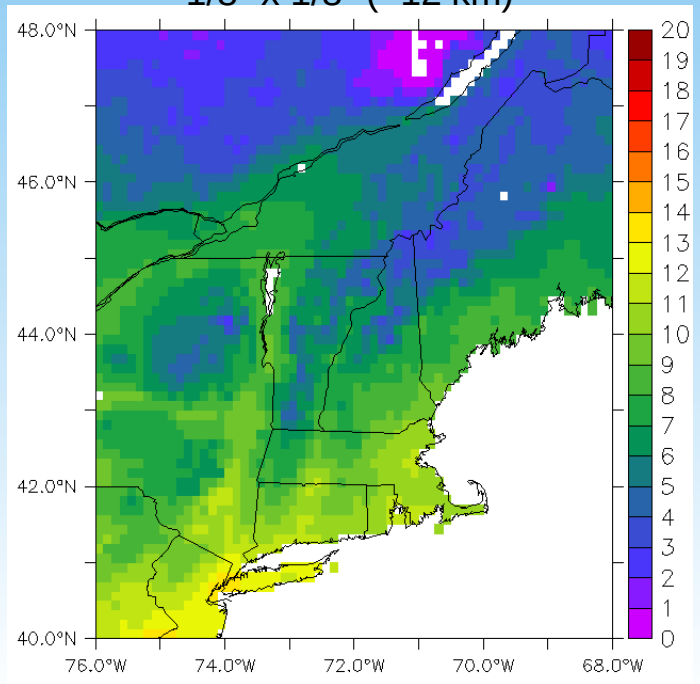
Basin Resilience to Extreme Events
in the Lake Champlain Basin

1. Deploy, calibrate, and evaluate a regional climate model (Weather Research and Forecasting Model; WRF)
2. Refine WRF to better capture extreme events (e.g., flooding, heatwaves, drought, cold snaps)
3. Work with Integration Team to include WRF climate scenarios in IAM

1.25º x 1 (~120 km)



1/8º x 1/8º (~12 km)



Deploy WRF: Nested Domains

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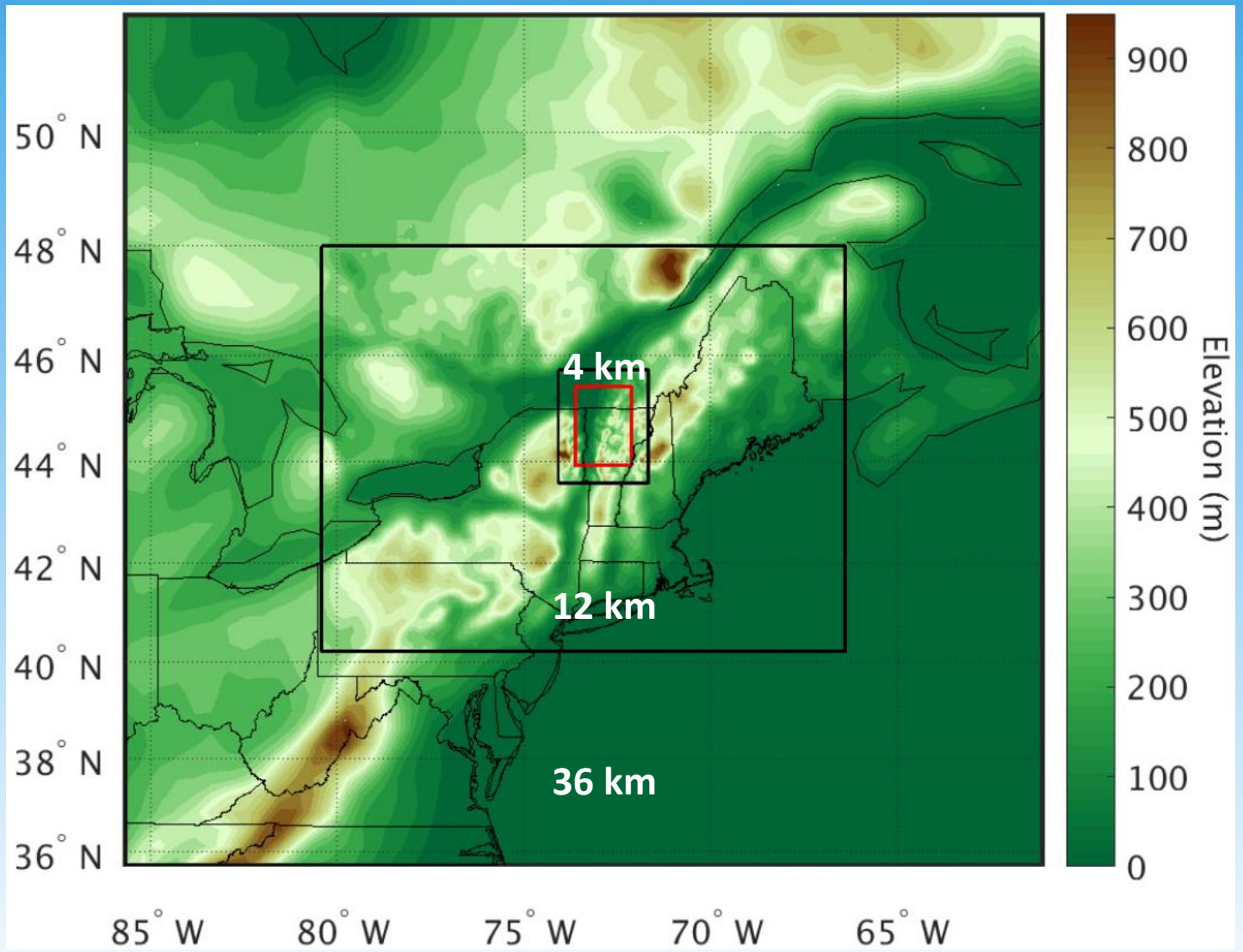
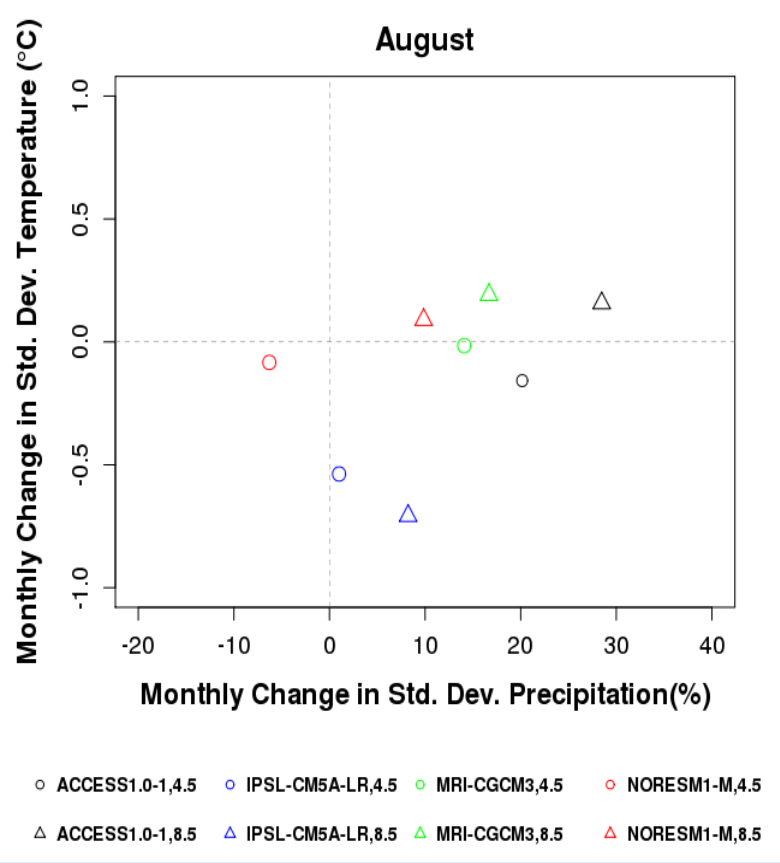
in the Lake Champlain Basin



Monte Carlo hypercube sampling experiments underway for simulating uncertainty in climatic variability and extremes in BREE IAM

- Compare daily precipitation and temperature simulated with plausible climate scenarios:
  - Baseline (1980-2009)
  - Future (2036-2065)
- Compute monthly changes in statistical moments and distribution parameters
- Examine changes in extreme events
- Perturb Daymet gridded data (1980-2009) using scenario-informed monthly changes



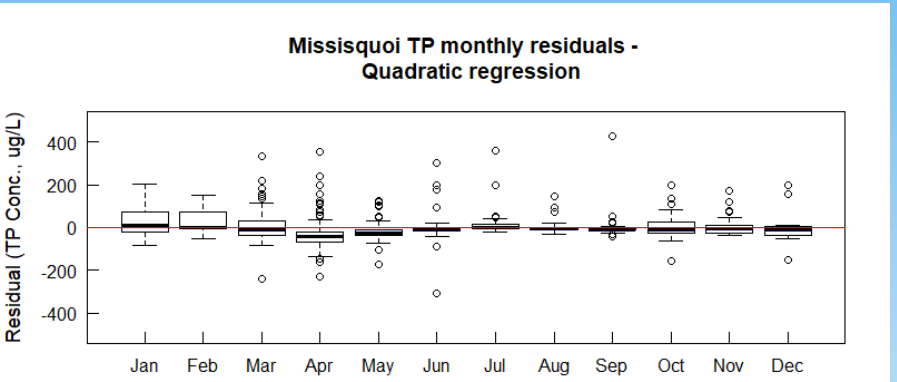
Dr. Jory Hechts

BREE IAM Simulations:

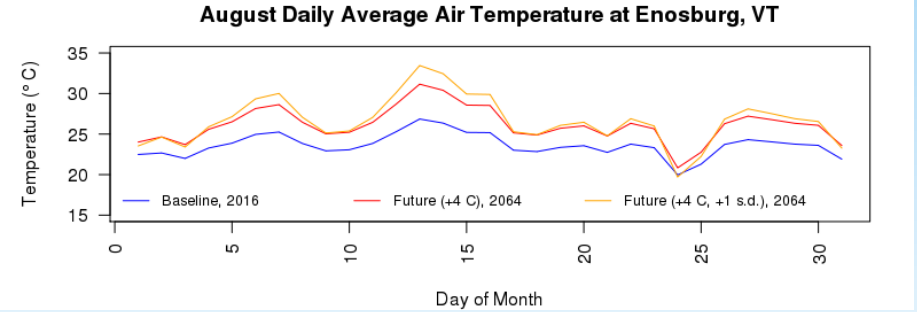
River Phosphorus Load Estimates

Sensitivity of Cyanobacteria Blooms to Changing Climate Variability

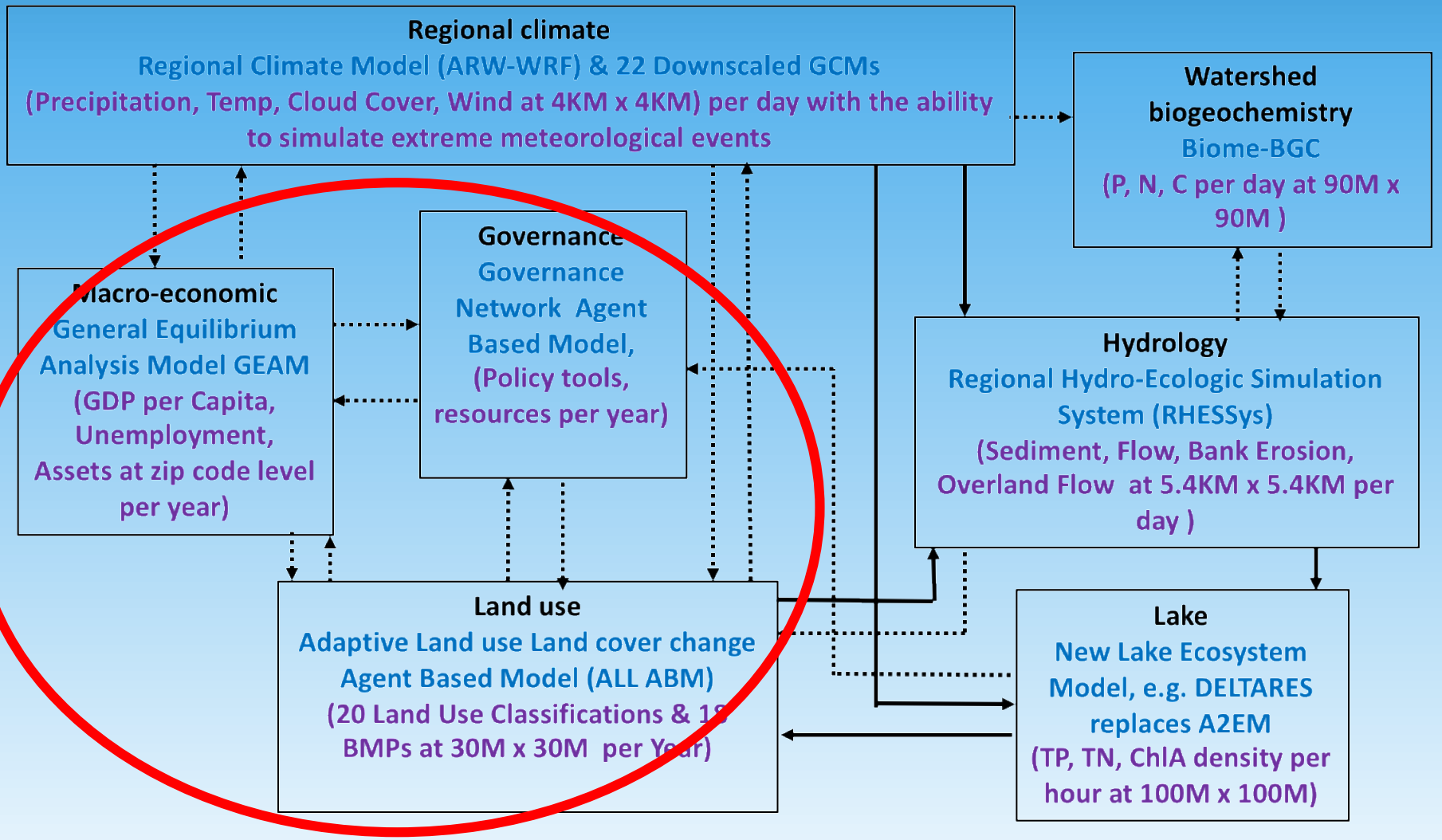
What is the most accurate statistical method for estimating phosphorus loads of LCB rivers?



How might changes in daily precipitation and temperature variability affect cyanobacteria blooms?



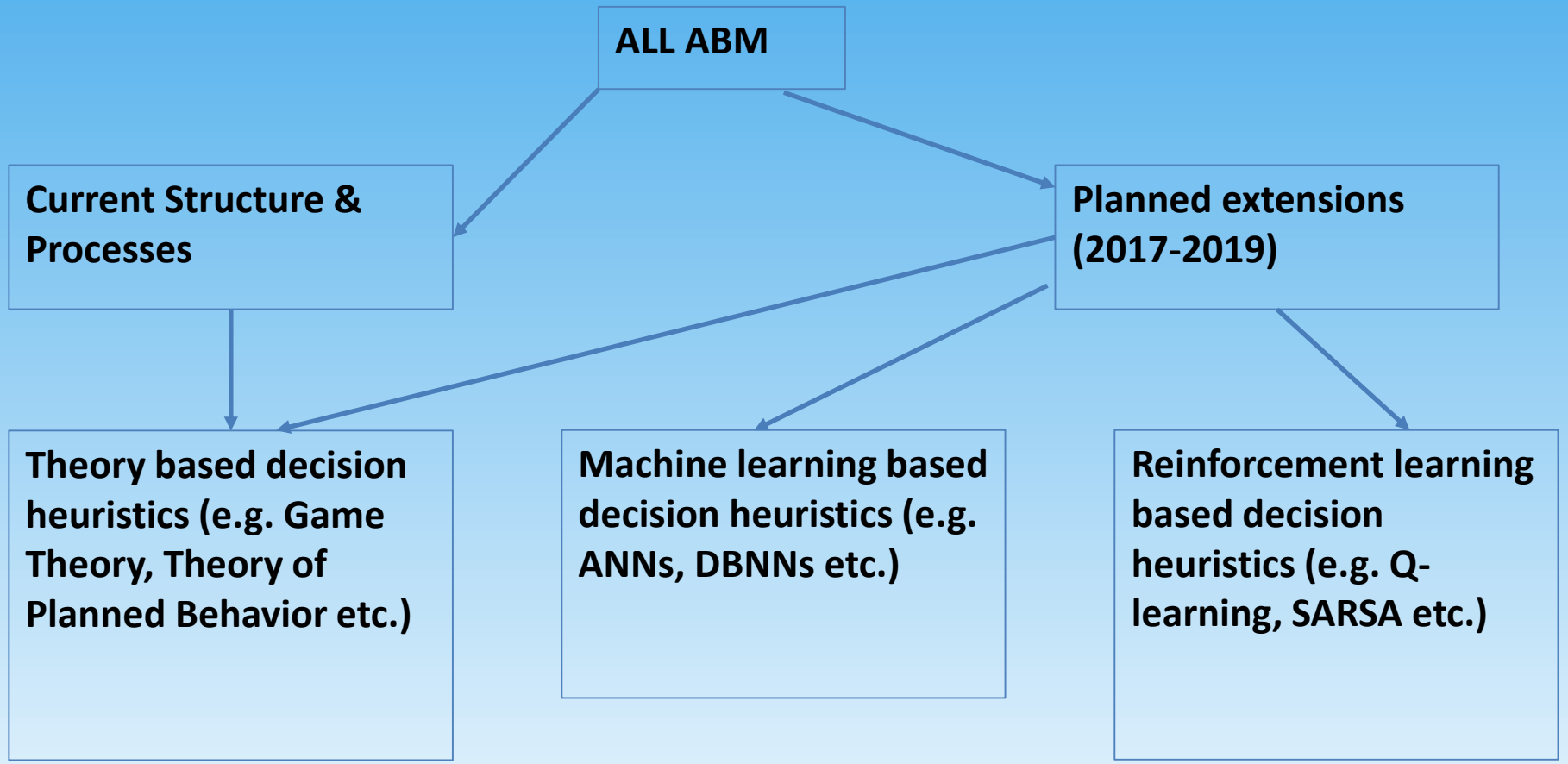
BREE IAM DEVELOPMENT PLAN: GEAM, ALL ABM and Gov. Net. ABM



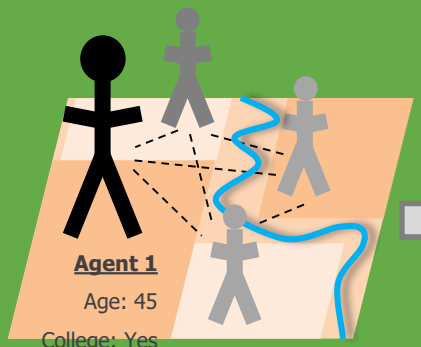
→ Integration is enabled in BREE IAM

⇢ Integration is being tested/planned in BREE IAM

Modeling behavioral change (e.g. BMP adoption) by multiple agents in ALL ABM



Who, and how likely are people – *farms* – to adopt specific best management practices?



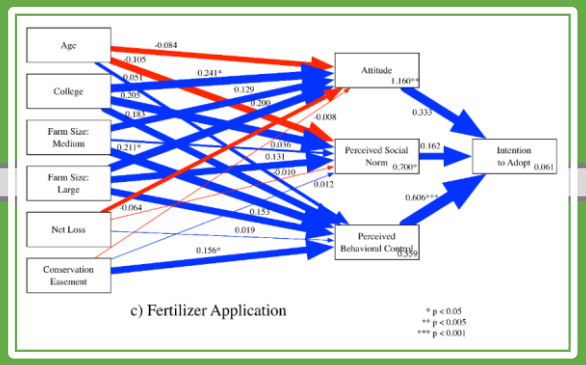
Agent 1

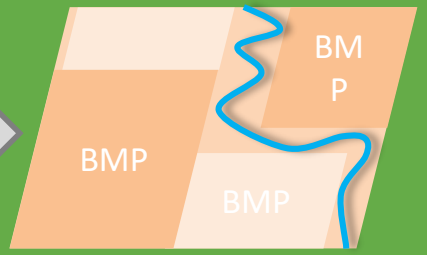
Age: 45

College: Yes

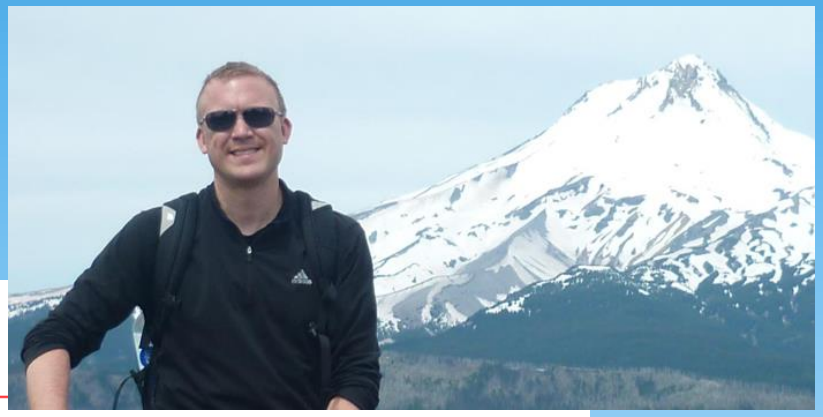
Farm Size: 14 acres

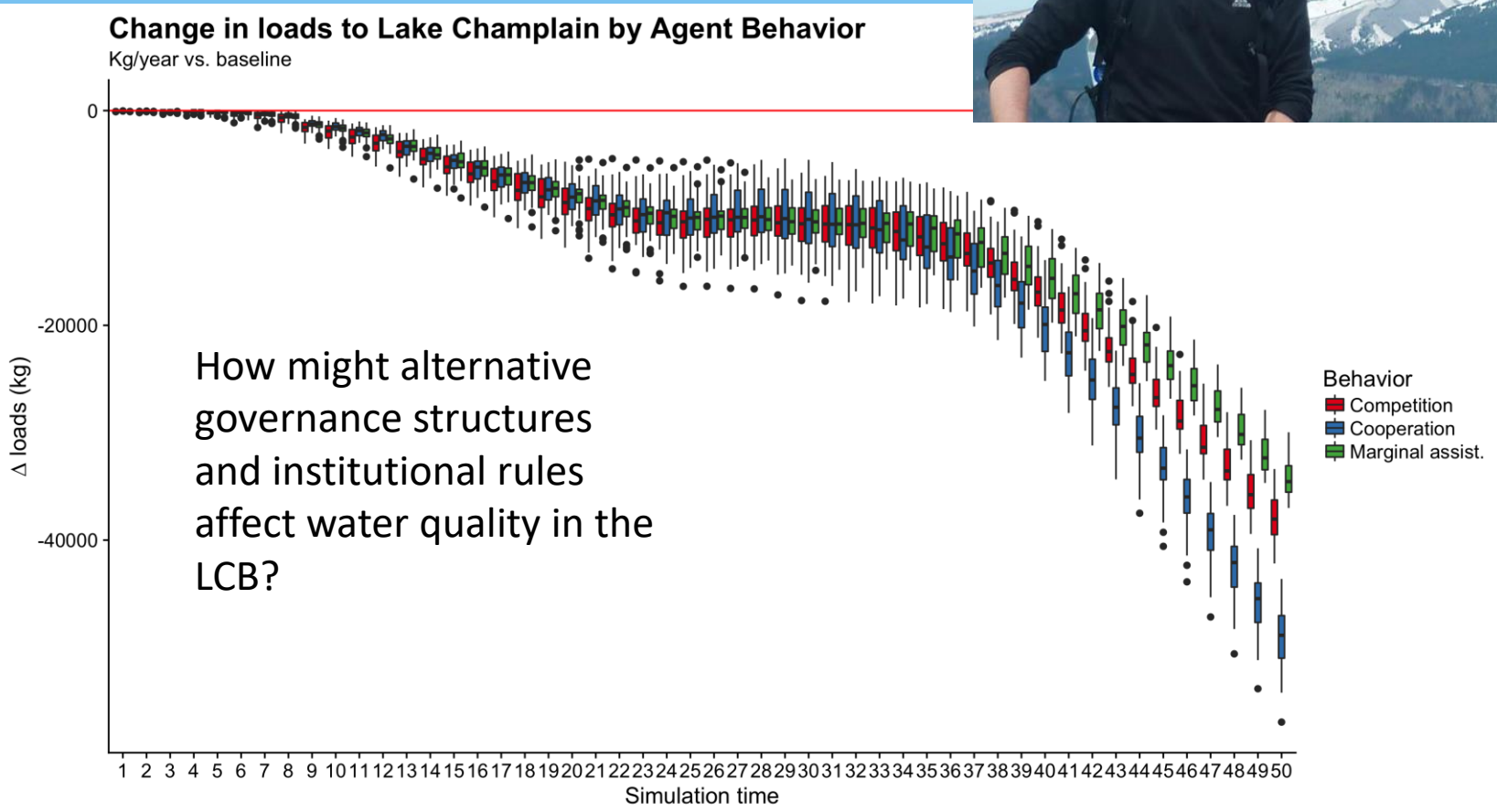
Land use type: Crop





Governance network modeling





How might alternative governance structures and institutional rules affect water quality in the LCB?

Embedding risk and spatial intelligence in adaptive agents of ALL ABM and Governance Network ABM

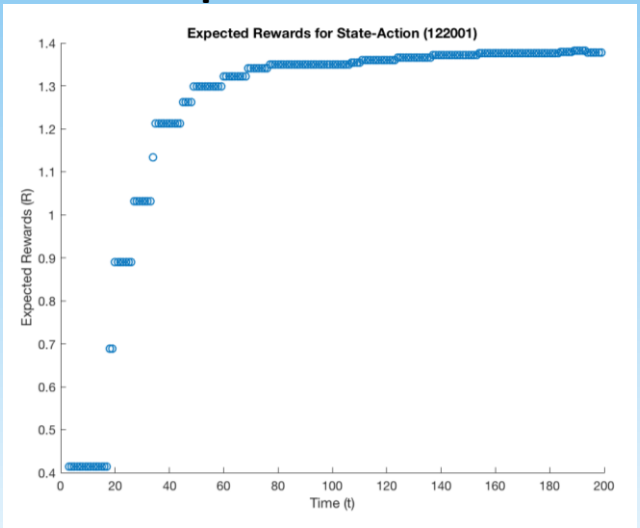
- Risk perception of lake water quality changes at the landscape agent level (farmers, urban firms, households, foresters) and their respective response strategies
  - Land value sensitivity to water quality
  - Adoption of BMPs by farmers and urban firms/households
- Risk perception of lake and watershed water quality changes among governance network actors (town governments, regional, state and federal agencies)
  - Reactive versus proactive design and implementation of policies
  - Spatial cognition of hysteresis

Integrating Policy and Behavioral Feedbacks: Reinforcement Learning Experiments for ALL ABM

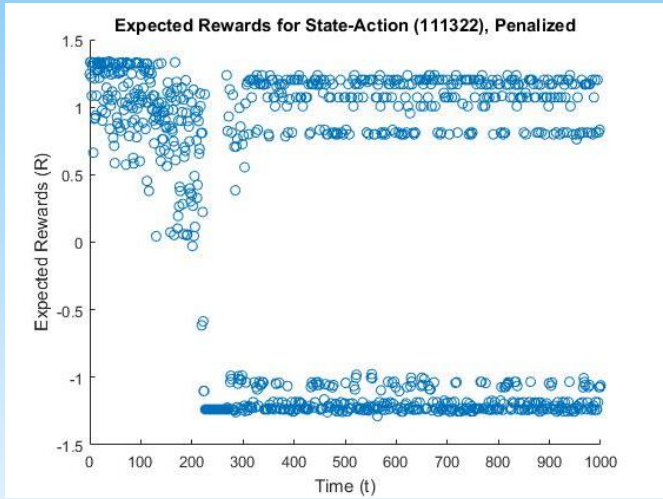
- The SARSA, or State-Action-Reward-State-Action, Algorithm is a reinforcement learning algorithm that generates a policy for each agent given their heterogeneous learning rates and expected utility functions

- A pilot GPU-enabled simulation with 1000 farmer agents consider two policies:
  - Adoption of BMPs is incentivized through payment for ecosystem services
  - Adoption of BMPs is penalized due to higher opportunity costs

BMP Adoption Incentivized

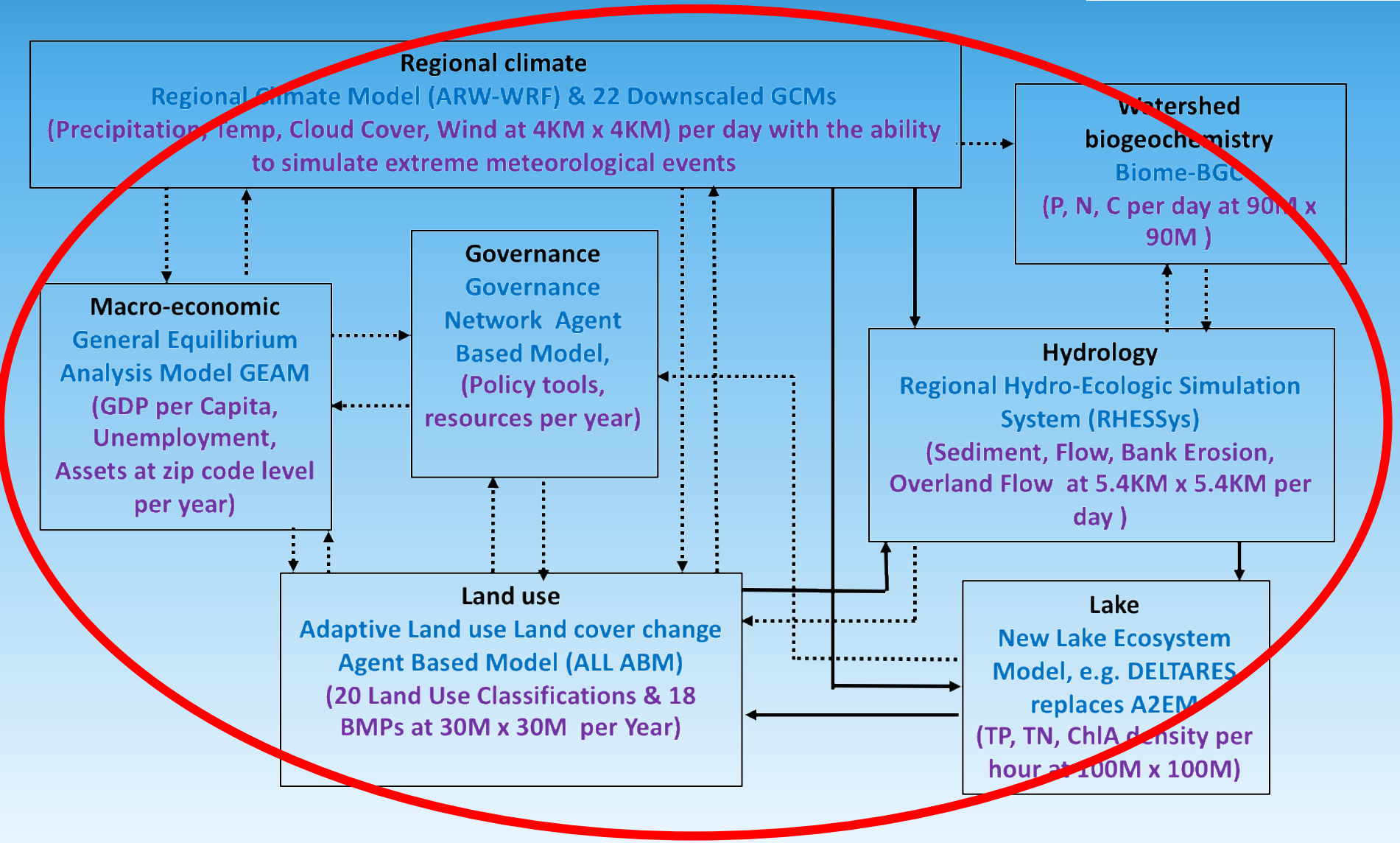


BMP Adoption Penalized



Thrust 3: Goal 3.2

BREE IAM DEVELOPMENT PLAN: SCENARIO DEVELOPMENT AND EVALUATION



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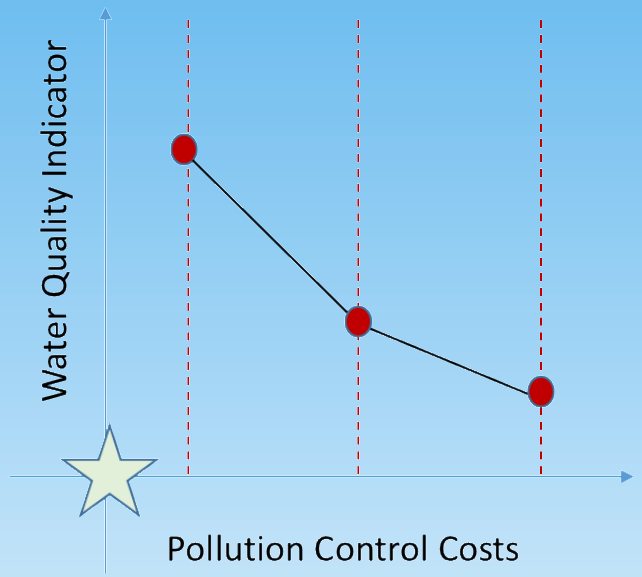
Multi-objective decision model for Identifying trade-offs among resilient strategies

BREE
Basin Resilience to Extreme Events
in the Lake Champlain Basin

OBJECTIVES:
Min eutrophic days
Min bloom duration
Min cost
Max economic output

DECISIONS:
Investments
Regulations
Incentives
Programs
Treaties

CONSTRAINTS:
Budget
Regulations
Site characteristics
Stakeholder equity



HIERARCHICAL MODELING

Missisquoi basin regulators

Subwatershed and municipal decision makers

Landowners (farmers, residents, businesses)

Objectives, decisions and constraints will be iteratively refined with stakeholders as extreme event cascades and couplings are simulated

Thank you!