Assessing impacts of climate change on discharge and nutrient loads from the Spring Creek basin

2017 Poland SWAT Conference

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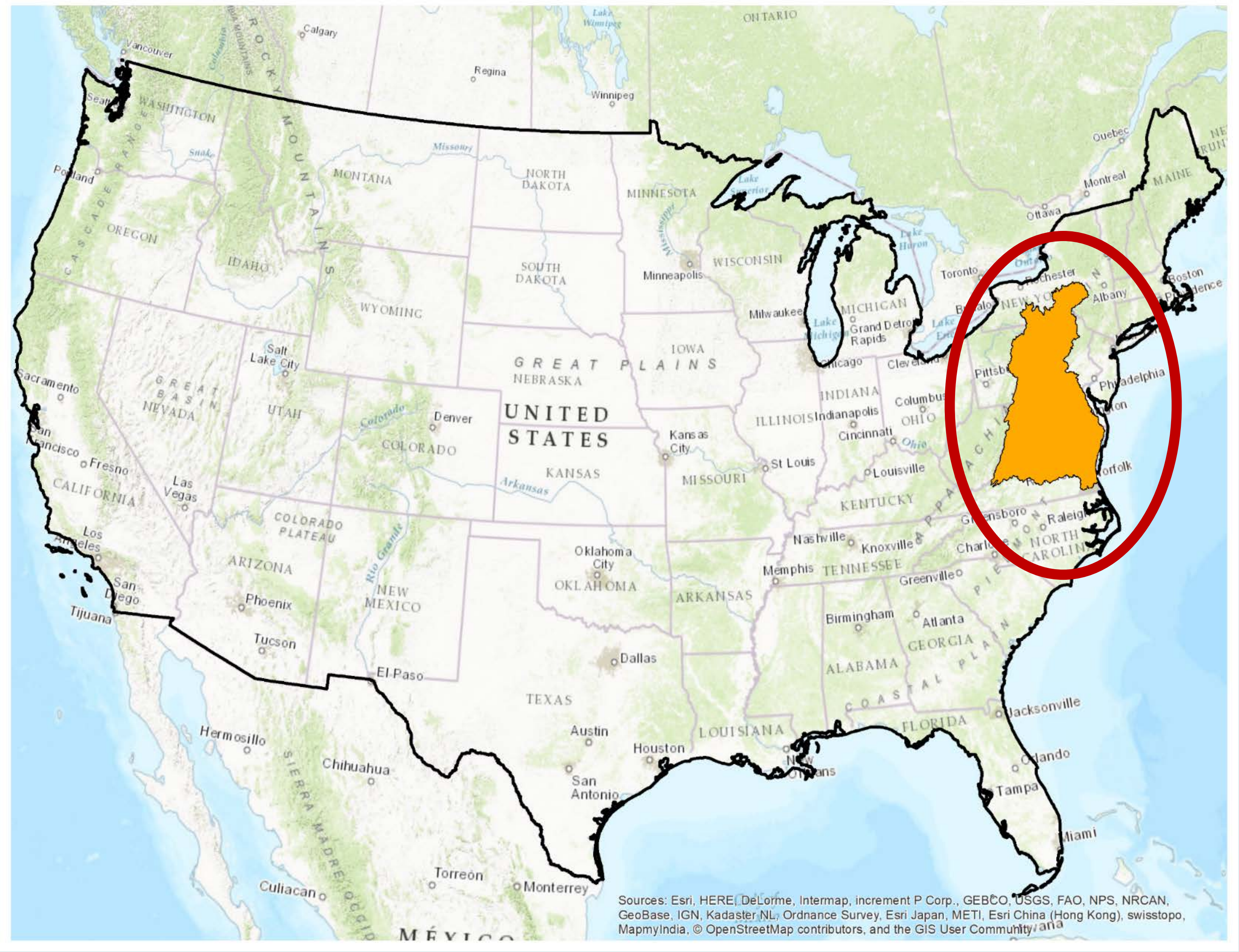
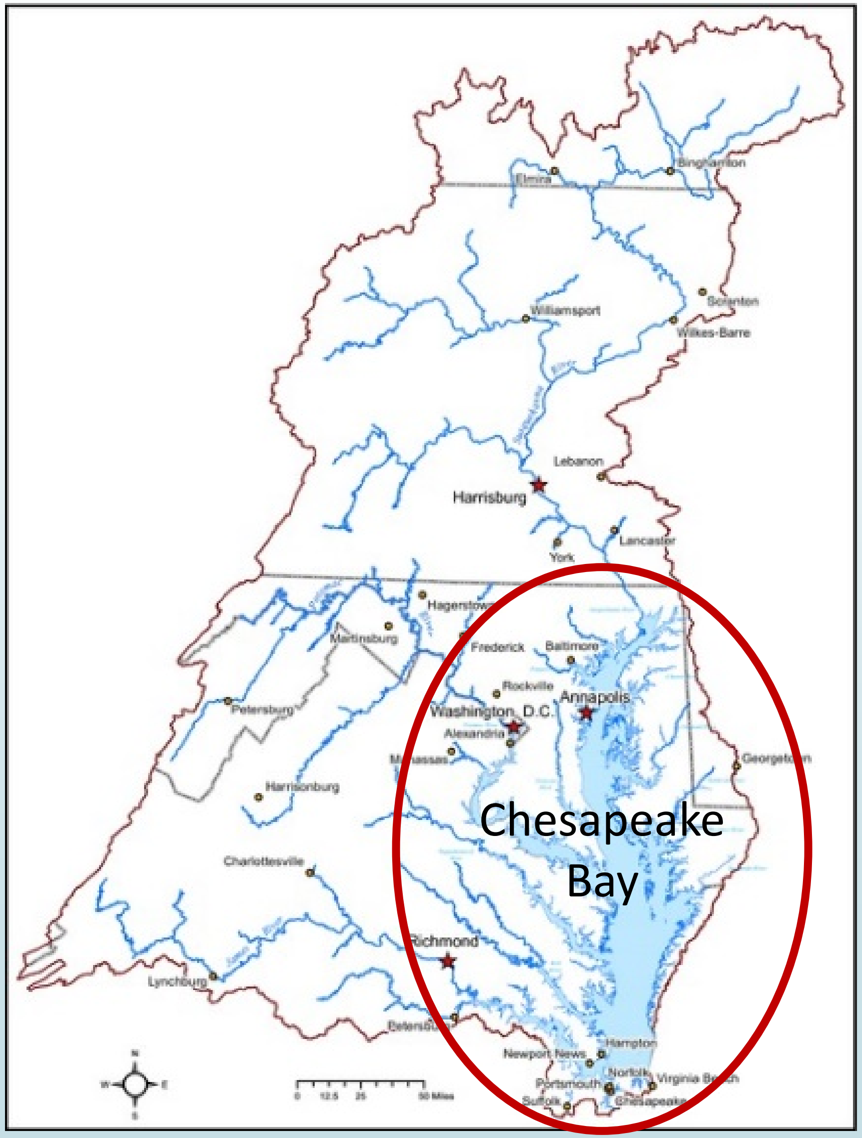
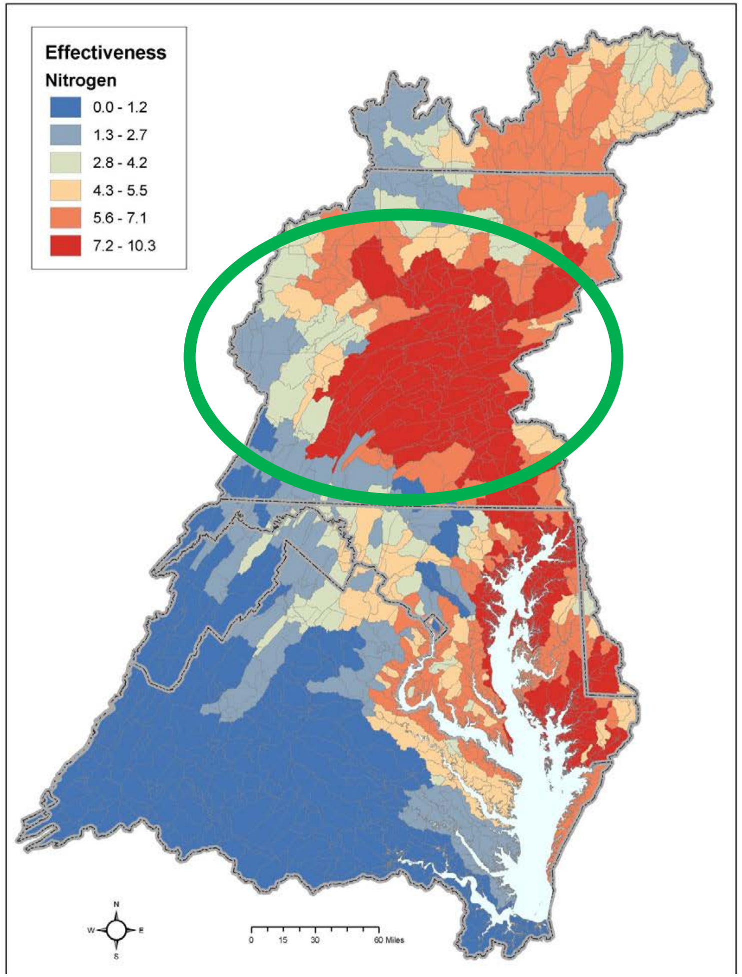
USDA Agricultural Research Service, Texas Tech University

Chesapeake Bay: largest estuary in North America





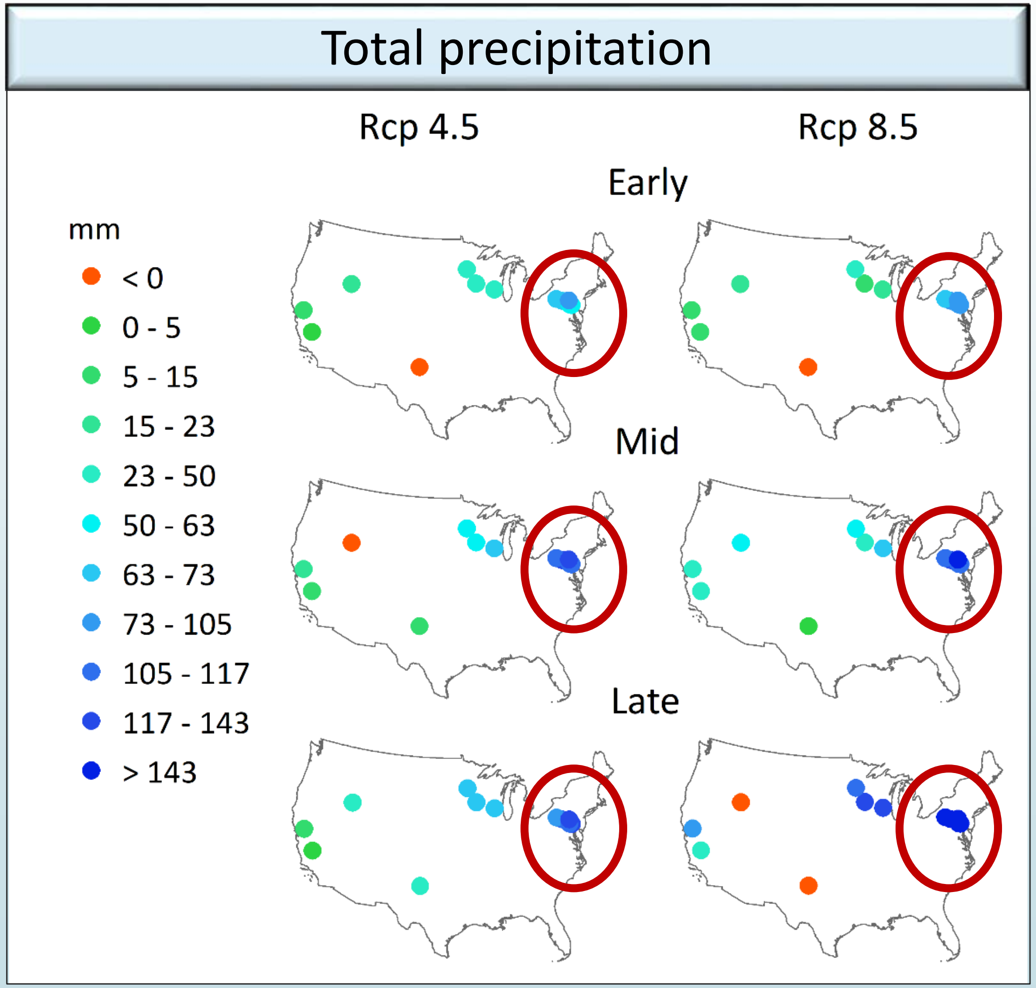
Cleanup effort to protect US fishing / recreation industries



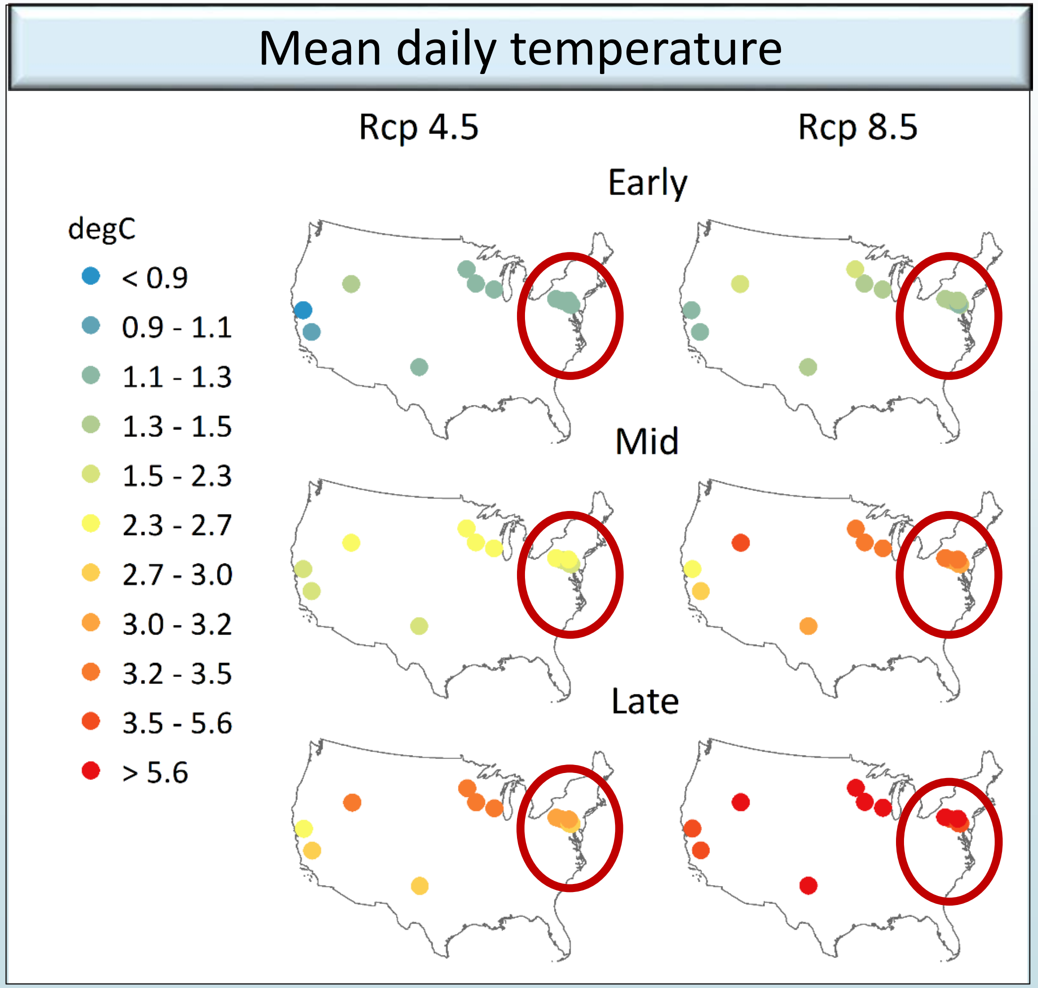
Highest (red) to lowest (blue) kg for kg nitrogen pollutant loading effect on Chesapeake Bay water quality (Chesapeake Bay TMDL)

- Impairment: excess agricultural N, P, and sediment loadings
- Largest contributor: central Pennsylvania
- 2010 EPA Chesapeake Bay TMDL: reduce N by 25%, P by 24%, and sediment by 20% from 2009 levels by 2025

Climate projections: changes from 1981-2000 (annual)



- Northeast wetter and hotter
- Most extreme in Northeast



Early century (2015 – 2034) Mid century (2045 – 2064) Late century (2081 – 2100)

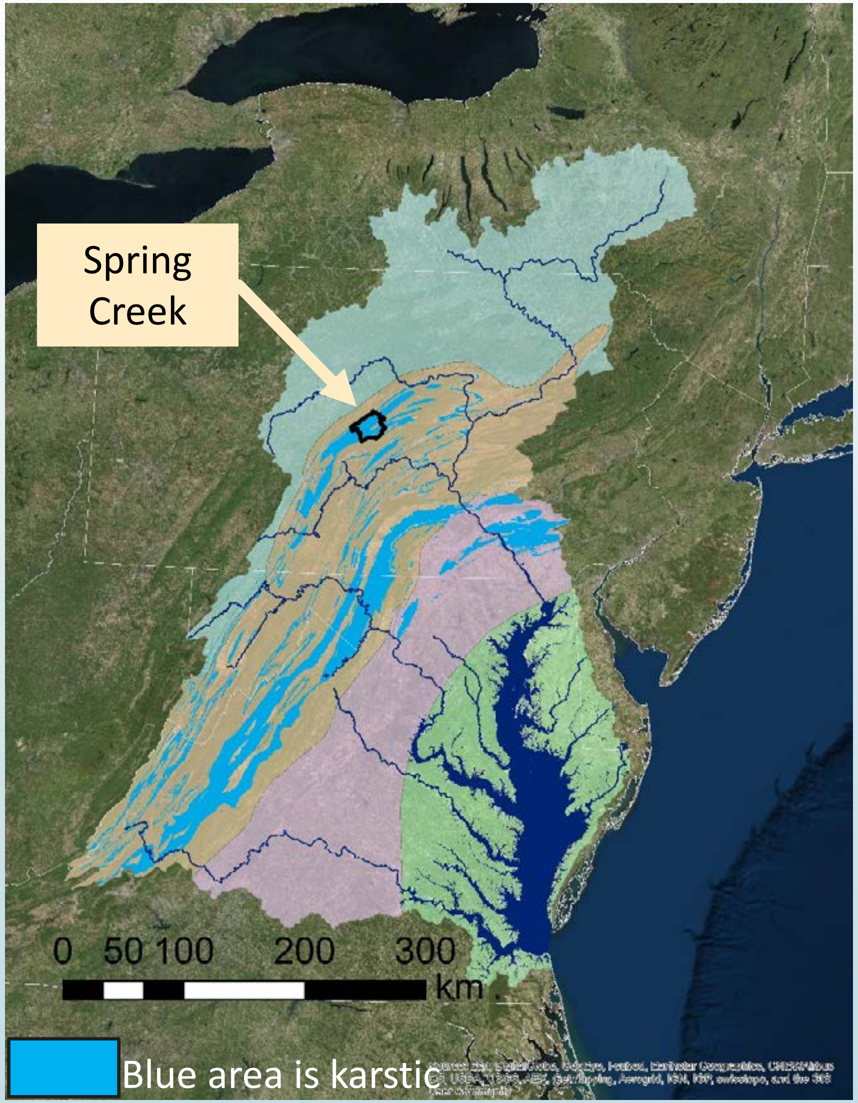
Investigate effects of climate change on long-term streamflow and nutrient loading in selected Chesapeake bay watershed sub-basins

1- Evaluate effects using current land use and management conditions

- Long-term experimental research watersheds
- Representations in Topo-SWAT
- Multiple current climate projections forcing

2- Use results to help identify and design agricultural management adaptation

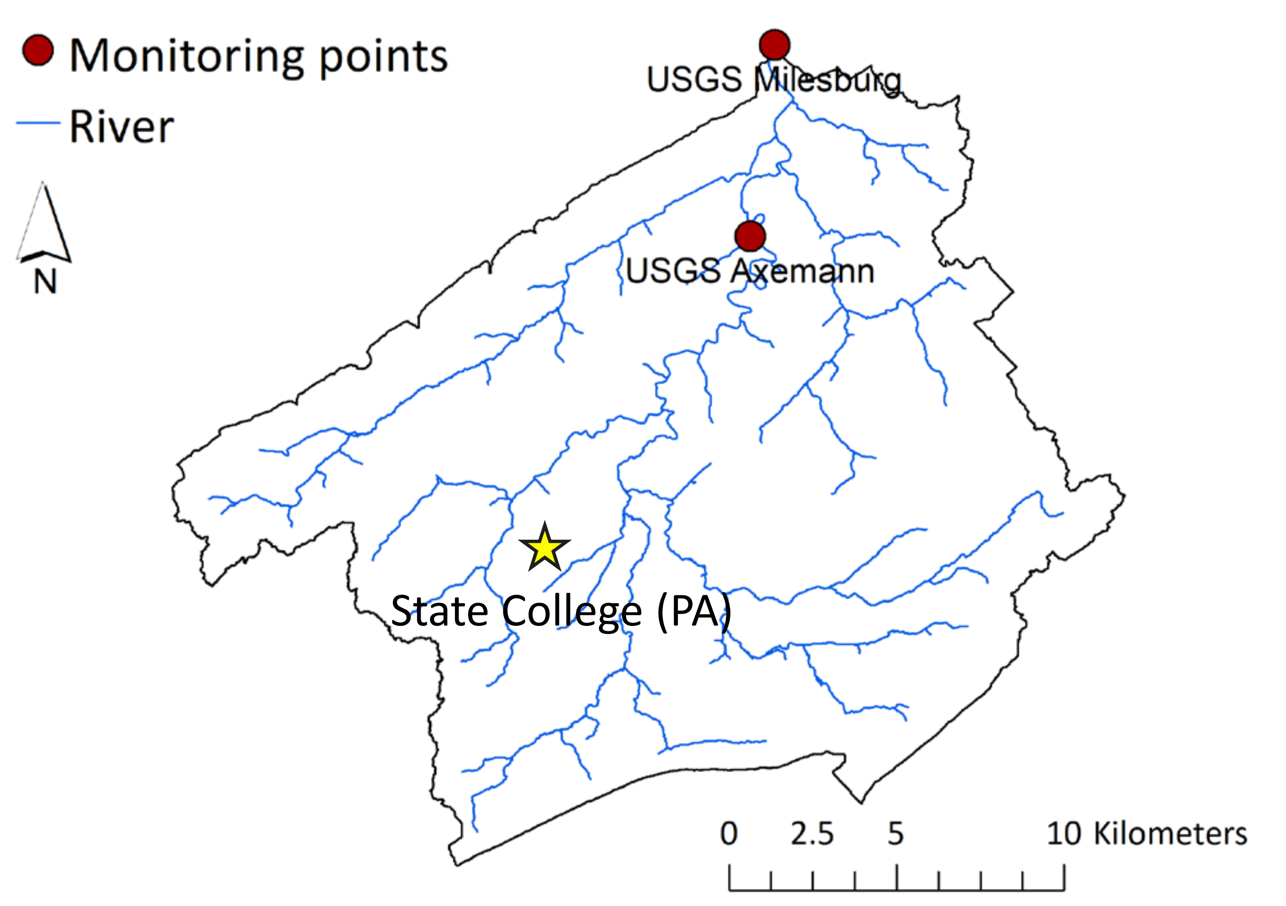
Case study: Spring Creek sub-basin underlain by karstic formations 7.2 – 10.3 kg/kg N loading effect on water quality



Spring Creek sub-basin
Rock Springs, PA

- Why TOPO-SWAT?
  - Variable source area (VSA) hydrology is common
  - Affords highly detailed analysis of hydrologic response units (HRUs)

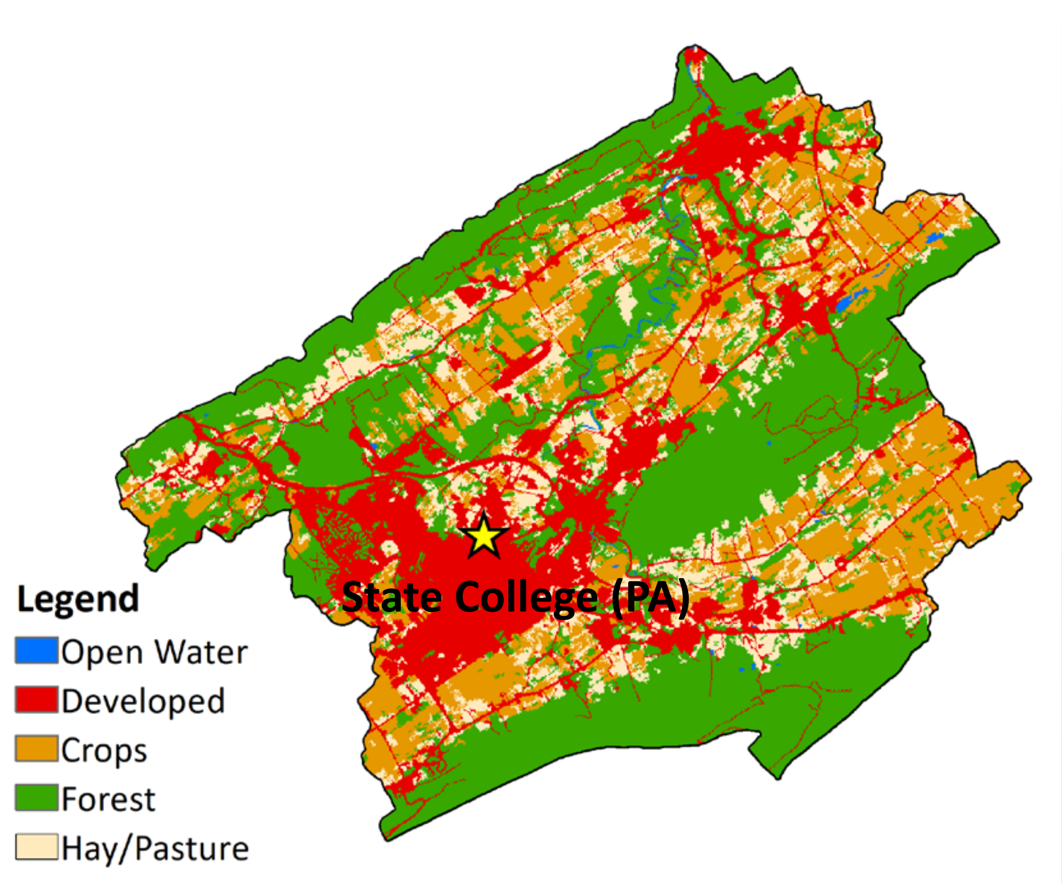
Spring Creek sub-basin characteristics



- Surface drainage area: 369 km^2
- > 80% streamflow from baseflow
- Annual precipitation: 800 - 1270 mm
- Important dairy production

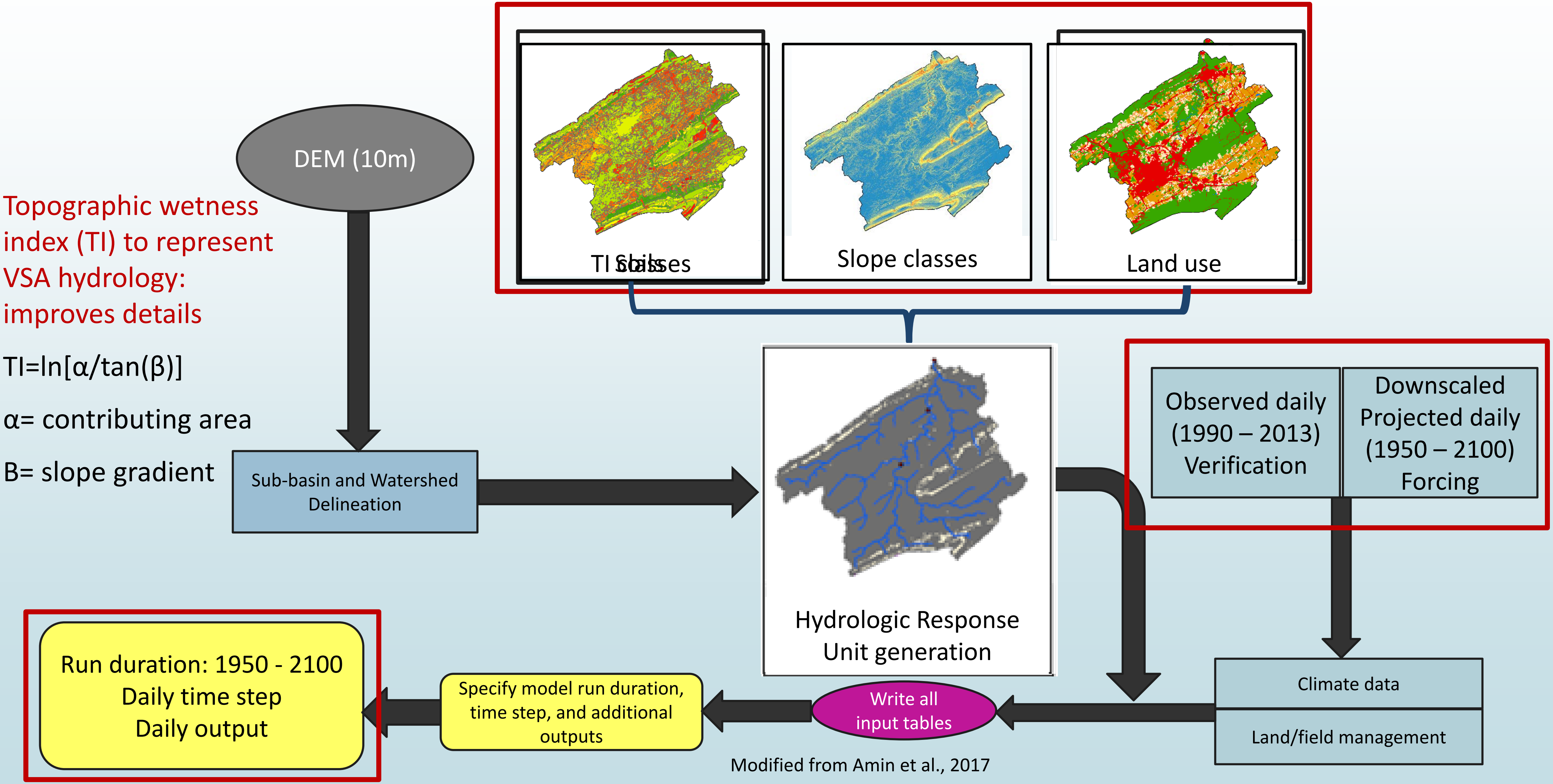
Current detailed land use and management

- Land use: 34% agriculture, 21% developed, 43% forest
- Crops: assumed 8-yr rotations
  - Grains: corn, soybeans, oats, winter wheat and barley
  - Hay and pasture
- Management: minimum tillage, no-tillage
- Soil amendment: dairy manure, N-P_2O_5-K_2O as corn starter or winter harvested crops



METHOD

REGULAR-SWAT
TOPO-SWAT

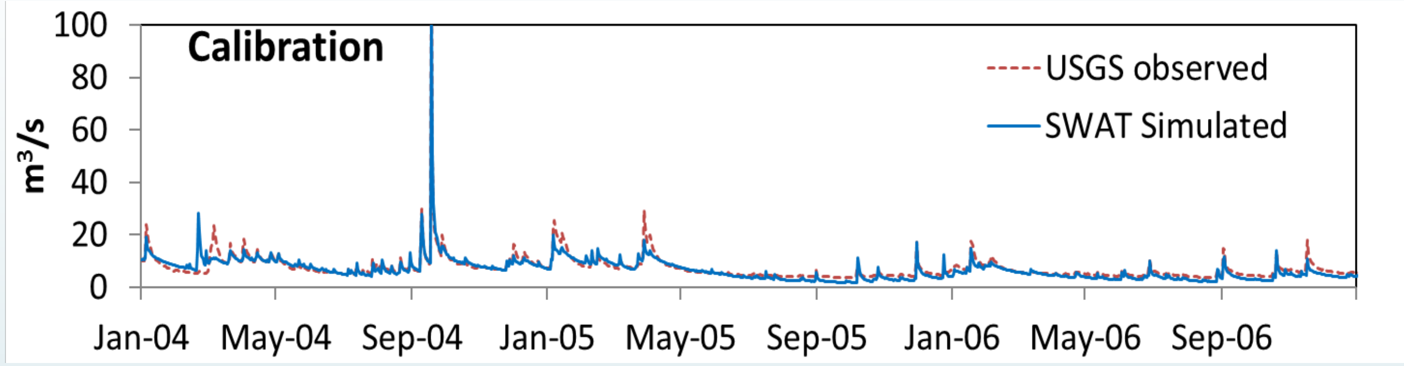


Modified from Amin et al., 2017

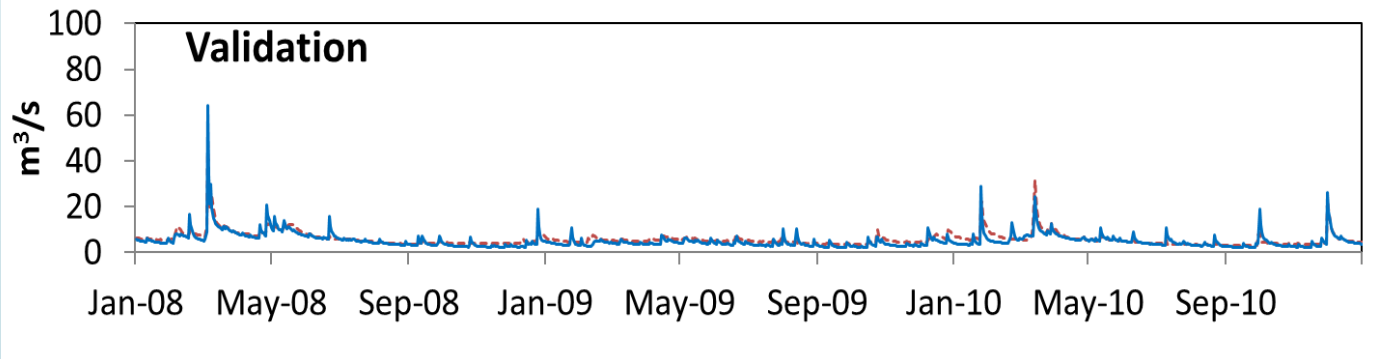
Forecasting climate change

- 9 general circulation models
  - Coupled Model Inter-comparison Project phase 5 simulation modeling
- 2 emissions scenarios: RCP 4.5, RCP 8.5
- Statistically downscaled to station-level using historical climate data (Stoner et al. 2013)

Daily mean streamflow at Milesburg: simulations match observations (Amin et al., 2017)



Daily NSE	Monthly NSE	PBIAS	Rating
0.77	0.80	-7.5	Good



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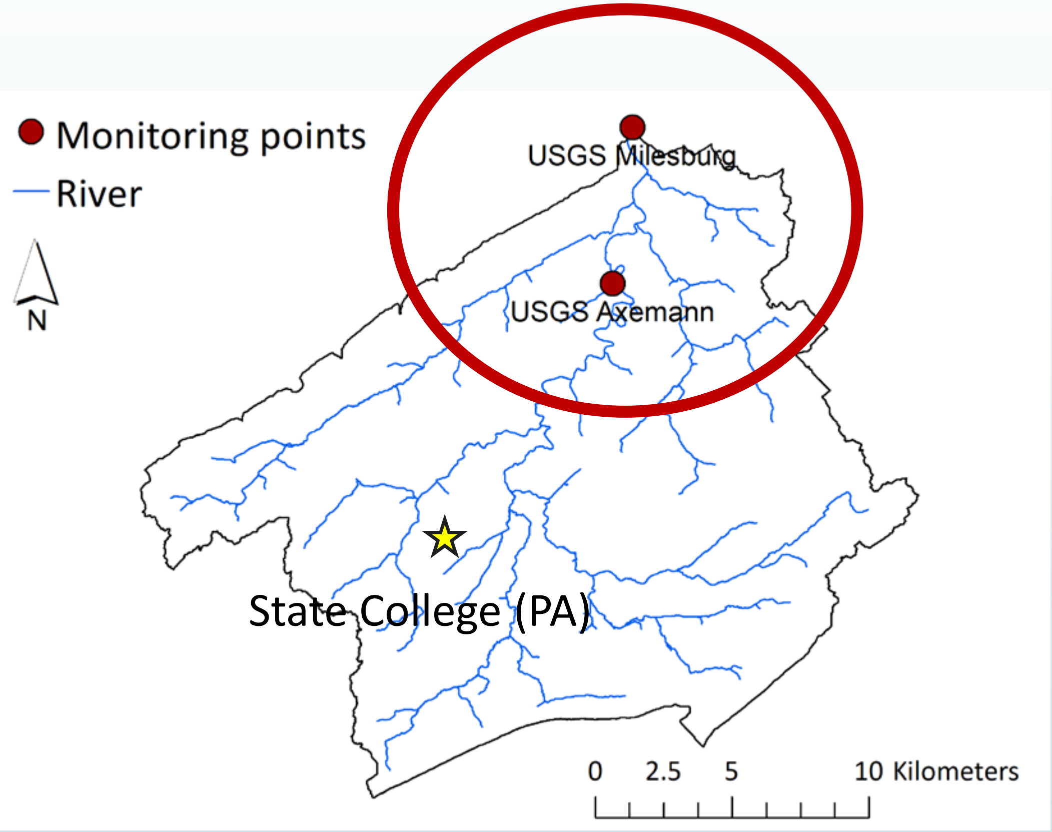
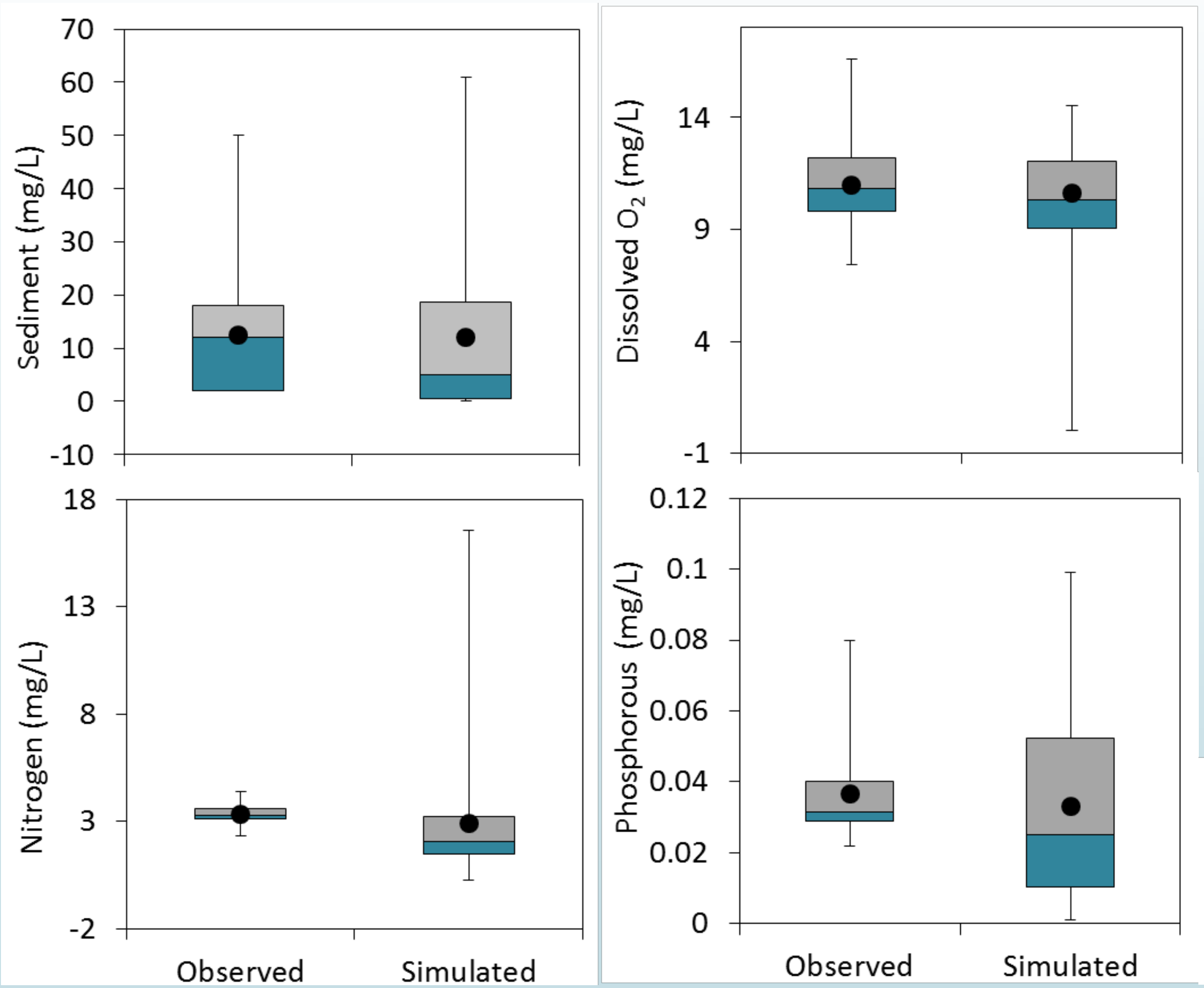


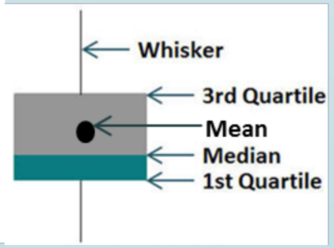
Peak and base-flow sometimes under-predicted

Mean daily nutrient concentrations at Axemann: simulations approach observations (Amin et al., 2017)

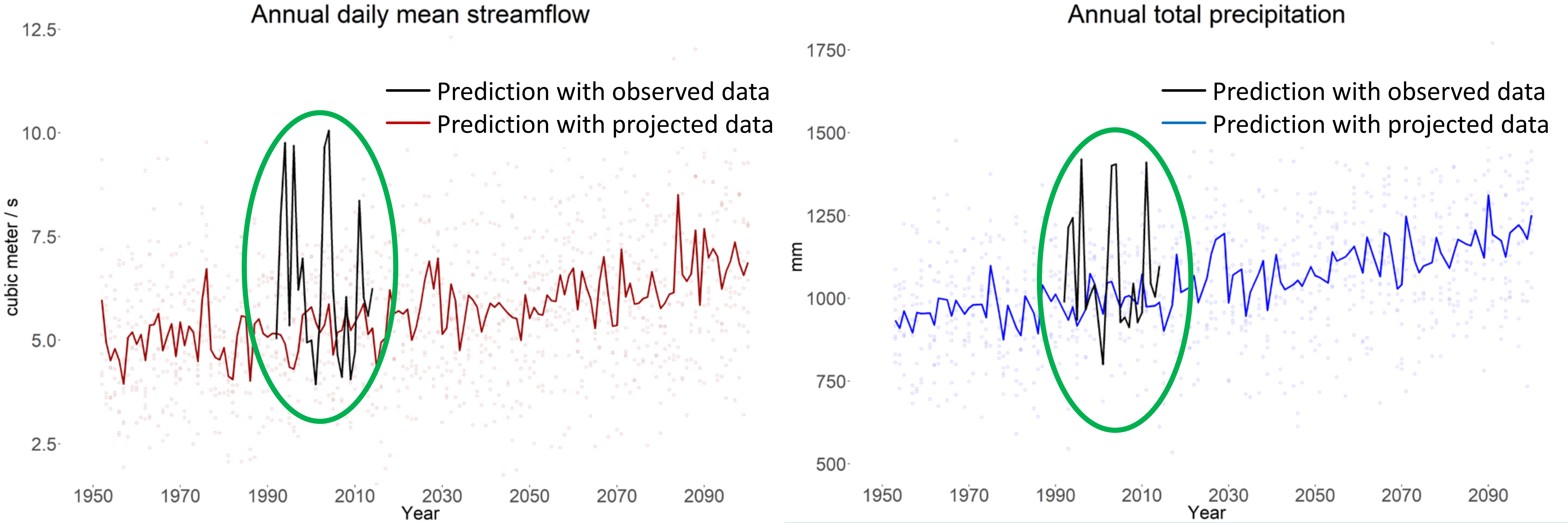


- Mean concentrations alike
- Different ranges: observed data only had one observation per season; SWAT simulations daily

Legend

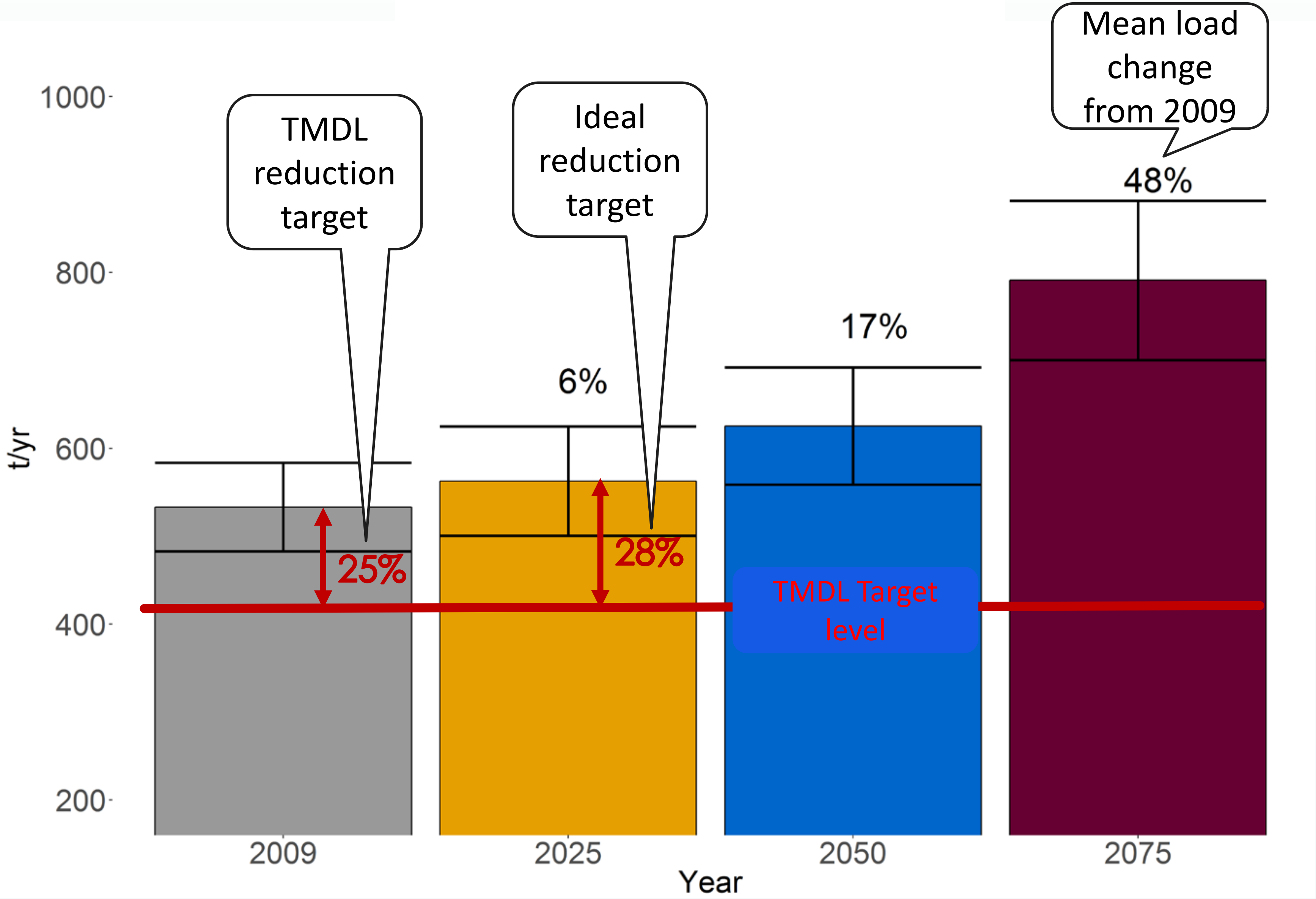


Daily streamflow increases under Rcp 8.5



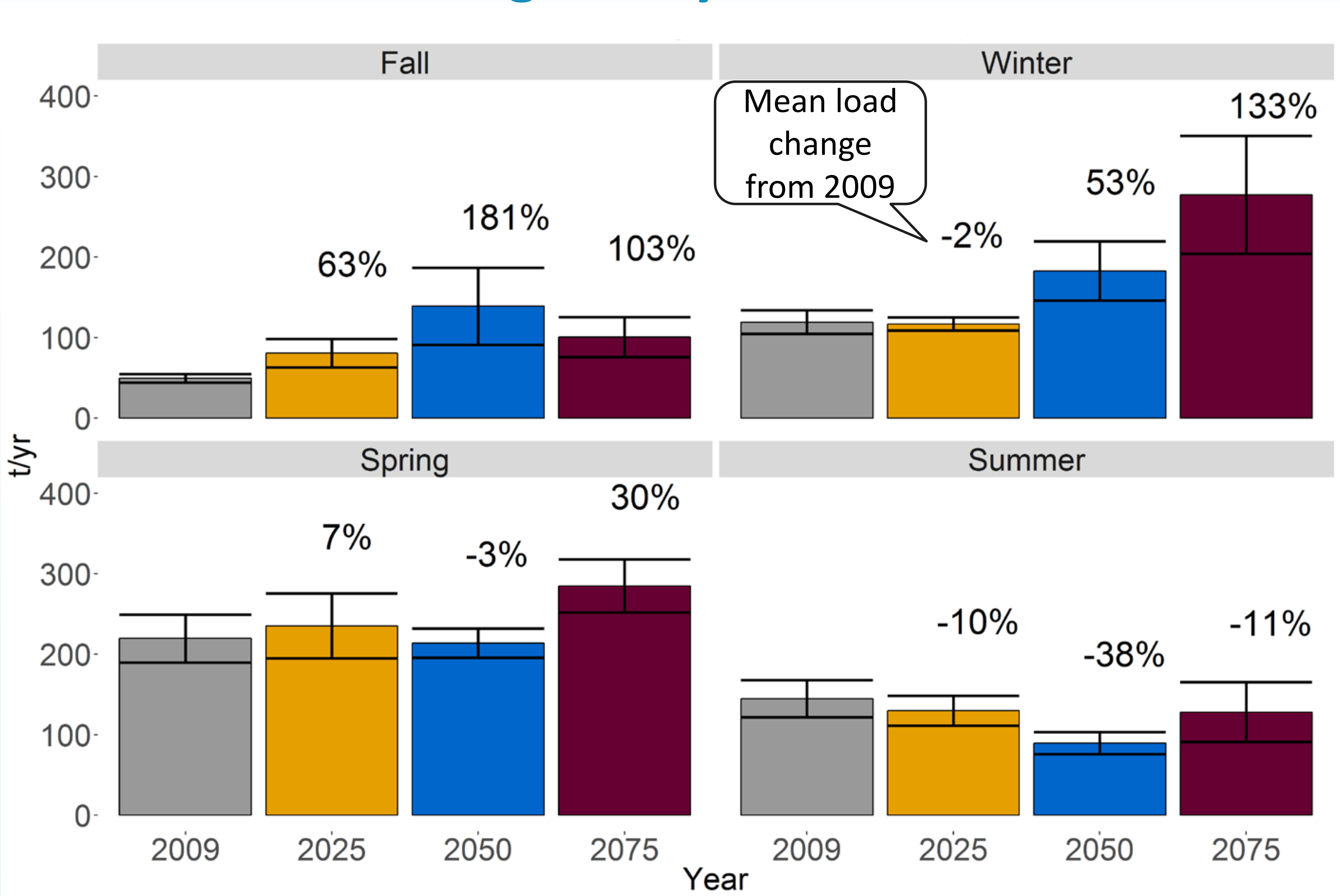
- Streamflow trend mirrors precipitation trend
- Peaks using observed data larger than mean peaks using projected data

Annual total nitrogen-N load increases under Rcp 8.5



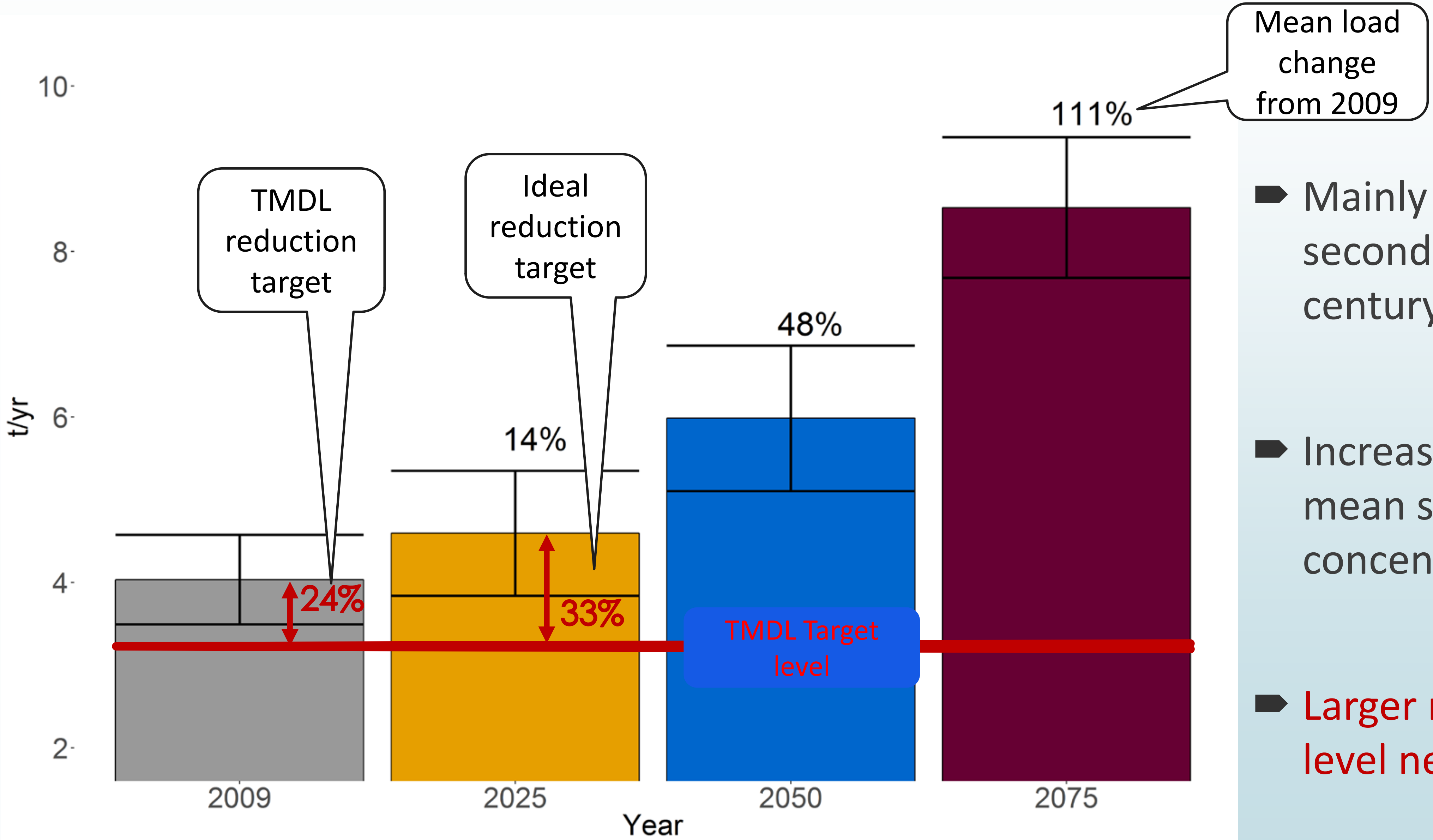
- Mainly during the last quarter of the century
- Moderately higher reduction level needed

N-Load changes vary between seasons under Rcp 8.5



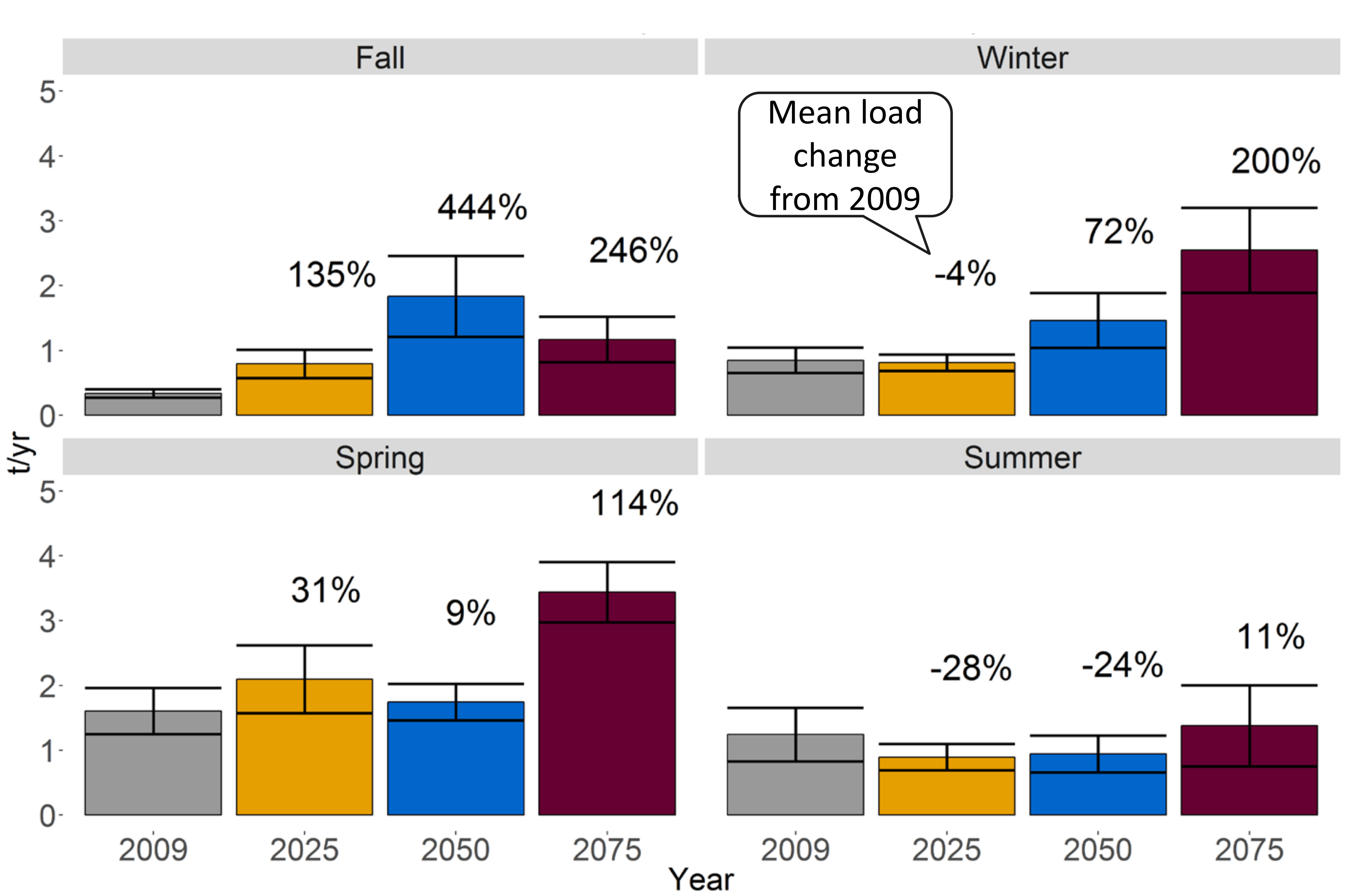
Fall and winter changes drive annual increase during mid- to end-century

Annual total phosphorus-P load increase under Rcp 8.5



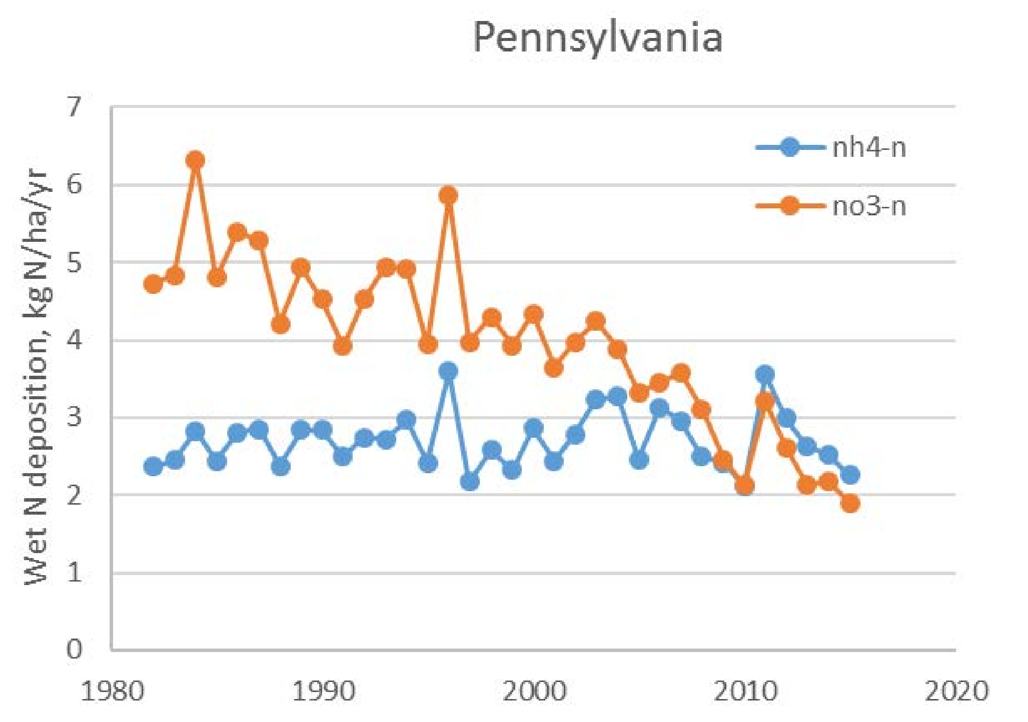
- Mainly during second half of the century
- Increase with mean sediment concentration
- Larger reduction level needed

P-Load changes also vary between seasons under Rcp 8.5



Fall and winter changes drive annual increase during mid-century

What happens if atmospheric nitrate-N deposition drops?

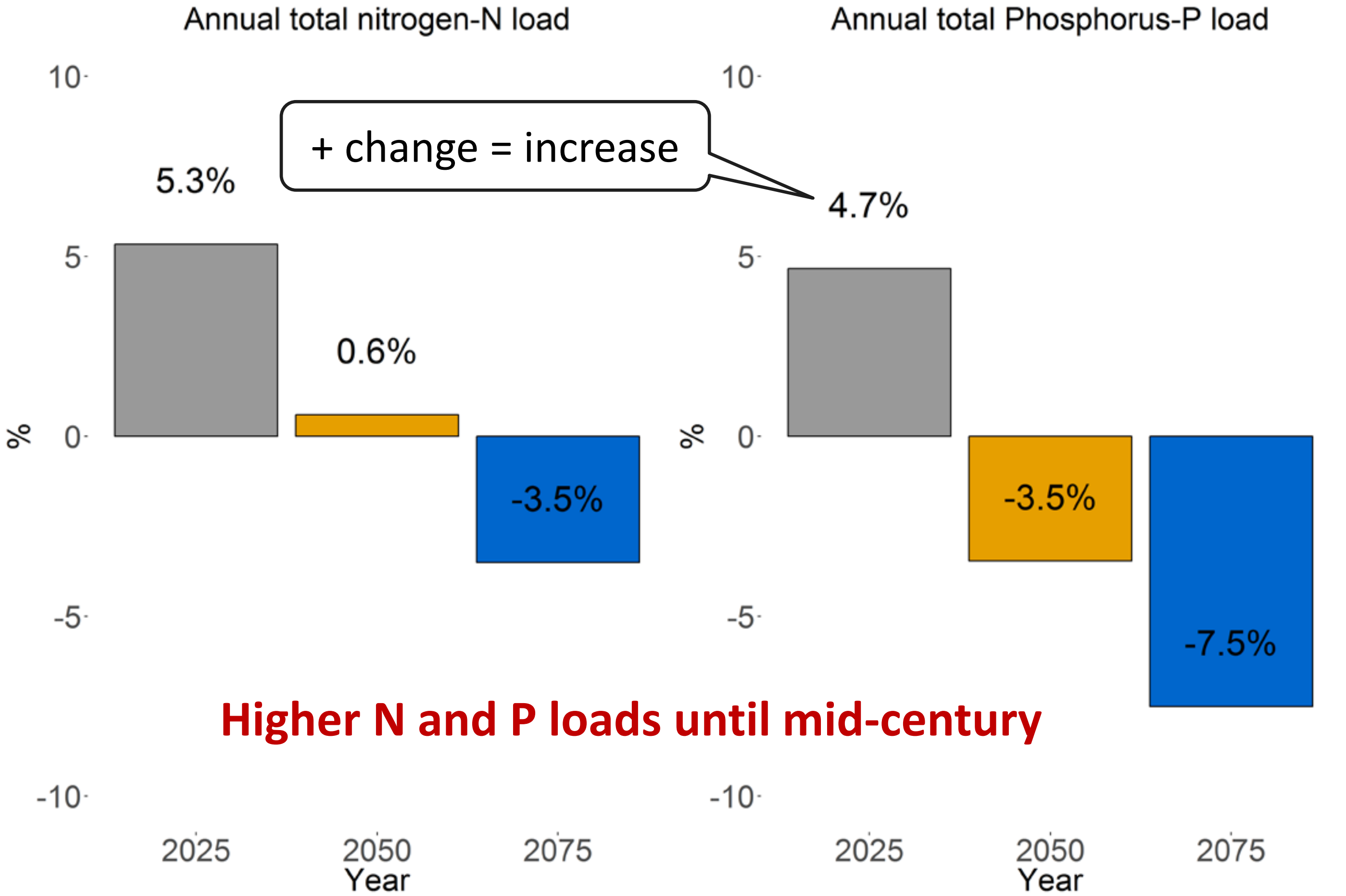


Atmospheric deposition monitoring (Boyer)

SWAT inputs

- Mean (1984 - 2013): 0.341 mg/l
- Sensitivity analysis (Mean-50%): 0.171 mg/l

Load difference between 1984-2013 atmospheric wet Nitrate-deposition and hypothesized mean under Rcp 8.5



Higher N and P loads until mid-century

Under higher emission and current management conditions

- Annual precipitation expected to increase by ~150 mm by end-century
- Daily mean temperature expected to increase by ~5°C by end-century
- N-load increases slowly and speeds up near end century
- P-load increases exponentially from mid-century onward
- Originally defined TMDL goals will not be reached
- Need to define higher load reduction goals

So what - Suggested management for adaptation

- Adjust crop planting date
  - Take advantage of longer growing season
  - Prevent summer moisture deficit
  - Promote nutrient use efficiency
- Diversify crop rotation / incorporate catch or cover crops (fall and winter)
  - Reduce erosion / runoff
  - Capture nutrients
  - Provide continuous land cover
- Incorporate crop residues / minimize field operations
  - Increase soil organic matter / infiltration
  - Reduce runoff and nutrient loads
- Adopt precision agriculture (field operations, fertilization, pesticide app, irrigation)

BIBLIOGRAPHIC REFERENCES

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- IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- Linker, L.C., Dennis, R., Shenk, G.W., Batiuk, R.A., Grimm, J., Wang, P. 2013. Computing Atmospheric Nutrient Loads to the Chesapeake Bay Watershed and Tidal Waters. JAWRA 1-17.
- Stoner, A. M. K., Hayhoe, K., Yang, X., & Wuebbles, D. J. (2013). An asynchronous regional regression model for statistical downscaling of daily climate variables. *International Journal of Climatology*, *33*(11), 2473–2494.

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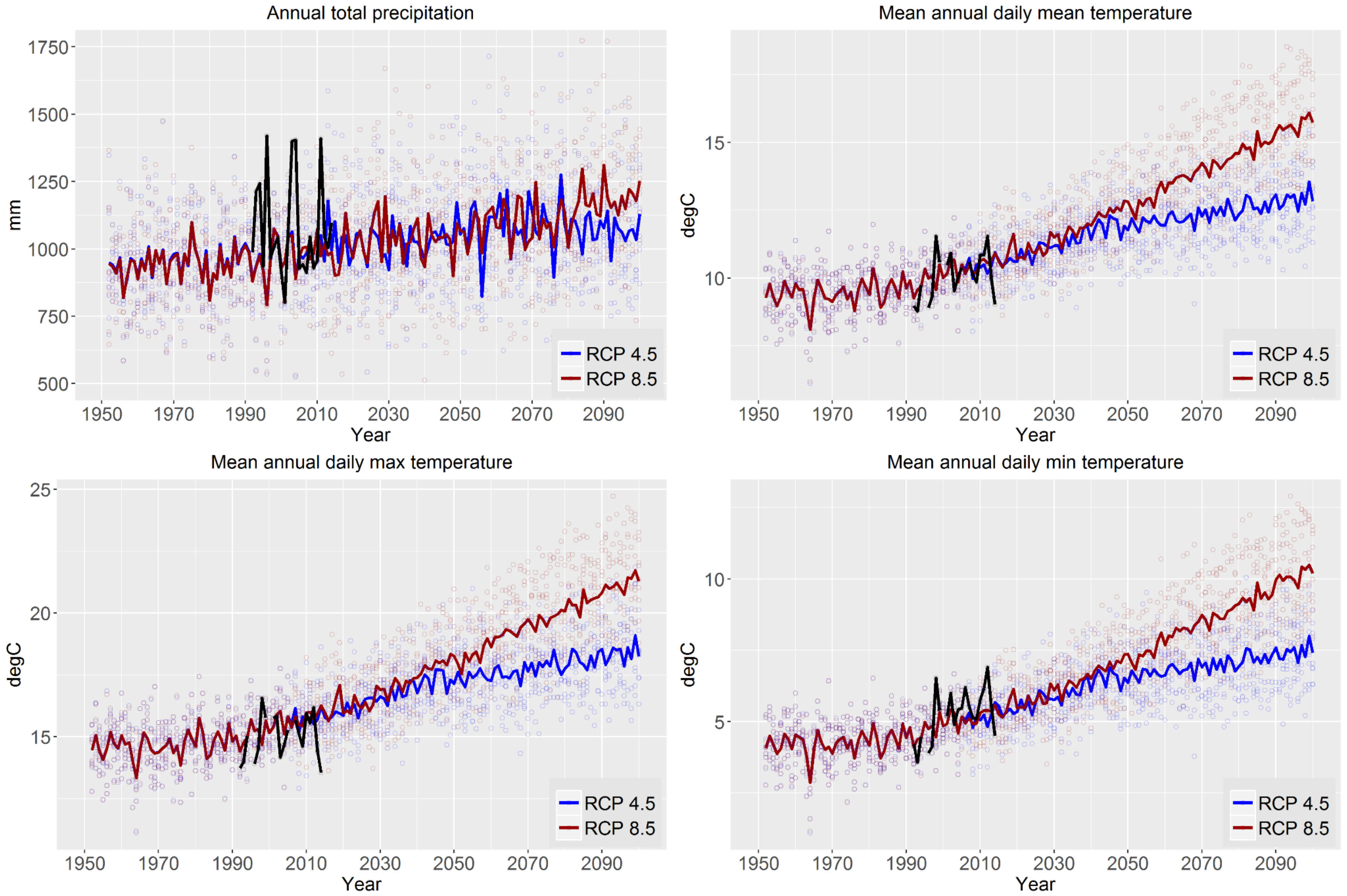
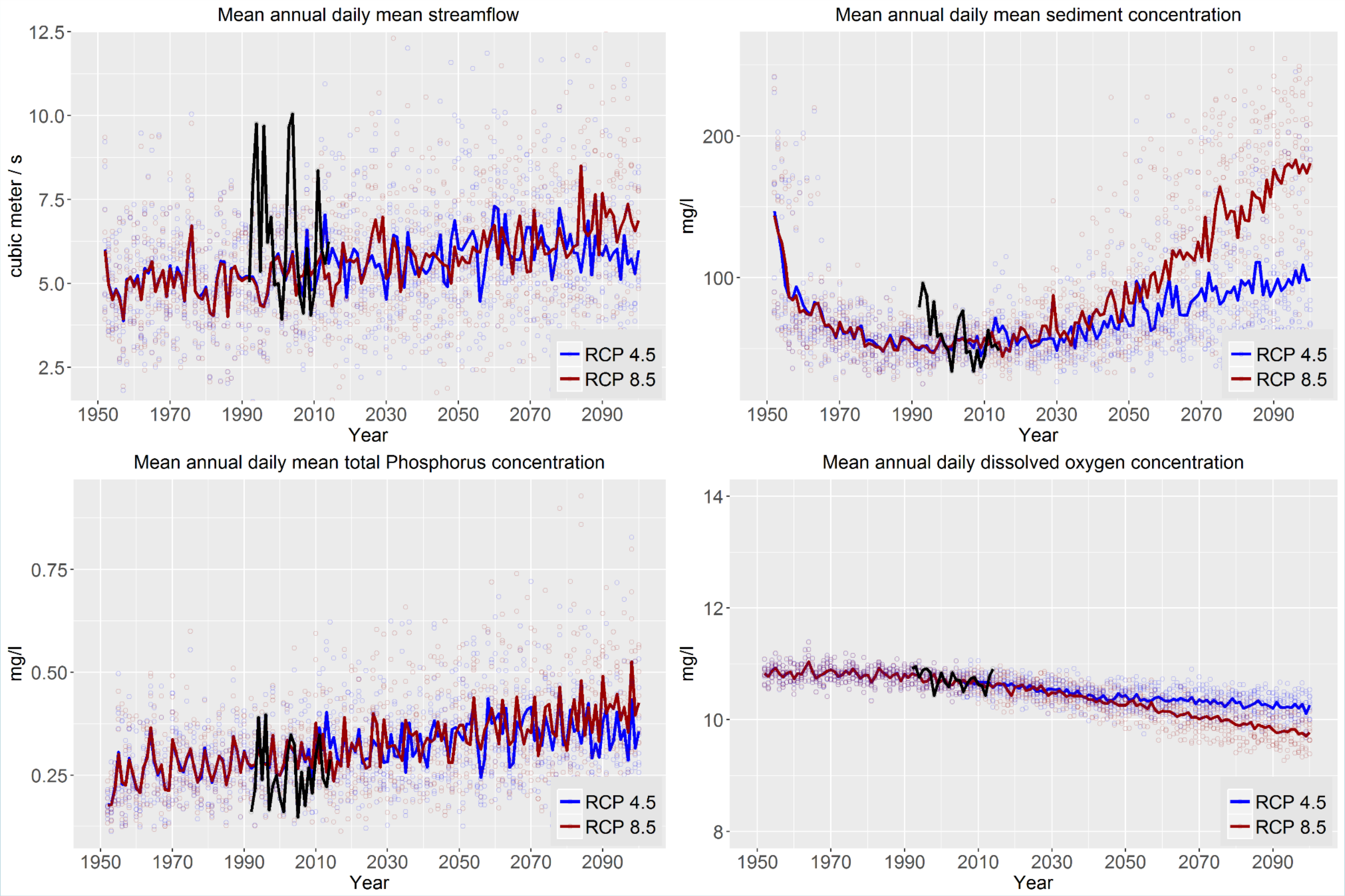
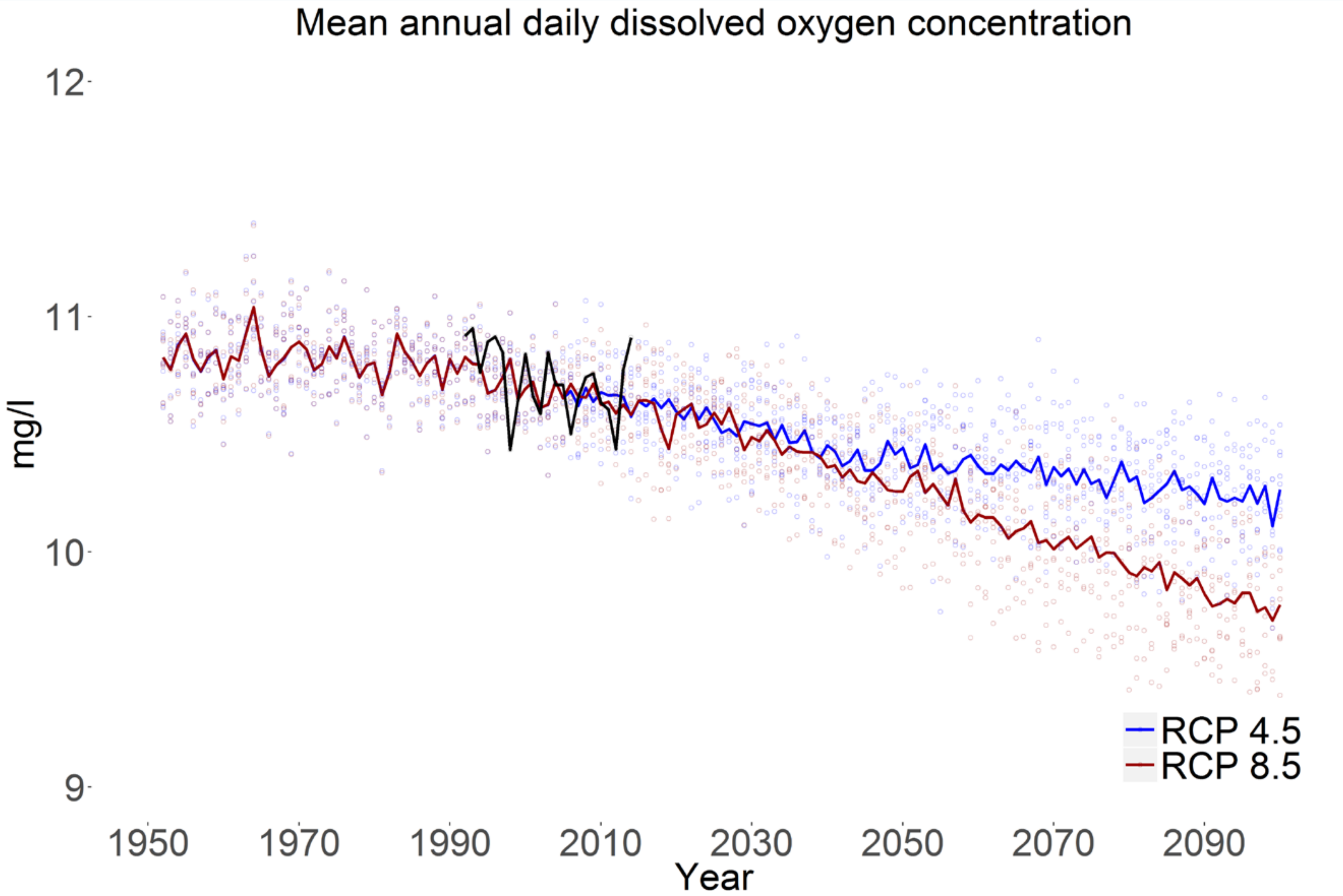
Projected climate at State College



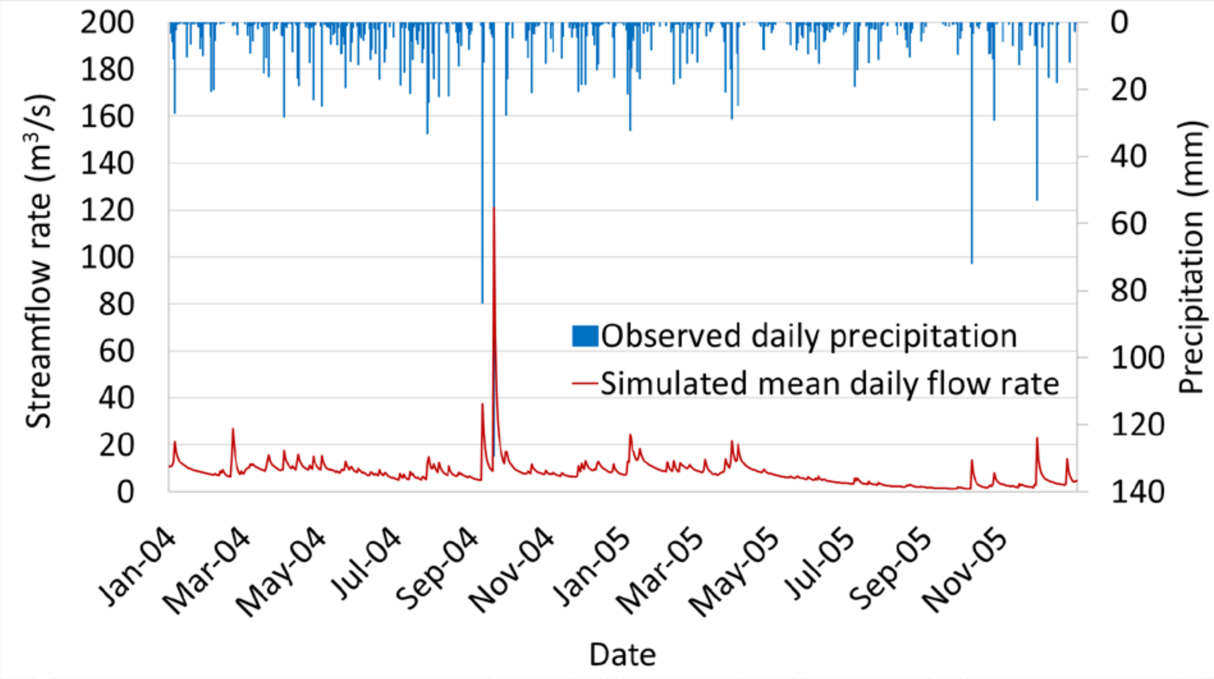
Streamflow and nutrients concentrations

- Simulation results with observed climate
- Data;
- Colored lines

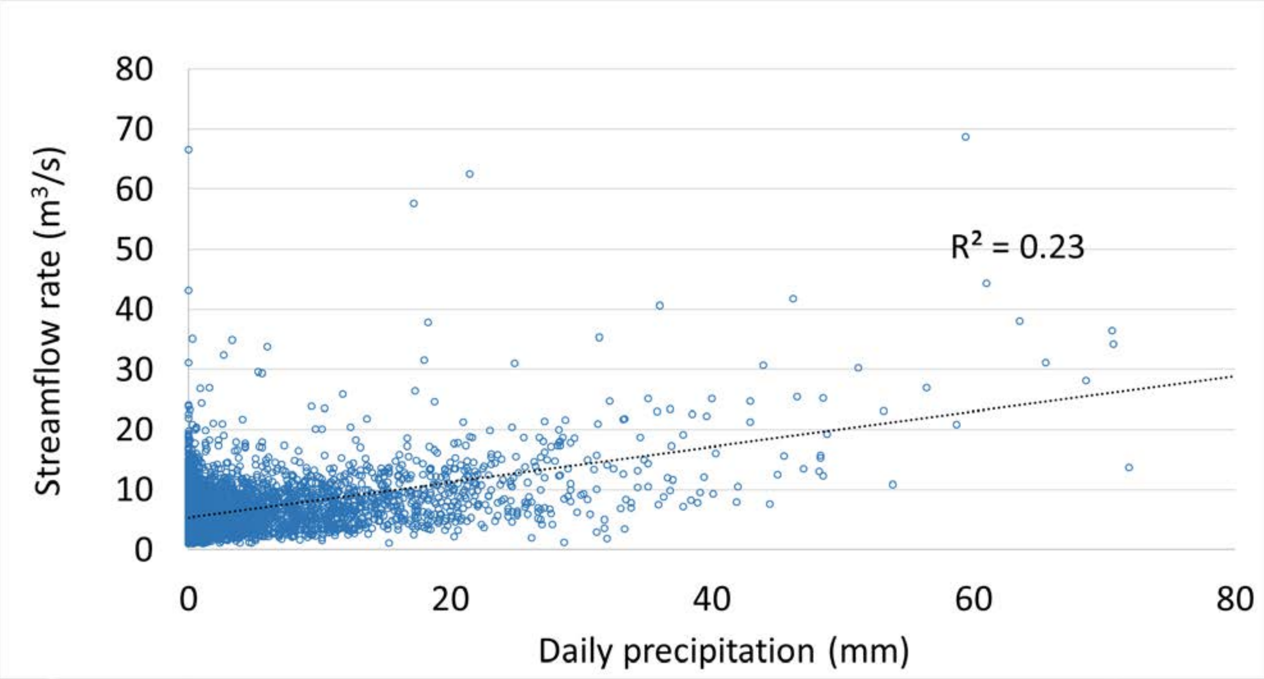




Mean annual daily dissolved oxygen concentration
12
11
10
9
mg/l
1950
1970
1990
2010
2030
2050
2070
2090
Year
RCP 4.5
RCP 8.5



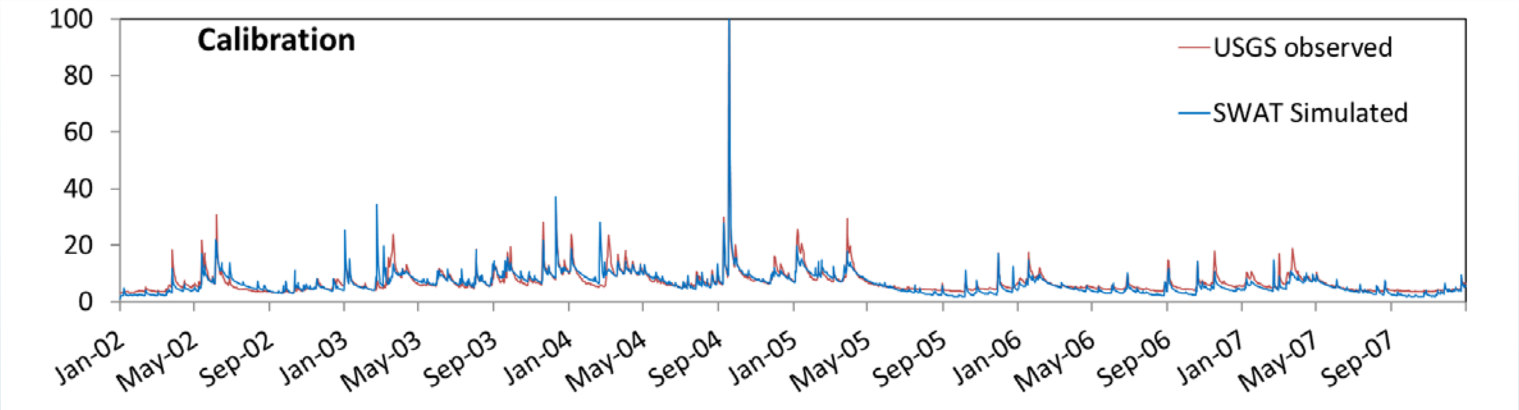
Streamflow rate (m3/s)
Precipitation (mm)
Observed daily precipitation
Simulated mean daily flow rate
Date
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05
Mar-05
May-05
Jul-05
Sep-05
Nov-05



Streamflow rate (m3/s)
R² = 0.23
Daily precipitation (mm)

Overall good outlet daily streamflow simulation

(Amin et al., 2017)



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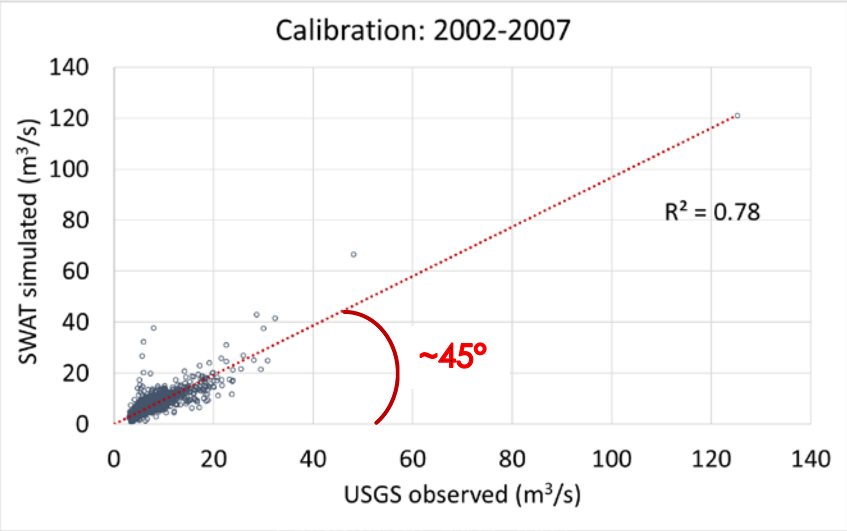

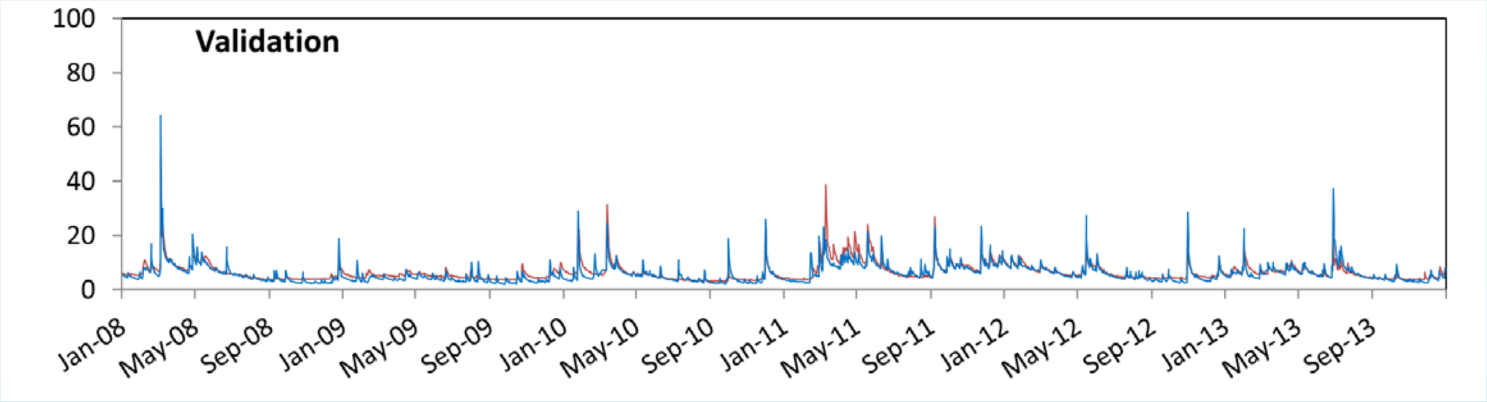

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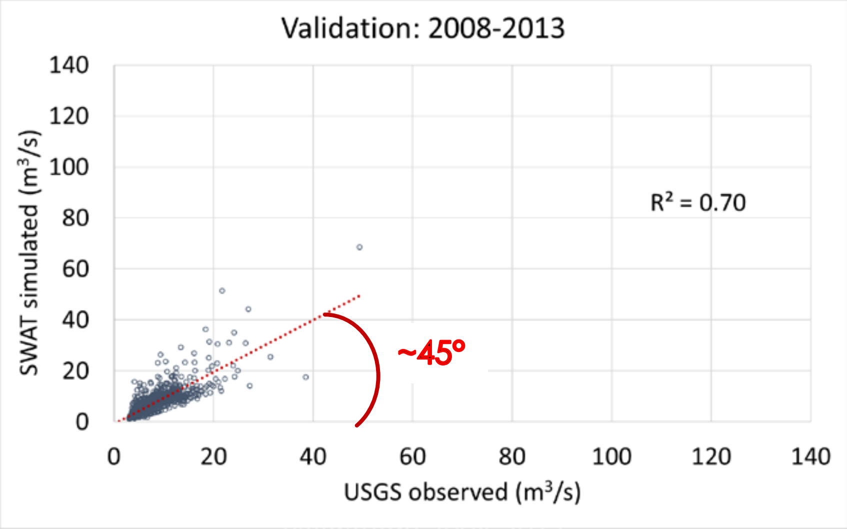
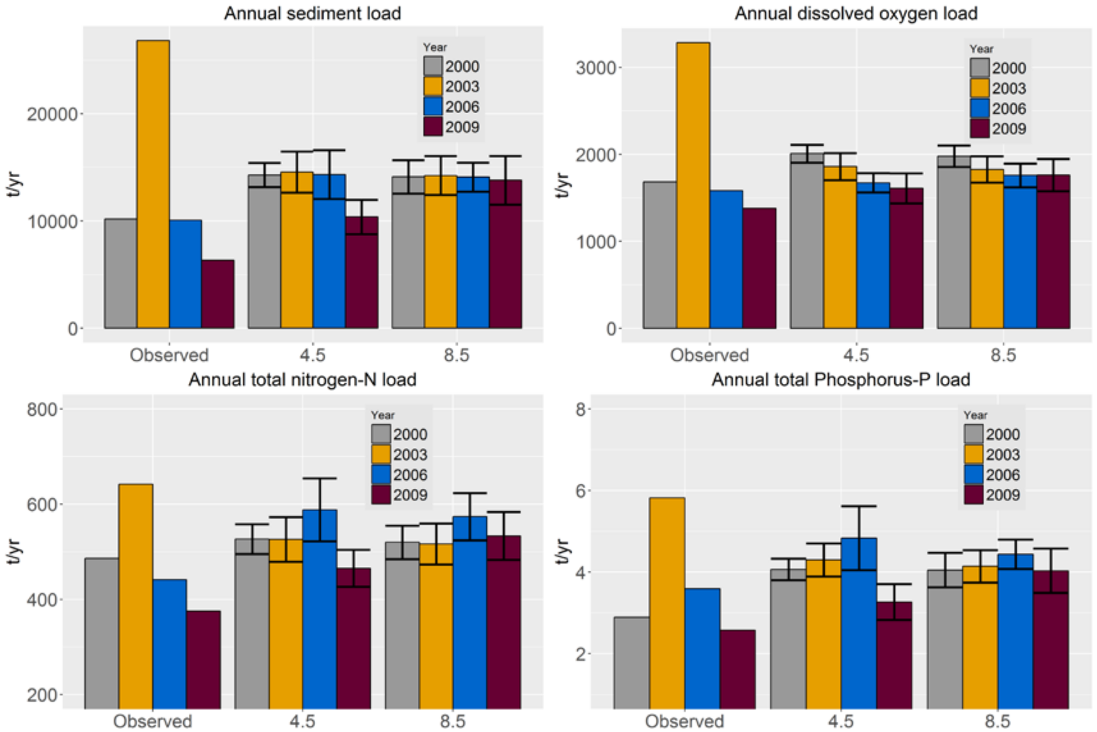
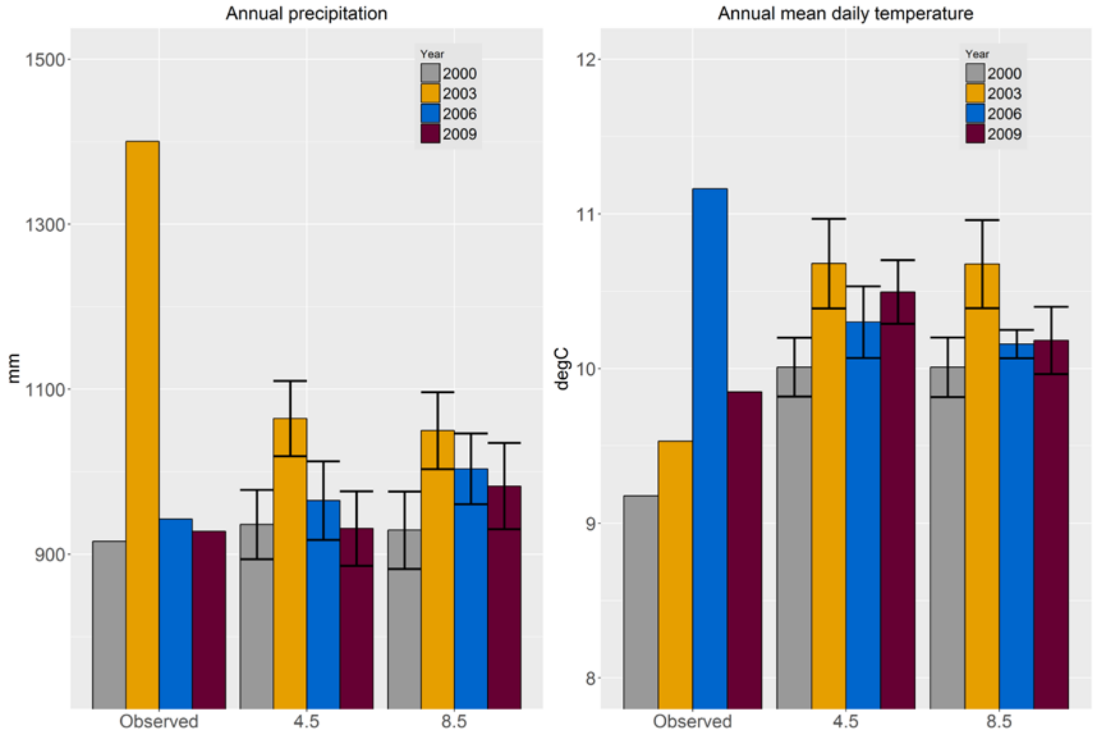


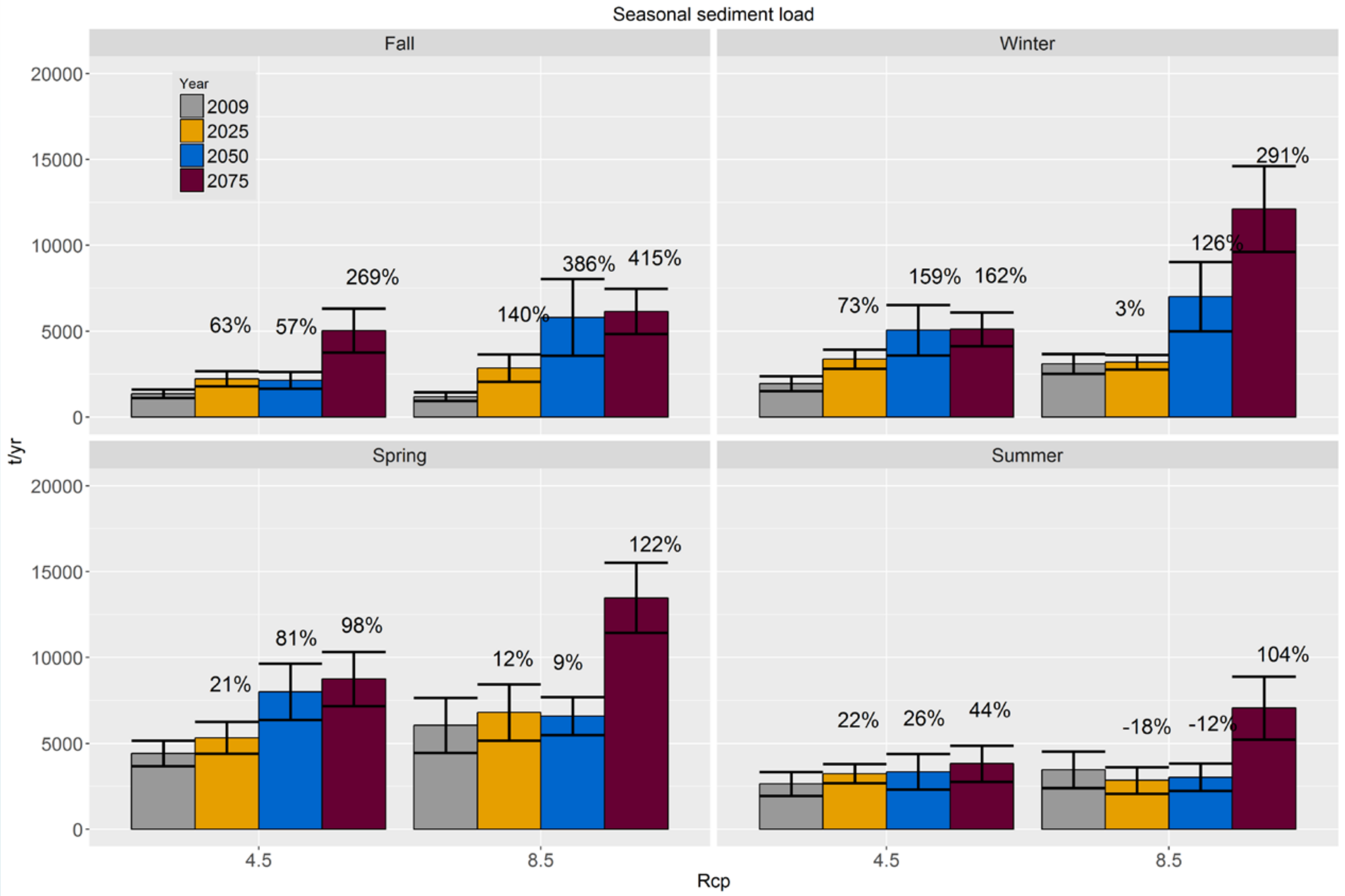
Mean annual simulated loads (± se) 2000-2009

Why the difference?

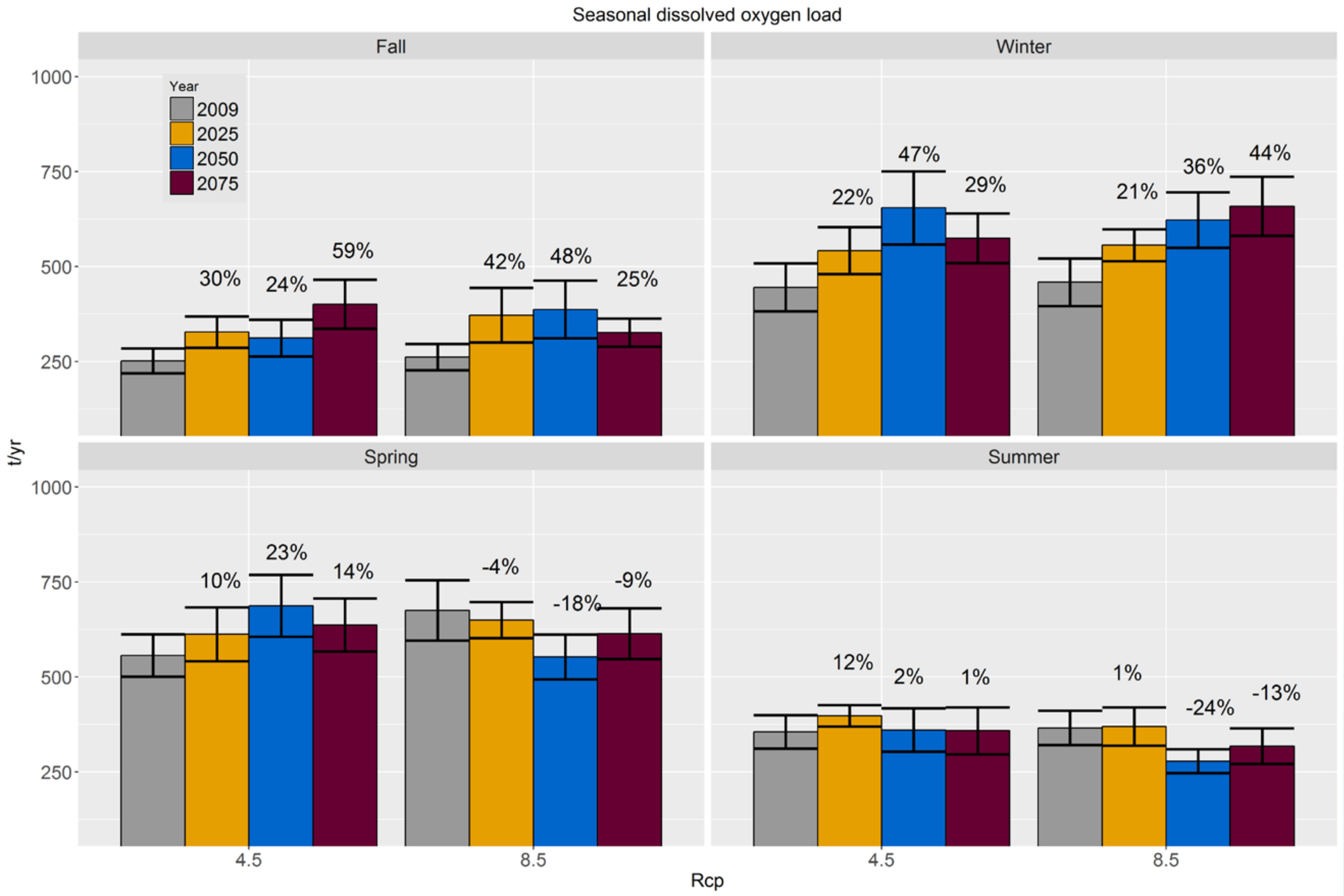




- Why the difference between loads based on observed data and loads based on simulated data
- Is 2003 a particular weather year? (el-nino,...

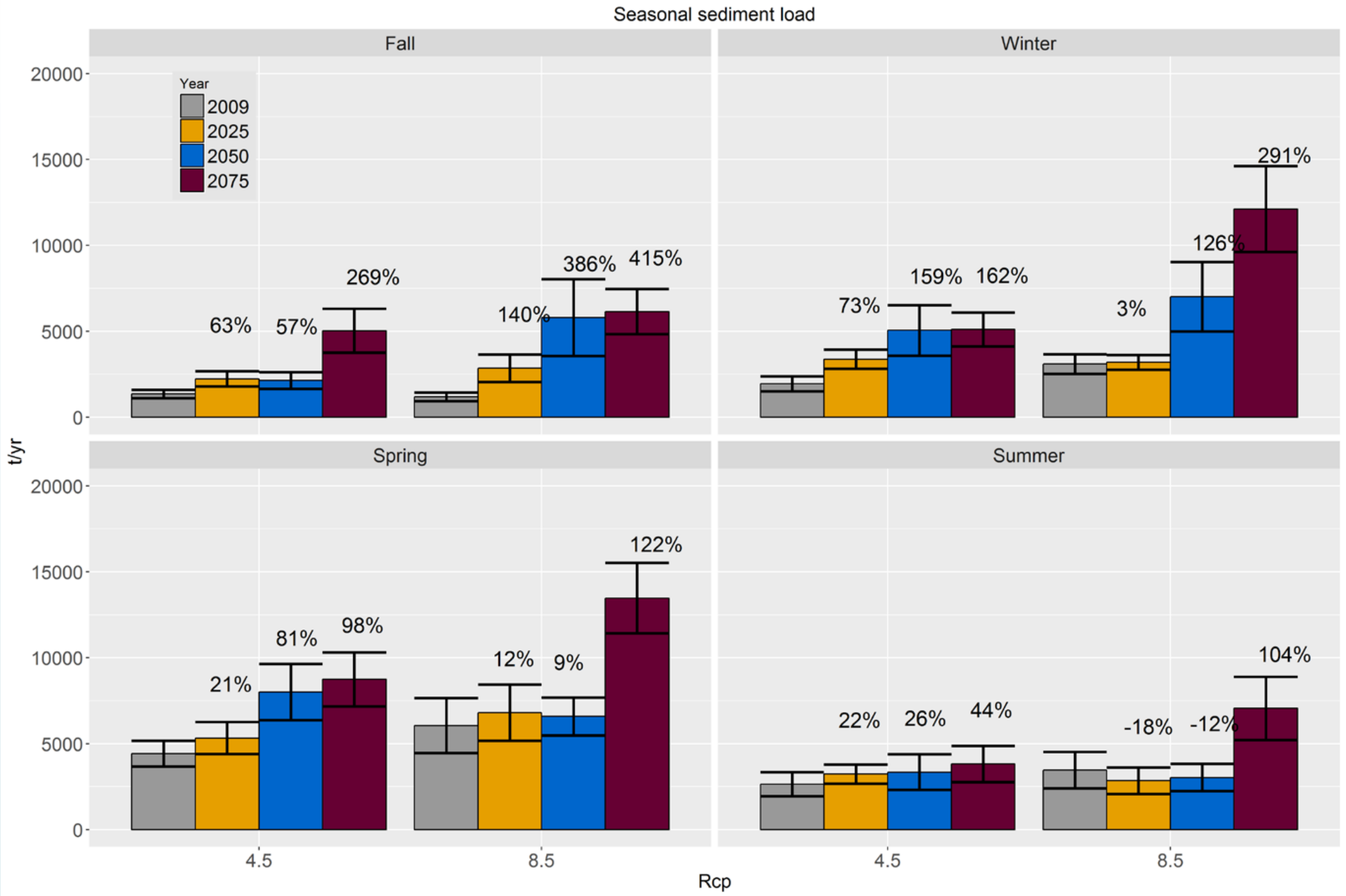


Seasonal sediment load
Fall
Winter
Spring
Summer
Year
2009
2025
2050
2075
t/yr
20000
15000
10000
5000
0
63%
57%
269%
140%
386%
415%
73%
159%
162%
3%
126%
291%
21%
81%
98%
12%
9%
122%
22%
26%
44%
-18%
-12%
104%
4.5
8.5
Rcp



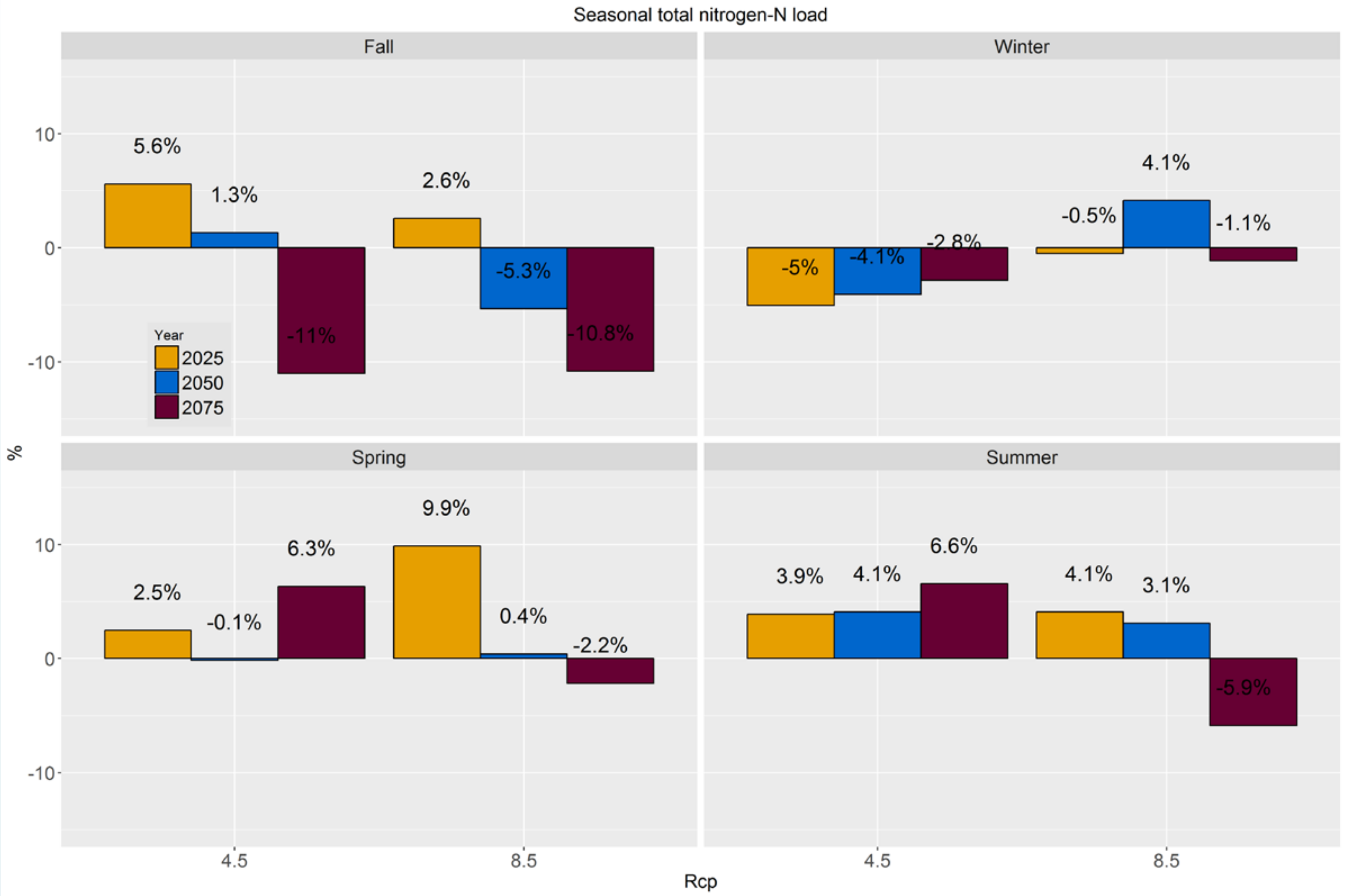
Seasonal dissolved oxygen load
Fall
Winter
Spring
Summer
Year
2009
2025
2050
2075
t/yr
1000
750
500
250
30%
24%
59%
42%
48%
25%
22%
47%
29%
21%
36%
44%
10%
23%
14%
-4%
-18%
-9%
12%
2%
1%
1%
-24%
-13%
4.5
8.5
Rcp

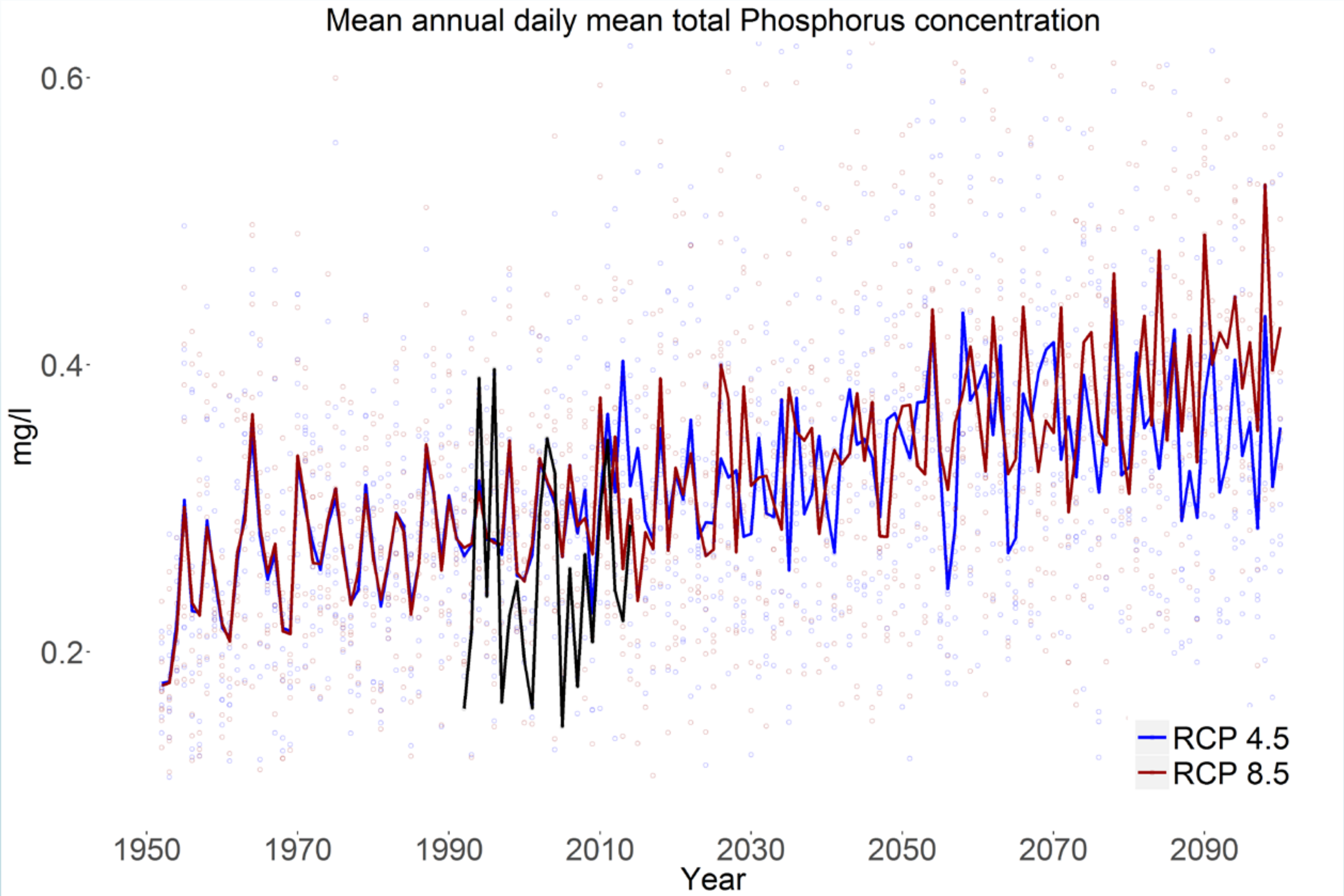
Seasonal sediment loads (± standard error)



Mean seasonal total-N load differences (± standard error)

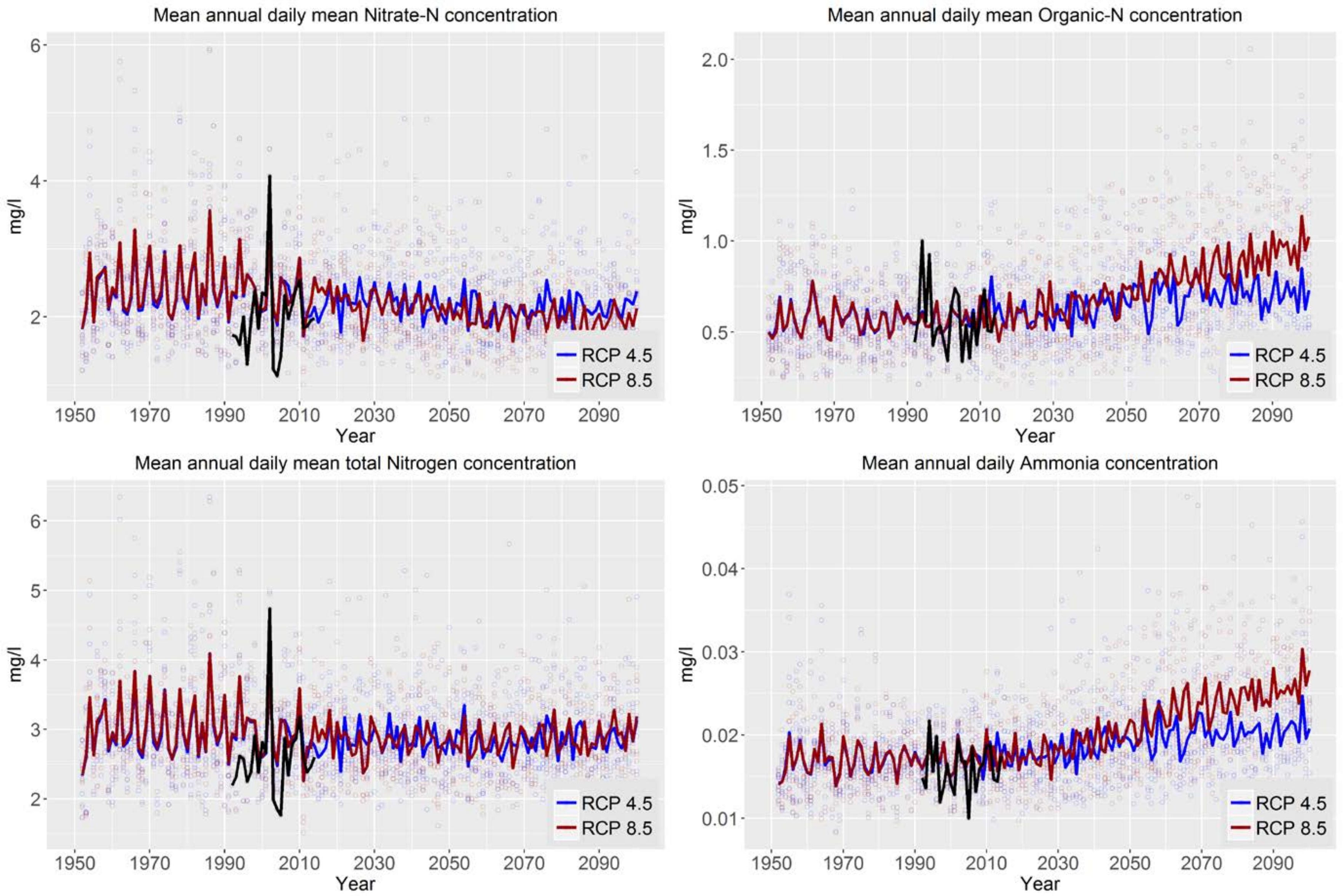
Load difference between 1984-2013 atmospheric wet Nitrate-deposition and hypothesized mean




Mean annual daily mean total Phosphorus concentration
0.6
0.4
0.2
mg/l
1950
1970
1990
2010
2030
2050
2070
2090
Year
RCP 4.5
RCP 8.5

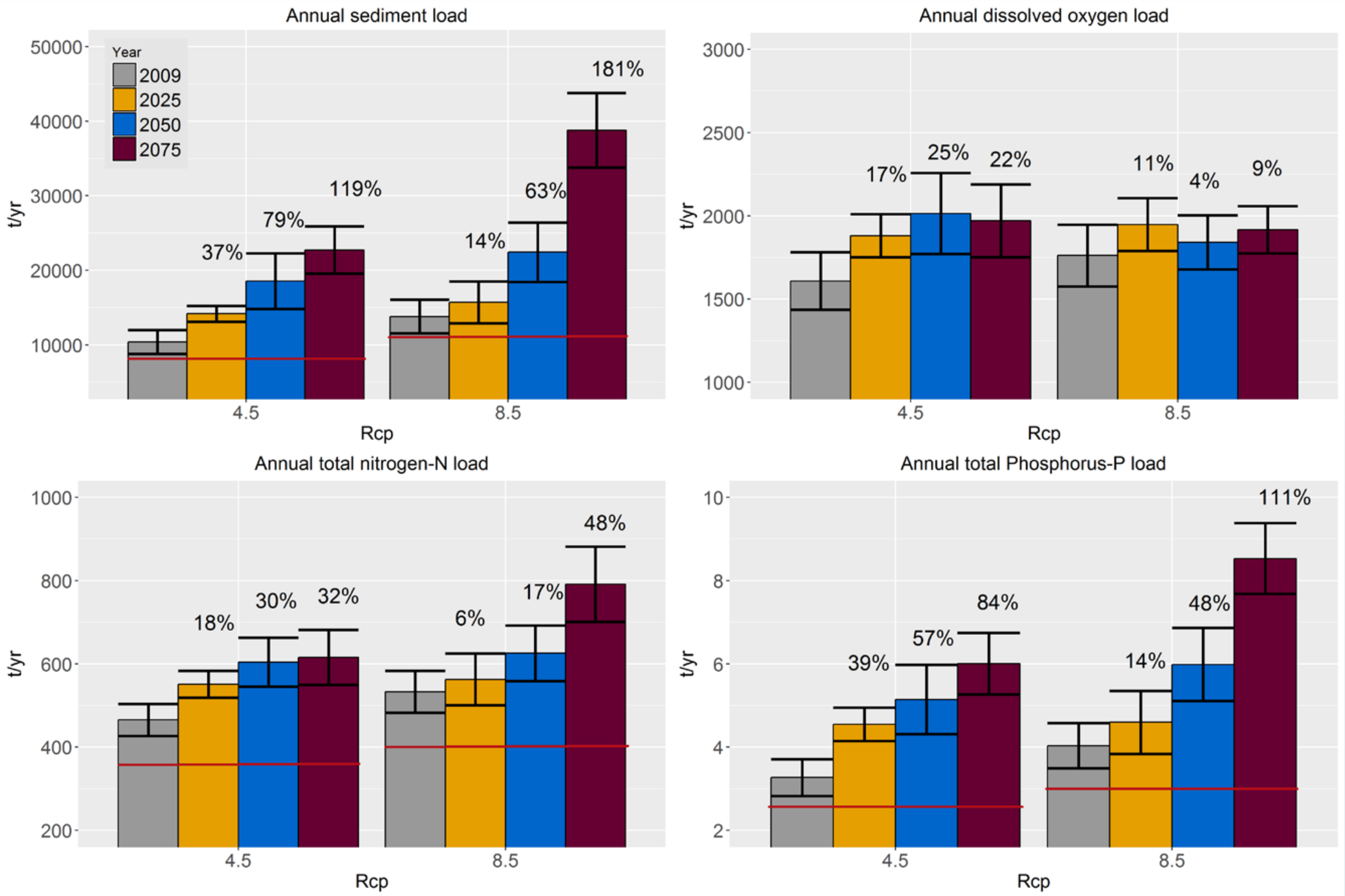
N-based nutrients concentrations

- Simulation results with observed climate
- Data;
- Colored lines



Annual loads (± standard error)

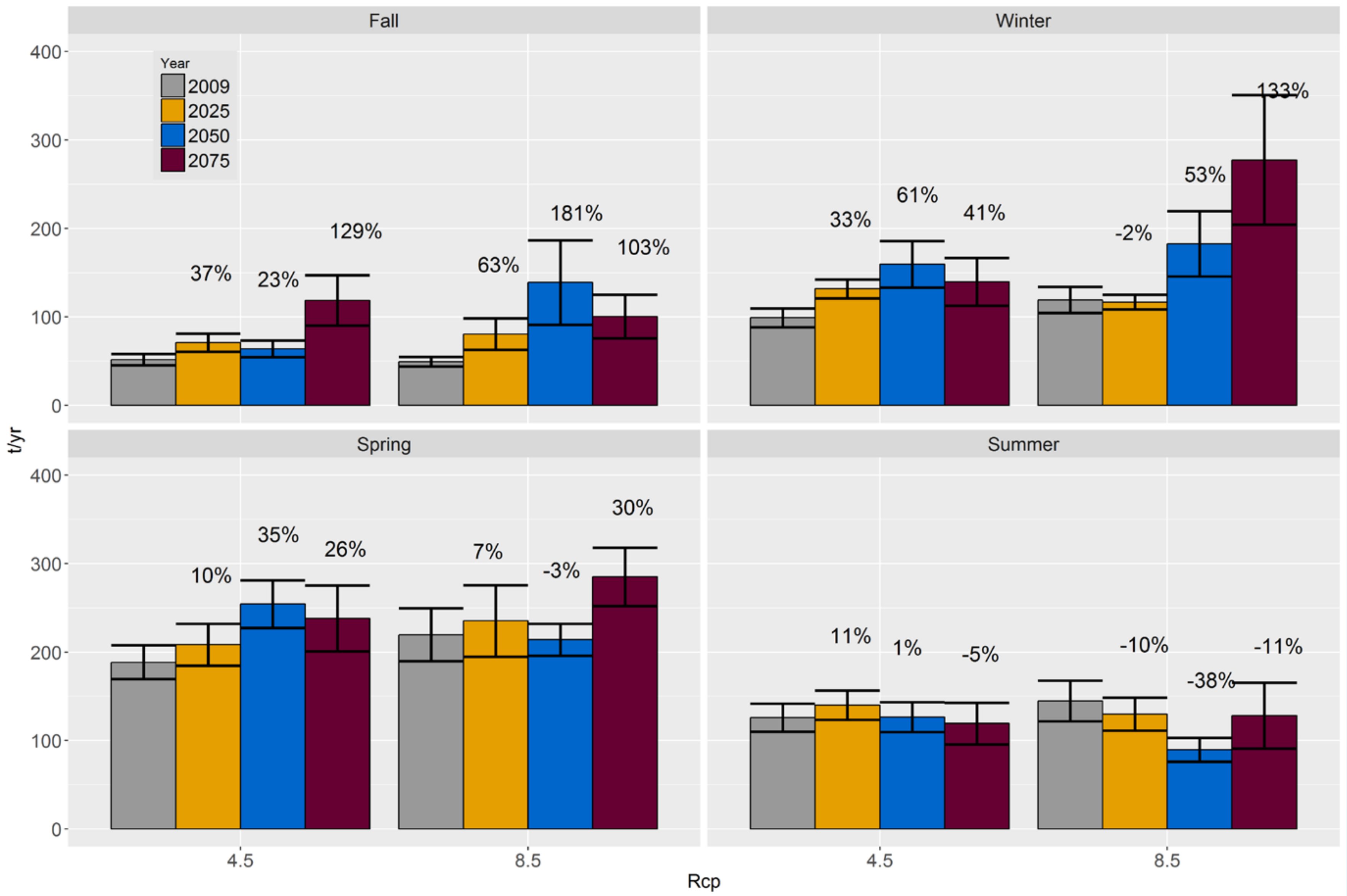
- Observed:
- Simulation results with observed climate
- Data;
- Rcp: simulation results with climate model data



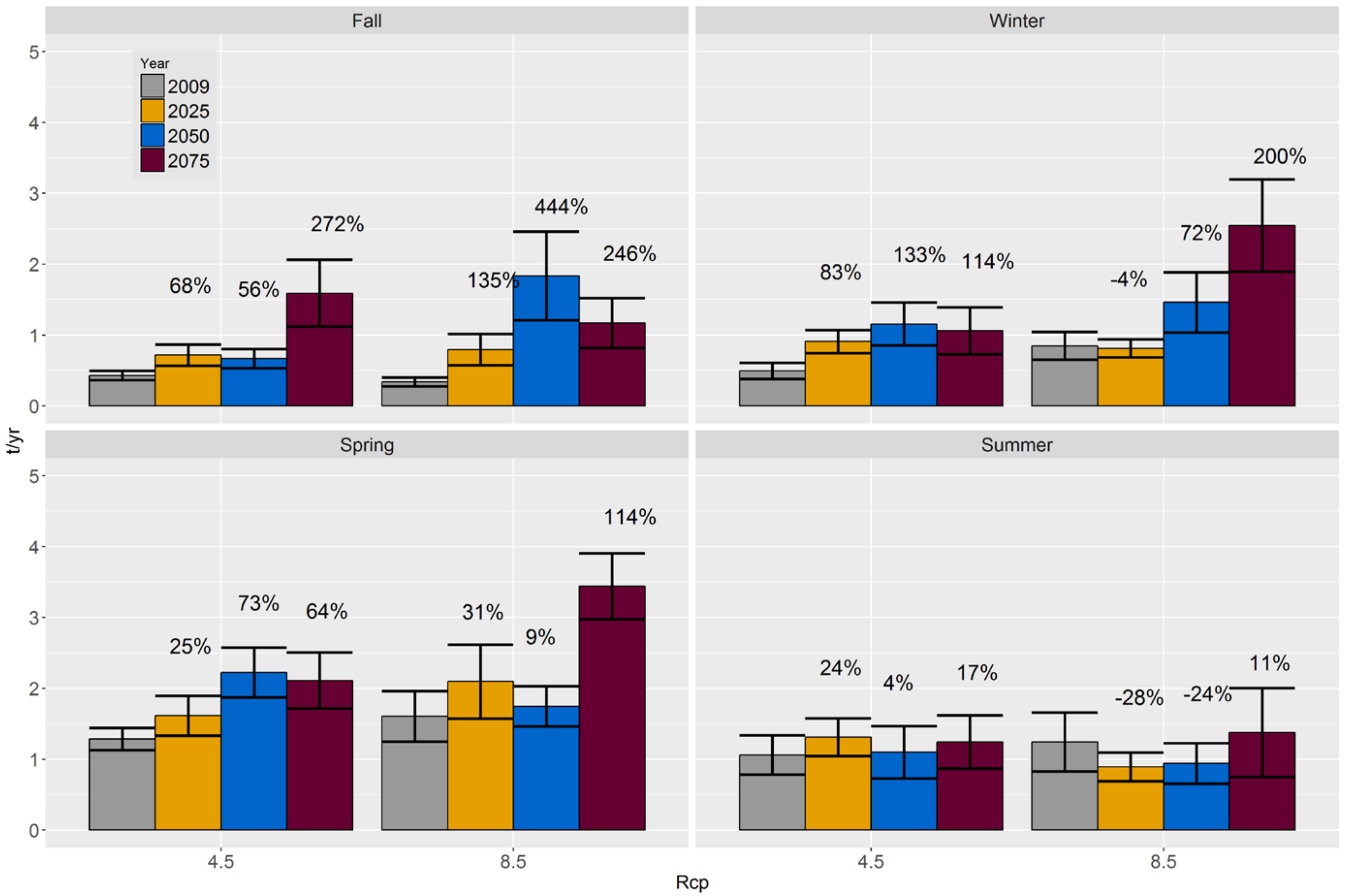
Red lines are the 2025 annual loading TMDL goals

Seasonal total-N loads (± standard error)

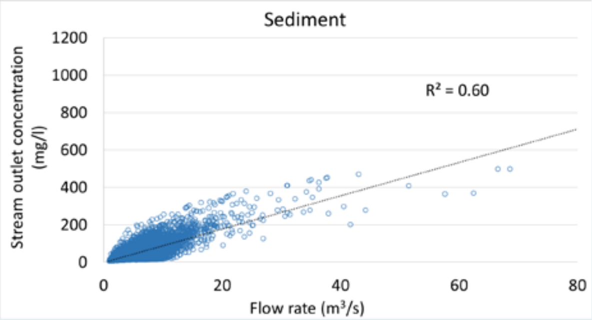
- sg

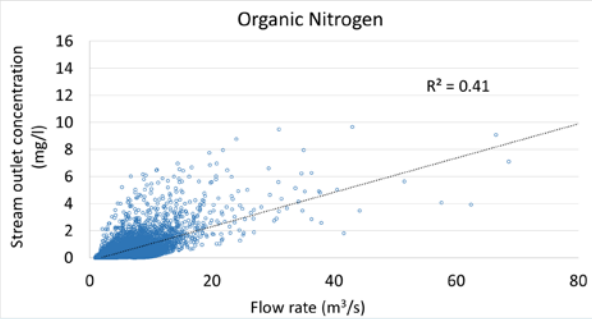


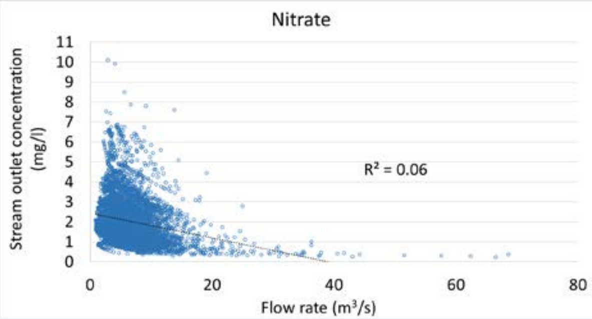
Seasonal total-P loads (± standard error)

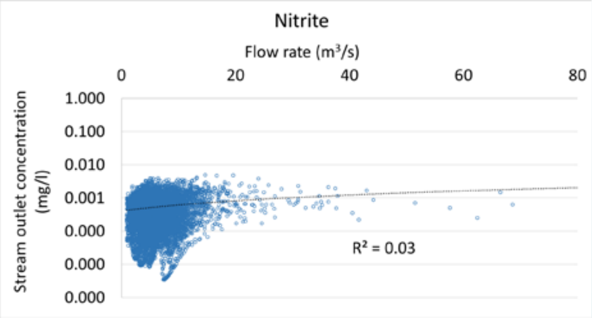


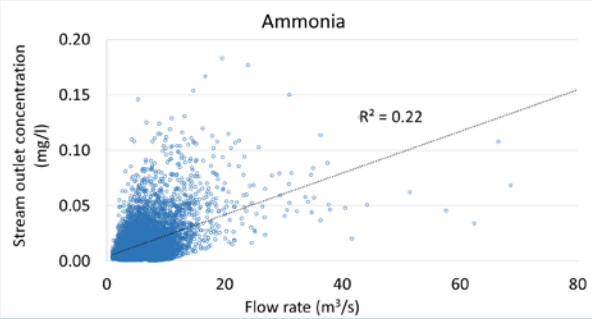
Concentrations vs. flow rate (simulation with observed climate data 1995 – 2014)

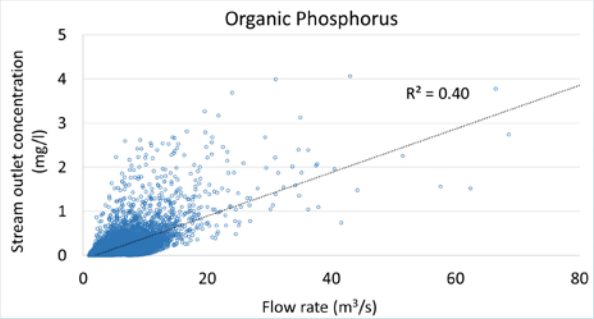


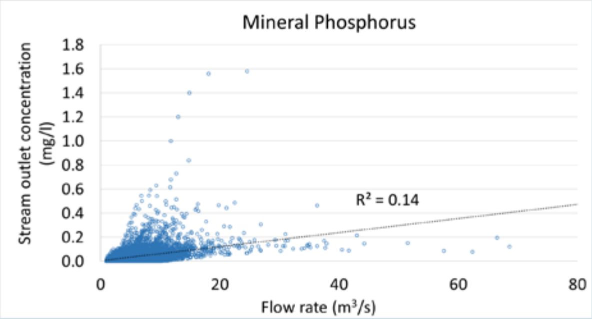




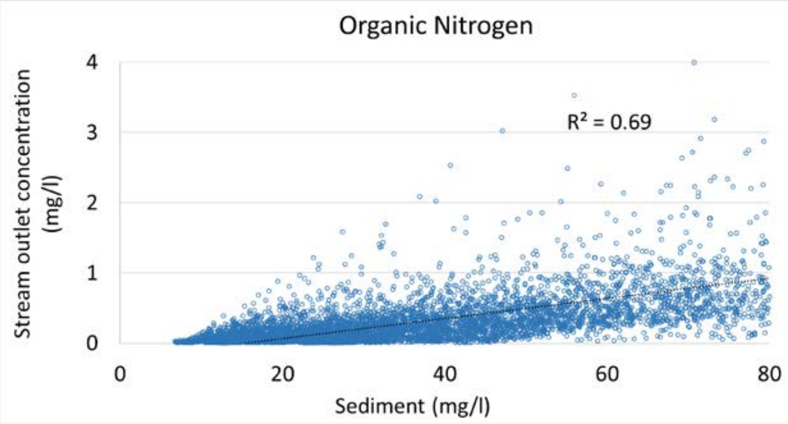


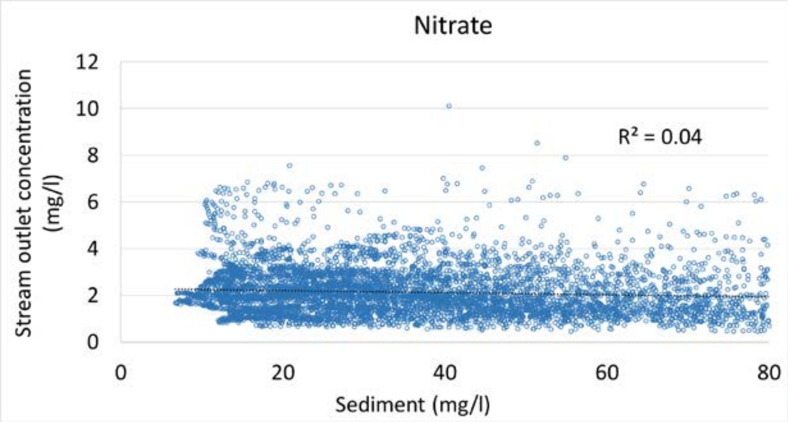


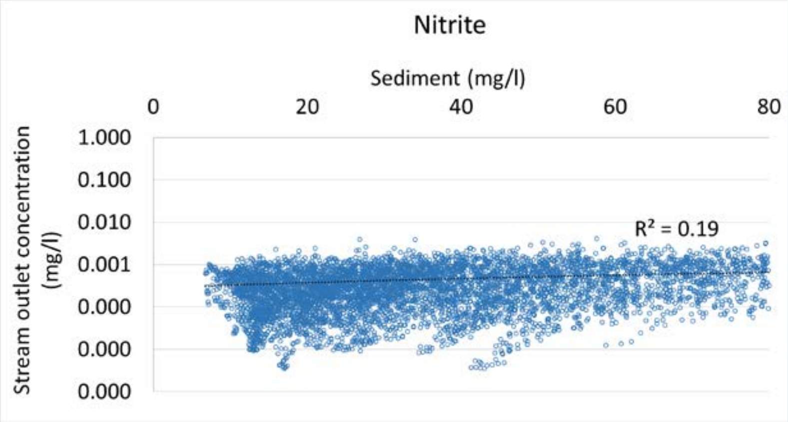


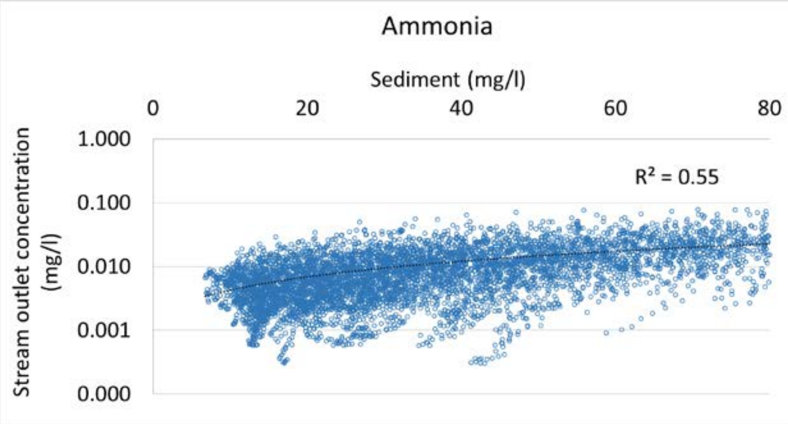


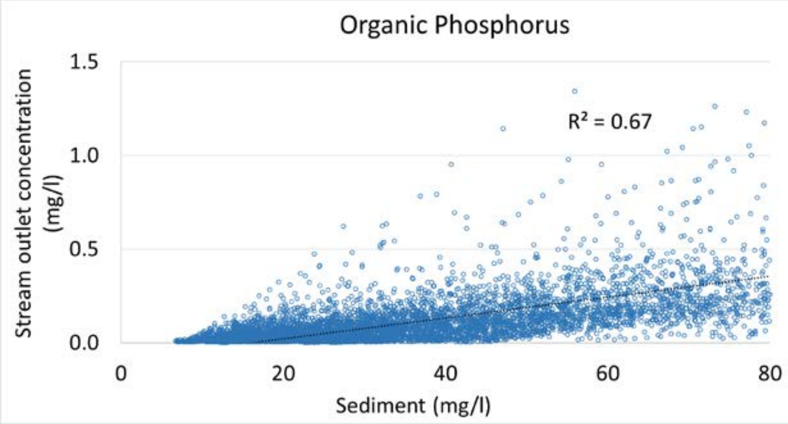
Sediment vs. others (simulation with observed climate data 1995 – 2014)

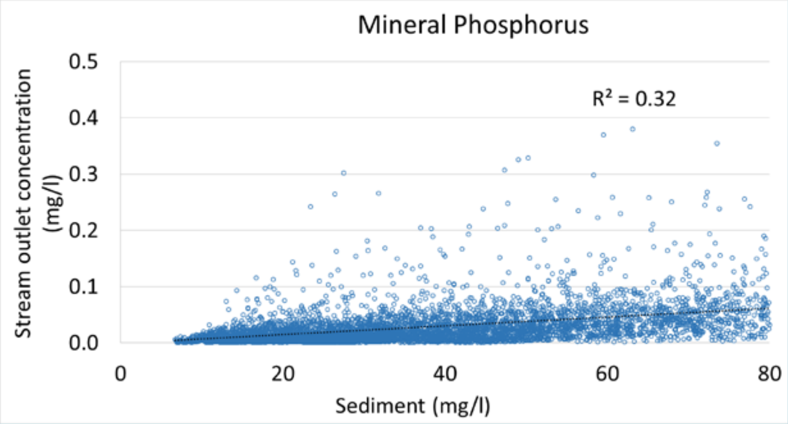




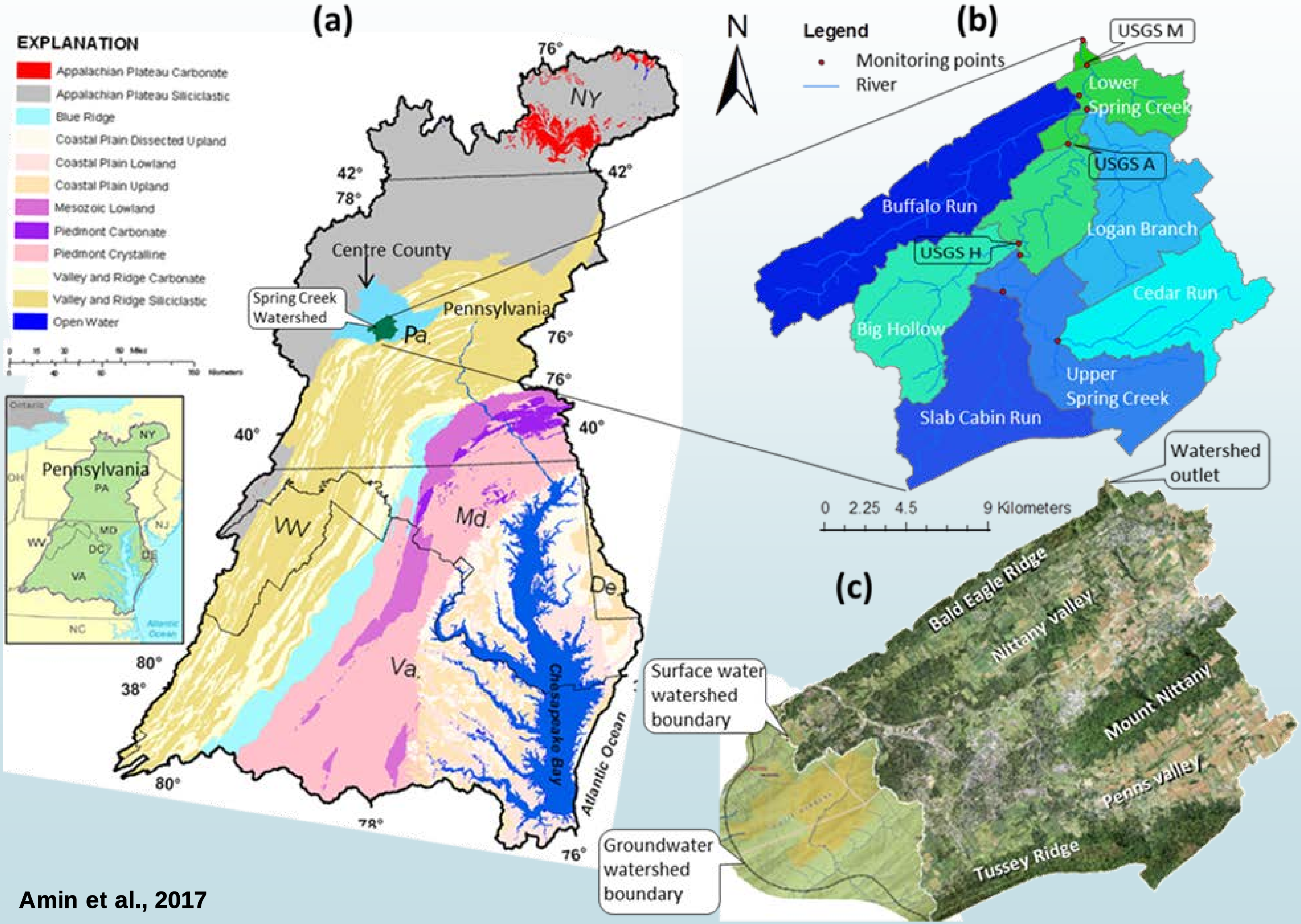








Spring Creek basin underlain by karstic geologic formations

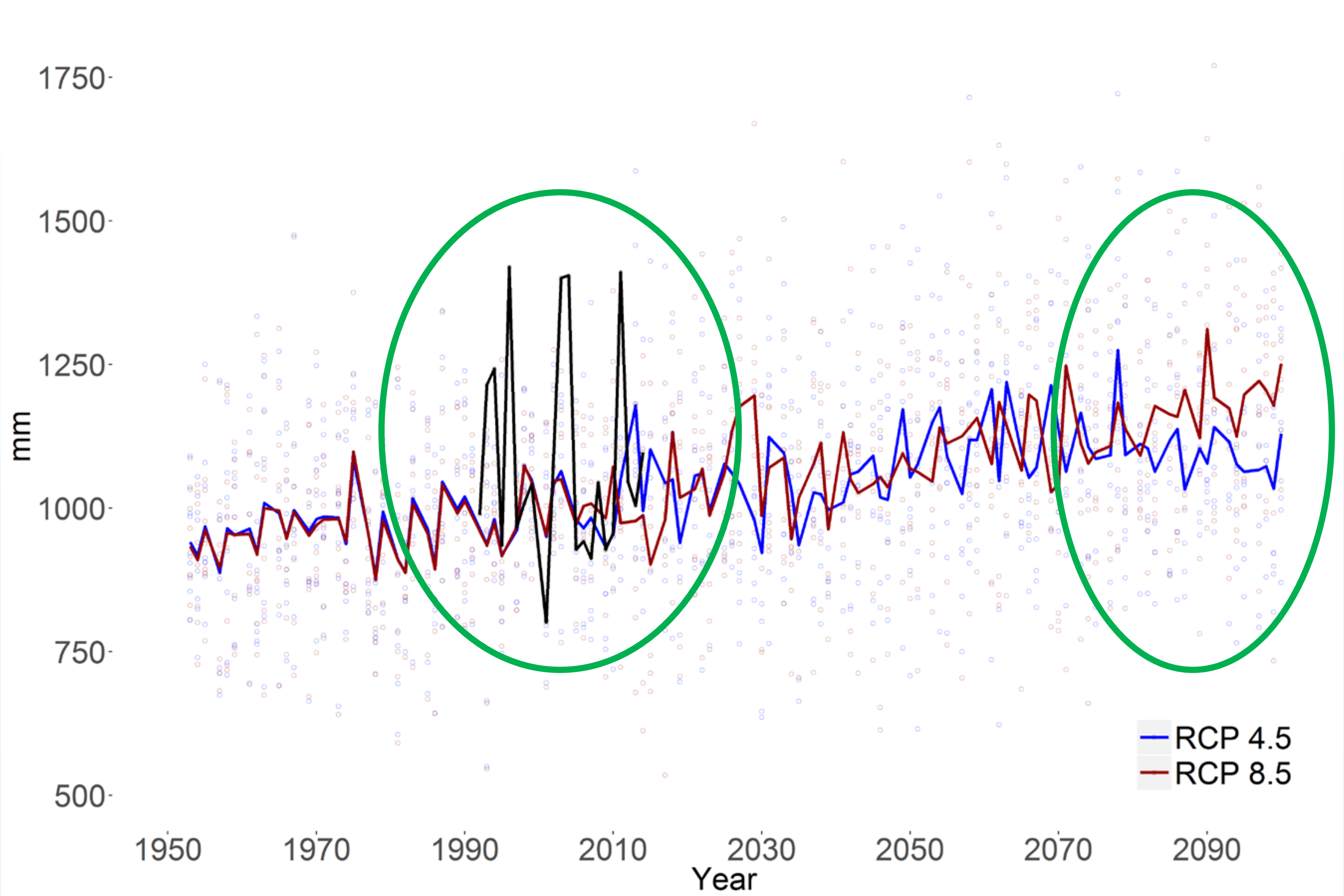


Amin et al., 2017

- Area: 369 km^2
- Land use:
  - 34% agriculture
  - 21% developed
  - 43% forest
- Base-flow:

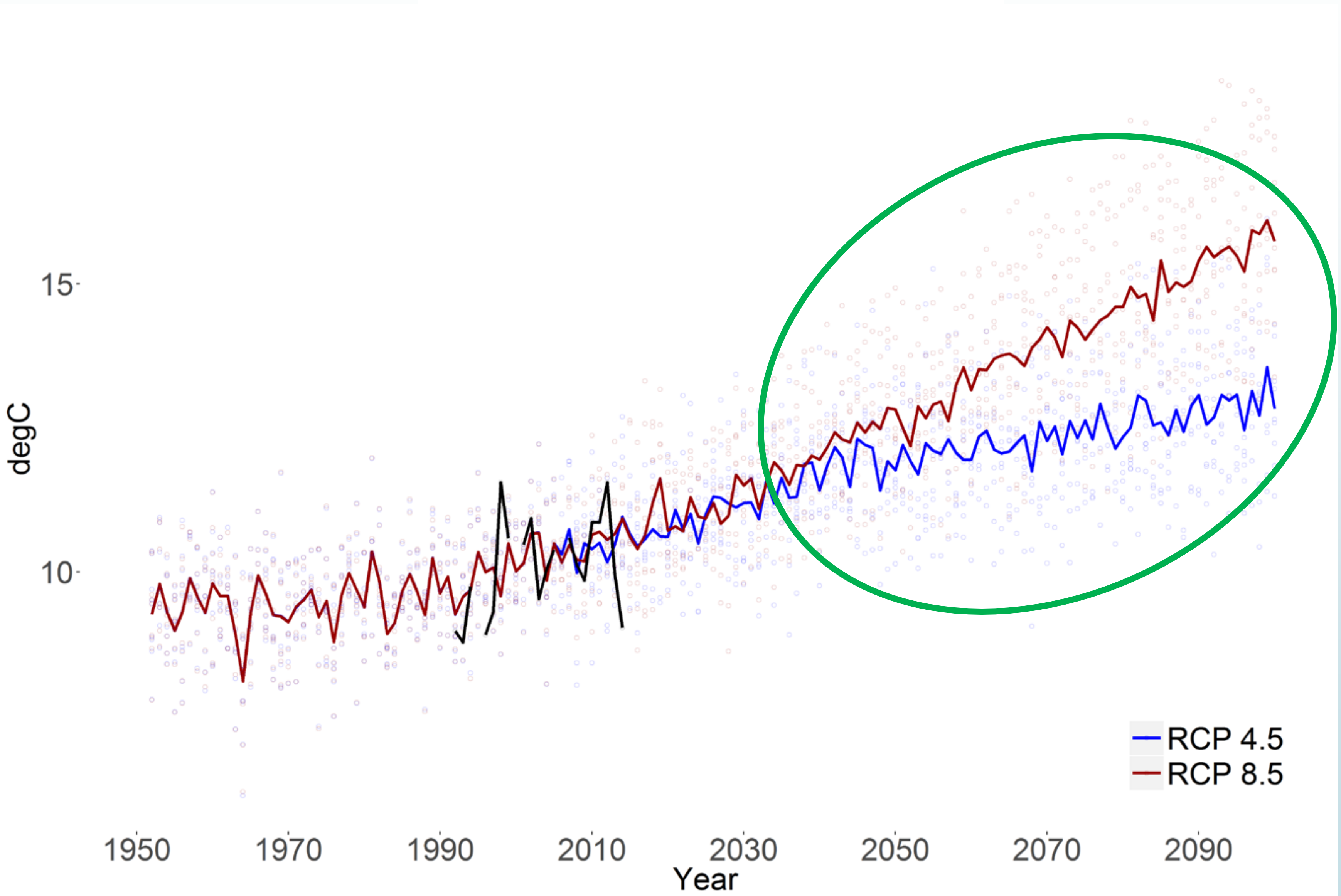
  > 80% streamflow

Annual total precipitation increases in State College (PA)



- ~150 mm increase between 2010 and 2100 in the worst case scenario
- Under-predicted peak total annual precipitation
- Stabilization under Rcp 4.5 after 2080

Annual mean daily temperature increases in State College (PA)



- ~5°C increase between 2010 and 2100 in the worst case scenario
- Departure from 2030's