Nitrate and Phosphorus Concentration Trends in Iowa's Rivers

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Collaborators and funding

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Concentrations vs Loads

- Concentration is mass of substance per volume, such as mg/l
- Load is the product of concentration times discharge, essentially the mass of a pollutant exported from a basin. Can be expressed as total tons, or tons per acre
- Both have important implications for streams
- Concentrations – drinking water, low flows, toxicity
- Loads – hypoxia, export from regions, total mass lost from an area or field

- Flow weighted concentrations are different – calculated by summing loads over time and dividing by discharge – they provide “weighted” or “normalized” concentrations

Concentrations were the focus of the Iowa Nutrient Reduction Strategy

- % Nitrate-N reductions were based on concentration reductions

Nitrogen Reduction Practices

	Practice	% Nitrate-N Reduction [Average (Std. Dev.)]
Nitrogen Management	Timing (Fall to spring)	6 (25)
	Source (Liquid swine compared to commercial)	4 (11)
	Nitrogen Application Rate	Depends on starting point
	Nitrification Inhibitor	9 (19)
	Cover Crops (Rye)	31 (29)
Land Use	Perennial – Land retirement	85 (9)
	Living Mulches	41 (16)
	Extended Rotations	42 (12)
Edge-of-Field	Drainage Water Mgmt.	33 (32)*
	Shallow Drainage	32 (15)*
	Wetlands	52
	Bioreactors	43 (21)
	Buffers	91 (20)**

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Study Objectives

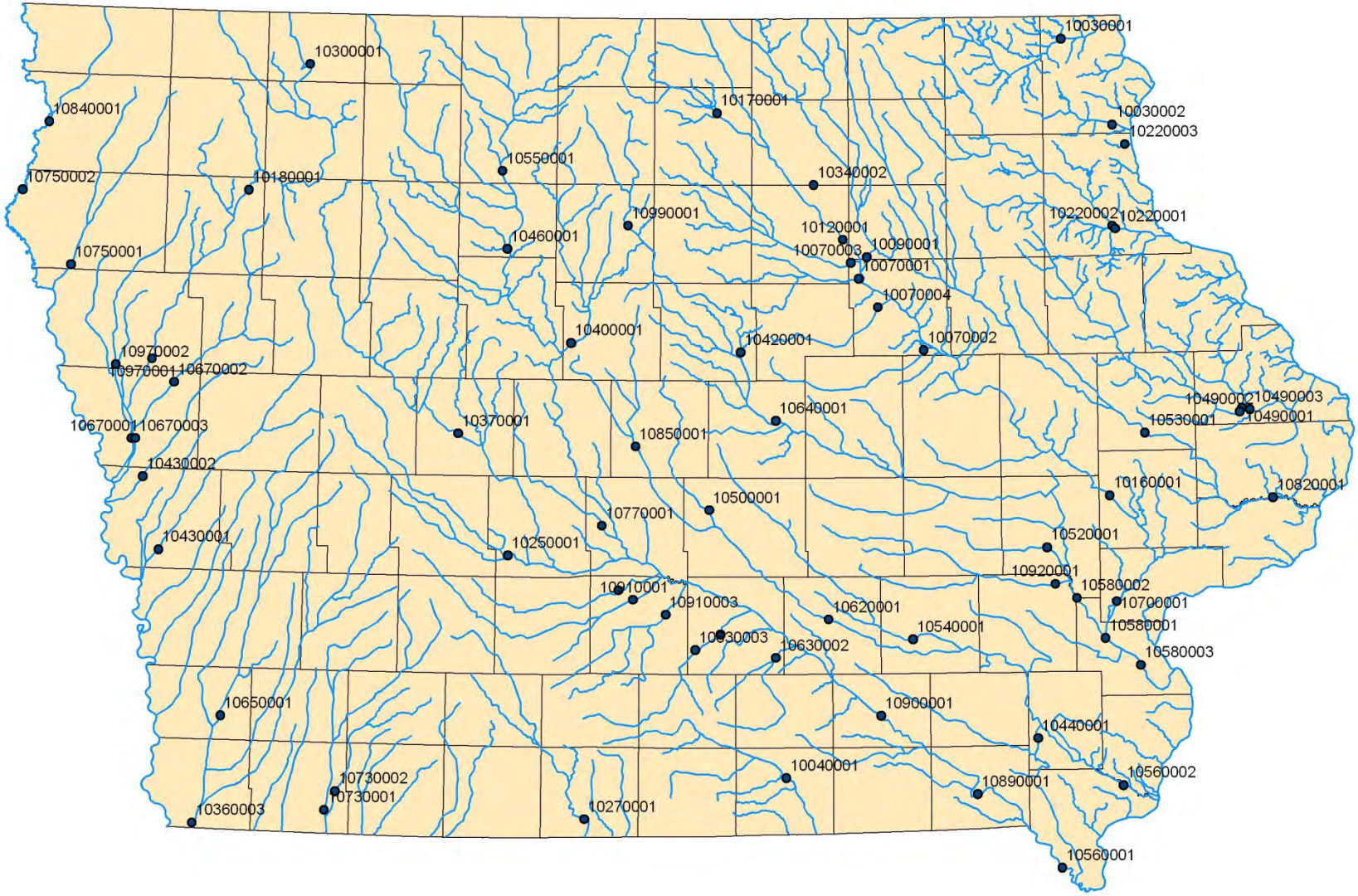
- Assess the presence of any linear trends in the concentration data using a time-series method that accounted for temporal correlation in the data
- Combine the trend information from individual sites into an assessment of the state-wide rate of change in river nitrate concentrations

Are concentrations increasing, decreasing, or staying the same since 1998?

Monitoring record

- N concentrations measured at 60 ambient sites (ambient = not under influence of point sources or cities)
- 14 sites contained fewer observations, so 46 sites assessed
- Sample size ranging from 120-165 for individual sites
- Average watershed area = 2,850 km^2 ranging from 88 km^2 (Bloody Run) to 20,152 km^2 (Cedar River at Conesville)
- All surface water samples were collected as grab samples at fixed monitoring sites following an EPA-approved Quality Assurance Project Plan and were analyzed by the State Hygienic Laboratory using EPA Method 353.2.
- All NO_3-N concentration data were obtained from the Iowa Department of Natural Resources Iowa STORET/WQX Water Quality Database (https://programs.iowadnr.gov/iastoret/).

Ambient River Monitoring Sites - Storet ID's



Modeling Approach

Let y_t be the NO_3-N concentration of the tth month at a generic site. A simple linear trend model is

$$y_t = \beta_0 + \beta_1 t + \eta_t, \tag{1}$$

where β_0 is the mean concentration of the 0th month, and β_1 is the monthly rate of change in concentration, with a positive (negative) β_1 indicating increasing (decreasing) concentration over the study period.

In practice, concentrations are correlated over time, with strong seasonal patterns. To account for temporal correlations in the data, we modeled the regression errors η_t by an autoregressive (AR) model, specifically, as an order-*p* AR model. The AR(*p*) model was employed because it can effectively capture various seasonal patterns and short-term transitory fluctuations. The AR(*p*) model for η_t is given as follows:

$$\eta_t = \varphi_1 \eta_{t-1} + \varphi_2 \eta_{t-2} + \ldots + \varphi_p \eta_{t-p} + \varepsilon_t, \tag{2}$$

Concentration fluctuations

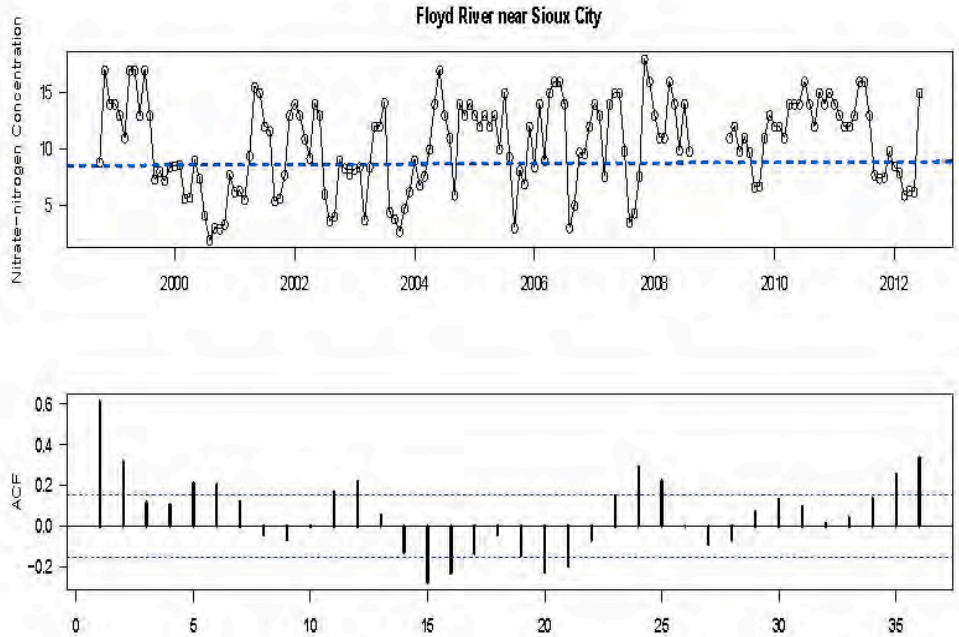


Figure 20: The monthly data and its ACF for Floyd River near Sioux City.

The fitted model is:

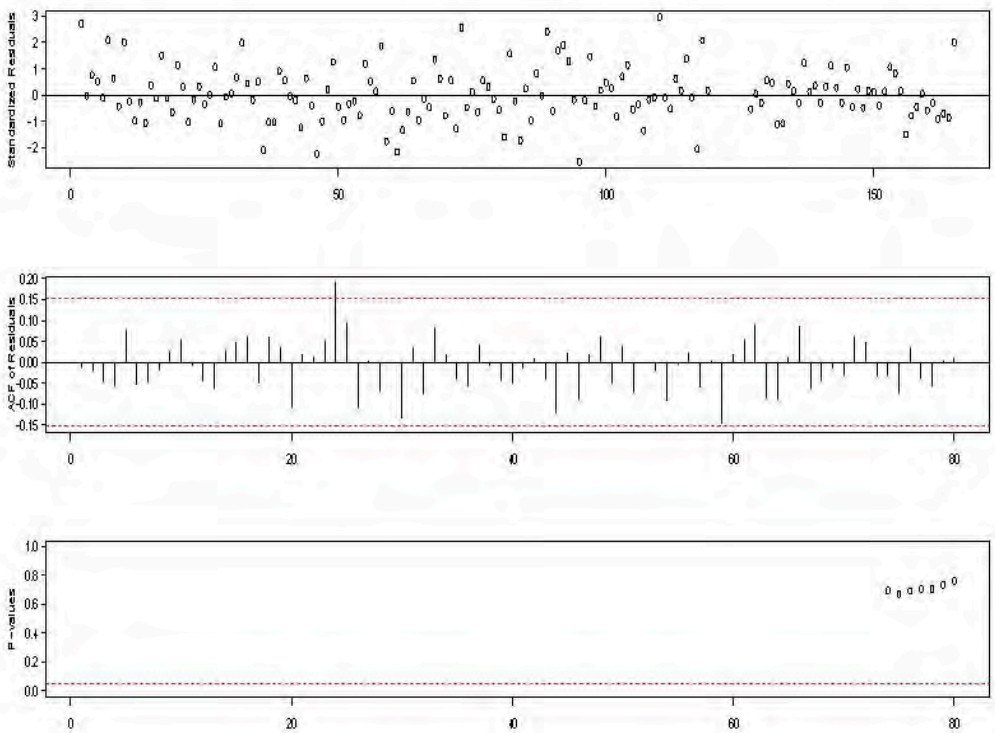
$\phi(B)(y_t - 8.2992 - 0.0243t) = \varepsilon_t, t = 1, \ldots, 165$, (0.5322) (0.0059)

where

$\phi(B) = 1 - 0.5344B + 0.1685B^{10} - 0.1473B^{11} - 0.1952B^{12}$, (0.0603) (0.0739) (0.0870) (0.0864) $+0.1870B^{13} + 0.2795B^{15} - 0.1236B^{18} + 0.2430B^{19}$ (0.0763) (0.0629) (0.0723) (0.0693)

the estimated variance of ε_t is 6.469, and the AIC is 771.06. The trend coefficient is significant at 5% level.

Model Diagnostics



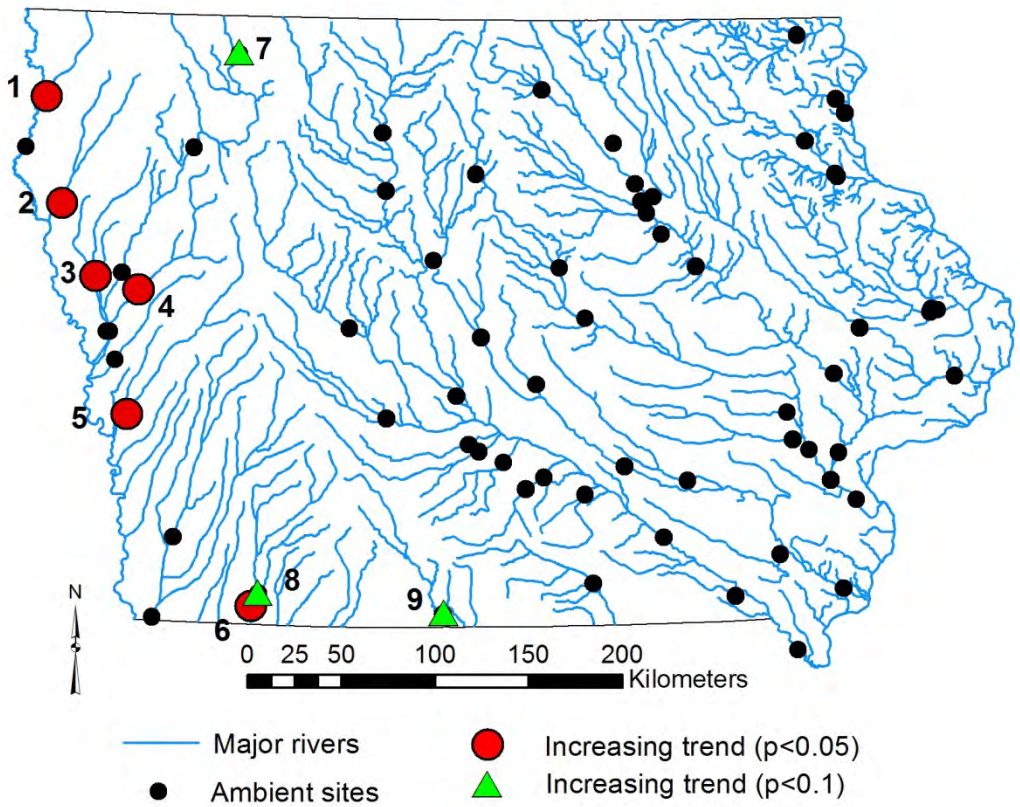
Residuals are uncorrelated

Residuals are uncorrelated

Residuals are uncorrelated

Figure 21: The diagnostic checking for Floyd River near Sioux City.

Nitrate Concentration Trends



- Of the 46 sites with sufficient record, 37 did not show a significant (p>0.1) trend (80%)
- 6 sites with increasing trends (p<0.05)
- 3 sites nominally significant (p<0.1)

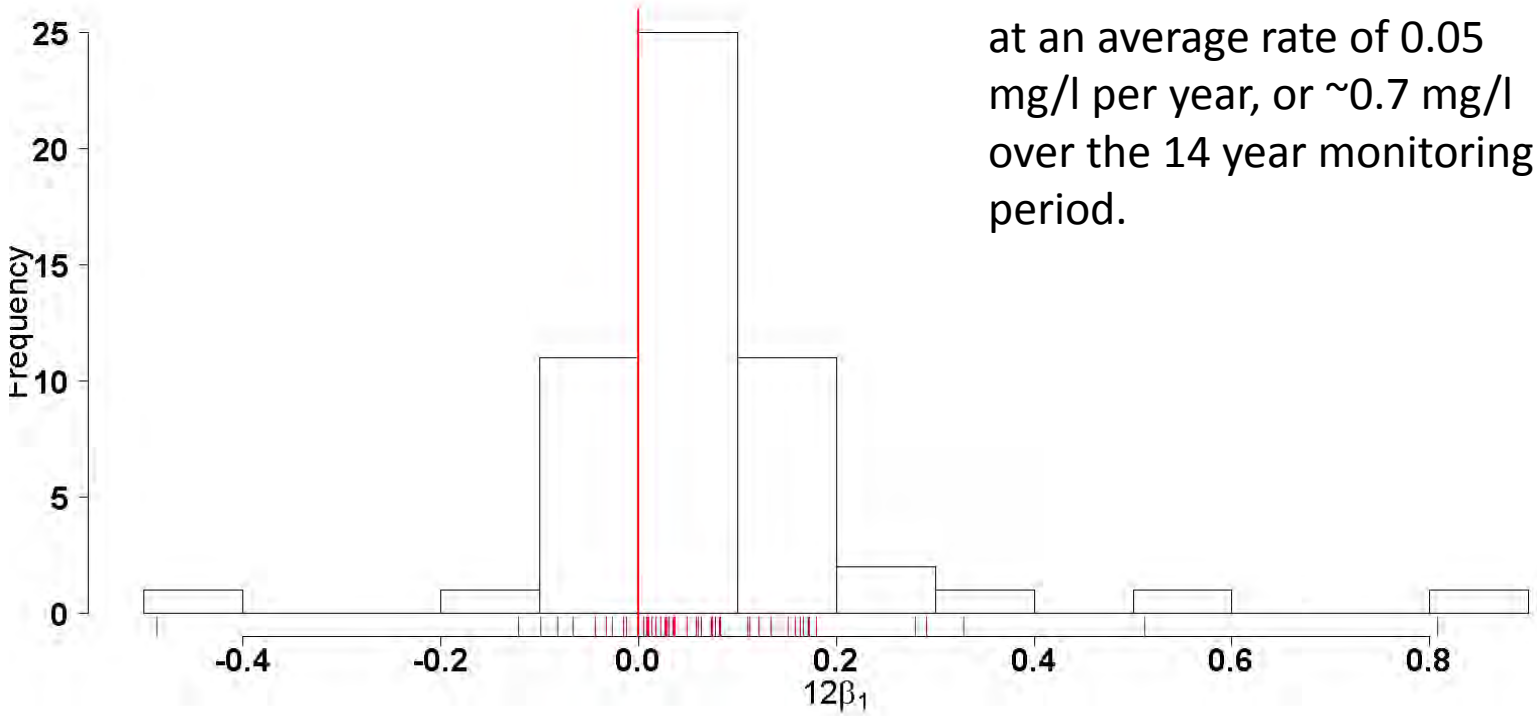
Location of ambient monitoring sites in Iowa and sites with statistically significant (p<0.1) trends in NO_3-N concentrations(1 = Rock River; 2 = Floyd River; 3 = West Fork Ditch; 4 = Maple River; 5 = Boyer River; 6 = West Nodaway River; 7 = Little Sioux River; 8 = East Nodaway River; 9 = Thompson River).

Increasing Trends

Site Name	ID No.	β_0	CI of β_0	$12\times\beta_1$	CI of $12\times\beta_1$	p-value
Floyd River near Sioux City*	10750001	8.30	(7.26,9.34)	0.292	(0.153,0.43)	0.000
Maple River near Mapleton	10670002	7.37	(6.24,8.51)	0.167	(0.009,0.326)	0.039
West Nodaway River near Shambaugh	10730001	2.13	(0.957,3.3)	0.173	(0.014,0.332)	0.033
East Nodaway River near Clarinda	10730002	1.79	(0.304,3.28)	0.164	(-0.033,0.36)	0.103
Rock River near Hawarden	10840001	5.27	(3.78,6.77)	0.329	(0.123,0.535)	0.002
West Fork Ditch at Hornick	10970002	8.15	(7.14,9.16)	0.151	(0.001,0.3)	0.048

mg/l increase per year

Histogram of Trends



As a collective population, concentrations are increasing at an average rate of 0.05 mg/l per year, or ~0.7 mg/l over the 14 year monitoring period.

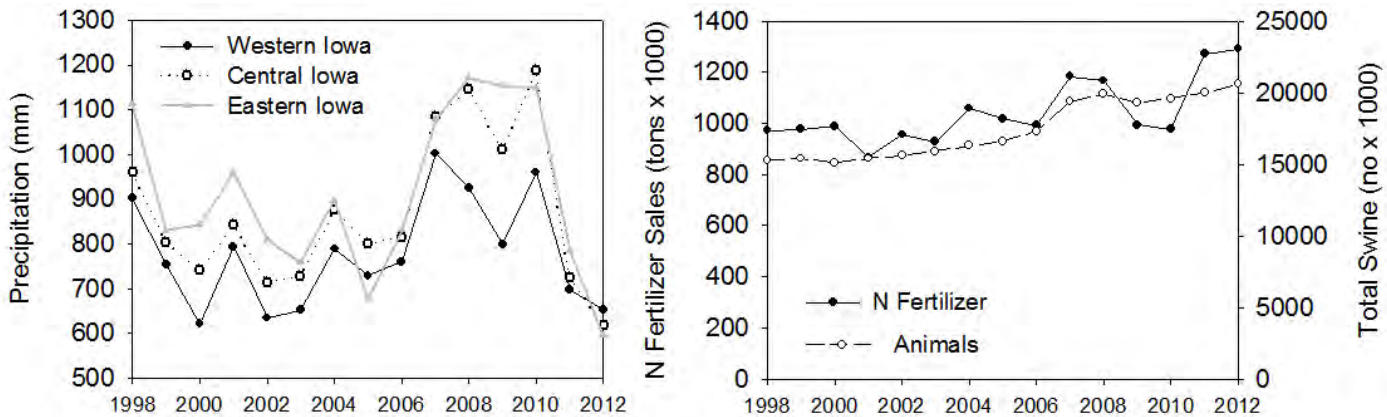
Histogram of annual rate of change in NO_3-N concentrations at 46 ambient Iowa sites. The tics at the bottom of the graph are the actual values within each box.

What have others seen?

- **Schilling and Lutz (2004)** used nonparametric tests to analyze a 28-year record of monthly NO_3-N concentrations from the Raccoon River in Iowa and found no statistically significant trends ($p<0.1$).
- **Jayasinghe et al. (2012)** utilized an autoregressive model of monthly NO_3-N concentrations patterns in the same watershed for the 1992 to 2008 period and similarly found no statistically significant time trend ($p<0.1$).
- **Sprague and Lorenz (2009)** examined both flow-weighted concentrations and observed values in their assessment of regional nutrient trends in U.S. rivers. They found no significant regional trends ($p<0.1$) in total-N for the 1993 to 2003 period using either observed or flow-weighted concentrations.
- **Sprague et al. (2011)** evaluated concentration patterns in eight major tributaries of the Mississippi River. Their results indicated a 0.2 mg/l increase in concentration in the Iowa River at Wapello and a 1.1 mg/l increase in the Mississippi River at Clinton, Iowa from 1980 to 2008.

Lack of trends in 80% of monitoring sites or otherwise increasing trends are consistent with other studies

Possible reasons for trends?



Left: Variations in annual precipitation within three regions of Iowa; Right: N fertilizer sales and swine production in Iowa during period of water monitoring record (data from the USDA Agricultural Statistics Service accessed at http://www.nass.usda.gov/Publications/Ag_Statistics/).

While precipitation was not different in the regions of Iowa, we did not account for changes due to discharge explicitly – could this be a possible reason?

NO_3-N Conclusions

- Linear trend models were fit to monthly NO_3-N concentration results from 46 river monitoring stations located across Iowa for the 1998 to 2012 time period.
- 37 out of 46 sites (80%) presented no statistically significant trend ($p>0.1$) over the monitoring period
- Six monitoring sites in western Iowa indicated statistically significant increasing trends ($p<0.05$) whereas three additional sites also located in western and southern Iowa showed nominally significant increasing trends ($p<0.1$)
- Aggregated across the state, the overall trend of concentrations in Iowa rivers is increasing with an average and median rate of 0.05 and 0.03 mg/l per year, respectively

Similar study recently completed for phosphorus concentrations

Statistical model: $Y_t = \psi_1 t + g(Q_t) + \eta_t$

where

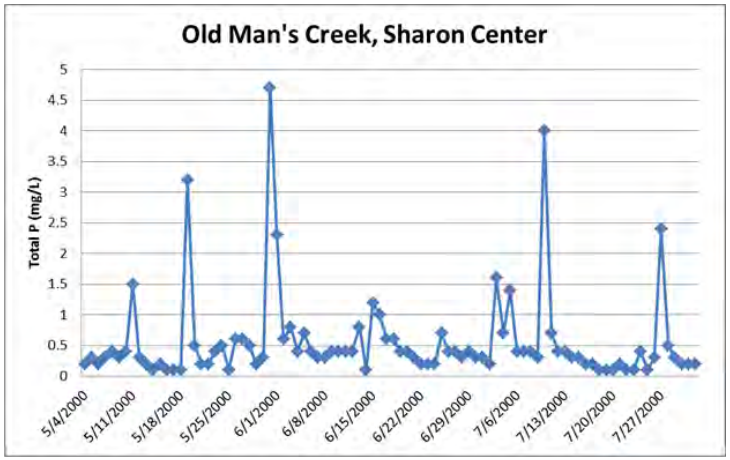
ψ_1 is the monthly rate of change of the P concentration after adjusting for discharge and serial correlation,

$g(Q_t)$ is some function of the discharge (can be either linear or seasonal; if seasonal, Q divided up into four quarters),

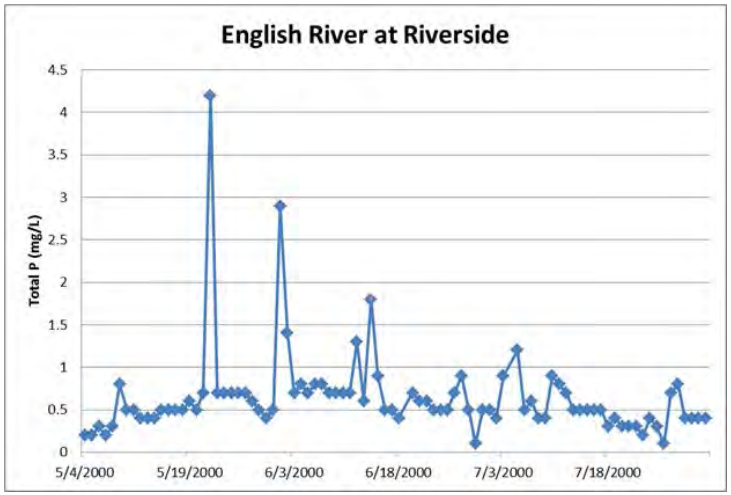
and η_t is the regression error.

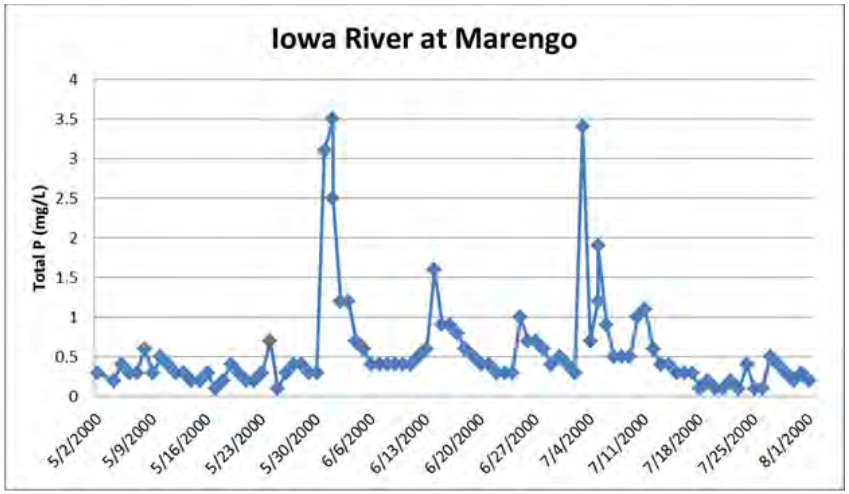
NOTE: We are factoring discharge into the P analysis

Phosphorus Concentrations - ***NOT*** well characterized by monthly samples

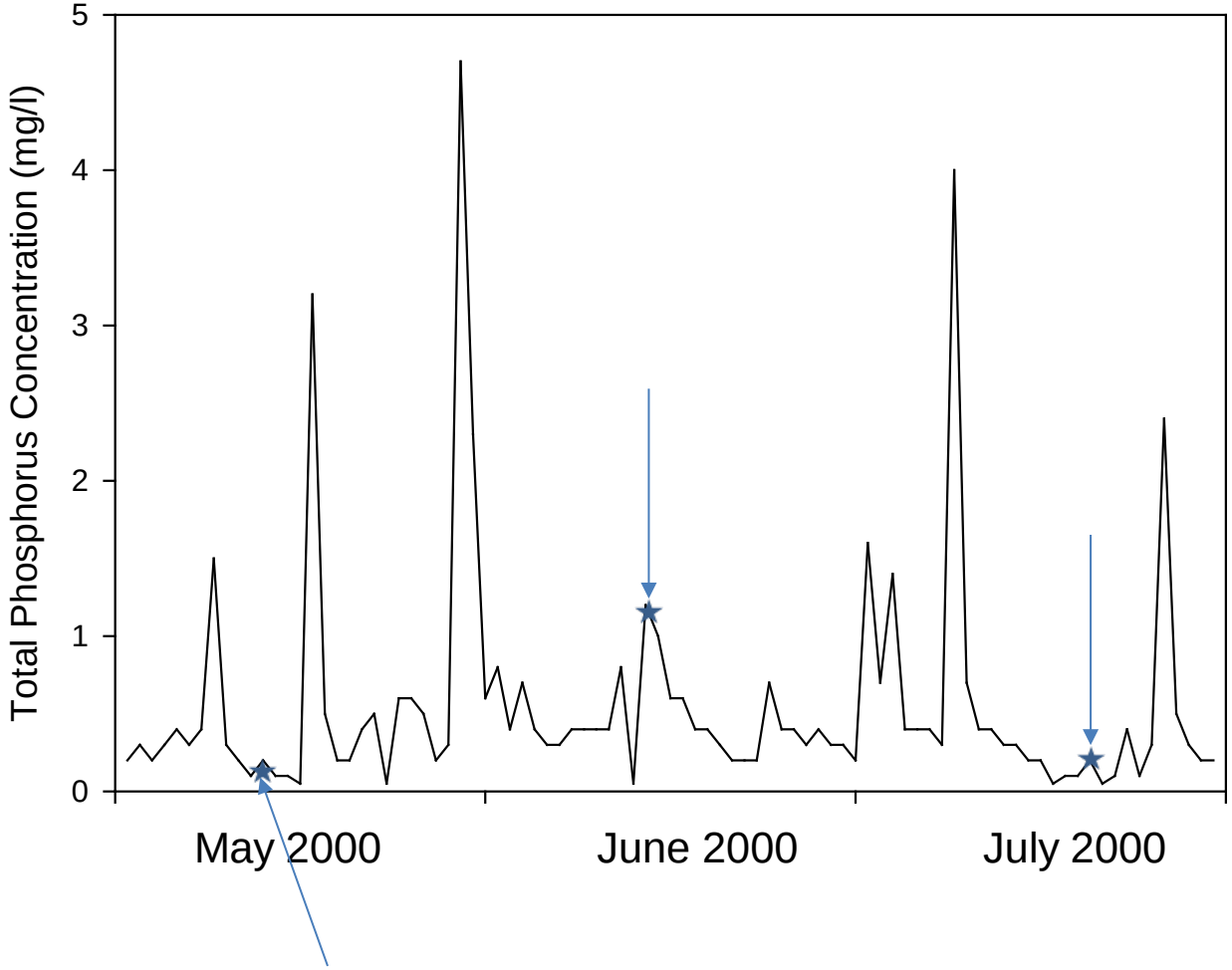


Note the daily variations in P concentrations measured in three different sized basins





Old Mans Creek



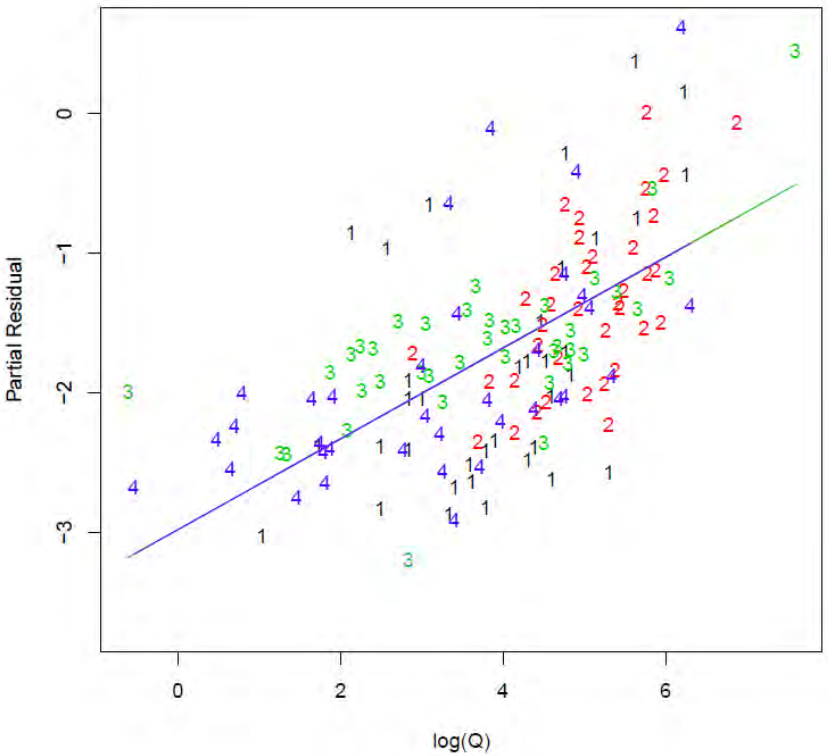
Do these hypothetical monthly concentrations characterize the P concentrations?

Unfortunately, almost all of the P concentration data available for Iowa rivers is *monthly* data

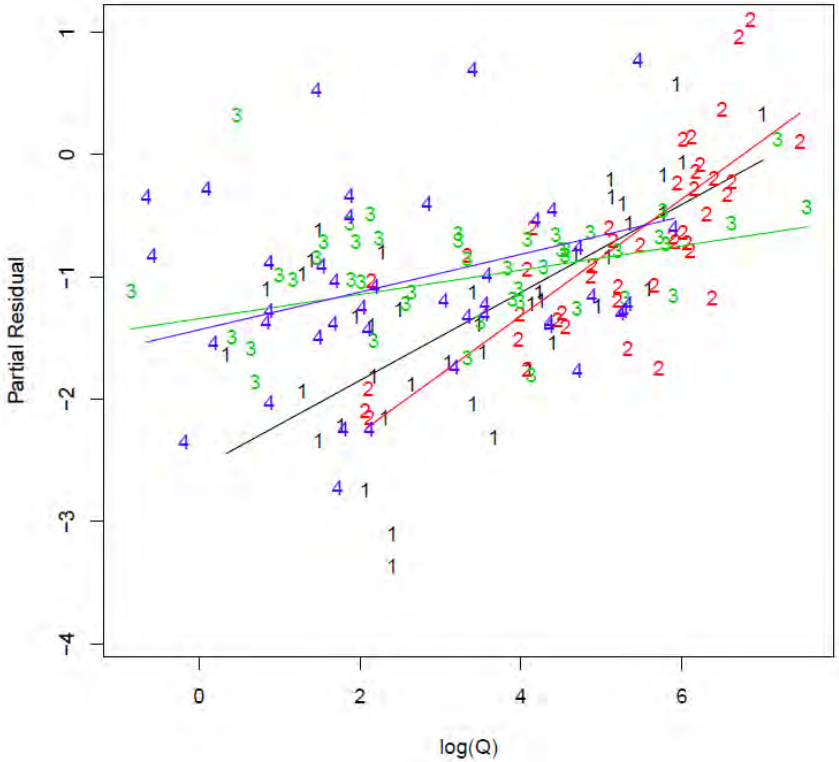
Assume samples collected on 15th of each month

Linear vs. Seasonal relations

Old Mans Creek

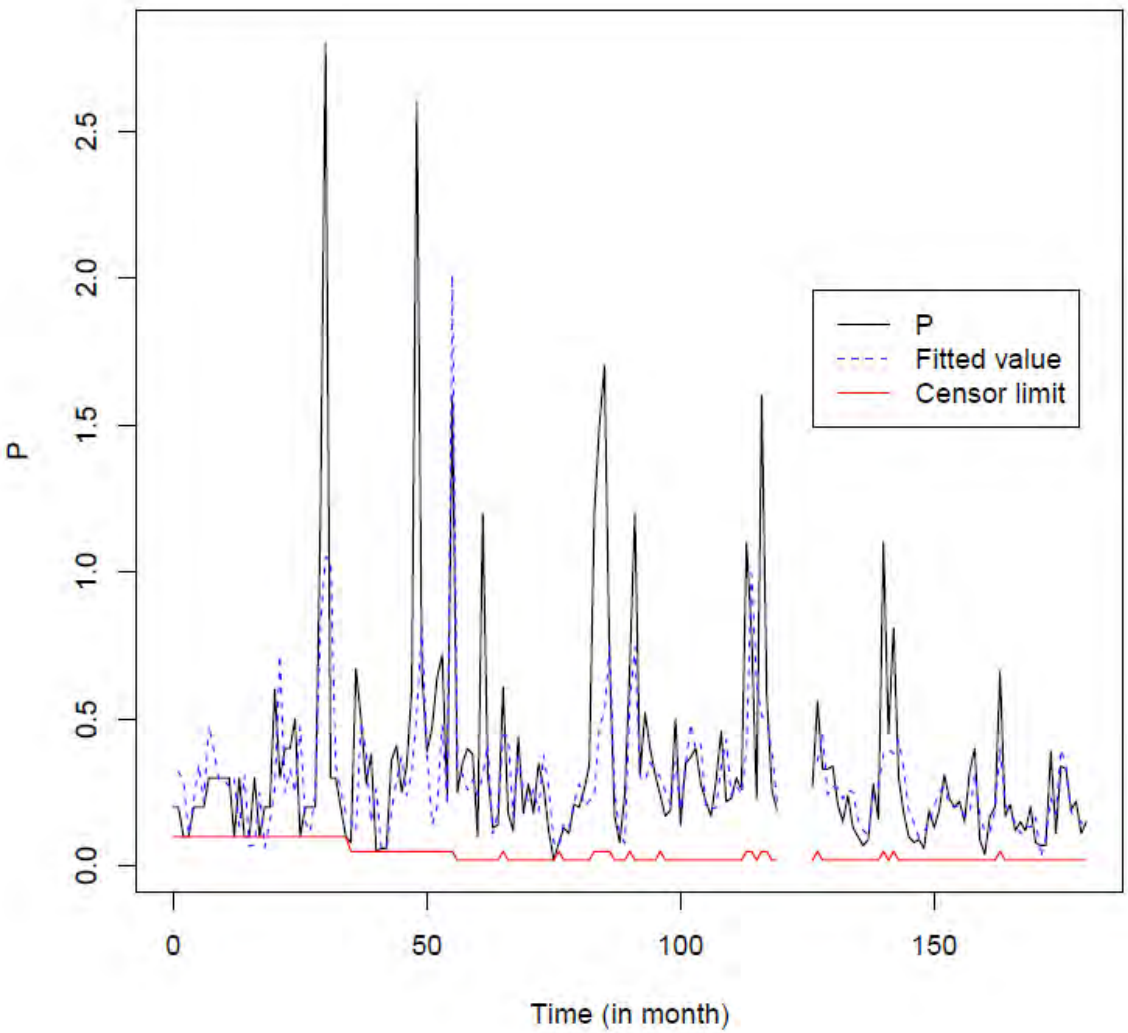


North River at Norwalk

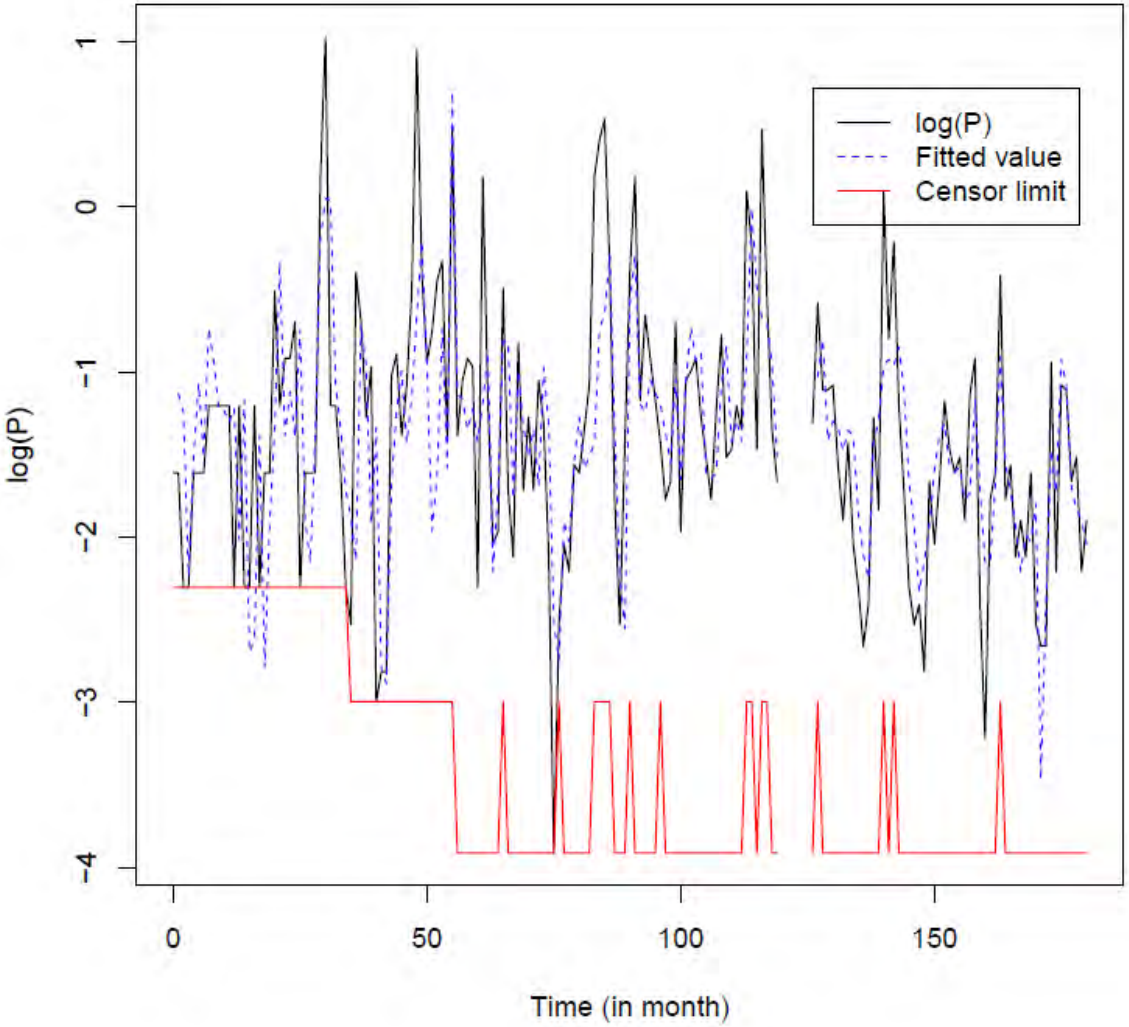


Some statistical models used linear relation of P to discharge, others used seasonal (quarterly) models – model picked by statistical criteria

P Concentrations in the North River

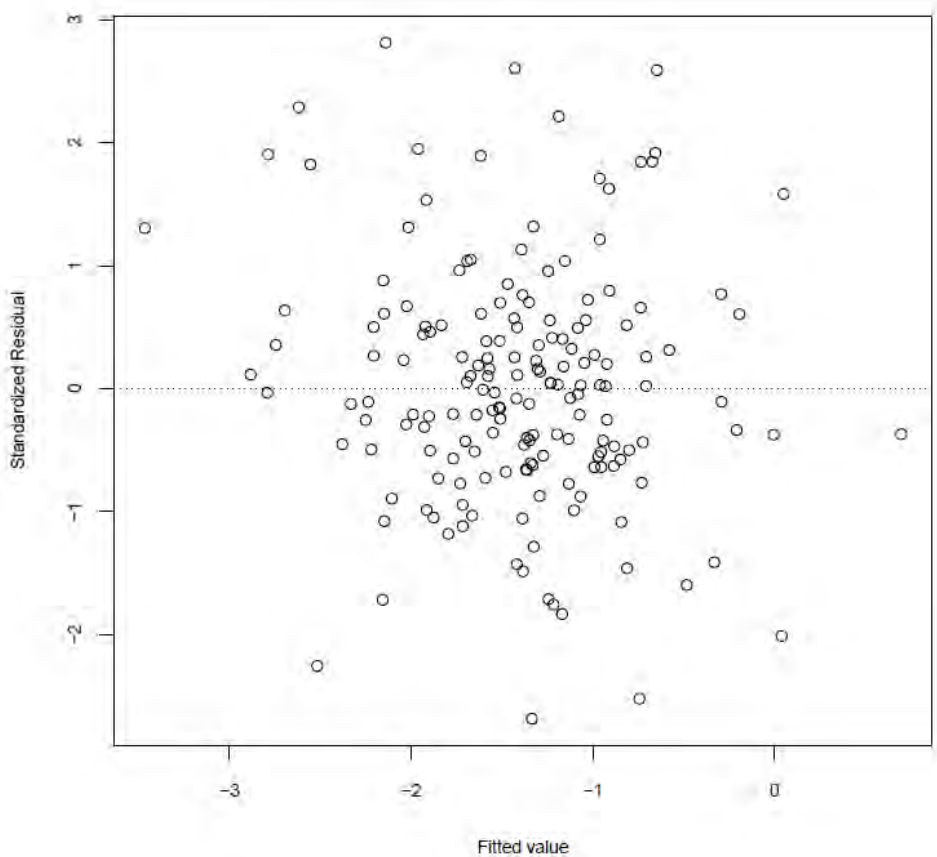


Model fit – North River



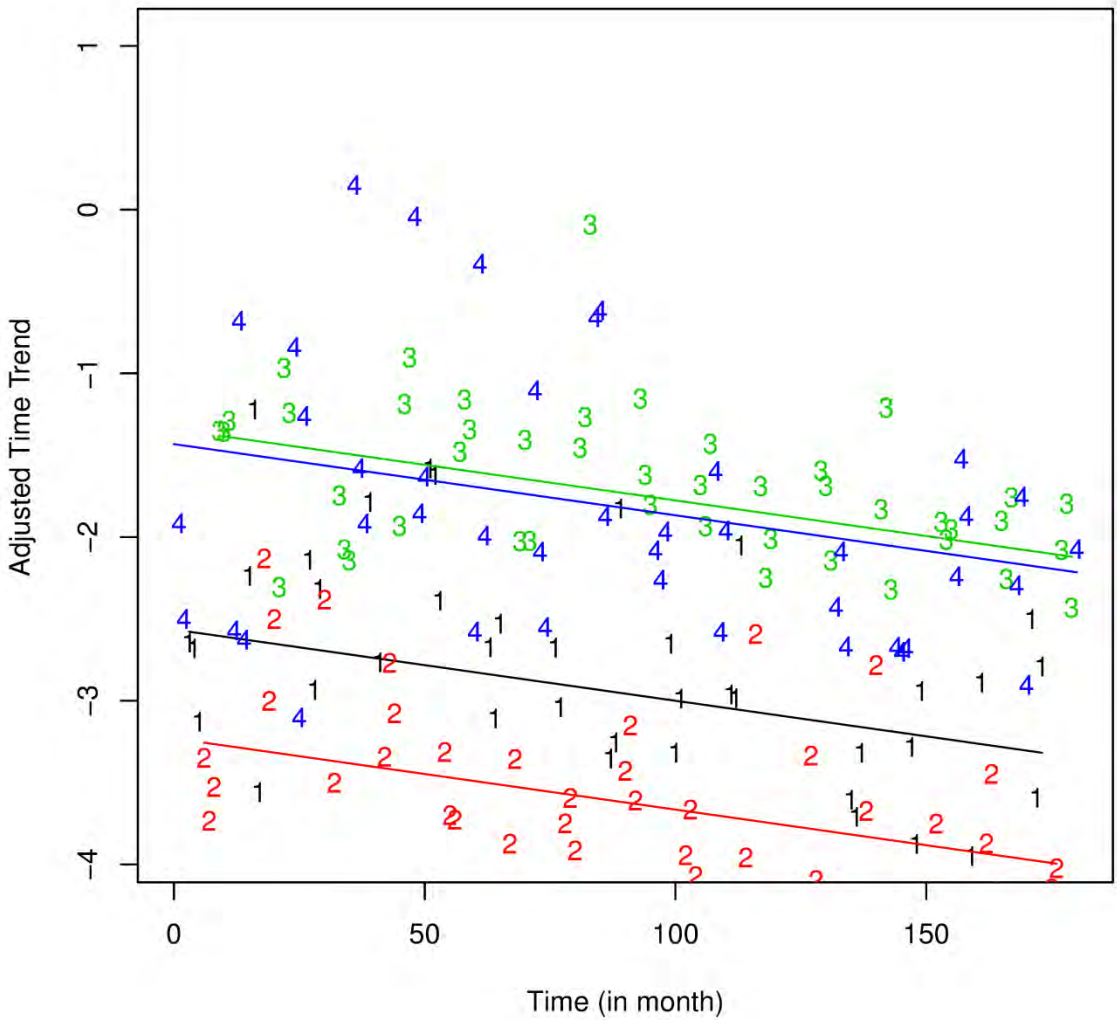
Note the changing detection limit

Residuals vs fitted values

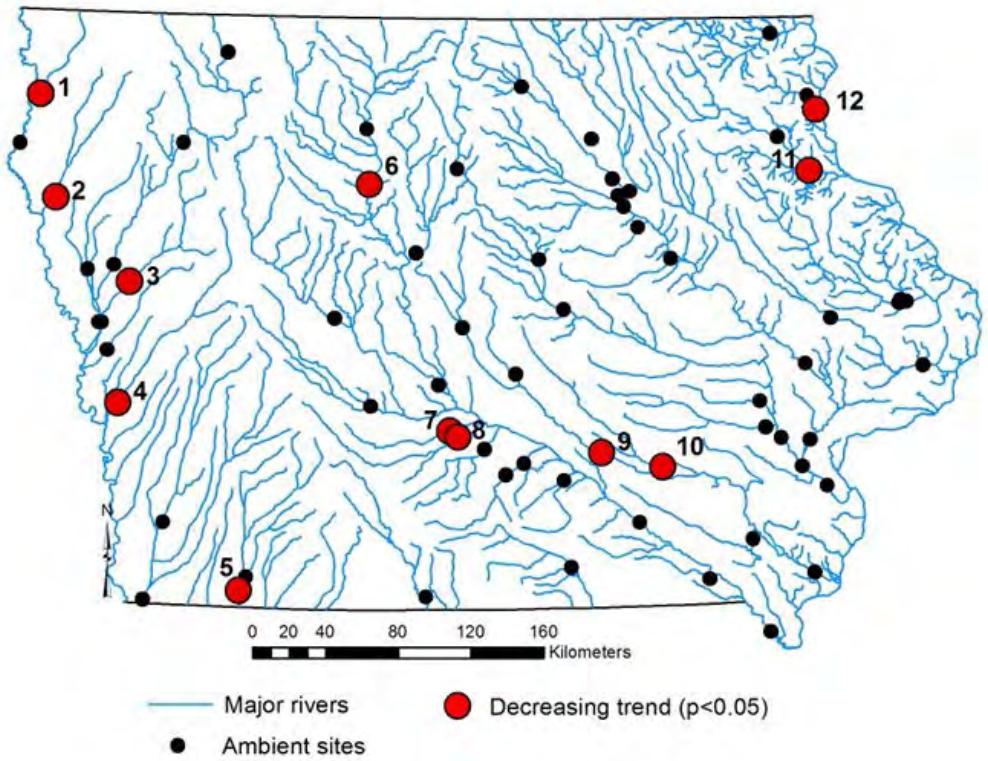


No remaining autocorrelation in the residuals – indicates good model fit

Seasonal trends in P concentrations in the North River



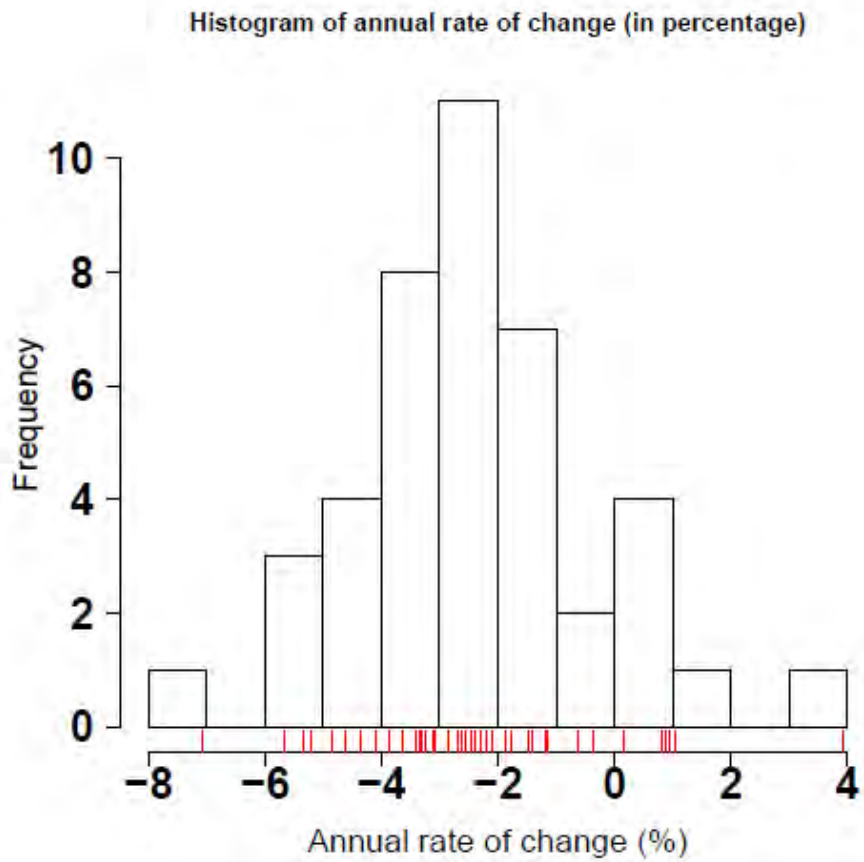
P Concentration Trends



- 42 sites with sufficient record,
- Annual %change ranged from -7.1% to 3.9%
- 8 positive trends (ns)
- 34 trend estimates were negative
- 12 series have significant decreasing trends

Location of ambient monitoring sites in Iowa and sites with statistically significant ($p<0.05$) trends in P concentrations (1 = Rock River; 2 = Floyd River; 3 = Maple River; 4 = Boyer River; 5 = West Nodaway River; 6 = West Fork DSM River; 7 = North River; 8 = Middle River; 9 = South Skunk River; 10 = North Skunk River; 11 = Turkey River; 12 = Bloody Run Creek)

Histogram of P trends

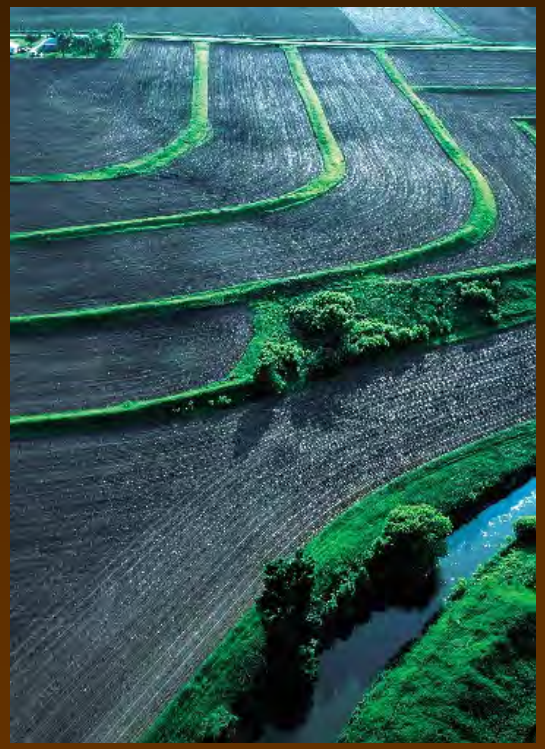


As a collective population, phosphorus concentrations are decreasing at an average rate of 2.3% per year

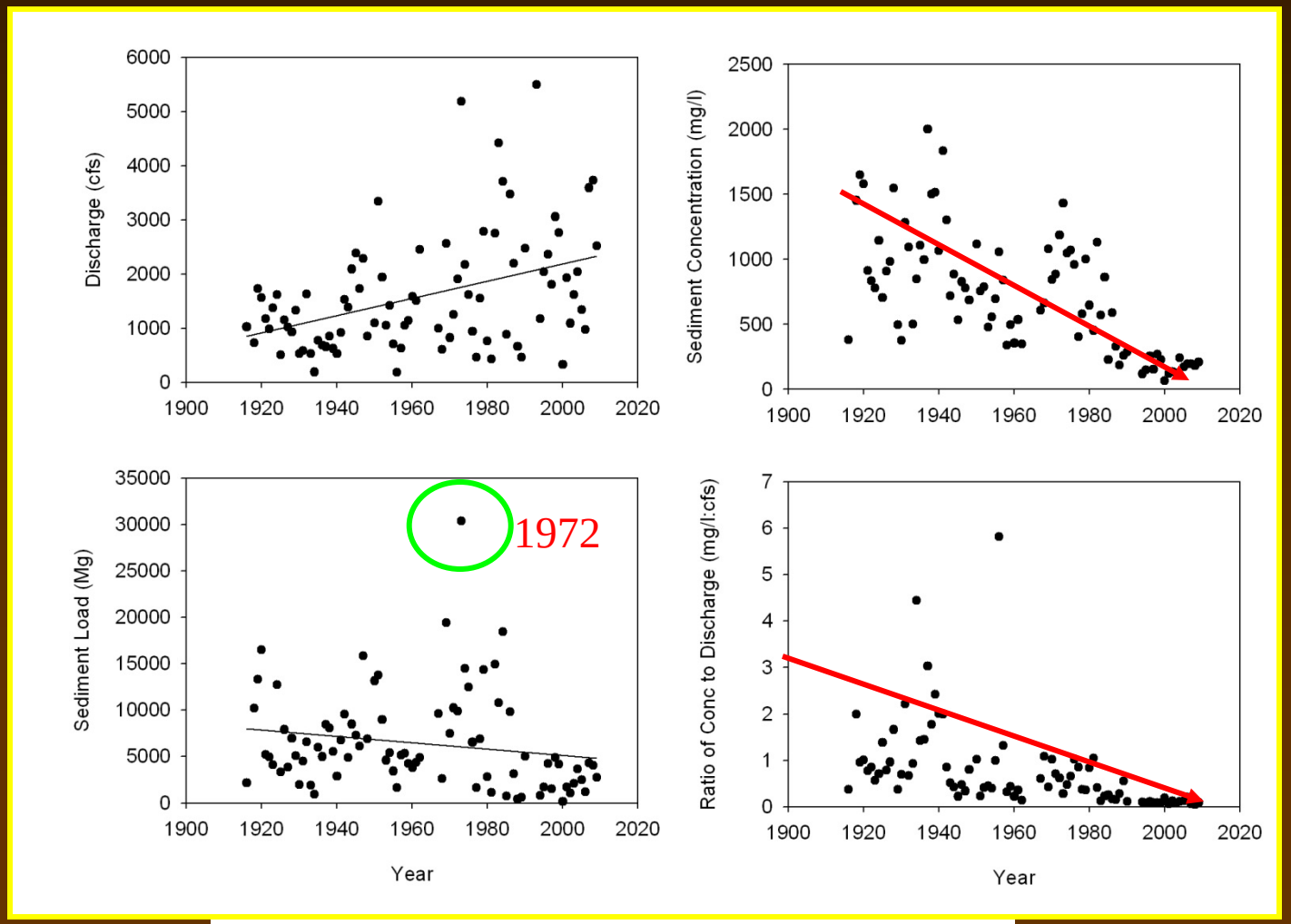
Histogram of annual rate of change in P concentrations at 42 ambient Iowa sites. The tics at the bottom of the graph are the actual values within each box.

Do decreasing P concentrations make sense?

- Great strides made in conservation
- Many practices designed to reduce runoff and sediment loss



Decreasing Suspended Sediment in the Raccoon River



Jones and Schilling, JEQ, 2011

P Conclusions

- Linear and seasonal trend models were fit to monthly P concentration results from 42 river monitoring stations located across Iowa for the 1998 to 2013 time period.
- 30 out of 42 sites (71%) presented no statistically significant trend ($p>0.05$) over the monitoring period
- Twelve monitoring sites across Iowa indicated statistically significant decreasing trends ($p<0.05$). The sites were located in all landform regions.
- Aggregated across the state, the overall trend of P concentrations in Iowa rivers is decreasing with an average annual rate of 2.3% per year, respectively

Links to Iowa Nutrient Reduction Strategy

- Reducing NO_3-N and P concentrations using conservation practices is a major focus of the recently proposed Iowa Nutrient Reduction Strategy
- Statistical results are an important step in documenting trends in river concentrations in Iowa across a time period that precedes implementation of a new strategic emphasis on nutrient reduction practices
- Studies provides important milestones preceding implementation of the INRS that has set the goal to reduce NO_3-N nonpoint loads from Iowa by 41% and P nonpoint source loads by 29%.
- Our studies suggest that meeting the NO_3-N goal may first require addressing increasing NO_3-N concentrations observed in some Iowa's rivers. However, most rivers are starting from no statistical trend.
- P concentrations are decreasing but the magnitude of decrease remains a long way from the P reduction goal.