

**Illinois Council on Food and Agricultural Research
Final Report of the Strategic Research Initiative (SRI) in Water Quality**

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Executive Summary

In 2000, the United States Environmental Protection Agency (USEPA) published ambient water quality criteria recommendations for rivers and streams and directed states to set water quality standards “to protect the physical, biological and chemical integrity of their waters”. These nutrient criteria were presented as recommendations, and the USEPA allowed for individual states to adopt other scientifically defensible criteria or adjust them to better reflect state-specific conditions. Since water quality standards consider both run-off and drainage from agricultural fields and discharges from factories and sewage treatment plants, they directly affect both rural and urban residents.

The C-FAR Natural Resources Working Group recognized that water quality concerns remain a high priority for Illinois and that any water quality standards need to be based on the best available science. They recommended that a strategic research initiative in water quality be developed to support this work. The goals of the SRI were to help develop the scientific basis for nutrient standards in the surface waters of Illinois, and to assist in the appropriate development and implementation of Total Maximum Daily Loads (TMDLs).

This initiative required close collaboration with regulatory agencies in Illinois. As part of the SRI, an advisory team that included Gregg Good, Bob Mosher, Matt Short, Roy Smogor, and Bruce Yurdin from the Illinois Environmental Protection Agency and Dennis McKenna from the Illinois Department of Agriculture was organized. The advisory team identified information gaps and prioritized the most important research needs. A request for proposals was developed from this priority list. The advisory team help select projects and met with individual researchers to help determine the final project funding. In August of 2003, Paul Terrio with the United States Geological Service was named the nutrient standards coordinator for the IEPA and became closely involved with the SRI.

The projects that were funded included scientists from the University of Illinois, Illinois State University, Southern Illinois University, the Illinois State Water Survey, and the Illinois Natural History Survey. The SRI was organized into four research teams, each with a slightly different focus. Project components included a detailed analysis of existing IEPA data, intensive sampling at fixed locations, state-wide temporal sampling at over 100 sites, investigating the effects of sediment on phosphorus dynamics in streams, and improving the methodology for collecting and analyzing algal samples. Laboratory experiments to isolate the effects of phosphorus on algal growth were also conducted. In addition, the SRI collaborated with two water reclamation districts to collect information on effects of sewage treatment plants on water quality.

Since data were to be shared among teams, it was essential that water quality analysis be consistent in all the laboratories. Beginning in August, 2003 and continuing through May, 2006, replicate water samples were delivered to each laboratory for analysis on a quarterly basis. A total of 29 sets of water samples were analyzed for dissolved reactive phosphate (DRP), total phosphorus (TP), nitrate-nitrogen (NO_3^- -N) and ammonium-nitrogen (NH_4^+ -N). Water samples included both natural stream samples and synthetic quality control samples purchased from SPEX Certiprep. Karen Starks coordinated the sample analysis and distributed results to the teams. The IEPA and the MWRDGC also participated in the laboratory comparison. If an individual lab deviated significantly from the mean, they could address the concern immediately.

A similar inter-laboratory comparison of algal extraction techniques was coordinated by Shari Fanta. Three times during the course of the project, homogenized periphyton slurries were delivered to participating laboratories. Laboratories compared different extraction techniques and solvents.

The C-FAR strategic research initiative has provided valuable insight on the development of nutrient standards. It has also raised additional questions and identified other factors that may have greater impacts on biotic integrity than nutrient concentration alone. Factors such as physical habitat, sediment, light availability, temperature, and hydrology are part of a complex relationship affecting biotic responses in rivers and streams.

Cause and effect relationships can be difficult to establish because Illinois lacks a wide range of nutrient conditions, and nutrients are almost never the primary limiting factor to algal production. The challenge remains for regulators to adopt practical and effective nutrient standards, but developing partnerships with the research community is an important first step.

Collaborative Support/Participation:

Illinois Environmental Protection Agency
Illinois Department of Agriculture
U.S. Environmental Protection Agency
U.S. Geological Survey
Metropolitan Water Reclamation District of Greater Chicago
Bloomington-Normal Water Reclamation District
The Nature Conservancy
Oak Ridge National Laboratory
Illinois Department of Natural Resources

Primary Objectives and Goals

The goals of the Water Quality SRI are: (1) to help develop the scientific basis for nutrient standards in the surface waters of Illinois, and (2) to assist in the appropriate development and implementation of Total Maximum Daily Loads (TMDLs).

Although each research team had specific and targeted goals, a shared objective was the consideration of practical and effective nutrient standards based on identified causes and thresholds of water body use impairment due to nutrient enrichment.

One central question that all the research teams sought to examine was the strength of cause and effect relationships between nutrient concentrations in water and biotic impairment. The original model suggested that nutrient enrichment promotes excess algal growth that leads to low dissolved oxygen concentrations that ultimately causes biotic impairment. The challenge was to evaluate whether or not this model could be applied to rivers and streams in Illinois. Each of the four research teams describe their approach and significant finding in the following sections:

Team 1: Nutrients, Chlorophyll, and Dissolved Oxygen in Illinois Streams

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Introduction

We used a combination of state-wide surveys and smaller scale, intensive studies to address questions of nutrient-algal-oxygen relationships across Illinois. State-wide surveys provided an opportunity to describe conditions and relationships across the varied stream types and geographic conditions of Illinois. The more focused studies allowed for examination of patterns and relationships within areas of similar land use and land cover. Our goals were to examine: i) the strength of the nutrient-algal biomass relationships in the streams and rivers of Illinois; ii) the relationship between nutrients and biotic integrity of invertebrate communities in wadeable streams across Illinois; iii) the degree to which nutrients and algal biomass influenced dissolved oxygen (O₂) patterns in selected streams and rivers; and iv) the role of environmental factors other than nutrients in controlling algal biomass, dissolved O₂, and biotic integrity in Illinois streams. Additionally, we used existing data in conjunction with data collected as part of the C-FAR water quality SRI to document input pathways of phosphorus to agricultural streams and long-term patterns in nitrogen (N) and phosphorus (P) loads in selected rivers of east-central Illinois.

Nutrient-Algal-Oxygen Relationships

Figueroa-Nieves et al. (2006) sampled eighteen streams in east-central Illinois (USA) during June and September 2003 to analyze factors possibly regulating algal biomass. Additionally, two shaded and two non-shaded sites in the Embarras River in east-central Illinois were sampled intensively from June through December 2003. Both sestonic and periphytic chlorophyll-*a* (chl-*a*) were analyzed, and periphytic chl-*a* was assessed on natural substrata and unglazed ceramic tiles. Although high concentrations of nutrients were found in these streams (mean total P = 0.09 to 0.12 mg L⁻¹ and mean NO₃-N = 4.4 to 8.4 mg L⁻¹), concentrations of sestonic chl-*a* were low among all sites and both sampling periods (< 18 mg m⁻³, median values of 5 and 3 in June and September, respectively). Filamentous algae was an important component of the algal communities in streams with stable substrata. Periphytic chl-*a* was generally not related to the concentration of N or P in the water column, and in non-shaded streams periphyton appeared at times be light-limited due to turbid water. Turbidity was found to be an important factor controlling chl-*a* on ceramic tiles across the eighteen sites and for the Embarras River sites; chl-*a* decreased exponentially in concentration (132 to 0 mg m⁻²) as turbidity increased from 4 to 39 NTU ($r^2 = 0.80$). In general, the interaction between hydrology and light (turbidity) likely controlled algal biomass in these nutrient-rich, agricultural streams.

Royer et al. (in press) used state-wide surveys of > 100 stream and river sites to assess the applicability of chl-*a* as a criterion for establishing nutrient standards for Illinois. Among all sites, the median total P and total N concentrations were 0.185 and 5.6 mg L⁻¹, respectively, during high discharge conditions. During low discharge conditions, median total P concentration was 0.168 mg L⁻¹, with 25% of sites having a total P of ≥ 0.326 mg L⁻¹. Across the state, 90% of the sites had sestonic chl-*a* values of ≤ 35 μ g L⁻¹ and watershed area was the best predictor of sestonic chl-*a*. During low discharge there was a significant correlation between sestonic chl-*a* and total P for those sites that had both canopy cover $\leq 25\%$ and total P of ≤ 0.2 mg L⁻¹. Results suggest sestonic chl-*a* may be an appropriate criterion for the larger rivers in Illinois, but is inappropriate for small rivers and streams. Coarse substrate to support benthic chl-*a* occurred in less than 50% of the sites we examined; a study using artificial substrates did not reveal a relationship between chl-*a* accrual and N or P concentrations. Overall, it appears that for many streams and rivers in Illinois, nutrients may not be the limiting factor for algal biomass because of generally high nutrient concentrations and the effects of other factors such as substrate conditions and turbidity.

Morgan et al. (2006) investigated the relationships between dissolved nutrients, algal abundance, and dissolved O₂ in five streams in east-central Illinois from March through November 2004. The streams drained watersheds ranging from 25 to 777 km² that were dominated by corn (*Zea mays* L.) and soybean (*Glycine max* L.) production on tile drained soils, with one stream site having an upstream (40 km) discharge of sewage effluent. Three sites had open canopies and two were bordered by a narrow gallery forest of deciduous trees. Algal abundance was measured as chlorophyll-*a* (chl-*a*) concentration in the water column (sestonic chl-*a*) and on the streambed (periphytic chl-*a*), and as biomass (dry mass m⁻²) and % coverage of filamentous algae. Mean NO₃-N concentrations ranged from 5.5 to 8.8 mg N L⁻¹ and did not relate to algal abundance. Sestonic chl-*a* values ranged from nearly zero to greater than 15 mg m⁻³ with no differences between open and shaded streams and only a weak correlation with dissolved reactive P (mean

concentrations were 44 to 479 $\mu\text{g L}^{-1}$). Because the abundance of sestonic chl-*a* was not related in any simple way with nutrients or periphyton, we suggest that chl-*a* in the water column is not a good criterion for assessing nutrient-related problems in these streams. The highest values of periphytic chl-*a* ($\sim 40 \text{ mg m}^{-2}$) occurred during extended periods of low flow from August through October, but periphyton occurred consistently in only two of the five streams. Therefore, we suggest that periphyton abundance in streams in this region will not show a consistent response to changes in nutrient concentrations. The abundance of filamentous algae explained 64% of the variation in the diel range in O_2 saturation, but was not correlated with discharge, turbidity, or any measure of water chemistry. Our results indicate hydrology and light, rather than nutrients, are the main controls on algal abundance in these streams. Reducing the biomass of filamentous algae in open-canopy streams may improve habitat conditions.

Nutrient-Biotic Integrity Relationship

Heatherly et al. (2007) sampled 53 streams throughout Illinois and examined relationships between macroinvertebrate community structure and numerous physicochemical parameters. Streams clustered into four major groups based on taxa dissimilarity. Habitat quality and dissolved nutrients were responsible for separating the major groups in a nonmetric multidimensional scaling ordination. Furthermore, the alignment of environmental factors in the ordination suggested there was a habitat quality-nutrient concentration gradient such that streams with high quality habitats usually had low concentrations of nutrients. Discrimination by community measures further validated the major stream groups and indicated that forested streams had generally higher biological integrity than agricultural streams, which in turn displayed greater integrity than urban streams. Results of this component of the study demonstrate that physical habitat degradation and nutrient pollution are important and often confounded determinants of biotic integrity in Illinois streams. In addition, patterns observed in this study suggest that Illinois stream management would benefit from further implementation of multivariate data exploration and stream classification.

Analysis of Long-Term Data

Gentry et al. (2007) examined long-term data on P transport and loads in several east-central Illinois streams. The objective of the analysis was to determine the dominant form of P in streams (dissolved or particulate) and identify the mode of transport of this P from fields to streams in tile drained agricultural watersheds. We measured dissolved reactive P (DRP) and total P concentrations and loads in stream and tile water in the upper reaches of three watersheds in east-central Illinois (Embarras, Lake Fork of the Kaskaskia River, and Big Ditch of the Sangamon). For all 16 water year by watershed combinations examined, annual flow weighted mean concentrations of total P were greater than 0.1 mg L^{-1} , and 7 water year by watershed combinations exceeded 0.2 mg L^{-1} . Concentrations of DRP and particulate P increased with stream flow; however, particulate P was the dominant form during overland runoff events, which greatly affected annual total P loads. Concentrations of DRP and particulate P in tiles increased with discharge, indicating tiles were a source of P to streams. Across watersheds, the greatest DRP concentrations (as high as 1.25 mg L^{-1}) were associated with a precipitation event that followed widespread application of P fertilizer on frozen soils. Eliminating this practice would

reduce overland runoff of P, although inputs from soil erosion and tile drainage would continue to be important for streams in east-central Illinois.

Royer et al. (2006) analyzed 8–12 years of data on NO_3^- -N, dissolved reactive phosphorus (DRP), and total P export from three watersheds in Illinois. Our goal was to assess how nutrient export was distributed across the range of discharge that occurred at each site and to examine mechanistic differences between NO_3^- -N and DRP export from the watersheds. We also used simple simulations to evaluate how nutrient load reductions might affect NO_3^- -N and P export to the Mississippi River from the Illinois watersheds. Artificial drainage through under-field tiles was the primary mechanism for NO_3^- -N export from the watersheds. Tile drainage and overland flow contributed to DRP export, whereas export of particulate P was almost exclusively from overland flow. The analyses revealed that nearly all nutrient export occurred when discharge was \geq median discharge, and extreme discharges ($\geq 90^{\text{th}}$ percentile) were responsible for $> 50\%$ of the NO_3^- -N export and $> 80\%$ of the P export. Additionally, the export occurred annually during a period beginning in mid-January and continuing through June. These patterns were consistent across all sites, which spanned a 4-fold range in watershed area. The simulations showed that reducing in-stream nutrient loads by as much as 50% during periods of low discharge would not affect annual nutrient export from the watersheds.

Dissolved Oxygen Patterns in Illinois Rivers

During 2006, we conducted a study of dissolved O_2 patterns, nutrients, and chl-*a* in 53 stream and river sites distributed across the state of Illinois. The goal was to determine if sites could be grouped on the basis of these variables in a manner that would facilitate development of nutrient standards. Multiple sites within two large river systems allowed us to examine longitudinal patterns and the influence of river size on the relationships among dissolved O_2 , nutrients, and chl-*a*. Although many studies have examined algal-nutrient relationships in streams across large geographic regions, this study is the first to include continuous monitoring of dissolved O_2 . We developed metrics that quantify dissolved O_2 patterns and that can be used to relate dissolved O_2 to algal biomass and nutrient status, the presumed drivers of hypoxia/anoxia and impaired biotic integrity.

From April through October of 2006, dissolved O_2 concentrations and water temperatures were monitored for 72+ hours at 53 stream sites throughout Illinois. Samples were collected for water chemistry and sestonic chlorophyll-*a* (chl-*a*) analyses and, if present, periphytic chl-*a* and filamentous algae were measured. The sites included a range of stream/river sizes with watershed areas from 21 to 5,026 km^2 with the majority of the watershed areas between 212 and 2010 km^2 . Of the 53 sites, 32 were separate streams while 21 were from longitudinal transects along three river systems: the Kaskaskia River ($n=8$), the Sangamon River ($n=9$), and the Embarras River ($n=4$). Dissolved O_2 concentrations below 5 mg L^{-1} were measured at 14 of the 53 sites for periods ranging from 0.3 to 24 average hours day^{-1} (median = 3.6); however, concentrations never decreased below 3 mg L^{-1} . Dissolved O_2 metrics (average daily: max, min, and diel range) were found to be weakly correlated with nitrogen, DRP, silica, sestonic chl-*a*, canopy cover, and watershed area. Diel changes in dissolved O_2 were relatively large (due especially to high afternoon maximums) in the headwater streams and the larger rivers where periphytic chl-*a* and sestonic chl-*a* concentrations were high, respectively. Cluster analysis separated the streams sites

primarily by watershed area and chl-*a* type and quantity into the following three groups: 1) large, high sestonic chl-*a* rivers, 2) small, high periphytic chl-*a* streams, and 3) medium, low chl-*a* streams. Conceptual models of the dissolved O₂ dynamics and other environmental effects on biotic integrity were developed for the three stream types.

Chl-*a* and Dissolved Oxygen in Urban Streams of Chicago

To assess the conditions in streams draining urban watersheds, we monitored 5 stream sites in the Chicago area in partnership with the Environmental Monitoring and Research Division of the Metropolitan Water Reclamation District of Greater Chicago. The monitoring was conducted from 2004-2006 on the North Branch of the Chicago River (1 site), Salt Creek (2 sites), and the Des Plaines River (2 sites). At each site, dissolved O₂ was recorded continuously and chl-*a* and nutrients were sampled at least monthly with more frequent sampling during high flow conditions. Data are being analyzed for patterns among the urban sites and will also be used to examine how nutrient-algal-oxygen relationships vary between urban streams and streams that drain predominantly agricultural landscapes.

Role of Sediments in Controlling Phosphorus Concentrations in Streams

We examined sediment equilibrium P concentrations at 105 sites across the state, as well biotic release of P at four intensive sites in east-central Illinois. Equilibrium P concentrations were correlated ($r_s = 0.76$, $p < 0.0001$) with DRP in the water column, indicating that sediments reflect stream P concentrations. Biological release of P (as assessed by alkaline phosphatase activity) in the coarse-textured sediments in east-central Illinois streams did not seem to be affected by stream water P concentrations. Our overall results suggest that during most flow conditions, sediments reflect stream water P concentrations, but do not likely influence them. During low flow conditions P retention may be increased by both biotic and abiotic processes in the sediment, possibly influencing stream water P concentrations.

Summary and Conclusions

Our studies found complex relationships at each step of our conceptual model relating nutrients to biotic integrity of streams. Many factors were confounded, which made it difficult to clearly document the role of nutrients. Few streams and rivers in Illinois have low nutrient concentrations, so that it was difficult to find strong relationships. In addition, physical habitat was often degraded (in conjunction with high concentrations of nutrients) and this appeared to be the major limit to biotic integrity. Overall, nutrients appeared to seldom be limiting to algal biomass, and other factors such as substrate, light, or residence time were limitations. Our analysis supports a series of conceptual models. The first is small streams with clear water, dominated by periphyton. These streams have a large diel range in dissolved O₂, but often the minimum dissolved O₂ is high as well; habitat modification (these are often channelized agricultural streams) has reduced biotic integrity, rather than low dissolved O₂. Our second model represents large rivers that support sestonic algae. This can lead to lower minimum dissolved O₂ concentrations together with a large diel range. However, physical processes often impact dissolved O₂ concentrations in these larger rivers and habitat is again a major limitation to biotic integrity. Finally, our third model describes a large number of intermediate-sized

streams in the state, with limited productivity (no periphyton and small amounts of sestonic algae) and limited diel range in dissolved O₂ concentrations. Again, habitat is a major limitation to biotic integrity, and algal production is limited by substrate, light, or water residence time. In each of these models, nutrients are rarely the limiting factor controlling algal biomass because both N and P typically occur at concentrations well above limiting levels.

We have proposed two decision tree analyses to support this conceptual framework, and suggest that our framework could be used to classify streams and decide which streams (or stream reaches) are likely affected by nutrients. The first decision tree accounts for reservoir or lake chl-*a* sources, nutrients, stream cover, and turbidity in classifying streams. The second decision tree uses patterns in dissolved O₂ to identify sites where nutrients are likely to be important.

Given the many factors that influence all aspects of the nutrient to chl-*a* to dissolved oxygen to biotic integrity pathway, it is difficult to isolate the role of nutrients in Illinois streams and rivers. Our results have indicated the complexity of these relationships, but have provided a basis for developing a strategy for determining where and when nutrients might be important.

Peer Reviewed Publications

Royer, T.V., M.B. David, L.E. Gentry, C.A. Mitchell, K.M. Starks, T.N. Heatherly II, and M.R. Whiles. 2008. Assessment of chlorophyll-*a* as a criterion for establishing nutrient standards in the streams and rivers of Illinois. *Journal of Environmental Quality* (in press).

Heatherly II, T., M.R. Whiles, T.V. Royer, and M.B. David. 2007. Relationships between water quality, habitat quality, and macroinvertebrate assemblages in Illinois streams. *Journal of Environmental Quality* 36:1653-1660.

Gentry, L.E., M.B. David, T.V. Royer, C.A. Mitchell, and K.M. Starks. 2007. Phosphorus transport pathways to streams in tile-drained agricultural watersheds. *Journal of Environmental Quality* 36:408-415.

Figuroa-Nieves, D., T.V. Royer, and M.B. David. 2006. Controls on chlorophyll-*a* in nutrient-rich agricultural streams in the midwestern USA. *Hydrobiologia* 568:287-298.

Morgan, A.M., T.V. Royer, M.B. David, and L.E. Gentry. 2006. Relationships among nutrients, chlorophyll-*a*, and dissolved oxygen in agricultural streams in Illinois. *Journal of Environmental Quality* 35:1110-1117.

Royer, T.V., M.B. David, and L.E. Gentry. 2006. Timing of riverine export of nitrate and phosphorus from agricultural watersheds in Illinois: implications for reducing nutrient loading to the Mississippi River. *Environmental Science and Technology* 40:4126-4131.

Presentations

Royer, T.V., M.B. David, L.E. Gentry, C.A. Mitchell, K.M. Starks, and M.R. Whiles. 2007. Is chlorophyll the appropriate indicator of nutrient enrichment in Illinois streams? North American Benthological Society Annual Meeting, Columbia, South Carolina.

David, M.B. 2006. Nutrients, Chlorophyll, and Dissolved Oxygen in Illinois Streams: CFAR Results. Illinois Association of Wastewater Agencies annual meeting. Peoria, IL.

David, M.B. 2006. The Transport and Fate of Nutrients Used in Crop Production. Illinois Fertilizer and Chemical Association annual meeting, Peoria, IL.

Royer, T.V., M.B. David, and L.E. Gentry. 2006. Nitrate and phosphorus export from agricultural watersheds in the midwestern U.S.: implications for programs to reduce nutrient loading to the Mississippi River. North American Benthological Society Annual Meeting, Anchorage, AK.

Heatherly, T., M.R. Whiles, M.B. David, T.V. Royer, C. Mitchell, and L.E. Gentry. 2006. Relationships between water chemistry, habitat quality, and biological integrity in Wadeable Illinois streams. North American Benthological Society Annual Meeting, Anchorage, AK.

David, M.B. 2005. Nutrients, chlorophyll, and dissolved oxygen in Illinois rivers and streams. Illinois Association of Wastewater Agencies annual meeting. Pere Marquette State Park, IL.

David, M.B. 2005. Nutrients, chlorophyll, and dissolved oxygen in Illinois rivers and streams. Metropolitan Water Reclamation District of Greater Chicago seminar, Chicago, IL.

Royer, T.V. and M.B. David. 2005. Long term patterns in stream export of dissolved organic carbon from agricultural watersheds. ASLO Aquatic Sciences Meeting, Abstract Book, p. 95.

Gentry, L.E., M.B. David, K.M. Starks, and C. Mitchell. 2004. Phosphorus concentrations and loads in surface waters in central Illinois. ASA, CSSA, SSSA Annual Meeting Abstracts.

Theses

Bedore, P.D. 2007. Mechanisms of phosphorus control in Chicago area streams receiving sewage effluent. M.S. thesis, University of Illinois at Urbana-Champaign.

McDaniel, M. 2007. Sediment controls on phosphorus in Illinois streams. M.S. thesis, University of Illinois at Urbana-Champaign.

Heatherly, T.N. II. 2006. Relationships between macroinvertebrate assemblages and physicochemical factors in Illinois streams: implications for bioassessment methodologies and the adjudication of impairment. M.S. thesis, Southern Illinois University, Carbondale.

Morgan, A. 2005. Controls on dissolved oxygen in streams of east-central Illinois: interactions of nutrients and chlorophyll. M.S. thesis, University of Illinois at Urbana-Champaign.

Figureroa-Nieves, D. 2004. Factors controlling chlorophyll in nutrient enriched streams of east-central Illinois. M.S. thesis, University of Illinois at Urbana-Champaign.

Team 2: Effects of Phosphorus Mediated Through Algal Biomass in Illinois Streams

Principal Investigators:

Walter Hill, Division of Ecology and Conservation Science, Illinois Natural History Survey
Timothy Smith*, Division of Ecology and Conservation Science, Illinois Natural History Survey

*Timothy Smith made major contributions to the design of the original proposal, carried out analyses of IEPA and IDNR data, lead much of the field work, and presented project results at numerous meetings, but was dropped from the original list of principal investigators in order to draw more than two month's salary.

Additional collaborators:

Shari Fanta, Division of Ecology and Conservation Science, Illinois Natural History Survey
Brian Roberts, Environmental Sciences Division, Oak Ridge National Laboratory

Project Objectives and Outcomes:

The overall objective of this project was to quantify the effects of phosphorus on algal biomass and associated parameters in order to provide a scientific basis for establishing nutrient criteria. The work done on this project was based on the conviction that understanding the quantitative response of stream algae to phosphorus concentration is essential to setting quantitative standards. The quantitative relationship between phosphorus and algal biomass and associated parameters was explored in four different subcomponents of the project, each of which represented a different scale of investigation.

1) Data mining. We linked biological data sets from the Illinois Department of Natural Resources (fish) and Illinois Natural History Survey (invertebrates) to water quality data in the Illinois Environmental Protection Agency's Ambient Water Quality Monitoring Network in order to explore statistical relationships between biota and water quality variables (e.g., phosphorus). The major results of the statistical analyses were:

- Fish diversity (species number) in Illinois streams was negatively correlated with dissolved phosphorus ($r=-0.57$, $p<0.001$, $n=35$). Fish diversity was also negatively correlated, although not as closely, with both total phosphorus ($r=-0.47$, $p<0.001$) and ammonia ($r=-0.51$, $p<0.001$).
- Bivalve diversity was negatively correlated with dissolved phosphorus ($r=-0.33$, $p=0.07$, $n=32$) and ammonia ($r=-0.41$, $p=0.02$).

Although correlation analysis does not prove causation, both sets of negative correlations are consistent with habitat degradation caused by eutrophication.

2) Extensive surveys. A variety of water quality, habitat, and benthic algal parameters were measured repeatedly at 13 Illinois streams in 2004 and at 8 different Illinois streams in 2005. Results:

- There was no statistically significant relationship between benthic algal biomass (as represented by chlorophyll *a*) and streamwater phosphorus concentration, despite uniform (artificial) substrata and consistent sampling technique.

3) Large-scale, single watershed experiment. This project subcomponent exploited the gradient of phosphorus loading caused by the establishment of the new Bloomington Wastewater Treatment Plant on Little Kickapoo Creek in McLean County. Sampling stations were established at 10 sites on the stream, 5 upstream and 5 downstream of the plant. Sampling commenced one year before the plant began discharging phosphorus-laden water and continued for two years afterwards. Artificial substrata were deployed at six separate locations at each site chosen to maximize diversity in the exposure to sunlight. Results:

- Benthic algal biomass (chlorophyll *a*) was most strongly related to light regime (% canopy cover) and current velocity, and only weakly related to total phosphorus in multiple regression analysis. The amount of variability accounted for by the multiple regression was 51%. Precision in both univariate and multivariate analyses was too limited to provide a reliable quantification of the relationship between phosphorus and algal biomass.

- Algal phosphorus content, which can be a useful measure of phosphorus limitation, was significantly ($p < 0.05$) related to both dissolved phosphorus concentration and canopy cover. A plot of algal phosphorus versus dissolved phosphorus alone showed a significant hyperbolic relationship. Fitting a Monod equation to the data resulted in an estimated half saturation concentration of approximately $20 \mu\text{g L}^{-1}$ dissolved reactive phosphorus (DRP).

4) Experimental streams. Large (22 m long) indoor streams at the Oak Ridge National Laboratory were used to perform controlled experiments in which stream algae were grown under a range of specific phosphorus concentrations and light regimes. One experiment was performed in 2005 and three experiments were performed in 2006 in which five or more concentrations of phosphorus were applied. Results:

- Controlled conditions (constant phosphorus concentrations, regimented lighting, no spates, no macrograzers, etc.) resulted in precise quantitative relationships between algae and phosphorus in all experiments. Measurements of biomass, growth, production, and carbon isotope content all exhibited the same hyperbolic response to phosphorus, increasing with increasing concentration up to $25 \mu\text{g L}^{-1}$ DRP, then leveling off at higher concentrations. These results strongly suggest that a phosphorus standard $\geq 25 \mu\text{g L}^{-1}$ DRP ($\approx 50 \mu\text{g L}^{-1}$ TP) will do little to constrain algal growth in streams.

- Light manipulations produced larger effects on algal growth than did phosphorus, indicating the potential for light effects to mute phosphorus effects in natural streams. The range of light levels used in the experiments was realistic and included irradiances typical of canopy covered sites to irradiances typical of open sites.

Initial objectives that were not accomplished:

The original project proposal called for surveys of stream invertebrates and pathogenic bacteria. These proposed surveys were eliminated from the project because of budget reductions. The original proposal also called for the controlled dose-response experiments to occur in streamside channels located alongside Little Kickapoo Creek. These experiments were moved to the indoor streams at Oak Ridge National Laboratory because of drought-related reductions in the water available for these experiments at the original location.

Peer Reviewed Publications

Hill, W. R., and S.E. Fanta. 2007. Phosphorus and light simultaneously limit benthic algal growth at subsaturating irradiances. *Freshwater Biology*. doi: 10.1111/j.1365-2427.2007.01885.x

Hill, W. R., S. E. Fanta, and B. J. Roberts. Accepted. ^{13}C dynamics in benthic algae: effects of light, phosphorus, and biomass development. *Limnology and Oceanography*.

Presentations

Hill, W. R., S. E. Fanta, T. B. Smith, and B. J. Roberts. 2007. Carbon stable isotope dynamics and stoichiometry in autotrophic biofilms. Invited presentation at the Aquatic Sciences Meeting of the American Society of Limnology and Oceanography, Santa Fe, February.

Hill, W. R., S.E. Fanta, and T. B. Smith. 2006. Simultaneous limitation of periphyton growth by phosphorus and light at subsaturating irradiances. Annual Meeting of the North American Benthological Society, Anchorage, June.

Fanta, S. E., T. B. Smith, and W. R. Hill. 2006. Light and nutrients effects on periphyton stoichiometry. Annual Meeting of the North American Benthological Society, Anchorage, June.
Hill, W. R. 2006. An experimental approach to the development of nutrient criteria in streams.

Hill, W. R. Invited seminar, Environmental Sciences Division, Oak Ridge National Laboratory, April 2006.

Smith, T. B., W. R. Hill, and S. E. Fanta. 2006. Effects of phosphorus mediated through algal biomass in Illinois streams. Illinois Water Conference, Champaign, IL, September.

Hill, W. R., T. B. Smith, and S. E. Fanta. 2005. Effects of phosphorus mediated through algal biomass in Illinois streams. CFAR Day at UIUC, November.

Hill, W. R., T. B. Smith, and S. E. Fanta. 2005. Effects of phosphorus mediated through algal biomass in Illinois streams. Illinois Nutrient Standards Science Committee Meeting, Springfield, IL, February.

Smith, T. B., and W. Hill. 2005. Use of statistical modeling to assist phosphorous criteria for midwestern streams. Annual Meeting of the North American Benthological Society, New Orleans, LA. May.

Smith, T. B., W. Hill, M. Short, and R. Smogor. 2004. Patterns of fish and mussel species richness and phosphorus concentration in Illinois streams: preliminary analysis of long term data sets. Illinois Water Conference, Champaign, IL, September.

Smith, T. B., and W. R. Hill. 2003. Data mining presentation. U.S. EPA Regional Technical Assistance Groups (RTAG) meeting in Chicago, IL

Hill, W. R., T. B. Smith, and S. E. Fanta. 2003. Effects of phosphorus mediated through algal biomass in Illinois streams. Illinois Nutrient Standards Science Committee Meeting, Springfield, IL, May.

Additional manuscripts are currently in preparation or in review.

Fanta, S. E., W. R. Hill, T. B. Smith, and B. J. Roberts. Testing the light nutrient hypothesis in periphyton with gradients of light and phosphorus. *Limnology and Oceanography*.

Hill, W. R., S. E. Fanta, and B. J. Roberts. Benthic algal response to simultaneous gradients of phosphorus and light. *Freshwater Biology*.

Hill, W. R., B. J. Roberts, and S. E. Fanta. Nutrient and light interactions in experimental streams: consequences for the metabolism, stoichiometry, and fatty acid composition of primary producers.

Roberts, B. J., W. R. Hill, and S. E. Fanta. Interactive effects of phosphorus and light on stream metabolism during community development.

Team 3: Seasonal dynamics of nutrients, algae and dissolved oxygen in agriculturally dominated headwater streams: the link between land-use and water quality.

Principal Investigator

William L Perry, Illinois State University

The goal of this research was to examine the relationship between nutrient concentrations, algal biomass, and dissolved oxygen in six agriculturally dominated headwater streams and the Mackinaw River that cover a range of low (0.03 mg total phosphorus/L) to high (0.25 mg total phosphorus/L) phosphorus concentrations. Our research expanded upon ongoing research in two headwater streams where long-term monitoring implicated algae as an integral component of the ecosystem physicochemical condition.

Nutrients, nitrogen and phosphorus, were studied biweekly for 15 months in the six headwater streams and combined with a parallel 5 year study in the two smaller streams and were found to

vary seasonally in response to changing discharge. High nitrate concentrations (>13 mg NO₃-N/L) observed from mid October through mid June decreased to near detection limits while phosphorus concentrations peaked during spring and fall flood events and varied among streams due to differences in watershed management practices.

We hypothesized that the range of phosphorus concentrations in these streams would provide us with the ability to determine if algal biomass varied according to phosphorus concentrations. We examined seasonal variation in algal biomass in these streams to determine when biomass was the highest and if the periphyton was nutrient limited by either nitrogen or phosphorus through the use of artificial nutrient diffusing substrata. We observed weak nitrogen limitation in these streams during summer periods but did not observe phosphorus limitation even in the lowest phosphorus systems. Highest algal biomass was observed in January as well as late summer and was associated with stable flow regimes. Because diurnal dissolved oxygen fluctuation might result from algal blooms in the water column, on rock substrata, or on soft substrata we then examined differences in algal biomass in these habitats. In these systems, water column algal biomass was only present during high flow events and did not occur during periods of low dissolved oxygen. This suggests that sampling the water column to determine the link between nutrients, algae and low dissolved oxygen is not appropriate.

Stream ecologists have historically focused on periphyton on rocks because of relative ease of sampling but have overlooked periphyton on soft sediments. Our third goal was to determine if periphyton on rocks was comparable to periphyton on soft sediments and if this would need to be included in sampling protocols if algal biomass was used as an indicator of excess nutrients. Soft sediments contain phosphorus that might be available to periphyton while periphyton on rocks obtain all nutrients from the water column and biomass and productivity was hypothesized to be significantly higher on soft substrata. We developed methods to sample periphyton biomass and estimate productivity of periphyton soft sediments.

Periphyton productivity on hard and soft substrata was not significantly different over the range of phosphorus concentrations in these systems but respiration rates on soft sediments were significantly higher on soft sediments and may contribute significantly to low dissolved oxygen concentrations. Chlorophyll a concentrations on soft substrata were significantly higher due to inactive, buried periphyton that was not photosynthetically active. The results of these studies suggest that periphyton over this range of phosphorus concentrations are not nutrient limited and in all systems dissolved oxygen fluctuations led to low dissolved oxygen during low flow periods.

Initial objectives that were not accomplished

The goal of this research was to establish a relationship between nutrients, periphyton and depressed dissolved oxygen over a range of similar streams and how this varied with watershed management practices. We were unable to develop this relationship even in systems that had low phosphorus concentrations. Further, although there were differences in phosphorus concentrations in these systems that appeared to vary in respect to watershed management practices, we were unable to get data on nutrient application rates in these systems. We were also unable to develop a metric that was useful in assessing observable differences in the systems

that could be used to examine relationships between management practices and observed phosphorus concentrations in streams.

Presentations

Perry, W.L., 2007. Effectiveness of best management practices in improving water quality. Conservation Expo 2007. Land Improvement Contractors of America. September

Perry, W.L., K.M. Slattery, K.G. Kirkham. 2006 Headwater stream periphyton dynamics: nutrients-periphyton-water quality. Illinois Water Conference. Champaign Urbana. October

Perry, W.L. 2006. Agricultural stream biogeochemistry, biodiversity, and mitigation – from sediments to slime. University of Illinois – Chicago. April.

Slattery, K.M. and W.L. Perry. 2006. Primary production of periphyton on soft and hard substrata: The role of sediment bound phosphorus. North American Benthological Society, Anchorage, AK. June 4-9, 2006.

Kizer, K.L., K.M. Slattery, S.J. Van Der Hoven, and W.L. Perry. Relationships between sediment-bound phosphorus and primary productivity in streams: Natural variability and impacts from treated wastewater. North American Benthological Society, Anchorage, AK. June 4-9, 2006.

Perry, W.L. and H.M. Invasions of rusty crayfish, *Orconectes rusticus*, in streams: does flow alter movement patterns? North American Benthological Society, Anchorage, AK. June 4-9, 2006.

Lemke, A.M., M. Herbert, W.L. Perry, and J.R. Herkert. Effectiveness of best management practices on freshwater conservation in an agricultural watersheds of the Mackinaw River, Illinois. North American Benthological Society, Anchorage, AK. June 4-9, 2006.

Kirkham, K.G. and W.L. Perry. Effects of seasonal nutrient dynamics on periphyton in agricultural streams. North American Benthological Society, Anchorage, AK. June 4-9, 2006.

Van de Hooven, S., K. Kizer, and W.L. Perry. 2005. Relationships between primary productivity and sediment-bound phosphorus in streams: natural variability and impacts from treated wastewater. Geological Society of America. 2005 Salt Lake City Annual Meeting (October 16–19, 2005)

Lemke M., M. Herbert, D. Kovacic, W.L. Perry. 2005. Effectiveness of agricultural best management practices on the ecological integrity of a Mackinaw River subwatershed, Illinois. Mississippi River Basin Nutrient Workshop

Theses

Slattery, K. M. 2007. Primary production and chlorophyll a differences between soft and hard substrata in agricultural streams of central Illinois. Masters Thesis. Illinois State University.

Kirkham, K.G. 2005 Effects of seasonal nutrient dynamics in periphyton in agricultural streams. Masters Thesis. Illinois State University.

Kizer, K. Effects of elevated water column phosphorus on sediment phosphorus fractions and langmuir isotherms in a 3rd order stream in central Illinois. (Anticipated, 2008)

Additional activities

I have been working with The Nature Conservancy (TNC) on a long-term project to assess the effectiveness of best management practices in improving water quality. The CFAR project is one aspect of this larger project. We have manipulated one watershed and maintained one as a reference watershed. The manipulation consisted of wide implementation of best management practices that are considered to lead to improved water quality including modified tilling practices, grass waterways, and buffer strips and we are now adding wetlands to reduce water flow and decrease nitrogen and phosphorus inputs. Tim Lindenbaum, a TNC employee and local farmer, works as our outreach person that works with local farmers to describe the potential benefits of best management practices and how to obtain funding to implement these practices.

The Nature Conservancy has produced a large number of flyers, meetings, and has been featured in several newspaper articles. A local landowner also recently participated in the Land Improvement Contractors of America Conservation Expo in 2007 and the TNC long-term project was presented at this expo. The research has also been presented at international meetings and departmental seminars. Because of the pairing with the long-term project, the CFAR funding has added a critical component to our understanding of phosphorus dynamics in these streams and this will become a critical component of both future research and presentations to local residents and in future departmental seminars.

Manuscripts are currently in preparation or in review.

Kirkham, K.G. and W.L. Perry. Seasonal patterns of algal biomass and nutrient limitation in two agricultural headwater streams. *Journal of the North American Benthological Society*

Kirkham, K.G. and W.L. Perry. Periphyton biomass and limitation across a phosphorus gradient in agricultural headwater streams. *Journal of the North American Benthological Society*

Kizer, K, S.J. van der Hoven, and W.L. Perry Effects of elevated water column phosphorus on sediment phosphorus. *Journal of the North American Benthological Society*

Lemke, M., W.L. Perry, K.G. Kirkham. Role of best management practices in agricultural headwater streams and associated changes in water quality and biodiversity. *Ecological Applications*

Slattery, K.M. and W.L. Perry. Primary production and chlorophyll *a* differences between soft and hard substrata across a phosphorus gradient in agricultural streams of central Illinois. *Journal of Freshwater Biology*

Slattery, K.M. and W.L. Perry. Method to estimate primary production on soft substrata. *Journal of the North American Benthological Society*

Team 4: The Impact of Sediments on the Potential Bioavailability of Phosphorus in Illinois Streams

Principal Investigators:

Michael L. Machesky and James A. Slowikowski
Center for Watershed Science, Illinois State Water Survey

The overall objective of this study was to clarify the impact of suspended and bed sediments on the bioavailability of P, and to determine the relationships between bioavailable and total P and important measures of eutrophication including dissolved oxygen and chlorophyll *a*. The Spoon River watershed in West-Central Illinois, a major tributary of the Illinois River, was the focus of our efforts. Within this watershed we intensively monitored two low-order tributaries, Court and North creeks, as well as the Spoon River mainstem at Seville. Our efforts included intensive low flow and storm sampling of suspended and bed sediments to determine phosphorus forms and bioavailability. While these intensive data were being collected, important water quality parameters such as pH, temperature, dissolved oxygen (D.O.), and chlorophyll *a* (both suspended and benthic) which is a measure of algal biomass were monitored, through *in situ* sampling and the use of continuous water quality monitoring instrumentation.

Bioavailable phosphorus (BP) is that portion of total phosphorus (TP) concentration that is readily available to algae and hence directly contributes to eutrophication effects. Previous research has shown that in most streams and rivers more than 90 % of dissolved forms of phosphorus, as separated using 0.45 micron filtration and measured as dissolved reactive phosphorus (DRP), are bioavailable. However, for particulate forms of phosphorus (PP; =TP-DRP) bioavailability is much more variable, ranging from 0 and 90%. Therefore, $BP = DRP + BPP$, where BPP is the bioavailable portion of PP. Our specific research objectives focused on determining BP and how it varied with flow, stream order within the watershed, between suspended and bed sediments, and if BP was related to algal biomass and the extent of eutrophication in the Spoon River basin.

Stream water BP concentrations were determined using filter paper discs coated with iron-oxide, which adsorbs both DRP and BPP. Of the BP fractions, average DRP concentrations were greater than those of BPP, especially for the Spoon River at Seville station. In addition, mean BP concentrations, were always considerably lower than inert particulate phosphorus concentrations (IPP=PP-BPP), and in percentage terms BPP comprised about 20%, 14%, and 10% of PP at our North, Court, and Spoon river stations, respectively. These percentages decreased with increasing stream order (North first order, Court second order, and Spoon fourth order) indicating that PP becomes less bioavailable as it is transported downstream in this

watershed. Finally, BP was about 34%, 28%, and 22% of TP (DRP+BPP+IPP), for our Court, North, and Spoon River sites, respectively, and these percentages agree with those from studies that have been conducted in other watersheds dominated by agriculture.

The predominant structure of stream bed sediments at all three stations is a thin (1-3 cm thick) silt/clay layer underlain by sand. The silt/clay layer is easily swept away during higher flows, with a fresh layer from upstream sources being deposited under low flows. We determined the BP content of this thin silt/clay layer, and its impact on the overlying water in several ways.

In one set of experiments, stream bed sediments were sieved through a 63 micron screen to isolate the silt/clay surface layer, and then small portions of this isolated sediment were incubated for 24 hours with filtered stream water (collected at the same time) to which DRP solutions of various known concentrations were added. The amount of DRP adsorbed by the sediments was then determined from the difference between the known amount of DRP added, and that remaining in the filtered stream water after 24 hours. These experiments were conducted several times with sediments from each station during this study. The primary finding from these experiments was that the DRP content of the thin silt/clay layer was similar to that in the overlying stream water, which indicates that this thin layer of fine sediments is neither an important source nor sink of bioavailable DRP for the overlying stream water.

In a more limited series of experiments conducted at our North creek station on 2 occasions, we isolated about 1.5 ft² portions of stream bottom sediments and about 14 inches of overlying water within plastic chambers for 16-24 hour periods, and then determined DRP concentrations in samples withdrawn from the water within the plastic chambers. DRP concentrations remained constant, which also indicated that the sediments were not taking up or releasing bioavailable DRP to the overlying stream water. On one other occasion we inserted 15 cm iron-oxide strips into the sediments at our three stations, retrieved them 2 days later, and then extracted and analyzed the DRP from thin (0.5 cm) sections cut from the 15 cm strip. Bioavailable DRP concentrations in the thin sections were very similar from the top to bottom of the 15 cm strips, which also indicated no uptake or release of DRP by the stream bottom sediments. In short, the silt/clay layer is probably just too thin (1-3 cm) to have much influence on BP concentrations in the overlying stream water.

Eutrophication impacts are most evident between about mid-April and mid-October because stream water temperatures are higher, days are longer, and stream flows are generally lower (especially after June), all of which promote the growth of algae, and corresponding large daily swings in D.O. concentrations. Of the physical factors impacting algal growth and associated eutrophication effects, stream flow is usually the most unpredictable since rainfall can be highly variable, both from place to place and from year to year. Therefore, knowing stream flows is very important for properly interpreting observed BP concentrations, and their relation to important measures of eutrophication such as chlorophyll *a* and daily dissolved oxygen swings. Because stream flow information is so important, all 3 of our field sites were located at stream gages.

Median stream flows from April to October at our stations increased in the order, 2005<2006<2007<2004, signifying generally drier to wetter years. May through October 2005

was classified as an extreme drought period for most of the Spoon River watershed, as evidenced by the very low median flows observed at our stations. These extreme low flow conditions were accompanied higher suspended chlorophyll *a* or algal biomass concentrations, and lower DRP concentrations since the greater algal biomass utilized more DRP (essentially 100% bioavailable), and was not periodically “flushed” downstream as happens during more normal flow regimes. In fact, DRP was negatively correlated with suspended chlorophyll *a*, and positively correlated with median flows for all 4 years, and especially at our North creek and Spoon river sites. Conversely, neither BP nor TP was strongly correlated with either median flow or suspended chlorophyll *a*.

Between 2005 and 2007 we also periodically determined the chlorophyll *a* concentration of the thin silt/clay sediment layer that predominates at our sites. These measures of the benthic algal population revealed chlorophyll *a* concentrations that usually exceeded those of the overlying stream water. Mean benthic chlorophyll *a* concentrations, as expressed in unit’s equivalent to those for suspended chlorophyll *a* were 136, 113, and 106 µg/L at our North creek, Court creek, and Spoon river sites, respectively. These means exceeded all of the corresponding mean suspended chlorophyll *a* concentrations. Benthic algal populations are usually greater than those suspended in the water column in small to medium-sized streams and rivers. However, the amounts found on our soft silt/clay sediments were somewhat surprising, especially since those sediments are easily washed away in higher flows. One possible reason for this abundance is that benthic algae are able to obtain at least part of their nutrient requirements from the sediments themselves, and the fine-grained nature of those sediments makes that easier to do.

Starting in mid-May 2004 water temperature, specific conductance, pH, and D.O. were continuously monitored at each of our stations with YSI data sondes, except for periods when ice cover was present (usually mid to late December through February). Diurnal swings in D.O., indicative of the algal production-respiration cycle, were observed during all times of the year (including December) provided flows were low and stable. However, the diurnal swings were greatest between about mid-June and mid-October, in response to higher water temperatures and longer days promoting greater algal growth and respiration.

There were 2 primary characteristics that we observed in our summer period D.O. data from all 3 stations. First, diurnal swings were often very large, with % saturation values often exceeding 150% near mid-day, and sometimes dipping below 50% near dawn. These large swings reflected abundant algal productivity, and most of this productivity was due to benthic algae. Second, abrupt increases in stage flushed algae downstream which resulted in dampened D.O. fluctuations. Hence, these flushing events “reset” the streams to a relatively less eutrophic state. However, diurnal D.O. fluctuations, and hence algal productivity, rebounded to pre-storm levels in about 1 week’s time, indicating that the effect of storms was only temporary.

Presentations

M.L. Machesky, J.A., Slowikowski, T.R. Holm, J. Stevens, K. Stevenson, and T. Snider, 2004. The Impact of Sediments on the Potential Bioavailability of Phosphorus in Illinois Streams. 27th Annual Midwest Environmental Chemistry Workshop, Madison, WI, October.

M.L. Machesky, J.A., Slowikowski, T.R. Holm, J. Stevens, K. Stevenson, and T. Snider, 2004. The Impact of Sediments on the Potential Bioavailability of Phosphorus in Illinois Streams. Illinois Water 2004 Conference, Urbana, IL, October.

T.R. Holm, M.L. Machesky, and J.A. Slowikowski, 2004. Chemical Fractionation of Phosphorus in Stream Sediment. Illinois Water 2004 Conference, Urbana, IL, October.

Michael L. Machesky, James A. Slowikowski, Thomas R. Holm, Josh Stevens, Kip Stevenson, and Ted Snider, 2005. The Impact of Sediments on the Potential Bioavailability of Phosphorus in Illinois Streams. Mississippi River Basin Nutrient Sciences workshop, St. Louis, October.

M.L. Machesky, J.A., Slowikowski, T.R. Holm, J. Stevens, and K. Stevenson, 2006. The Impact of Sediments on the Potential Bioavailability of Phosphorus in Illinois Streams. Illinois Water 2006 Conference, Urbana, IL, November.

Additional outcomes from the SRI

Another outcome of the SRI was the increased involvement of all researchers with both Illinois and national water quality issues. For example, Mark David was named to the U.S. EPA Science Advisory Board (SAB) Hypoxia Advisory Panel. This panel is charged with providing advice, through the chartered SAB, that evaluates the state-of-the-science regarding the Gulf of Mexico hypoxic zone. As result of his role in the SRI, Mark able to include Illinois water quality information that was highly relevant and was familiar with other sources of data including the Illinois EPA database. Two research paper that were made possible by C-FAR funding were referenced in the hypoxia advisory report: http://www.epa.gov/sab/pdf/11-5-07_hap_draft.pdf

Strategic Research Initiative (SRI) in Water Quality: Outreach

Outreach and public engagement have been important components of the Water Quality SRI from the beginning. The collaborative nature of the initiative provided for numerous opportunities for researchers, regulators, agricultural groups, municipalities, and environmental interests to review ongoing work and discuss possible applications of research findings.

Researchers have communicated their results in several ways. A list of conference proceedings, journal articles, seminars, and graduate theses can be found in the individual team sections of this report. Results of SRI projects have been widely distributed at numerous University of Illinois Extension meetings and other water quality events. Following are a few selected examples where SRI results were presented:

Connecting Illinois Watersheds Conference, 2004

Illinois Certified Crop Advisor (CCA) State Conference, 2006

Illinois River Barge Tours, Illinois Corn Growers Association, 2005, 2006

Regional Illinois Crop Management Workshops, 2005, 2006, and 2007

Southern Illinois Fertilizer and Pesticide Conference, 2003 and 2005

Upper Kaskaskia Watershed Showcase, 2006

University of Illinois Agronomy Day, 2003 and 2004.
University of Illinois Crop Protection Technology Conference, 2005

Czapar, G. F. 2006. Connecting regulators with researchers. Guest Editorial. *Journal of Soil and Water Conservation* 61(3) 80.

Czapar, G. F. 2006. Connecting regulators with researchers: Illinois approach for developing water quality standards. *Innovations in Reducing Nonpoint Source Pollution Conference*. Indianapolis, IN

Czapar, G. F. 2005. Developing nutrient standards for Illinois. Pp. 118-119. *Proceedings of the Illinois Crop Protection Technology Conference*. University of Illinois at Urbana-Champaign.

Czapar, G. F. 2004. Water quality research in Illinois. p. 70. *Proceedings of the Illinois Crop Protection Technology Conference*. University of Illinois at Urbana-Champaign

On several occasions, the entire Water Quality SRI team was invited to share their results in public forums. Researchers made presentations at the following:

Illinois Nutrient Standards Workgroup, Springfield, IL, November, 2007.

Nutrient Standards Forum, Springfield, IL, October, 2007.

Illinois Water 2006 Conference, Champaign, IL, September, 2006.

Mississippi River Basin Nutrient Sciences workshop, St. Louis, October, 2005.

Illinois Nutrient Standards Science Committee Meeting, Springfield, IL, February, 2005.

NRCS Phosphorus Workshops: March and June, 2005

Illinois Water 2004 Conference, Urbana, IL, October, 2004.

Illinois Nutrient Standards Science Committee Meeting, Springfield, IL, February, 2004.

U.S. EPA Regional Technical Assistance Groups (RTAG), Chicago, IL, November, 2003.

Illinois Nutrient Standards Science Committee Meeting, Springfield, IL, May, 2003.

The most comprehensive summary of the Water Quality SRI was presented to the public on October 23, 2007. All the Water Quality SRI researchers participated in a Nutrient Standards Forum that was held at the University of Illinois at Springfield. An agenda for the program is attached as Appendix A. Each research team presented key findings and summarized their work. Information about the meeting and copies of all presentations are available on the C-FAR web site at: <http://www.ilcfar.org/research/waterqualityforum.html>

Research teams provided updates to an audience of about 125 people representing C-FAR, the state legislature, and agribusiness. Audience evaluations after the water quality forum were very favorable. When asked to evaluate the program, the average response was 8.2 (1 = lowest, 10 = highest).

SRI Components Planned for Continuation through Funding Sources other than C-FAR

This CFAR project brought together several groups of researchers to examine phosphorus dynamics across a range of scales. New collaborations between Bill Perry and Mike Machesky and Jim Slowkowski have emerged. The detailed studies of sediment phosphorus performed by Mike and Jim and Bill's expertise in the biology of periphyton create a perfect pairing for future grants. New research projects are being developed with the intent of submitting grants to the United States Department of Agriculture (USDA) and the National Science Foundation.

In addition, this CFAR project enhanced collaboration with Steve van der Hoven, a geochemist, and Eric Peterson, a hydrologist, and led to a NSF submission last year on the changes associated with dredging and redevelopment of a hyporheic zone and changes in nutrient retention, algal biomass and dissolved oxygen variation over time. By working with local drainage managers Perry found that records on the time and frequency of dredging of headwater streams is available and will allow him to study these patterns in several replicate streams. They are also studying the effectiveness of wetlands in reducing both phosphorus and nitrate inputs into streams

Finally, this research on algal biomass in headwater streams will be expanded into larger river systems to determine if there is a change in the importance of sestonic to benthic algal biomass as it might vary with stream size and turbidity. This research will begin with an extension of the work done with CFAR and TNC to the Mackinaw River and Kickapoo Creeks or other similar nearby rivers. The potential funding sources will be The Nature Conservancy, the National Science Foundation, and United States Department of Agriculture.

SRI components planned for continuation via C-FAR funding

The collaborations and research conducted in this past CFAR grant has led to the development of three associated preproposals that will be submitted to CFAR external grants program. Bill Perry, Mike Machesky, and Jim Slowkowski, are interested in examining the factors contributing to algal bloom development in an upstream – downstream continuum in the Spoon River and Mackinaw River. Steve van der Hoven and Bill Perry are also submitting a grant to study the residence time and nitrogen and phosphorus dynamics in constructed wetlands and the method of nitrate loss. Finally, Maria Lemke and Bill Perry are submitting a grant to continue studying the nutrient dynamics of headwater streams and the effectiveness of constructed wetlands and best management practices on water quality and biodiversity.

Leveraged Funding

Czapar, G. F. 2006. Water Quality Strategic Research Initiative. Granting agency: Illinois EPA, Section 319 Program. Amount awarded: \$275,000.

Perry, W.L. and S. Van der Hoven. 2005. Effectiveness of constructed wetlands and subirrigation on water quality in agricultural drainage watersheds, Mackinaw River, Illinois. The Nature Conservancy. Amount awarded: \$30,150.

Perry, W.L. 2005. Role of wetlands and modified drainage systems on stream water quality. The Nature Conservancy. Amount awarded: \$48,000.

Although C-FAR provided the primary funding for this research, additional funding was provided by the Governor of Illinois and the Illinois Environmental Protection Agency through Section 319 of the Clean Water Act. Collaborators include the Illinois Environmental Protection Agency, Illinois Department of Agriculture, Metropolitan Water Reclamation District of Greater Chicago, Bloomington-Normal Water Reclamation District, Oak Ridge National Laboratory, and The Nature Conservancy.