Indiana Water Resources Research Center Annual Technical Report FY 2016

Introduction

During FY2016, the Indiana Water Resources Research Center (IWRRC) welcomed new leadership; Director, Dr. Linda S. Prokopy, Professor in the Department of Forestry & Natural Resources and Managing Director, Laura A. Esman. Our objectives included (1) support research opportunities that address water issues within Indiana through the 104(B) small grants program, (2) increase visibility and awareness of the Center throughout the state, and (3) explore the opportunity to directly train young scientists through the US Geological Survey (USGS) Student Internship Program.

Research Program Introduction

104(B) Small Grants Program The majority of the base funding received by the IWRRC is used to support a small grants program to fund research opportunities that address water issues within Indiana. All proposals submitted under the FY2015 Request for Proposals were externally reviewed by subject area experts within Indiana and outside of the state. Five proposals were funded including: • Floodplain restoration and nutrient retention in the Wabash River Basin. PIs: Dr. Sara McMillan and Dr. Venkatesh Merwade, Purdue University • Nutrient removal efficiency of a combined surface/subsurface flow wetland system. PI: Dr. Pierre-Andre Jacinthe, Indiana University Purdue University Indianapolis • Pilot investigation of variable contaminant loads in fish as a result of foraging and habitat specialization. PIs: Dr. Tomas Hook and Timothy Malinich, Purdue University • Predicting toxic cyanobacteria blooms in the Wabash River Watershed. PI: Dr. Allison R. Rober, Ball State University • Water and nutrient recovery from aquaculture effluents through vegetable production. PIs: Dr. Hye-Ji Kim, Dr. Paul Brown, Bob Rode, Dr. Cary Mitchell, Purdue University

In addition, one 104(G) project was active during this reporting period: • Can there ever be enough? Analysis of the adoption, penetration and effectiveness of urban stormwater best management practices. PIs: Dr. Laura C. Bowling and Dr. Linda S. Prokopy, Purdue University

We developed the 2017 RFP for the 104(B) program in consultation with other Water Resource Research Centers in the region. Water Centers within the Mississippi River Basin agreed to include a statement in the 2017 RFP indicating a focus area was funding complimentary research on Harmful Algal Blooms. We also expanded our funding opportunity by creating an option to apply for a larger grant that included a collaborative, interdisciplinary team, integrating social and physical dimensions. We also developed a new method for external peer review of applications that included collecting comments to return to grant applicants.

Increase Visibility and Awareness of the IWRRC One goal for the first year under new leadership was to increase awareness of the IWRRC throughout the state by increasing our visibility and organizing our communication with academic institutions throughout the state. Throughout the year, we have developed an updated website (iwrrc.org) that includes funding opportunities, such as 104(B) and 104(G) grant programs, projects funded through IWRRC, a list of upcoming relevant conferences and meetings, and our partners. We continue to develop the website and hope to include publications and reports and eventually information on the State of Indiana water resources. In addition, we created a listserv of statewide academic researchers working on water related issues. The listserv is being used to disseminate water related information and funding opportunities. We have also included the option to join this listserv through the new website.

We created an Advisory Council of key water stakeholders throughout the state, including representatives from federal and state agencies and academic institutions. We held one meeting of the Advisory Council and communicated with them through email throughout the year.

We also wanted to reconnect with the Indiana Water Resources Association (IWRA), which has a long history of being a main convener of water researchers within Indiana. The IWRA holds an annual symposium that is well attended by state and federal agencies, conservation partners, and academics. IWRA is also a huge supporter of student participation through presentations and posters. Dr. Linda Prokopy, Director, presented at the June 2016 symposium to introduce new leadership and review past, present and future perspectives of the IWRRC. In addition, the Director and Managing Director were able to attend the IWRA annual membership business meeting and gain support for IWRRC co-sponsorship of the 2017 Symposium.

On October 11, 2016, the Earth Resources Engineering Section of the US National Academy of Engineering hosted a Symposium on Groundwater Depletion. The symposium was part of the NAE’s continuing efforts to “draw national attention to the economic and environmental issues of groundwater depletion, and the urgent need for research and development in this rapidly developing field.” Dr. Cherkauer attended to represent the Indiana Water Resources Research Center (IWWRC) in the discussion along with about 50 other attendees from across the country representing agencies, universities, companies and NGOs. The symposium kicked-off with a Keynote presentation by Stavros Papadopulos, an internationally known expert on the analysis of groundwater systems and founder of S.S. Papadopulos & Associates, Inc. an environmental and water resources consulting firm. Filling the rest of the day were short presentations and panel discussions covering existing problems with groundwater depletion and efforts to improve groundwater management. Many of the presentations focused on parts of the country with severe depletion problems, primarily the Ogallala Aquifer and California. The broader discussions allowed Dr. Cherkauer and others to highlight the need to apply the methods and lessons learned from those regions to other areas where depletion has not been a significant problem historically, but where increasing demand and changing climate may increase groundwater use and depletion in the future.

February 2017, the Director and Managing Director attended the annual National Institutes for Water Resources (NIWR) meeting in Washington DC. This meeting provided valuable exposure to other Center Directors to learn the structure of other centers, how they fund research, and the various water issues. In addition, we met with Senator Joe Donnelly’s staff to discuss the importance of the water centers and the funding we receive.

In January 2017, IWRRC launched a webinar series with a discussion of the USGS National 104(G) Competitive Grant Program. Drs. Linda Prokopy, Laura Bowling, and Ron Turco, Purdue University, provided information on the new pre-proposal format for application, their experience of past proposal attempts and success, and tips learned from review panels.

Throughout the year, the Director has participated in conferences and on committees, increasing the visibility of the IWRRC, including: • Participated on the planning committee for the annual conference of the Soil and Water Conservation Society. She also presented on numerous projects that integrate social sciences into the management of water resources. • Attended meetings of the Nutrient Management and Soil Health group of the Indiana Land Conservation Partnership and provided insights into how to message nutrient management across the state. • Worked with Wabash River Enhancement Corporation – chaired Education Committee and member of Steering Committee for Great Bend of the Wabash River watershed project. • Served on Steering Committee for the Indiana Climate Change Impacts Assessment. • Developed insights into how the Agricultural Conservation Planning Framework can be used as part of holistic watershed planning efforts.

USGS Student Internship Program We learned of the USGS student internship program through a USGS partner, Deputy Director Jeff Frey at the Indiana-Kentucky Water Science Center, and decided to explore this opportunity to help train a future water scientist. Together, we investigated the requirements for both IWRRC and USGS to hire an intern. We were prepared to post the position in early 2017, but unfortunately, our funding was delayed due to the federal budget continuation. We plan to pursue this again in 2018.

Grant Applications Submitted Through/With IWRRC Researchers associated with the IWRRC and/or funded through the 104(B) small grants program have been able to use project outcomes to explore other funding opportunities. In addition, the Director was involved in the submission of numerous grants during the year that benefitted the IWRRC. Below is a list of grant applications submitted based on work with the IWRRC: • (Funded) USEPA $2,000,000 Right sizing tomorrow’s water systems for efficiency, sustainability and public health.

• (Funded) IDEM-319 $750,000 St. Mary’s Watershed Initiative.

• (Funded) The Nature Conservancy $257,902, Non-Operator Landowners and Soil Health: Understanding and Breaking Barriers to Adoption.

• (Funded) Walton Family Foundation $80,000 In-Depth Review of Farmer Adoption/Barriers to Adoption Literature. • (Funded) USDA-NIFA $499,161 Does Crop Insurance Inhibit Climate-Change Irrigation-Technology Adaptation?

• (Funded and ongoing) IDEM-319 $240,000 Region of the Great Bend of the Wabash River Implementation Project.

• (Submitted) USDA-NIFA SCRI Research and Extension Planning Project, Strategic Planning. Amount requested $50,000. Strategic Planning Aquaponics Conference for Specialty Crops (2017-2018).

• (Submitted) U.S.-Egypt Science and Technology Joint Fund. Amount requested $199,753.Water efficient food production systems for Egypt and U.S.

• (Submitted) NSF $2,405,594 Closing the Loop on Crop, Water and Land Use Impacts of Wind Energy in the FEW Nexus.

• (Submitted) EPA $750,000 Assessment of Conservation Initiatives in Four GLRI Watersheds.

• (Submitted) NOAA $3,500,000 Integrated Midwest Partnerships for Actionable Climate Tools and Science (IMPACTS).

Current IWRRC Leadership Director: Dr. Linda S. Prokopy, Department of Forestry and Natural Resources, Purdue University

Managing Director: Laura A. Esman, Department of Forestry and Natural Resources, Purdue University

Advisory Council: Jeff Frey, US Geological Survey Dr. Mark Pyron, Ball State University Jill Reinhart, Natural Resources Conservation Service MaryLou Renshaw, IN Department of Environmental Management Dr. Todd Royer, Indiana University Jordan Seger, IN State Department of Agriculture Dr. Ron Turco, Purdue University

Can there ever be enough? Analysis of the adoption, penetration and effectiveness of urban stormwater best management practices

Basic Information

Title:	Can there ever be enough? Analysis of the adoption, penetration and effectiveness of urban stormwater best management practices
Project Number:	2014IN377G
USGS Grant Number:	
Start Date:	9/1/2014
End Date:	8/31/2017
Funding Source:	104G
Congressional District:	IN-4
Research Category:	Water Quality
Focus Category:	Water Quality, Management and Planning, Non Point Pollution
Descriptors:	None
Principal Investigators:	Laura C. Bowling, Linda Stalker Prokopy

Publications

1. Gao, Y., N. Babin, A.J. Turner, C.R. Hoffa, S. Peel, and L.S. Prokopy, 2016. Understanding urban-suburban adoption and maintenance of rain barrels, Landscape and Urban Planning http://www.sciencedirect.com/science/article/pii/S0169204616300330
2. Gao, Y., N. Babin, A.J. Turner, C.R. Hoffa, S. Peel, and L.S. Prokopy, 2016. Understanding urban-suburban adoption and maintenance of rain barrels, Landscape and Urban Planning http://www.sciencedirect.com/science/article/pii/S0169204616300330
3. Bowling, L., Turco, R., Hoover, F., Peel, S. (2016). Region of the Great Bend of the Wabash River Water Quality Summary Report. Wabash River Enhancement Corporation. Available at:http://static1.1.sqspcdn.com/static/f/319113/27408873/1484172558920/IDEM+Water+Quality+Summary_F
4. Gao, Y., Church, S. P., & Prokopy, L. S. (2016). 2016 Great Bend of the Wabash River Watershed Urban Resident Survey Executive Summary Report. West Lafayette: Purdue University.

Indiana Water Resources Research Center Project Report

Annual Research Report 2017

Project Id: 2014IN377G

Title: Can there ever be enough? Analysis of the adoption, penetration and effectiveness of urban stormwater best management practices

Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: IN-004

Focus Categories: Water Quality, Management and Planning, Non Point Pollution

Keywords: urban stormwater BMPs, social indicators, water quality

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Abstract:

While agricultural systems have utilized Best Management Practices to reduce pollution for a number of years, work on urban stormwater management is lacking. The West Lafayette-Lafayette communities spanning the banks of the Wabash River in north central Indiana have a combined population of over 215,000 people. Like many similar sized communities across the country, the region is struggling to deal with increasing stormwater impacts on water quality. Stormwater conservation practices, such as rain gardens, rain barrels and permeable pavement offer the potential of decreasing stormwater volumes and reducing water quality impacts, but their utilization is generally lower than their agricultural counterparts. The goal of this proposed work is to improve water quality planning and implementation through recommendations to improve the overall adoption, penetration and permanence of urban stormwater BMPs. This will be achieved by: 1) Evaluating the level of adoption and intensity and duration of sampling needed to demonstrate statistically significant water quality change; 2) Assessing factors influencing practice adoption, penetration and permanence; and 3) Developing watershed management planning strategies for achieving urban water quality goals. Our research approach blends statistical analysis with social science techniques to determine 1) how many BMPs do we need? and 2) how can we get them in the watershed?

Problem:

Stormwater management, including the infrastructure for water conveyance, drainage and treatment, is an increasing water problem for communities of all sizes. This project is addressing the need to improve and enhance the nation's water supply through evaluation of what limits adoption of urban stormwater conservation practices. Urban streams are among those with the lowest water quality in the country. Improvements to stormwater conveyance and treatment infrastructure alone cannot resolve the problem.

Stormwater conservation practices, such as rain gardens, rain barrels and permeable pavement offer the potential of decreasing stormwater volumes and reducing water quality impacts, but their utilization is generally lower than their agricultural counterparts. Poor penetration is attributed to several reasons, including more numerous landowners with less property, a limited number of cost incentive programs and fewer formal public education programs than found in the agricultural community. Secondly, there is little demonstrated ability to show watershed-scale water quality improvement due to BMP implementation in urban environments, which is a function of both the needed intensity of BMP implementation to enact a desired change, as well as the statistical design of a monitoring program that can detect the expected rates of change.

Research Objectives:

This project will address the knowledge gap regarding the watershed-scale effectiveness of urban stormwater BMPS, starting with how many BMPs it takes to show statistically significant water quality improvement and extending to the willingness of landowners to adopt. Our specific project objectives include:

1. Evaluate the level of adoption and intensity and duration of sampling needed to demonstrate statistically significant change;
2. Assess the factors influencing practice adoption, penetration and permanence; and
3. Develop watershed management planning strategies for achieving urban water quality goals.

Methodology:

Our approach blends statistical analysis and physical modeling to determine the location and level of adoption and monitoring needed to reach water quality targets, with social science techniques to assess the level of BMP adoption in our urban watersheds, and the penetration and permanence of that adoption, to formulate overall recommendations. This overall methodology is described briefly here.

Objective 1 **-** Evaluation of the level of adoption and sampling intensity needed to demonstrate statistically significant change includes two primary tasks:

Analysis of the effectiveness of monitoring experimental design is using power analysis of the extensive Elliot Ditch and Little Pine Creek water quality datasets to quantify how the fundamental choice of experimental design (pre-/post- implementation analysis for a fixed site versus paired watershed) impacts the length of the monitoring program, the feasibility of detecting change and the overall sample analysis cost.

Quantifying the required level and location of adoption of BMPs to achieve the best case water quality target will be accomplished using the Long-Term Hydrologic Impact Assessment-Low Impact Development (LTHIA-LID) model (Ahiablame et al. 2012).

Objective 2 **–** The factors influencing practice adoption, penetration and permanence will be assessed with respect to three components:

Assessment of motivations to adopt urban BMPs will be completed through in-person surveys of people who have adopted BMPs in the Elliot Ditch watershed, , and people who received technical assistance from the Wabash River Enhancement Corporation but did not follow through with adoption of a BMP.

Understanding permanence of urban BMPs requires an assessment of both the property owner/manager and the actual practice. For the assessment of the property owner, everyone who adopted a BMP is being resurveyed at least 18 months after the preliminary survey. At the same time that in-person surveys are conducted, implemented projects will be photomonitored to document project installation, penetration and permanence.

Quantifying penetration will involve a spatial analysis of the mapped practices using spatial autocorrelation statistics to evaluate if there is clustering of individual types of BMPs with respect to different types of neighborhoods, the influence of peer-communication, and the influence of local businesses that have installed BMPs.

Objective 3 **-** After increasing our fundamental understanding of what is involved in motivating people, we will distill this information to provide strategies for watershed management planning.

Results:

Objective 1: Evaluate the intensity and duration of sampling and level of adoption needed to demonstrate statistically significant change.

Task 1: Analysis of the effectiveness of monitoring experimental design

Task 1 has largely been completed and has resulted in three tangible outputs in the form of two publications (Hoover et al. 2017; Bowling et al. 2016), and a formal presentation for the Indiana Department of Environmental Management.

In summary, minimum detectable difference (MDD) analysis (power analysis) was used to compare the number of samples needed to detect change for a single-site or paired-site statistical design. For changes in concentration, the single-site design consistently requires smaller magnitude of change (2 – 60% smaller change in concentration) for the same number of sampling events. In contrast, the paired-site statistical design results in smaller detectable differences in load and discharge than the single site design (5-45% smaller). The differences in statistical design performance reflects the fact that correlation between the treatment and control catchments tends to be higher for load and discharge variables (Pearson correlation ranging from 0.46 – 0.96, mean of 0.74) than for concentration variables (Pearson correlation ranging from 0.18 to 0.79, mean of 0.49). Total phosphorus (TP) concentration exhibited the lowest correlations, most likely reflecting differences in TP sources between these three watersheds.

- Total storm volume was a more robust discharge metric than the average of the peaks-over-threshold (POT) series, with correlations of 0.73 and 0.75, compared to 0.49 and 0.66 for POT in Elliot Ditch and Little Wea, respectively.
- Streamflow response tends to be more correlated between regional watersheds, so neighboring watersheds are more likely to form good pairs.
- Significant changes for storm volume were detected in both watersheds. The use of discharge may be especially important within urban watersheds where infiltration or peak discharge may be a way to identify a measurable change in water quality.
- If monitoring for concentration, using a single-site design will likely detect changes sooner in the watershed than under a paired-site design. However, attributing the change detected in the treatment is not possible using a single-site design due to weather and climate variability. If monitoring for load, discharge or peaks-over-threshold, a paired-site design will likely detect changes in the watershed sooner than a single-site design.

Task 2: Quantifying the required level and location of adoption

More qualitative judgement needed when modeling the place of the BMPs in this study. Work is proceeding on implementing the fully-distributed LTHIA-LID model in Elliot Ditch watershed by preparing all necessary input layers at 30 m resolution. Suitability criteria's for the placement of six stormwater BMPs within the LTHIA model are defined in Table 1.

Baseline model scenarios:

Seven baseline model scenarios will be implemented to assess how much runoff reduction is possible in the study area with the maximum number of each type of management practice and all the management practices combined, as follows:

- Scenario 1: Only rain barrel will be applied to all the buildings qualified.

- Scenario 2: Only permeable patio will be applied near all the buildings on Low Density Residential (LDR) land cover.
- Scenario 3: Only green roofs will be implemented on every qualified building.
- Scenario 4: Only grassed swale and bio swale will be implemented according to suitability criteria.
- Scenario 5: Only bioretention and rain garden will be applied.
- Scenario 6: Only porous pavement will be applied.
  Scenario 7: All practices will be implemented to all the possible locations qualified for maximum possible runoff reduction.

Table 1: Suitability criteria for implementing BMPs within the Elliot Ditch sub-basin.

	BMP	**Implementation/Suitability Criteria**
1	Rain Barrel	Buildings with area larger than 25 m^2 and less than 930 m^2
2	Permeable patio	Within 15 ft of buildings on Low Density Residential (LDR) land cover
3	Green Roof	All buildings on land cover classified as industrial and commercial
4	Grassed Swale/Bioswale	Within 30 m (1 pixel) of all roads
5	Bioretention/Rain Garden	Drainage are <2 acres and drainage slope <5%. No road or stream buffer restrictions
6	Porous Pavement	All roads, parking lots, driveways and sidewalks

Targeted implementation scenarios:

Other than implementing BMPs to the entire watershed, they can be applied to different zones of the study area to assess impact of zones on runoff reduction. These zones are industrial, business, and residential zones.

- Scenario A: Management practices only applied to the industrial areas. There are three subdivisions of industrial areas in the county zoning map, however all of them will be considered as one category.
- Scenario B: Management practices only implemented in the business areas.
- Scenario C: Management practices only implemented in the residential areas.

Objective 2: Assess factors influencing practice adoption, penetration and permanence.

Task 1: Assessment of motivations to adopt urban BMPs

In 2016, the Natural Resources Social Science (NRSS) lab conducted the Wabash Watershed social indicator survey of urban residents in Tippecanoe County, Indiana. The survey asked respondents about themselves and their residence, their perceptions about local water quality, their usage, perceptions, and attitudes of conservation practices, and their awareness of various local outreach efforts.

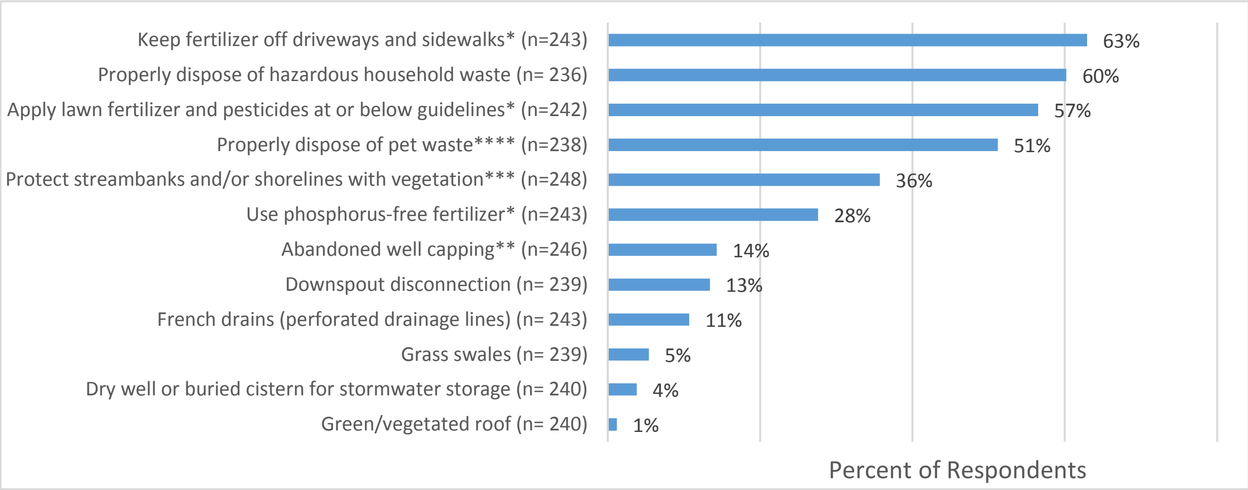
Characteristics of Urban Respondents and their Residence:

- 255 urban residents of Tippecanoe County responded to the survey, ranging in age from 19–98 years (average=56.5).
- 50.6% of the respondents were female, and 49.4% were male.
- 49.5% earned a bachelor's degree or higher.
- Most respondents (83.7%) owned their homes while 16.3% were renters.
- Most lived on ¼ of an acre or less (63.0%) while none lived on lots larger than five acres.

Practices to Improve Water Quality are summarized in Figure 1 and below:

- In terms of adoption of practices to improve water quality (when applicable), the highest percentage of respondents currently *keep fertilizer off driveways and sidewalks n=243* (63%), followed by *properly disposing of hazardous household waste n=236* (60%).

- Over half of respondents reported that they currently *apply lawn and fertilizer and pesticide at or below manufacture's guidelines n=242* (57%), but under a third of respondents reported they *use phosphorus-free fertilizer n=243* (28%).
- The lowest percentage of reported adoption of practices included structural changes such as *grass swales n=239* (5%), *dry well or buried cistern for stormwater storage n=240* (4%), and *green/vegetated roof n=240* (1%).



* 13.6% I do not have a lawn

** 91.5% My property does not have an unused well

*** 88.7% My property does not border or contain a ditch or waterway

**** 47.5% I do not have a pet

Figure 1: Usage of Water Quality Improvement Practices: Percent of 2016 survey respondents who currently use the practice

- Many respondents had never heard of several of practices, some of which are more difficult to implement than others, including
    - *Grass swales n=239* (68%)
    - *French drains (perforated drainage lines) n= 243* (58%)
    - *Downspout disconnection n=239* (49%)
    - *Green/vegetated roof n=240* (45%)
    - *Use phosphorus-free fertilizer n=243* (31%)
- In the 2016 survey, we asked separate, more detailed, questions that were applicable to practices highly promoted by WREC – rain gardens, rain barrels, and pervious pavement. Overall, very few people reported that they had installed/implemented the practice on their property: rain gardens (3%), rain barrels (8%), pervious pavement (1%), and native plant communities (8%).
- Respondents were also generally unfamiliar with the practices (Table 2). Over half of respondents had never heard of rain gardens (51%), 53% had never heard of native plant communities, and 65% had never heard of pervious pavement. Rain barrels appear to be more familiar overall: only 12% had never heard of them and 55% were somewhat familiar with them.
- Most respondents are also not interested in requesting technical assistance for rain gardens n=119 (50%), rain barrels n=204 (56%), pervious pavement n=82 (56%), and native plan communities n=110 (56%). However, a small percentage plan to request technical assistance for rain gardens (7%), rain barrels (4%), and native plant communities (7%). No one planned to ask for technical assistance for pervious pavement (0%).

Table 2: 2016 survey respondents' familiarity with rain gardens, rain barrels, and pervious pavement

How familiar are you with…	Rain Gardens (n=248)	Rain Barrels (n=245)	Pervious Pavement (n=243)	Native Plant Communities (n=240)
Never heard of them	51%	12%	65%	53%
Somewhat familiar with them/it	40%	55%	24%	33%
Know how to install one/use it but have not/are not using it	6%	19%	9%	7%
Owned one, haven't installed or no longer use it	n/a	6%	n/a	n/a
Have installed one/use one/it on my property	3%	8%	1%	8%

Survey respondents were asked to indicate their level of agreements with statements regarding Wabash River, which the statements were selected from the social indicator surveys in 2006 and 2009. The following section reports the significant difference[1] from 2006 to 2016.

- In 2016, respondents were more likely to value the importance of the river as compared with 2006 and 2009 (1=not a problem; 2=slight problem; 3=moderate problem; 4=severe problem).
  - *The Wabash River is important to me.***
    2006 mean = 4.0; 78% agree or strongly agree (n=344)
    2016 mean = 4.2; 83% agree or strongly agree (n=237)
  - *The Wabash River is a symbol of the region.*****
    2009 mean = 4.2; 83% agree or strongly agree (n=287)
    2016 mean = 4.4; 92% agree or strongly agree (n=239)
  - *I like having a river in town.*****
    2009 mean = 4.1; 82% agree or strongly agree (n=292)
    2016 mean = 4.3; 88% agree or strongly agree (n=239)
- In 2016, respondents were also more likely to agree that individuals should take a role in protecting the Wabash River as compared with 2009.
  - *I don't need to get involved because other people are taking care of the problems with the Wabash.***
    2009 mean = 2.6; 42% disagree or strongly disagree (n=277)
    2016 mean = 2.5; 51% disagree or strongly disagree (n=227)
  - *It is important for community members to take an active role in determining the future of the Wabash.***
    2009 mean = 4.0; 78% agree or strongly agree (n=292)
    2016 mean = 4.2; 83% agree or strongly agree (n=234)
- In 2016, respondents were also more likely to agree that funding to fix and revitalize the Wabash River is important, and the River has the potential to improve, as compared with 2009.
  - *Local funding to revitalize the Wabash is a great investment in our future.****
    2009 mean = 4.1; 69% agree or strongly agree (n=288)
    2016 mean = 4.2; 78% agree or strongly agree (n=232)
  - *The Wabash is too big of a mess to fix without federal money.****
    2009 mean = 3.1; 29% disagree or strongly disagree (n=258)
    2016 mean = 2.8; 38% disagree or strongly disagree (n=191)
  - *There is potential to make the Wabash a more accessible place for recreation.***
    2009 mean = 3.9; 84% agree or strongly agree (n=284)

[1] "Significant differences" indicate that differences are statistically significant (meaning that they are unlikely to have occurred by chance) at the p<.10 level (**=p<.05; ***=p<.01; ****=p<.001). For questions with a "don't know" response option, significance is calculated without accounting for such responses.

2016 mean = 4.1; 88% agree or strongly agree (n=229)

  - *Improvements to the riverfront have helped bring people back to downtown.*****
    2009 mean = 3.4; 47% agree or strongly agree (n=258)

    2016 mean = 3.8; 62% agree or strongly agree (n=213)

- However, respondents were less likely to recreate along the Wabash in 2016 as compared with 2009.
  - *I like outdoor activities, but I don't recreate along the Wabash.* ****
    2009 mean = 3.5; 58% agree or strongly agree (n=289)

    2016 mean = 3.8; 69% agree or strongly agree (n=235)

Task 2: Understanding Permanence of Urban BMPs

The NRSS lab conducted 16 in-person interviews in April 2017, to understand the specific motivation and constraint of adopting and maintaining the urban BMPs. Interview questions asked about how they learned about the urban BMP, their motivation for adoption, their adoption and maintenance concerns, their experience with other practices, who they talked to about the practice, and their sense of community. The participants included potential adopters of urban BMPs who requested technical assistance from WREC, adopters who discontinued their practice based on the initial practice assessment inventory, and residents who answered they saw practices anywhere in the 2016 Wabash Survey. Interview audio transcribing is in process. Intercept interviews with church members, employees and passersby of locations with BMPs are scheduled between June and July 2017, for the purpose to examine the influence of public sites urban BMPs on their diffusion among neighborhoods.

Task 3: Quantifying penetration

In 2016, the Natural Resource Social Science (NRSS) Lab at Purdue University collaborating with the Wabash River Enhancement Corporation (WREC) designed an on-site assessment sheet with criteria for evaluating the level of maintenance of bioretention practices. Targeted bioretention practices include bioswales and rain gardens installed in public sites and residential properties. The evaluation aims to examine the practice by its condition in surface erosion, mulch layer intact, weed growth, bare ground due to plant loss, trash accumulation, grass clippings and standing water, and the presence of informational signage. It is also required to record the number of days since last rain event and the type of weed presence in the evaluation sheet. Each practice receives a total score by adding up the score for each described criteria.

165 bioretentions were successfully assessed between August and September in 2016:

- 68 were rain gardens, 97 were bioswales.
- 125 were installed in non-residential sites, 40 were in residential properties.
- 70% of the practices were installed between 2013 and 2014.
- 15% of the practices had presence of soil erosion, 40% absence of mulch layer, 32% presence of bare ground, 35% presence of trash, 1% presence of grass clipping, 1% presence of standing water, and 30% presence of an information signage in the yard.
- The score range for the 165 practices was from 12 to 43, the average score was 37.46.

- There is no difference in average evaluation score between people who had a sign and people who did not, between practices installed in residential areas and non-residential areas, and between rain gardens and bioswales.

Objective 3: Development of watershed management planning strategies for achieving urban water quality goals.

WREC and partners developed education and outreach programs to engage the public in the implementation of stormwater management projects. One of the most integral aspects of these efforts is the inclusion of a diverse group of individuals throughout the community integrated into all facets of conservation—project siting, design, implementation, maintenance, and education. Peel and Payne (2016) performed an evaluation of stakeholder engagement in stormwater management and other environmental practices within the region and identified the following targeted efforts needed needed to increase urban stormwater BMP implementation in the Greater Lafayette area:

- Improved access to the necessary equipment and contractors that can assist with urban conservation practice installation.
- Increase awareness of installed practices and individuals that installed the practice. Installed urban BMPs will be promoted via weekly social media posts, installer's experience with urban BMPs will be promoted with monthly blog posts and highlighted in monthly newsletters, and additional opportunities for individual landowners to host tours and events to promote their urban BMP will be identified.
- Education event participants already feel an affinity for the Wabash River. This affinity needs to be cultivated and opportunities to convert Detrash the Wabash, Wabash Sampling Blitz, Wabash Riverfest and other volunteers into urban BMP adopters will be identified, prioritized and implemented. Research indicates that individuals that volunteer are interested in the Wabash River and its water quality, thus should be candidates for urban BMP adoption.
- More than 50% of individuals that take advantage of individual technical assistance opportunities implement an urban BMP. Promotion of and access to individual one-on-one conservation-based technical assistance.
- Strategically promote the use of rain barrels to gardeners and those that are interested in reducing the cost of water spent watering flowers and vegetables.
- Continue general promotion of rain barrels, native plants and trees as low cost options for increasing property values, improving water quality, and reducing negative impacts on the Wabash River. Specifically, unique uses for these practices, proof that they provide a water quality benefit, identification of ways that all properties support these types of practices.
- Promote the economic benefits of installing urban BMPs through social and traditional media as economic motivators such as water costs and property values are the highest motivators for early adopters.

References:

Ahiablame, L., B. Engel, and I. Chaubey (2012) *Representation and evaluation of low impact development practices with L-THIA-LID: An example for site planning. Environment and Pollution*, 1(2). Doi:10.5539/ep.v1n2p1.

Major Conclusions and Significance:

Our work to date has resulted in the following major conclusions:

- According to Hoover et al. (2017), the paired watershed approach has the potential to 1) increase the ability to detect statistically significant change, and 2) reduce the effect of weather variation on the ability to observe differences. The minimum detectable difference analysis shows that in many cases even though the paired watershed approaches requires double the number of analyses per sampling event, the overall number of analyses needed to detect change may still be less, and the sampling period reduced.
- The long term educational and outreach efforts through WREC appear to being having a positive effect on attitudes towards the Wabash River in the community, as evidenced by the comparison between survey questions in 2016 and 2006 indicating a statistically significant increase in positive attitudes regarding the importance of the Wabash River, interest in protecting the river and funding to fix the river.
- Gao et al. (2016) found that the major motivation for maintenance of rain barrels is the use of water for gardening. Users of signage were also more likely to maintain their rain barrels.

Publications:

Bowling, L., Turco, R., Hoover, F., Peel, S. (2016). *Region of the Great Bend of the Wabash River Water Quality Summary Report*. Wabash River Enhancement Corporation. Available at:http://static1.1.sqspcdn.com/static/f/319113/27408873/1484172558920/IDEM+Water+Quality+Summary_Final20161208.pdf

Gao, Y., Church, S. P., & Prokopy, L. S. (2016). *2016 Great Bend of the Wabash River Watershed Urban Resident Survey Executive Summary Report*. West Lafayette: Purdue University.

Gao, Y., Babin, N., Turner, A. J., Hoffa, C. R., Peel, S., & Prokopy, L. S. (2016). *Understanding Urban-Suburban Adoption and Maintenance of Rain Barrels*. Landscape and Urban Planning, 153, 99-110.

Gao, Y. (2016). *Understanding urban-suburban adoption and maintenance of rain barrels.* Oral presentation delivered at the IWRA annual conference, June 8-10, 2016, Angola, Indiana.

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Hoover, F-A, Bowling, L.C., Turco, R., Peel, S. Rahman, S. (2016). *Paired versus Single Site Catchment Analysis for Elliot Ditch and Little Wea Creek in Lafayette, IN*. Oral presentation delivered at the IWRA annual conference, June 8-10, 2016, Angola, Indiana.

Peel, S. and L. Payne (2016). *Engaging Stakeholders in Small Projects for Big Impacts in the Wabash River Watershed*. StormCon Conference 16th Annual Conference Proceedings.

Grant Submissions: None

Students:

Three PhD level graduate students are working in this project. Yuling Gao (PhD candidate, FNR) is working on the stakeholder interviews and assessment of attitudes, beliefs and other factors influencing the decision to implement and maintain best management practices in urban environments. Fushcia Hoover (PhD candidate, ABE) is working on the statistical analysis of water quality data and forecasting of the number of BMPs needed to show change. Sanoar Rahman (PhD candidate, ABE) is working on calculation of load reduction due to BMPs using the Long-Term Hydrologic Impact Assessment-Low Impact Development (LTHIA-LID) model.

Current Reduction Status Regional Tracker (CrsTracker)

Basic Information

Title:	Current Reduction Status Regional Tracker (CrsTracker)
Project Number:	2015IN401S
USGS Grant Number:	
Sponsoring Agency:	U.S. Army Corps of Engineers
Start Date:	6/1/2015
End Date:	5/31/2016
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Bernard Engel

Publications

1. None
2. None
3. None

Indiana Water Resources Research Center Project Report

Report 2016 Program Report Format

USGS Special Projects

Title: Current Reduction Status Regional Tracker (CrsTracker)
Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: (Great Lakes Watershed in parts of MN, WI, MI, IL, IN, OH)

Focus Categories: Water Quality and Nutrients

Keywords: STEPL, BMP, Phosphorous, Nitrogen

Principal Investigators:

Bernie Engel, Head and Professor;

Yaoze Liu, Postdoctoral Research Scientist;

Larry Theller, Geographic Systems Analyst;

Purdue University Department of Agricultural and Biological Engineering

Abstract / Summary

The objective of this project is to create a web-based tool, CrsTracker, that will allow users to evaluate the impacts of four best management practices (BMPs) which are installed, or proposed for installation, in multi-scale watersheds across the Great Lakes region. The goal of the impact analysis is to gain an understanding of the cumulative effects of these varied BMPs in the region. The CrsTracker ranking tool would tally total BMP acres and estimate impact (cumulative load reduction) of these specific classes of BMPs in reducing nitrogen, phosphorous, and sediment.

The CrsTracker tool will feed data into the STEPL model (Spreadsheet Tool for Estimating Pollutant Loads) engine, providing a "current standings" output which users can either quickly view or download to use as prepopulated parameters for their own detailed scenario modeling.

Problem:

There is a lack of an overall mechanism to estimate the pollution reduction produced by the many varied BMPs which have been installed or that are considered for installation by various NGO and governmental units around the Great Lakes since GLRI began. The Corps of Engineers could greatly benefit from a single catalog where various BMPs, either proposed or constructed, can be entered and tracked.

Research Objectives:

The ultimate goal of this tool is to provide information to allow the presentation of an "reduction status current standing" for each watershed, without requiring a dedicated analysis run by a specific user. The design would support tracking BMPs installed by particular groups to allow "crowd-sourcing" or addition of BMPs by the various groups and agencies responsible for them.

To facilitate the process, several new BMPs will be added to STEPL engine, which produces the pollution reduction estimates. Understanding the pollution reduction value of these new practices requires significant research, which will be done as part of this proposal.

The project team is working with Corps of Engineers personnel to expand the list of BMPs included in the STEPL tool. The BMPs to be added include:

1) the conversion of farmland to habitat with some wetlands
2) the restoration of degraded wetlands
3) enhancement of degraded wetlands
4) restoration of riparian habitat

For the new BMPs, pollutant reduction coefficients were developed for each practice based on scientific literature and expert opinion.

Methodology:

The research team adapted core technologies which are implemented in a current Purdue online model: Purdue STEPL Web. The CrsTracker tool uses the analysis module from STEPL to summarize the impacts of the proposed or installed BMPs. Data flows between the browser and the software engine using state-of-the-art REST services. This design, repurposing current software systems, allowed a rapid prototyping and development sequence for the tool. The design includes a public facing map-based interface. Stakeholders are able to monitor the current state of impacts by clicking on the map. To upload BMP implementation data, stakeholders will be able to click on the map or open a spreadsheet and indicate a new BMP.

The Purdue STEPL Web model is a web-enabled version of the STEPL spreadsheet tool. The original spreadsheet was created by EPA as a set of Excel macros and enhanced several times. This version has several adaptations by Purdue researchers, such as connection to an online database of precipitation, and enhancements to optimize selection of BMPs to attain water quality goals. STEPL uses two simple approaches to calculate nutrient and sediment loads from different land uses: USLE and SCS Curve Number (CN) method. As does the original, it calculates annual load reductions resulting from various BMPs. The algorithm uses precipitation, landuse, and soil data to compute surface runoff volume, nutrient loads, and sediment delivery. The nutrients include nitrogen and phosphorous. Sources considered include cropland, pastureland, farm animals, feedlots, urban runoff, and septic systems. This project created a software engine from the model's core and formated a website to feed parameters into the engine.

Management practices influence the computation through application of nutrient reduction efficiencies per BMP per applicable area for the list of supported practices. The list of current BMPs were extended to include additional practices of interest to the Corps of Engineers as described above.

Results: Project Research Still in progress

Major Conclusions and Significance: Project Research Still in progress

Publications: Project Research Still in progress

Grant Submissions: none yet

Students: postdoctoral associate Yaoze Liu

Floodplain restoration and nutrient retention in the Wabash River Basin

Basic Information

Title:	Floodplain restoration and nutrient retention in the Wabash River Basin
Project Number:	2016IN392B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	IN-004
Research Category:	Not Applicable
Focus Category:	Floods, Hydrology, Nutrients
Descriptors:	None
Principal Investigators:	Sara Kristen McMillan, Venkatesh Merwade

Publication

1. None

Indiana Water Resources Research Center Project Report

Report 2016 Program Report Format

Project Id: 2016IN392B

Title: Floodplain restoration and nutrient retention in the Wabash River Basin

Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: IN-004

Focus Categories: Floods, Hydrology, Nutrients, Water Quality

Keywords: Yellow Floodplains, nutrients, water quality, restoration, nitrogen, phosphorus

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Abstract / Summary

Excess nitrogen and phosphorus in receiving waters is associated with high nutrient inputs in watersheds that are intensively managed for agriculture. The majority of export occurs during high flows that mobilize dissolved nitrogen and phosphorus as well as sediment and associated pollutants. In undeveloped watersheds, floodplains intercept this flood pulse creating optimal conditions for sedimentation, increasing contact between nutrient-rich waters and biologically active soils, and filtering dissolved nutrients and other pollutants from groundwater. Reducing conditions that develop during inundation promote nitrogen removal via denitrification but can cause release of phosphorus from sorption sites that are maintained under oxic conditions. Quantifying the relative contributions of these opposing processes on water quality is critically needed for successful restoration design and implementation.

Through an integrated modeling and monitoring approach we are identifying the functional relationships that exist between sources and sinks of nutrients (e.g., denitrification, phosphorus release) and hydrodynamic and biogeochemical drivers using the Wabash-Tippecanoe River confluence as a model system. We have developed a 2-dimensional hydrodynamic model of the system and have begun seasonal measurement of nitrogen and phosphorus transformations in floodplain sediments. Preliminary modeling results highlight the potential for water storage in the floodplains that flood multiple days each year on average. While soil characteristics varied laterally with increased carbon and more bioavailable carbon nearest the river, these patterns were not observed in denitrification. Instead, denitrification rates were similar across the floodplain and higher in the spring ($p=0.0066$) than in the winter likely reflecting temperature control of biological activity. Future efforts are focused on continued seasonal measurement of nutrient biogeochemistry, development of hydrodynamic metrics that quantify river-floodplain connectivity, and integration of nutrient loading, retention and hydrologic connectivity through a statistical modeling approach. This will allow us to scale results temporally and spatially to estimate the net impact of floodplain processes on nutrient retention across the Wabash-Tippecanoe River confluence and the Wabash River Basin. Collectively, this will build the foundation for an integrated and interdisciplinary analysis of the complex environmental controls on nutrient retention in river-floodplain ecosystems.

Problem

Floodplains are responsive to flood pulsing and hydrologic connectivity with the channel (Junk et al., 1989; Tockner et al., 1999). Although floodplains occupy a small fraction of the total landscape, they retain a disproportionate amount of nutrients and sediment (Mayer et al., 2007; Noe and Hupp, 2009). During high flow events, riverine water overtops the channel banks and is hydrologically connected to the surrounding floodplain. The flowpath widens causing velocities to slow and retention times to increase, both of which are critical to sediment and nutrient trapping. Restoration of these functions through breaching of levees to re-establish natural flood pulsing is a management strategy that shows great promise. In fact, nearly 30,000 acres of riverine floodplains have been restored in the Wabash River Basin by the NRCS. A literature review of nutrient retention in floodplains of large rivers suggests that as much as 600 lb/acre may be retained annually (Dee et al., 2014). However, the primary controls on N and P transformations in floodplains remain poorly understood during flooding events in the complex, tile-drained landscape of the Midwestern U.S.

Spatial variation in sedimentation rates in floodplains is controlled by multiple variables including river discharge, channel morphology, duration of inundation, and lateral proximity to the stream sediment source (Steiger and Gurnell, 2002). Similarly, rates of nutrient transformation depend on lateral and longitudinal gradients in floodplains, with higher rates found in areas with greater organic matter, nutrient content and wetness (Noe et al., 2013). Flood duration is often linked to increased sedimentation and nutrient trapping (Noe and Hupp, 2005). However, much is still unknown about how fine-scale (e.g., topography, vegetation, groundwater flow) and large-scale (e.g., channel morphology, elevation) impact flow velocities. We expect those areas that are inundated more frequently to deposit greater amounts of sediment and associated nutrients. High water tables in these areas will also contribute to reducing conditions in the subsurface that enhance rates of nitrate removal via denitrification. However, these same flooded conditions can cause release of attached phosphorus. Additionally, during periods of intense flooding, solutes and sediment previously deposited on in these near-stream floodplains can be resuspended and transported downstream. Coupling these processes with a detailed hydrodynamic model to determine the extent and duration of flooding will allow us to link these processes at a larger scale and provide information to water quality managers regarding restoration of floodplains in the Wabash River Basin and throughout the agricultural Midwest.

Research Objectives

Our long-term goal is to develop a robust predictive tool to quantify river-floodplain connectivity and its impact on sediment and nutrient retention using the Wabash-Tippecanoe River confluence as a model system. This project is the start of that effort to by quantifying the extent and duration of inundation following storm-driven water and nutrient pulses with the biogeochemical processes that either retain or remove N and P. Specifically, we are (1) quantifying flooding hydrodynamics (e.g., frequency, extent and velocity) using a modeling approach, (2) measuring key ecosystem processes driving loading, transformation, and retention of N and P in floodplain sediments seasonally, and (3) scaling these results temporally and spatially to estimate the net impact of floodplain processes on N and P retention at the Wabash-Tippecanoe River confluence.

Methodology:

The Wabash-Tippecanoe River confluence at Prophetstown State Park includes restored prairies and floodplain wetlands on the western side of the Tippecanoe and Wabash Rivers. These floodplains were formerly used for agricultural production. Both sites become inundated multiple times each year on average and have relatively shallow subsurface aquifers. At each floodplain site, we established a network of 15 transects from river edge to the hillslope to capture variability in floodplain connectivity and soil type (Figure 1). Sedimentation markers have been placed at each tile to monitor deposition of alluvial sediments during inundation.

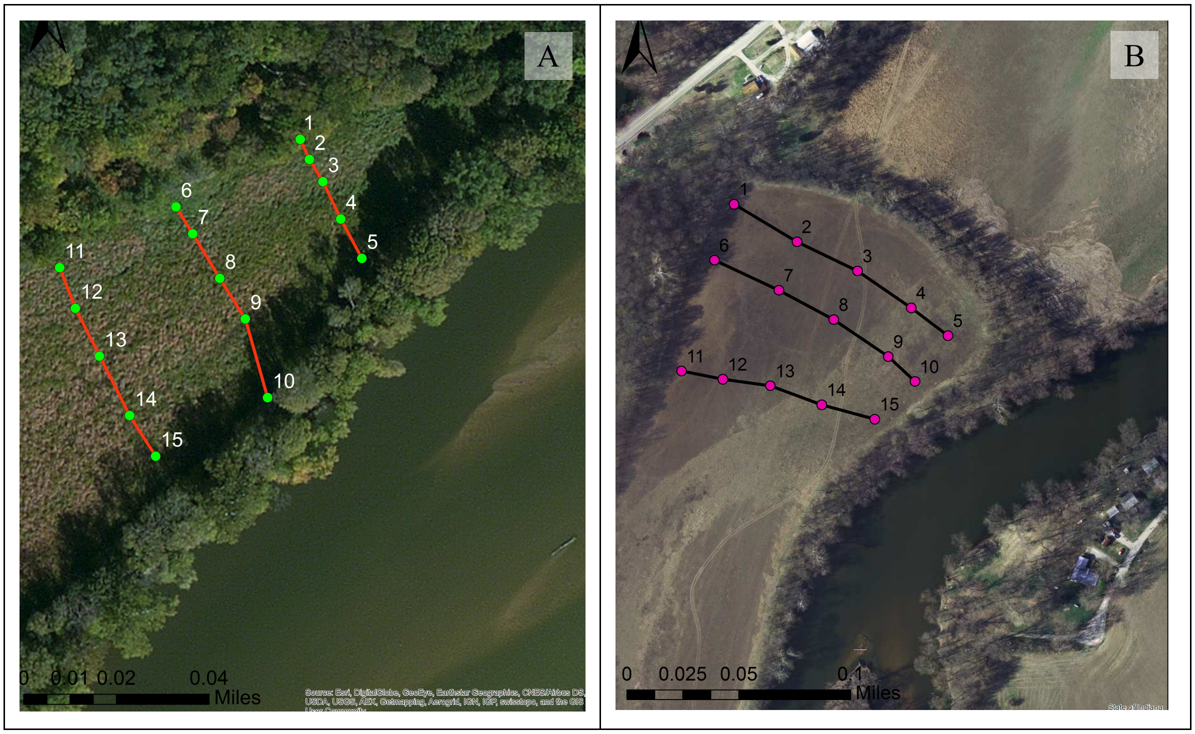


Figure 1: Floodplain transects at (A) Wabash River and (B) Tippecanoe River.

Through previous funding from INWRRC, USGS and Purdue, we developed a 1D steady-state HEC-RAS model of the Wabash-Tippecanoe confluence. This model is based on high-resolution bathymetry data for the river reaches and LIDAR data for the floodplain. We have used these data along with publicly available stream gauge and land use data to develop a flood prediction model using the Integrated Channel and Pond Routing (ICPR) model. This model is unique in that it is able to simulate surface and subsurface flow dynamics. While the ICPR model is being developed, we are using the ID HEC-RAS model to quantify spatial flooding extents based on expected storm return intervals.

We are currently measuring nutrient transformations seasonally at 9 locations in each of the floodplain sites (i.e., river edge (R) = 5,10,15; mid-floodplain (M) = 3,8,13; hill slope edge (HS) = 1,6,11). We collected intact sediment cores to a depth of 20 cm to measure net N and P flux in the laboratory under inundated conditions. Nutrient data are currently being analyzed and will be reported in the final report later this year. To quantify denitrification, we are using two methods: (1) acetylene block bottle assays which allow rapid measurement at multiple locations and is a method that has been used extensively over the past 30 years (Groffman et al. 2006) and (2) sacrificial bottle assays using membrane inlet mass spectrometry (MIMS) which provides a more precise estimate of in situ denitrification and respiration (Reisinger et al. 2016). Because the MIMS method is new and has not been applied in floodplain sediments, we are using both approaches to compare results and validate the new approach. We had unforeseen method development issues which limited our ability to make these measurements during the fall. As a result, we have a full set of both measurements in January 2017 (winter) and Spring 2017 (spring).

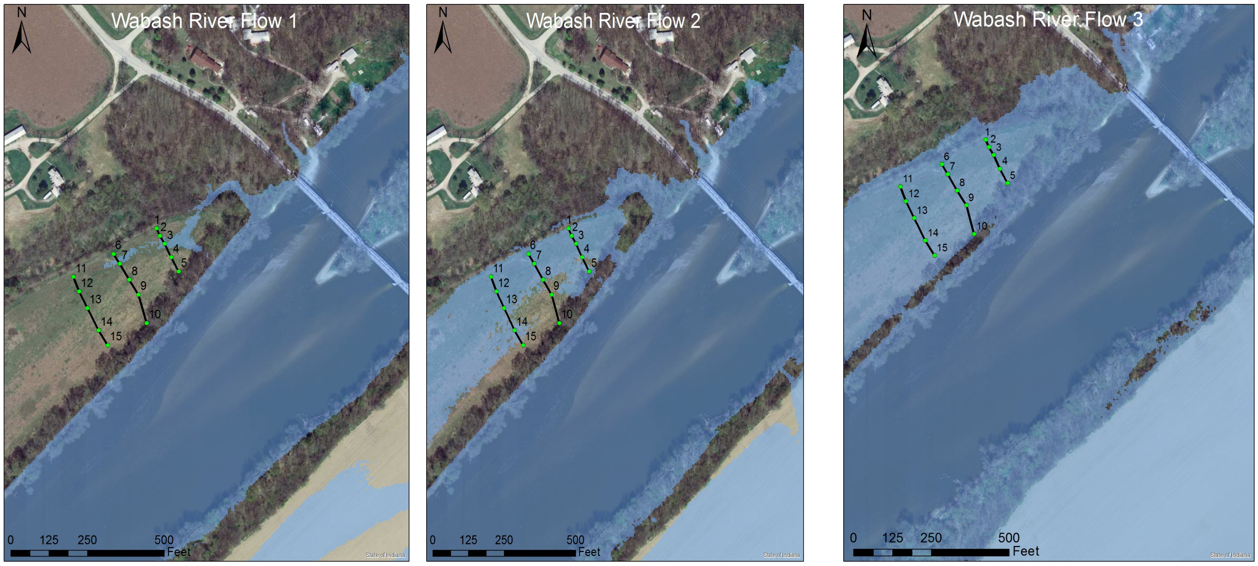
We are currently using the ICPR model to quantify the magnitude and direction of water velocities within the river and the floodplain, which is critical to understanding the potential for settling and resuspension of particles and attached pollutants. We will synthesize hydrodynamic modeling results into a series of metrics that quantify river-floodplain connectivity, such as time inundated, proportion of floodplain area inundated, variance in temporal and spatial connectivity, and surface water velocity at each floodplain biogeochemistry measurement location. We will then develop a time series of connectivity (e.g., water depth and velocity) across each of the floodplain sites, focusing initially on the transect locations. This will allow us to relate flooding hydrodynamics with the effects of topography, vegetation and sub-surface flows, but more importantly with fluxes of N, P and sediment. We recognize that 1 year of flux data is insufficient to develop a robust statistical model of nutrient loading and retention and have applied for additional funding to continue. However, we will use our data and values from the literature to develop an initial model that we can refine as more measurements are made.

Results

Hydrodynamics:

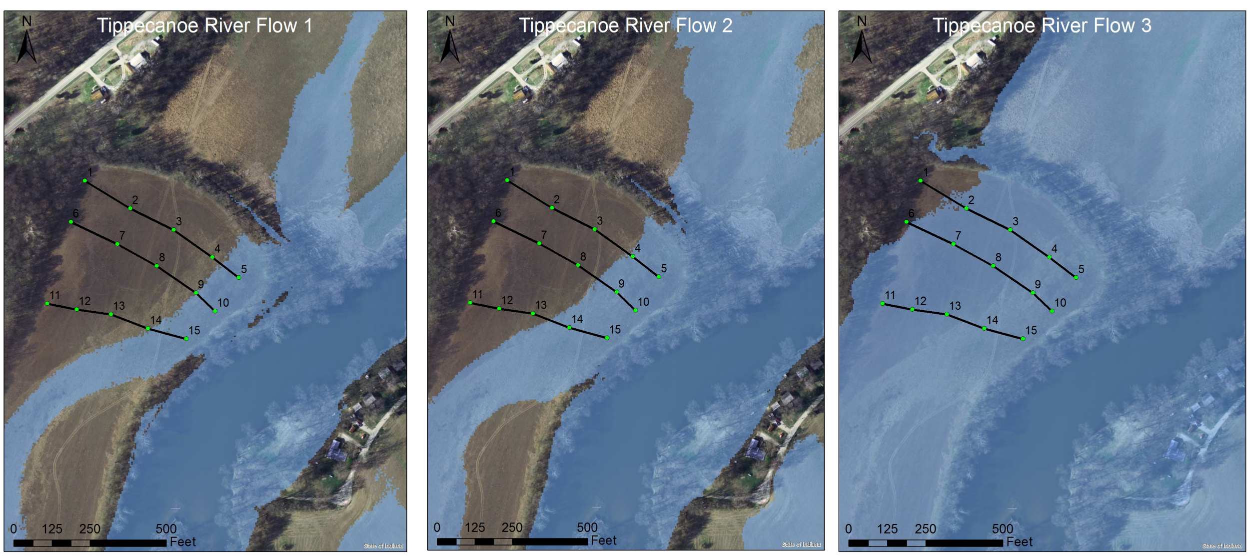
We analyzed flow records to produce a frequency distribution of daily flows throughout the year. These percentiles were calculated using the daily flows and show that for an average of 10% of the year (36 days) at least part of the floodplain is inundated for both locations and that nearly the entire floodplain is inundated 2% (7 days) of the year (Figure 2). Of note, is the relic channel on the Tippecanoe River that experiences more frequent and longer duration flooding.

Wabash River



Inundation at 90th percentile of daily flow | Inundation at 95th percentile of daily flow | Inundation at 98th percentile of daily flow

Tippecanoe River



Inundation at 90th percentile of daily flow | Inundation at 95th percentile of daily flow | Inundation at 99.8th percentile of daily flow

Figure 2. Flood extent and inundation at different flow percentiles at monitoring stations at Wabash and Tippecanoe sites.

Preliminary results from the IPCR model highlight the improvement in flood prediction accuracy using integrated models and high-resolution bathymetric data (Figure 3). Compared to results from the 1D model, these allow for finer scale resolution of stage dynamics. Fine topographic changes have been shown to be important controls on nutrient biogeochemistry (Wolf et al. 2013) and we plan to use both models to develop the most widely applicable and representative statistical model linking connectivity metrics with nutrient retention.

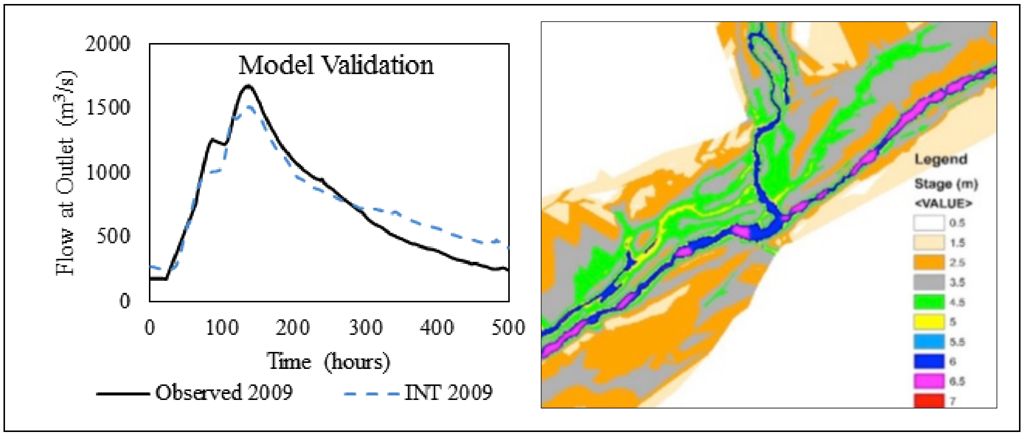


Figure 3: ICPR model validation and fine-scale resolution of water depth

Nutrient retention:

Preliminary data show distinct differences in soil characteristics laterally and between the sites. We collected sediment samples at all 15 locations at each site (Figure 1). These data revealed significant differences in C:N ratios which is an indicator of carbon quality (Figure 4). We observed more bioavailable carbon at the Tippecanoe River compared to the Wabash River (C:N 12.8 ± 0.95 versus 16.1 ± 0.82, p<0.0001). Additionally, C:N ratios increased laterally with the sites closest to the river having lower ratios. Comparison of total organic matter content (%) also showed significantly higher values at sites that are more frequently flooded near the river edge (R=10.02 ± 2.46, M=7.31 ± 0.80, HS = 7.43 ± 0.91; p=0.0005). Soil properties are an aggregate of multiple factors at the local and watershed scale, including flood frequency, vegetation, land use history and other sediment sources from the watershed. We

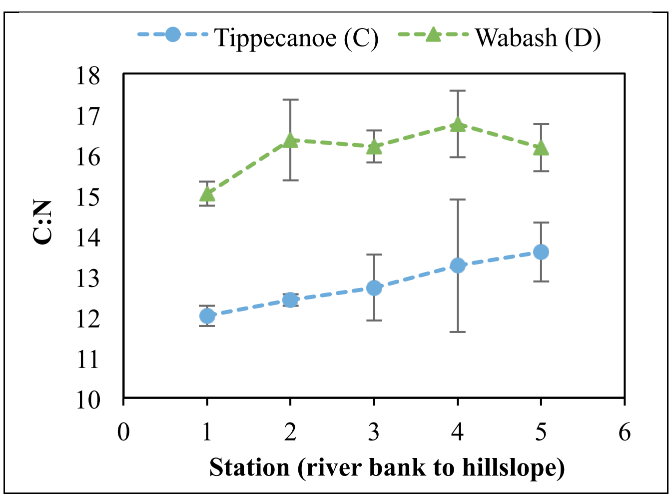


Figure 4: Carbon:nitrogen ratios at restored floodplains sites on Tippecanoe and Wabash Rivers. Error bars are one standard deviation, n=3 per station.

hypothesized that these differences would also affect trapping and processing of riverine nutrients and sediment. While loading data are still be analyzed, we did not observe similar patterns based on landscape position in denitrification rates determined using the acetylene block method (Figure 5). Rates were more variable and higher in the spring (p=0.0066) than in the winter likely reflecting temperature control of biological activity. We are currently investigating factors driving this variability including sediment carbon, water column nutrients, and hydrologic connectivity metrics.

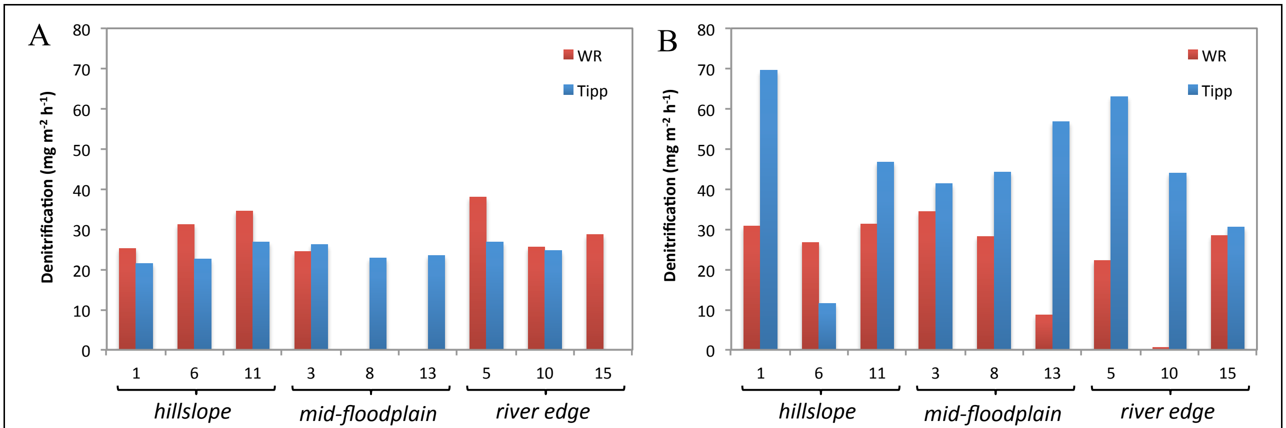


Figure 5: Denitrification rates as measured using acetelyne block bottle assays in the (A) winter and (B) spring of 2017 in the WR (Wabash River) and Tipp (Tippecanoe River) floodplains.

Major Conclusions and Significance

Impacts of this research are far-reaching as Indiana invests in activities to reduce nutrient loads from agricultural lands. Phosphorus export from Indiana's portion of the Lake Erie Basin contributed to the harmful algal blooms in Lake Erie that left more than 400,000 people in Toledo without drinking water in 2014 (Smith et al., 2015), and N and P from Indiana agricultural land contributes to hypoxia in the Gulf of Mexico (Rabalais, 2001). To address these concerns, Indiana has developed a Nutrient Reduction Strategy (ISDA, 2016) to reduce nutrient runoff by encouraging voluntary, incentive-based conservation practices. Great potential exists for floodplain restoration to significantly reduce nutrient loads and programs such as the Wetland Reserve Enhancement Partnership provide a mechanism for the National Resource Conservation Service to leverage resources to initiate restoration of high priority wetlands to improve water quality and wildlife habitat. However, characterization and prediction of the environmental factors driving successful restoration is needed to find optimal locations that achieve the greatest impact per dollar invested. This work will provide a needed synthesis of the impacts of floodplain reconnection on the net retention of nitrogen and phosphorus.

As floodplains intercept high riverine discharges, retention time increases and opportunities for biological and physical processes occur. However, reducing conditions created during flooding can have contrasting results, including retention of sediment and particulate bound phosphorus, removal of soluble nitrate via denitrification, and release of soluble reactive phosphorus. Preliminary results show that denitrification is indeed enhanced in these systems and changes as expected with seasonality. Phosphorus flux data are still pending analysis and will be compared to nitrogen results to determine if predicted patterns of N retention and P release occur. We will then link these biogeochemical measurements to metrics of hydrologic connectivity. While 2016 was a dry year with little flooding, 2017 has already provided multiple opportunities for flooding and assessment of the effectiveness of restoration at in Wabash-Tippecanoe River system.

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Publications

McMillan, S.K. Ecosystem restoration: Does restoring structure lead to function? Curriculum for the Environment and Ecology Seminar, University of North Carolina, Chapel Hill, NC. April 2017.

McMillan, S.K., V. Merwade, G. Noe. Nitrogen and phosphorus flux in restored riverine floodplains in agricultural watersheds. Indiana Water Resources Association Annual Meeting. Marshall, IN. June 2017

McMillan, S.K., V. Merwade, G. Noe. Nitrogen and phosphorus flux in restored riverine floodplains in intensively managed watersheds. Society of Wetland Sciences Annual Meeting. San Juan, PR. June 2017

Saksena, S., V. Merwade and P. Singhofen. Evaluating the impact of temporal and spatial scale variability on floodplain storage in the Upper Wabash River basin, 2016 AWRA Spring Specialty Conference on GIS and Water Resources, Sacramento, CA, July 2016.

Saksena, S. and V. Merwade. Evaluating the impact of spatial and temporal rainfall variability on river-floodplain hydrodynamics, Abstract H24B-05 presented at the 2016 Fall Meeting, AGU, San Francisco, CA Dec. 2016.

Grant Submissions

This project has allowed us to collect data and further refine our research questions. We have submitted proposals to the USGS and the USDA, both of which were not funded but we received positive feedback and will be re-submitting to the USDA this summer. We also submitted a more theoretical approach to the NSF-CBET in October 2016 which is still pending.

Students

Through this project, we have supported learning and discovery of 2 undergraduate students (Caitlin Nelligan, ABE and Evan Pesut, ABE), 1 MS student (Celena Alford, ABE) and 1 PhD student (Siddarth Saksena, CE).

Pilot investigation of variable contaminant loads in fish as a result of foraging and habitat specialization

Basic Information

Title:	Pilot investigation of variable contaminant loads in fish as a result of foraging and habitat specialization
Project Number:	2016IN393B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	IN-004
Research Category:	Not Applicable
Focus Category:	Ecology, Toxic Substances, None
Descriptors:	None
Principal Investigators:	Tomas Hook, Timothy Malinich

Publication

1. None

Indiana Water Resources Research Center Project Report

Report 2016 Program Report Format

Project Id: 2016IN393B

Title: Pilot investigation of variable contaminant loads in fish as a result of foraging and habitat specialization

Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: IN-004

Focus Categories: Ecology, Toxic Substances

Keywords: Yellow Perch, Mercury, Population Trophic Structuring

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Abstract / Summary

Contaminants such as mercury are typically quantified as measures of central tendency, i.e. averaged across all sampled fish of the same species within the same body of water. More recent studies suggest that individuals within a population do not all exhibit the same feeding and habitat residence patterns, therefore have varying risks to contaminant exposure and accumulation. If popular sport fish such as yellow perch, *Perca flavescens*, or black crappie, *Pomoxis nigromaculatus,* exhibit diet plasticity and specialize for pelagic or benthic habitats, then some groups of fish may pose a greater risk to consumers. Specifically, we hypothesize that diet plasticity and specialization in fish populations could lead to a bi-modal distribution of contaminant loads. Given that different contaminant exposure is likely to manifest through differential foraging strategies and habitat use, we will collect fish of each species within 3 different lakes in Northern Indiana to evaluate potential for relationships between the mercury and PCB loads of individual fish and their diet/habitat specialization. Understanding this relationship and the level of variation of contaminant loads within individual lakes could help federal and state agencies make informed decisions on fish consumption advisories.

Problem:

Mercury is a persistent contaminant in Indian's waterways (Management 2014). Mercury may directly impact Indiana residents by accumulating in body tissues through consumption of fish species such as catfish, yellow perch and black crappie. Accumulation of mercury through diet can increase risk of several debilitating diseases, brain damage and kidney damage. Elucidation of the extent of variability of contaminant loads within populations of fish can help us appreciate the risk to Indiana's recreational angling community.

Research Objectives:

Our objectives are to first: Determine the extent of diet specialization of two generalist species, yellow perch & black crappie, through examination of within-population variation of stable isotopes $\delta^{13}C$, $\delta^{15}N$) and morphology. Second, using the metrics gathered, determine if they may be used to identify fish with significant differences in mercury contamination.

Methodology:

Our project began in the Spring of 2016 with a collaboration with the Indiana Department of Natural Resources (IDNR). Fish samples were collected from 8 different lakes as part of annual collections by the IDNR (April-July). We focused our study on at least 3 lakes for each species based on collections of fish between 145-295 mm total length (to minimize size discrepancies), and previous data on mercury contamination courtesy of the Indiana Department of Environmental Management (personal communication). Our lakes included Back Water, Sylvan, and Lake Wawasee for yellow perch (n=96 fish total); Jimmerson, Skinner, Back Water, Wawasee, and Sylvan Lake for black crappie (n=146 fish total). All fish were transported to Purdue University and stored within -20 C freezers until removed for sample processing. Following the field sampling periods, we returned to lakes during August to characterize the physical environment by examining benthic, littoral and pelagic food availability. Benthic and littoral food sources were collected using a series of Ponar grabs. Pelagic food sources, zooplankton, were sampled using several horizontal zooplankton net tows.

Preparation of fish samples occurred within a few weeks of collections. Fish were measured for total length, weighed, sexed, and imaged for morphometric analysis. Diet contents will be analyzed using methods described in Roswell et al. (2013). Dorsal muscle tissue was removed from each fish and frozen in -20 (mercury samples) and -80 freezers (stable isotopes). Muscle tissue for $\delta^{13}C$ and $\delta^{15}N$ isotope analysis was dried and pulverized with mortar and pestle for sample preparation. The stable isotopes are ideal for analyzing an individual's long-term diet habits since $\delta^{13}C$ and $\delta^{15}N$ isotopes are incorporated from diet sources. All isotope samples were sent to Cornell's Stable Isotope Laboratory for analysis. Statistical analysis will examine fish within each lake and compare their trophic indicators ($\delta^{13}C$, $\delta^{15}N$) with measured total mercury. Mercury contamination was examined through a collaboration within Purdue University with the Santerre Lab in the Department of Nutrition Science. Mercury samples were tested in duplicate using a thermal decomposition (gold) amalgamation atomic absorption spectrophotometer direct mercury analyzer (DMA-80, Milestone Inc., Sheldon, CT) with a solid mercury standard (Tort-3). Fish samples were tested in duplicate.

Results

Preliminary results (n=26) of mercury analysis, suggests that yellow perch within and between lakes vary greatly in mercury concentration (min=27.29ug/kg, mean=71.08 ug/kg, max=152.05 ug/kg). Black crappie (n=46) also showed large differences among fish in mercury concentration (min=17.21 ug/kg, mean=101.51 ug/kg, max=403.58 ug/kg).

Major Conclusions and Significance

Mercury has been a persistent contaminant and danger to human health in both Indiana and the greater Great Lakes region. Recent studies in 2017 have noted an increase in mercury found in fish from the Great Lakes basin (Matheny 2017). Currently, contaminants such as mercury are often examined using measures of central tendency. These measures may not reflect within population differences that are commonly observed in the foraging habits of fish, such as yellow perch. At the conclusion of this study, we will have examined how populations of black crappie and yellow perch may display divergent intra-population contaminant loads due to differing trophic feeding behaviors. This study will act as a pilot examination of applying ecological views of diverse feeding and habitats of fish as mediating contaminant loads. In our study, we focus on concentrations of mercury, but our work may extend to other contaminants such as PCBs. Through our work we aim to improve understanding of the ecology of contaminant risk for recreational fish such as yellow perch and black crappie can better inform federal and state agencies on setting catch and consumption limits

Publications

None as of yet.

Grant Submissions: None

Students

Undergraduates-Two undergraduate technicians were employed and trained in scientific methods and procedures.

Masters- No Masters students were funded by this grant.

PhD-One PhD student (Malinich) will be using research funded by this grant as an important chapter in his doctoral dissertation.

PostDoc-One PostDoc (Feiner) is using the dataset to examine within population diet-metrics to understand within population variance, which may have implications for fisheries management and research beyond contaminant loading.

References

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Roswell, C.R., Pothoven, S. a., and Höök, T.O. 2013. Spatio-temporal, ontogenetic and interindividual variation of age-0 diets in a population of yellow perch. Ecol. Freshw. Fish **22**: 479–493. doi: 10.1111/eff.12041.

Water and nutrient recovery from aquaculture effluents through vegetable production

Basic Information

Title:	Water and nutrient recovery from aquaculture effluents through vegetable production
Project Number:	2016IN394B
Start Date:	3/1/2016
End Date:	2/28/2017
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Congressional District:	IN-004
Research Category:	Not Applicable
Focus Category:	Agriculture, Conservation, Irrigation
Descriptors:	None
Principal Investigators:	Hye-Ji Kim, Paul Brown, Cary Mitchell, Robert Rode

Publications

1. Yang, T. and H.J. Kim. 2016. Effect of Plant Species on Waste Water Recycle in Aquaponics. American Society for Horticultural Science, Atlanta, GA. August 7-11, 2016 (poster presentation).
2. Yang, T. and H.J. Kim. 2016. Comparison of Tomato Production between Aquaponics and Hydroponics. American Society for Horticultural Science, Atlanta, GA. August 7-11, 2016 (poster presentation).
3. Yang, T. and H.J. Kim. 2016. Effect of plant species on nitrogen and phosphorus recovery from aquaculture effluents. HLA Research Retreat. Four Points. May 9, 2016 (poster presentation).
4. Yang, T. and H.J. Kim. 2016. Conservation of aquaculture wastewater and nutrients through vegetable crop production. Agroenviron 2016: 10th International Symposium on Agriculture and the Environment. May 23-27, 2016 (poster presentation).
5. Wongkiew, S., B.N. Popp, H.J. Kim, and S.K. Khanal. 201X. Fate of nitrogen in floating-raft aquaponic systems using natural abundance nitrogen isotope. International Biodeterioration & Biodegradation (Under review)
6. Kim. H.J. and Yang, T. 2017. tentative title: N and P use efficiency of an aquaponics system (in preparation)
7. Yang, T. and H.J. Kim. 201X. tentative title: Comparison of aquaponics and hydroponics on the production of tomato, basil and lettuce (in preparation)

Indiana Water Resources Research Center Project Report

Report 2016 Program Report Format

Project Id: 2016IN394B

Title: Water and nutrient recovery from aquaculture effluents through vegetable production

Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: IN-004

Focus Categories: AG, COV, IG, NC, NU, WW, WS, WU

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Abstract / Summary

As an integrated food production system that links aquaculture with hydroponic crop production in a recirculating ecosystem, aquaponics holds great promise for helping to ameliorate agricultural challenges through efficient use of resources for crop production. It recycles more than 90% of its water, and dramatically reducing discharge of nitrogen (N)- and phosphorus (P)-rich wastewater to the environment. Improving N and P use efficiency through proper management practices is particularly important for better performance of an aquaponics system. Our objectives are to critically explore utilizing aquaculture wastewaters as sustainable water and mineral nutrient sources for food crop production and to develop stratgies to enhance resource use efficiency and crop productivity while minimizing environmental impacts. We have quantified N and P removal and recovery of vegetable crops with different morphological characteristics by evaluating their N and P use efficiency (conversion efficiency of environmental pollutants into valuable nutrient resources for biomass production), and investigated the efficiency of an aquaponic system in comparison to hydroponic system. We found that vegetable crops have different abilities to remove nutrients from aquaponic effluent (i.e. the highest degree of uptake in tomato) and that plants' shoot characteristics and/or their root characteristics are associated with their ability to effectively uptake these nutrients from aquaponic effluent, resulting in variations in water and nutrient use efficiencies of aquaponics systems. N and P use efficiency was higher in tomato, followed by basil and lettuce, and was 3 to 5 fold higher in aquaponics compared to hydroponics. Growth and performance of other vegetable crops was also evaluated in aquaponics and hydroponics, and differed greatly by the type of vegetable and production system. Variations in mineral nutrient content were also observed in the tissues of vegetable crops. N and P use efficiency of these vegetables will be determined. We are currently examining N and P distributions in the aquaponics system. Our critical mass-balance studies will allow better management and optimization of an aquaponics system, and help aid in developing guidelines for commercial aquaponic operation and management.

Problem:

The world's population continues to rise and is expected to increase to reach approximately 9.1 billion people by 2050 (United Nations, 2009). The population increase will occur mainly in developing countries, particularly in association with rapid urbanization, with about 70 percent of the world's population expected to live in cities or urban areas (FAO, 2014). Food demand increases as populations increase, and dietary patterns are shifting toward animal-based foods, imposing considerable pressure on agricultural resources (Fukase and Martin, 2014). In order to feed this rapidly growing, more urbanized population, global food-production systems must be adaptively managed to increase food production by 3 to 4 percent yearly, while providing safe, nutritious food to meet to dietary needs. Humans obtain the great majority of their nutrients from crops and livestock, and these nutrient sources require water, land, and energy for production (Pimentel et al. 2004). However, food supplies (cereal grains) per capita have declined by 17% over the past 20 years, due in part to an increase in human population but concurrent shortages of fresh water and cropland as well (FAO, 2014). Adding to the escalating costs of energy and resources, climate change, elevated carbon dioxide levels, and the growing incidence of extreme climatic *events* will pose major risks for long-term food security.

Further, current production of horticultural crops in the United States depends heavily on water-constrained areas. California is responsible for the production of more than half of the vegetables consumed in the U.S., as well as a large fraction of the export market for fresh vegetables (USDA-NASS, 2015). Considering the major environmental challenges that world agriculture will face in the coming decades, significant improvements to food-production systems are essential to meet the demands of the growing population by dramatically increasing agricultural productivity while using scarce natural resources more efficiently.

Global aquaculture production has expanded at an average annual rate of 6.2% during 2000-2012, with world aquaculture production of 66.7 million tons in 2012, outpacing world population growth rate of 1.6%. Aquaculture provides 50% of all fish consumed worldwide and is estimated to account for 62% of the world's fish supply for human consumption by 2030 (FAO, 2014). Indiana's aquaculture industry has grown rapidly in the past 5 years, and estimated sales account for more than $15 million in 2012, increased from a farm sales value of $3.5 million in 2006 (USDA-NASS, 2006). Aquaculture growth in Indiana is strongly sustained by the state's proximity to major markets and availability of the necessary production resources, including water and feed (Broughton and Quagrainie, 2013), and offers tremendous opportunities for growth of the economy by supporting related industries.

However, many aquaculture systems generate considerable amounts of wastewater containing compounds such as nitrogen (N), phosphorus (P), and suspended solids (Cripps et al, 2000), and therefore, the large-scale application of aquaculture is restricted by land and water utilization as well as by environmental concerns (Islam, 2005). In order to reduce pollutant loadings nationwide, the US Environmental Protection Agency (US EPA), has developed new effluent management standards for private and public aquaculture operations, which meet specific criteria (US EPA, 2004). If water supply and wastewater disposal issues are not addressed in a timely manner, they will become a major impediment to the growth and expansion of aquaculture industries. The further expansion of aquaculture now depends on the development and application of new technologies (Al-Hafedh et al., 2008), and it is imperative to develop efficient systems to intensify fish cultivation while maximizing water and nutrient reuse, and minimizing environmental impacts.

Aquaponics is an integrated system that links aquaculture with hydroponic production in a recirculating ecosystem by converting aquaculture wastewater into plant nutrients (Tyson et al., 2011). Aquaponic systems recycle more than 98% of their water (Al-Hafedh et al., 2008) and dramatically reduce discharge of nutrient-rich wastewater to the environment, with greater potential for profitability by simultaneously producing two cash crops. Since this is a soilless culture, many of the disease issues associated with conventional soil-based farming are not a concern. Although it is in its infancy, aquaponic food production has enormous potential to be the most efficient and space-saving method of farming, and to become the next green revolution to provide sustainable solutions for the nexus across water, energy, land and food.

The addition of feed is the main source of nutrient input and indirect production of pollutants in aquaculture-generated wastewaters. Approximately about 25% of the nitrogen input is converted into fish biomass, and over 70% is excreted into the aqueous phase in the form of total ammonia nitrogen (TAN; NH_3 and NH_4^+) (Hargreaves, 1998).

Nitrifying bacteria in aquaponic systems oxidize ammonium (NH_4^+) to nitrite (NO_2^-) and further convert it into nitrate (NO_3^-). Plants uptake NO_3^- and NH_4^+ to produce biomass as nitrogen is required in the highest amounts by plants, and NO_3^- is typically the preferred form of nitrogen (Marschner, 2012). Since fish feed is one of the most significant costs in operating an aquaponic system (Broughton and Quagrainie, 2013) and the release of nutrient-rich wastewater effluents can lead to eutrophication and other environmental concerns, *it is essential to effectively remove N and P from aquaculture wastewater effluents through crop production and to improve nitrogen and phosphorus use efficiency within the system.* Most plants have the capability of absorbing and assimilating both nitrate and ammonium ions; but the physiological responses to these ions can vary greatly among plant species (Kraiser et al., 2011). Although the effects of nitrogen form on plant growth have been demonstrated in other production systems, information on *nutrient flows through the continuum of feed, nutrients in aquaculture wastewater, and plant yield in aquaponic systems is lacking.* Different plant species display different shoot and root morphological and physiological characteristics, and therefore, some vegetables with higher growth rate of edible parts, and/or enhanced root characteristics may more effectively recover N and P from wastewater effluents for biomass production, while significantly reducing the release of these elements into the environment.

Research Objectives:

The ***specific objectives*** of the proposed research are to:

Objective 1: Investigate N and P removal and recovery from fish wastewater as affected by vegetable production.
Objective 2: Evaluate N and P use efficiency of vegetable crops from wastewater effluents.
Objective 3: Optimize mass balance of N and P in aquaponics through proper combinations of aquatic animals and plant species.

Methodology:

We have conducted a comparative study on the productivity of vegetable crops grown in hydroponics and aquaponics at a stocking density of 20-25kg Tilapia/m^3. Seeds will be germinated in a soilless medium, and seedlings will be transplanted to a grow bed at their optimum planting density. To elucidate N and P distribution in an aquaponic system, water samples from the aquaculture tank, biofilter system and grow bed will be taken every other day, and the concentrations of TAN, and NO_2^-, and NO_3^- as well as P will be determined using a DR3900 Spectrophotometer (HACH). The dissolved oxygen (DO), pH, temperature, and electrical conductivity (EC) of waters in fish tank and grow bed will be measured *in situ* daily using the portable water quality lab kits (HQ40d, HACH) throughout the production periods and were maintained within acceptable levels for all test crops. In the hydroponics arm of the study, crops were grown in a deep-water culture system within which electrical conductivity (EC) was maintained at 1.5-1.8dS/cm using commercial fertilizers, while, in the aquaponics arm, fish were fed commercial fish feed recommended for tilapia-based aquaponics systems (1% of fish weight daily) if not stated otherwise. The measured water temperature averaged at 20°C in the hydroponic system and 26°C in the aquaponic system.

Objective 1: This study was conducted to evaluate the role of plant species in N and P removal and recovery from wastewater effluents in an aquaponic system. Three model crops, lettuce, basil, and tomato, were chosen in this study for their differences in edible parts as well as morphological and physiological functions. The crops were separately grown in tilapia-based aquaponics and compared with the ones in hydroponics controls. Water quality parameters were monitored as stated above, and plant growth parameters (plant fresh weight, height, leaf number and length, and fresh weight) were recorded weekly. At harvest, the growth parameters were measured again, and plant tissues were separately harvested and processed for nutrient analysis. Water was sampled throughout production period for nutrient analysis using an ion chromatography.

Objective 2: We have compared the growth and yield of 10 vegetable crops (pac choi, mizuna, mustard, amaranth, bekana, Swiss chard, chia, basil, lettuce, and tomato) grown in aquaponics in comparison with hydroponics. In aquaponics, fish feed (1% of fish weight) was added as a source of fertilizer for plants, while commercial fertilizer was applied in hydroponics to maintain the electrical conductivity (EC) within the suggested range. Water was sampled for total ammonium nitrogen (TAN), nitrite, nitrate, and phosphate every four days. Crop growth parameters were measured weekly, including plant height, leaf length and number, SPAD value, photosynthetic rate (Pn) and leaf temperature. Initial and final fish and vegetable crop biomass was measured.

Objective 3: Fish were fed daily using two different feeding schemes: daily uniform feeding (DUF) and daily increasing feeding (DIF) by 1% fish fresh weight. DUF was designed to provide an initial spike of nutrients in recirculating water to aquaponics crops, while DIF is a common feeding practices for aquaponics. Two feeding schemes provided the same amount of fish feed for each production cycle, but the initial amount of fish feed (60 g and 40 g per day) and a subsequent difference in nutrient accumulation rate (0 g and 5 g increment per day) were the only two variables. A 30-day experiment was repeated three times.

Results

Objective 1&2: The EC of aquaponics increased gradually in all the aquaponics systems, with the highest increase in lettuce, followed by basil and tomato. N was one of the major contributors for such increase in the EC and increased by 3-fold in three months, however, the concentration remained low, ranging from 15 to 40% of hydroponics. Meanwhile, P maintained at the average of 30 ppm without differences among vegetable crops. Low N in aquaponics changed biomass partitioning patterns of all the vegetables, particularly in tomato promoting earlier fruiting.

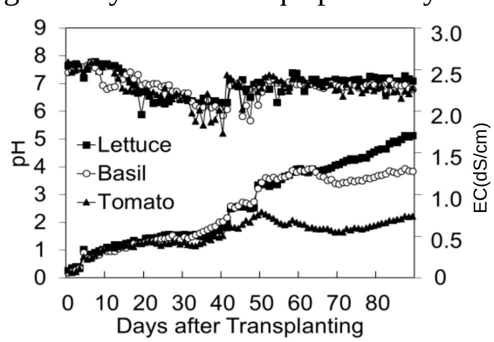

Fig.1. The effects of plant species on electrical conductivity (EC) of aquaponics effluents.

We found that EC continuously increases in aquaponics (Fig. 1), but was lower than in hydroponics throughout the 90 days of production. Growth and performance of vegetable crops differed greatly based the type of vegetable and production system (Fig. 2). Variation in mineral nutrient content was also observed in the vegetables (Fig. 3). In general, tomato preferentially accumulated nutrient elements in leaves and stems, but basil and lettuce either in leaves or roots, depending on the type of nutrients. In general, hydroponically grown vegetable crops had a higher accumulation of mineral nutrients including nitrate (NO_3^-) and nitrite (NO_2^-). However, sodium (Na) and chloride (Cl) content was significantly higher in aquaponic vegetables compared to hydroponic vegetables (in fact, no sodium was observed in the hydroponic vegetables) (Fig. 3). It is important to note that the variation in growth and productivity among vegetables is also representative of differences in growth rate and growth characteristics (data not shown). From this work, we have concluded that vegetable crops have different abilities to remove nutrients from aquaponic effluent (i.e. the highest degree of uptake in tomato) and that plants' shoot characteristics and/or their root characteristics may be associated with their ability to effectively uptake these nutrients from aquaponic effluent, resulting in variations in water and nutrient use efficiencies in aquaponics systems (Table 1). N and P use efficiency was affected by the type of vegetables and was 3 to 5 fold higher in aquaponics compared to hydroponics.

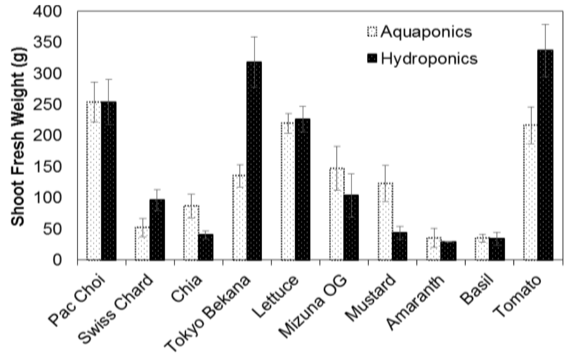

Fig.2. Variation in crop productivity as affected by vegetable species and production system.

EC in aquaponics increased from 0.7 to 1.4 mS·cm^{-1}, while EC in hydroponics was maintained at 1.8 mS·cm^{-1}. Nitrate level in aquaponics increased from 10 to 30 mg/L during 30 days, while it increased from 160 to 250 mg/L in hydroponics. Phosphate concentration in aquaponics increased from 7.2 to 45.2 mg/L, while that in hydroponics slightly increased from 62.4 to 81.9 mg/L. In general, crops in hydroponics showed increasing Pn over time, while in aquaponics, Pn quickly dropped down in the second week, then maintained or further decreased in following weeks, depending on vegetable species. The lower Pn in aquaponics might be partly due to low nutrient availability during the early-production phase. However, there were no significant differences between aquaponics and hydroponics in growth and

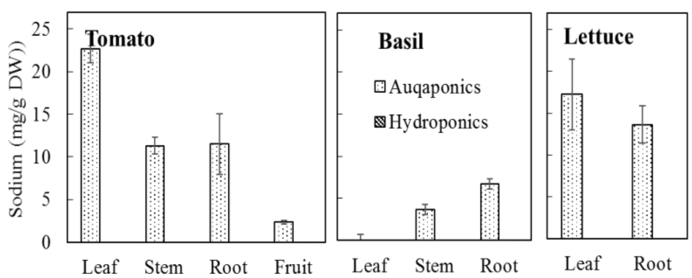

Fig.3. Sodium (Na) content in tissues of vegetable crops grown in hydroponics and aquaponics.

Table 1. Variation in water-, N-, and P-use efficiencies of an aquaponics system as affected by plant species.

	WUE* (g dry weight/L water)	NUE (g dry weight/g N)	PUE (g dry weight/g P)
Lettuce	0.005	0.004	0.014
Basil	0.045	0.032	0.118
Tomato	0.076	0.079	0.293

*WUE: Water-Use Efficiency, NUE: N-Use Efficiency, PUE: P-Use Efficiency yield parameters of most vegetable species.

Objective 3: The electrical conductivity (EC) increased over time in both systems, but there was no significant difference between the systems. Similarly, total ammonium nitrogen (TAN), nitrate, phosphate, pH and dissolved oxygen (DO) were not significantly different between the treatments. Mizuna in DUF showed higher yield than DIF resulting from significant greater leaf length, number, and area. Similarly, cherry tomato in DUF had a significantly higher fruit yield than DIF, while the rest of vegetable species did not show significant difference in fruit yield between DUF and DIF. Vegetable crops in DUF had a significantly higher photosynthetic rate (Pn) than those in DIF, while exhibiting a significant lower transpiration rate (Tr) than its counterpart. Data also showed that DUF resulted in a significant lower water consumption than DIF. The feed conversion ratio (FCR) were not significantly different between DUF and DIF (1.5 ± 0.5 and 2.0 ± 0.6, respectively), which indicates that DUF may potentially lead to a higher nutrient use efficiency for a long-term production.

Major Conclusions and Significance

With a projected world population of 9.7 billion by 2050 and growing scarcity of cropland, water, and fossil-fuel energy, it is an unprecedented challenge to provide sustainable solutions for food security while minimizing the global impacts of food production. With over 70% of people living in cities and urban areas, innovation to the current food-production systems is essential to meet demands of the growing urban population by dramatically increasing agricultural productivity while using scarce natural resources and land more efficiently.
One potential solution for these challenges is aquaponic crop production in urban or peri-urban areas close to local markets. Aquaponics holds great promise for helping to ameliorate today's food and agricultural challenges through efficient use of resources (reduced water and nutrient inputs and outputs, reduced energy for fertilizer production and reduced carbon-footprints) for simultaneous production of vegetables and animal protein.

Based on our studies, we concluded:

- Resource use efficiency of an aquaponics system can be further improved by selecting proper crops which produce higher biomass with the limited resources.
- Despite the limited nutrient availability in aquaponics, the growth and yield of aquaponically-grown vegetables were not significantly different from hydroponically-grown ones. Crop productivity may be enhanced by increasing nutrition availability during early-production phase in aquaponics.
- Nutrient management practice plays an important role in growth performance of vegetables and fish in aquaponics production and it is critical to optimize the best nutrient management strategy for better performance of an aquaponics system.

Publications

Papers

1. **Kim. H.J.** and Yang, T. 2017. tentative title: N and P use efficiency of an aquaponics system (in preparation)
2. Yang, T. and **H.J. Kim.** 201X. tentative title: Comparison of aquaponics and hydroponics on the production of tomato, basil and lettuce (in preparation)
3. Wongkiew, S., B.N. Popp, **H.J. Kim**, and S.K. Khanal. 201X. Fate of nitrogen in floating-raft aquaponic systems using natural abundance nitrogen isotope (submitted to International Biodeterioration & Biodegradation)

Abstracts

1. **Kim, H.J.** and T. Yang. 2017. Effects of plant species on nitrogen and phosphorus removal in aquaponic system. Aquaculture America 2017 Abstracts, p. XX. San Antonio TX.
2. **Kim, H.J.** and T. Yang. 2017. Growth and yield comparison of lettuce, basil, and tomato grown in aquaponics and hydroponics systems. Aquaculture America 2017 Abstracts, p. XX. San Antonio TX.
3. **Kim, H.J.** 2016. Aquaponics: the next generation farming system. HortScience 51(9):S75.
4. Yang, T. and **H.J. Kim.** 2016. Effects of plant species on nitrogen and phosphorus removal in aquaponic system. HortScience 51(9):S388.
5. Yang, T. and **H.J. Kim.** 2016. Growth and yield comparison of lettuce, basil, and tomato grown in aquaponics and hydroponics systems. HortScience 51(9):S388.

Presentations

1. •**Kim, H.J.** and T. Yang. 2017. Effects of plant species on nitrogen and phosphorus removal in aquaponic system. Aquaculture America 2017 Abstracts, p. XX. San Antonio TX. February 21, 2107(oral presentation).
2. •**Kim, H.J.** and T. Yang. 2017. Growth and yield comparison of vegetables grown in aquaponics and hydroponics systems. Aquaculture America 2017. San Antonio TX. February 21, 2107(oral presentation).
3. •Yang, T. and **H.J. Kim.** 2016. Effect of Plant Species on Waste Water Recycle in Aquaponics. American Society for Horticultural Science, Atlanta, GA. August 7-11, 2016 (poster presentation).
4. •Yang, T. and **H.J. Kim.** 2016. Comparison of Tomato Production between Aquaponics and Hydroponics. American Society for Horticultural Science, Atlanta, GA. August 7-11, 2016 (poster presentation).
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6. •Yang, T. and **H.J. Kim.** 2016. Conservation of aquaculture wastewater and nutrients through vegetable crop production. Agroenviron 2016: 10th International Symposium on Agriculture and the Environment. May 23-27, 2016 (poster presentation).

Grant Submissions

<u>External Grants Submitted (Full-proposals)</u>

- **Kim, H.J. (PD),** P.B. Brown, C. Mitchell, K. Quagrainie, R. Rode, H. Oliver, C. Hartleb, N. Mattson, M. Timmons, K. Fitzsimmons and C. Shultz. Strategic Planning Aquaponics Conference for Specialty Crops (2017-2018). Amount requested: $50,000. USDA-NIFA SCRI Research and Extension Planning Project, Strategic Planning. (pending)
- **Kim, H.J. (PI),** P.B. Brown, C. Mitchell, and L. Hoagland (5/12017-4/30/2020) Nitrogen and Phosphorus Cycling and Transformations in Aquaponics Systems. Amount requested: $330,000. Submitted to National Science Foundation. (not funded)
- Brown, P. and **H.J. Kim (Co-PI).** (1/1/2017-12/31/2019). Water efficient food production systems for Egypt and U.S. Amount requested: $ 199,753.11. Submitted to the U.S.-Egypt Science and Technology Joint Fund. (pending)
- **Kim, H.J. (PI)** (5/1/2017-4/30/2019). Water and nutrient recovery from aquaculture wastwater through aquaponic crop production. Amount requested: 2,000,000 Japanese Yen, ($ 19,276). Submitted to the Toyota Foundation, Japan. (not funded)
- **Kim, H.J. (PI),** P.B. Brown, and C. Mitchell, (2017-2020) Nitrogen and Phosphorus Cycling and Transformations in Aquaponics System. Amount requested: $499,965.56. Submitted to USDA AFRI. (not funded)
- Brown, P., S. Nof., C. Mitchell., D. Vincent, L. Liu., **H.J. Kim (Co-PI),** L. Hoagland., and V. Aggarwal (9/1/2016-8/31/2019). INFEWS/T1 Smart Food: decreasing the energy demand in water, conserving food production systems Sponsor Announcement: Innovations at the Nexus of Food, Energy and Water Systems (INFEWS). Amount requested: $2,380.441.38. Submitted to National Science Foundation. (not funded)
- **Kim, H.J. (PI)**, P.B. Brown, C. Mitchell, and R. Rode (2016-2019). Effective control of nitrogen and phosphorus from aquaculture effluents through vegetable production. Amount requested: $246,939.26. Submitted to U.S. Geological Survey. (not awarded; *mainly due to a significant typo-error made by one reviewer who gave 'Outstanding' rating but mistakenly gave 0 out of 25 points for Scientific Merit along with a positive comment "*This project will expand fundamental knowledge on nutrient needs and recommendations.") (not funded)

<u>External Grants Submitted (Pre-proposals)</u>

- **Kim, H.J. (PD),** P.B. Brown, C. Mitchell, K. Quagrainie, R. Rode, H. Oliver, C. Hartleb, N. Mattson, M. Timmons, K. Fitzsimmons and C. Shultz. Strategic Planning Aquaponics Conference for Specialty Crops (2017-2018). Preproposal-Submitted to USDA-NIFA SCRI Research and Extension Planning Project, Strategic Planning (invited to submit a full proposal).
- **Kim, H.J. (PI)**, P.B. Brown, C. Mitchell, R. Rode, and Jeffrey Frey (2017-2020). Effective water and nutrient removal and recovery system for food crop production. **USGS 104g National Competitive Grants,** IWWC, Purdue University (not invited)
- **Kim, H.J. (PI)**. Innovation in resource efficiency through aquaponics crop production (2017-2020). Preproposal Limited Submission Competition for Foundation for Food and Agriculture Research (FFAR), Submitted to EVPRP, Purdue University (due to eligibility requirements, I was not selected as Purdue's nominee;

EVPRP wrote me "The committee did like your proposal, but due to *your tenure track experience at UH, you was not selected as one of Purdue's nominee."*)

- **Kim, H.J. (PI),** C. Mitchell, P. Brown, B. Rode, K. Quagrainie and P. Langenhoven (2017-2020) Open-loop aquaponics systems for North Central Region farmers: low maintenance and high profitability. NCR-SARE. (not invited)
- Brown, P.B., **H.J. Kim (co-PI)**, V. Aggarwal, J. Tidwell, G. Ledford, M. Timmons, S. Wang, F. Conte, A. Chapman (2017-2020). Green Revolution 2.0 producing more food with less water. Foundation for Food and Agriculture Research. FFAR. (not invited)Aggarwal, V., P.B. Brown, **H.J. Kim (co-PI)**, C.A. Mitchell and S.Y. Nof. (2017-2019). Enhancing efficiency of future food production through optimization of energy, water, and nutrients. The Discovery Park Big Idea Challenge. Purdue University. ($571,197) (not invited)
- Brown, P.B. and **H.J. Kim (co-PI).** (2017-2018). Preproposal-Submitted to Soy Aquaculture Alliance (SAA). Soy-based feeds for integrated, multi-taxa aquaponics systems- developing the initial feeds for sustainable food production in the 21st century. (not invited)

Students

Undergraduate: 5

Masters: 0

PhD student: 1

PostDoc:0

Visiting scholar: 2

Predicting toxic cyanobacteria blooms in the Wabash River Watershed

Basic Information

Title:	Predicting toxic cyanobacteria blooms in the Wabash River Watershed
Project Number:	2016IN395B
Start Date:	3/1/2016
End Date:	2/28/2017
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Congressional District:	IN-006
Research Category:	Not Applicable
Focus Category:	Ecology, Management and Planning, Models
Descriptors:	None
Principal Investigators:	Allison R Rober, Kevin H Wyatt

Publication

1. Walls, J.T., K.H. Wyatt, J.C. Doll, E.M. Rubenstein, and A.R. Rober. In review. Hot and Toxic: Temperature regulates toxin release by cyanobacteria. Aquatic Microbial Ecology.

Indiana Water Resources Research Center Project Report

Report 2016 Program Report Format

Project Id: 2016IN395B

Title: Predicting toxic cyanobacteria blooms in the Wabash River Watershed

Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: IN-006

Focus Categories: Ecology, Management and Planning, Models

Keywords: cyanobacteria, harmful algal bloom, human health, microcystin, temperature, toxin, freshwater

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Abstract / Summary

In an effort to better understand environmental controls on toxin release in eutrophic freshwater ecosystems, this study assessed the effect of temperature on the release of microcystin by toxin-producing cyanobacteria. During this study, toxin producing cyanobacteria were grown at temperatures ranging from 5-30°C (5°C increments) in the laboratory to determine if there was a temperature threshold for toxin release. Laboratory experiments were coupled with a field survey of temporal variation in water temperature, cyanobacteria abundance, and toxin concentrations. Temperature ranged from 3-27°C and cyanobacteria biomass increased with warming up to 18°C, but declined rapidly with further increases in temperature. Extracellular microcystin concentration was coupled with changes in water temperature and was most elevated between 20-25°C, concurrent with the decline in cyanobacteria biomass. A similar trend was observed in laboratory incubations where productivity-specific microcystin release was greater (up to 4-fold) between 20-25°C compared to release rates between 3-19°C. However, productivity-specific microcystin release declined rapidly at 30°C. Generalized linear mixed modeling was used to evaluate the strength of water temperature as a predictor of cyanobacteria abundance and microcystin release, and determined that warming ≥ 20°C would result in an increase in microcystin release. These results show a temperature threshold for toxin release, which demonstrates a potential to use water temperature to forecast bloom severity.

Problem:

Understanding the effects of temperature on the production of harmful algae and the release of cyanotoxins is necessary because of the increasing prevalence of harmful algal blooms in freshwater ecosystems and their influence on water quality and human health. This issue is particularly important in eutrophic ecosystems which are more likely to develop toxin-producing cyanobacteria blooms, but have been shown to vary in toxicity. Furthermore, increasing surface water temperatures from ongoing climate change are anticipated to increase the frequency and duration of toxin-producing algal blooms.

Research Objectives:

The overall goal of the research was to better understand environmental controls on toxin release in an effort to develop a model to predict toxin production during harmful algal blooms in eutrophic freshwater ecosystems. The research addressed three objectives which were guided by the hypotheses that temperature regulates cyanobacteria production and warming promotes the release of cyanotoxins during photosynthesis:

- Objective 1: Conduct a year-round field survey to establish relationships between the presence and abundance of toxin-producing cyanobacteria and temperature.
- Objective 2: Perform controlled experiments to examine temperature controls on microcystin release by toxin-producing cyanobacteria.
- Objective 3: Link the field survey and laboratory incubation experiments to develop a model to predict toxin production during harmful algal blooms.

Methodology:

Field Survey: Sampling was conducted monthly except for bi-monthly sampling in Mar, Apr, May, and Nov to capture changes in water temperature. Samples were collected from 1m plankton tows using random stratified sampling for estimates of cyanobacteria biomass, community composition, toxin concentration, and nutrient concentration. Chlorophyll a was estimated from a subsample filtered onto a glass fiber filter (0.7 µm Whatman GF/F), extracted with 90% ethanol, and measured with a spectrophotometer at 665 and 750 nm after acidification to correct for phaeopigments (APHA 1998). Dry mass was determined from a second subsample after drying in pre-weighed aluminum pans at 65°C for 48hr. Algal taxonomic composition was estimated by counting and identifying algae to genus and algal abundance was quantified as cells/L of water. Chemical and physical data were collected concurrently with biological samples for analysis of soluble reactive phosphorus (SRP), total phosphorus (TP), dissolved inorganic nitrogen (DIN), and total nitrogen (TN). Samples for nutrient analysis were collected from 5 cm below the water surface with a syringe-driven filter unit and filtered through a 0.45 µm filter into a 20 mL acid-rinsed polyethylene bottle. Samples were analyzed using a Dionex ion chromatograph (Dionex Corporation, Sunnyvale, CA, USA). Temperature, dissolved oxygen, turbidity, pH, and conductivity were measured using Hydrolab multi-probes. A sample of water was collected at each site for measures of total microcystin-LR toxin concentration using an enzyme-linked immunosorbent assay (ELISA) test kit (EnviroLogix QuantiPlate Kit for Microcystins, Portland ME, USA). Microcystins were assayed in 96-well plates and the colorimetric response was measured at 450 nm on a microtiter plate reader according to the manufacturer's protocol.

Objective 2 – Temperature controls on toxin release: Controlled experiments were conducted in the laboratory at Ball State University. Toxin-producing cyanobacteria were grown in mesocosms (500mL) containing 400 mL of filtered lake water. Each mesocosm was assigned to 1 of the following experimental treatments (5, 10, 15, 20, 21, 22, 23, 24, 25, and 30°C), with three replicates each. Mesocosms were kept under a 12h light/dark cycle using grow lights and temperature was kept constant by circulating water around each flask using separate recirculating water baths. After four days of growth under experimental conditions, cyanobacteria were transferred to biological oxygen demand (BOD) bottles containing filtered water for estimates of productivity-specific toxin release. Productivity was measured as changes in dissolved oxygen (DO) in light and dark bottles following McCormick et al. (1998). Pre and post DO measurements from light and dark bottles were used to calculate net primary productivity and respiration, respectively. Estimates of primary production will be converted into carbon units based on a C:O molar ratio of 0.375 and a photosynthetic quotient of 1.2 (Wetzel and Likens 2000). Following productivity measures, a subsample was analyzed for total microcystin-LR toxin concentration using ELISA assays as described above. The contents of BOD bottles were transferred into pre-weighed aluminum pans for an estimate of dry mass. Productivity rates were expressed as biomass-specific production which were used to estimate productivity-specific toxin release for each experimental temperature treatment.

Objective 3 – Development of predictive model: A generalized linear mixed model was used with a gamma error distribution to predict microcystin concentration as a function of temperature. A gamma error distribution was selected as only non-negative continuous variables were included in the model. The model included environmental factors as covariates, an interaction term (temperature x chlorophyll *a*) that was treated as a fixed effect, and sampling site was treated as a random effect using the following equation:

$$g(\mu_{ism}) = \alpha + \boldsymbol{\beta X}_{\mathbf{i}} + \lambda * \mathrm{T_i} * \mathrm{Chla_i} + \delta_s$$

where $g(\mu_{ism})$ is the log link function, μ is the measured concentration of microcystin (µg l^{-1}), **β** is a vector of coefficients for the fixed effects, $\mathbf{X_i}$ is a matrix of covariates, λ is the coefficient for the interaction term, T_i is water temperature (°C) of observation i, $Chla_i$ is the amount of chlorophyll *a* measured at observation i, and δ_s is the random effect for site.

To improve the efficiency of estimating coefficients, all covariates were converted to z-scores using the following equation:

$$\text{z-score}(x_{ki}) = \frac{x_{ki} - \mathrm{AVG}(x_k)}{\mathrm{SD}(x_k)}$$

where x_k is covariate *k*, x_{ki} is covariate *k* for observation *i*, AVG(x_k) is the average value of covariate *k*, and SD(x_k) is the sample standard deviation for covariate *k*.

We evaluated all possible combinations of fixed effects and the most parsimonious model was selected using Akaike's Information Criterions corrected for small sample size (AICc). All models that had a change (Δ) in AICc of ≤ 2 were considered equally plausible. Highly correlated predictor variables were never used in the same model during the model-selection process. We used a model averaging technique to reduce all of the most plausible models to one global model used for prediction. The relative strength of each variable was assessed by an importance index. Importance was calculated by summing the AIC weights from all models that included an independent variable as a covariate. If a covariate was included in every model, the importance score would = 1.00 indicating that the influence of the covariate on the relationship between microcystin and temperature was significant 100% of the time. Lower importance scores indicated that covariates were not always strong predictors of microcystin release and were therefore included in fewer models. We used leave-one-out cross validation to evaluate the ability of the top models to predict microcystin concentration. All models that were selected based on a ΔAICc of ≤ 2 were fit using the original dataset with one observation missing and then averaged as above. The model averaged coefficients were then used to predict the missing value. This process was repeated for the original dataset with each observation missing.

To evaluate model fit and predictive ability we calculated the root mean squared error (RMSE). The RMSE is a measure of variability around the predicted regression line similar to standard deviation as a measure of variability around a mean. Thus, approximately 95% of the observed values fell within ±2 RMSE units of the predicted value. The RMSE was calculated using the following equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}}$$

where $\hat{y}_i$ is the predicted value of the *i*th observation, y_i is the observed value of the *i*th observation, and *n* is the total number of observations.

All analyses were conducted using the R statistical programming environment version 3.3.2 (R Core Team 2016). Mixed effects models were fit using the lme4 package version 1.1-12 (Bates et al. 2015), and multimodel inference was conducted using the MuMIn package version 1.15-6 (Barton 2016).

Results

Field survey

Year-round field sampling captured variation in environmental conditions that were used to predict cyanobacteria abundance and toxin levels (Fig. 1). Water temperature ranged from 1.5 ± 0.2 to 27.0 ± 0.4°C during the study. Dissolved nutrient concentrations remained above growth-saturating levels. Temporal variation in cyanobacteria abundance was related to changes in lake water temperature. Cyanobacteria biomass measured as chlorophyll *a* was most elevated when water temperature was 9-19°C (RM-GLM, $p < 0.0001$; Fig. 2a). At water temperatures >19°C, chlorophyll *a* declined nearly 4-fold (RM-GLM, $p < 0.0001$). Algal dry mass followed a similar pattern as chlorophyll *a*, showing a sharp decline at water temperatures >19°C (RM-GLM, $p < 0.0001$; Fig. 2b). Both measures of biomass (chlorophyll *a* and dry mass) recovered from the decline once water temperatures dropped below 19°C (Fig. 2a,b). Cell density (10^6 cells l^{-1}) was most elevated at 24°C (103.5 ± 8.0), but declined nearly six-fold with further increases in water temperature (RM-GLM, $p < 0.0001$; Fig. 2c). Cell density (10^6 cells l^{-1}) was dominated by *P. agardhii* which comprised ≥ 96% of community composition throughout the study (Fig. 2c). A total of 24 other algal genera were identified, but remained < 5% relative abundance. Tissue TN varied more than five-fold, and was unrelated to changes in biomass (Fig. 1). Conversely, algal tissue TP more closely followed changes in biomass.

Microcystin concentration was influenced by both water temperature and cyanobacteria abundance (biomass and cell density), but in opposing directions. Microcystin concentration tracked closely with water temperature throughout our study period and was greatest at temperatures ≥ 20°C and lowest during periods of ice cover when water temperature was at its minimum (Fig. 2a-c). Microcystin concentration was coupled with changes in cyanobacteria abundance at temperatures between 3-19°C (Fig. 2a-c). However, microcystin concentration was inversely related to measures of cyanobacteria abundance at temperatures >19°C, where there was a significant decline in cyanobacteria and a simultaneous two-fold increase in microcystin (RM-GLM, $p = 0.01$; Fig. 2).

The best model to predict microcystin concentration included water temperature, chlorophyll *a*, tissue TP, tissue TN, DOC, and the temperature x chlorophyll *a* interaction term. Based on their magnitude of coefficients and importance values, water temperature, chlorophyll *a*, tissue TP, and temperature x chlorophyll *a* were the strongest predictors of microcystin within the model. There was a significant relationship between microcystin concentration and the temperature x chlorophyll *a* interaction, indicating that the rate of microcystin release, as a function of temperature, increases as chlorophyll *a* decreases (Fig. 3). Specifically, at low temperatures (e.g., 5°C), the model predicted microcystin concentration to be 0.40, 0.46, and 0.54 µg l^{-1} when chlorophyll *a* was 1, 50, and 100 µg l^{-1}, respectively (Fig. 3). In contrast, at temperatures above 20°C, the model predicted microcystin concentration to be 1.26, 0.72, and 0.42 µg l^{-1} when chlorophyll *a* was 1, 50 and 100 µg l^{-1}, respectively (Fig. 3). Predicted microcystin values from the leave-one-out cross-validation (RMSE = 0.28) were within ± 0.56 µg l^{-1} of the observed values and were highest during the warmest months and lowest during the coldest months. Model predictions also indicated that microcystin concentration was expected to increase 36% when tissue TP increased from 100 to 200 µg P g^{-1} algae l^{-1} (estimates calculated with all other covariates held at their average value). However, there was greater uncertainty in estimates at the high range of tissue TP because of limited observations ($n = 5$) above 175 µg P g^{-1} algae l^{-1}. The remaining covariates (tissue TN, SRP, DOC, algal dry mass, specific conductivity, and DO) predicted ≤ 1% change in microcystin concentration.

Laboratory incubation experiment

Water temperature had a significant influence on microcystin release during our laboratory incubation ($F_{10,22}$ = 7.24, p < 0.001; Fig. 4). Mean GPP-specific microcystin release remained at reduced levels and similar among treatments up to 19°C (p ≥ 0.14; Fig. 4). Mean GPP-specific microcystin release increased 3-4-fold at 20°C and remained at elevated levels to 25°C (p ≤ 0.02; Fig. 4). Toxin release declined at 30°C to levels that were not significantly different from 3-19°C temperature treatments (p = 0.15; Fig. 4).

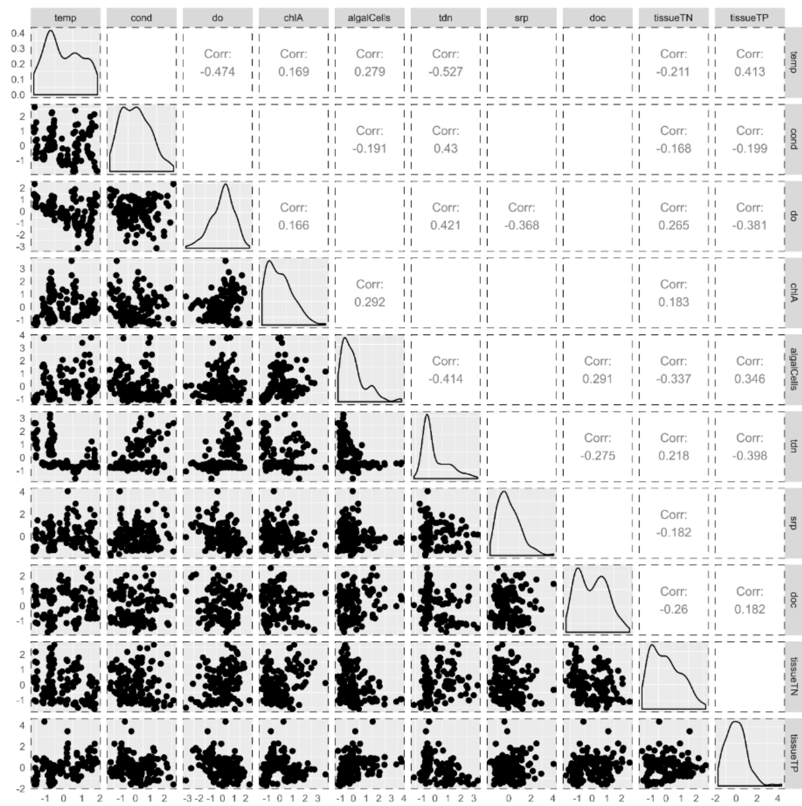

Fig. 1. Correlation matrix of predictor variables used in generalized linear mixed modeling. Only significant Pearson's correlations coefficients are shown. Temp = water temperature, cond = specific conductivity, DO = dissolved oxygen, chlA = Chlorophyll *a*, TDN = water column total dissolved nitrogen, SRP = water column soluble reactive phosphorus, DOC = dissolved organic carbon, tissue TN = tissue total nitrogen, tissue TP = tissue total phosphorus.

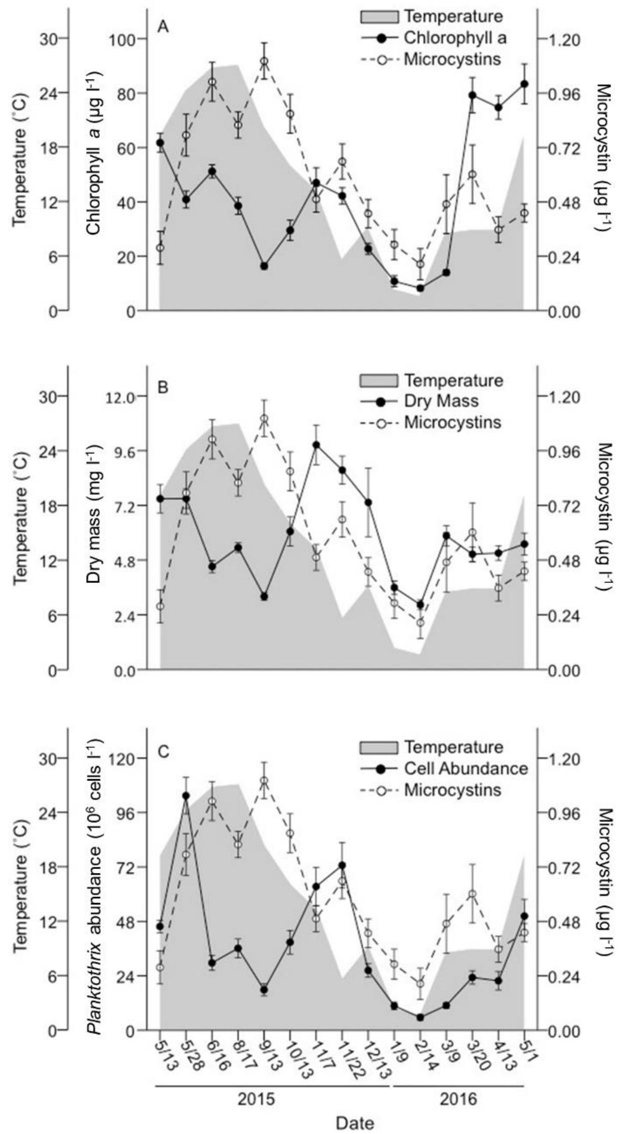

Fig. 2. The relationship between water temperature (°C) (grey shading), microcystin concentration (µg l^{-1}) (dotted lines with open circles), and cyanobacteria abundance (solid lines with closed circles) measured as (A) chlorophyll *a* (µg l^{-1}), (B) dry mass (µg l^{-1}), and (C) *Planktothrix* cell density (10^6 cells l^{-1}) during year-long sampling. Values are mean ±1 SE.

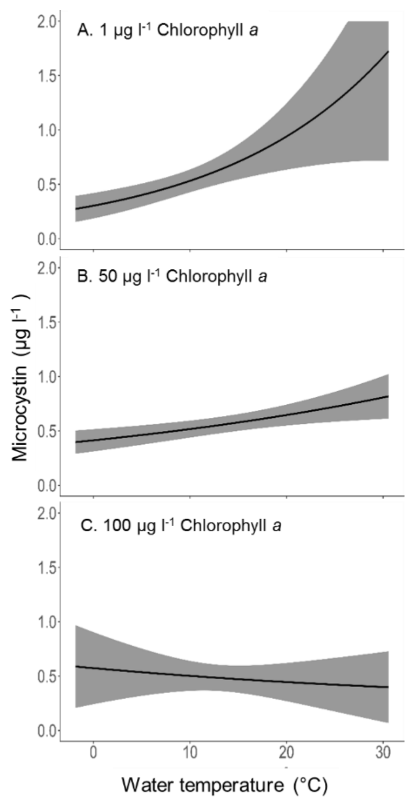

Fig. 3. Model averaged predictions of microcystin concentration (µg l^{-1}) as a function of water temperature (°C) with chlorophyll *a* fixed at (A) 1µg l^{-1}, (B) 50 µg l^{-1}, and (C) 100µg l^{-1} and other covariates held at their mean value. Solid lines represent the mean predicted microcystin concentration and grey ribbons represent the 95% confidence intervals approximated as ± 2*prediction standard error.

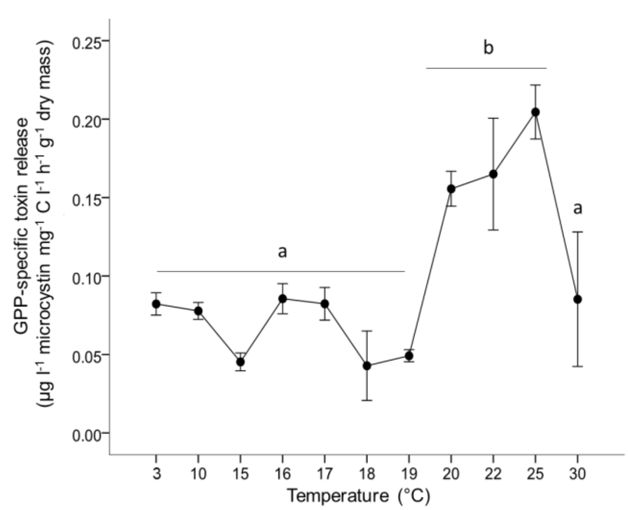

Fig. 4. Mean ± 1 SE gross primary productivity-specific microcystin release among experimental temperature treatments. Points with the same letter are not significantly different among treatments at the $\alpha = 0.05$ significance level.

Major Conclusions and Significance

Although the role of temperature has been widely recognized as a factor contributing to toxic cyanobacteria growth, our study provides new insight into the influence of temperature on toxicity. Specifically, our results show that toxin release from harmful cyanobacteria increases significantly at temperatures above optimal growth conditions for cyanobacteria. Although toxicity has frequently been reported to be a result of warmer temperatures supporting higher growth rates of toxic cells, we found that microcystin concentration was highest when cyanobacteria biomass and cell density were reduced. This inverse relationship occurred at temperatures between 20-25°C, pointing to a possible temperature threshold where cyanobacteria release a greater proportion of their toxins into the water column. This finding is notable since instances of water temperatures exceeding 20°C during warm summer months have become increasingly common. As a consequence, there is an increased likelihood that warming will generate a positive feedback on the frequency and severity of harmful blooms by promoting toxic cyanobacteria over non-toxic strains, stimulating intracellular toxin synthesis, and subsequently triggering toxin release. Furthermore, there is growing evidence that rapid rates of warming have facilitated the expansion of toxic cyanobacteria into ecosystems that were previously undisturbed. The results of our study point to the importance of monitoring temperature changes in these ecosystems, which may aid in forecasting the likelihood for warming to catalyze significant lake change at larger scales.

Publications *indicates student author

Manuscripts:

*Walls, J.T., K.H. Wyatt, J.C. Doll, E.M. Rubenstein, and A.R. Rober. In review. Hot and Toxic: Temperature regulates toxin release by cyanobacteria. *Aquatic Microbial Ecology*.

Presentations:

Walls, J.T.*, K.H. Wyatt, E.M. Rubenstein, J.C. Doll, & A.R. Rober. 2017. Temperature regulates microcystin release from toxin-producing cyanobacteria. Society for Freshwater Science (SFS) Meeting, Raleigh, NC, 4 June-8.

Tegeler, C.G.*, J.T. Walls*, T. Smith*, A.C. Shurzinske*, K.H. Wyatt, & A.R. Rober. 2017. Interactions among temperature, cyanobacteria and heterotrophic bacteria in eutrophic freshwater ecosystems. Ball State University Student Symposium, 21 March. *Winner of the Keys, Litten, Smith Symposium Award.*

Rober A.R., Walls, J.*, E.M. Rubenstein, & K.H. Wyatt. 2017. Hot and Toxic: Temperature regulates toxin release by cyanobacteria. Association for the Sciences of Limnology and Oceanography (ASLO) Aquatic Sciences Meeting, Honolulu, Hawaii 26 Feburary-3 March.

Grant Submissions:

Rober, A.R. 2017. Environmental Protection Agency, STAR Early Career Award (EPA-G2017-STAR-A2). “Evaluating the Role of Temperature in Promoting the Extracellular Release of Toxins by Harmful Cyanobacteria to Improve Predictive Modeling.” $319,626 (not funded).

Rober, A.R., K.H. Wyatt, M. Pyron, and J.W. Frey. 2016. National Institute for Water Research, U.S. Geological Survey (G16AS00016). “Developing a predictive model for toxic cyanobacteria blooms.” $498,838 (not funded).

Students

Masters:
Jeremy T Walls worked on this project for his MS thesis project

Undergraduate:
Caroline Tegeler
Amanda Shurzinske
Taylorann Smith
Maria Shoemaker
Crystal Nichol

Nutrient removal efficiency of a combined surface/subsurface flow wetland system

Basic Information

Title:	Nutrient removal efficiency of a combined surface/subsurface flow wetland system
Project Number:	2016IN396B
Start Date:	3/1/2016
End Date:	2/28/2017
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Congressional District:	IN-007
Research Category:	Not Applicable
Focus Category:	Wetlands, Nutrients, Water Quality
Descriptors:	None
Principal Investigators:	Pierre-Andre Jacinthe

Publications

There are no publications.

Indiana Water Resources Research Center Project Report

Report 2016 Program Report Format

Project Id: 2016IN396B

Title: Nutrient removal efficiency of a combined surface/subsurface flow wetland system

Project Type: Research

Period: March 1, 2016 – February 28, 2017

Congressional District: IN-007

Focus Categories: Wetlands, Nutrients, Water Quality

Keywords: constructed wetlands, edge of field, nitrate, SRP, greenhouse gas

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Abstract

Constructed wetlands located downslope from agricultural fields can intercept nutrients-laden runoff and tile waters, thereby contributing to water quality improvement in agricultural watersheds. However, wet soil conditions can lead to enhanced emission of greenhouse gases (GHG) and that could offset the water quality benefits of constructed wetlands. Thus, there is a need to identify the conditions for optimal nutrient removal and reduced GHG emissions. Treatment wetlands are constructed using different design concepts, including free water surface (FWS), horizontal subsurface flow (HSSF), and vertical subsurface flow (VSSF) wetlands. At the present, it is unclear how design parameters could affect wetland systems performance. A meta-analysis approach was adopted to address this question. We collected peer-reviewed studies, conducted in both natural and constructed wetlands, that reported on nutrient removal and GHG emissions (CO_2, CH_4, N_2O). Results showed a clear influence of the dominant vegetation community on both nutrient retention and GHG emission from wetlands. Under low-water table conditions, wetlands surprisingly acted as CH_4 sinks, whereas N_2O increased sharply (100-fold) under high-water table. Nutrient retention and GHG emission varied with wetland type. In general, both N and P removal was higher in FWS wetlands than in the other systems. Between the subsurface flow systems, greater rate of N and P removal was measured with the VSSF than with HSSF wetlands. Although CH_4 and N_2O emission rates were generally greater in the FWS than in the other wetland types, difference was only marginal. Our results suggest that: (i) when seeding constructed wetlands, plant species combinations can be selected to optimize nutrient removal and minimize GHG emission, and (ii) the FWS wetlands might provide similar environmental benefits as the more complex and expensive subsurface flow systems.

Problem:

Agricultural intensification has led to increased export of nitrogen (N) and phosphorus (P) from agricultural fields into streams, rivers, and lakes resulting in impairment of surface waters. In the Mississippi Basin, the export of nutrients from tile-drained US Midwest croplands is blamed water quality degradation observed both within and outside the region. The US Environmental Protection Agency (EPA) has established a maximum concentration limit of 10 mg N L^{-1} for nitrate (NO_3^-) in drinking water. This limit is often exceeded in rivers and streams, especially after rainfall events following fertilizer application to crop fields. In Indiana, 47% of streams assessed in 2016 were considered impaired (IDEM, 2016) due to elevated concentration of nutrients (total P > 0.3 mg/L; mineral N > 10 mg/L), toxicants (e.g. pesticides, cyanide), and bacteria (e.g. *E. coli*). These nutrient-enriched aquatic ecosystems often experience algal blooms with the subsequent decomposition of algal biomass resulting in hypoxia (oxygen-depleted waters; < 2 mg O_2 L^{-1}) and fish kills. Further, the Mississippi and the Atchafalaya river systems contribute an estimated 91% of total N delivered to the Gulf of Mexico (Rabalais et al., 2002). Therefore, the Corn Belt (Ohio, Indiana, Illinois, Iowa) has been identified as the main contributor to the expanding (doubling in size in 10 years) hypoxic zone or dead zone in the Gulf of Mexico (Dale et al., 2010).

Because of its climate and generally flat landscape, nearly half of all croplands in the Midwest is equipped with subsurface tile drainage that allows for rapid removal of excess moisture and timely implementation of farming operations. It is well recognized that tile drainage installation accelerates the flux of water and nutrients from croplands. The interception of agricultural runoff and tile-drainage discharge in wetlands (natural or constructed) strategically located downslope of cultivated fields could help reduce nutrient export and mitigate these water quality challenges. A constructed wetland is a setting where plant nutrients and other agricultural pollutants can be retained through physico-chemical reactions, used by emergent vegetation and transformed by soil microbes. Wetlands are transitional lands between terrestrial and aquatic systems, and can be connected to either surface water sources or a shallow groundwater system. Natural wetlands have well-documented ecological functions including wildlife habitats, groundwater recharge, water retention and flood control, sediment stabilization, carbon sequestration and nutrients removal (Woodward and Yong-Suhk, 2001). Constructed wetlands have received attention as a cost-effective approach to deal with diffuse pollution in the environment. They are designed to reproduce the biogeochemical processes occurring in natural wetlands and create optimum conditions for the biotransformation of pollutants into harmless products. Numerous studies have examined the effectiveness of constructed wetlands to retain and transform nutrients (e.g. Kovacic et al., 2000; Poe et al., 2003). Nitrogen and phosphorus removal rates can be variable but, in some cases, rates as high as 98% and 96% have been reported (Hunt and Poach, 2001; Newman et al., 1999; Schaafsma et al., 1999). Nutrient loading, water temperature, flow regime and wetland age are key controlling factors of that variability.

Constructed wetlands reported in the literature are based on various design concepts, but the free water surface (FWS), the horizontal subsurface flow (HSSF) and the vertical subsurface flow (VSSF) wetland are the most common types. The FWS typically consists of a basin that may or may not support an emergent vegetation community, and can be either a stagnant or a flow-through system. In contrast to the FWS system in which water is open to the atmosphere, the subsurface flow systems consist of porous media (sand, gravel, soil, bark mulch…) through which water flows underground either vertically (VSSF) or horizontally (HSSF).

While the water-quality protection benefits of wetlands (both natural and constructed) are widely reported, there is also a paucity of data regarding their impact on air quality, specifically emission from wetlands of the greenhouse gases (GHG) carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). These trace gases play important roles in the chemistry and energy balance of the earth's atmosphere. In addition, N_2O and CH_4 participate in stratospheric ozone depletion. Atmospheric concentration of these gases has steadily increased during the last 150 years (IPCC, 2013). Water saturation leads to O_2 exclusion from soil pore space and development of suboxic conditions in wetland soils. These conditions could result in enhanced production of N_2O (via denitrification) and CH_4 (via methanogenesis). Enhanced transfer of GHG from wetlands into the atmosphere is a legitimate concern since such emissions could offset the water quality benefits provided by these ecosystems. Therefore, information regarding GHG dynamics is an important component of our understanding of wetland ecosystems. Thus, there is a need to determine the environmental conditions and design options that result in efficient nutrient removal and at the same time minimize GHG emission from wetlands.

Research Objectives:

Most past studies have focused on wetlands efficiency as measured by nutrient removal. While some studies have examined the intensity of GHG exchange with the atmosphere, there has been to our knowledge no previous attempt to concurrently evaluate the impact of wetland design on nutrient removal and GHG emission from constructed wetlands. Here, we use a meta-analysis approach to address this information gap.

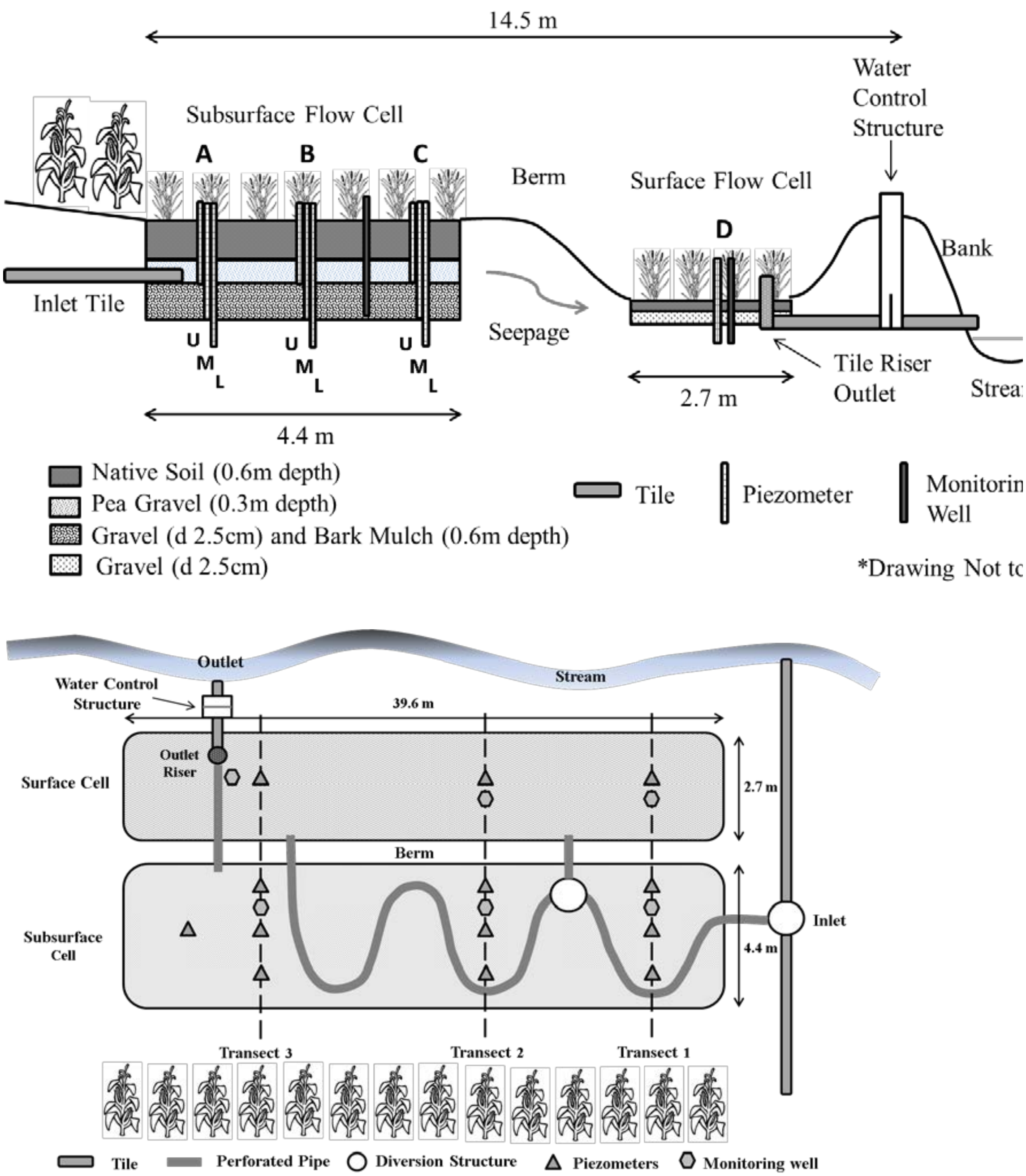

Fig. 1. Cross-sectional view (top) of a constructed wetland with two compartments – an horizontal subsurface flow (HSSF) and the free surface water flow (FSW) compartment. The top diagram shows the different layers of through which water flows in the HSSF. The bottom diagram is a top-down view of the wetland showing water flow directions in the HSSF compartment (water transported through serpentine-like perforated tube) and in the FSW compartment. Location of piezometers and monitoring wells is also indicated. This wetland is constructed downslope from an actively-managed agricultural field at Starkey Farms (Brownsburg, IN).

Methodology

A literature survey of peer-reviewed journal articles about natural and constructed wetlands, nutrient removal, and GHG emissions (CO_2, CH_4, N_2O) was conducted using the Web of Science and Google Scholar databases. Peer-reviewed articles published in English from 1977 to 2017 were collected (N = 100). Studies that did not provide results on nitrate, nitrite, ammonium, ammonia, total nitrogen, total phosphorus, phosphate retention or greenhouse gases emissions were excluded, narrowing the number of available studies to 40 (Table 1). Data collected focused on the factors and conditions associated with nutrient removal as well as GHG emission rates. Wetland conditions included type of wetland (e.g. FSW, subsurface flow), emergent vegetation (e.g. *Typha angustifolia*, *Zizania latifolia*), and water regime (e.g. dry or wet for x fraction of year).

Preliminary Results

Natural and constructed wetlands improve water quality via nutrient retention (i.e. nitrogen and phosphorus) and sedimentation. Nutrient retention involves N and transformation processes resulting in the emission of CO_2 (respiration), CH_4 and N_2O. Overall, our results showed that in both natural and constructed wetlands, vegetation (macrophytes species) had a marked influence on the efficiency of N and P removal as well as GHG emissions. Results also showed a clear effect of season with greater rates of CO_2, CH_4, and N_2O emission in the summer relative to spring, fall, and winter.

Vegetated wetlands had higher nutrient retention (via plant assimilation) than non-vegetated wetlands (e.g. NO_3: 14% vs. 11%; P: 50% vs. 33%). Wetlands supporting *Canna indica* and *Stenotapharum secundatum* had higher ammonia removal (10%) than wetlands dominated by *Typha latifolia* (6.8%) and *Phragmites australis* (9.1%). In contrast, P removal was lower in wetland systems colonized by *C. indica* and *S. secundatum* (4-8%) than in wetlands vegetated by *T. latifolia* and *P. australis* (12-16%). Greenhouse gases emission was influenced by the presence of vegetation and by the type of plants. Emission of CO_2 occurred at rates about twice as high in vegetated (452 g $CO_2/m^2/d$) than in non-vegetated wetlands (276 g $CO_2/m^2/d$). An effect of plant species was also detected, and that was likely related to plants root system and microbial communities associated with the rhizosphere. For example, *Zizania latifolia* (plants with shallow root system) promotes higher rates of CH_4 (65 mg $CH_4/m^2/h$) and N_2O (0.12 mg $N_2O/m^2/h$) emission than *Phragmites australis* (45 mg $CH_4/m^2/h$ and 0.04 mg $N_2O/m^2/h$).

Water regime, temperature and hydraulic retention time, and organic matter influenced nutrient removal and GHG emissions. Under wet conditions, increased rates of nutrient removal was observed with warmer temperature (seasonal temperatures changes), and longer hydraulic residence time (HRT). Similarly, in groundwater-fed wetland systems, high CH_4 fluxes were generally reported (197 kg CH_4/ha/y) under high water table conditions, whereas wetlands acted as CH_4 sinks (-6.9 kg CH_4/ha/y) when water table position is low. In contrast, the reverse was observed with regard to N_2O. Emission of N2O tended to be higher in wetlands with low water table (139 kg N_2O/ha/y) than high water table (-1.1 kg N_2O/ha/y).

Nutrient retention varied with wetland type. On average, N removal rate was higher in FWS wetland than either natural or constructed subsurface flow wetland systems (Fig. 2). Among the subsurface flow wetlands, N removal was generally greater in HSSF than in VSSF wetlands. In contrast, the opposite was observed with respect to P retention; the VSSF exhibited higher P removal rates than the HSSF wetlands (Fig. 2).

Greenhouse gas emission was also influenced by wetland type. We observed that FWS had higher CH_4, and N_2O emissions than VSSF, HSSF, and natural wetlands (Fig. 3). Among the subsurface flow wetlands, N_2O emission was generally higher in VSSF than in HSSF systems. Higher rate of CH_4 emission was generally recorded in the HSSF than in the VSSF systems. Carbon dioxide emission was generally highest in natural wetlands, followed by VSSF, HSSF, and FWS.

Summary/Conclusions

- Although nutrients in agricultural runoff and urban effluents can be successfully removed in constructed wetlands, GHG emission cannot be ignored. The intensity of GHG emission was found to vary with the type of vegetation. Although much remains to be learned about the coupling of vegetation community structure and GHG production/transport in wetlands, this finding suggests that it might be possible to select different plant species combinations to optimize nutrient removal and minimize GHG emission from constructed wetlands.

- Selection of wetlands design can have a definitive impact on system performance as measured by nutrient removal and GHG emission. More efficient N and P removal was achieved with the FWS wetlands (Fig. 2) than with either of the subsurface flow systems (HSSF and VSSF). Although GHG emission was generally greater in the FWS wetlands than in the other types, difference was minimal and likely not significant (Fig. 3). Taken together, these results suggest that both water quality and air quality objectives can be best achieved with the FWS design. This observation is significant, and specifically means that the FWS design can provide similar environmental benefits as the more complex and expensive subsurface flow systems. These preliminary results are certainly intriguing, and therefore will be the focus of further analysis and interpretation.

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Table 1. Peer-reviewed research articles included in the meta-analysis. Abbreviation: GHG = greenhouse gas.

Reference	Type of wetland	Location	Measurement
Barbera et al. 2014	constructed	Italy	GHG
Boyt et al. 1977	natural	Florida, US	Nutrients
Brix et al. 2001	natural	Denmark, Hungary, Czech Republic	GHG
Bubier and Moore 1994	natural	Minnesota, US	GHG
Calheiros et al. 2007	constructed	Portugal	Nutrients
Sim et al. 2008	constructed	Malaysia	Nutrients
Chiemchaisiri et al. 2009	constructed	Thailand	GHG
Christense et al. 2003	natural	Iceland, Siberia	GHG
Clair et al. 2002	natural	Canada	GHG, nutrient
Van der Gon 1995	natural	Phillipines	GHG
Gersberg et al. 1983	constructed	California, US	Nutrients
Gottschall et al. 2007	constructed	Canada	Nutrients
Hu et al. 2010	natural	China	Nutrients
Inamori et al. 2007	constructed	Japan	GHG
Jahangir et al. 2016	constructed	Estonia, Finland, Norway	GHG
Jordan et al. 2003	restored	Maryland, US	Nutrients
Lee et al. 2009	constructed	multiple locations, review	Nutrients
Liikanen et al. 2006	constructed	Finland	GHG
Liu et al. 2009	constructed	Japan	GHG
Maltais-Landry et al. 2009	constructed	Canada	GHG
Mander et al. 2014	constructed	multiple locations, review	GHG
Maucieri et al. 2017	constructed	multiple location, review	GHG
Morse et al. 2012	natural	North Carolina, US	GHG
Picard et al. 2005	natural	Ohio, US	Nutrients
Schrier-Ujil et al. 2011	natural	Netherlands	GHG
Sha et al. 2011	natural	Ohio, US	GHG
Silvan et al. 2004	constructed	Finland	Nutrients
Sovik and Klove 2007	constructed	Norway	GHG
Sovik et al. 2006	constructed	Norway	GHG
Strom et al. 2007	constructed	Sweden	GHG
Strom et al. 2003	natural	Sweden	GHG
Tai et al. 2002	constructed	China	GHG
Tang et al. 2009	constructed	China	Nutrients
Tao 2015	constructed	New York, US	GHG
Teiter and Mander 2005	constructed	Estonia	GHG
Vymazal 2007	constructed	NA	Nutrients
Wang et al. 2008a	constructed	Japan	GHG
Wang et al. 2008b	constructed	Japan	GHG
Wu et al. 2017	constructed	China	GHG
Lin et al 2002	constructed	Taiwan	Nutrients

Fig. 2. Mean nutrient removal (and standard deviation) expressed as percentage of nutrient input for different types of wetlands. Total N is the sum of total Kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate. Total P is the sum of soluble reactive and organic P. Abbreviations: FWS = free water surface wetland; HSSF = horizontal subsurface flow wetland; VSSF = vertical subsurface flow wetland.

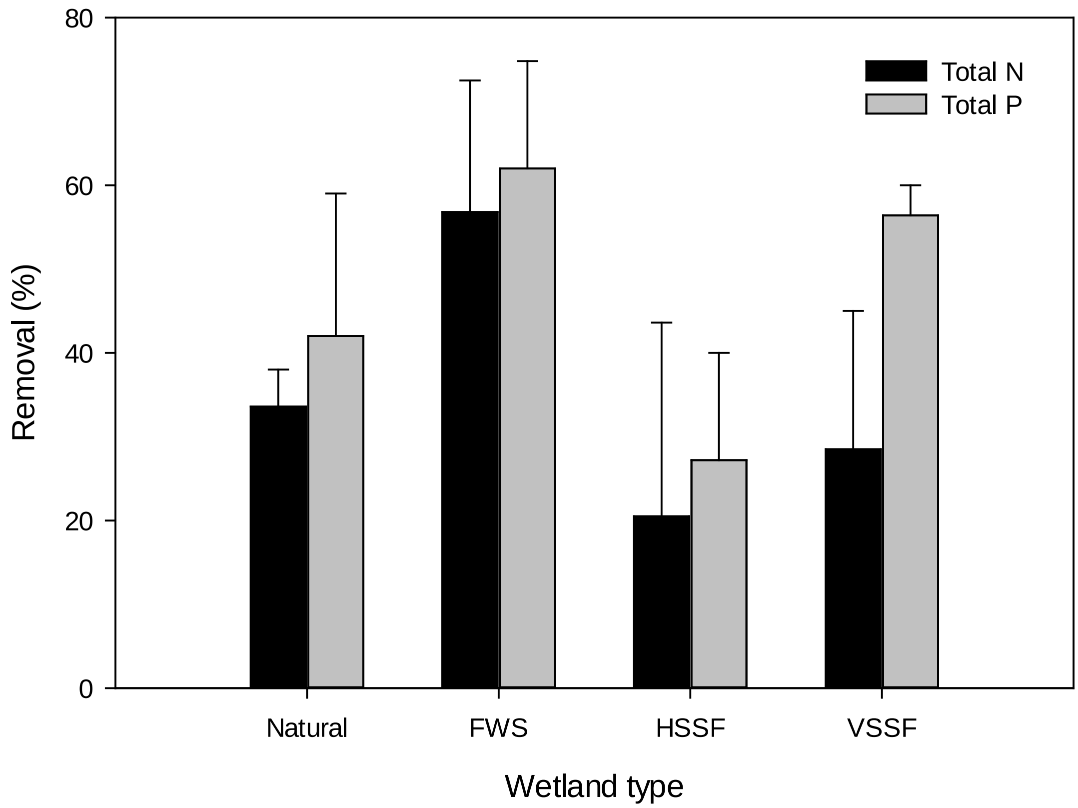
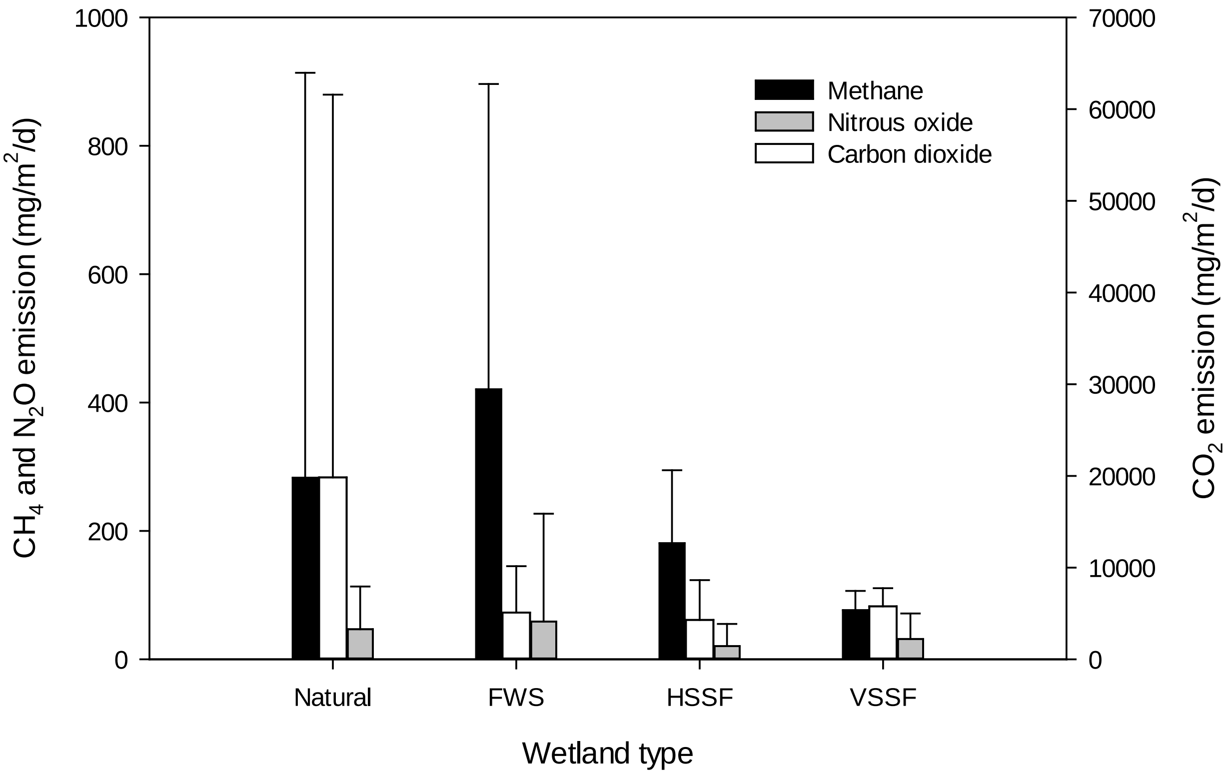


Fig. 3. Mean (standard deviation) emission of greenhouse gas (GHG) for different types of wetlands of methane. Gas fluxes are reported in units: CO_2-C mg/m^2/d, CH_4-C

mg/m^2/d and N_2O-N mg/m^2/d. Abbreviations: FWS = free water surface wetland; HSSF = horizontal subsurface flow wetland; VSSF = vertical subsurface flow wetland.



Publications

Two (2) manuscripts in preparation.

Grant Submissions:

None at this point.

Postdoctoral researcher

- Daniel Elias

Students

The following students have contributed to this project:

- Graduate student (1): Danielle Follette
- Undergraduate students (2): Amanda Evans, Jonathan Jacinthe

Information Transfer Program Introduction

None.

USGS Summer Intern Program

None.

Notable Awards and Achievements