# State of Washington Water Research Center Annual Technical Report FY 2014

# Introduction

Like most Western States today, The State of Washington faces substantial water resource challenges. As of this writing, the state is heading into one of the worst droughts since the 1940s, exacerbated by a warm winter and low snowpack throughout the Cascades. The Columbia River Treaty of 1964 between the U.S. and Canada is being considered for renegotiation, and legal and surface-groundwater interactions and conjunctive use are center stage in legal and policy developments regarding instream flows, Native American Treaty rights, and residential and municipal groundwater development. Proposals for more surface and aquifer storage and recovery continue to be introduced, while water market infrastructure continues to develop across the state to facilitate water transfers. Water quality issues relating to stormwater runoff into the Puget Sound and concentrated livestock production east of the Cascade are holding the attention of both the courts and the State Legislature. All of these issues and decisions require and can benefit from science-based research and outreach from water research and management professionals across the state. The State of Washington Water Research Center is working to position itself to be a critical provider and coordinator of these science-based research and information needs.

As it passes its 50th year this reporting period, the State of Washington Water Research Center (WRC) has been in a transitional and rebuilding phase. The previous Director stepped down during the summer of 2013 to take a position in a different state. The new administration, including a Director and Associate Director began their appointments on March 1, 2014. Three colleges at Washington State University have committed additional resources to the Center by, including funds to support a new Associate Director position and one-half FTE for a clinical assistant professor to help focus the Center’s research programs. We have developed a new strategic plan to further strengthen the productivity, relevance, and visibility in the State of Washington and the Pacific Northwest and are now pursuing the goals and objectives laid out in this plan.

In the spirit of the WRRA of 1964, the mission of the State of Washington Water Research Center has three components:

1) To conduct and facilitate applied water-related research.

2) To foster education and training of future water professionals.

3) To serve as a nexus between the academic community, water resource managers and water stakeholders.

These three elements of the WRC mission are the fundamental goals supporting the WRC vision, objectives, strategies, and assessment metrics described in this Strategic Plan.

The WRC administration will strengthen WRC impact through the following activities:

1) Developing broader collaborations among water researchers, managers and other water-focused organizations across the state.

2) Increasing programmatic and extramural funding to support the WRC and its activities.

3) Developing more focused and integrated water resource education programs at Washington State University and facilitating education elsewhere in the state where possible.

4) Creating a wider network for outreach, and contributing more broadly to information dissemination for water stakeholders and policymakers.

The mission and vision of the WRC will be guided according to the following principles:

1) WRC will focus on and facilitate integrative research and education throughout all core water-related programs. At the heart of modern integrative water research is a need for interdisciplinary collaboration.

2) WRC will endeavor to complement rather than duplicate the efforts and missions of other water-focused centers both within WSU and across other state and regional organizations.

3) WRC will continue and strengthen its direct involvement in water-related research, but will also strengthen its indirect contributions to impactful water research by increasing the level of support and incentives provided to prospective researchers in the form of administrative support, information provision, focus and guidance, and direct facilitation of and collaboration in research and academic pursuits.

4) WRC will maintain and strengthen its reputation as an independent and neutral provider of reputable science and policy research.

Administrative activities this year have included internal WRC team-building and hiring, strategic planning, grant management and planning, communications and branding development, and collaboration and network building.

With support from the Washington State University (WSU) College of Agricultural, Human, and Natural Resource Sciences, the Voiland College of Engineering and Architecture, and the College of Arts and Sciences, the WRC staff now includes a Director (0.5 FTE), and Associate Director (0.25 FTE), a Clinical Assistant Professor (0.5 FTE), a Principal Assistant (0.5 FTE), and grants and contracts support through the Office of Research. The principal assistant and the clinical assistant professor were both hired this year. In addition, the WRC has two advisory committees: a set of 3 Program Directors and a Science Advisory Committee comprising 9 individuals from throughout the state and with varying expertise. The makeup and responsibilities of the Program Director positions are being changed from a past focus on specific research areas to focus directly on the three respective categories of the WRC mission: Research, Education, and Outreach. The Science advisory committee provides guidance about the research emphasis of the WRC, and are is the review panel for the 104(b) grant applications.

One of the terms of the Internal Memorandum of Agreement (IMOU) between WSU and the WRC Administration is that the WRC develop a Strategic Plan. This strategic plan was completed and delivered in March 2015 to the Office of Research and the supporting Deans of the College of Agriculture, Human, and Natural Resource Sciences (CAHNRS), Voiland College of Engineering and Architecture (VCEA), and the College of Arts and Sciences (CAS).

Research, education and outreach activities will be described in more detail later in the report. Each of the underlying administrative efforts: team building and strategic planning, grant development efforts, network, communication, and collaboration building, and education program development will help the WRC move forward in pursuit of its three mission of research, education, and outreach in the area of water resource management.

# Research Program Introduction

WRC's research program is active along several dimensions. First, the WRC manages a seed grant program funded by the Water Resources Research Act (WRRA) 104(b) funds. Second, it is currently managing two extramural grants to support research. Third, it has submitted and has begun preparing several proposals this past year for additional funding. Finally, it is pursuing a broad strategy for developing and strengthening research funding opportunities and collaborative opportunities within and outside of WSU and the State of Washington.

The WRC funded three small water-related grants under the WRRA 104(b) FY2014 grant program:

- The effects of river restoration on nutrient retention and transport for aquatic food Webs. Project # 2014WA385B. Fremier, Alexander and Cailin Orr. Assistant Professors, Washington State University.

- Interactive effects of nutrients and grazing on the control of cyanobacteria blooms: a comparison across a eutrophication gradient in freshwater systems in Washington State. Gretchen Rollwagen-Bollens, Assistant Clinical Professor, Washington State University Vancouver, and Stephen Bollens, Professor and Director, Washington State University. Project # 2014WA381B.

- New Generation of Iron-Enhanced Compost for Stormwater Treatment. Zhenqing Shi, Markus Flury, and James Harsh, Assistant, Associate, and Full Professor (respectively), Washington State University. Project# 2014WA386B.

In addition to the seed grant projects, the WRC completed one legislatively mandated research project and initiated another one. The report entitled "Benefit-Cost Analysis of the Yakima Basin Integrated Plan Projects" was submitted to the State Legislature in December 2014 (http://swwrc.wsu.edu/2014ybip/). The 2016 Columbia River Basin Long-Term Water Supply and Demand Forecast is a three-year legislatively mandated study initiated in 2014.

The Administrative team is pursuing further extramural support in line with the WRC strategic plan. It was a major contributor to a proposal submission to the USDA AFRI CAP Water for Agriculture program, with a request for joint effort between three Centers at WSU and the School of the Environment. This submission was not among the 6% of proposals funded, but it received very strong reviews, and we are preparing to resubmit to the 2015 Water for Agriculture program. Adam and Yoder are PIs on a National Science Foundation (NSF) Interdisciplinary research in hazards and disasters (funded pending minor revisions). Director Yoder was also a participant in one other AFRI proposal in the same program, as well as a submission to the National Integrated Water Quality Program (NIWQP)/ Farm, Landscape and Watershed program area of AFRI, which was not funded. Resubmission is being considered. Associate Director Adam was a participant in several water-related proposals such as to the Department of Defense (DOD) Strategic Environmental Research and Development Program (SERP) call for adapting to changes in the hydrologic cycle, the Upper Columbia Salmon Recovery Board (UCSRB), and the Washington State Department of Agriculture's Specialty Crop program. These also were not funded but are being prepared for resubmission.

The WRC administration has been working to develop collaborative relationships with other organizations in the State and beyond with complementary expertise and/or with research needs and accompanying funding to support it. The most obvious collaboration building process is with the Center for Environmental Research, Education, and Outreach (CEREO), with which we share our administrative staff. CEREO and WRC are developing a working relationship that arises from our shared mission of facilitating multidisciplinary research, focusing on complementarities and synergies between the two Centers and making use of our shared personnel resources.

Locally, the WRC is working with the Palouse Basin Aquifer Committee (PBAC) to provide the two cities and the two universities in the basin the science to help address the problem of declining aquifers and increasing water demand. WRC is also building ties to the USGS Water Science Center (WSC) in Tacoma, Washington. There has been little collaboration between these two centers in recent years, but we are exploring opportunities to take advantage of funding opportunities for USGS Science Centers and NIWR Center collaboration. The WRC staff visited the USGS WSC in early 2015 to kick start seminar exchanges and collaborative research efforts.

The WRC currently has two primary connections to State government: the Washington State Department of Ecology, and the State Legislature. The Department of Ecology has been the source of a substantial share of WRC extramural funding in recent years to support WRC research to provide long-run water supply and demand forecasts for the State of Washington, which the Ecology Office of Columbia River oversees on a five year cycle. The WRC is also currently building stronger ties to the Ecology Water Resource Program, which oversees a broader array of water resource and regulatory issues. The State legislature has over the last several years identified the WRC as a source of independent research on water-related issues. The Yakima Basin Integrated Plan Benefit-Cost analysis was a legislatively funded mandate, and we have been charged also to review certain U.S. Bureau of Reclamation Benefit-Cost analyses as they are produced, relating to large Yakima Basin infrastructure projects. The WRC administration is in communication with the WSU office of State relations to begin to explore ways of securing additional state base funding to support personnel for actively, permanent outreach and research programs.

The WRC intends to continue fostering its role as an independent source of quality research and information to help address the State of Washington's needs. The WRC administration is in communication with the WSU office of State relations to begin to explore ways of securing additional state base funding to support personnel for actively, permanent outreach and research programs.

# Interactive effects of nutrients and grazing on the control of cyanobacteria blooms: a comparison across a eutrophication gradient in freshwater systems in Washington state

## Basic Information

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|---|---|
| **Title:** | Interactive effects of nutrients and grazing on the control of cyanobacteria blooms: a comparison across a eutrophication gradient in freshwater systems in Washington state |
| **Project Number:** | 2014WA381B |
| **Start Date:** | 3/1/2014 |
| **End Date:** | 2/28/2015 |
| **Funding Source:** | 104B |
| **Congressional District:** | Washington, 3 |
| **Research Category:** | Biological Sciences |
| **Focus Category:** | Water Quality, Ecology, Toxic Substances |
| **Descriptors:** | None |
| **Principal Investigators:** | Gretchen Rollwagen-Bollens, Stephen M. Bollens |

## Publications

There are no publications.

**FINAL REPORT:**

**Interactive effects of nutrients and grazing on the control of cyanobacteria blooms: a comparison across a eutrophication gradient in freshwater systems in Washington state**

2014WA381B

**Submitted by Gretchen Rollwagen-Bollens and Stephen Bollens**

## Problem and Research Objectives

Seasonal blooms of cyanobacteria and other algae are natural occurrences in lakes of varying morphology and location, and may naturally increase in frequency as lakes evolve from clean and unproductive states to more shallow and eutrophic conditions (Hutchinson 1973). However, increasing evidence demonstrates that the eutrophication process in lakes is being accelerated by human activity, through sewage and fertilizer inputs, deforestation, road construction, real estate development and other disturbances in lake watersheds, and is contributing to an increase in frequency and intensity of cyanobacteria blooms (e.g. Sellner et al. 2003, Paerl 2008). Moreover, several recent studies suggest that increased eutrophication under conditions of a warming climate may result in increased dominance of cyanobacteria in aquatic systems (Kosten et al. 2012, O'Neill et al. 2012) and may actually favor harmful cyanobacterial taxa over non-toxic forms (Paerl & Huisman 2009).

Excessive abundance of cyanobacteria may have detrimental effects on lake ecosystems and water quality, including development of surface scums and depleted oxygen levels (Sellner et al. 2003). In addition, many cyanobacteria species can produce potent hepatotoxins that can negatively affect aquatic life and in particular cause harm or even death to humans and other mammals (Chorus et al. 2000, Codd et al. 2005). This phenomenon is of great concern to water resource managers in Washington State, since cyanobacteria blooms have become an increasing problem in the Pacific Northwest (Jacoby & Kann 2007), and pose particular challenges to human health. For example, the Washington Department of Ecology Freshwater Algae Bloom Monitoring Program Harmful reported that, between 2007 and 2013, 81 Washington lakes had at least one instance in which cyanotoxin levels exceeded maximum thresholds considered safe for human contact (www.nwtoxicalgae.org). Thus cyanobacteria blooms are of concern to the public, as well, since their use and enjoyment of valued aquatic environments may be prohibited as a result.

Since 2007 we have been monitoring water quality and plankton abundance and diversity in Vancouver Lake, located in Clark County, WA, in the floodplain of the lower Columbia River. Vancouver Lake has experienced numerous summertime blooms of *Anabaena* and *Aphanizomenon* cyanobacteria over the past 20 years, however the blooms have been variable in intensity from year to year (Lee et al. in press). In addition to monitoring the plankton in Vancouver Lake, from 2007-2010 we also investigated the biotic and abiotic factors that influence the late summer cyanobacteria blooms. Our research has revealed that both small (<20 µm), single-celled planktonic grazers ("microzooplankton") and large (1-5 mm), crustacean grazers ("mesozooplankton" such as copepods and cladocerans) have measurable impact on the timing of bloom onset and decline in Vancouver Lake, but do not prevent the blooms from occurring. Specifically, mesozooplankton feeding on microzooplankton in the weeks just prior to a cyanobacteria bloom event sets up a "trophic cascade" in which those microzooplankton are prevented from grazing cyanobacteria, allowing cyanobacteria to increase rapidly in abundance (Rollwagen-Bollens et al. 2013). After the cyanobacteria bloom reaches its peak, mesozooplankton grazers appear to be inhibited, and grazing by microzooplankton increases to maximal levels, contributing to a rapid decline in cyanobacteria abundance (Boyer et al. 2011).

Also, in a multivariate statistical analysis conducted on weekly measurements of water quality (e.g. temperature, turbidity, pH, dissolved oxygen), inorganic nutrient concentration (e.g. nitrate, nitrite, ammonia, orthophosphate), and the abundance and taxonomic composition of algae and cyanobacteria from 2007-2010 in Vancouver Lake, we found that the environmental factors most strongly associated with cyanobacteria blooms were orthophosphate and ammonium concentrations. However, nutrient availability could only explain ~35-50% of the variance in algal abundance (Lee et al. in press).

Our results in Vancouver Lake, coupled with observations in other temperate lakes, strongly suggest that both nutrient availability and zooplankton grazing influence cyanobacteria bloom dynamics, in a combination of “bottom up” and “top down” forces; but the interactive effects of these forcings have not been examined in Pacific Northwest lakes or reservoirs. Moreover, it is completely unknown how the relative impacts of enhanced nutrient concentrations and zooplankton grazing may differ in lakes and reservoirs of variable trophic status (eutrophic vs. oligotrophic).

In this project our overall goals were to better understand the interactive effects of nutrient availability and zooplankton grazing on cyanobacteria bloom dynamics in Washington freshwater lakes and reservoirs across a gradient of eutrophication, and to share our results and interpretations with resource managers to better inform decision-making on steps to prevent and/or mitigate freshwater cyanobacteria blooms in the state.

We focused our research on four lakes/reservoirs in Washington state that represent a range of trophic state, from highly to moderately eutrophic (Vancouver Lake and Lacamas Lake) to more oligotrophic (Lake Merwin and Cle Elum Lake) (Figure 1).


**Figure 1.** Locations of four lakes/reservoirs in Washington state that were sampled three times over the course of the summer algal bloom period in 2014.

Our objectives for achieving the project goals were as follows:

*Objective 1:* Conduct cyanobacterial/algal growth experiments three times over the bloom cycle in each of four lakes/reservoirs along a gradient of eutrophication, using natural unfiltered water collected from each lake in a 2x2 factorial design with a control and three treatments (Fig. 2): 1) lakewater containing the natural assemblage of algae/cyanobacteria (control), 2) lakewater with added nutrients (orthophosphate), 3) lakewater with added zooplankton grazers (copepods), 4) lakewater with added nutrients and zooplankton grazers.

*Objective 2:* Measure a suite of water quality variables (e.g., nutrients, temperature, dissolved oxygen, etc.) in each lake/reservoir.

*Objective 3:* Conduct multivariate statistical analyses of field data to assess the relative importance of bottom-up (nutrient availability) and top-down (grazing) factors in influencing cyanobacteria abundance and composition.

*Objective 4:* Combine the experimental results (objective 1) with the field results (objectives 2 and 3) to develop predictions of how increased eutrophication will likely impact lakes that currently experience cyanobacteria blooms and those that as yet do not suffer from these blooms.

## <u>Methodology</u>

***Field and experimental program.*** Field sampling and experiments were conducted in each of four lakes/reservoirs from May to October 2014. Each lake/reservoir was sampled for water quality variables and plankton once per month and algal/cyanobacterial growth rate experiments were conducted three times over the sampling period: in June, prior to any summer bloom, in August during the bloom peak, and in October following any bloom's decline. All analyses were conducted at WSU Vancouver.

**Approach 1: Field sampling for water quality and plankton.** At each sampling time, temperature and dissolved oxygen profiles was obtained using a YSI 85 probe, and relative water clarity estimated by measuring the Secchi depth. In addition, water samples were collected from the surface using a clean, acid-washed bucket, and subsamples taken for later laboratory analyses of chlorophyll *a* concentration (Strickland & Parsons, 1972). In addition, bucket samples were collected from the surface, and subsamples preserved in 5% acid Lugol's solution, for enumeration and identification of cyanobacteria and all protist (i.e. unicellular eukaryotic) plankton. Finally, triplicate vertical tows were conducted with a 0.5-m diameter, 73-µm mesh zooplankton net, and the contents concentrated and preserved in 5-10% buffered formalin. Abundance and composition of plankton were assessed via light microscopy following the approach outlined in Rollwagen-Bollens et al. (2013).

**Approach 2: Lakewater incubations to measure cyanobacterial/algal growth rates under variable conditions of nutrient availability and zooplankton grazing pressure.** Growth experiments were conducted following a 2 x 2 factorial design with a control and three treatments: lakewater plus added nutrients, lakewater plus added zooplankton grazers, and lakewater plus nutrients and grazers (Figure 2).

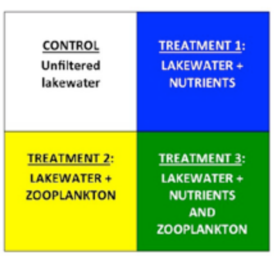


**Figure 2.** Diagram illustrating the 2 x 2 factorial design for the cyanobacteria/algal growth experiments.

Experimental protocols were slightly modified from the methods described in Rollwagen-Bollens et al. (2013), to include multiple treatments. Each treatment consisted of four replicate 500-ml polycarbonate incubation containers filled with unfiltered lakewater containing the natural assemblage of plankton obtained from the surface using a clean, acid-washed bucket. Four bottles containing only the natural assemblage were established as Initial Controls, and immediately preserved and subsampled. Sixteen additional bottles were filled with unfiltered lakewater and then supplemented as follows: four bottles were sealed to serve as Final Controls, four bottles received amendments of inorganic nutrients (orthophosphate and nitrate) as

Treatment 1, four bottles received additions of adult zooplankton representing five times the ambient abundance of the dominant taxon present as Treatment 2, and the remaining four bottles received both added nutrients and zooplankton as Treatment 3. Zooplankton were collected via vertical hauls of a 73-µm plankton net and adults of target species sorted under dim light into holding beakers before being added to incubation bottles. All final control and treatment bottles were incubated in a temperature-controlled chamber for 24 hours on a slowly rotating (0.5-1 rpm) plankton wheel under natural light-dark conditions. All bottles were subsampled and analyzed to enumerate and identify the algae and cyanobacteria as described above (Approach 1). Cyanobacteria and algal growth rates were estimated according to Frost (1972).

**Approach 3. Statistical analyses to assess interactive effects of nutrients and zooplankton on cyanobacteria abundance and blooms.** We are employing an ordination technique called non-metric multidimensional scaling (NMDS) to identify the relationships between nutrient concentrations, zooplankton abundance, and other environmental variables (e.g. temperature, turbidity) and cyanobacteria community composition and abundance. Ordination techniques are very useful in community ecology because they can detect numerous relationships between species, or assemblages of species, and environmental data. NMS is an effective ordination technique for these data since it can be used with non-normal and discontinuous distributions and does not assume linear or modal relationships (McCune & Grace 2002).

## Principal Findings

Each lake (Vancouver, Lacamas, Merwin, Cle Elum) was sampled for water quality variables once per month from May to October, 2014. Experiments were conducted in each lake during June (pre-bloom), August (bloom), and October (post-bloom).

The lakes varied in a range of physical and chemical factors over the 2014 sampling period (Fig. 3). Vancouver Lake, located within the city limits of Vancouver, WA, was the shallowest

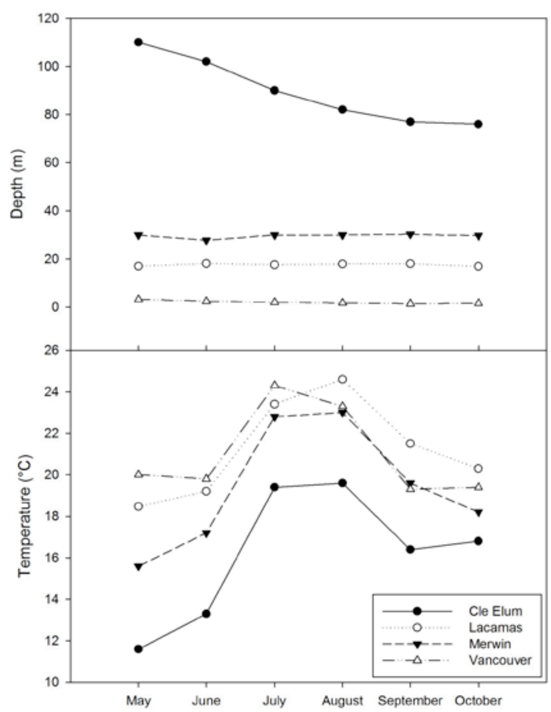


**Figure 3.** Variations in lake depth (upper panel) and surface temperature (lower panel) from May to October 2014, in four Washington lakes.

lake sampled, averaging ~2 m over the summer, with variations associated with changes in the tidal phase and water levels in the Columbia River. Lacamas Lake, located ~10 miles east of Vancouver Lake, is a reservoir of Lacamas Creek, where lake levels were maintained at ~17 m depth throughout the summer. Merwin and Cle Elum lakes are also reservoirs, along the East Fork Lewis River and Yakima River, respectively. Water depths in Lake Merwin averaged ~29 m and remained steady over the sampling period, however water depth in Cle Elum Lake decreased consistently over the summer from a high of 110 m in May to a low of 76 m in October, 2014 (Fig. 3 upper).

Surface temperatures varied with change in season in all four lakes in a similar pattern: the lowest temperatures were observed during May and June, ranging from 12-15 °C in the deeper lakes (Merwin and Cle Elum) and 18-20 °C in the shallower lakes (Vancouver and Lacamas); the highest temperatures were observed in July and August, where three lakes (Vancouver, Lacamas and Merwin) recorded temperatures between 23-25 °C and Cle Elum reached 19.6 °C; and temperatures in all four lakes fell to moderate levels in October, between 16-20 °C (Fig 3 lower).

Algal/cyanobacterial biomass, as measured by chlorophyll (chl) *a* concentration, was lowest in the two large river reservoirs, Lake Merwin and Cle Elum Lake, from May to October 2014 (Fig 4 upper). Chl *a* concentration did not vary measurably in these two reservoirs over the sampling period (0.1-3 µg/L). Whereas chl a concentrations varied significantly in Vancouver Lake, from lows of 20-25 µg/L in May and October, to peak levels of 150 µg/L observed in August 2014. Chl *a* concentrations were moderately high and variable (range 15-41 µg/L) in Lacamas Lake from May to October (Fig 4 upper).

Changes in water clarity (as measured by Secchi depth) were substantial in Lake Merwin and Cle Elum Lake over the 2014 sampling period, ranging from a low of 4-6 m in May to a maximum of 11 m in August in Lake Merwin. Both lakes showed similar water clarity of ~8 m in October. In contrast, the shallow lakes (Vancouver and Lacamas) had lower water clarity that did not vary much from May to October (Fig 4 lower).

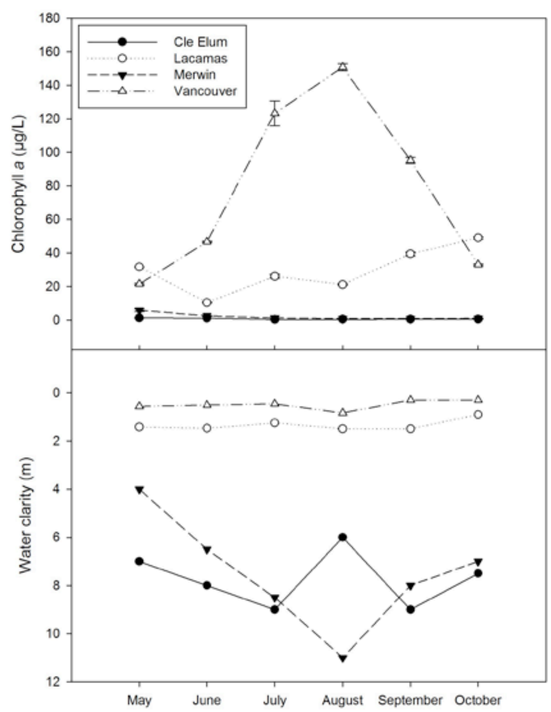


**Figure 4.** Variations in surface chlorophyll *a* concentration (upper panel) and water clarity (lower panel) from May to October 2014, in four Washington lakes.

A total of 12 growth rate experiments were conducted over the 2014 sampling period, 3 experiments per lake. Preliminary analyses of changes in chl *a* concentration in the experimental bottles indicate that the effects of nutrients and zooplankton grazers on algal/cyanobacterial growth rates differed between the four lakes and over the summer growth season.

In June 2014, preliminary results from the growth experiments suggested that nutrients (phosphate) were limiting to algae/cyanobacteria in Lacamas Lake and Lake Merwin, since addition of phosphate resulted in significantly higher growth rates relative to controls. And while the addition of 5x the ambient abundance of the dominant zooplankton species did not result in reduced algal growth when added to lakewater, this zooplankton addition did prevent algal growth from exceeding the controls when nutrients were also amended ("Both" treatment). A similar pattern, although quite muted, was observed in Vancouver Lake, while in Cle Elum the addition of both phosphate and zooplankton resulted in substantially lower growth rates, suggesting strong grazer influence (Fig. 5).

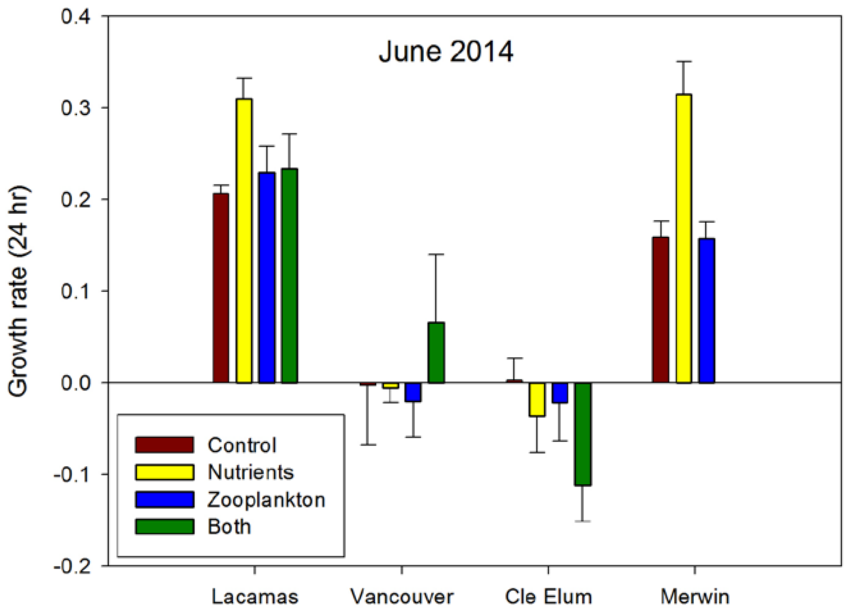


**Figure 5.** Growth rates (day$^{-1}$) of algae/cyanobacteria in experiments conducted during June 2014 in four Washington lakes. Control = lakewater alone; Nutrients = amended with phosphate; Zooplankton = amended with 5x ambient levels of dominant grazer; Both = amended with phosphate and 5x ambient zooplankton.

During August, the addition of zooplankton grazers resulted in highly significant reductions in algal/cyanobacterial growth rates in the two deep, oligotrohic lakes (Merwin and Cle Elum), while the addition of phosphate did not result in significant changes in growth rate. However, in the two eutrophic lakes (Vancouver and Lacamas) the addition of phosphate appeared to enhance algal growth (Fig. 6). This was particularly true in Vancouver Lake, which was experiencing a substantial phytoplankton bloom at the time, and suggests that phosphate had become limiting. Moreover, algal/cyanobacterial growth rates were quite low in Vancouver Lake in August, lending further weight to the conclusion that the bloom was waning.

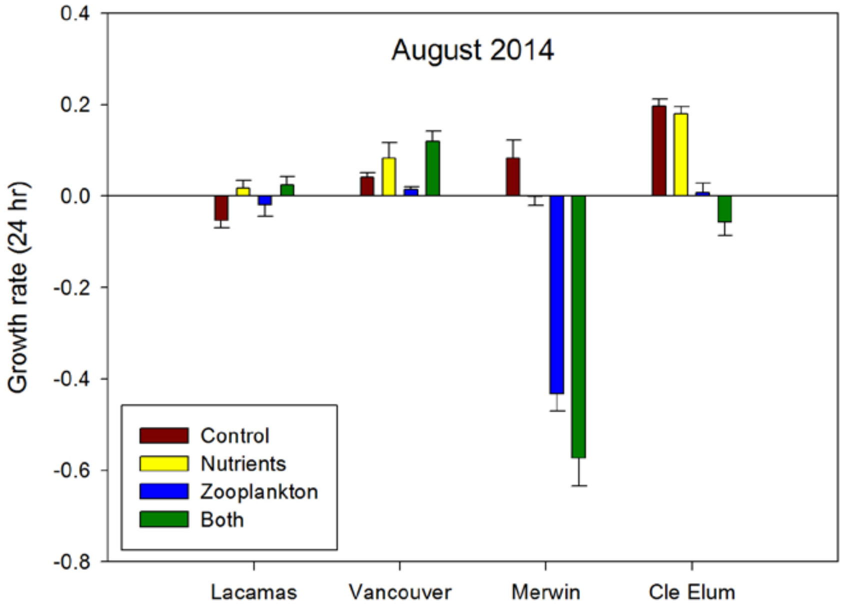


**Figure 6.** Growth rates (day$^{-1}$) of algae/ cyanobacteria in experiments conducted during August 2014 in four Washington lakes. Control = lakewater alone; Nutrients = amended with phosphate; Zooplankton = amended with 5x ambient levels of dominant grazer; Both = amended with phosphate and 5x ambient zooplankton.

Finally, during October the individual and interactive effects of added nutrients and zooplankton grazers did not appear to influence the growth rates of algae/cyanobacteria in Lacamas Lake nor Cle Elum Lake, as there were no significant differences in growth rates among the four treatments in the experiments conducted in these lakes. However, the addition of nutrients resulted in a significant increase in growth rate in Vancouver Lake, while the addition of zooplankton grazers resulted in a significant reduction in growth rate in Lake Merwin (Fig. 7).

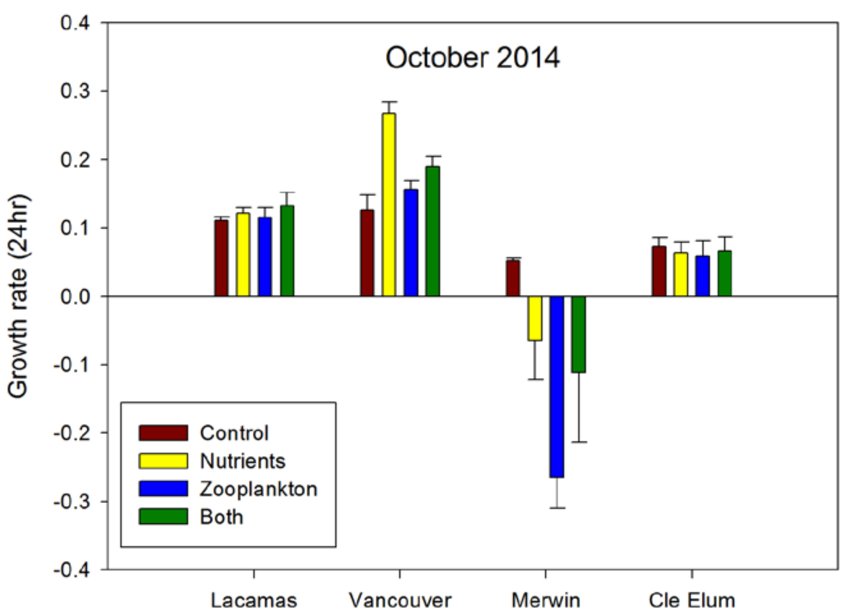


**Figure 7.** Growth rates (day$^{-1}$) of algae/ cyanobacteria in experiments conducted during October 2014 in four Washington lakes. Control = lakewater alone; Nutrients = amended with phosphate; Zooplankton = amended with 5x ambient levels of dominant grazer; Both = amended with phosphate and 5x ambient zooplankton.

## Analyses to be completed

We have estimated algal/cyanobacterial growth rates based on changes in chl a concentration in the experimental treatments of each experiment in each of the four lakes/reservoirs. This provides us with a good estimate of bulk community dynamics, however the next step is to microscopically examine subsamples from each experimental treatment replicate to identify and enumerate the particular algal and cyanobacteria taxa present in each experiment. This will allow us to calculate taxon-specific growth rates to determine which components of the phytoplankton community were responding to the effects of nutrient amendment, zooplankton grazing, and their interactive effects. These analyses are on-going, but extremely time consuming, and we anticipate completing the microscopy work over the summer and fall of 2015.

Having a complete picture of the taxonomic composition of the phytoplankton community will also allow us to assess the potential impacts of other, indirect effects of added nutrients and grazing, such as the effect of "trophic cascades" in each experimental bottle. The added zooplankton grazers may be selectively consuming large algae or protozoans, which could provide a more favorable environment for smaller algae or cyanobacteria to thrive. This would lead to paradoxically higher algal/cyanobacteria growth rates in treatments with added grazers, as estimated based only on changes in chl a concentration. But our taxon-specific growth rates will help to remove this masking effect and potentially reveal the indirect, cascading effects of selective grazing.

Finally, the taxon-specific growth rate analyses will allow us to examine specifically the impacts of nutrients and grazers on cyanobacteria in particular. Harmful cyanobacteria blooms are already a problem in Vancouver and Lacamas lakes. Merwin and Cle Elum lakes have not experienced substantial blooms, but cyanobacteria abundance in both lakes has been variable in recent years, and the potential for nutrient increases due to land use change in their surrounding watersheds warrants concern for cyanobacteria to become a nuisance in these systems, as well.

## Significance

Toxic cyanobacteria blooms in freshwater lakes are an increasing problem worldwide, that are also impacting lakes in Washington and the Pacific Northwest. Results from this research will provide novel information about the dynamics of toxic cyanobacteria blooms in lakes across a eutrophication gradient in Washington state, which will be applicable to temperate freshwater systems more generally. In particular, this research will address the <u>interactive effects</u> of nutrients (bottom-up) and grazing (top-down) on controlling the timing and magnitude of toxic cyanobacteria blooms in both eutrophic and oligotrophic systems.

Finally, identifying the potential biotic and/or abiotic factors associated with cyanobacteria bloom dynamics will provide critical information for natural resource managers to develop strategies for managing blooms based on empirical evidence. For example, if nutrients are found to be a primary factor associated with toxic cyanobacteria blooms in Washington state lakes, then a focus on measures to reduce nutrient loading into the lakes may be most effective for mitigating these blooms. Similarly, if a major control of cyanobacteria blooms is grazing impact from zooplankton consumers, then efforts to manipulate the system to maximize grazing pressure (e.g., via biomanipulation of fish stocks and cascading trophic effects) may be a possible approach to reduce toxic blooms. These results will therefore benefit state and county agencies as they make decisions about our four lakes/reservoirs, but will also be applicable to regional and national resource management agencies who face similar challenges with cyanobacteria blooms in other temperate aquatic systems.

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**Students supported**

Ms. Vanessa Rose, MS candidate in Environmental Science (degree expected Spring 2016).

## **Publications resulting from this award**

None as yet.

## **Notable awards and achievements**

*Lane Graduate Research Fellowship in Environmental Science* and *Boeing Graduate Research Fellowship in Environmental Science*, both awarded from the School of the Environment to Vanessa Rose, Spring 2015.

# The effects of river restoration on nutrient retention and transport for aquatic food webs

## Basic Information

| | |
|---|---|
| **Title:** | The effects of river restoration on nutrient retention and transport for aquatic food webs |
| **Project Number:** | 2014WA385B |
| **Start Date:** | 3/1/2014 |
| **End Date:** | 2/28/2015 |
| **Funding Source:** | 104B |
| **Congressional District:** | 3 |
| **Research Category:** | Biological Sciences |
| **Focus Category:** | Hydrogeochemistry, Hydrology, Ecology |
| **Descriptors:** | None |
| **Principal Investigators:** | Alexander K. Fremier, Cailin Huyck Orr |

## Publication

1. Parzych, JM, AK Fremier, C Hyuck Orr.(August 2015) Impacts of logjam installation on hyporheic exchange and nutrient uptake in a 4th order Washington stream. To submit to: Freshwater Science

Project ID 2014WA385B, 2014

# The effects of river restoration on nutrient retention and transport for aquatic food webs

Principal Investigators: Alexander Fremier, Cailin Orr – Washington State University
Students: Joe Parzych, Laura Livingston, John Jorgensen – Washington State University

> *The resilience of Pacific salmon is influenced by watershed processes that supply structural components of the aquatic environment such as coarse sediment and large wood, as well as those that support the transfer of energy and nutrients through aquatic food webs (Bisson et al. 2009).*

## Timeline note

This project has received a no-cost extension to continue this work through the summer of 2015 to complete the proposed work. Specifically, we completed the fieldwork and analysis for Question 1 and we are writing up the thesis for publication. We started the fieldwork for Question 2 on May 20th and will be completed by September 2015. Question 2 analysis and write-up are part of Laura Livingston's thesis (May 2016 expected completion).  The remaining USGS funds (~$4,000) will be spend by July 15th, 2015.

## Problem and Research Objectives

Stream restoration in the United States is a multi-billion dollar industry. Federal agencies spent $1.5 billion between 1997-2001 to recover steelhead and salmon in the Columbia River Basin (US GAO 2002). More recently in 2010, $80 million was spent on Columbia basin watershed restoration to improve salmon and steelhead populations, with $30 million allocated to Washington State alone. Allocations to Washington State are high because much of the Columbia watershed lies in the state, and 61% of Washington's area is affected by ESA listings of salmon and steelhead.

NOAA listed channel structure and nutrients limitation as major factors limiting listed steelhead and salmon populations in the interior Columbia River watershed. *While the investment in engineering stream restoration projects is immense, our knowledge of how logjam structures influence hyporheic exchange and nutrient retention is lacking; in addition, we lack clear evidence of the effectiveness of salmon carcass additions to increase the biomass of listed fish.*

Our study used two restoration actions as experiments to understand the ecological influence of a logjam installation and addition of salmon carcass analogs. Specifically, (1) we used a reach scale restoration of logjams as a field-manipulative experiment to quantify their effect on transient storage, hyporheic exchange, and nutrient uptake on the Tucannon River, WA; and, (2) we are conducting a pilot study in the Methow River Basin, WA to understand how salmon carcass analogs influence invertebrate community production. We used the field experiments to resolve two questions:

- **Q1. How do log jam installation impact transient storage, hyporheic exchange, and nutrient uptake in mid-order, low nutrient streams?**
- **Q2. How do salmon carcass analogs influence invertebrate community composition and secondary production compared to non-salmon and salmon bearing streams?**

*Note: Our original proposal asked similar questions for application in the Methow Basin. Unfortunately, large fires and instability in knowing when the logjams were to be installed forced us to move out of the Methow Basin for Question 1 and a year later for Question 2.*

## Methodology

**The influence of logjam installation on shallow ground water exchange and nutrient uptake**

Bonneville Power Administration (BPA) funded logjam installation in the Tucannon River in southeastern Washington in the summer of 2014. The Tucannon River in is a strongly nitrogen limited system that is currently experiencing low returns of steelhead and Chinook salmon. These logjams are intended to improve habitat for juvenile salmonids as well as add instream channel complexity and floodplain connectivity.

Our study involved evaluating how hyporheic exchange and nitrogen uptake changed after logjam installation. We applied a before after control impact, (BACI) experimental design to isolate the impacts of log jam installation on hyporheic exchange and nutrient uptake. We established two 750 m reaches: one study reach and one reference reach. Washington Department of Fish and Wildlife and Snake River Salmon Recovery Board in the study site installed engineered logjams in July 2014, while the upstream reference was not influenced by restoration activities. We measured hyporheic exchange and nutrient uptake in July, August, and September, with an additional nutrient uptake measurement taken in October. Hyporheic exchange was measured using piezometers installed 30 cm into the streambed. Nutrient uptake was measured using slug injections of ammonium, where a known mass of ammonium was injected at the upstream end of each reach and grab samples taken to measure the mass recovered downstream.

**The influence of salmon carcass addition on secondary production and composition**

The effect of restoration actions typically focus on monitoring fish and not on trophic production. Fish population dynamics are highly influenced by multiple factors, both within the basin and outside, which make them poor ecological indicators. This study aims to quantify the influence of salmon carcass additions on secondary production and composition, as these are the trophic basis of production for fish. The study asks 'what are the nutrient subsidy effects to lower trophic levels along both direct and indirect pathways?' We hypothesized that direct consumption is a relatively small contribution to salmon carcass effects on secondary production.

Using a controlled field manipulation, we will quantify invertebrate consumption of salmon carcasses and salmon carcass analogs. We will also compare invertebrate community composition in reaches with and without salmon carcass material. This composition data will be used to determine if salmon carcass subsidies affect invertebrate community composition and to compare relative invertebrate densities with invertebrates consumed by salmon. These manipulations will use natural salmon carcasses (spring Chinook) and salmon carcass analogs. Salmon carcass analogs are pellets of ground-up salmon that fisheries managers can use to stimulate growth of food resources for juvenile salmon.

We will conduct five controlled experiments and concomitant observational studies in the Methow River in north-central Washington in the summer of 2015. We will place salmon carcass analogs in non-salmon spawning streams during early summer and once again in early fall and measure colonization and consumption. Colonizing invertebrates will be sample and identified to species level to describe composition and abundance. We will extract gut contents from a selected number of ubiquitous taxa to quantify secondary production related to carcass addition. We will sample from control streams in both salmon spawning and non-spawning reaches. We will use stable isotopes of nitrogen ($N^{15}$) and carbon ($C^{13}$) to track enriched nutrients.

We consider the trophic transfer of nutrients to secondary production a better metric than fish population metrics for evaluating the influence of nutrient addition to restore salmon rearing ecosystems.

## Principle Findings and Significance

**The influence of logjam installation on shallow ground water exchange and nutrient uptake**
Our results indicate that logjam installation led to increased hyporheic exchange. Immediately after log jam installation, hyporheic exchange in the study site increased 56% compared to a 31% decrease in the reference site. The study site also changed from 100% upwelling to 63% upwelling and 37% downwelling immediately after restoration, demonstrating how logjams increase the heterogeneity of hyporheic exchange. Nutrient uptake was not significantly impacted by logjam installation, which could be due to a lag time either between installation and biotic response or methodological issues.

The patchwork of upwelling and downwelling sections observed following restoration has important implications for hyporheic flow paths and the solutes they bring into the hyporheic zone. Before installation in the study site, upwelling dominated the reach which were likely from long residence time hyporheic flows that originated upstream of the reach. The patchwork of upwelling and downwelling sections after restoration makes it possible that upwelling sections are now the result of downwelling sections occurring in the same reach. This shorter residence time water is likely higher in oxygen, and the greater magnitude of flux creates better habitat for spawning fish, insects, and other hyporheic organisms.

To our knowledge, this is the largest stream where hyporheic response to large wood installation has been measured using piezometers. Expanding our knowledge of hyporheic exchange is important in streams like the Tucannon where multiple anadromous salmonids live for at least a portion of their life cycle (Chinook, steelhead, bull trout). Future work should seek to evaluate how large streams respond to wood structures over time, by monitoring both geomorphic and hyporheic flow changes after high flow events mobilize bed material. Understanding the process of how hyporheic flows establish and develop will make predicting hyporheic response to restoration actions like log placement possible in other systems.

**The influence of salmon carcass addition on secondary production and composition**
Marine derived material from salmon may affect secondary production through direct consumption and indirect recycling pathways (Gende et al 2002). Direct consumption represents a more efficient transfer of salmon material to secondary production than the indirect pathway. However, direct consumption of salmon carcasses may be limited to a few taxa or may be inhibited by fungal growth on carcasses (Kohler et al 2008, Garman 1992). These limits on direct consumption of salmon material suggest that direct consumption effects on secondary production may be relatively small.

Previous studies on the effects of salmon carcasses and salmon carcass analogs have shown positive effects of salmon material on invertebrate communities (Honea and Gara 2009, Kohler et al 2012, and Minakawa et al 2002). Quantifying biomass changes and tracking enriched nutrients in invertebrate communities indicate invertebrate community responses to salmon. However, these measurements do not indicate the contribution of direct consumption to salmon carcass and salmon carcass analog effects on secondary production responses. By examining invertebrate gut contents, we will provide an estimate of the contribution of direct consumption to salmon carcass effects on secondary production. While direct consumption may have a relatively small contribution to secondary production, we expect that the insect taxa directly consuming salmon carcasses will have a high dietary reliance on that material.

## List of Students Supported

Joseph Parzych, MS – Environmental Science and Natural Resources May 2015
Laura Livingston MS – Environmental Science and Natural Resources May 2016 (expected)
John Jorgensen PhD -– Environmental Science and Natural Resources May 2018 (expected)

## Publications, and Awards and Achievements

Parzych, JM, AK Fremier, C Hyuck Orr. Impacts of logjam installation on hyporheic exchange and nutrient uptake in a 4th order Washington stream. To submit to: Freshwater Science (August 2015)
Robert Lane Fellowship, WSU School of the Environment (J. Parzych)
School of the Environment Graduate Research Stipend (2014-2015) (J. Parzych)

Invited speaker to the Regional Technical Team on restoration of hyporheic flow. Wenatchee, WA December 10 2014. (AK Fremier and JM Parzych)

Clearwater Fly Casters Scholarship (L. Livingston)
Newsroom Report, WSU Center for Environmental Research, Education, and Outreach (L. Livingston)
Boeing Environmental Award, WSU School of the Environment (L. Livingston)

Washington Department of Fish and Wildlife adopted our hyporheic monitoring protocol for monitoring logjam installation in the Tucannon in 2015. We provided the equipment and expertise for installation and study design.

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# New Generation of Iron-Enhanced Compost for Stormwater Treatment

## Basic Information

| | |
|---|---|
| **Title:** | New Generation of Iron-Enhanced Compost for Stormwater Treatment |
| **Project Number:** | 2014WA386B |
| **Start Date:** | 3/1/2014 |
| **End Date:** | 2/28/2015 |
| **Funding Source:** | 104B |
| **Congressional District:** | Washington 5 |
| **Research Category:** | Water Quality |
| **Focus Category:** | Toxic Substances, Water Quality, Models |
| **Descriptors:** | None |
| **Principal Investigators:** | Zhenqing Shi, Markus Flury, James Harsh |

## Publications


1. Zhenqing Shi, Patrick Freeze, Jonathan Abarca, Markus Flury, and James B. Harsh. A new generation of Fe-enhanced compost for urban stormwater treatment. In preparation for Water Research
2. Jonathan Abarca, Zhenqing Shi, Jeff Boyle, James Harsh. Iron-Enhanced compost for soil remediation. Poster for 2014 WSU SURCA
3. Jonathan Abarca, Zhenqing Shi, Jeff Boyle, James Harsh. A new iron-enhanced compost for stormwater treatment. Poster for 2014 WSU SURCA.

New Generation of Iron-Enhanced Compost for Stormwater Treatment

Principal Investigators: Zhenqing Shi, James Harsh, Markus Flury

Project Annual Report

2014WS386B

May 24, 2015

- **Problem and Research Objectives**

Stormwater is the major conduit of pollutants into the Puget Sound. Many streams and wetlands have been degraded by urban development and associated stormwater impacts and require habitat and water quality improvement, while others still support endangered salmon and require protection. Improving stormwater management to reduce levels of pollutants entering the Sound is one of six key state policy objectives of the Puget Sound Partnership to protect water quality, habitat, and aquatic resources, thus reversing the Sound's decline and restoring it to health by 2020. In the Puget Sound, more than 13,000 lb of toxic metals are released into the Sound daily (Ecology and King County 2011). Lead (Pb) is one of the major toxic heavy metals that pose threats to human health and environmental quality statewide. The major sources of Pb in stormwater in the Puget Sound area include human activities such as shooting and fishing, leaching from roofing material, and fuel combustion. In the Spokane area, Pb contamination sources include Pb-based paint and residual deposits from past use of leaded gasoline, pesticides containing Pb, and mine waste from the Coeur d'Alene Basin. Elevated nutrients in stormwater is another major concern that impairs environmental habitats through. In the state of Washington, more than 260 bodies of water are known to be polluted with nutrients such as P and N.

Compost is one of most popular amendments used in bioretention systems for stormwater treatment because it retains a variety of stormwater constituents. Traditional compost made with various organic wastes improves retention of toxic heavy metals and organic pollutants but, over time, it can contribute to P export as the compost decomposes. Iron-enhanced compost, in which Fe is added to complex with organic functional groups in the compost, has been developed specifically for sequestering both heavy metals and oxyanion contaminants (Brown et al. 2012; Shi et al. 2012). Using Fe-enhanced compost for stormwater treatment has several advantages, such as superior ability to remove both toxic metals and P, low cost by using natural and waste materials (both plant materials and Fe compounds), improved soil properties such as increased water retention and fertility, and urban agriculture promotion while minimizing the impact on stormwater quality. However, critical questions remain concerning the capacity and stability of Fe-enhanced compost for contaminant removal both in existing bioretention systems and in development of urban gardens. There are no predictive tools for the efficiency of Fe-compost and its long-term effects on environmental quality.

The goals of the proposal are to evaluate the stormwater treatment capabilities of our newly developed Fe-compost for the retention/removal of stormwater pollutants. Our specific objectives include:

(1) Characterize reactive sites in Fe-compost with a suite of chemical and spectroscopic techniques and determine the capacity of Fe-compost retention of Pb;

(2) Evaluate the efficiency, stability, and longevity of Fe-compost for stormwater treatment in stirred-flow experiments and develop mechanistic-based kinetics models for predicting stormwater quality and fate of sequestered contaminants.

- **Methodology**

**1. Preparation of the Fe-compost.**

<u>Initial Compost Development</u>. The compost used for this study was pulled from Washington State University Composting Facility, Pullman, Washington. The compost feedstock was derived from university food and chemical laboratory waste, as well as local woody biomass and

animal bedding. The compost product in our study was the result of a 30-day thermophilic composting method utilizing 12 ft wide x 5 ft tall windrows with an initial C:N ratio of 35/40:1 and a moisture content of approximately 65% impregnated with treatment bags. 21 fine-mesh bags were inserted in three separate but relatively close (1 m apart) locations within a composting pile. The mesh bags contained two iron treatments at three concentrations each (50, 150, 300 g/kg for iron (II) gluconate (FG); 31, 93, and 190 g/kg for iron (II) sulfate (FS) incorporated into 1 kg of compost, plus three control bags containing no amendments. At the end of the 30-day composting process, the bags were removed and the contents air dried and stored at -20 $^{o}$C to halt microbial activity in sealed ziplock bags.

Second Compost Development: Minimizing Dissolved Organic Carbon (DOC). Compost utilized in bioretention systems requires a stable, well-developed, and uniform media. The maturity of compost can have a direct impact on its sorption capacity for metals in the environment and ultimately their transport. One such transport mechanism correlated to compost maturity is the lower molecular-weight mobile component of compost, dissolved organic carbon (DOC) which, in turn, is connected to microbial decomposition of organic matter during the various composting stages (Zmora-Nahum, 2005). To assess DOC as a function of compost maturation time, 63 fine-mesh bags were separated by month (1 month, 2 month, and 3 month) and inserted in three separate but relatively close (1 m apart) locations within a composting pile. A single set of mesh bags (21) contained three varying amounts of each treatment (50, 150, 300 grams for iron (II) gluconate; 31, 93, and 190 grams for iron (II) sulfate) incorporated into 1 kg of compost, plus three controls bags containing no amendments, and all 3 sets were identical. The bags were removed in one month increments. Upon removal, the bags were weighed, and air/oven dried weights were determined. Roughly 400 grams was air dried, ground, and stored in a 1-liter ziplock bag; the rest was refrigerated at -20 $^{o}$C to halt microbial activity.

Third Compost Development: Minimizing DOC by Managing the Carbon Source. Beginning in the fall of 2014, 4×4×4 foot composting bins were purchased from O2 Compost® Company (Snohomish, WA) and assembled. Seven bins were constructed as outlined in diagram 1: 3 Fe-sulfate treatments (31, 93, and 131 g Fe/kg compost), 3 Fe-gluconate treatments (50, 150, 300 g Fe/kg compost), and one control. Similar to the previous approaches, each bin will house one treatment and will be composted until the final curing stage is reached.

**2. Compost Characterization**

Solid State Nuclear Magnetic Resonance (NMR). Removal of paramagnetic material is required prior to analysis due to the magnetic interference of iron in NMR spectroscopy. Compost sample preparation for solid-state NMR analysis followed a modified version of Skjemstad et al (1994). Compost samples were sieved (2 mm) and approximately and 3 grams were placed in 30 mL of 2% HF solution in a 50 mL polypropylene centrifuge tubes. The tubes were then placed on a reciprocal shaker on low for 24 hours. They were then spun at 20,000 rpm for 20 minutes, and the supernatant was removed and disposed. A successive 5 rinses with deionized water followed, coupled with spinning and removal of the supernatant. The compost was removed and air dried for 2 days.

Compost samples were initially milled with a mortar-and-pestle, and processed sequentially under the same NMR acquisition parameters. A 5 mm zirconia rotors (Revolution NMR, LLC, AMP4089-001 5 mm, 160 ul, Rotor Assembly, Teflon Caps, Zirconia, CS) was filled with approximately 100 mg of milled compost. Solid state $^{13}$C cross polarization/magic angle spin (CP/MAS) analyses was conducted using the Bruker Avance 400 spectrometer (400 MHz), with a frequency of 100.63 MHz (Bruker AXS, Inc., Madison, WI, U.S.A.) at Washington State University's NMR Center (Pullman, WA). The spectrometer employed a 7.5 mm double resonance HX MAS probe (Chemagnetics, Varian, Inc., Palo Alto, CA, U.S.A.). $^{13}C$ CP/MAS NMR spectra acquisition used a spinning speed of 6 kHz, with a cross polarization contact time of 1 ms followed by an acquisition time of 5.1 ms, a pulse width of 14 µs, and a relaxation delay of 4s. The spectra produced were the result of 17,261 scans, with chemical shifts set at units of parts per million (δ).

Attenuated Total Reflectance – Fourier Transform Infrared Spectroscopy (ATR-FTIR). ATR-FTIR analysis utilized dried and ground compost samples. Sixty scans per sample were acquired using a Shimadzu IR-Prestige 21 (Columbia, Md., USA) analyzer modified with an Attenuated Total Reflectance (ATR) unit (PIKE Technologies, Madison, Wis., USA). Focusing on the spectral range of 4000 to 500 $cm^{-1}$, absorbance intensities were used to compare changes across the sample set, disclosing differences in both carbon and functional groups.

**3. Batch Adsorption Experiments**

Adsorption Edge Experiment. Pb adsorption on selected iron-compost samples was studied at a fixed total Pb concentration (~0.8-1.0 mM) for each compost while reaction pHs varied from low to high (pH 3 – 8) using a batch method. The reaction pHs were adjusted by adding NaOH or HCl. The solid:solution ratio was fixed at 5 g/L.

Adsorption Isotherm Experiment. The Pb adsorption on selected iron-compost samples was studied at pH 6.0 and 7.0 while total Pb concentrations varied from low to high (up to about 0.8 mM). The reaction pHs were adjusted by adding NaOH or HCl. The solid:solution ratio was fixed at 5 g/L (for pH 6.0) and 10 g/L (for pH 7.0).

**4. Stirred-flow Kinetics Experiments**

Pb adsorption was conducted by continuously pumping Pb stock solution through the stir flow chamber at varying flow rates and Pb concentrations. About 0.02 g of compost was put in stir flow chamber with background electrolyte and a stir bar, which was covered with a filter (Figure 1). Filtrate was collected by a fraction collector. Filtrate samples were analyzed using a Microwave Plasma-Atomic Emission Spectrometer (MP-AES).

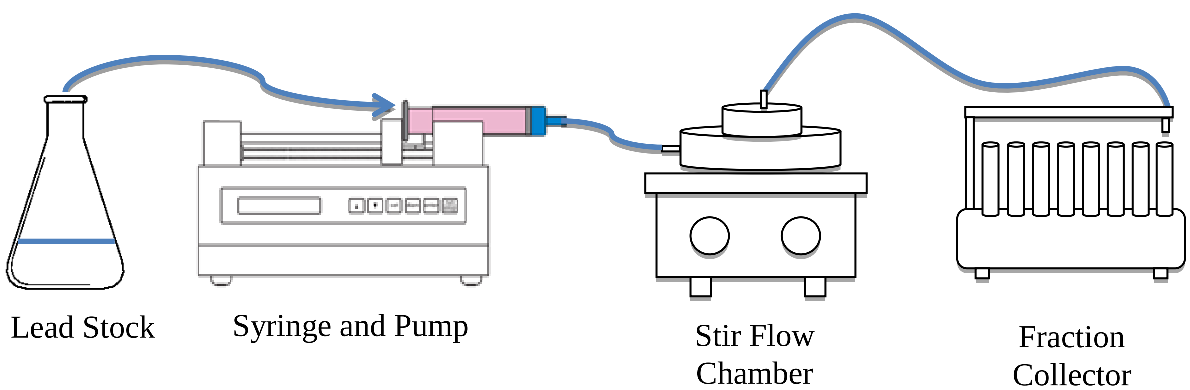


Figure 1: Illustration of Pb adsorption experiment.

- **Principle Findings and Significance**

**1. Preparation of the Fe-compost.**

During our initial experiments, Fe was successfully amended into the Fe-compost samples, while higher Fe loadings were achieved using FG compared with FS salts. The final Fe concentrations in Fe-compost samples were summarized in Table 1.

| Samples | Estimated [Fe] mol/kg | [Fe] mol/kg | Std | pH |
|---|---|---|---|---|
| Control | --- | 0.0569 | 0.0308 | 8.6 |
| FG50 | 0.2 | 0.206 | 0.0218 | 5.9 |
| FG150 | 0.6 | 0.493 | 0.0668 | 4.9 |
| FG300 | 1.2 | 1.47 | 0.180 | 4.6 |
| FS31 | 0.2 | 0.214 | 0.0362 | 5.9 |
| FS93 | 0.6 | 0.293 | 0.0484 | 5.1 |
| FS190 | 1.2 | 0.308 | 0.0547 | 3.3 |

**Table 1. Iron gluconate (FeG) and Iron sulfate (FeS) final concentrations in compost after 1 month**

In our second trial, we observed varying DOC concentrations in different Fe-compost samples. Table 2 shows the final DOC (g/kg) of various treatments after three months of composting process. The large windows at the WSU Compost Facility housing the treatment bags were found to be a source of excess DOC in the final compost product. It was understood that to ultimately minimize DOC in the final compost product, limiting the total carbon source used for our compost was required so that the final maturation stage and lowest release of DOC can be achieved. Instead of using large, compost windrows, smaller composting bins were employed.

| Treatment | DOC (g/kg) |
|---|---|
| FG300B1 | 50.6 |
| FG300A3 | 14.5 |
| FS93B1 | 4.37 |
| FS93A3 | 4.51 |
| Control | 15.5 |

| | |
|---|---|
| A1 | |
| Control B3 | 18.4 |

**Table 2. Dissolved organic carbon in compost samples with various treatments. FG300 represents the Fe-gluconate 300g/kg treatment; FS93 represents the Fe-sulfate 93g/kg treatment**

The results from the first two trials help to produce Fe-compost with low DOC concentrations, which is in process for our third trial.

**2. Characterization of Fe-compost using both NMR and FTIR**

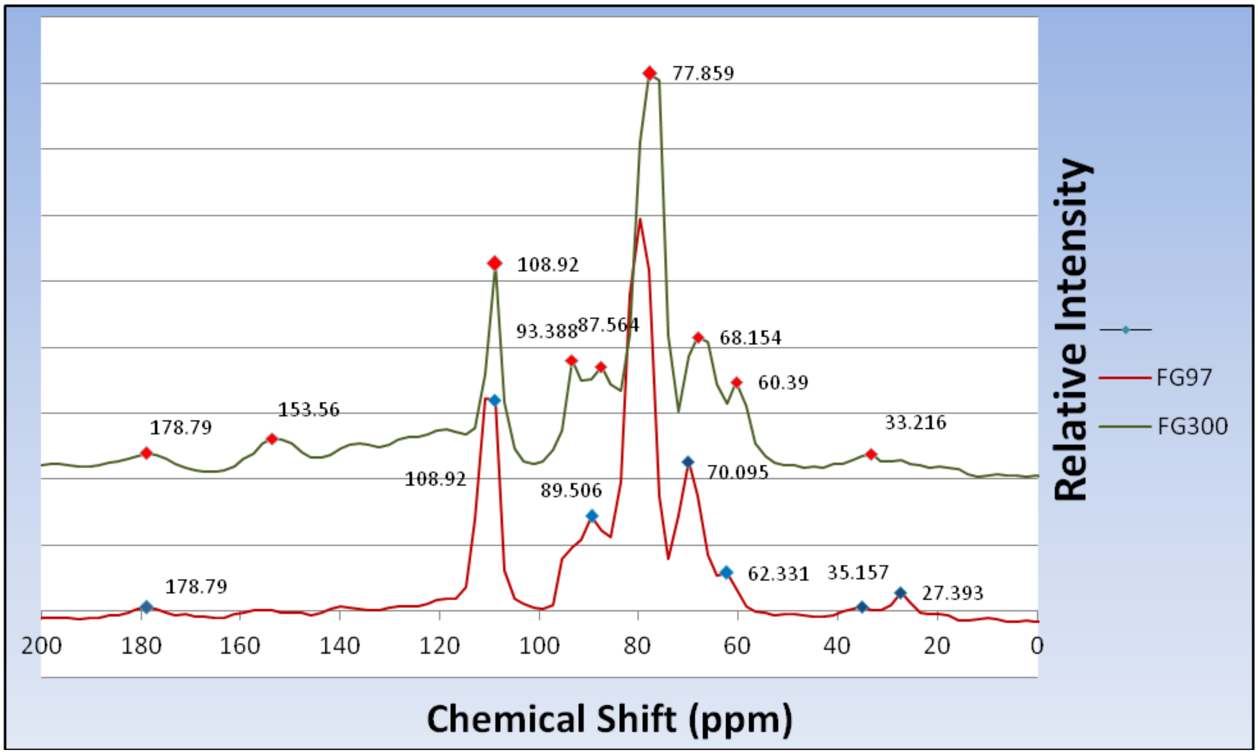


**Figure 2. $^{13}$C-NMR spectra of FG300 and FG97 samples.**

The $^{13}$C-NMR spectra pictured above were sourced from two different iron-gluconate concentrations, 300g Fe/kg (FG300) and 97g Fe/kg (FG97). Besides the iron concentrations, the other difference in the sample treatments was the FG97 compost, a compost product composted to completion (i.e. reached the final, low temperature curing phase of the composting process). FG300 was 30 day compost, by comparison, a relatively young compost. Both spectra show very similar peaks with prominent differences in various carbon groups. The peak assignments are based on findings from the literature (Spaccini and Piccolo, 2008; Gao et al., 2015). For both spectra pictured, the major peaks of interest occurred in the regions of 0-110 ppm (aliphatic) and 160-190 (carboxylic).

For the higher iron treatment, FG300, the most intense peaks occurred at 68.1, 77.9, 87.6, and 108.9 ppm, which are specific to carbons of cellulose (Spaccini and Piccolo, 2008; Gao et al., 2015). The peak at 60.4 ppm denotes lignon methoxy carbons groups (Gao et al., 2015). FG300 Phenolics are associated with the peaks at 153.6 and carboxylic carbons are noted at 178.8 ppm (Gao et al., 2015). Comparatively, FG300 shows a much higher concentration of carbon phenolics and available ligno-cellulose, with lower recalcitrant aliphatic region (33.2 ppm), especially when compared to FG97. There is a similar composition, overall, in both in carbon types, showing a relatively similar composition of the two compost samples.

**ATR-FTIR Solid Compost Samples**

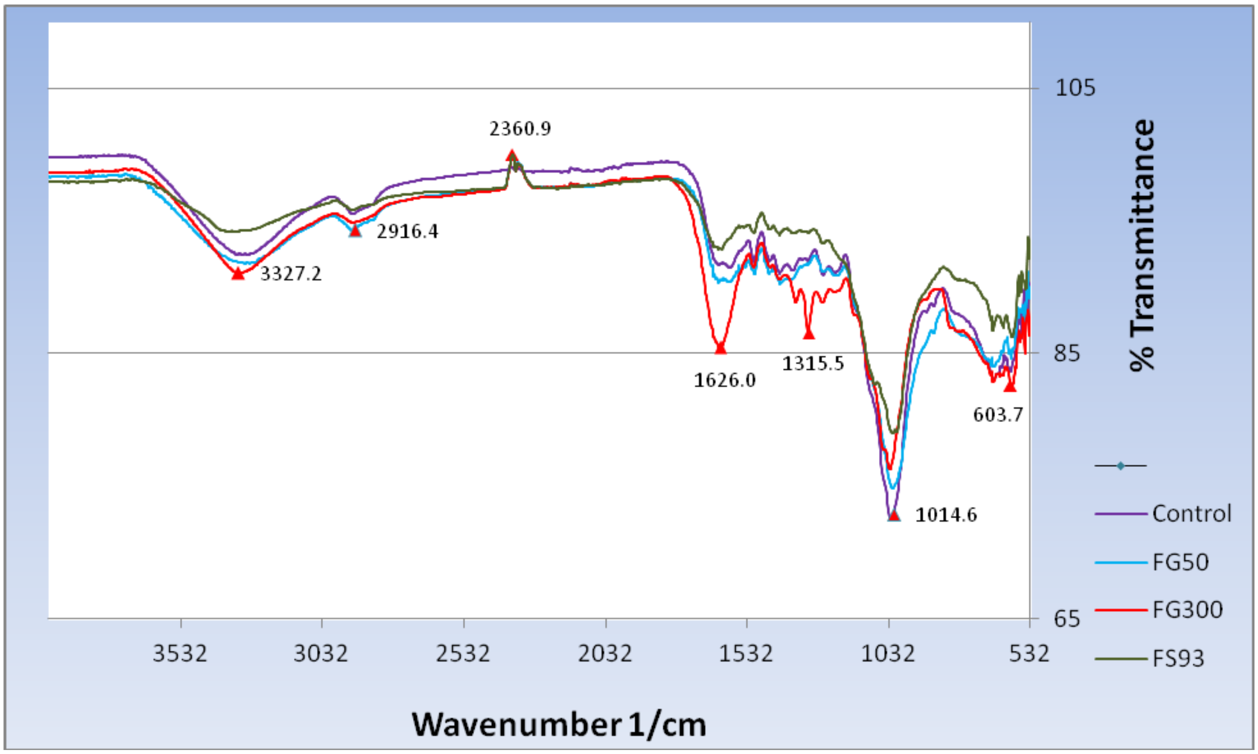


**Figure 3. ATR-FTIR of four compost products: control (no iron), FG50 (50g/kg Fe), FG300 (300g/kg Fe), and FS93 (93g/kg Fe from Fe-sulfate)**

Selected samples were analyzed using ATR-FTIR. Disclosing the stretch and vibrational nature of various covalent bonds within a sample, ATR-FTIR supports not only the compost NMR data but may also show iron complexation with organic functional groups within our selected samples (Sharma, Ofner, & Kappler, 2010). Assignments were gathered from published literature (Smidt & Meissl, 2007; Huang et al, 2006; and Carballo et al. 2008). Analysis of the solid compost shows nearly identical peaks. When overlain, it was difficult to compare and extrapolate from the various peak intensities, but the highest iron treatment, FG300, showed the most unique peaks overall.

The greatest peak intensities in all samples were at the 1014-1024 peak (between Abs = 0.14 to 0.10). This peak range is indicative of either C-O-C or C-O-P bonds in polysaccharides. Both the C-O-C and C-O-P bonds correlate with the high fraction of structural cellulose as indicated in the solid state carbon NMR. The slightly higher intensity of the polysaccharide region in both the FT-IR and the solid state $^{13}C$-NMR are expected with the younger FG300 compost, as this region is highly accessible and subject to microbial degradation during the composting process; an older compost of the same feedstock will show an overall decrease in the region (Spaccini & Piccolo, 2008).

The next highest peak intensities were seen in the very broad region between 594-665 range for all compost samples (Abs: control = 0.081, FG50 =0.076, FG300 = 0.079, FG 93 = 0.064 for both). This broad peak is associated with the S-O bending of sulfate, but the upper broader shoulder on the FG300 peak might be more associated with the C-O bending of carbonate. The FS (iron-sulfate) treatment did not show any prominent peaks with these regions. Given the high solubility of $FeSO_4$ and the higher anion competition with DOC during the composting process, less inorganic sulfate would likely remain in the pile after completely composting.

The next highest peak intensities were seen at the peak range marked at 1626. This large peak is associated with C=C bonding in aromatic ring structures. FG300, by far, had the largest and most distinctive peak in this region among all the spectra. According to Sharma et al (2010), this specific peak may be indicative of iron complexation with carboxylic groups within organic matter, shifting the peaks slightly to the right in the spectra. This occurs at roughly 1600 and at <1350 range in the IR spectra for both COO- and phenolic groups, respectively (Sharma, Ofner, & Kappler, 2010).

Closely behind are the peaks marked at 1315 (Abs = 0.03 - 0.06). This specific peak is associated with the COO- stretch of carboxylic acid groups or the C-O stretch of carbonate. Compared to the organic carbon source, inorganic carbonate would likely have a less prevalent influence in peak intensities. A small fraction of the peak at 1014 may be attributed to the Si-O stretch of clays as the peak at 3327 is indicative of the SiO-H stretch sourced form clay minerals with in the compost.

**3. Batch Adsorption Experiments**

Lead adsorption on various compost samples is presented in Figures 4-6. Pb adsorption was linear at low Pb concentrations, and Pb adsorption linearly increased with solution Pb concentrations. Pb adsorption approached saturation at high Pb concentrations and is well-described by the Langmuir equation. Pb adsorption to the Fe-gluconate compost was comparable to that of the $FeSO_4$- compost even though the concentration of Fe was lower.

At pH 7 in the linear adsorption range, compost samples with Fe-gluconate showed higher adsorption than that of compost samples with $FeSO_4$, suggesting Fe-gluconate may be more effective than $FeSO_4$ for Pb adsorption at the low Pb concentrations expected in soils and water.

The adsorption edge occurs at a significantly lower pH on the $FeSO_4$-based compost than that made using Fe-gluconate. This indicates that the nature of Pb-sorbing sites on $FeSO_4$-based compost are different than those on the Fe-gluconate-based compost. One possibility is that there are more Pb-OM sorption sites in the $FeSO_4$-based compost whereas the Fe-gluconate sample has more Fe-OH sites.

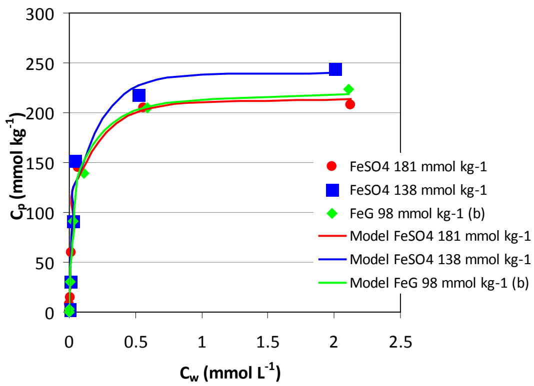


**Figure 4: Pb adsorption isotherms with selected composts at pH 6 and modeling results obtained using Langmuir equation. Model parameters are presented in Table 1.**

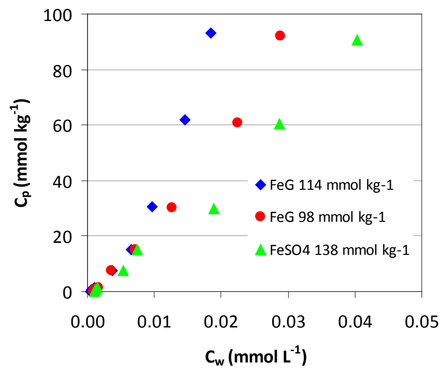


**Figure 5: Pb adsorption isotherms with three selected composts at pH 7.**

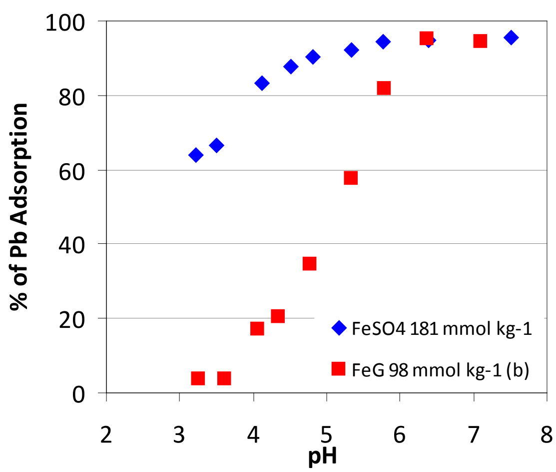


**Figure 6: Pb adsorption edge curves made by representative compost samples of FeSO4 and FeG.**

Overall, all iron-compost samples showed high Pb adsorption ability based on our adsorption experiments. The effect of Fe content in compost on Pb adsorption is not conclusive, and a better understanding of both Fe-OH and OM sites in the mixed system will be required. Pb adsorption is more effective in a higher pH solution because there is less $H^+$ to compete with Pb for both organic and Fe-OH adsorption sites, and the capacity and affinity of selected compost samples for Pb adsorption can be estimated by the Langmuir adsorption model. At pH 6, the capacity of the Fe-gluconate-based compost is comparable to those of the $FeSO_4$-based composts with much higher Fe contents. Interestingly, the higher affinity of Pb for the $FeSO_4$-based composts is the opposite of what is observed at pH 7, implying the nature of sorption sites depends on Fe source.

**4. Stirred-flow Kinetics Experiments**

During the stirred-flow kinetics experiments, the effluent Pb concentrations increased with longer leaching time, due to more binding sites occupied by the adsorbed Pb, and then approached a plateau close to the influent Pb concentration. The adsorption rates of Pb on FG 97 and FG 134 are dependent on the flow rates (Figures 7-8), with lower flow rates favor Pb adsorption since slower flow rates allowed for more time and contact for chemical reactions to occur.

At the similar experimental conditions, Pb adsorption ability FG 134>FG97>FS 138 (Figure 9), suggesting that FG compost generally has higher adsorption ability than FS compost. Consistent with the batch adsorption experiments, all Fe-composts demonstrate a high Pb adsorption capability.

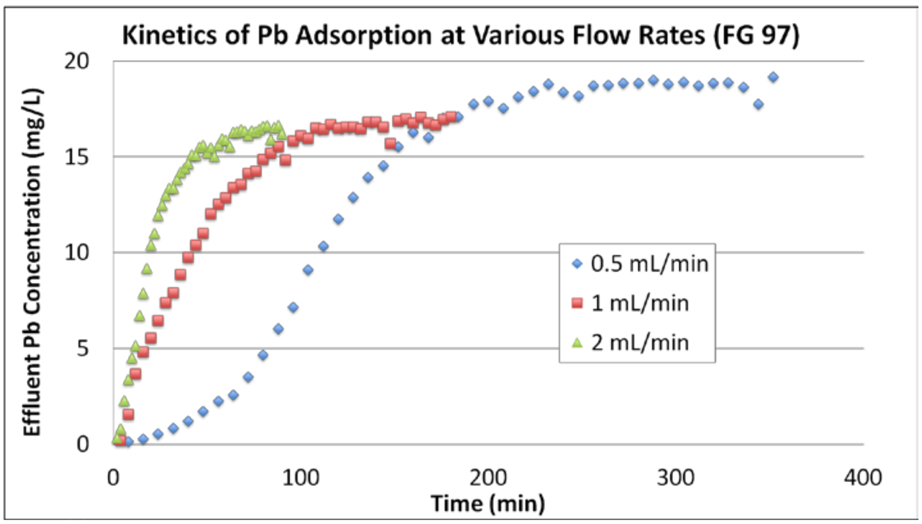


**Figure 7. Kinetics of Pb adsorption on FG97 compost at various flow rates.**

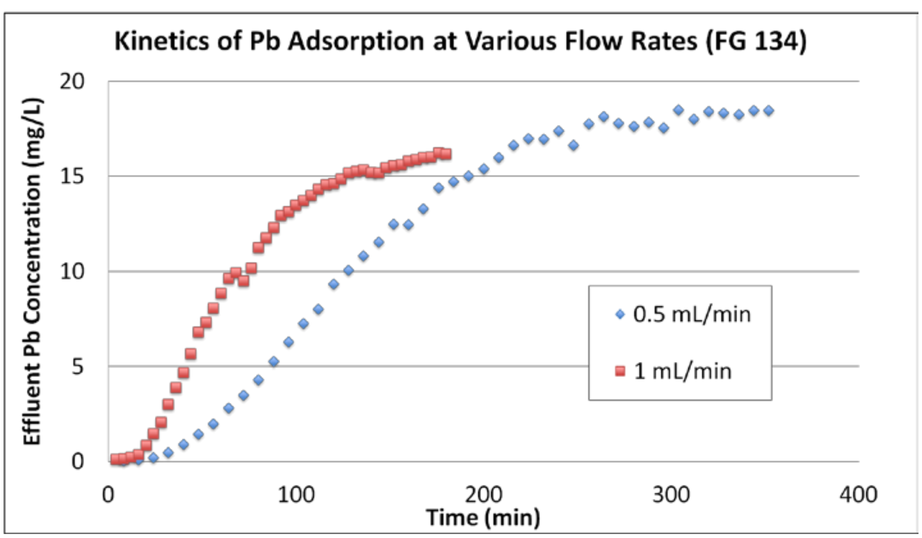


**Figure 8. Kinetics of Pb adsorption on FG134 compost at various flow rates.**

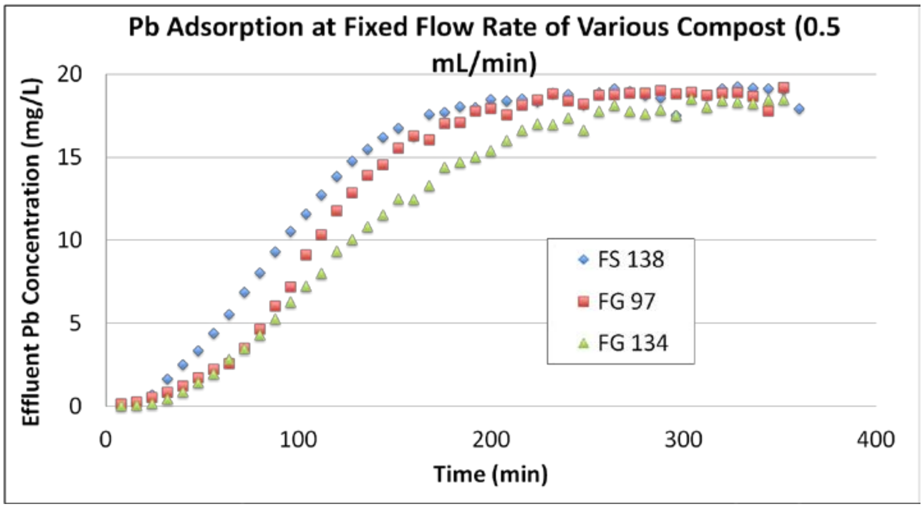


**Figure 9. Kinetics of Pb adsorption on various compost samples at the fixed flow rate.**

## 5. Discussion and Summary

Given we are able to achieve a final maturation/curing stage during the final compost process with the bins from $O_2$ Compost®, the DOC should be low enough to minimize transport of heavy metals within our study. This is also important for field applications in general as bio-filtration systems may facilitate heavy metal transport if improper composting methods are used. Zmora-Nahun et al (2005) focused on dissolved organic carbon as a function of feedstock material and composting time and found that, regardless of the source material, an average DOC concentration of 4 g/kg was achieved with all compost, the ultimate variable being composting time. The measure of this level of decomposition can be tied to the water-extraction or soluble carbon phase of the decomposition process, which makes DOC analysis useful for metal sorption and transport studies (Bernal, Sánchez-Monedero, Paredes, & Roig, 1998).

The NMR coupled with ATR-FTIR data is a useful method for characterization of compost. Overall, the compost samples sourced from 30 day composting show a relatively young media, rich in labile carbon groups. With the successive subsampling during the composting process, we would be able to see a gradual decrease in cellulose carbon and an increase in stable, aromatic carbon groups (Spaccini & Piccolo, 2008). The FG97 compost, a fully composted media, shows lower labile carbon and more recalcitrant or stable (lignin) components. With DOC analysis during these same subsampling points, we would be able to relate DOC behavior with compost maturity. Comparing compost maturity with solid-state NMR has been demonstrated to be a useful and even quantitative method for compost analysis (Spaccini & Piccolo, 2008). As our compost is amended with iron and requires a pretreatment removal step prior to NMR analysis, ATR-FTIR would likely be a useful and feasible approach for iron analysis within organics (Sharma, Ofner, & Kappler, 2010), especially coupled with other adoption analyses (arsenate or phosphate adsorption).

Both batch and stirred-flow experiments demonstrated that Fe-compost is a promising product for removing Pb from the stormwater, with high Pb adsorption capacity and fast adsorption rates. To further understand the mechanisms of Pb reactions with Fe-compost, the characterization of Fe associated functional groups is essential. Currently we are conducting experiments at the Pacific Northwest National Laboratory to investigate Fe species in Fe-compost using Mossbauer Spectroscopy at EMSL. A mechanistic model is also under development to predict Pb reactions with Fe-compost. Furthermore, we will investigate the ability of P removal with our latest Fe-compost products from the 3rd trial.

As a whole, we have learned that compost used in biofiltration systems, specific for urban settings, is something that should be approached with a complete understanding of the biological, chemical, and physical controls that go into proper compost production. Improper development would likely result in the compost serving as a contamination source rather than a sink, a result directly counter to it primary purpose, which is mitigating the impacts of environmental contaminants sourced from urban development. Iron compost as a novel product will significantly improve the current practice to design effective bioretention systems for stormwater treatment.

- **List of Students Supported**
  1. Patrick M. Freeze, Ph.D. Graduate Research Assistant, Department of Crop and Soil Sciences, Washington State University, Pullman
  2. Jonathan Abarca, Undergraduate Intern, Department of Crop and Soil Sciences, Washington State University, Pullman

- **Publications**
  1. Zhenqing Shi, Patrick Freeze, Jonathan Abarca, Markus Flury, and James B. Harsh. A new generation of Fe-enhanced compost for urban stormwater treatment. In preparation for *Water Research*
  2. Jonathan Abarca, Zhenqing Shi, Jeff Boyle, James Harsh. Iron-Enhanced compost for soil remediation. Poster for 2014 WSU SURCA.
  3. Jonathan Abarca, Zhenqing Shi, Jeff Boyle, James Harsh. A new iron-enhanced compost for stormwater treatment. Poster for 2014 WSU SURCA.

- **Awards and Achievements**
  1. The U.S. Fulbright award (2015-2016) for Patrick Freeze.
  2. The Association of International Agriculture and Rural Development Future Leader Forum (AIARD-FLF) award for Patrick Freeze.

**Reference:**


Bernal, M. P., Sánchez-Monedero, M. A., Paredes, C., & Roig, A. (1998). Carbon mineralization from organic wastes at different composting stages during their incubation with soil. Agriculture, *Ecosystems & Environment*, 69(3), 175-189.

Brown, S. L., I. Clausen, M. A. Chappell, K. G. Scheckel, M. Newville and G. M. Hettiarachchi (2012). High-Iron Biosolids Compost-Induced Changes in Lead and Arsenic Speciation and Bioaccessibility in Co-contaminated Soils. *Journal of Environmental Quality* 41(5): 1612-1622.

Carballo, T., Gil, M., Gomez, X., Gonzalez-Andres, F., & Moran, A. (2008). Characterization of different compost extracts using Fourier- transform infrared spectroscopy ( FTIR) and thermal analysis. *Biodegradation*, *19*(6), 815-830.

Ecology and King County (2011).Control of toxic chemicals in Puget Sound: assessment of selected toxic chemicals in the Puget Sound basin, 2007-2011. Washington State Department of Ecology, Olympia, WA and King County Department of Natural Resources, Seattle, WA.

Gao, X., Laskar, D. D., Zeng, J., Helms, G. L. and Chen, S. (2015). A 13CCP/MAS-based nondegradative method for lignin content analysis. *ACS Sustainable Chem. Eng.* 3, 153-162.

Huang, G., Wu, Q., Wong, J., & Nagar, B. (2006). Transformation of organic matter during co-composting of pig manure with sawdust. *Bioresour. Technol.*, *97*(15), 1834-1842.

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Shi, Z., Y. W. Chan and J. B. Harsh (2012).Lead adsorption on iron-amended composts. The 22nd V.M. Goldschmidt Conference. Montreal, Canada.

Smidt, E., & Meissl, K. (2007). The applicability of Fourier transform infrared ( FT- IR) spectroscopy in waste management. *Waste Manage.*, *27*(2), 268-276.

Spaccini, R., & Piccolo, A. (2008). Spectroscopic Characterization of Compost at Different Maturity Stages. *CLEAN – Soil, Air, Water*, 36(2), 152-157.

Zmora-Nahum, S. M. O. T. J. C. Y. (2005). Dissolved organic carbon (DOC) as a parameter of compost maturity. *Soil Biology & Biochemistry*, 37(11).

# Information Transfer Program Introduction

The administration and Staff of the WRC includes Jonathan Yoder (Director, 50% appointment in WRC), Jennifer Adam (Associate Director, 25% appointment in WRC), Julie Padowski (Clinical Assistant Professor, 50% appointment in the WRC), as well as administrative support staff. In addition, outreach activities have been carried out by other affiliated researchers through extramural research programs.

The WRC administration has been active in outreach with water research and management professionals, and other stakeholders in relation to WRC research activities and in response to requests by stakeholders on other pressing issues. The WRC administration and staff have presented their research in numerous professional conferences, stakeholder workshops and meetings, legislative testimony and work sessions, have interacted with stakeholders and policymakers in various other ways, including conference sponsorship and session organization, expert panel participation, and university and external administrative activities. The WRC has also been active redesigning the Center's website, and reinvigorating and modernizing its communications strategy.

# SWWRC Information Transfer Program

## Basic Information

| | |
|---|---|
| **Title:** | SWWRC Information Transfer Program |
| **Project Number:** | 2014WA387B |
| **Start Date:** | 3/1/2014 |
| **End Date:** | 2/28/2015 |
| **Funding Source:** | 104B |
| **Congressional District:** | Wa 5th |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Education, Management and Planning, None |
| **Descriptors:** | None |
| **Principal Investigators:** | Jonathan Yoder, Jennifer Adam |

## Publications

1. Jonathan Yoder, Michael Brady, Joseph Cook Stephen Katz, Daniel Brent, Shane Johnston, Keyvan Malek, John McMillan, and Qingqing Yang. 2014. Benefit-Cost Analysis of the Yakima Basin Integrated Plan Projects. Report submitted to the Washington State Legislature December 15. 196 pp. http://swwrc.wsu.edu/2014ybip/
2. Yoder, Jonathan, Adrienne Ohler, and Hayley Chouinard. 2014. What floats your boat? Preference revelation from lotteries over complex goods. Journal of Environmental Economics and Management} 67:412-430.
3. Ohler, Adrienne, Hayley Chouinard, and Jonathan Yoder. 2014. Interest group incentives for post-lottery trade restrictions. Journal of Regulatory Economics 45(3):281-304. http://dx.doi.org/10.1007/s11149-014-9246-y.
4. Liu, M.L., J.C. Adam, Z. Zhu, and R. B. Myneni, 2015. Vegetation dynamics play a role in changing water fluxes over the conterminous U.S. during 1983-2009, J. Geophysical Research (submitted).
5. Clark, M.P., Y. Fan, D.M. Lawrence, J.C. Adam, D. Bolster, M. Kumar, L.R. Leung, D. Scott Mackay, C. Shen, S.C. Swenson, X. Seng, et al, 2015. Improving the representation of hydrologic processes in Earth System Models, Water Resources Research (in review).
6. Reyes, J.J., J. Schellberg, S. Siebert, J.C. Adam, M. Elsaesser, and F. Ewert, 2015. Refining estimates of nitrogen uptake in grasslands: Application of the nitrogen dilution curve, Agronomy for Sustainable Development (accepted).
7. Brown, S., A. Easley, D. Montfort, J.C. Adam, B. Van Wie, A. Olusola, C. Poor, C. Tobin, A. Flatt, 2014. Effectiveness of an interactive learning environment utilizing a physical model, Journal of Professional Issues in Engineering Education and Practice, 140(3), 04014001.
8. Padowski, J.C. and Gorelick, S.M., 2014. Global analysis of urban surface water supply availability. Environ. Res. Lett. 9 104004 doi:10.1088/1748-9326/9/10/104004.
9. McDonald, R.I., Weber, K., Padowski, J., Flörke, M., Schneider, C., Green, P.A., Gleeson, T., Eckman, S., Lehner, B., Balk, D., Boucher, T., Grill, G., Montgomery, M., 2014. Water on an Urban Planet: Urbanization and the Reach of Urban Water Infrastructure. Global Environmental Change 27: 96–105.

# State of Washington Water Research Center Information Transfer Program

## 2014WA387B

Much of the administrative activity of the WRC this year has been focused on outreach, collaboration, and information transfer as described in the Introduction of this report.

### Website and communications infrastructure

After assessing the WRC's past communications and branding, the WRC administration decided to revamp the WRC's branding, web presence, and communications systems from the ground up. WRC has been working with the WSU Office of Communications to develop the initial website and brand. New WRC logo and letterhead have been selected. Because the old WRC website was outdated both in its content and overall structure, the WRC administration decided to rebuild the Center's web presence from scratch as well. The website, swwrc.wsu.edu, is in development stage. Because the WRC has a statewide identity rather than being solely a part of WSU, we worked with the WSU Office of Communications to create a basic design that is visually striking, but different than the WSU brand per se. We are considering hiring an additional web developer to help us take the next step to a vibrant, information-rich website.

### Education and curriculum

To pursue the WRC's education mission, in addition to supporting graduate student research through the seed grant program and extramural research efforts, The WRC is actively engaged in the process of developing a Certificate in Water Sciences and Management for undergraduate and graduate students at WSU. In an effort to be sensitive to other department's course development and to most effectively use the existing water-related curriculum, we are identifying a core curriculum of existing WSU water-related courses. These courses will be grouped into several major themes a student can pursue, for example Riparian/aquatic ecology, Water management and policy, Water Quality, Groundwater, and Surface Water. Certificate requirements will be consistent with WSU guidelines. In addition to a Certificate, the WRC is also reviewing different strategies for implementing a "floating" interdisciplinary graduate program. Several universities have successful examples of these types of programs.

### Collaboration and network building

We are developing collaborations with other Centers at WSU and beyond. The WRC and the Center for Environmental Research, Education, and Outreach (CEREO) administrators jointly submitted a USDA AFRI CAP proposal in 2014 through the Center for Sustaining Agriculture and Natural Resources (CSANR). We are also working to build operational connections with the Washington Stormwater Center, which has a strong WSU presence and a home in Western Washington. This Center has expertise and a focus that is both historically and currently different but complementary to the focus and expertise of the

WRC, and there are some promising opportunities for collaboration. The Ruckelshaus Center is a joint effort between WSU and UW that focuses on conflict resolution. They relatively frequently are asked to become involved in water-related conflicts, and we are working with them to assure that we utilize our complementary positions in science and policy activities to help resolve water-related conflicts.

## Presentations by WRC Administration and Staff, and presentations relating to WRC grant-funded research

- Yoder, Jonathan. 04/17/2014. Guest lecture for ESRP 490/590 Tri-Cities: Yakima Basin Integrated Plan Economic Analysis. Open to the public.
- Yoder, Jonathan. 04/22/2014. Panelist for WSU Center for Civic Engagement Earth Day Events: "Are we using our water sustainably?"
- Yoder, Jonathan. 11/7-8/2014. Water Markets Design Workshop, Bren School of the Environment.
- Yoder, Jonathan. 12/18/2013, 6/4/2014, and 12/17/2014. Yakima River Basin Watershed Enhancement Project Workgroup quarterly meeting research reports.
- Yoder, Jonathan. 1/15/2014. Testimony to Washington State Senate Ways and Means Committee in regards to the *Benefit-Cost Analysis of the Yakima Basin Integrated Plan Projects* research.
- Adam, Jennifer and Jonathan Yoder. 1/29/2015. Columbia River Policy Advisory Group meeting presentation of the 2016 Long-Term Supply and Demand Forecast research plan.
- 09/09/2014: Research presentations and posters at the Pacific Northwest Science Climate Conference which is attended by numerous water-related stakeholders in the region.
    - Adam, J.C., J.C. Stephens, S.H. Chung, M.P. Brady, R.D. Evans, C.E. Kruger, B.K. Lamb, M.L. Liu, C.O. Stöckle, J.K. Vaughan, K. Rajagopalan, J.A. Harrison, C.L. Tague, A. Kalyanaraman, Y. Chen, A. Guenther, F.Y. Leung, L.R. Leung, A.B. Perleberg, J. Yoder, E. Allen, S. Anderson, B. Chandrasekharan, K. Malek, T. Mullis, C. Miller, T. Nergui, J. Poinsatte, J. Reyes (*presenting*), J. Zhu, J.S. Choate, X. Jiang, R. Nelson, J.H. Yoon, G.G. Yorgey, K.J. Chinnayakanahalli, A.F. Hamlet, B. Nijssen, V. Walden, 2014. BioEarth: A regional biosphere-relevant earth system model to inform agricultural and natural resource management decisions. *PNW Science Climate Conference*, Seattle, WA, Sep. 9-10.
    - Baxter, H., T. Nguyen, M. Barber, A. Hossain, and J.C. Adam, 2014. Impacts of future changes on groundwater recharge and low flow in highly-connected river-aquifer systems: A case study of the Spokane River and the Spokane Valley-Rathdrum Prairie Aquifer. *PNW Science Climate Conference*, Seattle, WA, Sep. 9-10.
    - Malek, K., C.O. Stockle, J.C. Adam, R. Nelson, K. Chinnayakanahalli, and K. Rajagopalan, 2014. Impacts or irrigation management on water and energy fluxes over the Yakima River basin. *PNW Science Climate Conference*, Seattle, WA, Sep. 9-10.
- Kruger, C.E. 2014. What does the science currently tell us about climate change, variability and risk on PNW cropland agriculture? Presented at USDA Specialty Crop Listening Session, Mt. Vernon, WA; 21 Acres Earth Day Celebration, Woodinville, WA; King County Horses and Climate Workshop; WA DNR Climate Experts Council; Madrona Institute Climate Series, San Juan County; Western Ag Directors Meeting; AFS 501 Seminar; Columbia County Farm Bureau Annual Meeting; Focus on Farming; EPA Region 10 Agriculture Meeting.

## Other Outreach and Information Transfer Activities

- Adam and Yoder are Delegate and WSU Lead Delegate, respectively, for the Universities Council on Water Resources (UCOWR). Yoder was nominated for Universities Council on Water Resources Board of Directors, and was elected to the board in May 2015.
- Yoder is a member of the Washington State Department of Natural Resources Expert Council on Climate and Environmental Change, with day-long meetings in May and August 2014 and January 2015 (Olympia and Ellensburg, Washington). Report development ongoing.
- Adam organized a multiple-center (including the WRC) joint WSU-UI poster session entitled "Climate, Land Use, and Agricultural and Natural Resources: Activities in Interdisciplinary Research, Education, and Outreach" in Pullman, Washington. 10/7/2014.
- Adam, Jennifer and Jonathan Yoder. 2013-4/2015: CAHNRS Water Resources Management Task Force. Yoder, Co-chair; Adam ex officio member and contributor.
- Yoder is on the WSU Sustaining Health Initiative Steering Committee, representing water-related interests in the area of global health. 3/2014 – present.
- Adam and Yoder participated in the WSU Office of Research 120 Day Study for Research strategy and focus. Adam and Yoder submitted Water Research Vision Statement on behalf of WRC. Yoder served on the Research Themes Subcommittee. 9/2014-2/2015.
- Adam provided services to professional organizations, including the following committee assignments: AGU Hydrology Section: Horton Research Student Grant Program Reviewer and Panelist; American Meteorological Society (AMS): Hydrology Committee member; CUAHSI hydrologic model benchmarking working group member
- Yoder was invited and attended Washington State House of Representatives meetings on water market development in Washington State. 1/15/2015, 1/30/2015.
- Yoder testified to the Washington State Senate Ways and Means Committee about the WRC-funded research "Benefit-Cost Analysis of the Yakima Basin Integrated Plan Projects", January 2015.
- Yoder attended the National Institutes for Water Resources (NIWR) Administrative meeting, 2/9-12/2015.
- Several stakeholder meetings were organized and attended by WRC administration and affiliated researchers in regards to the 2016 Columbia River Basin Long Term Supply and Demand Forecast (WRC extramural funded research for the Washington State Department of Ecology): Washington Department of Fish and Wildlife, 6 Nov 2014; Columbia River Basin Policy Advisory Committee meeting, 29 Jan 2015; Department of Ecology Water Resources Advisory Council meeting 23 march 2015. Groundwater Integration meeting 12 May 2015.
- The WRC co-sponsored the Spokane River Forum, November 18-20. Coeur d'Alene, ID. The WRC also co-developed and managed a WSU workshop on the Food-Energy-Water Nexus. Organization occurred in part during the reporting period. The workshop occurred in May 2015 (after the reporting period).

# USGS Summer Intern Program

None.

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 NCGP Award** | **NIWR-USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 1 | 0 | 0 | 0 | 1 |
| **Masters** | 2 | 0 | 0 | 0 | 2 |
| **Ph.D.** | 8 | 0 | 0 | 0 | 8 |
| **Post-Doc.** | 3 | 0 | 0 | 0 | 3 |
| **Total** | 14 | 0 | 0 | 0 | 14 |

# Notable Awards and Achievements

Padowski, J.C. and Gorelick, S.M., 2014. Global analysis of urban surface water supply availability. Environ. Res. Lett.: This article was also included in the ERL Highlights of 2014: http://iopscience.iop.org/1748-9326/page/Highlights-of-2014 and was awarded paper of the year.

Yoder, Jonathan, Adrienne Ohler, and Hayley Chouinard. 2014. What floats your boat? Preference revelation from lotteries over complex goods. Journal of Environmental Economics and Management 67:412-430. Winner of the Western Agricultural Economics Association Outstanding Published Research Award for 2014.

Adam, J.C., Outstanding Research Faculty Award, Department of Civil and Environmental Engineering, WSU, 2014

Adam, J.C., Leon Luck Most Effective Professor Award, Department of Civil and Environmental Engineering, WSU, 2014

Lane Graduate Research Fellowship in Environmental Science and Boeing Graduate Research Fellowship in Environmental Science, both awarded from the School of the Environment to Vanessa Rose, Spring 2015. Vanessa Rose has been supported by GRant 2014WA381B, "Interactive effects of nutrients and grazing on the control of cyanobacteria blooms: a comparison across a eutrophication gradient in freshwater systems in Washington state", Gretchen Rollwagen-Bollens and Stephen Bollens, PIs.

# Publications from Prior Years

1. 2009WA265B ("Influence of Large Wood Addition on Nitrogen Transformations at the Surface water/groundwater interface") - Articles in Refereed Scientific Journals - Arango, Clay, Paul James, and Kyle Hatch. In press (2014). Rapid ecosystem response to restoration in an urban stream. Hydrobiologia 749:197-211
2. 2011WA328B ("Ecohydrology of Invasive Reed Canary Grass") - Dissertations - Gebauer, Adam. 2013. Ecohydrology Effects of an Invasive Grass (Phalaris arundinacea) on Semi-Arid Riparian Zones. M.S. Thesis, Department of Biology, College of Science, Health, and Engineering, Eastern Washington University, Cheney, Washington, 76 pp.
3. 2011WA328B ("Ecohydrology of Invasive Reed Canary Grass") - Conference Proceedings - Gebauer, A., R. Brown, C. McNeely, C. Nezat, S. Schwab, 2012, Ecohydrology of Invasive Reed Canary Grass (Phalaris arundinacea): Evapotranspirtation Rates and Biomass, In ESA 2012. Annual Meeting Abstracts. Bulletin of the Ecological Society of America 93:S89 S89. http://dx.doi.org/10.1890/2012.abstracts
4. 2012WA346B ("Climate change, land-water transfer, and in-stream fate of nitrogen in an agricultural setting") - Dissertations - Moon-Nielsen MS Environmental Science 2013.Thesis: Using stable isotopes to determine source and fate of nitrate in the semi-arid Palouse River watershed . Washington State University
5. 2012WA346B ("Climate change, land-water transfer, and in-stream fate of nitrogen in an agricultural setting") - Dissertations - Bellmore, Rebecca A., Ph.D. in Environmental and Natural Resource Sciences, 2014, Thesis: Hydrologic dynamics control dissolved organic matter export from watersheds: filed-scale processes in a small, artificially drained agricultural catchment, and patterns across ecosystems
6. 2012WA346B ("Climate change, land-water transfer, and in-stream fate of nitrogen in an agricultural setting") - Articles in Refereed Scientific Journals - Bellmore, R.A., J.A. Harrison, J.A. Needoba, E. Brooks, and C.K. Keller, Hydrologic control of dissolved organic carbon and nitrogen and dissolved organic matter quality in a semi-arid artificially drained agricultural catchment, Water Resources Research.
7. 2012WA346B ("Climate change, land-water transfer, and in-stream fate of nitrogen in an agricultural setting") - Articles in Refereed Scientific Journals - Bellmore, R.A., J.A. Harrison, J.A. Needoba, E. Brooks, C.K. Keller (Submitted) DOM export from artificial subsurface drainage during storm events is controlled by source and processing along flow paths, J. Geophysical Research.
8. 2011WA326B ("Understanding Toxin Production by Harmful Algae: Vancouver Lake as a Model System") - Articles in Refereed Scientific Journals - Lee* Tammy, Gretchen Rollwagen-Bollens, Stephen Bollens, Josh Faber-Hammond. (2014) Environmental influences on cyanobacteria abundance and microcystin toxin production in a shallow temperate lake. Ecotoxicology and Environmental Safety doi: 10.1016/j.ecoenv.2014.05.004
9. 2011WA326B ("Understanding Toxin Production by Harmful Algae: Vancouver Lake as a Model System") - Articles in Refereed Scientific Journals - Lee* Tammy, Gretchen Rollwagen-Bollens, Stephen Bollens. (2014)(accepted, with revisions) The influence of water quality variables on cyanobacteria blooms and phytoplankton community composition in a shallow temperate lake. Environmental Monitoring and Assessment.
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