Dr. Jeffrey M. Bielicki, Assistant Professor in Department of Civil, Environmental and Geodetic Engineering, with a joint appointment at the John Glenn College of Public Affairs, at the Ohio State University completed an Ohio Water Resources Center funded project via joined Office of Energy and Environment at OSU and USGS 104(b) subaward. This project titled "**Co-Optimizing Enhanced Water Recovery and CO_2 Sequestration"** seeks to improve our understanding of how carbon dioxide (CO_2) injection and brine extraction in CO_2-Enhanced Water Recovery (CO_2-EWR) can be co-optimized for the physical and economic tradeoffs between the amount of CO_2 that is injected and the amount of brine that is extracted. The long-term goal of this research is to identify viable locations for CO_2-EWR, the potential costs associated with a location, and optimal injection/production management strategies. The project could inform present and future water and energy planning, as well as public utilities commissions and regulatory agencies with oversight for subsurface injection and production of fluids by identifying the risks, costs, and benefits associated with the use of CO_2-EWR.

The relationships between water and energy are complex when considering CO_2 capture and storage (CCS) technology to reduce CO_2 emissions, which are a principle driver of human-induced climate change. The tradeoffs identified in this study include the amount of CO_2 injected into the storage formation and the amount of brine removed, reservoir pressure build up or relief due to injection and extraction, increased storage at the expense of brine treatment costs, and dependence on the value of water and CO_2 prices through a future CO_2 tax or cap-and-trade mechanism. The initial expectation of the study was that brine extraction increased the storage capacity of CO_2 within the reservoir. Yet when the relationship was investigated using the Finite Element Heat and Mass Transfer (FEHM) code (fehm.lanl.gov), a decreasing correlation between the total CO_2 injected and brine extracted resulted in higher CO_2 storage for scenarios with less extraction due to early breakthrough of CO_2 (Figure 1).

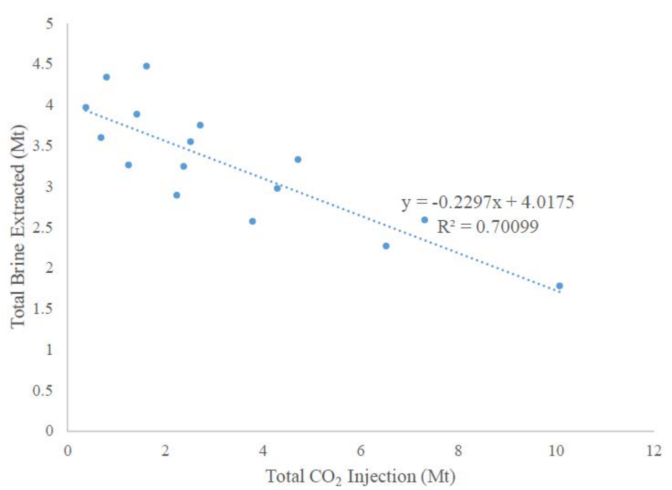

Figure 1 Relationship between CO_2 injection and brine extraction

Further research indicated that the high brine extraction rate pulled CO_2 through the reservoir at a faster rate because CO_2 could travel with less restriction in empty pore space. This suggested that the brine extraction rate had a greater impact on the lifetime of the CO_2-EWR system compared to the CO_2 injection rate and reservoir storage. When these results were combined with overpressure modelling of the reservoir, we concluded that the optimal brine extraction rate will be balanced between opening pore space and decreasing the time before CO_2 breakthrough at the extraction well. An equation, parameterized by the reservoir modeling, will be developed with the capabilities to estimate the viability of CO_2-EWR in various deep, saline aquifers and remove the current requirement to run a site specific subsurface flow model.

Researcher Profile: Dr. Jeffrey M. Bielicki holds a joint appointment in the Department of Civil, Environmental, and Geodetic Engineering and the John Glenn College of Public Affairs. He researches issues in which energy, environmental systems, and policy interact. He focuses on understanding opportunities, causes, and consequences of energy development and technology deployment in order to understand how energy systems have evolved and how this evolution can be directed in ways that will improve environmental, economic, and social conditions.

Dr. Gil Bohrer, Associate Professor in Department of Civil, Environmental and Geodetic Engineering at the Ohio State University completed an Ohio Water Resources Center funded project via Ohio Water Development subaward. This project titled "**Baseline measurements of methane emissions from rivers and lake waters in the proposed site of the OSU hydrofracking research station"** aims to provide baseline measurements of methane emissions from natural and agricultural aquatic ecosystems around the proposed locations of a shale gas development site. These observations will allow developing an empirical model for the natural methane emissions from the site and will allow determining whether these emissions increase due to diffused methane release into the ground water after the drilling operations started.

Due to unavailability of the proposed OSU hydrofracking research station, the research had to be relocated and the baseline measurements were conducted on similar site in West Virginia on private land near fracking pad. Fracking activity is scheduled to start later this summer. This funding provided an additional components of methane chamber measurements in a larger NSF-funded project that will fund the construction of a flux tower and the methane flux analysis activity. The methane chamber measurement campaign was performed in the field surrounding the flux tower, and from the near-by river. At each patch type (field, river) duplicate chamber measurements were taken at three locations. The results show that the grass field produces no methane, and some very low rate of methane oxidation occur in the soil (Figure 1). As expected, some methane emission occurred from the river. Nonetheless, the emissions from the river were very low. For example, they are about two orders of magnitude lower than emissions we typically observe in natural wetlands. This is important for the interpretation of the measurements from the flux tower, as it indicates that observations will represent remote sources of methane and are not influenced by baseline emissions at the local field around the tower. These observations will allow developing an empirical model for the natural methane emissions from the water system at the site and will allow determining whether these emissions increase due to diffused methane release into the ground water after the drilling operations started.

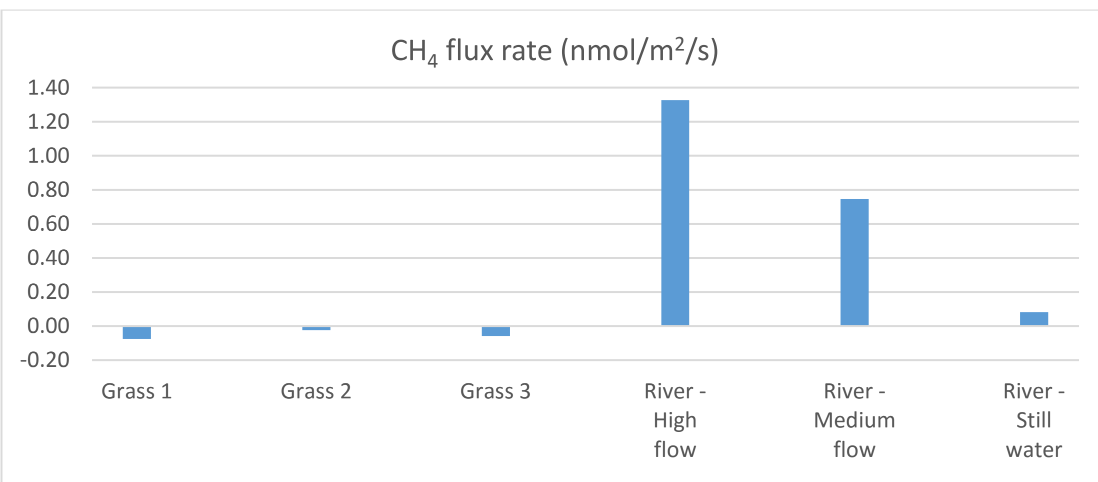

Figure 1. Methane fluxes from grass field and river near flux tower location and fracking site

<u>Researcher Profile:</u> Dr. Gil Bohrer develops and uses physical and empirical models to capture the interactions between individual biological organisms and atmospheric and hydrological processes. His research bridges the physical scale gap between regional atmospheric processes and individual plant-scale function and structure. He develops new approaches to parameterize the effects of small-scale heterogeneity on surface fluxes, on water movement from the soil through plants to the air, and on advection and dispersion of green-house gasses, VOCs and particulate matter.

Dr. Zuzana Bohrerova, Associate Director of the Ohio Water Resources Center at the Ohio State University collaborates with her partners, the Friends of the Lower Olentangy Watershed (FLOW) and the Ohio Chapter of Sierra Club on an information transfer project funded by the Ohio Environmental Protection Agency's Environmental Education Fund. This project titled **"Adopt Your Waterway"** aims to increase awareness and participation of individuals in water quality related issues. Educating citizens about how changes in a watershed impact water quality, collecting water quality data for rarely sampled tributaries and training of "champions" of the tributaries will help the residents to make science- based decisions about development of their local communities.

One of the program goals was to ensure long-term viability of this citizen science involvement and a bottom-up approach for citizens to inform their neighbors about the stream quality. Therefore we created a system where "trainers" (water quality specialists) train citizen scientist for several years in water quality monitoring of a stream near their residence and hopefully these citizens will be confident to eventually become trainers, learn more about their environment and talk to their neighbors and friends about water quality issues. Over 70 citizen volunteers were trained to monitor small Olentangy River tributaries using the Water Sentinel chemistry method of the Ohio Chapter Sierra Club and the macroinvertebrate evaluation method based on the Ohio EPA's Headwater Habitat stream quality monitoring program (Figure 1).

Figure 1 Classroom Water Sentinel training and hands-on outdoor macroinvertebrate evaluation training

Currently, two sites on eleven Olentangy River tributaries are monitored by thirty-eight active volunteers. Last year, most of the sites had a fair to poor macroinvertebrate index throughout the year and poor water chemistry, with average conductivity values higher than 600 uS (many had values higher than 1000 uS), seasonally high phosphates and nitrates and other poor water quality indicators. Many volunteers continue to be involved in the program, some of them monitoring their location for a third year in a row. Citizen scientist indicated in a survey that they talk to their neighbors about their monitoring work. FLOW, Sierra Club and the Ohio Water Resources Center are committed to continuing this program and partnership and we are looking for better ways to communicate our results, educate citizens about their streams and assure long- term sustainability of this program.

Project Collaborators: Ohio Water Resources Center is the federally-authorized and state-designated Water Resources Research Institute for the State of Ohio. We promote innovative, water-related research in the State of Ohio through research grant competitions, coordination of interdisciplinary research proposals, and educational outreach activities. FLOW (Friends of the Lower Olentangy Watershed) is a non-profit organization whose mission is to keep the Olentangy River and its tributaries clean and safe for all to enjoy, through public education, volunteer activities, and coordination with local decision-makers. The Sierra's Club Ohio Water Sentinel Program seeks to educate, engage, and empower volunteers to restore, improve, and protect Ohio's waterways.

Dr. Soryong Chae, Assistant Professor in the Department of Biomedical, Chemical, and Environmental Engineering at the University of Cincinnati completed an Ohio Water Resources Center funded project via Ohio Water Development Authority subaward. This project titled "**Prevention of harmful algal blooms through nutrient zero wastewater treatment using a vertical membrane bioreactor with food waste"** aimed to develop and optimize an engineering process for the efficient removal of nutrients from municipal wastewater. This research will allow for development of novel engineering solutions for the production of easily degradable organic matter that will eventually increase nutrient removal efficiency in biological nutrient removal (BNR) systems and also reduce HABs' risks to public health and the environment.

There is an increase need to limit nutrient input from all sources into aquatic ecosystem, including limiting the concentration of nitrogen and phosphorous from municipal wastewater treatment effluents. BNR is one of the most cost-effective method to achieve decrease of nutrients in effluent, but there is many uncertainties in practical optimization of this process. Dr. Chae investigated utilization of food waste to improve nutrients removal in a vertical membrane bioreactor (VMBR).

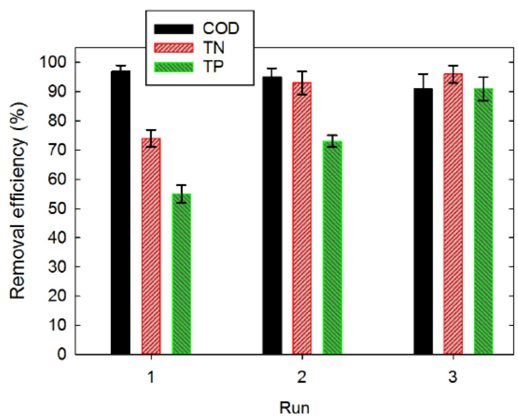

Figure 1 Removal efficiencies of carbon (COD), nitrogen (TN) and Phosphorous (TP) without food waste added (Run 1), with ~378 and 606 mg/L of soluble food waste aded in influent (Run 2 and 3, respectively)

A bench-scale VMBR (treatment capacity = 10 L/day at HRT = 8 hr) with anoxic and oxic zones in one reactor was operated over 4 months with synthetic wastewater and synthetic wastewater supplemented with condensate of food waste created by sonication. As shown in Figure 1, typical removal efficiencies of nitrogen and phosphorus by the VMBR with synthetic wastewater were 74% and 55%, respectively (Run 1). As the soluble organic carbon concentration increased from 150 to 605.5 mg/L by adding the carbon from sonicated and fermented food waste, removal efficiencies of nitrogen and phosphorus significantly increased up to 96% and 91%, respectively (Run 3). However, the supplemented food waste increased carbon concentration in the effluent and increased membrane resistance. The results provide a fundamental understanding of 1) the effects of ultrasound on the fate and conversion of recalcitrant organic compounds in food waste, and 2) the effects of organic matter originated from food waste on the enhanced biological phosphorous removal (EBPR) efficiency and membrane fouling in membrane bioreactor. Such investigations are critical for the development of eco-friendly management of food waste and the enhancement of biological phosphorus removal activity in biological nutrient removal systems to protect watersheds in Ohio from nutrient enrichment.

Researcher Profile: Dr. Soryong Chae received his Ph.D. from Korea Advanced Institute of Science and Technology (KAIST) in 2004 and he's pioneered research in the application of nanotechnology for membrane, water and energy. His research interest includes environmental implications and applications of engineered nanomaterials; membrane technology for drinking water production; and membrane bioreactor (MBR) for municipal and industrial wastewater recycling.

Dr. David Costello, Assistant Professor in the Department of Biological Sciences at Kent State University continues an Ohio Water Resources Center funded project via USGS 104(b) subaward. This project titled "**Trace metal limitation of biofilm growth and metabolism: potential consequences for storage of nutrients in headwater streams"** attempts to address the unknown importance of limiting concentrations of trace metals on primary production in small streams draining into Lake Erie. This proposed research will provide important information about in-stream processing of nutrients in tributaries to Lake Erie.

Figure 1 Dr. Costello's students installing trace metal diffusing substrates in stream.

Small streams can be very efficient at slowing nutrient transport to downstream ecosystems by storing nutrients in biomass and potentially removing nitrogen and phosphorous through burial and nutrient transformations. The hypothesis of this research is that that low trace metal concentrations in eutrophic streams in Northwest Ohio limit biofilm growth, contribute to saturation of nutrient removal processes, and limit biofilm storage of nitrogen and phosphorous. After a water chemistry survey of twenty-six headwater streams in northeast Ohio, five streams with potential nutrient and/or trace metal limitation were chosen for biofilm growth limitation tests. Trace metal nutrient diffusing substrates increase nutrient and trace metal concentrations in a small area of the stream allowing for greater algal growth if nutrients or metals supplied by the cup cannot be found in the stream water (Figure 1). Algal biomass on the cups in these five streams was measured after 4 weeks of growth. Algal growth differed greatly among streams, but single element addition did not stimulate biomass growth as much as multi-element combinations (Figure 2). The multi-element additions show that trace metals (especially Zn) may be a pathway for promoting biomass growth in streams, which can increase nutrient removal rates and ultimately reduce or delay the export of macronutrients to Lake Erie. Given that controlling nutrient sources is a major technique for controlling HABs, management efforts that consider trace metals may be an important new tool for addressing nutrient load reduction goals.

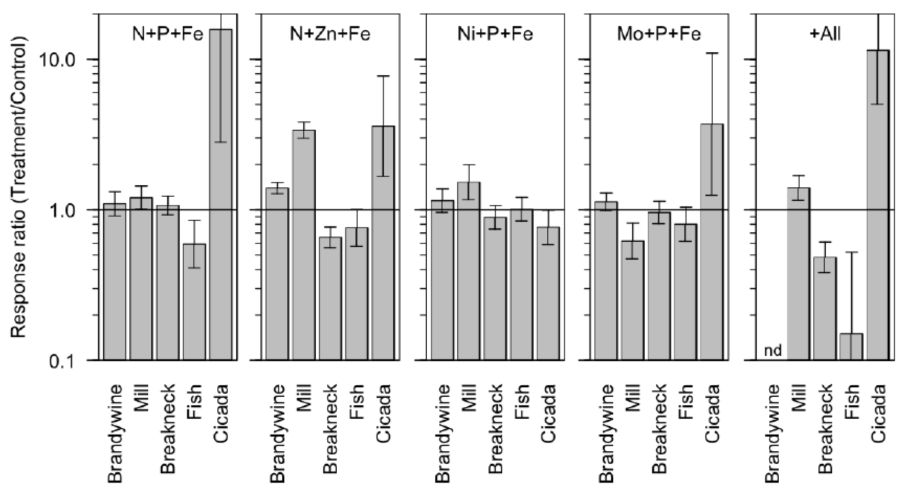

Figure 2 Response of algal biomass (as chlorophyll *a*) to multi-element additions. Response ratios >1 indicate greater biomass with nutrient amendment relative to controls and ratios <1 had lower biomass relative to controls. Error bars indicate standard errors. nd = no data.

Researcher Profile: David Costello received his BS from Hobart College in 2004 and his PhD in Biology from the University of Notre Dame in 2009. After finishing his PhD, Dave was a postdoc at the University of Michigan's School of Natural Resources & Environment. Broadly, Dave is interested in how human activities affect the functioning of freshwater ecosystems. Dave has interests in coupled biogeochemical cycles, ecotoxicology, and ecological stoichiometry.