Environmental, Water Resources and Coastal Engineering Graduate Research Symposium

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Keynote Presentation

Scott C. Hagen, *Ph.D., P.E., D.CE, D.WRE, F.ASCE*

Dr. Scott C. Hagen is a leader among scientists and engineers studying rising sea levels and their impacts, along with modeling tidal flow and coastal flooding from extreme weather events. As holder of the John P. Laborde Endowed Chair for Louisiana Sea Grant Research and Technology Transfer at Louisiana State University (LSU), his primary research focus is on massively parallel, high performance computational modeling of ocean, coastal and inland shallow water flows. He is also the director of the Louisiana Board of Regents chartered LSU Center for Coastal Resiliency. His recent efforts expand into transport and ecological modeling, particularly with respect to the coastal dynamics of sea level rise. Dr. Hagen's research has led to a shift in the paradigm of how climate change in general and sea level rise in particular are assessed at the coastal land margin. Dr. Hagen, his colleagues and their students conduct transdisciplinary research that helps government agencies issue more accurate emergency advisories during storms and understand complicated coastal hydrodynamics and related biological behaviors from historical, present-day, and future perspectives.

How to assess climate change impacts at the coastal land margin and produce transdisciplinary research outcomes

Extensive transdisciplinary efforts since 2010 in the northern Gulf of Mexico (Mississippi, Alabama, and the Florida panhandle) have resulted in an advanced capability to model and assess hydrodynamic and ecological impacts of climate change at the coastal land margin (http://agupubs.onlinelibrary.wiley.com/hub/issue/10.1002/(ISSN)2328-4277.GULFSEARISE1/). The concerted efforts of natural and social scientists as well as engineers have contributed to a paradigm shift that goes well beyond "bathtub" approaches. Potential deleterious effects to barrier islands, shorelines, dunes, marshes, etc., are now better understood. This is because the methodology enables assessment of not just eustatic sea level rise (SLR), but gets to the basis of projections of climate change and the associated impacts, i.e., carbon emission scenarios. The paradigm shift, input from coastal resource managers, and future expected conditions now provides a rationale to evaluate and quantify the ability of natural and nature-based feature (NNBF) approaches to mitigate the present and future effects of surge and nuisance flooding.

Over the majority of the 20th century, the largely linear rate of eustatic SLR was realized by thermal expansion of seawater as a function of a gradual increase in the average annual global temperature. Global satellite altimetry indicates that the rate of global mean SLR has accelerated from approximately 1.6 to 3.4 mm/year. While the year-by-year acceleration of the rate of rise cannot be measured adequately, it is reasonable to assume that it was relatively stable throughout the 20th century. For the 21st century, general circulation models project that posed atmospheric carbon emission scenarios will result in higher global average temperatures. A warmer global system will introduce new mechanisms (e.g., land ice loss, isotatic adjustments, and changes in land water storage) that will contribute to relatively abrupt changes in sea state levels. The additions to thermal expansion will drive higher sea levels and the increases in sea level will be attained by further accelerations in the rate of the rise. Because of the nature of the new mechanisms that will govern sea levels, it is unlikely that future accelerations in the rate of rise will be smooth.

To further address the complications associated with relatively abrupt changes in SLR and related impacts of climate change at the coastal land margin we intend to: (1) refine, enhance, and extend the coupled dynamic, bio-geo-physical models of coastal morphology, tide, marsh, and surge; (2) advance the paradigm shift for climate change assessments by linking economic impact analysis and ecosystem services valuation directly to these coastal dynamics; (3) pursue transdisciplinary outcomes by engaging a management transition advisory group throughout the entire project process; and (4) deliver our results via a flexible, multi-platform mechanism that allows for region-wide or place-based assessment of NNBFs. This presentation will share examples of our recent efforts and discuss progress to-date.

Air Pollution Engineering

Impacts of prescribed fire and meteorology on air quality in the Southeastern U.S. evaluated with a unified prescribed burning database

Sadia Afrin
Fernando Garcia Menendez (Advisor)

Prescribed fire is one of the most important land management approaches used to reduce wildfire risk and restore ecosystems. However, smoke produced from prescribed burns can contribute to air quality concerns by increasing emissions of $PM_{2.5}$ (fine particulate matter) and precursors of ozone and secondary $PM_{2.5}$. Prescribed burning is commonly practiced in the Southeastern U.S., where it represents one of the most significant sources of carbonaceous aerosols. Fire and emissions data for prescribed burning in the region are available from different satellite-based products and burn records from government agencies. However, satellite-derived estimates underestimate emissions and often not detect the low-intensity fires, making them an unreliable data source. In addition, there is no central bottom-up inventory of prescribed fire, as burn records vary widely across different states. For instance, burn permit records in Florida and Georgia are organized in structured databases, whereas digital burn records for North Carolina are incomplete. In contrast, North Carolina fire records contain defined spatial locations, while Georgia data does not include detailed geo-coordinates. In this study, we are developing an integrated database for prescribed fire data in the Southeast by unifying and systematizing available burn permit records. We use this database to further explore the relationships between air quality, meteorology, and the burn records at monitoring stations in Georgia and Florida. Here the system is used to quantify correlations between prescribed burning activities and observed high $PM_{2.5}$ concentration at each of the stations. In addition, the effect of meteorology is assessed by incorporating different meteorological parameters such as wind speed, wind direction, temperature, relative humidity and precipitation as predictors in the statistical analysis.

Keywords: prescribed burning, $PM_{2.5}$, meteorology.

Category: Air Pollution Engineering

Characterizing emissions from diverse domestic biofuel uses in rural Malawi

Ashley Bittner
Andrew P. Grieshop (Advisor)

Malawi is a low-income, energy-poor rural country in Southern Africa, where only ~9% of the population has electricity grid access. The majority of household energy is provided by biofuel use, i.e. collected firewood and/or charcoal. Many of the common emission sources in Malawi and their respective emission factors (mass of pollutant emitted per mass of fuel burned) are unquantified, limiting understanding of air quality trends and impeding evaluation via atmospheric models. As an initial step, we identify various, diverse small-scale biomass burning activities (cooking, charcoal making, brick burning, whiskey distillation, etc.) for emission characterization. We conduct village-level emission sampling using a portable Stove Emission Measurement System (STEMS). The STEMS measurement system records real-time measurements of carbon monoxide (CO), carbon dioxide (CO2), particulate matter (PM) scattering, black carbon (BC) absorption and integrated measurements of PM and organic carbon/elemental carbon (OC/EC). In summer 2017, we monitored 2 charcoal ovens, 3 whiskey distillation events, and 20 cooking events [13 three-stone fires (TSF) and 7 simple improved clay cookstoves (ICS)]. Preliminary analysis of all cooking events showed that the improved clay cookstoves had ~40% lower CO and ~50% lower PM average emission factors (EFs) than the TSF. The cookstove pollutant EFs measured in this study are comparable to those measured in previous studies. The average CO EFs associated with charcoal making and whiskey distillation were ~56% and ~27% higher, respectively, compared to cooking events. The PM EFs followed a different trend: relative to cooking events, charcoal making had an average PM EF ~44% lower, while the average PM EF for whiskey distillation was ~30% higher. In addition to these preliminary results, we will discuss supporting measurements (BC absorption, modified combustion efficiency, etc.) used to characterize biofuel burning emissions.

Keywords: biofuel combustion, air pollutant emissions, low-income countries, field measurements

Category: Air Pollution Engineering

Impact of climate model response on projections of future air quality under various climate scenarios

James East
Fernando Garcia Menendez (Advisor)

Studies of the impact of climate change on air quality suggest that changes to meteorology under a warmer climate can induce a 'climate penalty' on air quality. Here, we use output from a modeling framework based on the MIT Integrated Global System Model (MIT IGSM) to analyze projections of mid- and end-of-century climate and the associated impacts on air quality. Major sources of uncertainty include climate policy (greenhouse gas and aerosol emissions), climate model response (climate sensitivity to changes in greenhouse gas concentrations), and natural variability. Previous studies have identified significant contributions from climate policy and natural variability to uncertainty in projections of climate-induced air quality impacts. However, the role of uncertainty associated with climate model response remains unexplored. We analyze this source of uncertainty by comparing model output produced using climate sensitivity parameters based on lower bound, best estimate, and upper bound climate sensitivity estimates from the IPCC Fourth Assessment Report, corresponding to values of 2.0, 3.0, and 4.5°C per doubling of atmospheric CO_2 concentration, respectively. On an annual basis, estimated increases in U.S. projected population-weighted mean ozone concentrations at end-of-century are 1.9 ± 0.3 ppb, 3.2 ± 0.3 ppb, and 5.7 ± 0.4 ppb for lower bound, best estimate, and upper bound climate sensitivity estimates, respectively. Increases in projected population-weighted $PM_{2.5}$ concentration at end-of-century for matching climate sensitivity estimates are 0.8 ± 0.1 μg/m^3, 1.5 ± 0.1 μg/m^3, and 2.2 ± 0.1 μg/m^3. Ozone and $PM_{2.5}$ concentrations show a clear trend of increasing climate penalty on air quality with increasing climate sensitivity. The potential threat to human health posed by higher mean pollutant concentrations and greater risk for extreme values motivates the examination of this source of uncertainty in air quality projections.

Keywords: air quality, climate penalty, climate model response, climate sensitivity, model uncertainty

Category: Air Pollution Engineering

Linking indoor air quality and emissions measured during a cookstove intervention trial in rural India

Mohammad Maksimul Islam
Andrew Grieshop (Advisor)

Combustion of biomass in residential cookstoves is a major source of household air pollution, an acknowledged threat to human health. However, there are limited number of studies where both emission and indoor air quality were measured across different seasons and at different locations, making the quantitative linkage between cookstove emission and indoor air quality poorly constrained. This study aims to improve our ability to quantify the link between emissions and indoor PM2.5 by analyzing data measured during three ~3-month-long measurement periods (baseline, follow-up-1, follow-up-2) in two rural areas in India (Kullu in Himanchal Pradesh; Koppal in Karnataka). Gravimetric and real time indoor PM2.5 concentrations were measured during ~5000 cooking events of traditional and alternate stove/fuel combinations with mobile instruments (RTI micro-PEMS). For a subset of those cooking events, simultaneous emission measurements were conducted by a portable instrument. Median indoor 24-hour average PM2.5 concentration in households in Kullu having Himansu Tandoor (improved chimney heating stove) as primary stove was 138 $\mu g/m^3$ during follow-up-1, approximately a factor of two lower than for those with Traditional Tandoor stoves (267 $\mu g/m^3$), indicating reduced pollution was associated with improved chimney stoves. The households in Kullu and Koppal having LPG had median PM2.5 concentrations of 91 and 111 $\mu g/m^3$ respectively, about 1.5-2 times less than households having no LPG stoves (Kullu: 142; Koppal: 207 $\mu g/m^3$). The median PM2.5 concentration for houses having primarily traditional stoves was higher for Koppal (206 $\mu g/m^3$) than Kullu (132 $\mu g/m^3$), strong evidence of inter-site variability in PM2.5. Higher air exchange rate (AER) in Kullu households (11±5 h-1) compared to Koppal (7±4 h-1) may explain this variability. Stove influence (SI) analysis showed positive correlations between stove-influenced PM2.5 and indoor daily average PM2.5 concentrations (r2=0.89 and 0.68 for Koppal and Kullu respectively, during baseline), indicating as expected, a strong association between cookstove emissions and indoor PM2.5. PM2.5 emission factor will be calculated from emission measurement, and with the help of AER and SI analyses, the link between emission and exposure will be assessed quantitatively.

Keywords: cookstove, indoor air, $PM_{2.5}$, emissions, air exchange rate

Category: **Air Pollution Engineering**

Estimating air pollution impacts of the 2016 Southern Appalachian wildfires

Megan Johnson
Fernando Garcia Menendez (Advisor)

In late 2016, wildfires burned over 150,000 acres across five states in the Southeastern U.S., including North Carolina. Emissions of fine particulate matter (PM2.5) from wildfire events can be harmful to human health by causing respiratory problems and exacerbating existing health issues. We aim to quantify the contribution of the 2016 wildfire episodes to ambient PM2.5 concentrations and air pollution-related morbidities and mortalities in North Carolina. Wildfire-attributable PM2.5 is estimated using measurements from EPA monitoring sites and fire activity information reported to InciWeb. Morbidities and mortalities are estimated with concentration-response functions, which use baseline health incidence rates and changes in pollutant concentration to estimate a change in health impacts. Uncertainties in the concentration-response functions and the PM2.5 concentrations are quantified.

Keywords: wildfire, health impact assessment, PM2.5, concentration-response

Category: Air Pollution Engineering

Evaluation of air-conditioning effects on light duty gasoline vehicles fuel economy

Tanzila Khan
H. Christopher Frey (Advisor)

MOVES Lite is a simplified version of the regulatory energy and emission estimation model Motor Vehicle Emission Simulator (MOVES). MOVES Lite estimates the air-conditioning (AC) effects adjusted fleet average vehicle energy use rates and fuel economy (FE), following the same approach as MOVES2014a. The purpose of this work is to evaluate MOVES Lite predicted AC-adjusted FE based on empirical measurements. U.S. EPA derived the MOVES AC adjustment factors based on numerous driving cycles and 1990 to 1999 model year (MY) vehicles. More recent MY vehicles have improved AC performance and, thus, are expected to have less FE penalty. Also, MOVES2014a predicted AC-adjusted FE have not been validated based on empirical measurements. There are limited studies on the effect of AC operation on FE for newer vehicles.

For the evaluation of MOVES Lite AC-adjusted FE, chassis dynamometer-based FE test results for regulatory driving cycles are the most comprehensive recent empirical data. The test results are available for light duty gasoline vehicles (LDGVs) including passenger cars (PCs) and passenger trucks (PTs). The regulatory cycles used for LDGV FE rating include the Federal Test Procedure, Highway Fuel Economy Test, US06, and SC03. SC03 is the only of these tests for which AC is turned on. SC03 FE test results are available since 2010 MY. MOVES Lite is based on 2015 calendar year. MOVES Lite will be evaluated for six MYs from 2015 through 2010 for PCs and PTs. Preliminary results show that for PCs, MOVES Lite and SC03 estimates are not significantly different, on average. For PTs, MOVES Lite FE estimates average 13% significantly lower than the SC03 average FE. The validity of the MOVES-based AC adjustment incorporated into MOVES Lite will be assessed. Implications of the effect of AC on fuel economy will be discussed.

Keywords: MOVES, air-conditioning effects, fuel economy, vehicles, driving cycles

Category: Air Pollution Engineering

Estimation of rail grade and horizontal curvature from non-proprietary data sources

Nikhil Rastogi
H. Christopher Frey (Advisor)

Train energy use and emissions depend on running resistance. Running resistance depends on grade, curve radius, and other factors. Practical methods to measure or estimate grade and curve radius are identified and evaluated. Grades and curve radius can be obtained from track design drawings or track inspection data. However, such data are proprietary. Low-cost GPS receivers fitted with barometric altimeters measure position and elevation from which grade and curve radius can be estimated. Digital Elevation Models (DEMs) based on LIDAR data provide position and elevation of general ground topography, except for rail bridges. Grade is estimated by fitting a linear regression between elevation versus distance for consecutive track segments. A track route GIS shapefile and GPS position data were used to estimate track radius. Curve radius was estimated by fitting a least-squares circle through track position coordinates within each track segment. Grade and radius estimates were compared to design drawings available for a limited number of segments on a case study route. Except at station stops, GPS data were found to provide reliable estimates of grades. DEM data provided more precise and accurate grade estimation for 60 percent of segments but led to inaccurate estimates on segments with bridges and sloping terrain adjacent to tracks. Both GPS and GIS data provided curvature estimates comparable to design drawings.

Keywords: train energy use, rail grade, track curvature

Category: Air Pollution Engineering

Assessment of a field portable oxidation flow reactor (OFR) measurement system for biofuel emission characterization in remote settings

Aditya Sinha
Andrew Grieshop (Advisor)

Oxidation flow reactor experiments in our lab have explored the properties of secondary organic aerosol (SOA) formed from photochemical aging of emissions from cookstoves like those used by billions daily. Lab experiments have explored the physical and chemical properties of SOA formed from emissions for stove types of varying efficiencies and different fuel types. However, field emission monitoring efforts have consistently shown a clear distinction between in-field performance of cookstoves and that from standardized lab tests. Typical lab experiments have characterized cookstove emissions utilizing sophisticated instrumentation like the Aerosol Chemical Speciation Monitor (ACSM) and Photoacoustic Extinctiometer (PAX). But since the ability to move and power advanced instruments is limited in rural locations, we are developing and evaluating an ensemble consisting of portable low power instruments. Preliminary evaluation indicates that OA enhancement, quantified in the lab using an ACSM correlates fairly well with the enhancement in light scattering coefficient (Bscat), quantified using a PAX. We expect a high degree of inter-test variability in field measurements and so having a measurement metric such as this that can capture a large range of enhancements is useful. Filters are a standard method for determining PM, OC and elemental carbon (EC) EFs from a combustion event. In prior lab cookstove emission OFR experiments, we evaluated closure between PM from filters and parallel ACSM measurements. In these comparisons, filters under-predict the OA EFs relative to the ACSM, and so further work is required to evaluate the use of filters for measuring aged OA from an OFR. A hypothesis to be tested is that residual ozone from the OFR, (not fully denuded prior to reaching filters) interacts with and degrades filter-bound organic matter. Experiments will be designed to probe this disparity since filters are often a relatively inexpensive and operationally efficient way to gather important descriptors of OA from a combustion event.

Keywords: oxidation flow reactor, low cost measurement system

Category: Air Pollution Engineering

A Comparative Quantitative Analysis of Volatile Organic Compound Emissions from Wood Burning Cookstoves

Daniel Sodano
Andrew Grieshop (Advisor)

Wood-burning cookstoves are used by billions of people in developing countries. Such cookstove emissions have documented toxicological effects to humans and result in secondary organic aerosol (SOA) formation, which contributes to atmospheric particulate matter. The composition for part of the complicated mix of volatile organic compounds (VOCs) in wood smoke can be quantitatively analyzed with gas chromatography-mass spectrometry (GC-MS) technology. However, this equipment is expensive and typically requires off-line sample collection and analysis. Therefore, lower-cost, on-line measurement techniques have been explored. Calibration of a GC with automated sorbent trapping and a flame ionization detector (GC-FID) have been performed, including 95% confidence intervals of retention time windows and minimum detection limits (MDLs). Several water boiling tests were completed using a variety of cookstove and wood fuel-type combinations. Collaborations with the U.S. EPA involved collection of whole air samples during tests, which were analyzed offline using GC-MS. Quantitative comparisons between the GC-FID and GC-MS cookstove emissions data have been performed. Preliminary analysis from the cookstove tests shows that a distinctly identifiable analyte, benzene, shows a strong correlation (R^2>0.90) when concentrations are compared between the two instruments. Comparisons with other semi-volatile organic compounds (SVOCs) are currently being performed, but these peaks are more difficult to identify and quantify. During calibrations, these compounds show a very consistent ratio between peak area and analyte mass (R^2>0.92). Future work in inter-instrument comparisons is likely required before further conclusions for cookstove data can be drawn. Gas standards from the EPA will be used to further quantify the capabilities and limits of the GC-FID relative to well-established quality protocols for GC-MS. Future work will improve detection of more volatile analyte peak signals, continue water boiling test data collection to further measure replicability, and continue collaboration with the EPA to refine calibrations and testing parameters of GC-FID analysis.

Keywords: air quality, analytical chemistry, bioenergy

Category: Air Pollution Engineering

Modeling a diesel-electric train energy consumption index using simulated speed trajectories

Weichang Yuan
H. Christopher Frey (Advisor)

Diesel-electric train energy consumption is related to emissions of criteria air pollutants and greenhouse gases (GHG). In the U.S. in 2015, rail transport consumed 569.4 trillion Btu energy and emitted 43.6 million metric tons of carbon dioxide equivalent. Modeling train energy consumption is a key step to identify train energy-efficient operation strategies.

Speed is a critical input for modeling energy consumption of diesel-electric trains. Speed trajectories can be measured using Global Positioning System (GPS) receivers. To estimate total train energy consumption of a rail system, measurements are required for each segment, which is defined as a one-way rail track between adjacent stations. Moreover, to obtain representative speed trajectories for each segment, multiple measurements for the same segment may be necessary. Such measurements are time-consuming. The purpose of this study is to demonstrate a method to simulate speed trajectories for each segment of a diesel-electric train system based on a relatively small sample size of measured speed trajectories. The simulated speed trajectories are used for calculating an energy consumption index, which accounts for the energy consumed by overcoming running resistance, starting resistance, and acceleration resistance.

The Virginia Railway Express (VRE) system is used as an example. Speed trajectories were measured with GPS receivers on selected segments of each line. The measured trajectories were post-processed to remove outliers and noise using cubic-spline interpolation and Savitzky-Golay filter, respectively. Multiple speed trajectories of each segment were simulated by mimicking the Markov Chain process. Transitional probabilities between combinations of speeds and accelerations are based on second-by-second measured speed trajectories. For each segment, 100 speed trajectories were simulated. The simulated segment trajectories match scheduled segment travel time and known segment distance. Energy consumption indices will be calculated. The calculated indices will be evaluated by comparison to energy use reported in the National Transit Database (NTD).

Keywords: speed trajectory, energy index, simulator, GPS

Category: Air Pollution Engineering

Coastal and Ocean Engineering

Wind effects on the Choctawhatchee River Plume at Destin Inlet, Florida

Rosemary Cyriac
Casey Dietrich (Advisor)

Winds can exert a significant forcing on the ebb-phase buoyant river plume that emerges out of a tidal inlet and thus influence its effectiveness to act as a natural barrier that prevents surface transport into the inlet. The Choctawhatchee Bay and River System, situated along the Florida Panhandle connects to the Gulf of Mexico via the Destin Tidal inlet and receives 95% of its freshwater input from the Choctawhatchee River (CR). In December 2013, a series of experiments (Surfzone Coastal Oil Pathways Experiment) were performed in this region to study mechanisms that influence near-shore surface transport. SCOPE satellite imagery showed a visible brackish surface outflow at Destin during low tide. The goal of this study is to examine wind effects on this plume and its effectiveness as a natural barrier to surface transport at Destin Inlet during December 2013.

Density driven flows at Destin Inlet are modeled using three dimensional, baroclinic capabilities of ADCIRC (Advanced CIRCulation). Starting with an existing triangular finite element mesh with highly-resolved elements, we incorporated freshwater discharge by refining this mesh to resolve the upstream reaches of CR. Modeled tides are validated against measured water levels at NOAA gages along the Florida Panhandle. The plume behavior in successive tidal cycles can differ due to the rotary winds associated with the multiple winter storms that pass over the study region. Wind effects on the plume orientation, structure and geometry are modeled and validated with SCOPE drifter movements, CTD cast data and satellite imagery. Differences in the extent of surface transport into Destin Inlet during different wind conditions are examined using Lagrangian particle tracking. During light winds and moderate northerly winds, the plume is expected to have a larger offshore extent and be more effective in preventing particle transport into the inlet. Southerly winds are expected to restrict the surface outflow and thereby allow particle transport into the inlet.

Keywords: Choctawhatchee Bay, ADCIRC, river plume, surface transport, baroclinic flows

Category: Coastal and Ocean Engineering

Modeling the erosion on Hatteras Island during Hurricane Isabel: resolution requirements for coupling with circulation-wave models

Alireza Gharagozlou
J. Casey Dietrich (Advisor)

Coastal areas are affected by extreme storm events, during which high waves and storm surges cause overwash, flooding and erosion at the beach. Hurricane Isabel, a very powerful Atlantic Ocean storm that made landfall on the Outer Banks of North Carolina on Sep 18, 2003 as a Category 2 hurricane, caused overwash, flooding, and breaching, destroying infrastructure in several spots along the NC coast. Understanding beach behavior and coastal morphodynamic evolution during storms improves forecasts and helps emergency managers in taking better precautions during a storm. We explore storm impacts on coastal morphodynamics by modeling a stretch of the NC Barrier Islands between Avon and Salvo and investigating the effect of Isabel on beach evolution. We use XBeach, an open-source tool for hydrodynamic and morphodynamic modeling. The initial bathymetry and topography of the model were derived from pre-storm topographic (LiDAR) data, and the data for waves and water levels at the boundaries were extracted from a tightly-coupled, circulation-wave simulation. Model results were compared to post-storm LiDAR data, and the volume of dune erosion and dune crest elevation change were calculated. Moreover, for optimizing the efficiency of simulations on large domains and when coupled with wave and circulation models, we explored the sensitivity of the results to computational mesh resolution. The modeled dune erosion matches the post-storm data well, proving the reliability of our model in predicting storm impacts on beach morphology. The accuracy of the morphology in the model decreases as the mesh spacing increases in the cross shore direction, but coarsening the mesh in the alongshore direction does not affect the results. We show that the computed amount of water passing the dune crest varies for high and low resolution morphodynamic models, which may allow for parameterizations of erosion in larger-domain flood models.

Keywords: beach morphology, erosion, XBeach, ADCIRC+SWAN

Category: Coastal and Ocean Engineering

Quantifying pond expansion in two North Carolina salt marshes using remote sensing

Faith M. Johnson
Alejandra C. Ortiz (Advisor)

Coastal salt marshes are highly productive ecosystems under threat from climate change (i.e. sea level rise). In general, marshes are expected to retreat if local sea level rise (SLR) is greater than the vertical sediment accretion (marsh drowning) and be stable or expand otherwise. However, in a sediment starved region, edge erosion of marshes can be wave induced, with the erosive power of locally generated waves depending on the width and depth of the tidal flat over which those waves develop. Ortiz et al (2017) show that for the Mississippi River Delta Plane, ponds were expanding and moving in the direction of dominate winds, a phenomenon that cannot be explained by marsh drowning alone. Two salt marshes in North Carolina, Roanoke Marsh and Mackay Island, have visibly lost area over that last three decades. I am analyzing those marshes to determine if the change can be attributed to local wave climate along the exterior of the marsh and locally generated waves (dominate wind direction) in interior ponds of the marshes. I am using Google Earth Engine (GEE), to access Landsat imagery from the last 34 years, create cloud-free temporal composites using built-in functions, and calculate spectral indices to separate land and water pixels. The indices will be binarized using Otsu thresholding, a method that automatically sets where the threshold should be to achieve good separation based on a histogram of the index values in the area. Properties of each pond (i.e. area, fetch, and centroid location) are calculated from the binarized images and tracked through time to quantify how these metrics (and the ponds) are changing. Once marsh change has been quantified, it will be compared to wind data and other potential forcing data for both locations to see if there are any correlation.

Keywords: salt marshes, remote sensing, Google Earth Engine, edge expansion

Category: Coastal and Ocean Engineering

An investigation of Marine Hydrokinetic structure stability on sloping seabed with respect to sediment transport

Hanieh Mohamadi Moghadam
Alejandra C. Ortiz (Advisor)

The instability and potential collapsing of Marine Hydrokinetic (MHK) Devices due to sediment transport around the structure are of major concerns. The instability of these structures may be due to extensive erosion caused by wave-induced or current-induced bed shear stress depending on the depth of installation, wave climate, and seabed slope. The main focus of this study is to investigate the potential of erosion and consequent transport of the sediment near the embedded MHK structure. In order to investigate and model the efficiency of the MHK device, a simple numerical model of marine sediment transport is used. We use Delft3D, which is a coupled hydrodynamic and morphodynamic model for understanding long-term coastal evolution around a bed-mounted MHK. By coupling wave and current modules in Delft3D, we can accurately simulate the interaction of sediment and the MHK device to understand the morphodynamic response of the ocean bed. We explore a range of parameter space by varying bed slope to have a better estimate for potential maintenance of the MHK device in a given wave climate with certain sediment characteristics. Our focus is on the impacts of sediment transport on MHK devices under extreme (storm event) conditions in North Carolina coasts. Having a constant large offshore wave for 2 days, our initial results suggest that the erosion on the upstream and downstream sides of the structure are relatively the same, around 2 meters. After 10 days, the downstream erosion remains constant while the upstream erosion increases by more than double, 5 meters. The results are in good agreement with the bed shear stress analysis around the MHK device and this amount of erosion implies the possibility of toppling or failure of the MHK.

Keywords: sediment transport, Marine Hydrokinetic structure, Delft3D

Category: Coastal and Ocean Engineering

High-Resolution Modelling of Surge during Hurricane Matthew (2016)

Ajimon Thomas
J. Casey Dietrich (Advisor)

This research addresses the question of how changes in the timing or speed of a hurricane can change the amount and extent of coastal flooding. Storm surge due to hurricanes can cause significant damage to property, loss of life and long-term damage to coastal landscapes. Hurricane Matthew was a category 5 storm that made landfalls along the coasts of Haiti, Cuba, Grand Bahama Island and South Carolina during October 2016. This research employs the spectral wave model Simulating Waves Nearshore (SWAN) and the shallow water circulation model Advanced CIRCulation (ADCIRC): a coupled model that has achieved prominence in coastal flood forecasting and analyses. Results have indicated that the model was able to accurately predict water levels and peak surges during Matthew in comparison to observations along the U.S. east coast. The impact of Matthew varied significantly along the U.S. east coast and we hypothesize that this is due to the storm interacting nonlinearly with tides. By changing the time of occurrence of the storm by both half and full tidal periods, it was seen that there were differences in storm surge along the coast due to regions coinciding with different periods in the tidal cycles. These differences were as high as one meter at certain locations. Looking at the influence of the storm forward speed on the surge, it was seen that as the speed of the storm was reduced, there was an increase in flooding due to the storm having more time to impact the coastal waters. The faster storm moved quickly across the shoreline, thus flooding only a narrower section of the coast.

Keywords: storm surge, ADCIRC, SWAN, Hurricane Matthew, inundation

Category: Coastal and Ocean Engineering

Improving accuracy of real-time storm surge inundation predictions

Nelson Tull
J. Casey Dietrich (Advisor)

Emergency managers rely on fast and accurate storm surge forecasts from numerical models to make decisions and estimate damages during storm events. One of the challenges for such models is providing a high level of resolution along the coast without significantly increasing the computational time. Models with large domains, such as the Advanced CIRCulation (ADCIRC) model used in this study, may be accurate in predicting water levels, however predicting flooding at the spatial scale of buildings and roadways is often difficult due to limited resolution. A new tool has been developed that uses Geographic Information System (GIS) scripts to enhance the resolution of maximum water level predictions at the boundary of predicted flooding using a high-resolution Digital Elevation Model (DEM). The water levels predicted by the lower resolution model are extrapolated outward to where the water would intersect with the higher resolution elevation dataset. This tool can process a 50-ft DEM for all 32 coastal North Carolina counties in less than 15 minutes during a storm event. Comparison of results using spatial building datasets for Carteret County showed that for a simulation of Hurricane Matthew there was an increase of 60 percent in the number of inundated buildings after enhancing the resolution of the forecast. This dramatic increase in flooded buildings shows the importance of achieving high accuracy in floodplains, as a relatively small change in predicted flooding extent can have a substantial impact on the predicted number of flooded buildings. The validity of these results was tested by comparing them to results of an ADCIRC model with the same 50-ft resolution as the DEM in Dare County. Preliminary comparisons have shown that results are more similar in coastal regions with steeper slopes and less similar in flatter, low-lying areas.

Keywords: storm surge, numerical modeling, enhancing resolution, DEM, GIS

Category: Coastal and Ocean Engineering

Energy System Analysis

US Energy-Related Greenhouse Gas Emissions in the Absence of Federal Climate Policy

Hadi Eshraghi
Joseph F. DeCarolis (Advisor)

The planned US withdrawal from the Paris Agreement as well as uncertainty about federal climate policy have raised questions about the country's future emissions trajectory. Our model-based analysis accounts for uncertainty in fuel prices and energy technology capital costs and suggests that market forces are likely to keep US energy-related greenhouse gas emissions relatively flat or produce modest reductions. We employ a global sensitivity analysis method called Method of Morris to identify the inputs to which our model is most sensitive, and then use a suite of Monte-Carlo simulations to obtain the distribution of the greenhouse gas emis sions. Our results show that in the absence of new federal policy, 2040 greenhouse gas emissions range from +5% to -21% of the baseline estimate. Natural gas versus coal utilization in the electric sector represents a key tradeoff, particularly under conservative assumptions about future technology innovation. The lowest emissions scenarios are produced when – relative to the baseline – the capital cost of solar photovoltaics and wind decline by more than 20%, and fossil fuel prices increase by at least 20%.

Keywords: energy system modeling, sensitivity analysis, Monte-Carlo simulation, greenhouse gas emissions

Category: Energy System Analysis

Economic analysis and life-cycle assessment of solar powered integrated greenhouses

Joe Hollingsworth
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Controlled agricultural environments such as greenhouses are an increasing important way to supply food to growing populations. Our research investigates how organic solar photovoltaic (OPV) technology can be integrated into greenhouses to reduce land use and environmental impacts associated with crop production. This project is built on the concept of a Solar PoweRed INtegrated Greenhouse (SPRING) system. The goal of this study is to assess the potential advantages of a SPRING system in terms of cost and environmental benefits. The LCA takes a cradle-to-farm-gate approach to compare a SPRING system with a conventional greenhouse in terms of environmental impact. The economic analysis considers the cost of greenhouse construction, operations and maintenance, and crop revenue to evaluate the net present value associated with both greenhouse designs. Although greenhouses allow for high productivity and extended growing seasons, optimal environmental control comes with additional costs compared to open field crops. OPVs have the potential to selectively capture infrared wavelengths used for electricity production, while transmitting red and blue wavelengths necessary for plant growth. OPVs are semi-transparent, lightweight, and cheap to manufacture and install compared to traditional silicon-based photovoltaic modules. We have found that integrating OPV modules onto greenhouses can meet in-house electrical demand associated with cooling, supplemental lighting, and operations while acting as a shading mechanism to reduce the overall cooling demand. Results show that a SPRING system largely benefits from cost savings in the summer months when cooling demands are high due to trapped solar radiation and the "greenhouse effect." The SPRING system also results in significant offsets of global warming potential and acidification associated with electricity consumption. Although the US does not currently have a price on carbon, emissions reductions could play a significant role in cost savings under more stringent environmental regulations or higher emission prices.

Keywords: sustainable agriculture, organic solar photovoltaics, life cycle assessment, emerging technologies, greenhouse design

Category: Energy System Analysis

Assessing solar photovoltaic technology diffusion and grid stability using an agent-based modeling approach

Jacob G. Monroe
Emily Z. Berglund (Advisor)

Solar photovoltaics (PV) enables households, private companies, and governmental institutions to access an abundant energy source that is both free and clean. However, high penetration of solar PV systems can result in operational problems for electric utility managers and cause severe physical damage to distribution equipment. Previous research has addressed solar PV technology diffusion and associated short-term impacts to grid stability, but the long-term damage to electric distribution infrastructure from grid instability caused by distributed solar PV technology diffusion has not been assessed. Also unexplored is the feedback mechanism between increasing solar PV technology adoption and increasing electricity price and the associated impact on power system infrastructure. New modeling techniques are needed to elucidate the effect of rooftop solar photovoltaic (PV) system adoption on power systems. This research develops a method to simulate the dynamics between the adoption of solar PV technology and energy infrastructure performance. An agent-based modeling approach is demonstrated by implementing a cellular automata system to represent the diffusion of technology through single-family household neighborhoods. The agent-based adoption model is coupled to a power system model, and simulations are performed to determine the effects on grid stability. Results indicate that solar PV technology diffusion can create long-term stability issues for low-voltage distribution networks. This research raises important questions about the appropriate strategy for both incentivizing solar PV technology adoption and maintaining an adequate level of grid stability.

Keywords: agent-based modeling, cellular automata, solar adoption, power system modeling

Category: Energy System Analysis

Using life cycle assessment and ecological payback period to evaluate commercial building replacement

Katelyn Mueller
Joseph F. DeCarolis (Advisor)

There is growing interest in improving building energy efficiency, and environmental impacts are increasingly cited as a consideration for new building construction and operation. Ecological payback period (EPP) is an existing metric that applies the concept of economic payback period to environmental impacts. This project investigates the application of a similar methodology to commercial buildings in order to make recommendations regarding building replacement, informing the point at which existing, underperforming buildings should be replaced with new, high-performing ones.

The EPP estimation model developed in this work includes the application of life cycle assessment (LCA) to generate an emissions inventory that includes building construction, demolition, and operation. The inventory is used to calculate environmental impacts, which are in turn used to estimate the EPP by impact category. The model is capable of applying variations in discount rate, energy efficiency, and the timing of project execution. While global warming potential is frequently used as the benchmark for the environmental performance of buildings, this project seeks to determine if other, often unassessed impact categories may be areas of concern for building projects, indicated by high EPPs. The selected case study is a college administrative building. Payback periods are not uniform across impact categories, but decrease to less than 25 years for a majority of impact categories when annual energy savings exceed 30%. By contrast, increases in discount rate and decreases in operational efficiency provide conditions for which payback does not occur. The ratio of construction impacts to operational savings for each impact category is found to be indicative of sensitivity to changes in discount rate and operational efficiency.

Keywords: life cycle assessment, ecological payback, building modeling

Category: Energy System Analysis

Effects of High Renewable Penetration in US Energy System

Neha Patankar
Joseph F. Decarolis (Advisor)

Many government policies worldwide have aimed to increase the share of renewable energy to reduce greenhouse gas emissions. The presence of such renewables policy affects the level of electrification in the heat and transport sectors and can also promote the use of distributed renewables. In this work, an open source energy system optimization model is used in conjunction with a national US input dataset to assess the effect of varying renewable energy targets on the energy system and how it affects overall emissions, total system cost, technology mix, and electrification level in various end-use sectors. The scenarios can be used to identify the technologies that contribute to various renewable energy targets to be achieved through 2040. We analyze the degree to which end-use energy services are electrified. Results suggest that higher renewables targets promote electricity sector decarbonization and an increased level of electrification across the energy system. Model results indicate that a maximum 44% renewable share can be achieved with a 10% increase in total system cost and a 54% reduction in CO2 emissions in 2040. We also identify potential policy measures and barriers to electrification within renewable energy systems.

Keywords: high renewable penetration, electrification, energy system models, emission reduction, climate change

Category: Energy System Analysis

Evaluation of the effect of passenger load on transit bus energy use

Tongchuan Wei
H. Christopher Frey (Advisor)

There are over 1,000 transit bus systems in the U.S. Over 40% of the transit bus fleet is diesel-fueled, with almost 30% fueled by natural gas. In 2015, total energy consumption for the U.S. transit bus system was 82 trillion BTU. There are few empirical studies regarding the effect of passenger load on transit bus energy use. The objective is to evaluate the effect of passenger load on bus tractive power, to use chassis dynamometer data to evaluate the effect of passenger load on bus energy use and develop a model for energy use rate versus passenger load, and to evaluate the model using available real-world measurement data. The scope includes 40-foot-long compressed natural gas (CNG) and diesel buses. To quantify the expected effect of passenger load on tractive power, scaled tractive power (STP) was calculated for selected driving cycles for empty and full buses. Empirical data for measured cycle-average energy use were obtained from the Integrated Bus Information System (IBIS). Measured cycle-average energy use rate versus passenger load was analyzed for driving cycles selected based on data sufficiency criteria. Measured bus energy use per mile increases and energy use per passenger-mile decreases when passenger load increases. The relative effect of passenger load on energy use rates is larger for the lowest cycle-average speed, which is consistent with the results from the theoretical STP analysis. The reduction in energy consumption per passenger-mile for another passenger is larger when buses are less occupied. The developed energy use rate models predict relative changes in energy use per passenger-mile consistent with available measurements reported for real-world bus operation. Therefore, the results provide a systematic framework for incorporation of bus passenger load into energy estimation models. Personal energy consumption for transit buses can be compared among multiple transportation modes and for different driving cycles.

Keywords: transit bus, energy, passenger load, chassis dynamometer

Category: Energy System Analysis

Environmental Process Engineering

Desalination using ionic polymer coated electrodes in flow-through capacitive deionization

Yazeed Algurainy
Douglas Call (Advisor)

Although water desalination has been recognized as an alternative water source, water produced by desalination technologies is still not economically attractive. Reverse osmosis (RO), for example, requires high pressures to force feedwater to pass through a permeable membrane while preventing the passage of salts and other minerals. Capacitive deionization (CDI) is a competitive desalination technology in which a low potential (~1 V) is applied across a pair of porous carbon electrodes, and salts from the feedwater are removed via electrosorption. In most CDI designs, flow is directed parallel to the electrodes. Directing flow perpendicular to the electrodes in flow-through (FT) CDI, eliminates the need for a thick spacer between electrodes, resulting in a compact and low resistance system. However, charge efficiencies and salt adsorption capacities reported in the literature for FT-CDI systems are low relative to flow-past CDI. They range from 55-70% and 7-8.5 mg/g, respectively, depending on feedwater salt concentrations, electrode materials, and applied potentials. These results are mainly attributed to co-ion effects that exist in electrical double layers (EDLs) of the porous carbon. To overcome this limitation, we hypothesized that applying ion selective polymers onto activated carbon (AC) cloth electrodes would improve charge efficiency and adsorption capacity because the co-ions in the EDLs would be blocked by the polyelectrolyte layers from returning to the feedwater channel. This hypothesis was tested by applying a Nafion cation exchange solution (5% by weight) to the AC electrodes. To examine the effectiveness of coating, coated and uncoated electrodes were tested under identical conditions. Our results show that coating electrodes with the ionic polymers can increase charge efficiency and adsorption capacity by up to 51.1% (85.35%) and 93.3% (14.99 mg/g), respectively, relative to the uncoated electrodes. This work introduced a new FT-CDI architecture and may have important implications for a reliable desalination technology.

Keywords: capacitive deionization, ion exchange membrane, electrical double layer, ionic polymer

Category: Environmental Process Engineering

Using fluorescence spectroscopy of dissolved organic matter to understand constructed wetland unit processes

Austin Burke
Tarek Aziz (Advisor)

Constructed wetlands (CW) are low cost water treatment systems that have been shown to effectively remove COD and nitrogenous species from wastewater. In addition, more recent research has also shown the promise of constructed wetlands for the removal of contaminants of emerging concern (CECs) through dissolved organic matter (DOM) mediated photodegradation. The characterization of DOM is critical for understanding both the photodegradation of CECs and more traditional wastewater treatment in constructed wetlands. A significant source of DOM in wetlands is senescent plant material from emergent macrophyte species like broad-leaf cattails (Typha latifolia). Despite knowing the primary source of DOM in constructed wetlands, little is known about the engineering design of vegetative constructed wetlands cells for the purpose of enhancing photo-reactive DOM and/or DOM utilized in nitrate removal. This poster describes our preliminary work to better understand the role of wetland design and operation on DOM production and composition. Preliminary field monitoring results of Walnut Cove constructed wetland are presented relating fluorescence spectroscopy measures (to characterize DOM quantity and quality) with water quality parameters. We also present our experimental plan to build macrophyte unit-process reactors to better identify the specific role of common plants on DOM, DOM mediated photodegradation of CECs, and wetland water quality.

Keywords: constructed wetlands, nitrogen removal, dissolved organic matter, fluorescence spectroscopy, excitation emission matrix

Category: Environmental Process Engineering

Adding electrically conductive materials to anaerobic digesters to improve methane generation: the role of material properties

Qiwen Cheng
Douglas F. Call, Francis L. de los Reyes III (Advisor)

Electron flow within microbial communities significantly affects reaction rates during anaerobic digestion of organic matter to methane. Electrons can be transported via production of intermediates (e.g. hydrogen and formate), or direct interspecies electron transfer (DIET), which has been suggested to enable direct cell-to-cell electron exchange from syntrophic fermenters to methanogens. Supplementation of electrically conductive materials has been proposed to enable DIET and expedite methane production. However, other material properties such as adsorptive behavior, surface roughness, and influence on bulk pH have been largely overlooked in DIET studies, which has limited our ability to draw clear conclusions about a material's potential to stimulate DIET. Our objective, therefore, was to determine the impact of conductive material amendments on methane production from anaerobic digesters, and to investigate the roles of several physical and chemical properties of amended materials, including electrical conductivity. Graphite, biochar and activated carbon particles were each added to anaerobic reactors fed with swine wastewater and the resulting methane generation rates and recoveries recorded. Our findings indicate that there was no relationship between methane production and material conductivity. Moreover, material adsorptive behavior was a critical property that influenced reactor performance. In particular, organic matter adsorption to biochar and activated carbon reduced chemical oxygen demand (COD) conversion to methane relative to controls lacking particle amendments. The maximum methane production rate was decreased by 76 ± 1.1% with the powdered activated carbon amendment. To further examine the impact of conductivity, graphite pencil leads with varying conductivities but more consistent surface properties were tested, but no clear correlation between methane production and conductivity was observed, suggesting an insignificant role of electrical conductivity. Our findings serve to guide the design and selection of material properties that may be more favorable for accelerating methane production in anaerobic digesters.

Keywords: anaerobic digestion, wastewater, electrically conductive materials, direct interspecies electron transfer, adsorption

Category: Environmental Process Engineering

Heat generation and accumulation in municipal solid waste landfills

Zisu Hao
Morton Barlaz, Joel Ducoste (Advisor)

Elevated temperatures have been reported in some municipal solid waste (MSW) landfills in North America and often require increased monitoring and management. At elevated temperature landfills (ETLFs), a number of exothermic reactions occur when MSW and other non-hazardous wastes are buried in landfills, including both aerobic and anaerobic biodegradation, anaerobic metal corrosion, acid-base neutralization, ash hydration/ carbonation, and thermochemical (pyrolytic) reactions in biomass. Recently, a batch reactor model demonstrated that anaerobic Al corrosion, ash hydration/carbonation, and hypothesized pyrolysis reactions have the potential to significantly increase landfill temperature. In the batch reactor model, the landfill temperature and concentrations do not vary spatially, which is not appropriate for actual landfills. In this work, a transient finite element model was developed to incorporate gas-liquid-heat reactive transfer in a landfill with biological and chemical reactions. The heat balance equation considered the effects of heat generation from abiotic and biotic reactions, conduction, evaporation and condensation, and liquid and gas convection. The impacts of local air intrusion, local disposal of ash, anaerobic Al corrosion, the synergistic effect of ash hydration/carbonation on metal corrosion, and the spatial distribution of gas and leachate collection systems will be presented to display the accumulation and transport of heat in a landfill. Transient and spatially resolved temperature profiles will illustrate the initiation and hypothesized propagation of elevated temperature events.

Keywords: elevated temperature landfills; heat generation; municipal solid waste; temperature

Category: Environmental Process Engineering

Detection and treatment of per- and polyfluorinated compounds in Cape Fear River water

Zachary Hopkins
Detlef Knappe (Advisor)

Health implications associated with long-chain per- and polyfluorinated substances (PFASs) have caused a shift in PFASs manufacturing and usage towards shorter-chain PFASs and fluorinated alternatives. Fluorinated alternatives include perfluoroalkyl ether carboxylic acids (PFECAs) and sulfonic acids (PFESAs), in which ether oxygen atoms are incorporated into the perfluoroalkyl chain. In the Cape Fear River basin of North Carolina, PFECAs and PFESAs have dominated the PFAS signature downstream of a fluorochemical manufacturer. Furthermore, PFECA removal was negligible by conventional surface water treatment processes as well as advanced treatment processes such as ozonation, biofiltration, and disinfection by ultraviolet light. Our research aims to 1) assess the removal of emerging PFASs by granular activated carbon (GAC) adsorption and 2) introduce a novel approach to enhance PFAS adsorption by amine-modified cyclodextrin (am-CD). PFAS samples were collected at various locations upstream and downstream of a PFAS source from May-November 2017. Samples were analyzed by ultra-performance liquid chromatography - tandem mass spectrometry (UPLC-MS/MS) and liquid chromatography - time-of-flight mass spectrometry (LC-TOF-MS) for 11 PFASs and 10 PFECAs/PFESAs. GenX, a replacement for perfluorooctanoic acid, was below the method reporting limit of 10 ng/L upstream of the PFAS source, but present at levels of up to 2,400 ng/L at a downstream drinking water treatment plant intake. Other PFECAs exhibited peak areas up to 45 times those of GenX. PFECA adsorption was studied over the same period in a full-scale GAC contactor, and onset of GenX breakthrough occurred after treating approximately 4,000 bed volumes of water. Other PFECAs were removed less effectively, while a 7-carbon PFESA was removed more effectively than GenX. To improve GAC service life for poorly adsorbing PFECAs, we are currently exploring the use of am-CD, which is expected to form strong host-guest interactions with PFECAs.

Keywords: surface water, drinking water treatment, per- and polyfluorinated compounds, granular activated carbon

Category: Environmental Process Engineering

Seasonal variation of salinity gradient energy extraction from coastal North Carolina

Elvin Hossen, Zoe Gobetz
Douglas Call, Orlando Coronell (Advisor)

Coastal salinity gradients can be used to generate electricity using a technology called reverse electrodialysis (RED). In RED, two waters with different salinity flow between a stack of alternating ion exchange membranes, resulting in flow of ions. Electricity is generated when ions are converted to electrons at two terminal electrodes. Power output using real waters ranges from 0.07-0.59 W.m-2 (normalized to membrane surface area). Power is influenced by several factors, including salinity gradient magnitude, presence of natural organic matter (NOM), and ionic composition. Variation in these properties has not yet been considered either experimentally nor when estimating the energy recovery potential of RED in coastal environments. Accordingly, our objective was to determine the impact of seasonal variation on RED performance. We compared the performance of RED using seawater samples collected from three different sources along coastal North Carolina at five different times spanning 2016-2017. We used a single low-strength water (treated wastewater effluent from the coast) and focused on two key parameters: temperature and conductivity. Our results indicate that power output varied across the seasons, reaching as high as 0.247 $W.m^{-2}$ (July 2016) and low as 0.014 $W.m^{-2}$ (September 2016) in a given location. The variation in both temperature and conductivity in seawater was positively correlated with maximum power density. Using our experimental results, we developed a predictive model of RED power output as a function of real water temperature and conductivity. The model predicted actual power density at approximately 81% of theoretical value at the 95% confidence level. To improve this model, we suggest that other factors representing water quality such as the presence of inorganic constituents and NOM need to be considered. In conclusion, we show that taking seasonal variations of temperature and conductivity need to be considered when estimating actual power outputs from coastal salinity gradients.

Keywords: salinity gradient, reverse electrodialysis, seasonal variation, predictive model

Category: Environmental Process Engineering

A life cycle analysis framework for the end-to-end microalgae-to-biofuel system

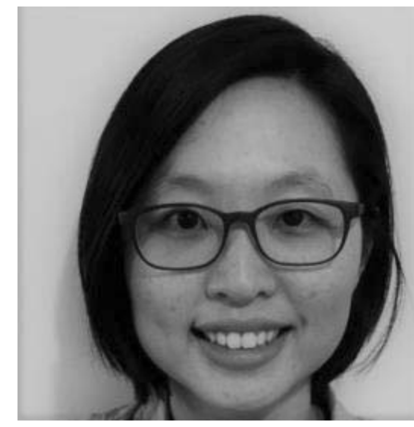
Mathew Jacob
James W. Levis, S. Ranji Ranjithan (Advisor)

There is a growing interest in developing low-carbon renewable biofuels. Production of microalgae-based biofuels in photosynthetic biorefineries (PSBRs) has the potential to reduce fossil fuel consumption and greenhouse gas emissions compared to conventional fuels. Microalgae have higher growth rates and lipid concentrations compared to terrestrial fuel crops, and microalgae-based biofuels have the potential to reduce land and freshwater consumption compared to corn or soybean-based biofuels. There are currently no industrial-scale microalgae PSBRs due to the relatively high cost of large-scale cultivation and harvesting of microalgae. Previous studies have shown that algae harvesting is an expensive and energy intensive step in the conversion of microalgae into fuels. Therefore, it is important to optimize the overall system to reduce costs, resource consumption, and environmental impacts. The objective of this research is to develop a dynamic Life Cycle Analysis (LCA) model for the end-to-end microalgae-based biofuel production system. With each process within the system (i.e., cultivation, harvesting, extraction, and conversion), there are multiple alternatives, each with their own advantages and disadvantages. The focus of this research is to develop an LCA model for the complete microalgae-to-biofuel system including multiple system pathways. The model estimates the mass flows, costs, emissions, and energy consumption for each process in the system. Results indicate that among the harvesting alternatives, electroflocculation has lower costs and emissions compared to electrocoagulation and centrifugation. Among the lipid extraction and fuel conversion methods, combined hydrothermal liquefaction and catalytic hydrothermal gasification costs more than wet extraction but produces more fuel. The dynamic life cycle modeling framework is a valuable tool for estimating the trade-offs among cost, energy production, and environmental impacts associated with different alternatives for the microalgae-to-biofuel systems.

Keywords: photosynthetic biorefineries, life cycle analysis model, microalgae-to-biofuel systems

Category: Environmental Process Engineering

Optimizing lipid production of *Dunaliella viridis* in a lab-scale photobioreactor with continuous light monitoring



Yi-Chun Lai
Francis L. de los Reyes III, Joel J. Ducoste, Ranji Ranjithan, and James W. Levis (Advisor)

Microalgae are a promising renewable energy source, because they grow fast, do not need land, and have the ability to capture CO_2. *Dunaliella viridis* (*D. viridis*) is a potentially good source of biofuel because of its high content of neutral lipids, which are building blocks of biodiesel. In addition, the lack of a cell wall allows potential extraction of lipids through osmotic lysis.

To produce high lipid yields from *D. viridis*, optimizing growth is necessary. Previous work suggests that under environmental stress conditions such as light or nitrogen limitation, lipids would accumulate in the algae cell. To date, most of the research on *D. viridis* growth has been conducted in lab-scale flasks. Microalgae kinetic growth tests in a photobioreactor (PBR) with continuous light and pH monitoring have not been conducted before. Our group designed and constructed a lab scale PBR system to closely control *D. viridis*'s growth environment, such as pH, light, and CO_2 input.

In this study, we used a novel lab-scale PBR with a continuous light monitoring system to explore the interactive effects of light intensity (100, 300, 400, and 600 μmol/m^2-s (PPFD)) and nitrogen level (0.5 and 5 mM nitrate) on the growth of *D. viridis*. The results showed lipid production rate peaked at 300 μmol PPFD and low nitrogen conditions (3.15 g/m^3-day), and biomass production rate peaked at 400 PPFD and high nitrogen conditions (70.84 g/m^3-day). Through continuous light monitoring, we showed that at high nitrogen conditions, light stress occurred during the latter stages of growth due to growing biomass which induced higher levels of chlorophyll, carbohydrates and lipids within cell. This work increased our understanding of more optimal growth environments to enhance lipid yield of *D. viridis* in a PBR system, and generates needed data that can be used as inputs to D. viridis growth models.

Keywords: *Dunaliella viridis*, lipid, nitrogen, light, photobioreactor

Category: Environmental Process Engineering

Household water filters for removal of perfluoroalkyl substances

John Merrill
Detlef Knappe (Advisor)

Perfluoroalkyl substances (PFASs) are used in the manufacture of numerous industrial and consumer products. Accumulating evidence of adverse human health impacts associated with exposure to long-chain PFASs has led to recent regulatory attention and development of fluorinated alternatives, such as hexafluoropropylene oxide dimer acid (HFPO-DA, also known as "GenX"), with limited understanding of the potential health implications. GenX, legacy PFASs, and other fluorinated alternatives have been identified in drinking water sourced from the Cape Fear River (CFR). Previous studies have demonstrated that reverse osmosis (RO) and activated carbon (AC) can be effective for removing long-chain PFASs at centralized water treatment plants. We hypothesize that point-of-use (POU) water filters employing these technologies could be an effective barrier for PFASs at the household scale. My research objectives are to (1) quantify PFAS removal by POU filters and (2) identify POU filter characteristics that govern PFAS removal. Eleven household water filters installed by homeowners within the CFR basin were tested for PFAS removal, with water samples taken before and after filtration. Six RO filters were tested, with total PFAS removal ranging from 95 to 99%. Of the five AC filters tested, four filters showed PFAS removal ranging from 94 to 99%, while a fifth filter demonstrated significant desorption ($C/C0 = 2.27$). We suspect that desorption in the fifth filter was a result of decreased PFAS concentrations in the CFR after household filter installation, reversing the concentration gradient between the heavily loaded activated carbon and the bulk solution. Lab-scale testing of POU devices will be conducted in accordance with NSF/ANSI standards to control for extraneous variables unable to be controlled during home sampling. Further, AC and RO characteristics will be identified to determine filter properties that contribute to PFAS removal effectiveness. Results of this research have helped home owners in the Wilmington area select effective home filters.

Keywords: drinking water treatment, emerging contaminants, activated carbon, reverse osmosis

Category: Environmental Process Engineering

Measurement of heat released by ash hydration and carbonation using an isothermal calorimeter

Asmita Narode
Morton Barlaz (Advisor)

Recently, there have been several reports of municipal solid waste (MSW) landfills that have been experiencing temperatures in excess of 80 – 100 °C. Elevated temperatures have a number of deleterious effect. In recent work, we developed a model for heat accumulation in a landfill that treats the landfill as a batch reactor. The model identified several reactions that contribute significant heat to landfills including the hydration and carbonation of calcium-containing wastes such as ash from MSW and coal combustion. Model predictions were based on published information on reaction thermodynamics and kinetics but there is limited quantitative data on heat evolution from actual calcium-containing wastes.

The objective of ongoing research is to develop methods to measure heat released by ash hydration and carbonation in an isothermal calorimeter. Initial tests were conducted to compare the heat released by calcium oxide (CaO) and hydroxide Ca(OH)2 to theoretical values. Experiments were conducted by adding known weights of CaO and Ca(OH)2 to 20 mL vials for measurement of heat evolution in an isothermal calorimeter. To measure carbonation, were pressurized with 80/20 CO2/N2 humidified gas. After the reaction was completed, the CO2 concentration in the vials was measured by using a gas chromatograph. In addition, the presence of calcium carbonate (the product of Ca(OH)2 carbonation) was verified by adding strong acid (H2SO4) to the sample and checking for the formation of bubbles indicative of CO2 release. Further, the amount of calcium carbonate in the system was verified by running the reacted sample through thermogravimetric analysis (TGA).

The results to date show that the measured heat is within 100% of theoretical amount expected for hydration and 50% theoretical amount for carbonation. Additional work is in progress to understand why we are not reaching theoretical values for the control compounds.

Keywords: elevated temperature landfills, isothermal calorimeter, batch reactor, ash hydration, ash carbonation

Category: Environmental Process Engineering

Nitrogen fixation and potential ammonia production in Microbial Electrochemical Technologies

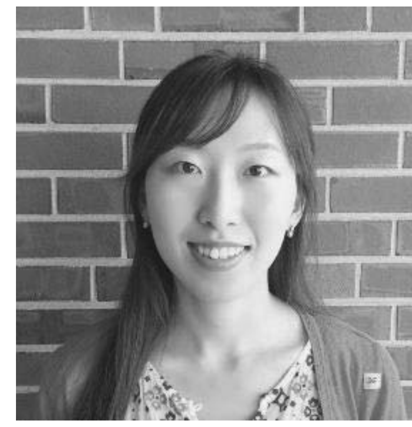
Juan Fausto Ortiz Medina

Douglas Call (Advisor)

Nitrogen gas (N_2) fixation (or diazotrophy) is a microbial process that generates ammonia (NH_3) at ambient conditions, mainly driven by the enzyme nitrogenase and involving energy gained from respiration. Some bacteria capable of N_2 fixation, among them species of the genus *Geobacter*, can respire on the anode electrodes of microbial electrochemical technologies (METs) and generate electrical current. The ability to influence the metabolic rates of anode biofilms by applying small voltages suggests that it may be possible to drive N_2 conversion to NH_3, providing new alternatives to generate this valuable fertilizer and fuel. However, N_2 fixation in METs is poorly understood. Accordingly, our objectives were to determine 1) if electrical current generation is affected when cells fix N_2, 2) N_2 fixation rates during electrode respiration in the presence versus absence of ammonium (NH_4^+), and 3) the influence of an applied cell potential on those rates. To fulfill these objectives, we operated several METs with an enriched anode respiring community and with either only N_2 as a nitrogen source or both N_2 and NH_4^+. Acetylene reduction tests to assess nitrogenase activity allowed us to estimate a nitrogen fixation rate of 1.92 nmol N_2 per minute when a cell voltage of 0.7 V was applied, whereas a voltage of 1.0 V increased the rate to 6.61 nmol N_2 per minute. Furthermore, the addition of methionine sulfoximine to inhibit NH_3 uptake allowed the detection of 0.14 mM NH_3 at 0.7 V, and 0.34 mM NH_3 at 1.0 V. These results indicate that anode respiring organisms are capable of N_2 fixation and that fixation rates are influenced by applied voltages. Considering that NH_3 is also a high-value compound whose industrial production (via the Haber-Bosch process) consumes 1-2% of the global energy, METs may offer the possibility to generate NH_3 in a more sustainable way.

Keywords: nitrogen fixation, microbial electrochemical technologies, ammonia, nitrogenase

Category: Environmental Process Engineering



Removal of short-chain perfluorinated compounds by electrically enhancing adsorption

Sol Park, Conner Murray

Douglas Call, Detlef R. U. Knappe (Advisor)

Industrially produced per- and polyfluoroalkyl substances (PFASs) are suspected carcinogens and are present in many ground and surface waters. Activated carbon (AC) is a widely used sorbent to remove PFASs. Two limitations of AC are 1) the inability to effectively remove some PFASs, especially short-chain species, and 2) the lack of cost-effective regeneration methods. Capacitive Deionization (CDI) is an emerging technology in which ions are removed via electroadsorption onto electrodes when a small (~1.0 V) voltage is applied between them. Since PFASs ionize under neutral pH, we hypothesize that we can use CDI to enhance their adsorption on and desorption off AC electrodes. Our initial experimental cell obtained approximately 50% removal of a high concentration (1 g/L) of the short-chain perfluorobutanoic acid (PFBA) species, compared to only 8% without an applied voltage. Our current objective is to optimize a new CDI design for removal of low (ppm to ppb range) concentrations of PFASs. We are currently validating a CDI design using sodium chloride (NaCl). Our preliminary results show that the cell can obtain adsorption capacities of up to 14.2mg-NaCl/g-AC and charge efficiencies (ratio of ions removed to charge accumulated) of 90-95%. Our next step is to determine the ability of our optimized design to remove PFBA at a range of different concentrations. We expect that charging AC will enhance adsorption, but that competitor ions (namely Cl-) may outcompete PFBA for adsorption sites. Nevertheless, we will provide new insight into PFAS adsorption behavior under an electrical field.

Keywords: Capacitive Deionization, perfluoalkanoic acid removal, electrochemistry, ionic forces, van der Waals forces, water quality treatment

Category: Environmental Process Engineering

Tertiary mainstream deammonification in pilot-scale ANAMMOX filters

Eric W. Polli[1,2], Katya Bilyk[2], Wendell Khunjar[2]
Tarek Aziz[1] (Advisor), Francis L. de los Reyes[1] (Advisor)
[1]NC State University, [2]Hazen and Sawyer

As effluent nutrient limits become more stringent, an economical nitrogen removal process that meets new regulations needs to be developed. Mainstream deammonification is a nitrogen removal process that saves both carbon and oxygen costs when compared to conventional nitrification/denitrification processes. The goal of this research is to investigate the feasibility of converting existing filters at wastewater treatment facilities into mainstream deammonification filters.

To explore deammonification filter startup and operation, two pilot-scale filters will be seeded with anaerobic ammonia oxidizing (ANAMMOX) bacteria and operated continuously for approximately 300 days. NH_4^+ and NO_2^- will be dosed at a concentration of 3 mg/L into each filter. The flowrate through the 3.5-foot column of sand will produce an empty bed hydraulic retention time of 90 minutes. The temperature of the influent will be held at around 30°C. Three sample ports, located along the side of each filter column will be used to measure intermediate filter performance. The ports correspond to hydraulic retention times of 26, 52, and 77-minute HRT, respectively. These sample ports will allow for a vertical profile analysis of the reactor. Real-time data will be collected on the influent via a pH probe and an ammonia-nitrate ISE probe, and on the effluent via Amtax and Nitratax sensors, automated wet-chemistry water quality analyzers. In addition, Hach vial kits will be used to monitor NH_4^+, NO_2^-, NO_3^-, and COD in both the influent and effluent. In this experiment we will investigate the effects of backwashing, variations in nitrogen loading, and phosphorus limitations on the bacterial colonies.

Keywords: deammonification, ANAMMOX, mainstream, filters, nitrogen removal

Category: Environmental Process Engineering

Engineering electricity-responsive metabolic pathways in bacteria

Mark Poole
Douglas Call (Advisor)

Biological fermentations are important across many industries but have proven to be environmentally unsustainable. A major challenge is the redox-imbalanced nature of many fermentations, which can severely hinder kinetics and selectivity. Oxygen can be added to serve as an electron sink for unbalanced fermentations, but its solubility limits require constant aeration. Electrofermentation is a new field that provides an alternative to standard fermentation by utilizing electrogenic organisms. Electrogenic organisms utilize an electrode as the final electron acceptor, providing fast reaction rates and higher selectivity. Further, these electrodes are not subject to solubility limits and are inexpensive. However, the pathways responsible for electrofermentation still remain relatively unknown. In the upcoming research, a model fermentative and electricity-generating organism, *Shewanella oneidensis,* will be examined to determine the pathways responsible for electrode response. *S. oneidensis* is particularly attractive for this technique because it has been shown to activate different pathways based upon the poised potential of the electrode. These pathways will be identified and exploited to generate several foreign products. These products will be "electro-inducible" because their production will be tied only to electrode potential. The information gained from this work will not only provide a transformative platform for biochemical generation, but will lead to new insights into electrically driven metabolic pathways.

Keywords: microbial fuel cell, electro-induction, metabolic engineering, fermentation

Category: Environmental Process Engineering

Solving a trashy issue in pit latrine emptying: Adequate sanitation for all

Giovanna Forti Portiolli
Francis L. de los Reyes III (Advisor)

Billions of people around the world still lack access to adequate sanitation. Many low and middle income countries that do not have sewer infrastructure rely on pit latrines as their main solution for human waste disposal. In order to remain an effective alternative, pit latrines require periodic emptying. A simple solution of emptying these pits by contracting a vacuum truck is not feasible due to its high costs and oversized equipment, which is not able to reach many pits usually located in overcrowded and tight areas. Unfortunately, the often go-to solution is manual emptying, which exposes the workers and the environment to non-sanitary and degrading conditions. Even though there are technologies being developed to address this problem, an additional hindrance is the high amount of solid waste found inside pit latrines, which ends up being a huge obstacle for the functionality of any emptying system. The Flexcrevator is a pit latrine emptying vacuum system developed at NC State University; it is a differentiated technology due to its implemented trash exclusion mechanism. Amongst different trash exclusion designs, a perforated pipe and an auger head have shown promising initial results. In this research project, both designs will be tested under varying circumstances such as sludge thickness, amount of trash, vacuum strength and RPM to optimize conditions of operation. A successful system will have a 3 L/sec flow rate and minimum clogs or trash acceptance into the system. The results will lead to the development of an affordable, hygienic and efficient technology for pit latrine emptying in the developing world, minimizing public health concerns and environmental contamination.

Keywords: pit emptying, trash removal, Flexcrevator, developing countries

Category: Environmental Process Engineering

Constructed wetlands for photochemical degradation of wastewater-derived contaminants

Arpit Sardana
Tarek N. Aziz (Advisor)

In this presentation, we will discuss our previous work monitoring the photochemical behavior of wastewater effluent in a regional constructed wetland, describe the functioning of wetland microcosms and report preliminary irradiation experiments wherein we explore the degradability of a known contaminant of emerging concern (CECs). The objective of these efforts is to test the hypothesis that terrestrially influencing effluent streams via vegetated surface flow constructed wetlands modifies effluent dissolved organic matter (DOM) composition to enhance indirect photodegradation of CECs. We have used a suite of spectroscopic and chromatographic techniques to characterize DOM photoreactivity reactors.

The DOM composition of effluents from field and lab wetlands was characterized by UV-vis spectra and excitation emission matrix fluorescence spectroscopy (EEMs). The effluent samples from the Walnut Cove, NC, treatment wetlands were observed to transition from a microbially sourced protein-like DOM to a higher molecular weight terrestrial DOM with higher aromaticity. This transition coincided with enhanced formation rates and steady state concentrations of singlet oxygen and excited triplet states of DOM. The effluent collected from vegetated wetland microcosms had a predominantly humic-fulvic like DOM fingerprint. These microcosms validated the theory that plant interaction is a source of photosensitizing DOM and is a crucial component of DOM processing in wetlands.

The effect of sunlight exposure on the photostability/photolability of wetland DOM was evaluated by irradiating collected samples in a solar simulator. The change in DOM composition due to irradiation was monitored by UV-vis spectra and EEMs pre and post irradiation exposure. Furthermore, photolysis experiments were designed to compare the photodegradation potential of wetland influenced DOM with wastewater derived DOM. Effluent samples spiked with amoxicillin were irradiated and monitored for photo-decay by periodically measuring concentrations using an HPLC.

Keywords: wetlands, photodegradation, DOM, CECs

Category: Environmental Process Engineering

Life cycle assessment of municipal solid waste conversion to liquid fuels through a combined gasification-Fischer-Tropsch process

Mojtaba Sardarmehni
James W. Levis (Advisor)

Over 130 million tons of municipal solid waste (MSW) are disposed in landfills in the US annually leading to over 4 million tons of CH_4 emissions. There is increasing interest in cost-effective technologies to reduce the environmental emissions, impacts, and resource use associated with waste management. Converting MSW to liquid fuels has the potential to increase landfill diversion while reducing fossil fuel demand and greenhouse gas (GHG) emissions. Fuels developed from MSW also require less land and water than first generation biofuels (e.g., corn-based ethanol), making them a potentially attractive alternative source of renewable liquid fuels. Combined gasification-Fischer-Tropsch (GFT) processes have been used to convert coal and biomass into liquid fuels since the 1920s, and there is an increasing interest in using GFT for MSW treatment. The objective of this analysis is to assess the life-cycle emissions, environmental impacts, and resource use from the conversion of residual MSW (i.e., MSW excluding source-separated recyclables) to liquid fuels via GFT. The GFT life-cycle process model includes the production of a homogenized refuse-derived fuel (RDF), drying, gasification, conversion of the generated syngas to syncrude via Fischer-Tropsch, and refining of the produced syncrude into fuels. Drying the waste prior to gasification allows the system to treat MSW with high moisture content (e.g., food and yard waste) that are often more difficult to recover than traditional recyclables. The process models were developed in a spreadsheet and the gasification process was simulated in Aspen Plus to develop input values for the spreadsheet model. Results indicate that GFT has the potential to reduce GHG emissions and fossil energy demand compared to landfilling. Sensitivity analyses explored the effects of MSW composition and moisture content on the life-cycle results.

Keywords: Municipal Solid Waste, gasification, Fischer-Tropsch, Life Cycle Assessment, modeling

Category: Environmental Process Engineering

Microbial communities in full scale wastewater treatment plants are shaped by inoculum dominated stochastic processes

Joseph E. Weaver, Aditi Murthy, Ling Wang
Francis L. de los Reyes III (Advisor)

Understanding the factors shaping the diverse and highly variable microbial communities within activated sludge basins can lead to improved operation and designs. Early studies applying first generation molecular data suggest that rather than traditional niche-selection, random processes of immigration, reproduction, and deaths drive community assembly.

An opportunity for a unique natural experiment to test community assembly drivers arose when the Western Wake Water Reclamation Facility (WWRF), was inoculated with sludge from the nearby North Cary Water Reclamation Facility (NCWRF). The plants differed in that they received influent from different collection systems and used different aerobic processes. We hypothesized that any community divergence from the initially identical populations could be related to differences in influent and operation.

We conducted a 16S rRNA metagenomic survey of the two plants and their respective influent streams over six months. The influent communities of each plant were distinct and relatively stable. In contrast to the influent populations, the basin communities contained dynamically changing microbial communities which appeared to converge and were more strongly influenced by the inoculum than the influent.

Differential expression analysis methods similar to those used in gene expression research suggest which taxa are significantly responsible for driving these differences. For example 12 phyla are primarily responsible for the differences between the plant influents. Comparing the realized communities with null models shows that stochastic processes strongly dominated assembly, which is consistent with high turnover and dominance of habitat generalists driving the community differences between basins. Given these findings, it is likely that one of the most important steps towards a robust wastewater treatment plant is careful inoculum selection from an existing plant with a proven treatment history. Further, attempts to use 'probiotic' analogues to treat failing plants are likely to prove unsuccessful.

Keywords: wastewater treatment, activated sludge, microbial ecology, community assembly, metagenomics

Category: Environmental Process Engineering

The effect of varying shear and extracellular polymeric substances on aerobic granulation

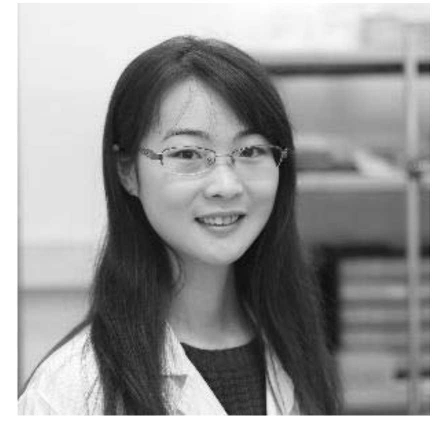
Jacqueline Yeh
Francis L. de los Reyes III (Advisor), Joel J. Ducoste (Advisor)

The efficiency of activated sludge (AS), the most common secondary wastewater treatment process, could be improved by converting the slow-settling flocs to larger, denser, and more regularly shaped microbial aggregates known as aerobic granular sludge (AGS). Advantages of AGS over AS include higher settling velocity, increased toxicity tolerance, and higher biomass residence time. Previous research has shown that AGS formation is affected by hydrodynamic shear force, organic loading rate, and hydraulic selection pressure. However, although these factors are known to be important to the granulation process, their impacts are not fully understood. This project aims to determine whether variations in hydrodynamic shear force and extracellular polymeric substances (EPS) are necessary factors for aerobic granulation by comparing the formation of AGS and its performance in Couette-Taylor Bioreactors (CTBs) and a control sequencing batch reactor (SBR). The SBR represents varying shear due to aeration from the bottom of the reactor while the movement of concentric cylinders in CTBs allows a consistent total average shear due to aeration and rotation. Three CTBs were compared to the SBR: one with lower, one with equal, and one with higher total average shear to the SBR. Granules were determined to be particles with an equivalent diameter above 200um and roundness above 0.6. The results showed the SBR achieved a higher percentage of granules than each of the CTBs, which did not consistently accumulate AGS. The SBR granule percentage peaked around day 40. EPS will be extracted and measured as a ratio of protein (PN) and polysaccharide (PS) components found in soluble, loosely-, and tightly-bound EPS. Patterns in the PN/PS ratio will be used to determine whether EPS and specific ratios of EPS components are correlated to the formation and stability of aerobic granules.

Keywords: activated sludge, aerobic granular sludge, hydrodynamic shear, extracellular polymeric substances

Category: Environmental Process Engineering

Bromide and Iodide incorporation into DBPs with and without GAC treatment



Chuhui Zhang
Detlef R. U. Knappe (Advisor)

Chemical disinfection using chlorine during drinking water treatment is an important step to assure the microbial safety of drinking water. However, chemical disinfection also leads to the formation of disinfection byproducts (DBPs), which are linked to adverse human health outcomes such as cancer and miscarriages. Currently, U.S. EPA regulates 11 DBPs: four trihalomethanes (THMs), five haloacetic acids (HAAs), bromate, and chlorite. Risk associated with DBP exposure can be exacerbated by elevated concentrations of bromide and iodide in drinking water sources and the resulting formation of brominated and iodinated DBPs.

Granular activated carbon (GAC) adsorption is shown to be an effective treatment process for the removal of many DBP precursors. The removal of regulated DBP precursors by GAC has been widely studied, but the treatment effectiveness for the precursors of emerging DBPs is not well understood. This study evaluated the formation of regulated DBPs, emerging DBPs, and total organic chlorine, bromine, and iodine (TOCl, TOBr, TOI) using rapid small scale column tests (RSSCTs). The impact of various bromide and iodide levels was also evaluated. Under the conditions of different bromide and iodide concentrations, GAC effectively reduced the formation of dissolved organic carbon (DOC), regulated and identified emerging DBPs and total organic halogen. Besides, GAC showed a reduction of the calculated cytotoxicity and genotoxicity (24-70%) using the TIC-Tox approach (Plewa et al., 2017). Results of this study are expected to aid drinking water treatment utilities control the formation of both regulated and unregulated DBPs in chlorinated drinking water.

References

Plewa, M. J.; Wagner, E.D.; Richardson, S. D., TIC-Tox: A preliminary discussion on identifying the forcing agents of DBP-mediated toxicity of disinfected water. *J. Environ. Sci.* 2017, 58, 208-216.

Keywords: disinfection byproducts; granular activated carbon; bromide and iodide

Category: Environmental Process Engineering

Development and use of photochemical microsensors for evaluating light dose distributions within photobioreactors

Amanda L. Karam
Joel J. Ducoste, Francis L. de los Reyes III (Advisor)

Optimal design and operation of photosynthetic bioreactors (PBR) for microalgae cultivation is essential for improving the environmental and economic performance of microalgae-based biofuel production. Since microalgae are photosynthesizing organisms, an accurate prediction of the overall light distribution throughout the PBR is critical for optimization. Light distribution is difficult to measure, and thus, the model predictions are difficult to validate.

This presentation describes the development and testing of a Lagrangian method for quantifying light dose distributions within PBRs using novel photochemical microsensors. These microsensors were developed using 3-μm microspheres coated with a caged dye that increases in fluorescence when exposed to photosynthetically-relevant blue wavelengths of light. The dose-response kinetics of these microsensors were established by exposing them to known doses of collimated light and quantifying the fluorescence responses in a flow cytometer on an individual particle basis. A deconvolution scheme was then used to determine the light dose distribution using the fluorescence distribution of the microsensors.

As a proof-of-concept test, these microsensors were used to quantify the light dose distributions within a gently mixed, 3L flat-plate, batch PBR with and without algae, and without algae but with gas bubbling. These novel microsensors not only illuminated information about the light distributions within the PBRs, but also predicted the average light attenuation due to algal cells within 1% of estimates made with an *in-situ* light sensor. Moreover, these results suggest that bubbling—under the conditions tested—increased the overall light irradiance by 18%; a result not captured by static measurements. These microsensors have demonstrated great potential for optimizing the design and operation of PBRs and could help bring algal-based biofuels one step closer to a reality.

Keywords: microalgae, biofuels, microsensors, light distribution, photobioreactors

Category: Environmental Process Engineering

Biological treatment of 1,4-dioxane at low microgram per liter concentrations by mixed cultures enriched from aquatic ecosystems in North Carolina

Amie McElroy

Detlef Knappe, Michael Hyman (Advisor)

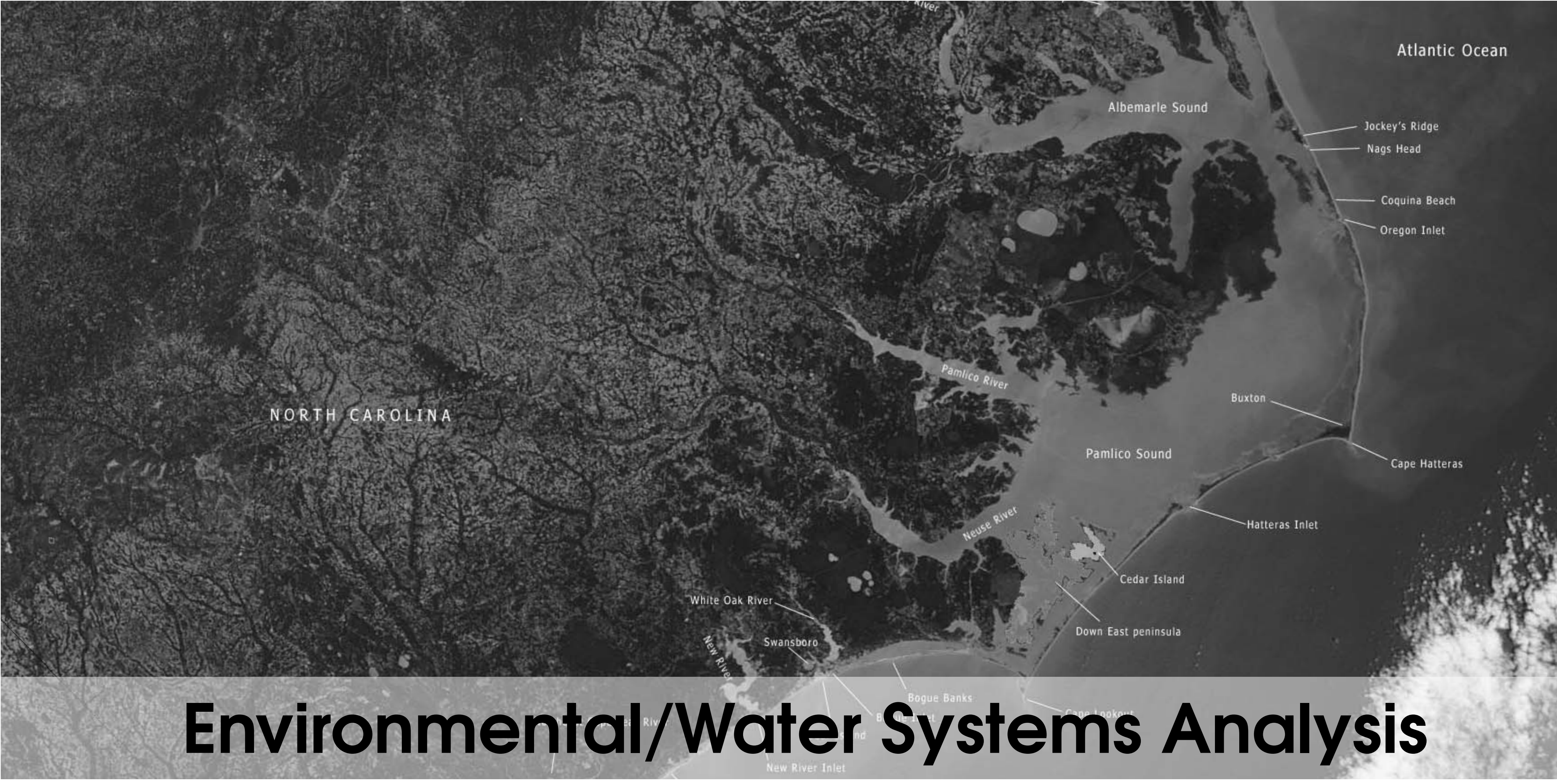
1,4-dioxane is a cyclic diether and a likely human carcinogen. An excess one-in-one million cancer risk is associated with lifetime consumption of drinking water containing 0.35 μg/L 1,4-dioxane. Some of the highest 1,4-dioxane concentrations in the nation (up to 80 μg/L) have been measured in drinking water produced from the Haw and Cape Fear Rivers. Conventional drinking water treatment is ineffective for 1,4-dioxane control, and physicochemical treatment processes for 1,4-dioxane control are costly. Biological treatment processes offer an opportunity for cost-effective control of 1,4-dioxane. Previously we determined that a variety of axenic bacterial strains grown on gaseous alkanes cometabolically degraded 1,4-dioxane to sub μg/L concentrations.

This research aims to (a) determine whether isobutane-metabolizing bacteria that cometabolize 1,4 dioxane can be consistently enriched from surface water microflora (b) probe the relationship between 1,4-dioxane degradation rates and the concentration of alkane-oxidizing monooxygenase enzymes and (c) identify alternative substrates for maintenance of cometabolism.

Water samples from NC rivers and a drinking water treatment plant were used as inocula for enrichment cultures with isobutane as a sole source of carbon and energy. All assayed enrichment cultures cometabolically degraded 1,4-dioxane at low concentrations (100 μg/L). ABPP analysis suggests that the same monooxygenase enzyme is expressed by all site enrichments. Using ABPP the relative concentration of the active monooxygenase enzyme in cell suspensions can be determined. This research establishes that 1,4 dioxane degradation at environmentally relevant, (μg/L) concentration ranges can be achieved by native NC microorganisms. Future research will focus on engineering biofilters for treatment of 1,4-dioxane and developing an ABPP assay to determine active monooxygenase enzyme activity in the biofilter.

Keywords: unregulated contaminants, biofiltration, enzyme activity, molecular methods

Category: Environmental Process Engineering



Environmental/Water Systems Analysis

Characterizing the risk of lead in well water

Mohammad Ali Khaksar Fasaee
Emily Z. Berglund (Advisor)

Following the industrial revolution, the presence of heavy metal ions dissolved in water has become a major threat to human health. Lead remains a common contaminant in drinking water and can cause serious neurological problems, even at low levels of exposure. Owners of private wells remain disadvantaged and may be at an elevated level of risk, because utilities or governing agencies are not responsible for ensuring that lead levels meet the Lead and Copper Rule for private wells. This research explores interactions among household and geological parameters and their effects on the risk of lead in tap water at private wells. Relationships are explored through the use of statistical and machine learning techniques. The Virginia Household Water Quality Program (VHWQP) collected water samples and conducted household surveys at 2146 households in Virginia between 2012 and 2013. A Bayesian Belief Network (BBN) was constructed and fitted to the dataset to predict the risk of lead for households and identify the dependency of lead on other factors, including plumbing type, source water, household location, and treatment options. Preliminary results demonstrate that the presence of lead in Virginian households is predictable for the presence of blue stains on plumbing, aquifer system, and location. Understanding the risk of lead at private wells provides insight for mitigating this threat by identifying effective remediation strategies based on the level of risk. The BBN model can be applied for other datasets to draw national risk maps to help protect citizens from lead in drinking water.

Keywords: lead in drinking water, Bayesian Belief Network, public health, private drinking water systems

Category: Environmental/Water Systems Analysis

Effects of vertical mixing on phytoplankton community shifts in a light-limited environment laboratory experiment

Alexandre Mangot
Tarek N. Aziz (Advisor), Daniel Obenour (Advisor) ,
Astrid Schnetzer

The formation of harmful algal blooms (HABs) in freshwater systems is an increasingly common occurrence. HABs produce a range of negative consequences from taste and odor issues in drinking water to the endangerment of human and ecosystem health. Artificial mixing has been utilized in a number of reservoirs as a means for source water control, however our understanding of the effects of mixing on phytoplankton community dynamics is limited due to the numerous factors affecting mixing in natural systems. Our research group has built three laboratory-based Water Column Reactors (WCRs) to mimic shallow lake conditions in a controlled environment to better understand the effects of mixing on phytoplankton community dynamics. The WCRs are 30 cm in diameter and 2 m tall, with 13 ports evenly spread to facilitate sampling at variable depths. An artificial light source allows the growth of algal species through photosynthesis, and a flexible mixing system allows the exploration of mixing intensity and duration. Suites of experiments were performed using natural assemblages from nearby lakes. WCR mixing scenarios included no mixing, constant mixing, and intermittent mixing in order to mimic typical diurnal mixing cycles of shallow lakes. A flow cytometer (FlowCAM) coupled with image recognition software was used to characterize phytoplankton community shifts. In vivo fluorescence and extracted chlorophyll-a were captured over time and depth to characterize phytoplankton growth in a light-limited environment. Finally, a phytoplankton competition model was developed using WCRs results to characterize the various factors influencing phytoplankton community shifts. In this presentation we will describe our physical and numerical results and discuss the insights gained from studying phytoplankton dynamics using the WCRs.

Keywords: harmful algal blooms, phytoplankton community, cyanobacteria, mixing, laboratory experiment

Category: Environmental/Water Systems Analysis

Modeling chloramine decay in full scale drinking water supply systems using EPANET-MSX

Henry Ricca
Kumar Mahinthakumar, Vasanthadevi Aravinthan (Advisor)

Chloramines are commonly used as secondary disinfectants in drinking water treatment, providing a residual for long lasting disinfection as drinking water moves through pipes to consumers. It is important for a disinfection residual to be maintained throughout a distribution system to ensure that potentially harmful organisms entering the system are deactivated. Though chloramines are generally considered less reactive than free chlorine, they are inherently unstable, and undergo auto-decomposition reactions even in the absence of reactive substances. In the presence of natural organic matter (NOM), chloramine loss is accelerated due to additional reaction pathways resulting in NOM oxidation. In this study, we have modeled chloramine loss due to autodecomposition and the presence of NOM both in a batch system using MATLAB and in a distribution network accounting for hydraulic effects using the EPANET-MSX toolkit. A case study was carried out for the Town of Cary's water treatment facility and distribution network. First, a hydraulic model of Cary's water distribution system, which has about 27,000 nodes, was developed and calibrated using the EPANET toolkit with operational and water demand data supplied by Cary. Then an EPANET-MSX water quality model was developed and calibrated using water quality data from Cary's water treatment plant and sampling points throughout the distribution network. Finally, the calibrated hydraulic model and water quality model were used together to predict chloramine concentrations spatially and temporally throughout the network. The predicted concentrations can be used to identify locations that may need booster chloramines in order to maintain a suitable disinfection residual.

Keywords: chloramine decay, water distribution, EPANET-MSX, water quality modeling

Category: Environmental/Water Systems Analysis

Modeling flow regimes and their influence on macroinvertebrate health

Erick Saunders
Daniel Obenour (Advisor) Jonathan Miller (Co-Advisor)

The ecological health of streams can be greatly affected by anthropogenic activities that change flow regimes and increase pollutant loads. In order to understand the effect of flow regimes on stream health, four ecologically relevant components of streamflow (duration, frequency, timing, and magnitude) were compared to the biotic index of macroinvertebrate communities in NC piedmont streams. Seventy US Geological Survey (USGS) sites that record daily flow data were analyzed using Indicators of Hydrologic Alteration (IHA) software to determine flow metrics. These sites were delineated in order to obtain watershed data (like mean permeability, impervious, and land use), which were used as predictors for ecologically relevant components determined by IHA outputs. Variation in frequency flow metrics was highly explained by watershed characteristics (average $r^2 = 0.78$), followed by duration and magnitude, while the variation in timing metrics was the least explained by models (average $r^2 = 0.28$). Flow metrics were then predicted at sites used to sample macroinvertebrates and compared to their biotic indices at these spots. Frequency metrics had the highest correlation between predicted flow metrics and macroinvertebrate health ($r^2 = 0.36$), followed by magnitude, duration and finally timing ($r^2 = 0.23$). Results suggest that flow metrics that measure frequency are the best for predicting stream health and are the easiest to predict from watershed characteristics.

Keywords: flow regime, ecological health, predictive models, flow metrics

Category: Environmental/Water Systems Analysis

Mechanistic and statistical exploration of factors affecting cyanobacterial algal blooms in three North Carolina reservoirs

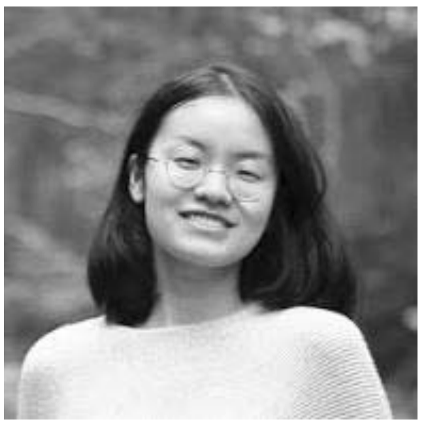
Jeremy Smithheart
Tarek Aziz (Advisor), Daniel Obenour (Advisor)

Cyanobacterial harmful algal blooms (HABs) are a growing concern for freshwater reservoirs. Issues related to HABs include aesthetic problems, hypoxia, taste and odor, and the potential release of cyanotoxins. Artificial mixing technologies have been proposed as an on-site treatment method to suppress HAB formation, but quantitative understanding of these technologies is limited. In this project, physical, chemical, and biological data were collected from summer 2015 to 2017 from three Piedmont reservoirs in North Carolina with different types of artificial mixing technologies. A one-dimensional heat budget model was used to simulate hourly temperature profiles of the lakes using meteorological data from nearby weather stations, and was calibrated using hourly temperature profiles from thermistor strings deployed in each of the lakes. Algal blooms were characterized by synthesizing phytoplankton assemblages and chlorophyll grab samples with profiles of *in vivo* fluorescence data in a multi-level modeling framework. These bloom metrics were used as response variables for a multiple linear regression statistical model developed using meteorological conditions, physical lake characteristics, nutrients, the diffusion estimates from the simulated temperature profiles, and the presence of artificial mixing as candidate predictor variables. The poster will discuss how the modeling results lead to a better understanding of the role that artificial mixing and natural variables have on HABs by analyzing the significance these factors have on algal bloom formation.

Keywords: harmful algal blooms, cyanobacteria, artificial mixing, hierarchical modeling, linear regression

Category: Environmental/Water Systems Analysis

An assessment of the dynamic global warming impact associated with long-term emissions from landfills



Yixuan (Wendy) Wang
James W. Levis (Advisor)

Landfills are responsible for 2% of greenhouse gas (GHG) emissions in the US and are the third leading source of anthropogenic CH_4 emissions behind fossil fuels and livestock. Therefore, it is important to understand the global warming impact associated with landfilled waste. The GHG emissions associated with landfilling a ton of waste occur over decades or centuries and therefore the standard static approach to estimating global warming impact does not accurately represent the dynamic global warming impact of landfill gas emissions over time. Traditional static estimates of global warming consist of summing emissions of each GHG over time and multiplying them by static global warming potentials (GWPs) for a set time period (e.g., the 100-year static GWP for emitting 1 kg CH_4 is 28 kg CO_2e). Dynamic GWPs instead consider the additional radiative forcing from GHG emissions in each year relative to the radiative forcing from the emission of 1 kg CO_2 at time zero. Dynamic GWP calculations have been used for buildings and bioenergy systems but have not been applied to landfills. The objective of this analysis is to assess the dynamic global warming impacts associated with the landfilling municipal solid waste (MSW). A landfill life-cycle process model was used to estimate the annual GHG emissions (i.e., CO_2, CH_4, CO, and N_2O) over 1,000 years from fuel and material use, landfill gas generation, collection, oxidation, and combustion (flare and electricity generation), and biogenic carbon storage. Multiple scenarios were developed to compare GWP results based on static and dynamic approaches for two gas treatments: flare and electricity recovery and four decay rates: 0.02 yr^{-1}, 0.04 yr^{-1}, 0.06 yr^{-1}, and 0.12 yr^{-1}. Results indicate that the use of static GWPs may overestimate the actual global warming impact associated with landfilling MSW.

Keywords: Landfills, dynamic LCA, dynamic GWP, Biogenic Carbon Storage

Category: Environmental/Water Systems Analysis

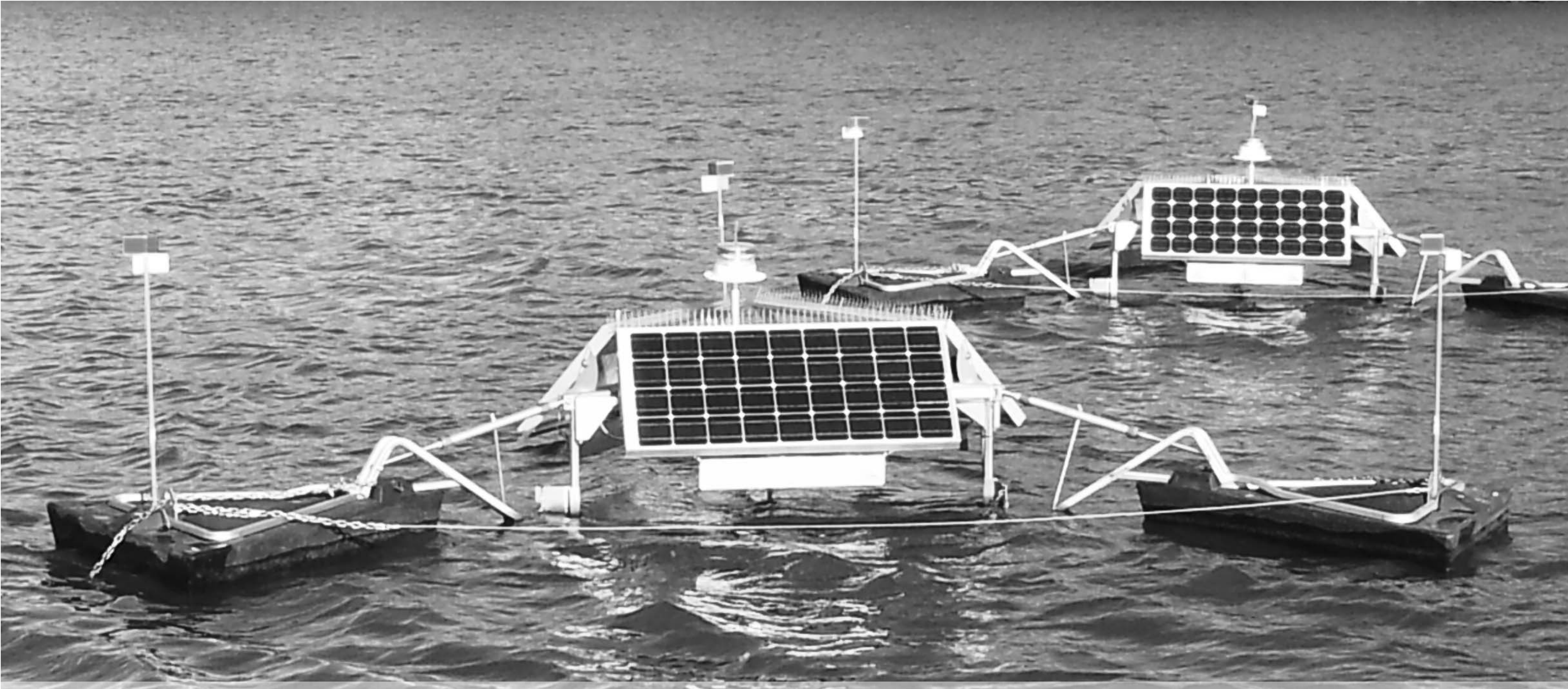
Simulation of microalgal growth and storage molecule production under different light and nitrogen conditions: a balanced growth kinetic model and parameter estimation

Diyuan Wang
Joel Ducoste (Advisor)

Microalgae as third generation biofuel feedstock has two main storage molecules, triacylglycerol (TAG) and starch, that can be used for biodiesel and bioethanol production. However, the growth of microalgae and production of storage molecules are strongly affected by culturing conditions such as light intensity and nutrient availability. Thus, maintaining the optimal condition for microalgal growth and biofuel production is a challenge to scaling up the algae biofuel production process. Mathematical models have been developed to estimate algal growth and carbon allocation in response to different operation conditions. However, most of the models described in prior literature carried out analysis based on parameters fitted from limited set of experiments under specific conditions. Models applicable for a wide range of light and nutrient conditions are yet explored. In addition, most models have not described the accumulation of stored carbohydrate and the carbon partitioning from starch to TAG. Comparing to prior arts, our balanced growth kinetic model systematically describes microalgal (Dunaliella viridis) growth, carbohydrate and lipid production, chlorophyll-a synthesis, intracellular nitrogen characterization and nitrate uptake in response to wide-ranging light and nitrogen conditions. Photosynthesis, biomass growth and intracellular carbon flows are regulated by light and nitrogen conditions based on modifications to prior theories. Eight sets of experimental data obtained from a bench-scale photobioreactor system under four light levels and two nitrogen conditions have been used to calibrate and validate the model (75% for calibration, 25% for validation). The modeling results demonstrated a good agreement with experimental data. The uncertainty quantification analysis of the model parameters will be carried out using profile likelihood method to improve the reliability of parameter estimates and model predictions. Such will help formulate a more predictive model for microalgal biomass growth and product formation.

Keywords: Microalgae, biofuel, mathematical model, growth kinetics, profile likelihood, uncertainty analysis, photobioreactor

Category: Environmental/Water Systems Analysis



Water Resources Engineering

Impact of dams on the natural flow regimes in the United States

Dol Raj Chalise
Sankar Arumugam (Advisor)

Dams provide multiple benefits to society by storing water in reservoirs to provide flood control, water supply, navigation, recreation activities and power generation. At the same time, dams alter natural flow regimes such that hydrologic regimes differ significantly from prior dam construction. Any alteration to the natural flow regime can impact biodiversity and threaten the aquatic ecosystem. The Nature Conservancy's Indicators of Hydrologic Alterations (IHA) consists of 33 hydrologic parameters and is commonly used worldwide to characterize flow variations for annual and inter-annual periods. More recently, some studies have proposed a Fourier analysis method to estimate the seasonal and inter-annual variation of environmental flow instead of using IHA. The focus of my study is to compare these two methods to analyze hydrologic alteration at USGS sites located downstream of dams across the US.

Keywords: Dam, flow regime, hydrologic alterations, IHA, Fourier analysis

Category: Water Resources Engineering

Effects of Infrastructure Investment Choices on Costs, Water Quality, and Criticality in Water Distribution Systems

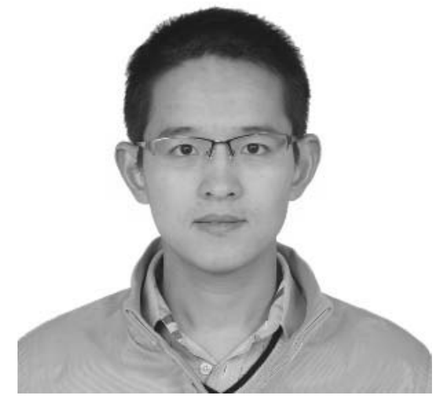
Hana Chmielewski
S. Ranji Ranjithan (Advisor)

Water distribution systems face multiple long-term planning challenges. Investments in water source development, treatment facilities, and other critical components often have interrelated consequences for system functionality and resilience, especially for operating costs under normal conditions and service continuity under disruptions, such as natural hazards. This work formulates a system-level model for a case study groundwater-based water supply utility at an early decision stage, where pumping and treatment location and technology are still open questions. The model can be used as a part of an integrated model-based planning process, where the well pumping scheme, as well as the placement, design, and operating conditions of different types of water treatment technologies, can be optimized under different planning objectives and constraints. The goal of this research is to demonstrate the system-specific nature of long-term water planning objectives, and to investigate the effects of different planning strategies and modeling approaches on decision-making. Three analyses are presented: 1) comparing optimal 30-year pumping and treatment schemes under varying maximum contaminant levels for two different emerging contaminants; 2) comparing resilience planning decisions under different development scenarios in a simulation framework, where system damage and recovery are modeled after a hurricane; and 3) investigating the effects of investment and decision timing on system operating costs and system resilience over a 30-year planning horizon. The analyses demonstrate that different capital investment strategies, such as centralizing treatment, are optimal under varying potential emerging contaminant regulations. Due to interactions between decisions, there are also further improvements that can be made in both cost and system resilience objectives by optimizing decision timing over a long-term planning horizon.

Keywords: long-term infrastructure planning, multi-objective optimization, natural hazard resilience, Treatment cost modeling

Category: Water Resources Engineering

Space-time geostatistical modeling of harmful algal blooms dynamics in Western Lake Erie



Shiqi Fang
Daniel Obenour (Advisor)

Harmful algal blooms (HABs) have occurred more frequently in western Lake Erie over the last two decades, and substantial efforts have been made to track these blooms using in-situ sampling and remote sensing. The resulting bloom measurements are critical to HAB management, but do not fully capture their spatial and temporal variability. Our study is focused on improving HAB tracking through development of a spatio-temporal geostatistical model. To synthesize available chlorophyll a data from four independent in-situ sampling programs in western Lake Erie, we treat each observation as a realization from a Gaussian random process subject to a Matérn space-time covariance function parameterized through restricted maximum likelihood estimation. Model performance is characterized through cross-validation exercise, and uncertainty is quantified. The results illustrate bloom dynamics, with blooms typically forming near the Maumee River outfall in early August and persisting for different durations in different years. Through conditional simulation, we develop probabilistic estimates of bloom extent, duration, and severity for each year (2008-2015). The results generally compare well with satellite imagery, though some exceptions are noted. We discuss future plans to incorporate remote sensing information within the geostatistical modeling framework, along with potential challenges related to the vertical movement of the bloom within the water column.

Keywords: harmful algal blooms, space-time, geostatistical modeling, Western Lake Erie

Category: Water Resources Engineering

Modeling vertical diffusion and algal bloom potential in a shallow Piedmont reservoir

Yue Han
Daniel Obenour (Advisor), Tarek Aziz (Advisor)

Transport phenomena are important drivers of water quality in natural waters. In lakes and reservoirs, vertical mixing through turbulent diffusion is expected to influence the dominance of problematic cyanobacteria relative to other algal taxa. In this study, a systematic approach for calibrating and evaluating a vertical mixing model is presented, using a shallow eutrophic reservoir (Jordan Lake, North Carolina, USA) as a case study. Jordan Lake was selected as a case study because artificial mixing was recently explored as a mechanism to reduce algal blooms that are dominated by cyanobacteria in summer. To simulate vertical diffusion, a mathematical heat model with meteorological inputs is first constructed to predict time series of water-column temperature profiles. Non-linear optimization is applied to calibrate unknown parameters to within literature-specified bounds based on the fit of the model to in situ thermistor chain records. A variety of optimization metrics (i.e. Schmidt stability, thermocline gradient) have been developed and compared. The model is evaluated using cross validation and through comparison with in situ estimates of diffusion obtained from a temperature micro-profiler (SCAMP) and dye tests. The model is applied to simulate diffusion over a decadal period, inter- and intra-annual variability in mixing is characterized, the relative importance of different meteorological drivers of mixing are compared, and the impact of artificial circulation is examined. Finally, simulated time series of water column temperature and water stability (i.e., Peclet Number) are correlated with phytoplankton community sampling data.

Keywords: surface water quality, heat transfer, diffusion, phytoplankton, numerical model

Category: Environmental/Water Systems Analysis

Modeling physical and biogeochemical factors controlling bottom water dissolved oxygen (BWDO) in the Neuse River Estuary using a Bayesian framework

Alexey Katin
Daniel Obenour (Advisor)

Hypoxia or BWDO depletion below 2 mg/l frequently occurs in the Neuse River Estuary (NRE). It causes fish kills, reduces biodiversity and decreases the aquatic habitat, as well as diminishes aesthetic and recreational value of coastal waters. Hypoxia in the estuaries is driven by a combination of nutrient loads and other environmental factors. Here, we develop a water quality model for the NRE in order to provide fisheries and watershed managers with timely forecasts of estuarine system response to meteorological and nutrient loading conditions. In developing the model, the NRE was divided longitudinally into three segments and vertically into two layers. Segments were treated as well-mixed reactors, on which flow and nutrient balances were performed. The resulting series of differential equations were solved using numerical methods with a daily time step. Biweekly observed BWDO concentrations were used for model validation and calibration. Mechanistic model was incorporated into the Bayesian statistical framework, which allowed for objective model optimization, uncertainty quantification and hypothesis testing. In this poster, we present a model formulation and results for predicting BWDO for the NRE. This model explores how river discharge, nutrient loads, sediment oxygen demand (SOD) and climate conditions affect hypoxia in the estuary. The final model explains on average 48% of BWDO variability in all three segments and it is the first attempt to calibrate this system over 19-year period. The results of the model indicate that about 30% of BWDO is consumed meeting water column oxygen demand, while the rest is depleted during organic matter decomposition in the sediment. Interannual SOD variation was found to be associated with November to April discharges and phosphorus concentrations. Elevated phosphorus concentrations enhance primary production leading to increased SOD, while high flows flush out nutrients from the estuary lowering summer SOD rates.

Keywords: hypoxia, Bayesian framework, dissolved oxygen, Neuse River Estuary

Category: Water Resources Engineering

A non-parametric bootstrapping framework embedded in a toolkit for assessing water quality model performance

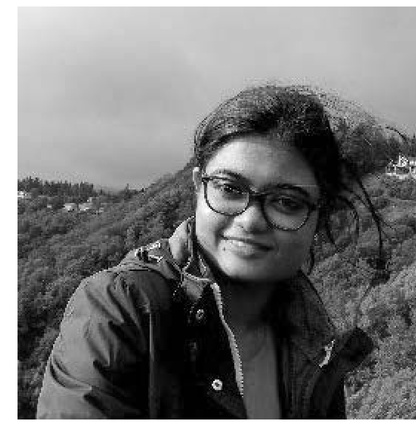
Dominic Libera
Sankar Arumugam (Advisor)

Assessing the ability to predict nutrient concentration in streams is important for determining compliance with the Numeric Nutrient Water Quality Criteria for Nitrogen in the U.S. Evaluation of the LOADEST and the WRTDS models in predicting total nitrogen loads over 18 stations from the Water Quality Network show good performance (NSE >0.8) in capturing the observed variability even for stations with limited data. However, both models captured only 40% of observed variance in TN concentration (NSE < 0.4). Thus, the same dataset performed differently in predicting two attributes – TN load and concentration – questioning the predictive skill of the models. This study proposes a non-parametric resampling approach for assessing the performance of water quality models particularly in predicting TN concentration. Null distributions for three common performance statistics having no skill are constructed through bootstrap resampling to calculate a p-value for testing the statistical significance in predicting TN concentration.

Keywords: water quality modeling, performance assessment, non-parametric resampling

Category: Water Resources Engineering

Sub-seasonal-to-seasonal Reservoir Inflow Forecast using Nonhomogeneous Hidden Markov Model



Sudarshana Mukhopadhyay
Sankar Arumugam (Advisor)

Sub-seasonal-to-seasonal (S2S) (15-90 days) streamflow forecasting is an emerging area of research that provides seamless information for reservoir operation from weather- to seasonal- time scales. From an operational perspective, sub-seasonal inflow forecasts are highly valuable as these enable water managers to decide short-term releases (15-30 days), while holding water for seasonal needs (e.g. irrigation and municipal supply) and to meet end-of-the-season (typically 12 weeks) target storage at a desired level. We use a Nonhomogeneous Hidden Markov Model (NHMM) to develop S2S inflow forecasts for the upper Tennessee Valley Area (TVA) reservoir system. Here, the hidden states are climate conditions dependent on relevant modes of variability that influence the inflows at S2S time scale. NHMM captures the spatial and temporal hierarchy in predictors that operate at S2S time scale. Reservoir inflow forecasts are issued and updated continuously every day at S2S time scale. We consider daily precipitation forecasts obtained from NCEP Coupled Forecast System (CFSv2) as one of the predictors for developing S2S streamflow forecasts along with low frequency variability patterns – Madden Julian Oscillation (MJO), Pacific/North American (PNA) and North Atlantic Oscillation (NAO), for predicting the hidden states. Spatial dependence of the inflow series of reservoirs are also preserved in the multi-site model. To circumvent the non-normality of the data, we consider NHMM in a Generalized Linear Model setting. Skill of the proposed approach is tested using split sample validation against a traditional multi-site canonical correlation model developed for TVA. From the climate dynamics of hidden states, we comment on improved predictability of dry and wet periods in the region. From the inflow forecasts, we also highlight different system behavior under varied global and local scale climatic influences from the developed NHMM. These findings shed light on potential applications of this model in producing S2S time scale inflow forecasts which would be useful in hydropower scheduling and water management in TVA reservoir network.

Keywords: sub-seasonal to seasonal forecast, reservoir management, nonhomogeneous hidden Markov Model, climate predictability

Category: Water Resources Engineering

Modeling and forecasting water demand variation among consumers using smart meters

Jorge Pesantez
Emily Berglund (Advisor)

The advent of smart metering, or Advanced Metering Infrastructure (AMI) for water systems will generate large datasets about water demands that can provide new insight about consumer behaviors for managing water resources and infrastructure. Improved accuracy and precision in estimates of household consumption can be used in planning long-term water supply, designing expansion plans to support new development, and improving control and operation of the water system. In this research, we explore water demand data collected at hourly intervals for a set of residential customers in Cary, North Carolina. Machine learning algorithms are applied to explore the influence of social variables, including household size, lot size, income, and land use, and climate conditions, including temperature, humidity, pressure, and precipitation on variation in water demands. The performance of machine learning algorithms is compared with performance of other algorithms, as shown in previous research. A second set of regression models are developed to explore the influence of these independent variables on seasonal changes in water demands. New demand models will be applied to project demand for all consumers served by the water distribution network for alternative urban development scenarios. Results demonstrate the utility of applying analytic approaches and predictive models using large data sets available through smart meters.

Keywords: water demand modeling, forecasting, smart meters, automated metering infrastructure

Category: Water Resources Engineering

Assessing drivers and quantifying variations in macroinvertebrate sampling in NC Piedmont streams using hierarchical modeling

Jonathan Miller
Daniel Obenour (Advisor)

Urban streams are expected to have lower biological conditions than natural streams due to the anthropogenic influences that lead to altered hydrology and larger pollutant loads. City water quality managers are tasked with improving the ecological health of urban streams without fully knowing what best possible conditions might be for these highly degraded sites. This study uses over 3,200 macroinvertebrate stream samples from both state and city sampling programs to predict the biotic index (BI) and species richness of "pollution intolerant species" (i.e. EPT counts; Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)) of macroinvertebrate communities in NC Piedmont streams. A hierarchical modeling framework accounts for natural factors (i.e. soil conditions, antecedent precipitation), anthropogenic factors (i.e. % imperviousness, hydrologic alteration), and spatial variability within the sampling data. Preliminary results show major predictors of BI and EPT counts to be % imperviousness and agriculture in upstream watersheds, canopy cover in stream buffers, upstream lakes and wastewater treatment plants, antecedent precipitation and geologic soil conditions among others. Preliminary models suggest that older development is more damaging to stream health compared to more recent development. Furthermore, anthropogenic disturbance of the buffer zones can be more impactful on streams than other watershed development. Model predictions can be used as baselines to judge the expected biological condition in highly impaired systems while hierarchical site offsets (i.e random effects) can give insight into sampling locations that are in relatively better or worse ecological conditions than others. Both of these results can help city managers prioritize and allocate resources accordingly to improve the biological health of the streams they manage.

Keywords: ecological health, water quality, hierarchical modeling, wadeable streams

Category: Environmental/Water Systems Analysis

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