NC STATE UNIVERSITY

Department of Civil, Construction, and Environmental Engineering

2021 EWC

Graduate Research Symposium

Environmental, Water Resources and Coastal Engineering

February 26, 2021

Meet the minds of the future!

EWC Symposium Program

NC State University

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2021 EWC

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Schedule

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AIR POLLUTION

Presentations are from 9:20 to 10 AM

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1

Implementing satellite observations of NO2 air pollution in an air quality model to identify emissions biases

James East
Barron Henderson, Shannon Koplitz, Sergey Napelenok, Allen Lenzen, Brad Pierce
Advisor: Fernando Garcia Menendez

Air pollutant emissions inventories are a crucial part of air quality modeling endeavors which help determine the environmental, climate, and health impacts of human activities. However, inventories constructed with conventional data sources can be time and data intensive to build, can suffer from temporal lag, and can be inaccurate for low and middle-income countries. Observations from satellite instruments provide valuable opportunities for evaluating and improving emissions inventories at a global scale in near real time. In particular, the recently launched TROPOMI instrument provides daily global coverage of NO2 observations at unprecedented resolution. Here we utilize a 3-D variational data assimilation technique to fuse TROPOMI NO2 observations with an air quality model over the northern hemisphere. We use the assimilated results to identify NOx emissions biases in air quality simulations and to update the NOx emissions inventory. The presentation will describe the method for making emissions inferences from satellite data, present results from a case study over the northern hemisphere and share current progress and results of ongoing simulations.

Keywords: air pollution, air quality modeling, satellite, emissions, atmospheric chemistry

2

Quantification of Variability in Human Exposure to Air Pollution in Hong Kong

Sailaja Eluri
Advisor: Christopher Frey

Exposure to air pollutants causes adverse human health effects. The U.S.-Environmental Protection Agency's stochastic, microenvironmental, population-based Air Pollution EXposure (APEX) model was adapted to estimate NO 2 , O 3 and PM 2.5 air pollutant exposures in Hong Kong (HK). HK is divided into Tertiary Planning Unit (TPU) sectors. Key inputs are: (1) ambient pollutant concentrations and meteorological data; (2) infiltration factors for combinations of pollutants and microenvironments; (3) population and commuting data; and (4) individual time-location data. Hourly ambient pollutant concentrations for 2019 were obtained from 16 air quality monitoring stations (AQMS). Meteorological data were obtained from stations close to each AQMS. Infiltration factors were obtained from previously conducted microenvironmental measurements. Population data were obtained from the 2016 HK By-census. Commuting data were imputed using a double-constrained gravity model. Time-location data were generated from HK Travel Characteristics Survey data. The hourly average ratio of air pollutant exposure to ambient concentration (E/C) were estimated for all TPUs. The hourly average inter-individual variability in (E/C) ratios were compared for: (1) two seasons and (2) among population subgroups. The results of the model can be used to help prioritize exposure mitigation interventions..

Keywords: exposure, microenvironment, population, individual, variability

3

An analysis of smoke modeling tools used to estimate prescribed burning impacts on air quality

Megan Johnson
Advisor: Fernando Garcia Menendez

Prescribed burning is an important land management practice used for fuel management and ecological purposes across the U.S., but adequate smoke management is a requirement for practitioners. Several modeling tools are available to predict smoke transport from a burn. These vary in complexity, data requirements, and ease of use, which affect their smoke predictions and likelihood of adoption. However, there are few systematic comparisons and analyses of these tools. In this work, we evaluate smoke modeling tools commonly used to estimate the potential smoke impacts of prescribed fire projects. Using data from a year of prescribed burning activity in NC State Parks, we model smoke plumes generated with the Simple Smoke Screening Tool, VSmoke-Web, and HYSPLIT, as well as the chemical transport model CMAQ. Model output is compared using spatial overlap of areas of concern and populations experiencing smoke. The tools are further evaluated considering ease of use for land managers. We find large discrepancies in populations experiencing smoke as estimated by the different tools and that more accessible models seem to provide the least protective projections. This work provides insights into smoke impacts in areas with frequent burning and highlights research needs to improve tools for operational fire planning.

Keywords: prescribed fire, smoke, modeling, tools

4

Personal exposure to carbon monoxide and particulate matter for cooks during baseline measurements of a cookstove intervention in urban Zambia

Stephanie Parsons
Advisor: Andrew Grieshop

62% of households in Zambia lack electricity access, requiring solid fuel use for cooking and resulting in poor indoor air quality. A 2-year stove intervention trial was undertaken in Lusaka, Zambia. Local stove distribution companies selected four neighborhoods, two with penetration of alternative stoves (Matero, Kamanga) and two with traditional stoves (Kalingalinga, Ngombe). Here, we present baseline carbon monoxide (CO) and particulate matter (PM2.5) exposure of 496 and 68 cooks in these neighborhoods. Cooks wore Lascar CO and MicroPEM PM2.5 monitors at breathing height for 24 hours. Matero cooks had 4 times lower 24-hour CO exposure (4ppm) than other neighborhoods; Kamanga cooks had the highest at 19ppm. PM2.5 exposure was relatively consistent, but above health guidelines, for all neighborhoods (97 +/- 61 µg m-3). CO and PM2.5 diurnal trends were similar across neighborhoods but differed between pollutants; CO peaked at mealtimes while PM2.5 peaked in the morning and evening. Monitor temperature peaks aligned with the evening CO peak, conflicting with ambient trends and suggesting evening CO could be induced by cookstove use for warmth. Diurnal PM2.5 exposure was similar to ambient trends from PurpleAir monitors in Kabwe, Zambia (140km north), suggesting exposure is dominated by regional sources rather than cooking.

Keywords: cookstove, intervention, exposure, indoor air pollution

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Energy and Electrochemical Process

Presentations are from 10:15 to 10:55 AM

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5

Improving the symmetry of salt ion removal in capacitive deionization using asymmetrical electrode configuration

Yazeed Algurainy
Advisor: Douglas F. Call

Capacitive deionization (CDI) is an emerging desalination technology. In CDI, a voltage is applied across two activated carbon electrodes, and ions from the feedwater are removed via electrosorption. We previously observed uneven removal of monovalent ions (Na^+, Cl^-) in flow-through CDI. We attributed lower removals of Na^+ on the cathode compared to Cl^- on the anode to reactions involving O_2 reduction. We hypothesized that O_2-based reactions changed the capacity of the cathode to store (adsorb) Na^+. To test this hypothesis, we varied the mass ratio of the electrodes (asymmetrical-CDI). We found that a near 1:1 Na^+:Cl^- removal occurred when a 1:2 cathode:anode mass ratio was used. The reason this orientation improved Na^+ removal is that the applied voltage was distributed across the two electrodes in such a way that most of that voltage, due to cathode mass limitation, fell into the minority electrode. The greater voltage applied to the cathode (making it more negative) maximized Na^+ removal because it allowed the electrode to stay lower than the potential of zero charge (the potential where minimum adsorption occurs). Our results demonstrate that electrode symmetry is an important consideration for improving overall salt removals in CDI.

Keywords: Desalination, capacitive deionization, adsorption, asymmetric electrodes

6

Electrically assisted Removal of Organic Ions using Porous Carbon-based Materials

Elvin Hossen
Advisor: Douglas F. Call

Capacitive deionization (CDI) is an emerging technology for removing ions from water. Developed for brackish water desalination, operational advantages make CDI a lucrative option for broader application, like water softening or selective ion removal. Studies on electrosorption of small inorganic ions are abundant yet large organic ions are rarely investigated even though they commonly occur in the environment. Little is still known about the fundamental understanding of electrosorption of organic ions and how to design and operate CDI cells to improve its selectivity. In this study, we investigated the effectiveness of voltage application to remove organic ions in CDI. We selected aliphatic carboxylates which are valuable intermediates in many biological treatment processes such as anaerobic digestion to represent organic ions due to its orderly structural differences. Three carboxylates were chosen: formate, acetate, and butyrate, with 3 different voltages (1.0, 1.2, 1.4V) to apply. We proposed modelling approach to better understand electrosorption mechanism and to help optimizing the design of electrode materials to improve removal of target ions. Dynamic Langmuir and modified Donnan models were investigated, and we tested our model with experimental results for validation. Ultimately, accurate models for electrosorption could serve as predictive tools for optimized organic ions removal.

Keywords: Capacitive deionization, organic ions, ion removal, modeling

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Assessing the effectiveness of global thermostat adjustment in commercial buildings for load shifting demand response

Aditya Keskar
Advisor: Jeremiah Johnson

The thermal inertia of commercial buildings allows us to shift their power consumption on minutely to hourly timescales to provide balancing grid services while maintaining occupant comfort. Global thermostat adjustment (GTA) provides a readily-available and scalable approach for implementing load shifting demand response using commercial HVAC systems, since it leverages the inherent sophistication of modern building automation systems. We explore the effectiveness of GTA in this work by analyzing results from over one thousand experiments on eight campus buildings in Michigan and North Carolina. Using GTA, we manipulate each building's thermostat setpoints using pre-defined setpoint signals that cause the building to shift its power consumption with respect to its baseline. We focus on four key areas: quantifying the magnitude of HVAC response as a function of the setpoint signal parameters and ambient weather, overall HVAC energy consumption impacts, and impact on occupant comfort. We analyze the magnitude and efficiency of HVAC fan power response and also investigate impacts on chilled water and terminal reheat systems, allowing us to conduct a more holistic energy efficiency impact assessment of GTA on different subsystems of standard commercial building HVAC systems. We find that while GTA can be used to provide load shifting on hourly timescales, the asymmetry of building response, impact of polarity on additional energy consumed and impacts on the chilled water and terminal reheat systems are parameters that impact the ability of a building to accurately shift its power consumption.

Keywords: Demand Response, Commercial Buildings, HVAC, Energy Efficiency

8

Effectively mitigating health impacts while decarbonizing the power sector

Qian Luo
Advisors: Fernando Garcia Menendez, Jeremiah Johnson

As one of the highest greenhouse gas emitters in the United States, the power sector has great potential for climate change mitigation by adopting decarbonization strategies. These strategies have co-benefits to air quality from decommissioning coal power plants, reducing air pollutants emissions. Therefore, there is growing interest in quantifying air quality co-benefits from climate change mitigation strategies to facilitate relevant policy making. However, most of them examine long-term decarbonization pathways, considering impacts in 50 to 100 years at global or national scales and do not weigh near-term co-benefits or capture the spatial distribution of health impacts at community levels. To fill this knowledge gap, this study will quantify the near-term health co-benefits once the decarbonization strategies are fully implemented in a realistic power system under different decarbonization scenarios and examine how these benefits are distributed among different population groups, including by race, income, age, and educational level. The preliminary results show different strategies lead to similar reductions in air pollutant emissions, but result in different spatial distribution, which will ultimately influence human exposure to PM2.5. This study will provide insights on effectively mitigating human health impacts while decarbonizing the power sector and reducing disparities in health co-benefits from electricity decarbonization.

Keywords: power system decarbonization, air quality, human health co-benefits

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Modeling and Systems

Presentations are from 11:10 to 11:50 AM

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Modeling and analysis to improve water distribution system resilience

Lochan Basnet
Advisors: Ranji Ranjithan, Kumar Mahinthakumar, James Levis, Downey Brill

Aging critical infrastructure systems (CIS), including water distribution systems (WDSs), face many challenges, including disruptions due to natural hazards and component failures. Resilience, in general, is defined as the ability of a system to absorb shocks, minimize loss, and recover from failure, when subjected to perturbations. Most reported WDS resilience studies have quantified resilience using a single measure of performance, which can be inadequate because resilience encompasses, for example, technical, organizational, social, and economic dimensions. Most studies also ignored interdependencies of WDS with other CIS that can cause cascading failures and potentially increase the scope and time of recovery. The objective of our research is to study the resilience of WDSs considering the interdependencies among CIS components and the multi-dimensionality of resilience to achieve better reliability, robustness, redundancy, resourcefulness, and rapidity. A computational framework, which couples system simulation and optimization models, is being developed to identify efficient, holistic CIS resilience improvement strategies that are also cost-effective. The framework will be applied to some test networks and real-life WDSs.

Keywords: Water distribution system, critical infrastructure systems, resilience, interdependencies, modeling and optimization

10

Understanding the food-energy-water nexus through hydroeconomic modeling under regional development portfolios in the Flint River Basin, GA

Hemant Kumar
Advisor: Sankar Arumugam

Understanding the nexus between food, energy and water (FEW) systems is critical for basins with intensive agricultural water use as they face significant challenges under changing climate and regional development. We consider Flint River basin, GA, where potential changes in climate indicate drier summer months and also increased competition between public utility and agricultural water. We investigate the associated FEW nexus through a hydroeconomic modeling framework that considers groundwater pumping under various scenarios. Using a crop simulation model, AquaCropOS, calibrated for six major field crops, we estimate the yield under rainfed, fully irrigated, and deficit (lack of irrigation controlled by the frequency and rate) irrigation scenarios. A regional hydroeconomic optimization (RHEO) model using Positive Mathematical Programming is developed. Interestingly, analyses show that optimal deficit irrigation is economically better than full irrigation because the increase in yield decreases with each additional unit of water supplied. As expected, wet years have higher total regional profits compared to dry years indicating the critical role of changing climate. RHEO model will be used to explore scenarios such as increased irrigation costs, reduced summer precipitation, reduced water availability and the portfolio management strategies to under the regional FEW nexus

Keywords: Hydroeconomic model, Food Energy Water nexus, AquaCropOS

11

A Smart Water Grid for Micro-Trading Rainwater: Hydraulic Feasibility Analysis

Elizabeth Ramsey, Jorge Pesantez, Mohammad Ali Khaksar Fasaee, Morgan DiCarlo, Jacob Monroe
Advisors: Emily Berglund

Urban water availability is growing increasingly stressed globally. Novel water markets and supply paradigms are emerging to address water shortages in the urban environment. This research develops a new peer-to-peer non-potable water market that allows households to capture, use, sell, and buy rainwater. A dual reticulation system receives water from residential rainwater tanks and distributes it to households for irrigation purposes. The smart water grid would be enabled through technologies that provide capabilities for automated and real-time metering of water flow, control of infrastructure, and trading between households. This research tests the hydraulic feasibility of a micro-trading system through an agent-based modeling approach. Prosumer households are represented as agents that store rainwater and pump rainwater into the network; consumer households are represented as agents that withdraw water from the network for irrigation demands. An all-pipe hydraulic model is constructed and loosely coupled with the agent-based model to simulate network hydraulics. A set of scenarios are analyzed to explore how micro-trading performs based on the level of irrigation demands that could realistically be met through decentralized trading; pressure and energy requirements at prosumer households; pressure and water quality in the pipe network

Keywords: Smart Cities, Rainwater Harvesting, Agent-Based Modeling; Hydraulic Network

12

Solid Waste Optimization Life-cycle Framework in Python (SwolfPy)

Mojtaba Sardarmehni
Advisor: James Levis

Over 2 billion tons of municipal solid waste is generated annually globally, and this value is expected to grow by over 70% by 2050. Given the heterogeneity of the waste entering solid waste management (SWM) systems and the complex interrelationships between SWM processes, it is important to comprehensively consider the interactions among the waste management processes, energy system, and environment to avoid negative unintended environmental or economic consequences when developing SWM systems and strategies. The objective of this work is to develop a novel SWM life-cycle assessment (LCA) optimization framework with built-in parametric and Monte Carlo sensitivity and uncertainty analysis capabilities. SwolfPy (go.ncsu.edu/swolfpy) is open-source and implemented in Python using several scientific computing packages including Pandas, NumPy, and SciPy for optimization, PySide2 for creating the graphical user interface, and Brightway2 for storing life-cycle inventory data and performing the LCA calculations. SwolfPy's modular design enables it to be easily coupled with other packages, and to facilitate the addition of new processes, materials, and environmental flows and impacts. The current version of SwolfPy includes life-cycle models for landfills, mass-burn waste-to-energy, composting, anaerobic digestion, material recovery facilities, reprocessing, and collection processes, for 46 waste fractions, ~4300 biosphere flows, and ~700 impact assessment methods.

Keywords: Life Cycle Assessment (LCA), Municipal Solid Waste (MSW), Uncertainty Analysis, Optimization, Open-source software

13

Evaluation of the Fugitive Methane Emissions from a Municipal Solid Waste Landfill

Yixuan (Wendy) Wang
Advisor: James Levis

Landfills are complex engineered facilities and the third leading source of anthropogenic methane emissions in the US behind fossil fuel and livestock. The complexity is derived from how the waste is disposed and landfill gas is generated over time, the influence of regulations on the timing to collect and control gas, the varying extent of gas collection and oxidation efficiency, whether landfill gas is used beneficially. The objective is to develop a life-cycle assessment model for a representative US municipal solid waste landfill based on various configurations, non-methane organic compound (NMOC) concentration thresholds, and practices. We considered three gas treatment scenarios (i.e., passive venting, flare, and combustion for energy recovery), four schedules to install the gas collection wells, and two NMOC thresholds (50 vs 34 Mg yr^{-1}) to govern the gas collection and control. The results show that the stricter NMOC threshold is relatively unimportant in improving collection efficiency for landfills that are already required to collect their gas compared to the stricter California collection schedule, energy recovery scenarios, and larger landfill sizes that allow energy recovery longer. These results will provide insights into how fugitive methane emissions vary in landfills with different sizes and gas collection practices and regulations.

Keywords: municipal solid waste, landfill, life-cycle assessment, gas collection regulation

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Water Resources

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Comparing statistical models in estimating climate elasticities

Chandramauli Awasthi
Advisor: Sankarasubramanian Arumugam

Several studies have estimated sensitivity of annual runoff (Q) with respect to precipitation (P) and potential evapotranspiration (PET). These sensitivity estimates are referred to as precipitation elasticity (P) and potential evapotranspiration elasticity (PET), respectively. Previous studies have failed to reproduce the Dooge's complementary relationship (DCR), i.e. P+ PET=1, using statistical models for elasticity estimation. In the present study, we have developed panel and hierarchical models along with the traditional linear regression models to estimate the climate elasticities of Q. We have also considered log-based formulation of elasticity estimation and compared it with the conventional mean anomalous formulation approach. The models are calibrated for 84 USGS stations using the observed dataset of Q, P, and PET. We found that the statistical models following the log-formulation perform better compared to their mean anomalous formulation not only in predicting the flows but also in reproducing the DCR. The hierarchical models showed that site aridity index and elevation are two important basin attributes in reproducing the DCR. The spatial distribution of P and PET also depends on the site aridity index, and moisture and energy phase relationship.

Keywords: Climate elasticities, Dooge's complementary relationship

15

What is causing the FOG deposits to adhere to the sanitary sewer line surfaces?

Samrin Ahmed Kusum
Advisors: Mohammad Pour-Ghaz, Joel Ducoste

In the United States, Fat, Oil, and Grease (FOG) related deposits inside the Sanitary Sewer Line (SSL) cause around 3 to 10 billion gallons of sewage overflow, three-quarters of which reach surface water, representing a serious threat to public health. Therefore, strategies to reduce the accumulation of FOG deposits inside SSL are essential. Research shows that FOG deposits are formed from a saponification reaction between calcium and long chain free fatty acids. A recent study suggests that the adherence of these FOG deposits formed inside SSL may vary based on sewer line construction material's surface roughness, pH, calcium availability and porosity. This study aims to evaluate these properties to understand the FOG deposits adhesion mechanism inside SSL. To accomplish the study objective, porous ceramic cups (PCCs) with 31% and 45% porosity are saturated with two different pH (7 and 12) solutions. These saturated PCCs are then submerged into synthetic wastewater prepared by mixing 700 ml deionized water, 30g oleic acid, 30g canola oil, and 125 mg/l Ca^{2+} to observe the accumulation of FOG deposits on their surface. Surface roughness parameters of PCCs are measured using Confocal Laser Scanning Microscope (CLSM). Results from FOG deposits adhesion tests will be presented.

Keywords: FOG Deposits, Sewage Overflow, Surface Roughness, Porosity, Saponification

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Risk of Lead Contamination in Private Wells: Using Citizen Science and Predictive Models

Mohammad Ali Khaksar Fasaee, Jorge Pesantez
Advisor: Emily Berglund

The World Health Organization identifies lead as one of the major chemical contaminants threatening public health, and high levels of lead have been identified in drinking water at locations across the globe. This research develops tools that can be used to predict the risk of lead at private wells. A Bayesian Belief Network model is used to model interactions among household and water quality parameters and the risk of lead in tap water at private wells. Models are learned from a dataset collected by the Virginia Household Water Quality Program (VAHWQP), which collected water samples and conducted household surveys at about 10,000 households in Virginia during the period of 2012-2017. Predictors include household characteristics, water observations, geographical information, and water quality parameters. Some water quality parameters, such as pH, iron, and hardness, can be measured by homeowners using at-home water test kits. Water quality data from at-home kits are tested as predictors in Bayesian Belief Network models to predict lead concentrations at households. The prediction model developed through this research provides a tool for owners of private wells to assess the risk of lead contamination. New models can be implemented within a citizen science platform to improve knowledge about drinking water threats.

Keywords: Bayesian Belief Network, Lead in Drinking Water, Contamination Classification, Water Quality

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Balancing Human and Ecosystem Needs: A Framework for Ecological Flow Allocation in Multiple Reservoir Operation in Apalachicola-Chattahoochee-Flint River Basin

Dol Raj Chalise
Advisor: Sankarasubramanian Arumugam

Optimal water allocation based on trade-offs human and ecosystem needs pose a challenge to water resources management due to non-stationary hydroclimate and water demand. Here we propose a multi-reservoir framework that explicitly considers both human water demands and ecological flow requirements, in order to maximize outcomes with independence of historical climate baselines. This framework was implemented and tested in the Apalachicola-Chattahoochee-Flint River Basin, Southeastern U.S., a basin that supports high levels of imperiled native biodiversity (including endemic mussels and fish) as well as a productive estuarine ecosystem. We studied three major multiple-purpose reservoirs that alter flows in the basin, leveraging reservoir operation data (storage, inflows, outflows, water supply, and hydropower generation) from the U.S. Army Corps of Engineers. We used a newly-developed multi-reservoir simulation program, Generalized Reservoir Analyses using Probabilistic Streamflow, to analyze the system. Feasible sequential quadratic programming was then used to solve the multi-objective problem. This framework could advance sustainable water management in other river basins, as optimal water allocation strategies that recognize flow for humans and nature will become increasingly important under changing climates.

Keywords: Reservoir, Environmental flow, Simulation, Optimization

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Leak detection in water distribution systems using artificial intelligence

Shreya Sabu
Advisors: Gnanamanikam Mahinthakumar, Ranji Ranjithan, E Brill, James Levis

Recent advances in cloud computing technologies, the Internet of Things (IoT), and smart water technologies make it possible to develop automated systems that can generate real-time reports of leakage locations in a water distribution system. This research focuses on developing machine learning techniques that can leverage real-time data and hydraulic modeling to detect and reduce water leakages in water distribution systems. The leakage detection analytics module is implemented using a Multi-Layer Perceptron Algorithm (MLPA) based on artificial neural networks. The model will learn the structure, i.e., mapping of various leak nodes with pressure responses at sensor nodes in an area with the aid of a hydraulic model, to detect leak nodes based on the pressure readings with reasonable accuracy. The MLPA model is trained, validated, and tested using pressure data generated with simulated leaks using a hydraulic model for different test networks with various levels of model and measurement errors. The efficacy of the algorithm is tested for both regression (size of leaks) and classification (leak or no leak) accuracy. Preliminary results for a medium-sized network show that classification accuracy exceeds 90% even in the presence of significant noise. This can lead to a cost-effective solution to detect leakages from routine pressure measurements, which in turn leads to significant water savings and reduced pipe breakage frequencies..

Keywords: Leakage Detection, Analytics, Artificial Intelligence, IoT, Cloud

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Global WaSH

Presentations are from 10:15 to 10:55 AM

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Assessment and Reporting of North Carolina Private Well Water Quality

Nancy Lee Alexander
Advisor: Detlef Knappe, Catherine LePrevost

The overarching objective of this study was to assess the quality of private well water in North Carolina. We developed a new analytical method using high-resolution mass spectrometry for the identification of pesticides in drinking water, which enables us to perform non-targeted analysis to assess drinking water for a more comprehensive suite of pesticides. Samples from 80 wells in three counties were analyzed using the non-targeted method as well as targeted methods to quantify metals, anions, volatile organic contaminants, and coliform bacteria. On average, 45% of targeted analytes were not detected. Six analytes were detected at levels above their maximum contaminant levels (MCLs) and 14 analytes were detected at levels above their MCL goal or secondary drinking water standard in at least one well. Two analytes most commonly found above the MCL were lead and copper, and a 5-minute flush reduced their levels on average by 67% and 73%, respectively. Reports containing private well water quality results are being developed using Silent Spring Institute's Digital Exposure Report-Back Interface (DERBI). These reports will contain participants' individualized water quality information and comparisons to the results of other de-identified wells included in our study.

Keywords: private wells, drinking water quality, community engagement

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Modeling exposure to fecal contamination in drinking water due to multiple water source use

Sean Daly
Advisor: Angela Harris

The Joint Monitoring Programme estimated that 71% of the global population had access to 'safely managed' drinking water in 2017. However, standard data collection practices focus only on primary water sources accessed, ignoring exposures from supplemental water sources. A recent systematic review revealed evidence that multiple water source use (MWSU) is globally prevalent among households in low- and middle-income countries. Additionally, the practice of supplemental unimproved source use (SUSU) was reported globally, representing households with 'improved water access' that also access unimproved water throughout the year. To assess potential exposure to fecal contamination due to this behavior, an exposure model was created using Monte Carlo simulations and previously published water ingestion and quality data. A statistically significant (α=0.05) increase in total exposure to fecal contamination and portion of year exceeding the WHO standard for drinking water (i.e., 0 E. coli/100mL) was found for individuals practicing SUSU as compared to sole-use of improved sources for drinking over the course of a year. However, depending on the mean and variability of contamination, SUSU may not always increase exposure to *E. coli*. These practices represent neglected exposure pathways and should be considered to accurately classify access to safe drinking water globally.

Keywords: drinking water, multiple water source use, Monte Carlo simulations, global water monitoring, LMIC

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Do the Health Benefits of Boiling Drinking Water Outweigh the Associated Impacts of Increased Household Air Pollution Exposure?

Emily Floess, Ayse Ercumen, Angela Harris, Andrew Grieshop
Advisor: Andrew Grieshop

Globally, 1 and 2.8 billion people lack access to safe drinking water and cook with solid fuels, resulting in an estimated 1.7 and 2.6 million annual deaths, respectively. Boiling drinking water is a common treatment, but using solid fuels increases indoor air pollution (IAP). A Monte Carlo simulation is used to model 24-hour indoor fine particulate matter ($PM_{2.5}$) exposure and daily doses of three pathogens, *Campylobacter*, *Cryptosporidium* and *Rotavirus*, for different scenarios of boiling water and stoves, to calculate the total change in Disability Adjusted Life Years (DALYs) and deaths from IAP and drinking water contamination. For scenarios with effective boiling, we estimate a net decrease in DALYs from boiling water regardless of fuel type, but if water is ineffectively boiled on solid fuels, there is a net increase. Effectively boiling high risk water and replacing wood stoves with LPG has an average decrease of 358 DALYs per 10,000 people, while ineffectively boiling with solid fuels increases the DALYs by 109 DALYs per 10,000 people. This study emphasizes the need for proper boiling practices, use of clean fuels, and investigation of tradeoffs between health impacts/benefits and costs for different scenarios.

Keywords: Environmental health, drinking water treatment, indoor air pollution, clean cooking, solid fuels

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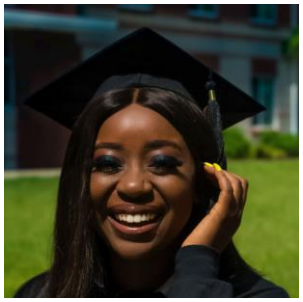

Detecting Antibiotic Resistant *E. coli* Using an IDEXX-defined Substrate Assay

Temitope Ibitoye, Gracie Hornsby
Advisor: Angela Harris

Antibiotic resistance has been identified as a key threat to human health worldwide. The Centers for Disease Control and Prevention (CDC) estimates that each year in the United States, 2.8 million people contract an antibiotic resistant infection and more than 35,000 die. Consequently, addressing this challenge is a public health priority. *Escherichia coli* has one of the highest rates of resistance in bacteria. The World Health Organization has classified Extended-Spectrum Beta-Lactamase (ESBL)-producing *E. coli*, an antibiotic resistant pathogen, as a public health threat that requires prompt and sustained action. This is due to its ability to spread rapidly and cause or complicate infections in otherwise healthy individuals. We performed a validation study to evaluate the use of an IDEXX-define substrate assay to enumerate presumptive ESBL *E. coli*. Then, we employed this method to assess the presence of presumptive ESBL *E. coli* in soil, water, and waterfowl feces at 4 locations in an urban area. We further assessed temporal trends in contamination related to a rainfall events.

Keywords: antimicrobial resistance, IDEXX, WASH, E. coli

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Impact of fecal sludge depth in pit latrines on pathogen detection in peri-urban Malawi

Savanna Smith, Drew Capone, Petros Chigwechokha, Rochelle Holm, Benjamin Risk, Elizabeth Tilley, Joe Brown
Advisor: Francis de los Reyes

Wastewater based epidemiology (WBE) is increasingly used to provide decision makers with actionable data about community health. WBE efforts have primarily focused on sewer-transported wastewater in high-income countries, but at least 1.8 billion people in low- and middle-income countries (LMIC) use onsite sanitation systems. Like wastewater, fecal sludges from such systems also offer the potential for epidemiological modeling. To evaluate the spatial distribution of enteric pathogens inside pit latrines – which could inform sampling methods for WBE in LMICs not covered by sewers – we collected fecal sludges from the top, middle, and bottom of 33 pit latrines in urban and peri-urban Malawi and analyzed the 99 samples for 20 common enteric pathogens via multiplex quantitative reverse transcription PCR. Using logistic regression adjusted for household population, latrine sharing, the presence of a concrete floor or slab, water source, and anal cleansing materials, we found no significant difference in the odds of detecting the 20 pathogens assessed in the middle samples and top samples compared to the bottom samples. These results suggest that, for the purposes of a WBE approach, pit latrine sampling depth does not strongly influence the odds of detecting molecular markers of enteric pathogens. A single top, or a composite of top samples, may be preferred as it represents the freshest stool contributed to the pit and is the easiest to collect. We are currently working to analyze the full microbial communities, beyond the 20 common enteric pathogens we previously examined, for each of the 99 samples. This will determine if the complete microbial communities are significantly different at top, middle, and bottom depths and therefore if pit latrine depth plays a role in microbial community composition.

Keywords: sanitation, pathogen detection, fecal sludge

2021 EWC
Graduate Research Symposium

Coastal Engineering

Presentations are from 11:10 to 11:50 AM

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Assessing coastal highway vulnerability on a barrier island

Adam Behr
Advisor: Elizabeth Sciaudone

Coastal highways are important evacuation infrastructure for barrier island communities, and they're especially susceptible to impacts like flooding, over-wash, erosion of the pavement, and damage due to island breaching. Coastal monitoring studies have used simple morphological parameters including island width, dune crest height, and distance from road to ocean shoreline as indicators of coastal infrastructure's vulnerability to short and long-term impacts from storms and erosion. Indicators are computed on a cross-shore transect basis and compared to threshold values to identify areas vulnerable to storm impacts. The first objective of this research was to evaluate the performance of 14 different indicators in predicting vulnerability to storm impacts from a data set of eight storms with documented roadway impacts. The second objective of this research was to explore development of an empirical, linear function of simple, morphologic indicators that could assess the vulnerability at each highway transect. Results from the evaluation showed that the distance from road to ocean shoreline was the most skilled predictor of vulnerability. A weighted linear function of dune crest height and distance from road to ocean shoreline was found to be slightly more skilled than the distance to edge of pavement alone.

Keywords: coastal infrastructure, highway vulnerability, coastal vulnerability, vulnerability indicators, storm impacts to coastal infrastructure

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Coastal Barrier Island Habitat Evolution and Modeling

Faith Johnson
Advisor: Elizabeth Sciaudone, Liliana Velasquez Montoya

Coastal barrier islands are dynamic coastal systems that are shaped by short- and long-term processes including storms, erosion, and sea level rise. Landcover changes due to these processes can impact infrastructure and wildlife habitats; therefore, it is important to track the changes to inform coastal management decisions. Color infrared photography and digital terrain models are used in a semi-automated classification method to create annual habitat maps for a North Carolina barrier island (2012-2019). Twelve habitat classes are identified including infrastructure, managed wetlands, and other vegetated and sandy landcover types. These maps capture trends of habitat change including an overall decrease in total dune area due to storm impacts. The area of bare sand has an overall decreasing trend with increases after significant ocean-side storms (overwash). Shrub and marsh habitat classes display an inverse behavior with marsh habitat area slightly increasing. A dynamic model of the barrier island was created using the STELLA modeling package and the mapped trends from 2012-2019. This model was used to predict future evolution of the habitat classes and potential impacts on infrastructure and wildlife. Model results indicate that areas of bare sand and dunes decrease by 2030 while ponds and marsh areas increase.

Keywords: Barrier Islands, Landcover Change, Habitat Change, Coastal Modeling

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Impact of storm events on density stratification in the Pamlico and Albemarle Estuarine System

Brooke Rumbaugh
Advisor: Casey Dietrich

This project is focused on the Pamlico and Albemarle Sounds, located near the Outer Banks of North Carolina. Within the estuarine systems there exists both horizontal and vertical density stratification that allows for key circulation. When storm events occur, this stratification is disrupted, which can have disastrous influence on the ecosystem. The purpose of this research is to investigate how storm events impact the density stratification?
To begin to answer this question, development of a three-dimensional model that included density circulation was key. This could be accomplished by utilizing an ocean circulation model and starting with an initial two-dimensional density constant model. In this two-dimensional model, forcings of wind, tide, and river flows were applied. These input values were developed from multiple sources, including output from the North American Mesoscale model and discharges from United States Geological Survey. Initial results from the model indicate stability and realistic results. With this, development of the three-dimensional with density forcing model began. Future work will include using observed data from the North Carolina Department of Environmental Quality for density stratification and creating simulations of storm events.

Keywords: ADCIRC, Baroclinic Model, 3D Modeling

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Subgrid corrections in finite-element models of storm-driven coastal flooding

Johnathan Woodruff
Advisor: Casey Dietrich

Coastal flooding models are used to predict the timing and magnitude of inundation during storms, both for real-time forecasting and long-term design. However, there is a need for faster flooding predictions that also include the highest-resolution datasets to represent flow pathways and barriers at the scales of critical infrastructure. This need can be addressed via subgrid corrections, which use information at smaller scales to `correct' the flow variables (water levels and current velocities) averaged over the model scale. Traditionally, subgrid studies do not implement corrections in a finite element framework due to difficulties in defining averaged areas and wetting and drying schemes.
In this study, subgrid correction factors are added to the widely used ADvanced CIRCulation (ADCIRC) shallow water model to better understand how they can improve the accuracy and efficiency of inundation predictions. The benefits of the subgrid corrections are demonstrated on a domain in southwestern Louisiana over which Hurricane Rita (2005) storm forcing is applied. It is shown that the subgrid corrections can increase model speed by 10 to 50 times without sacrificing accuracy. The addition of subgrid corrections to numerical storm surge models opens the door to probabilistic modeling frameworks and more efficient use of computational resources.

Keywords: storm surge, subgrid, ADCIRC, wetting and drying, shallow water equations

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Granular activated carbon treatment of drinking water for PFAS removal: Predicting field-scale performance with rapid small-scale column tests

Zachary Hopkins
Advisor: Detlef Knappe

Per- and polyfluoroalkyl substances (PFAS) are important drinking water contaminants. To reduce exposure to PFAS, drinking water utilities are considering the installation of advanced treatment processes such as granular activated carbon (GAC) adsorption. Design and cost information is typically developed from time-intensive pilot tests. Rapid small-scale column tests (RSSCTs) offer the possibility to rapidly evaluate GAC performance, but fundamental questions remain about RSSCT design and the scale-up of RSSCT data. The overarching aim of this research is to develop and validate a protocol for the design of RSSCTs and the scale-up of RSSCT data. This presentation will demonstrate an approach to rapidly and accurately assess GAC performance at the field-scale.

At the bench-scale, PFAS removal was evaluated with RSSCTs based on both proportional diffusivity (PD) and constant diffusivity (CD) designs. Using a scale-up protocol involving the pore-surface diffusion model, data from both RSSCT designs could be used to predict the pilot data. An advantage of the CD-RSSCT approach is that data can be collected very quickly (100,000 bed volumes in 4 days, requiring 8 liters of water). The developed scale-up protocol effectively predicted pilot-scale removal of legacy and emerging PFASs for GACs prepared from sub-bituminous coal and coconut shells.

Keywords: Per- and polyfluoroalkyl substances, granular activated carbon, drinking water treatment, surface water

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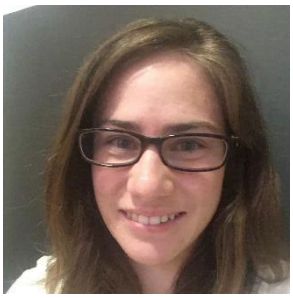


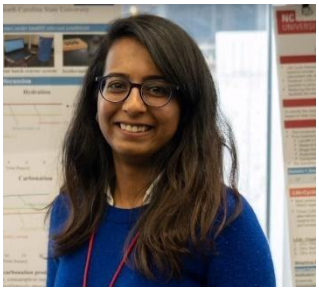
Does Bioaugmentation Work? A Field-Scale Experiment of Aerated Stabilization Basins in the Pulp and Paper Industry

Amanda Johansen Mattingly
Advisor: Francis de los Reyes III

Continuous bioaugmentation is widely employed across the pulp and paper industry as a means to improve resilience of wastewater treatment systems or performance in undersized (in terms of volume, aeration or nutrient supply) systems. In theory, bioaugmentation should work, but independently derived data and analysis providing evidence of efficacy in real systems as typically operated across the industry is scarce. A 6 month field scale trial of a continuous bioaugmentation system at a southeastern pulp and paper mill aerated stabilization basin (ASB) was completed. The ASB consisted of 2 identical trains of ponds, allowing for a controlled study. Over the 6 month period, BOD and TSS data from the trains did not provide evidence that bioaugmentation contributed to better wastewater treatment. Measurements used to evaluate mechanisms of bioaugmentation, such as oxygen uptake rate (OUR) and ATP, did not provide evidence that trains treated with bioaugmentation were significantly different from untreated trains. These results indicate that under typical ASB operation conditions, addition of bioaugmentation products does not confer significant benefits.

Keywords: wastewater treatment, pulp and paper, bioaugmentation, secondary treatment

30



Measurement of heat release during hydration and carbonation of ash disposed in landfills using an isothermal calorimeter

Asmita Narode
Advisor: Morton Barlaz, M. Pour-Ghaz, Joel Ducoste

A recently published model describing landfill heat accumulation identified reactions that contribute significant heat to landfills, including the hydration and carbonation of Ca-containing wastes such as ash from MSW and coal combustion. The objective of this study was to develop a method to measure heat release from Ca-containing ash by isothermal calorimetry. The method was confirmed by comparing measured heat release from hydration and carbonation of pure CaO and $Ca(OH)_2$ to the theoretical heat. Theoretical heat release was determined by characterizing test materials before and after experiments using thermogravimetric analysis (TGA) and X-ray diffraction (XRD). Heat recovery efficiencies with both water and synthetic leachate ranged from 79 to 90% for CaO hydration and between 65 and 74% for $Ca(OH)_2$ carbonation, with no effect attributable to leachate. The developed method was applied to eight samples that were excavated from a landfill and known to contain coal ash. The developed method can be used by landfill operators to evaluate the heat potential of a waste, thereby facilitating decisions on the quantity of a waste that can be buried in consideration of landfill temperatures. Work is in progress to extend the method to a reactor system that better represents landfill conditions.

Keywords: Landfills, elevated temperature, calorimeter, hydration, carbonation, ash

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Tertiary partial denitrification-anammox (PdNA) filters for sustainable nitrogen removal

Anthony Young
Advisor: Tarek Aziz, Francis de los Reyes

Concentrated discharges of nitrogen into our waterways have led to serious environmental impacts, such as eutrophication and algae blooms. Due to these discharges, stringent total nitrogen (TN) discharge limits have been placed on Water Reclamation Facilities (WRFs). Mainstream deammonification offers a solution to improve nitrogen removal at these facilities through the use of anaerobic ammonia oxidizing bacteria (Anammox). However, the success of this process has been limited. Previous research at NC State explored the conversion of tertiary filters into mainstream deammonification filters which were capable of an average total inorganic nitrogen (TIN) removal rate of 91%, with effluent TIN reaching below 2 mg/L-N. However, this research suggested that nitrate loading was a key limiting factor in meeting rigorous effluent limitations. Incorporating partial denitrification (PdN) into this process has offered a promising solution. The goal of our research was to explore the TN removal capability of a PdN-Anammox (PdNA) filter. Utilizing pilot scale filters, we were able to compare carbon loading strategies and will be identifying the microbes involved within the PdNA process. This treatment technique has provided improved TN removal efficiencies and has the opportunity to provide stable TN removal at WRFs, as well as the possibility of substantial savings.

Keywords: Wastewater, Nitrogen, Anammox, Filters

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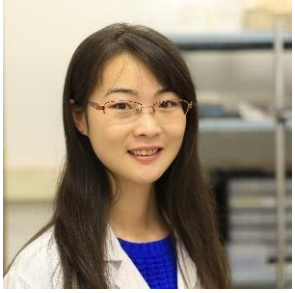

Stability and Reactivity of Per- and Polyfluoroalkyl Substances in Solvents Relevant to Environmental and Toxicological Analysis

Chuhui Zhang
Advisor: Detlef Knappe

Per- and polyfluoroalkyl substances (PFASs) are widely used anthropogenic chemicals. For environmental and toxicological analysis, it is important to understand the stability of PFASs, including novel per- and polyfluoroalkyl ether acids (PFEAs), in commonly used solvents. In this study, we investigated the effects of PFAS characteristics, solvent type, water-to-organic solvent ratio, and temperature on the stability of 19 PFASs. None of the studied PFASs showed measurable degradation in deionized water, methanol, and isopropyl alcohol in 30 days; however, some PFEAs degraded in the aprotic solvents including acetonitrile, acetone, and dimethyl sulfoxide (DMSO). PFEA degradation followed first-order kinetics, and first-order rate constants increased with increasing temperature and decreasing water-to-organic solvent ratio. Monoethers containing a carboxylic acid functional group adjacent to a tertiary carbon degraded more rapidly than multiethers, in which the carboxylic acid was adjacent to a $-CF_2-$ group. Using high resolution mass spectrometry, we determined that hexafluoropropylene oxide-dimer acid (HFPO-DA or GenX), HFPO-trimer acid, and HFPO-tetramer acid were stoichiometrically converted in aprotic solvents to fluoroethers E-1, E-2, and E-3, respectively. The PFEA degradation results highlight the importance of solvent choice when preparing dosing solutions for environmental and toxicological assessments of PFEAs.

Keywords: per- and polyfluoroalkyl substances, stability, solvents

Industry/Alumni

1 Jason Patskoski, P.E., PhD
Summit

Jason Patskoski graduated with a B.S. in Civil Engineering from Clemson in 2010 and graduated with an M.S. and Ph.D. in Civil Engineering from NC State in 2012 and 2014. His dissertation focused on improving reservoir sizing using observed data, reconstructed data from paleo observations, and forecasted data. After graduation, he worked for Amec (now Wood) where he conducted Hydraulic and Hydrologic (H&H) studies and designed spillway repairs and replacements for high hazard dams. He left Amec to work for Garrett and Moore focusing on stormwater components of landfill design. Jason then accepted a Postdoctoral position at NC State. His research was focused on statistical modeling of hydrologic and hydraulic systems. In 2017, he left NC State to go work for Summit Design and Engineering Services as a Water Resources Engineer. He is now the manager of the Hydraulic Design team at Summit. His job responsibilities include managing transportation projects, floodplain analysis and modeling, hydraulically analyzing and designing bridges and culverts, developing the No-Rise packages, CLOMRs, and LOMRS, and designing closed system drainage systems, ditches, erosion control plans, Stormwater Control Measures (SCMs), and sanitary sewer and water distribution relocations. He is a PE in SC, NC, VA and WV.

2 Lauren Wellborn, P.E.
Geosyntec

Ms. Wellborn is a Senior Engineer with more than 11 years of experience in environmental site investigation and remediation with a focus on metals and recalcitrant compounds, including mercury, pesticides, polychlorinated biphenyls (PCBs), chlorinated solvents, and per- and polyfluoroalkyl substance (PFAS) compounds. Her work has focused primarily on contaminated sediments sites, and she has significant involvement in investigation and remedial design for complex, multi-stakeholder projects. Ms. Wellborn has managed efforts related to sampling, investigation, and remedial design, and she has experience with all phases of environmental site characterization, including sampling plan design and work plan development, quality assurance plan and health and safety plan development, field investigation programs, data management and analysis, data visualization, and report preparation. She has experience with pre-design investigations (PDIs) and remedial design, and she has supported PDIs and remedial designs in U.S. Environmental Protection Agency (EPA) Regions 2 and 4. Ms. Wellborn excels at managing and directing large teams to support a variety of project objectives while maintaining exceptional quality.
Degrees: 2006 BS, 2009 MS, both from NCSU Environmental Engineering

3 William Eleazer, P.E.
Brown and Caldwell

William Eleazer, P.E. is the Chief Engineer for the Southeastern Business Unit of Brown and Caldwell. He has been an Engineer and Project Manager for large wastewater treatment plant upgrades for Brown and Caldwell for the past 25 years and is currently based in the Brown and Caldwell—Miami office. Brown and Caldwell is a national environmental engineering consulting firm with more than 50 offices throughout the United States. He holds a bachelor's and master's degrees from North Carolina State University in environmental engineering.

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