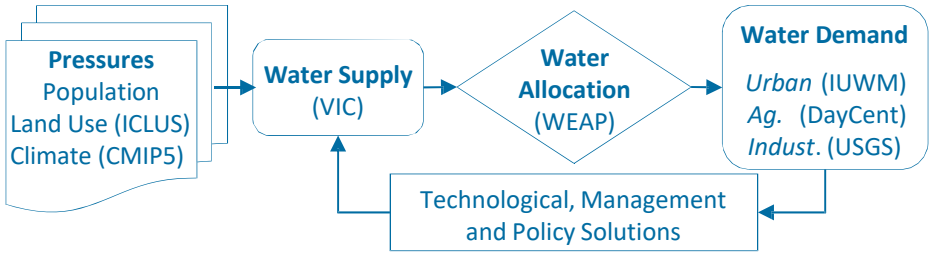
PROJECT A1-1:
QUANTIFYING VULNERABILITY, RESILIENCY, AND ADAPTABILITY OF U.S. URBAN WATER SYSTEMS TO CLIMATIC AND SOCIO-ECONOMIC CHANGES

National Science Foundation

MOTIVATION AND OBJECTIVES

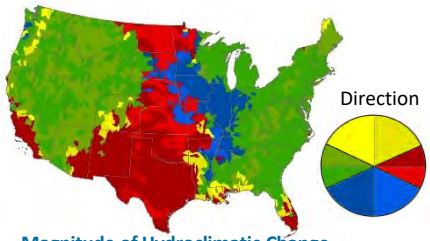
- Climatic changes combined with rapid population growth and land use change can increase the vulnerability to water shortage.
- The goal of the study is to assess regional/municipal water shortage vulnerability under nonstationary supply and demand conditions over the 21st century.



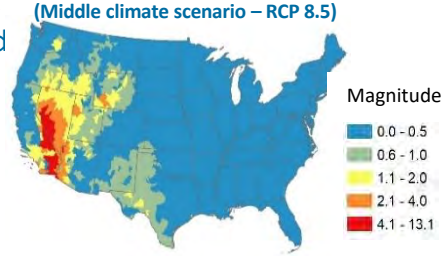
PROGRESS

- U.S hydroclimatic parameters are projected at HUC8 level over the 21st century and a web-based tool (HCAT) is developed to provide the data (https://hcat.erams.com/docs/)
- Long-term shifts in regional hydroclimatic conditions of U.S river basins are assessed in response to climate change.
- The impacts of hydroclimatic changes on U.S agricultural regions are evaluated over the 21st century.

Direction of Hydroclimatic Change (Middle climate scenario – RCP 8.5)



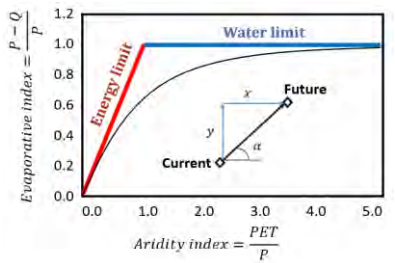
Magnitude of Hydroclimatic Change (Middle climate scenario – RCP 8.5)



APPROACH

- **Climate projection:** future changes in climatic variables are obtained from the downscaled Multivariate Adaptive Constructed Analogs (MACA) datasets ranging from the driest to wettest and least warm to hottest projections were projected.
- **Hydrologic projection:** the projected climatic variables are then used as inputs to the Variable Infiltration Capacity (VIC) model to evaluate the hydrologic responses of future climate projections.
- **Hydroclimatic projection:** The Budyko hydroclimatic assessment is applied to estimate changes in hydroclimatic conditions of the CONUS at HUC8 river basin scales.
- **Clustering:** K-means method is used to cluster HUC8 river basins to the seven regions with unique hydroclimatic behavior.
- The baseline is 1986-2015 while the 2070-2099 represented the future conditions.

Shifts in Budyko space

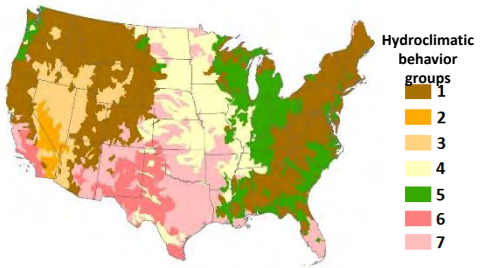


ACHIEVEMENTS AND SIGNIFICANCE

- The systematic hydroclimatic behavior of river basins are highly associated with their regional landform, climate and ecosystem.
- Under the Middle climate scenario, the majority of river basins in Southern U.S. move to the right-up in the Budyko space with high magnitude indicating that this region is likely to experience warmer and drier condition. However, most river basins in the American West move to the left-down with high magnitude indicating that this region is more likely to experience less arid and wetter condition.
- The direction of hydroclimatic change under different climate change scenarios varies by region.

Behavior Group	Direction (D) and Magnitude (M)
1	D (135-190) with M (<0.095)
2	D (135-190) with M (>3.4)
3	D (135-190) with M (0.95-3.4)
4	D (220-360)
5	D (190-220)
6	D (0-45) with M (>0.5)
7	D (0-45) with M (<0.5)

U.S hydroclimatic behavior groups



PROJECT A1-1:
QUANTIFYING VULNERABILITY, RESILIENCY, AND ADAPTABILITY OF U.S. URBAN WATER SYSTEMS TO CLIMATIC AND SOCIO-ECONOMIC CHANGES

PRODUCTS

- Warziniack, T., Brown, T. C. (2019). The importance of municipal and agricultural demands in future water shortages in the United States, *Environmental Research Letters*, 14(8), 084036. https://doi.org/10.1088/1748-9326/ab2b76.
- Heidari, H., Arabi, M., Ghanbari, M., Warziniack, T. (2020). A Probabilistic Approach for Characterization of Sub-Annual Socioeconomic Drought Intensity-Duration-Frequency (IDF) Relationships in a Changing Environment, *Water*, 12(6), 1522.
- Heidari, H., Arabi, M., Warziniack, T., Kao, S.C. (2020). Assessing Shifts in Regional Hydroclimatic Conditions of U.S River Basins in Response to Climate Change, *Earth's Future*, in review.
- Heidari, H., Arabi, M., Warziniack, T., Kao, S.-C. (2020). Assessing the Impacts of Climate Changes on the Regional Hydroclimatic Conditions of U.S River Basin over the 21st Century. *Hydrology Days 2020*, April 13 – 15. Fort Collins, CO.
- Heidari, H., Arabi, M., Warziniack, T., Kao, S.-C. (2020). Changes in Hydroclimatic Characteristics of River Basins in the U.S. over the 21st Century. *AGU Fall Meeting*, Dec 9 – 13, San Francisco, CA.
- Heidari, H., Arabi, M., Ghanbari, M., Warziniack, T. (2019). A Mixture Gamma-GPD Probability Model for Characterization of Water Shortage Vulnerability under Nonstationary Supply and Demand Conditions. *World Environmental and water resources congress*, May 19 – 23. Pittsburgh, PA.
- Heidari, H., Arabi, M., Ghanbari, M., Warziniack, T. (2019). A Mixture Gamma-GPD Probability Model for Characterization of Water Shortage Vulnerability under Nonstationary Supply and Demand Conditions. *Hydrology Days 2019*, March 27 – 29. Fort Collins, CO.
- Heidari, H., Arabi, M., Ghanbari, M. (2018). A Novel Probabilistic Approach for Characterization of Municipal Water Shortage Vulnerability under Nonstationary Supply and Demand Conditions. *AGU Fall Meeting*, Dec 10 – 14. Washington, D.C.
- Heidari, H., Arabi, M., Dozier, A., Tasdighi, A. (2018). An Analytical Framework for Assessing Water Shortage Vulnerability under Nonstationary Supply and Demand Conditions. *International Congress on Environmental Modelling and Software 2018*, June 24 – 28. Fort Collins, CO.
- Heidari, H., Arabi, M., Dozier, A., Tasdighi, A. (2018). Water Shortage Vulnerability under Land use and Climate Changes Scenarios. *Hydrology Days 2018*, March 19 – 21. Fort Collins, CO.

PROJECT TEAM

- Mazdak Arabi, Professor – Colorado State University
- Hadi Heidari, PhD Candidate, Colorado State University
- Jorge Ramirez, Professor, Colorado State University
- Travis Warziniack, Economist – USDA Forest Service
- Thomas C. Brown, Economist – USDA Forest Service

PROJECT A1-2:
IMPACTS OF WATER PRICES ON ECONOMIC GROWTH, SOCIAL EQUITY AND EQUAL OPPORTUNITY

National Science Foundation

MOTIVATION AND OBJECTIVES

Motivation: Understand water price trends and impacts of these trends on household income, regional income, and regional employment.

Objectives:
1.Create database of water prices (past, present, future)
2. Analysis of water price trends
3.Analyze economic impacts of changing consumer expenditures on water
4.Train undergraduate and graduate students in economic analyses of water prices and associated regional impacts

PROGRESS

-Collection of water rates for select U-WIN regions complete

-Analysis of water rate data

-Analyzing consumer expenditure questions about purchasing decisions due to rising water rates

-Participation of 3 graduate students and 2 undergraduate in research at Michigan State

-Started work on Integration paper, co-led with Matei Georgescu

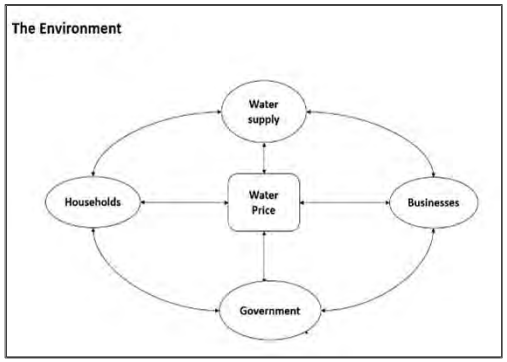
APPROACH

Implementation of a mix of quantitative methods:

-Input-output modeling to model feedbacks in regional economic systems.

-Spatial analysis of water rates

-Econometric modeling to understand linkages between water price trends and hypothesized regional drivers of prices external to utiliities.



ACHIEVEMENTS AND SIGNIFICANCE

-- Completion of water rate database

-Training of students in water data sources and research

-Development of new indicators for analysis of water issues

-Collaboration with Philadelphia Water Department to work towards affordability solutions

PROJECT A1-2:
IMPACTS OF WATER PRICES ON ECONOMIC GROWTH, SOCIAL EQUITY AND EQUAL OPPORTUNITY

PRODUCTS

Papers:

Mack, E. A., Wrase, S., Dahme, J., Crosby, S. M., Davis, M., Wright, M., & Muhammad, R. (2020). An Experiment in Making Water Affordable: Philadelphia's Tiered Assistance Program (TAP). *JAWRA Journal of the American Water Resources Association*. https://doi.org/10.1111/1752-1688.12830

White, J. **Mack. E,A.****, Harlan, S., Krayenhoff, S. Georgescu, M. and K. Redican. (2019). Regional Multivariate Indices of Water Use Potential for the Continental United States. *Sustainability.* 11(8): 2292

Articles in preparation (indicates student name):

- Spatial analysis of water rates in Detroit
- Perceptions of water affordability (Laura Medwid and Michelle Church)
- Analysis of water expenditures paper (Laura Medwid)

Data sets:

Presentations:

- Household Expenditure Change and Cascading Effects as a Result of Increasing Costs of Water Services. North American Regional Science Conference. Pittsburgh, PA November 13-16. Presenter: Elizabeth Mack

- Perceptions of Water Affordability. North American Regional Science Conference. Pittsburgh, PA November 13-16. Presenter: Laura Medwid

- Mack, E.A. Water Affordability Assessments and Solutions. Vanderbilt University October 4, 2019
- Interview on Sirius XM Radio about Water Affordability and Conserving Water for Doctor Radio April 19, 2019
- Water Rates in Detroit. Global Water Justice Summit: The Michigan Conference January 24-25

PROJECT TEAM

- Elizabeth Mack, Assistant Professor, Department of Geography, Environment, and Spatial Sciences, Michigan State University
- Michigan State graduate students: Jonah White, Sarah Wrase, Michelle Church, and Laura Medwid
- Michigan State undergraduate students: Madison Wimberly and Isabella Catalano

PROJECT A2-1:
LAND-ATMOSPHERE-HYDROSPHERE INTERACTIONS IN URBAN TERRAIN

National Science Foundation

MOTIVATION AND OBJECTIVES

- Integrate existing models of the atmosphere, surface, and subsurface in urban terrain into a comprehensive framework.
- Expand and validate the Princeton Urban Canopy Model (PUCM) into a more general framework that can dynamically represent the interplay between urban water, energy and climate (e.g. thermal comfort, role of green infrastructure and trees, urban water demand and how it is modulated by weather, etc.)
- Apply the integrated model to understand urban sustainability, particularly under historic extreme events (e.g., heat waves, floods, droughts).

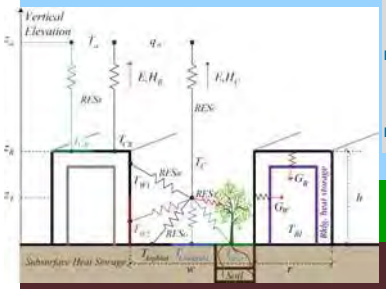
PROGRESS

- Analyzed how a strong urban heat island (UHI) might create recirculation bubbles in cities and decrease environmental quality.
- Collaborated on the development of a simplified urban heat island model that can be applied worldwide, and analyzed the climatological and population drivers of the surface UHI, as well as the seasonal UHI hysteresis in various cities.
- Applied the newly developed WRF(LES)-PUCM-ParFlow model to a small test watershed in Baltimore to investigate the effect of highly-resolved urban hydrometeorological processes and three-dimensional groundwater flow on output variables such as overland flow, soil moisture, and surface temperature.

APPROACH

Atmosphere:
Weather model (WRF) or Climate model (GCM)

- The Weather Research and Forecasting Model for the Atmosphere
- The Princeton Urban Canopy Model for the urban surface
- ParFlow for subsurface water flow



Surface: NOAH or CLM + UCM

Subsurface (Parflow)

ACHIEVEMENTS AND SIGNIFICANCE

- Despite their significance and wide application, urban geophysical models in many respects remain rudimentary. This project's primary focus is on the development of individual model components, their coupling, and their testing.
- Over 23 peer-refereed journal papers resulted so far from the project (5 key new ones listed on the next slide)
- Findings broadly communicated in conferences and talks.
- All modeling components have been coupled, and the application have begun.
- Developed modeling components have been delivered to other projects (A2-2).
- 5 Ph.D. students and 3 Postdocs trained through project.

PROJECT A2-1:
LAND-ATMOSPHERE-HYDROSPHERE INTERACTIONS IN URBAN TERRAIN

PRODUCTS

- Omidvar H, Bou-Zeid E., Li Q., Mellado J.P., and Klein P. (2020) “Plume or bubble? mixed convection flow regimes and city-scale circulations”, Journal of Fluid Mechanics, in press.
- Llaguno-Munitxa M. and Bou-Zeid E. (2020) "The environmental neighborhoods of cities and their spatial extent", Environmental Research Letters, in press, DOI: 10.1088/1748-9326/ab8d7e
- Manoli G., Fatichi S., Bou-Zeid E. and Katul G.G. (2020) “Seasonal hysteresis of surface urban heat islands”, Proceedings of the National Academy of Sciences, 201917554; DOI: 10.1073/pnas.1917554117.
- Li Q., Bou-Zeid E. (2019) “Contrasts Between Momentum and Scalar Transport Over Very Rough Surfaces”, Journal of Fluid Mechanics, 880, 32-58. DOI: 10.1017/jfm.2019.687.
- Manoli G., Fatichi S., Schläpfer M, Yu K., Crowther T.W., Meili N, Burlando P., Katul G.G., and Bou-Zeid E. “Climate and population explain temperature anomalies in world cities”, Nature, 573, 55–60. DOI: 10.1038/s41586-019-1512-9.
- Barnes, M.L. and Welty, C. (2019) “Quantifying water balance components at a permeable pavement site using a coupled groundwater–surface water model” ASCE J of Hydrologic Engineering, DOI: 10.1061/(ASCE)HE.1943-5584.0001789.

PROJECT TEAM

- Elie R. Bou-Zeid, Professor, Princeton University
- Zhihua Wang, Associate Professor, Arizona State University
- Hamidreza Omidvar, Ph.D. student, Princeton University
- Jiachuan Yang, Postdoc, Princeton University
- Mahdad Talebpour, Ph.D. student, University of Maryland, Baltimore County
- Claire Welty, Professor, University of Maryland, Baltimore County
- Qi Li, previous student, Princeton University
- Chenghao Wang, Ph.D. student, , Arizona State University
- Maider Llaguno-Munitxa, Postdoc, Princeton University

PROJECT A2-2:

LAND-ATMOSPHERE-HYDROSPHERE INTERACTIONS IN URBAN TERRAIN: PROJECTING FUTURE ENVIRONMENTAL CHANGE IN URBAN AREAS

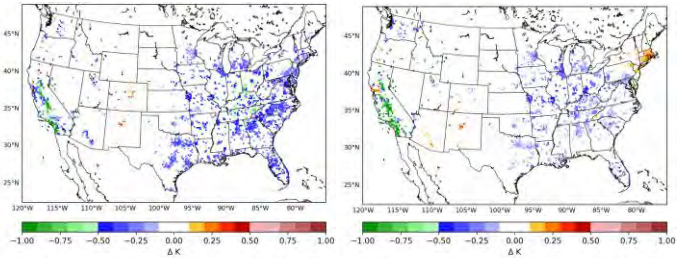
National Science Foundation

MOTIVATION AND OBJECTIVES

- Quantify the dynamically interactive effect of increased emissions of greenhouse gases (GHGs) and anthropogenic landscape change associated with urban expansion for CONUS.
- Examine the diurnally varying efficacy of locally deployed urban adaptation and mitigation solutions (e.g., street trees, cool and evaporative roofs, and lightweight materials) at continental and local scales.

PROGRESS

- Quantified the relative magnitude of urban expansion relative to GHGs across the diurnal cycle and determined that climate change and corresponding urban expansion interact nonlinearly to reduce

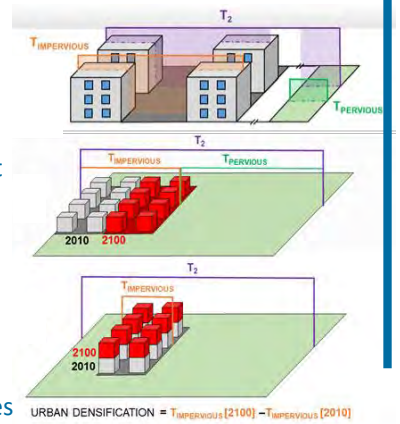


Summertime urban air temperature change resulting from dynamic interaction between 30-year projections of urban expansion and climate change. Climate models downscaled and scenarios are CESM RCP 8.5 (left panel) and GFDL RCP 8.5 (right panel). Data shown for 0300 Local Mean Solar Time (LMST). Each point represents a decadal mean JA subgrid near-surface urban temperature change within a 20 km by 20 km model grid square (from Krayenhoff et al., 2018).

APPROACH

Utilized state-of-the-art Weather Research and Forecasting model within a high performance computing framework with modifications that include:

- Spatially-explicit urban fraction from ICLUS impervious surface projections into the WRF preprocessor to better represent static terrestrial data;
- MODIS IGBP 500 m resolution land cover was input to WRF such that all areas previously designated as urban are converted to the most common vegetation type within a 100 km radius which are consistent with locally dominant vegetation;
- Two additional near-surface air temperature diagnoses are added ($T_{impervious}$ and $T_{pervious}$), based on the sensible heat flux and surface temperatures of impervious urban (i.e. street-canyon plus roofs), and pervious (non-urban) portions of the grid cell.



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- G-induced warming and adaptation cooling across CONUS.
- Developed a scenario-based multi-terabyte dataset (of unprecedented temporal resolution: 3-hourly frequency for a contemporary and a future decade) that includes multiple projections (through dynamical downscaling) of:
  - multiple GCMs/RCPs and,
  - urban expansion and,
  - infrastructure related solutions
  - The temperature dataset has been housed on erams.com

The work, aimed at reducing urban heat, will be of value to a broad spectrum of scientists ranging from economists to climatologists.

PROJECT A2-2:
LAND-ATMOSPHERE-HYDROSPHERE INTERACTIONS IN URBAN TERRAIN: PROJECTING FUTURE ENVIRONMENTAL CHANGE IN URBAN AREAS

National Science Foundation

PRODUCTS

[Only 2019/2020 published manuscripts listed – several still under peer-review or in progress]

- Cao, Q., Liu, Y., Georgescu, M., & Wu, J. (2020). Impacts of landscape changes on local and regional climate: a systematic review. *Landscape Ecology*, 1-22. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Broadbent, A. M., Krayenhoff, E. S., & Georgescu, M. (2020). Efficacy of cool roofs at reducing pedestrian-level air temperature during projected 21st century heatwaves in Atlanta, Detroit, and Phoenix (USA). *Environmental Research Letters, doi:* https://doi.org/10.1088/1748-9326/ab6a23. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Heusinger, J., Broadbent, A. M., Sailor, D. J., & Georgescu, M. (2020). Introduction, evaluation and application of an energy balance model for photovoltaic modules. *Solar Energy*, *195*, 382-395. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Aragon, N. U., Stuhlmacher, M., Smith, J. P., Clinton, N., & Georgescu, M. (2019). Urban agriculture's bounty: contributions to Phoenix's sustainability goals. *Environmental Research Letters*, *14*(10), 105001. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Baniassadi, A., Sailor, D. J., Krayenhoff, E. S., Broadbent, A. M., & Georgescu, M. (2019). Passive survivability of buildings under changing urban climates across eight US cities. *Environmental Research Letters*, *14*(7), 074028. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Broadbent, A. M., Krayenhoff, E. S., Georgescu, M., & Sailor, D. J. (2019). The observed effects of utility-scale photovoltaics on near-surface air temperature and energy balance. *Journal of Applied Meteorology and Climatology*, *58*(5), 989-1006. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.

PROJECT TEAM

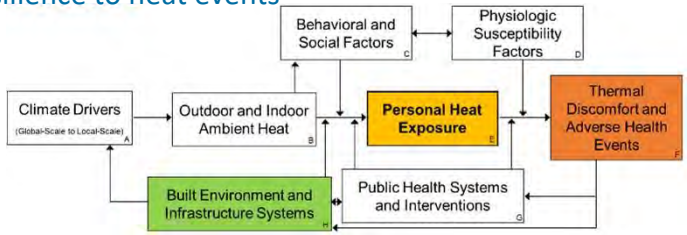
- E. S. Krayenhoff, Assistant Professor, Guelph University
- M. Moustaoui, Associate Professor, Arizona State University
- A. M. Broadbent, Post-doctoral Scholar, Arizona State University
- V. Gupta, Research Assistant, Basis High School/Arizona State University (now enrolled at Stanford University)
- M. Stuhlmacher, Research Assistant, Arizona State University
- J. Lee, Research Assistant, Arizona State University
- A. Middel, Assistant Professor, Arizona State University
- Jennifer Vanos, Assistant Professor, Arizona State University
- Meng Wang, Research Technician, Arizona State University
- Chingwen Chen, Assistant Professor, Arizona State University
- M. Georgescu, Associate Professor, Arizona State University
- Aldo Brandi, Research Assistant, Arizona State University

PROJECT A2-3:
ASSESSING THE THERMAL COMFORT IMPLICATIONS OF URBAN WATER

National Science Foundation

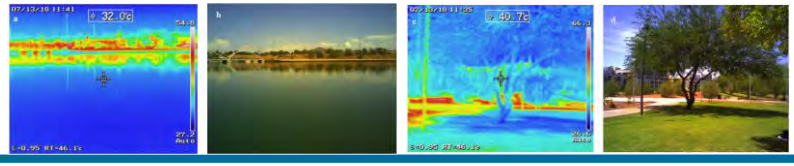
MOTIVATION AND OBJECTIVES

- Measure microclimatic conditions experienced by urban residents
- Understand microclimate effects on human health and well-being
- Assess role of urban water infrastructure in supporting resilience to heat events



PROGRESS

- Conducted national-scale assessment of urban thermal equity using satellite imagery and census data
- Compared residents' perceptions of urban trees with biophysical properties and social data in the Phoenix metro area
- Conducted regional survey on water and energy affordability
- Used innovative fish-eye lens technique to quantify tree shade in urban parks



APPROACH

- Targeted thermal comfort assessments
- Citywide temperature and humidity measurements
- Human energy balance modeling
- Statistical modeling of heat-health risks
- Thematic coding of vignette-style interviews

ACHIEVEMENTS AND SIGNIFICANCE

- Inequitable distributions of urban heat are prevalent in cities across the country and tied to historical planning and zoning
- More than 30% of heat-related deaths in Maricopa County (AZ) may be attributable to the urban heat island effect
- Urban tree canopy lowers daytime air and radiant temperatures but increases those parameters at night
- Water bodies are less effective at reducing ambient and radiant temperatures than urban tree canopy
- Conventional measures for water and energy affordability underrepresent impacts of utility costs on residents
- Water and electricity shutoffs amplify heat-health risks for urban residents

PROJECT A2-3:
ASSESSING THE THERMAL COMFORT IMPLICATIONS OF URBAN WATER

PRODUCTS

- Hondula, D. M., Balling, R. C., Andrade, R., Krayenhoff, E. S., Middel, A., Urban, A., ... & Sailor, D. J. (2017). Biometeorology for cities. *International journal of biometeorology*, *61*(1), 59-69.

- Kuras, E. R., Richardson, M. B., Calkins, M. M., Ebi, K. L., Hess, J. J., Kintziger, K. W., ... & Hondula, D.M. (2017). Opportunities and challenges for personal heat exposure research.

- Hondula, D. M., Davis, R. E., & Georgescu, M. (2018). Clarifying the connections between green space, urban climate, and heat- related mortality.

- Hondula, D. M., Middel, A., Vanos, J. K., Herdt, L., & Kaiser, A. (2017). Urban Water Infrastructure for Cooling: Case Studies from Humid and Arid Cities. *Regions Magazine*, *306*(1), 20-23.

- Harlan S.L., Chakalian P.M., Declet-Barreto J., Hondula D.M., & Jenerette D.G. (2019). Pathways to Climate Justice in a Desert Metropolis. In: People and Climate Change: Vulnerability, Adaptation, and Social Justice. Lisa Reyes Mason and Jonathan Rigg, eds., published April 2019.

PROJECT TEAM

- David Hondula, Assistant Professor, Arizona State University
- Jennifer Vanos, Assistant Professor, Arizona State University
- Ariane Middel, Assistant Professor, Arizona State University
- Graduate students at ASU: Riley Andrade, Liza Kurtz, Mary Wright
- Undergraduate students at ASU and URP participants: Alanna Kaiser, Tiffany Justice, Harrison Ambrose, Lolya McWest, Samuel Meltzer, Manny Herrera, Ryan Correa

PROJECT A2-4:
ASSESSMENT AND DESIGN OF INNOVATIVE DESIGN OF BUILDING SYSTEMS AND URBAN INFRASTRUCTURE

National Science Foundation

MOTIVATION AND OBJECTIVES

We aim to improve the understanding of how the systems and infrastructure designed in the urban environment can be improved through applied research. The motivation is from the significant role that buildings play in developing demand for energy and water, and the role that urban fabric plays at the building scale urban heat and on water and climate interactions, which have carryon heat impacts on social/environmental equity. Our goal is to provide analyses at the building and neighborhood scale radiant heat transfer that can inform modeling of climate, watershed, and integrated water management. We also aim to provide a link to conceptual design frameworks to help bridge between disciplines through architecture and urban planning contexts.

PROGRESS

We have successfully mapped urban heat in NYC using thermal cameras.

We have successfully deployed new sensing techniques for radiant heat in Philadelphia with Araine Middel – SMART sensor + MarRTy, and have a paper forthcoming

We have discovered the most common tool for measuring radiant heat, the black globe, has a systematic flaw in its use.

We analyzed the variation of humidity around cooling towers

We have modeled new geothermal systems tied to district heating that could be used in conjunction with wastewater heat sources

We built several prototype cooling panels that leverage desiccant systems and evaporation to more efficiently manage water and cooling

New collaboration with Torino on atmospheric water capture

APPROACH

We use sensors and thermal imaging techniques to evaluate the variation of urban surfaces. The thermal mapping is used to identify problems with heat and water storage in physical materials, and also identifies opportunities for green infrastructure to mitigate heat.

We are developing new sensor systems and techniques to more accurately map and understand the radiant heat transfer related to urban water

We are also using modeling techniques to identify synergies between district water demand and district heating systems.

We design new evaporative/desiccant based humidity management systems that can capture water from the atmosphere

Finally, we use studio teaching and to develop new design pathways for novel systems

ACHIEVEMENTS AND SIGNIFICANCE

We published a paper on challenges urban heat in NYC

We built a prototype pavilion in Singapore that managed to create cool radiant spaces with surfaces below the dewpoint, but that avoided any condensation and by surveying occupants showed that under hot humid outdoor conditions in Singapore novel radiant surface deployment can make people feel cool.

We published a paper reviewing the use of Mean Radiant Temperature for measuring radiant heat

We presented several new systems we have designed that use evaporation and desiccation and received Exxon support.

We presented research on several water system projects at Building Simulation conference and CISBAT conference.

PROJECT A2-4:
ASSESSMENT AND DESIGN OF INNOVATIVE DESIGN OF BUILDING SYSTEMS AND URBAN INFRASTRUCTURE

PRODUCTS

- Teitelbaum, E., Jayathissa, P., Miller, C., & Meggers, F. (2020). Design with Comfort: Expanding the psychrometric chart with radiation and convection dimensions. Energy and Buildings, 209, 109591. https://doi.org/10.1016/j.enbuild.2019.109591
- Teitelbaum, E., Chen, K. W., Meggers, F., Guo, H., Houchois, N., Pantelic, J., & Rysanek, A. (2020). Globe thermometer free convection error potentials. Scientific Reports, 10(1), 1–13. https://doi.org/10.1038/s41598-020-59441-1
- Guo, H., Ferrara, M., Coleman, J., Loyola, M., & Meggers, F. (2020). Simulation and measurement of air temperatures and mean radiant temperatures in a radiantly heated indoor space. Energy, 193, 116369. https://doi.org/10.1016/j.energy.2019.116369
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PROJECT TEAM

- Forrest Meggers
- Hongshan Guo
- Dorit Aviv
- Kianwee Chen
- Eric Teitelbaum

PROJECT A3-1:
VEGETATION, BIODIVERSITY, ECOSYSTEM FUNCTIONING RELATIONSHIPS AND GREEN INFRASTRUCTURE

National Science Foundation

MOTIVATION AND OBJECTIVES

Develop a set of biodiversity and ecosystem services indicators that characterize current and alternative future climate land covers.

Assess vegetation biodiversity distributions and vegetation density distributions.

Evaluate effects of vegetation density on a key amenity, local cooling within UWIN regions.

Provide training opportunities for graduate students, undergraduate students, and citizen scientists to better understand urban ecological concepts associated with water sustainability.

PROGRESS

Developed new method for mapping urban ET associated with outdoor vegetation.

Deploying a network of air temperature sensors distributed across 900 sampling locations in nine cities.

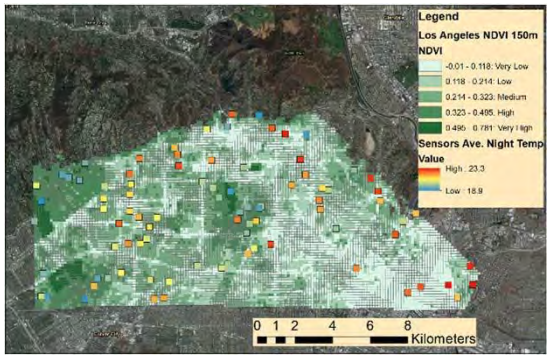
Developing algorithms for processing Landsat satellite imagery to evaluate monthly vegetation and surface temperature relationships at metropolitan scales.

Inventoried plant diversity in parks from Baltimore, MD and greater Los Angeles, CA.

Developed new citizen science engagement platform for urban vegetation.

APPROACH

Field inventories
Mobile eddy covariance
Environmental sensor networks
Repeating satellite image analysis



ACHIEVEMENTS AND SIGNIFICANCE

Documented urban response to a major drought was associated with changes in vegetation and water use.

Identified air temperature cooling by urban vegetation primarily measured at night while surface temperature cooling primarily occurs during the day throughout southern California.

Engaged more than 1000 citizen scientists and 25 community groups in southern California.

Identified park biodiversity and user desires

PROJECT A3-1:
VEGETATION, BIODIVERSITY, ECOSYSTEM FUNCTIONING RELATIONSHIPS AND GREEN INFRASTRUCTURE

National Science Foundation

PRODUCTS

- Jenerette GD. 2018. Ecological contributions to human health in cities. Landscape Ecology 33:1655-1668
- Tayyebi A and GD Jenerette. 2018. Assessing diel urban climate dynamics using land surface temperature harmonization model. International Journal of Remote Sensing 39:3010-3028
- Swan, C. M., Johnson, A., Nowak, D. (2017). Differential organization of taxonomic and functional diversity in an urban woody plant metacommunity. Applied Vegetation Science, 20(1), 7-11.
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- Johnson, A., Borowy, D., Swan, C. M. (2017). Land use history and seed dispersal drive divergent plant community assembly patterns in urban vacant lots. Journal of Animal Ecology.
- Jenerette GD, LW Clarke, ML Avolio, DE Pataki, TW Gillespie, S Pincetl, J McFadden, D Nowak, L Hutyra, M McHale, and M Alonzo. 2016. Climate tolerances and trait choices shape continental patterns of urban tree biodiversity. Global Ecology and Biogeography 25:1367-1376
- Crum SM and GD Jenerette. 2017. Vertical and horizontal micrometeorological variation among urban land covers. Journal of Applied Meteorology and Climatology 56:2531-2543.
- Crum SM, S Shiflett, and GD Jenerette. 2017. Vegetation and the moderation of urban microclimates. Journal of Environmental Management 200:295-303
- Liang LL, RG Anderson, SA Shiflett, and GD Jenerette. 2017. Urban outdoor water use and response to drought assessed through mobile energy balance and vegetation greenness measurements. Environmental Research Letters 084007

PROJECT TEAM

- Darrel Jenerette, Professor, University of California Riverside
- Peter Ibsen, Graduate Student, University of California Riverside
- Julie Ripplinger, Postdoctoral Researcher, University of California Riverside
- Dion Kucera, Graduate Students, University of California Riverside
- Chris Swan, Professor, University of Maryland Baltimore County
- Dorothy Borowy, Graduate Students, University of Maryland Baltimore County
- Tom Meixner, Professor, University of Arizona
- Anthony Luketich, Graduate Student, University of Arizona
- Mary Santelman, Professor, Oregon State University
- Michelle Talal, Graduate Student, Oregon State University
- Shirley Papuga, Associate Professor, Wayne State University

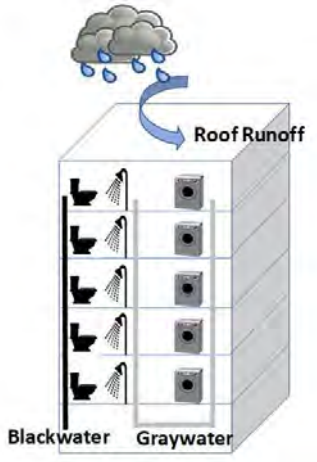
PROJECT B1-1a:
WATER MANAGEMENT SOLUTIONS TO ENAHNCE CAPACITY FOR USE OF ALTERNATE WATER SOURCES

National Science Foundation

MOTIVATION AND OBJECTIVES

Assess benefits and consequences of various scales (building to neighborhood) and configurations of water management solutions:

- Use of alternate water sources (graywater, roof runoff, wastewater, stormwater)
- Separate supply of non-potable water
- Impact of development patterns



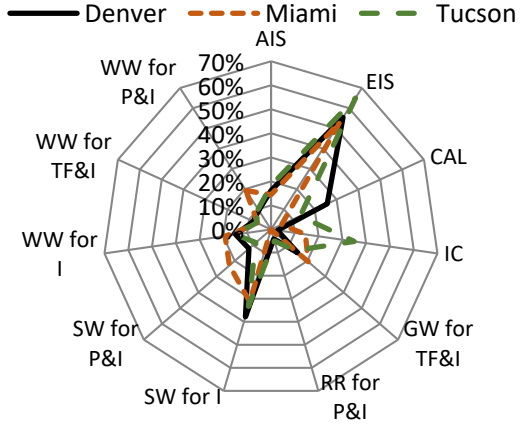
PROGRESS

- Assessed centralized and decentralized strategies for separate supply of potable water via enhanced decision support framework
- Assessed tradeoffs between cost and demand reduction potential in Miami, Tucson, and Denver
- Conducting national scale study to assess water conservation and reuse strategy efficacy
- Assessing impact of changes in climate, land use and population on efficacy of water conservation and reuse strategies.
- Assessing co-benefits of water conservation and reuse strategies across regions

APPROACH

- Enhance Integrated Urban Water Model for application in UWIN Study Cities (Denver, CO, Miami, FL and Tucson, AZ)

ACHIEVEMENTS AND SIGNIFICANCE



Frequency of strategies in optimal solutions

Source Waters
- GW: graywater
- WW: wastewater
- SW: stormwater

End Uses
- TF: toilet flushing
- P: potable
- I: irrigation

Conservation
- AIS: advanced irrigation system
- EIS: efficient irrigation system
- IC: indoor conservation
- CAL: climate appropriate landscape

PROJECT B1-1a:
WATER MANAGEMENT SOLUTIONS TO ENAHNCE CAPACITY FOR USE OF ALTERNATE WATER SOURCES

PRODUCTS

- Neale, M.R.,Sharvelle, S., Arabi, M., Goemans, C. (2020) Assessing Tradeoffs for Urban Water Conservation and Fit for Purpose Water, Journal of Hydrology, accepted with revision, Status = Accepted; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Lacky, Katy, S. Sharkey, S. Sharvelle, P. Kehoe, T. Chang (2020) Decentralized Water Reuse: Implementing and Regulating Onsite Non-Potable Water Systems, Journal of Sustainable Water in the Built Environment, 6(1):0251901 6(1):02519001. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Luthy, R. G., Sharvelle, S. E., Dillon, P. (2019) Urban Stormwater for Enhancing Water Supply *Environmental Science and Technology,* 53:10. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Daigger, G. T., Sharvelle, S. E., Arabi, M., Love, N. G. (2019). Progress and Promise: Transitioning to the One Water/Resource Recovery Integrated Urban Water Management Systems. *Journal of Environmental Engineering*, 145(10):04019062. Status = Published; Acknowledgement of Federal Support = No; Peer Reviewed = Yes.
- Cole, J., Sharvelle, S., Grigg, N. S., Pivo, G., Haukaas, J. (2018). Collaborative, Risk-Informed, Triple Bottom Line, Multi-Criteria Decision Analysis Planning Framework for Integrated Urban Water Management. *Water, 10*(12), 1722. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Neale, M., Sharvelle, S., Arabi, M. (2019) "Cost-benefit evaluation of water conservation and reuse strategies using the Integrated Urban Water Model for three U.S. cities", Hydrology Days, Fort Collins, CO. Status = published, acknowledgment of federal support = no, peer reviewed = no.
- Sharvelle, S. (2019) "Fostering Fit for Purpose Use of Alternate Water Sources via Health Risk Based Treatment Targets", Water Now Alliance, Austin, TX. Status = published, acknowledgement of federal support = no, peer reviewed = no
- Sharvelle, S., R. Luthy, P. Dillon (2019) "Urban Stormwater to Enhance Water Supply", Groundwater Protection Council, Oklahoma City, OK. Status = published, acknowledgement of federal support = yes, peer reviewed = no
- Alja'fari, J., Sharvelle, S., Crall, A., Newman, G. (2019) "Off the Roof: A Citizen Science Project to Measure the Microbial Characteristics of Roof Runoff", Hydrology Days, Fort Collins, CO. Status = published, acknowledgment of federal support = no, peer reviewed = no.
- Neale, M., Sharvelle, S., Dozier, A., Arabi, M. (2018) "Identifying Optimal Water Conservation and Reuse Strategies Using an Urban Water Demand Model for a Selection of U.S. Cities with Distinct Climatic Conditions and Land Cover Characteristics," 9th International Congress on Environmental Modelling and Software Fort Collins, CO. Status = published, acknowledgement of federal support = no, peer reviewed = no
- Batista, G, Sharvelle, S., Dozier, A., Arabi, M., (2018) "Evaluation of Water Conservation Strategies Using the Integrated Urban Water Model in Sao Paulo, Brazil," 9th International Congress on Environmental Modelling and Software, Fort Collins, CO. . Status = published, acknowledgement of federal support = no, peer reviewed = no
- Sharvelle, S., A. Dozier, M. Arabi, B. Reichel (2017). A Geospatially-Enabled Web Tool for Urban Water Demand Forecasting and Assessment of Alternative Urban Water Management Strategies. Environmental Modelling and Software, 97:213-228. Status = Published; Acknowledgement of Federal Support = Yes; Peer Reviewed = Yes.
- Sharvelle, S., N. Ashbolt, E. Clerico, R. Holquist, H. Leverenz and A. Olivieri (2017) Risk Based Framework for the Development of Public Health Guidance for Decentralized Non-potable Water Systems, WEFTEC 2017, Chicago, IL. Status = published, acknowledgement of federal support = no, peer reviewed = no.
- Sharvelle, S., N. Ashbolt, E. Clerico, R. Holquist, H. Leverenz and A. Olivieri (2017) Risk Based Framework for the Development of Public Health Guidance for Decentralized Non-potable Water Systems, International Water Association Conference on Water Reclamation and Reuse, Longbeach, CA. Status = published, acknowledgement of federal support = no, peer reviewed = no.
- Sharvelle, S. (2017) Developing Guidelines for Performance of Decentralized Non-Potable Water Systems, WE&RF Onsite Systems Workshop, Los Angeles, CA. Status = published, acknowledgement of federal support = no, peer reviewed = no.
- Neale, M., A. Dozier, S. Sharvelle, M. Arabi (2018) Identifying Optimal Water Conservation and Reuse Strategies Using and Urban Water Demand Model for a Selection of US Cities with Distinct Climatic Conditions and Land Cover Characteristics, Hydrology Days, Fort Collins, CO. Status = published, acknowledgement of federal support = yes, peer reviewed = no.
- Sharvelle, S., M. Arabi, M. Sukop (2018) The National Science Foundation's Research Networks Program, Resilient Utility Coalition – Operationalizing Resilience Summit, Miami, FL. Status = published, acknowledgement of federal support = yes, peer reviewed = no.

PROJECT TEAM

- Sybil Sharvelle, Associate Professor, Colorado State University
- Andre Dozier, Post-doctoral Associate, Colorado State University
- Jeanne Cole, PhD candidate, Colorado State University
- Michael Neale, MS student, Colorado State University

PROJECT B1-1b:
ASSESSMENT OF URBAN INFRASTRUCTURE RESILIENCE

National Science Foundation

MOTIVATION AND OBJECTIVES

Evaluate long-term resilience of urban water infrastructure

- Examine technological and infrastructure solutions to enhance urban water infrastructure resilience in both demand and supply sides
- Develop integrated simulation models of urban water infrastructure system resilience (Fig 1)

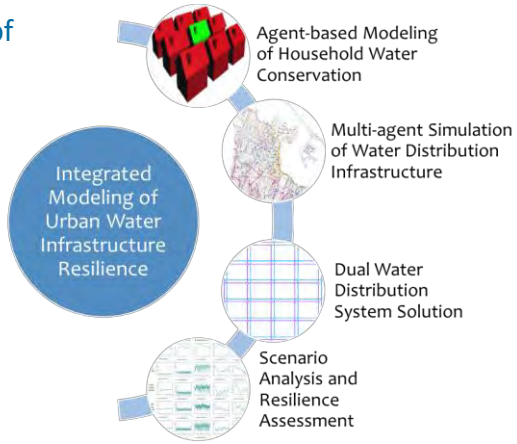


Fig 1. Project Overview

PROGRESS

- Analyzed households behavior related to adoption of water conservation technologies in the City of Miami Beach using agent-based modeling (Fig 3)
- Examined long-term resilience behavior of urban water distribution networks to population changes, aging infrastructure, and funding constraints
- Compared long-term performance and life-cycle costs of dual and singular water distribution systems for the City of Fort Collins (Fig 4)

Fig 3. Agent-based Model of Water Conservation

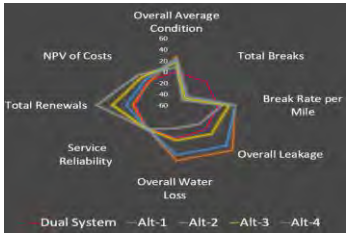


Fig 4. Multivariate Comparison of Dual vs. Singular

APPROACH

- Propose a complex systems resilience framework for assessment of water infrastructure resilience (Fig 2)
- Develop Agent-based and Multi-agent simulation models to understand underlying mechanisms of water infrastructure resilience

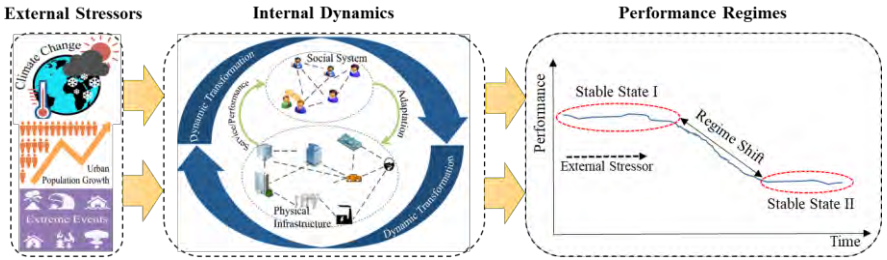


Fig 2. Complex Systems Resilience Framework

ACHIEVEMENTS AND SIGNIFICANCE

- Theoretical Achievement: Built a complex system-based framework for infrastructure resilience through a better understanding of internal dynamics, performance regimes, and tipping points.
- Computational Achievement: Developed a novel agent-based model capturing adaptive mechanisms, such as peer effect and innovation diffusion, in households water conservation; And created a multi-agent model simulating various performance measures (e.g., average condition, service reliability, leakage and breakage) of water distribution networks over a 100-year horizon
- Practical Achievement: Identified infrastructure renewal strategies, water pricing structures, and other decision factors leading towards a resilient and sustainable water infrastructure system

PROJECT B1-1b:
ASSESSMENT OF URBAN INFRASTRUCTURE RESILIENCE

PRODUCTS

Journals Papers

- Rasoulkhani, K. and Mostafavi, A., 2018. Resilience as an emergent property of human-infrastructure dynamics: A multi-agent simulation model for characterizing regime shifts and tipping point behaviors in infrastructure systems. PloS one, 13(11), e0207674.K
- Rasoulkhani, K., Logasa, B., Presa Reyes, M. and Mostafavi, A., 2018. Understanding Fundamental Phenomena Affecting the Water Conservation Technology Adoption of Residential Consumers Using Agent-Based Modeling. Water, 10(8), p.993.Conference

Presentations/Papers

- K Rasoulkhani, MP Reyes, A Mostafavi (2017). Emergence of Resilience from Infrastructure Dynamics: A Simulation Framework for Theory Building. International Workshop on Computing for Civil Engineering (IWCCE 2017). Seattle.
- K Rasoulkhani, BN Logasa, MP Reyes, A Mostafavi (2017). Agent-based modeling framework for simulation of complex adaptive mechanisms underlying household water conservation technology adoption. Winter Simulation Conference (WSC 2017). Las Vegas.
- K Rasoulkhani, BN Logasa, MP Reyes, A Mostafavi (2017). From Factors to Actors: Uncovering Fundamental Mechanisms Underlying Adoption of Residential Water Conservation Technology Using Agent-based Modeling. International Workshop on Computing for Civil Engineering (IWCCE 2017). Seattle.
- K Rasoulkhani, A Mostafavi (2018). Long-term performance and life-cycle cost assessment of dual vs. singular water distribution infrastructure systems. ASCE Construction Research Congress (CRC 2018). New Orleans.

PROJECT TEAM

- Ali Mostafavi, PhD - Principal Investigator; Assistant Professor, Zachary Department of Civil Engineering, Texas A&M University
- Sybil Sharvelle, PhD - Co-Principal Investigator; Associate Professor, Civil and Environmental Engineering, Colorado State University
- Kambiz Rasoulkhani – Research Scientist; PhD Candidate, Zachary Department of Civil Engineering, Texas A&M University

PROJECT B1-2:
SPATIALLY-AND-TEMPORALLY-INFORMED LIFE-CYCLE ASSESSMENT OF URBAN WATER SYSTEMS

National Science Foundation

MOTIVATION AND OBJECTIVES

- To support a shift to water- and energy-efficient communities.
- To provide model and decision-support tool for evaluating water systems and innovations under current and future conditions using life-cycle assessment (LCA).
- To characterize existing centralized urban water infrastructure in UWIN case-study cities (Denver, Tucson, Miami) compared to future water supply scenarios on the basis of life-cycle energy and environmental performance.

PROGRESS

- Quantified energy demand and greenhouse gas emissions from water consumption trends in urban water systems in Denver, Tucson, and Washington, DC.
- Quantified electricity demand and greenhouse gas emissions from wastewater generation in Denver, Tucson, and Washington, DC.
- Quantified electricity demand and greenhouse gas emissions from several water saving technologies in Denver, Tucson, and Miami.

APPROACH

In case-study cities, analyze urban water systems using LCA.

Quantify
INPUTS
(materials, energy, water, etc)

Estimate
OUTPUTS
(products, byproducts, emissions, wastes, etc)

To :

Target improvements Benchmark utility performance Educate consumers
Set design goals Evaluate technology performance Identify tradeoffs
Prioritize investments Enable more sustainable solutions Inform planning & policy

ACHIEVEMENTS AND SIGNIFICANCE

- Quantified the differences in life-cycle energy demand and greenhouse gas emissions between water systems in three major cities.
- Found that water savings and reduction in energy use and greenhouse gas emissions are possible even with population growth.
- Quantified the differences in life-cycle energy demand and greenhouse gas emissions between wastewater systems in three major cities.
- Significant differences found, depending on wastewater technologies employed and local electricity mix.

PROJECT B1-2:
SPATIALLY-AND-TEMPORALLY-INFORMED LIFE-CYCLE ASSESSMENT OF URBAN WATER SYSTEMS

PRODUCTS

Journals or Juried Conference Papers

Gursel, A. P., Chaudron, C., Kavvada, I. and Horvath, A. (2020), "Reduction in Urban Water Use Leads to Less Wastewater and Fewer Emissions: Analysis of Three Representative U.S. Cities." Environmental Research Letters, https://doi.org/10.1088/1748-9326/ab8dd8

Conference Presentations/Papers

Horvath, A., Gursel, A. P., Chaudron, C. and Kavvada, I. (2020), "An Integrated Model of Urban Water-Wastewater-Stormwater-Energy Systems." EGU General Assembly 2020, May 4-8, 2020, Vienna (Austria)

Technologies or Techniques:

Life-cycle assessment (LCA) model of energy demand and greenhouse gas emissions from water treatment, wastewater treatment, and anaerobic digestion in U.S. cities.

Websites:

WEST/WWEST decision support tools: west.berkeley.eduo.

PROJECT TEAM

- Arpad Horvath, UC Berkeley, Lead
- Camille Chaudron, UC Berkeley
- Aysegul Petek Gursel, UC Berkeley

PROJECT B2-1:
COMPARATIVE IMPACT OF GREEN INFRASTRUCTURE ACROSS URBAN SYSTEMS

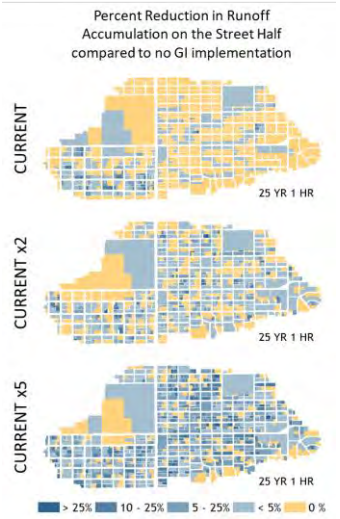
National Science Foundation

MOTIVATION AND OBJECTIVES

We are seeking to understand how GI influences hydrologic response and water quality response across cities

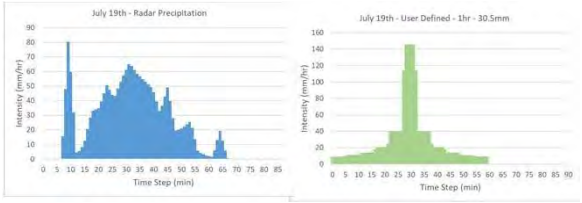
PROGRESS

1. Simulated runoff under various GI scenarios
2. Work resulted in determining GI could significantly alter runoff volumes and peaks
3. Current level of implementation does not have a significant effect



APPROACH

1. Further development of KINEROS2 urban modelling capability
   A. Build data sets
   B. Use LIDAR and land cover data to develop initial model
   C. Develop GI scenarios for basin
   D. Analyze scenarios for impact on water quantity and quality
2. Collaborate broadly across UWIN
   A. Link KINEROS2 to HEC modelling of flood inundation
   B. Use Radar developed rainfall



ACHIEVEMENTS AND SIGNIFICANCE

1. Successfully showed that maintenance practice can have a significant impact on infiltrations rates and thus function of Green Infrastructure
2. GI can generally support vegetation growth with no irrigation to supplement
3. GI has significantly higher water holding capacity and hydraulic conductivity than surrounding soils
4. In stream infiltration is a significant loss process in urban areas.

PROJECT B2-1:
COMPARATIVE IMPACT OF GREEN INFRASTRUCTURE ACROSS URBAN SYSTEMS

PRODUCTS

- Guertin, D. Phillip, Yoganand Korgaonkar, I. Shea Burns, Carl Unkrich, David C. Goodrich, and William Kepner. 2016. Using AGWA and the KINEROS2 Model to Model Green Infrastructure in Two Typical Residential Lots in Prescott, AZ. Presented at: 2016 AWRA Summer Specialty Conference: GIS and Water Resources IX, Sacramento, CA, July 11-13, 2016.
- Gupta, Neha - Comparison of Runoff Data to Assess Impact of Stormwater Green Infrastructure, Presentation at El Dia Del Agua y la Atmosfera, Department of Hydrology and Atmospheric Sciences, Tucson AZ, University of Arizona April 9,2018.
- Korgaonkar, Y., Guertin, D.P., Goodrich, D.C., Unkrich, C., Kepner, W., and Burns, I.S. (2018). Modeling Urban Hydrology and Green Infrastructure using the AGWA Urban Tool and the KINEROS2 Model. Submitted to Frontiers in Built Environment.
- Meixner, T., Papuga, S.A., Luketich, A.M., Rockhill, T., Gallo, E.L., Anderson, J., Salgado, L., Pope, K., Gupta, N., Korgaonkar, Y. and Guertin, D.P., 2017, December. Green Infrastructure Increases Biogeochemical Responsiveness, Vegetation Growth and Decreases Runoff in a Semi-Arid City, Tucson, AZ, USA. In AGU Fall Meeting Abstracts.
- Meixner, Thomas— Green Stormwater Infrastructure Increases Infiltration, Soil Carbon and Biogeochemical Response, 2018 – Arizona Hydrological Society Annual Symposium, Flagstaff AZ, September 7, 2017.
- Anderson, Jack - Bioswales: Benefit or Burden?, Presentation at El Dia Del Agua y la Atmosfera, Department of Hydrology and Atmospheric Sciences, Tucson AZ, University of Arizona April 9,2018.
- Rockhill, Tyler, Influence of Soil Physical and Chemical Properties on Soil Co2 Flux in Semi-Arid Green Stormwater Infrastructure, MS in Hydrology, University of Arizona, December 2017, pp. 63.https://arizona.openrepository.com/handle/10150/626391
- Swartz, Samantha - Evaluating Rainwater-Harvesting Basin Curb-Cuts: How Volunteer Maintenance Impacts Infiltration Rates. Presentation at El Dia Del Agua y la Atmosfera, Department of Hydrology and Atmospheric Sciences, Tucson AZ, University of Arizona April 9,2018.

PROJECT TEAM

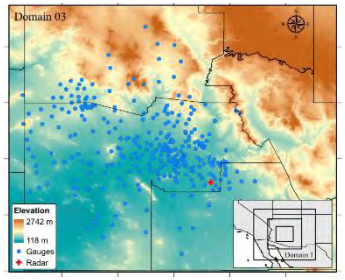
- Thomas Meixner, Professor University of Arizona
- Phil Guertin, Professor, University of Arizona
- Yoganand Korgaonkar, Grad Assistant, University of Arizona
- Neha Gupta, Grad Assistant, University of Arizona
- Jack Anderson, Grad Assistant, University of Arizona
- Tyler Rockhill, Grad Assistant, University of Arizona
- Samantha Swartz, Grad Assistant, University of Arizona
- Adriana Arcelay, Grad Assistant, University of Arizona

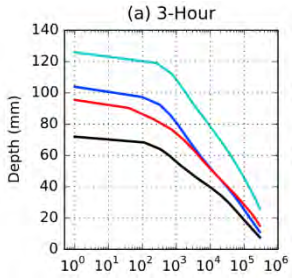
PROJECT B2-2a:
FLOOD HYDROLOGY AND RAINFALL FREQUENCY

National Science Foundation

MOTIVATION AND OBJECTIVES

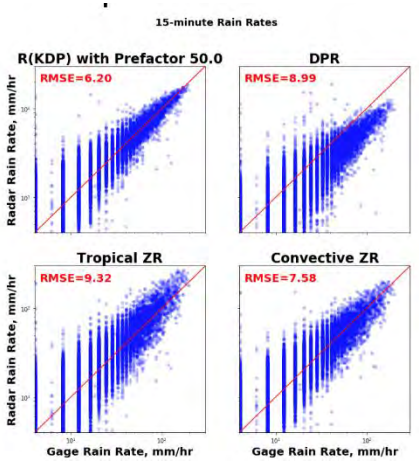
- Demonstrate a predictive understanding of urban flood hydrology
- Characterize the climatology of flood-producing storm systems in urban regions
- Develop procedures for rainfall and flood frequency analysis that can serve as the foundation for assessing urban flood hazards.





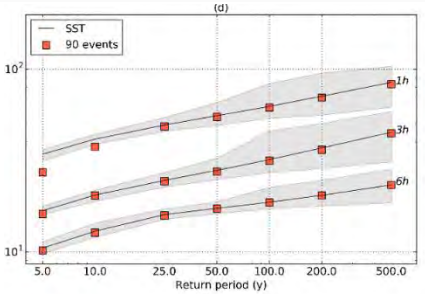
PROGRESS

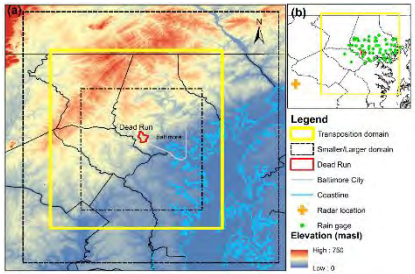
- Development of 20 year (2000 – 2019) high-resolution rainfall data set for the Baltimore – Washington metropolitan region.
- Significant advance in polarimetric rainfall algorithm for extreme rainfall in urban environments.
- Analyses of extreme rainfall and flooding in urban environments – Ellicott City storms of 2016 and 2018. and major flood episodes in Houston.



APPROACH

- Storm Catalogs of radar rainfall fields
- Stochastic Storm Transposition (SST) methods for rainfall frequency analysis
- Hydroclimatological analyses using the Weather Research and Forecasting Model





ACHIEVEMENTS AND SIGNIFICANCE

- 20 year rainfall data set for Baltimore – Washington provides capability for assessing changes in extreme, short-term rainfall rates.
- New polarimetric rainfall algorithm provides significant advances in monitoring extreme rainfall rates at short durations and small spatial scales – a critical requirement for analyses of urban flooding.

PROJECT B2-2a:
FLOOD HYDROLOGY AND RAINFALL FREQUENCY

PRODUCTS

Yang, Long, J A. Smith, M. L. Baeck and E. Morin, Flash flooding in arid/semi-arid regions: climatological analyses of flood-producing storms in central Arizona during the North American Monsoon, J. Hydrometeorology, 20, 1449 – 1471, DOI: 10.1175/JHM-D-19-0016.1, 2019.

Yang, Long, J. A. Smith and D. Niyogi, Urban impacts on extreme monsoon rainfall and flooding in complex terrain, Geophysical Research Letters, 46(11), 5918 – 5927, 2019.

Yang, Yan, Long Yang, J. A. Smith, M. L. Baeck and G. Ni, Regional impacts of urban irrigation on surface heat fluxes and rainfall in central Arizona, J. Geophysical Research, 124(2), pp. 6393 - 6410, 2019.

Cristiano, E., ten Veldhuis, M.-C., Wright, D. B., Smith, J. A., & van de Giesen, N. (2019). The influence of rainfall and catchment critical scales on urban hydrological response sensitivity. Water Resources Research, 55 (4),3375 – 3390, https://doi.org/10.1029/2018WR024143, 2019.

PROJECT TEAM

- Jim Smith
- Mary Lynn Baeck
- Yibng Su
- Molly Chaney

PROJECT B2-2b:
HYDROLOGY AND HYDRAULICS OF URBAN FLOODPLAINS

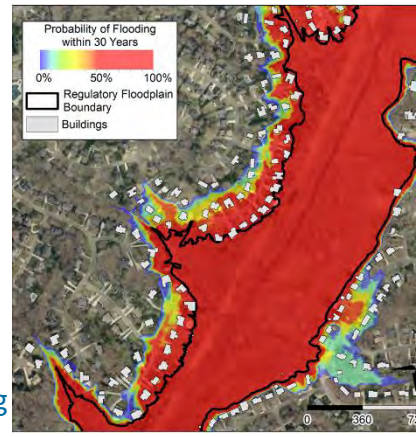
National Science Foundation

MOTIVATION AND OBJECTIVES

- Addresses interactions between flood flows and urban channels, floodplains and riparian zones as influenced by green infrastructure and efforts to mitigate impacts of urban development on flood response and other environmental consequences.
- Overarching goal is to use hydraulic analysis of urban floodplains to examine how integrated floodplain networks and sustainable urban drainage systems can be strategically designed and positioned to simultaneously enhance flood resilience, moderate temperatures and improve human comfort, and support biodiversity.

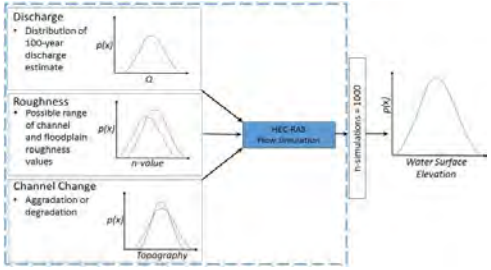
PROGRESS

- Implemented novel frameworks for conducting uncertainty analysis of floodplain hydraulics to create probabilistic flood inundation maps.
- Quantified and compared the level of uncertainty around inundation probability in two hydro-climatically distinct regions.
- Constructed high-resolution topographic models of several urban stream restoration sites using structure from motion and used in 2D hydraulic modeling in HEC-RAS to observe changes to the hydraulics of the channel.



APPROACH

- Uncertainty around model input and parameters are statistically quantified and sampled in a Monte-Carlo framework to simulate floodplain hydraulics.
- Used photography from UAV flights to create high resolution DEMs using Structure from Motion
- Compared the 2D hydraulic modeling outcomes of historical versus current channel morphology in HEC-RAS.



ACHIEVEMENTS AND SIGNIFICANCE

- Probabilistic flood inundation maps helped elucidate how uncertainty in traditional flood hazard estimates is spatially distributed across the landscape. Practical approaches accurately simulate the uncertainty in inundation extents estimated by Monte-Carlo simulations.
- Probabilistic flood inundation maps provide an alternative method of hazard depiction that incorporate uncertainty and serve as a tool for floodplain management.
- Examining the evolution of simulated hydraulic modeling of flood behavior in pre- and post-restoration and current channel morphology provides insight into how successful urban restoration projects are in the long run and how successful the restoration projects were in their stated goals.

PROJECT B2-2b:
HYDROLOGY AND HYDRAULICS OF URBAN FLOODPLAINS

PRODUCTS

- Lee, G., and A.J. Miller, 2017. Monitoring Urban Stream Restoration Efforts in Relation to Flood Behavior Along Minebank Run, Towson, MD. Abstract H31I-1629, Fall 2017 Annual Meeting, AGU, New Orleans, LA, 11-15 Dec.
- Miller, A.J., G. Lee, B.P. Bledsoe, and T. Stephens, 2017. Mitigation of Flood Hazards Through Modification of Urban Channels And Floodplains. Abstract H31I-1630, Fall 2017 Annual Meeting, AGU, New Orleans, LA, 11-15 Dec.
- Stephens, T., B.P. Bledsoe, A.J. Miller, G. Lee, 2017. Mapping flood hazards under uncertainty through probabilistic flood inundation maps. Abstract H31I-1633, Fall 2017 Annual Meeting, AGU, New Orleans, LA, 11-15 Dec.

PROJECT TEAM

- Brian P. Bledsoe, Professor, University of Georgia
- Tim Stephens, PhD student, University of Georgia
- Andrew J. Miller, Professor, UMBC
- Gina Lee, PhD student, UMBC

PROJECT B3-1:
FLOOD RISK TO ASSETS AND SOCIOECONOMIC SECTORS IN A CHANGING WORLD: PREVENTION, ADAPTATION AND MITIGATION STRATEGIES

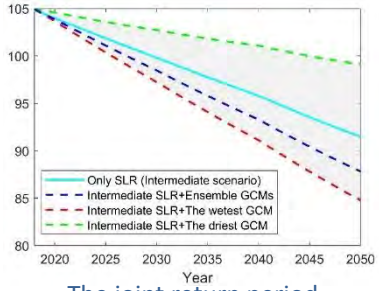
National Science Foundation

MOTIVATION AND OBJECTIVES

- Develop a coherent statistical model for coastal flood frequency analysis under nonstationary sea level conditions and corroborate the model for long term tidal stations along the Contiguous U.S. (CONUS) coast.
- Estimate the chronic and acute coastal flood risks to assets and communities in Southeast Florida.
- Evaluate the potential increase in flood risks due compound coastal riverine flooding events across the CONUS coast.
- Evaluate adaptation pathways to mitigating flood risks in NYC region under climate including SRL and future precipitation scenarios.

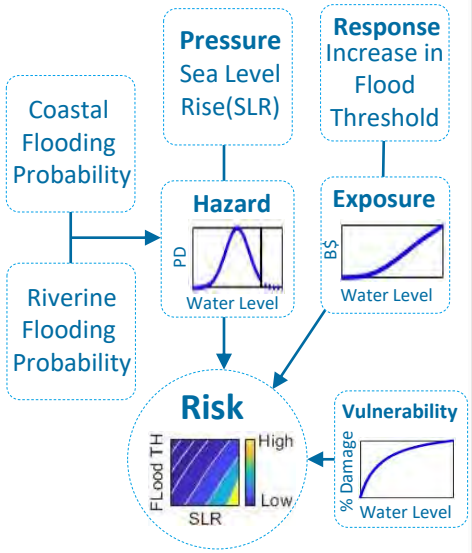
PROGRESS

- A mixture probability model was developed to simultaneously assess the frequency of acute and chronic coastal flooding under nonstationary sea level conditions for 68 tidal stations in U.S.
- The application of the mixture model in a risk framework was demonstrated for Miami-Dade County to assess impacts of SLR on chronic and acute coastal flooding.
- A bivariate flood risk assessment framework was developed that accounts for compound coastal riverine flooding events with consideration of impacts of climate change.



The joint return period (JRP) of compound major coastal riverine flooding in Washington D.C.

- The frequency of coastal flooding is estimated using a nonstationary mixture Normal-Generalized Pareto distribution.
- The HAZUS-MH model is used to estimate damages to buildings.
- Copula function is used to model the dependence structure of extreme sea water level and river extreme river depth regardless of their marginal distributions.



ACHIEVEMENTS AND SIGNIFICANCE

- Pacific coast regions should expect the highest major flood frequency amplification. Highest frequency amplification in minor flooding is expected along the Gulf and northeast Atlantic coasts.
- Under current sea-level conditions, expected annual damages are dominated by the exposure to occasional extreme events in Miami-Dade County. However, the expected damages from repetitive minor flooding will exceed those from extreme floods under future sea-level scenarios.
- Bivariate flood risk assessment in Potomac River estuary, Washington DC, indicates that the joint return period of coastal riverine flooding could be lower when sea level rise and nonstationarity of river discharge are considered. However, the impact of SLR was found to be more important.

PROJECT B3-1:
FLOOD RISK TO ASSETS AND SOCIOECONOMIC SECTORS IN A CHANGING WORLD: PREVENTION, ADAPTATION AND MITIGATION STRATEGIES

PRODUCTS

Journals Papers:

- Ghanbari, M., Arabi, M., Obeysekera, J., & Sweet, W. (2019). A coherent statistical model for coastal flood frequency analysis under nonstationary sea level conditions. *Earth's Future*, 7, 162–177. https://doi.org/10.1029/2018EF001089.
- Ghanbari, M., Arabi, M., and Obeysekera, J. (2020). Chronic and acute coastal flood risks to assets and communities in southeast Florida. *Journal of Water Resources Planning and Management*, 2020, 146(7): 04020049, DOI: 10.1061/(ASCE) WR.1943-5452.0001245.
- Ghanbari, M., Arabi, M., Kao, Shih-Chieh. (2020). A probabilistic approach for the assessment of compound coastal riverine flooding risks under climate change. *Water Resources Research*, in review.

Conference Presentations:

- Ghanbari, M., Arabi, M. Kao, S.-C. (2020). Increasing Risks of Compound Flooding under Climate Change and Sea Level Rise Scenarios. *Hydrology Days 2020*, April 13 – 15, Fort Collins, CO.
- Ghanbari, M., Arabi, M. (2019). Impacts of Sea Level Rise on Compound Fluvial and Coastal Flooding. *American Geophysical Union Fall Meeting 2019*, December 9-13, San Francisco, CA.
- Ghanbari, M., Arabi, M., Obeysekera, J., & Sweet, W. (2019). A coherent statistical model for coastal flood frequency analysis under nonstationary sea level conditions, *EWRI World Environmental & Water Resource Congress*, 20-23 May 2019, Pittsburgh, Pennsylvania.
- Ghanbari, M., Arabi, M., Obeysekera, J., & Sweet, W. (2019). A nonstationary statistical model for coastal flood frequency analysis, *AGU Hydrology Days*, 27-29 March 2019, Fort Collins, Colorado.
- Ghanbari, M., Arabi, M., Obeysekera, J., & Sweet, W. (2018). Coastal flooding risks on the rise, *AGU Fall Meeting 2018*, 10-14 December 2018, Washington D.C.
- Ghanbari, M., Arabi, M., Obeysekera, J., & Sweet, W. (2018). Risk to assets and communities from coastal flooding: Quantifying the effect of sea level rise and flood adaptation strategies, *International Congress on Environmental Modelling and Software*, 24-28 June 2018, Fort Collins, Colorado.
- Ghanbari, M., Arabi, M. (2018). Risk to assets and communities from coastal flooding: Quantifying the effect of sea level rise and flood adaptation strategies, *AGU Hydrology Days*, 19-21 March 2018, Fort Collins, Colorado.
- Ghanbari, M., Arabi, M. (2017). Current and future flood losses in southeast Florida, *EWRI World Environmental & Water Resource Congress*, 22-25 May 2017, Sacramento, California.

PROJECT TEAM

- Mazdak Arabi, Professor - Colorado State University
- Mahshid Ghanbari, PhD Student, Colorado State University
- Jayantha Obeysekera, Research Scientist, Florida International University
- William Sweet, Research Scientist, NOAA

PROJECT B4-1:
GREYWATER REUSE: PATHOGEN REMOVAL BY A MEMBRANE BIOREACTOR

MOTIVATION AND OBJECTIVES

Motivation: This research project will provide important information about the treatability of a variable greywater from dorm building on the campus of Howard University. Quantitative data on the effluent quality of treated greywater will be collected and analyzed, as will the log reduction of pathogens in the effluent.

Objectives:

- Determine the operational parameters and evaluate pathogen removal efficiency of a small membrane bioreactor (MBR) designed to treat grey water for reuse as irrigation water for urban gardens.

PROGRESS

- Design of greywater collection system. Two 250-gallon storage tank will be placed on the rooftop as source water supply to the MBR system. Each storage tank is equipped with air mixer to avoid septic conditions.
- Collaboration with Suez on integrated membrane bioreactor setup. Suez will supply Lab-scale ZeeWeed 500 membranes for this project.
- Development of testing protocols for model bacteria and virus.

APPROACH

- Set up greywater collection system for the MBR system. A Membrane Bioreactor (MBR) will be operated on the rooftop using commercial microfiltration membranes.
- Water parameters of the influent and effluent will be tested continuously, and removal efficiency will be evaluated.
- Pathogen surrogates (e.g. bacteria phage MS-2, *E-coli* k12) will be added into MBR influent individually and the concentrations will be tested.

ACHIEVEMENTS AND SIGNIFICANCE

•Established greywater collection, transportation, and storage plans. Grey water will be collected from three-dorm laundry rooms and mixed onsite every day. Model pathogens will be mixed into one tank to reach target concentration. The storage tank will be thoroughly disinfected between each set of pathogen experiment.

•Developed MBR testing system. We will install two lab scale MBR systems to compare the efficiencies in pathogen removal. Each system is supplied with fresh collected greywater. And water parameters will be tested continuously, and removal efficiency will be evaluated.

•Culture and testing protocols established for *E coli* and MS2

PROJECT B4-1:
GREYWATER REUSE: PATHOGEN REMOVAL BY A MEMBRANE BIOREACTOR

PRODUCTS

Papers:

Data sets:

A webpage is currently under development to routinely release project progress and major results to communities.
Routine conference calls with industrial collaborators will provide useful information to design and refresh membrane product.

Presentations:

PROJECT TEAM

- Dr. Kimberly Jones serves as the project lead. Dr. Fennell oversees the project plan, design, and implementation. Mr. Hamid Nazarlou, a PhD student, is in charging of constructing the filter systems and monitor the treatment processes.Mr. Binaya Paudel, a senior CEE student with 2 years of membrane treatment experience, will aid in data collection.

PROJECT C1-1:
UNDERSTANDING ADOPTION OF SUSTAINABLE URBAN WATER SOLUTIONS

National Science Foundation

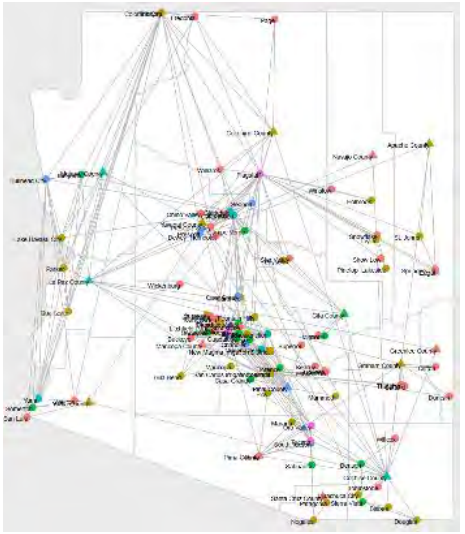
MOTIVATION AND OBJECTIVES

How do networks between organizations and local governments influence the adoption of water sustainability innovations?

Key questions about networks:
1) What network structures are most likely to promote learning of new water sustainability innovations?
2) What does a "typical" network look like among water organizations in the five UWIN regions?
3) How do these networks self-organize?
4) How do external factors, such as collaborative institutions, influence the structure of these networks?

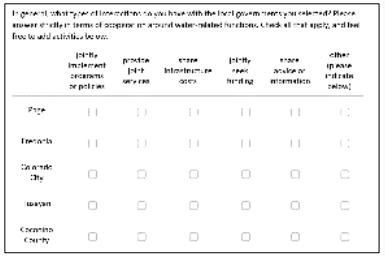
PROGRESS

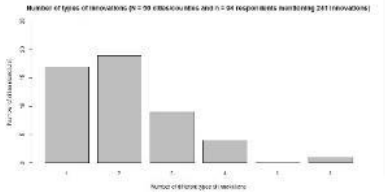
- Completed surveys of local water governments and water organizations in 5 UWIN regions.
- Networks analysis on local government and organizations completed.
- Paper published on related research and theories.
- Data analysis and papers underway.



APPROACH

- Sampling of local water organizations (public private, nonprofit) and identification of water professionals working in these organizations through archival research and by nominations of other water professionals.
- Survey of water organizations to measure network relationships as well as water sustainability practices.
- Statistical modeling of networks using network correlation and exponential random graph models.





ACHIEVEMENTS AND SIGNIFICANCE

- Local government innovation is related to intensity of collaboration with other local governments.
- Collaboration in turn is driven by a perception of having shred problems, and to some extent the innovativeness of other places.
- Results presented at major public management meetings including APPAM and PMRC.

Table 1: Effect of collaboration network on water sustainability innovations

	Perceived innovativeness (logit)	Program diversity (OLS)
Degree centrality	0.279 **	0.088 *
Betweenness centrality	-0.004 #	0.000
% collaborators using GI	-0.746	-0.146
Constant coeff.	-3.518	1.477
N	69	47
R^2 (OLS) / pseudo-R^2 (logit)	0.219	0.145

Note: Regression models estimated with robust standard errors; stars indicate significance of coefficients: # p<0.1, * p<0.05, ** p<0.01, *** p<0.001.

Table 2: ERG models of network structure

	NETWORK TYPE				
	jointly implement programs	provide joint services	share infrastructure costs	jointly seek funding	share advice or information
Shared problems	0.093	-0.540 **	0.235	0.863 ***	7.292 ***
Innovative alter	0.261	0.094	0.570 *	1.618 *	6.415 ***
Triadic closure	-0.029 ***	-0.323 ***	-0.087 ***	-0.141 ***	-0.180 ***

PROJECT C1-1:
UNDERSTANDING ADOPTION OF SUSTAINABLE URBAN WATER SOLUTIONS

LIST OF PRODUCTS

- Pivo, G, AD Henry, and L Berger, (2020) Essential Elements in Local Environmental Policy Change: Guide for the Perplexed, *Environmental Science & Policy* 106.
- Gomez-Fernandez, EL, 2020. PhD Dissertation: Three Essays on Urban Water Management and Innovative Outcomes.
- Berger, L, AD Henry and G Pivo, Integrated Water Management Recommendations in Practice, *Water Policy*, accepted and forthcoming.
- Bell, E., AD Henry and G Pivo, Assessing Sectoral Heterogeneity and Leadership in Urban Water Management, *Water Policy*, 2nd review.
- Berger, L, AD Henry and G Pivo, Current strategies & future pathways in assessing urban environmental sustainability, *Sustainable Cities and Societies*, in review.
- Berger, L, AD Henry and G Pivo, Nexus between municipal networks and practices for urban water sustainability, *Public Administration Review*, in review.
- Henry, AD, EL Gomez-Fernandez, G Pivo, November 2019. APPAM Annual Research Conference, Water Policy Innovations through Collaborative Networks
- Gomez-Fernandez EL, AD Henry, G Pivo, June 2019. Political Networks Conference. Collaboration in Urban Water Management in Arizona. Duke University.
- Henry, AD, EL Gomez-Fernandez, G Pivo, November 2018. APPAM Research Conference, Sustainability Innovations through Collaboration in Urban Water
- Henry, AD. EL Gomez-Fernandez, G Pivo, May 2018. Ann Public Mgt Rsch Conf, Network-Based Measurement of Functional Fragmentation in Gov Systems
- Henry, AD. EL Gomez-Fernandez, G Pivo, April 5-8, 2018. Midwest Political Science Conf. Analyzing Drivers of Water Innovation Adoption
- Gomez-Fernandez, EL, AD Henry, G Pivo, 2018. Southern Political Science Association, A Network Approach to Understanding Innovations in Urban Water Mgt
- Gomez-Fernandez, E.L., A.D. Henry, G. Pivo, & A. Sanderford, October 2017. ACSP Conference, Measuring Fragmentation of Water Governance in US Cities
- Bell, E., A.D. Henry & G. Pivo, November 2017. APPAM Annual Fall Research Conference, A Coding Frame to Link Policies and Beliefs.
- Henry, A.D., E.L. Gomez-Fernandez, & G. Pivo, November 2017. APPAM Annual Fall Research Conference, A Network Approach to Understanding Fragmentation and Sustainability in Local Governance.
- Henry, A.D., E.L. Gomez-Fernandez, & G. Pivo, March 2017. Intl Assoc. for Studies of the Commons. Investigating Polycentricity in Common Pool Resources.
- Henry, A.D., L. Berger, G. Pivo, May, 2018. Network Drivers of Local Water Sustainability Innovations. 2018 Public Management Research Conference, Singapore.
- Gomez-Fernandez E. Liliana, A. Henry, G. Pivo, August 2017. UWIN 2nd Annual Meeting, Influence of Governmental Fragmentation in Adoption of Sustainable Policies and Innovation in Urban Water Management.
- Henry, A., E. L. Gomez-Fernandez, G. Pivo. February 2018. APPAM, May 2018. Network-Based Measurement of Functional Fragmentation in Governance Systems: An Application to Urban Water Management

PROJECT TEAM

Gary Pivo, Professor, College of Planning and Landscape Architecture
Adam Douglas Henry, Associate Professor, School of Government and Public Policy
Edna Liliana Gomez Fernandez, PhD candidate, School of Government and Public Policy
Lena Berger, Post-Doctoral Research Association, School of Government and Public Policy

THE UNIVERSITY OF ARIZONA

PROJECT C2-1:
USING DYNAMIC INFORMATION ACCELERATION (CHOICEFLOW) TO UNDERSTAND AND FORECAST HOMEOWNER ADOPTION OF GREYWATER TECHNOLOGIES

National Science Foundation

MOTIVATION AND OBJECTIVES

- One of the greatest challenges in forecasting homeowner adoption is accurately predicting demand for products and technologies that do not currently exist or that people are not knowledgeable about
- "Choiceflow" allows for laboratory-based study of choice behavior in realistic, user-designed, environments where individuals gather information from different media, learn, and make decisions based on those media
- To understand and predict adoption behaviors including:
  - Processes people prefer for learning about technologies (e.g., news, social media, technical reports); and
  - The choices that will be made, conditional on learning path.

PROGRESS

Tasks completed

- Choiceflow software design
- Sample frame development
- Data collection across 5 UWIN regions, 1500 responses
- Second round of data collection underway

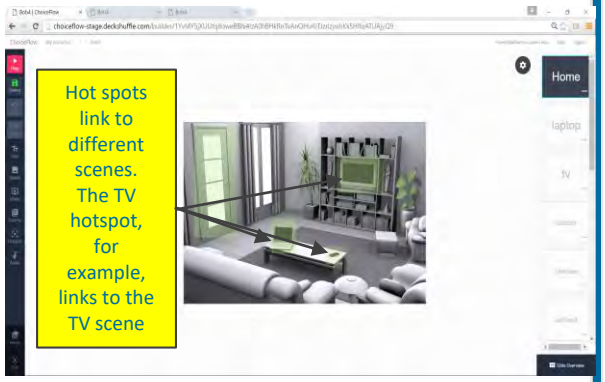
Tasks in progress

- Preliminary analysis of round 2 results
- Data analysis
- Manuscript development

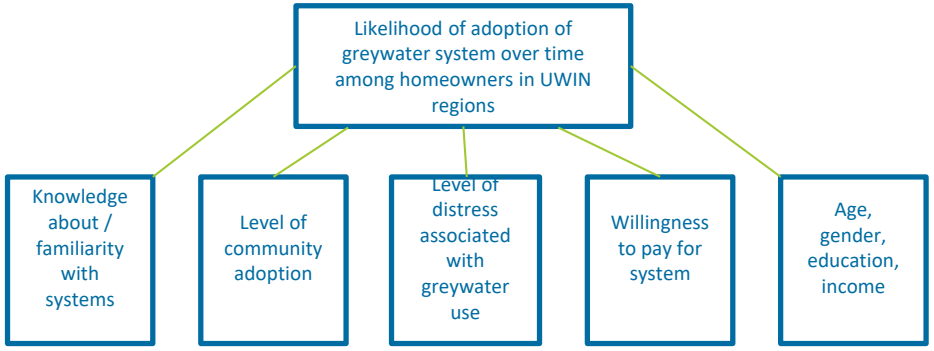
Virtual living room used for experiment

APPROACH

- Greywater systems adoption experiment developed for Choiceflow
- Pre and post simulation surveys created through Qualtrics
- Choiceflow software linked directly to Qualtrics survey software
- 1500 surveys and simulations administered



ACHIEVEMENTS AND SIGNIFICANCE



The Choiceflow software has been developed for rapid experimental design. Results from 5 UWIN regions are revealing relationships between different factors and adoption of innovative water saving technologies and indicating individual preferences for information.

PROJECT C2-1:
USING DYNAMIC INFORMATION ACCELERATION (CHOICEFLOW) TO UNDERSTAND AND FORECAST HOMEOWNER ADOPTION OF GREYWATER TECHNOLOGIES

National Science Foundation

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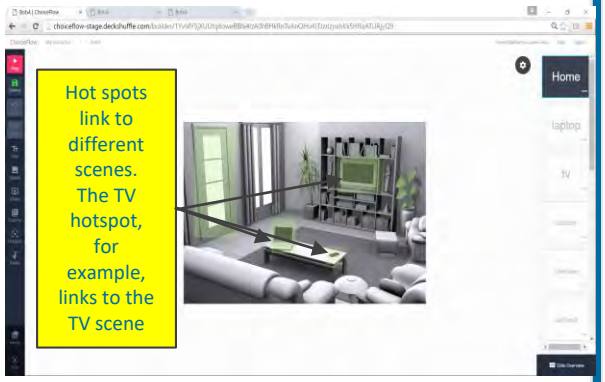
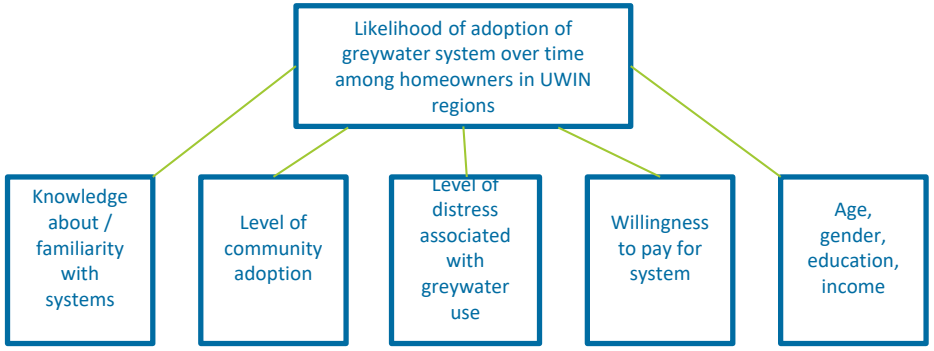


ACHIEVEMENTS AND SIGNIFICANCE



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PROJECT C2-1:

USING DYNAMIC INFORMATION ACCELERATION (CHOICEFLOW) TO UNDERSTAND AND FORECAST HOMEOWNER ADOPTION OF GREYWATER TECHNOLOGIES

PRODUCTS

PROJECT TEAM

- Jessica Bolson- Postdoctoral Fellow, Florida Int. Univ. Southeast Environmental Research Center
- Robert Meyer- Professor & Co-Director, Risk Management & Decision Processes Center, Wharton- Univ. Pennsylvania
- Kenny Broad- Professor & Director Abess Center for Ecosystem Science and Policy, Univ. Miami
- Dave Letson- Professor Department of Marine Ecosystems and Society, Univ. Miami
- Tim Kirby- PhD student, FIU

PROJECT C3-1:
SOCIAL EQUITY AND ENVIRONMENTAL JUSTICE IN URBAN WATER SYSTEMS

MOTIVATION AND OBJECTIVES

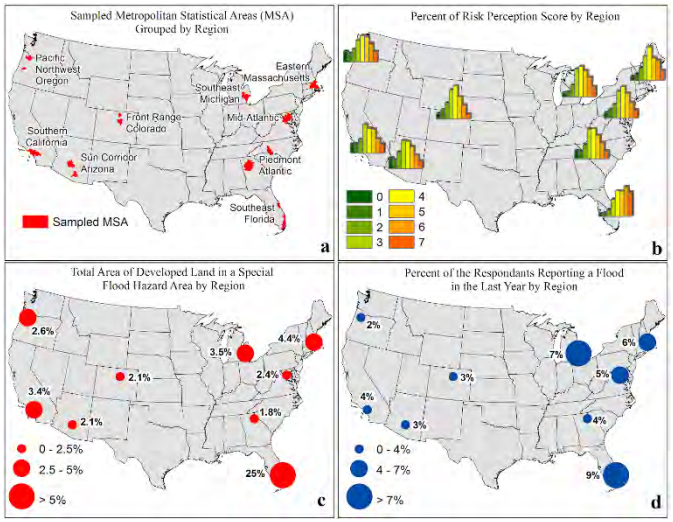
- Conduct two original research projects on water-related social equity and environmental justice (SEEJ) issues perceived by urban households and community leaders
- Analyze 9,250 geographically-referenced household surveys and interviews with 45 community organizations in nine UWIN study regions
- Collaborate with UWIN climate and flood researchers to highlight SEEJ issues
- Train social science students to participate in and lead interdisciplinary environmental projects

PROGRESS

- Analyzing household survey data and writing articles for publication on floods and water affordability in low-income households with student co-authors
- Using semi-structured interviews with leaders of community organizations in eight UWIN study regions to write articles for publication with students as co-authors
- Articles published and in progress with UWIN collaborators
- SEEJ collaborating on integration efforts

APPROACH

- Mixed methods using rigorously designed sample surveys, GIS for merger with economic and biophysical data, and best practice qualitative methods



Tim Stephens, SWISSH and FEMA data

ACHIEVEMENTS AND SIGNIFICANCE

- Completed seed grant with Northeastern University School of Law to study policies on water shutoffs, tax liens, water assistance programs and impacts of high water bills on public health in Massachusetts communities
- Michigan State University collaborated with the Philadelphia Water Department to publish an article describing the city's solution to the water affordability challenge in Philadelphia
- Successful collaboration with UWIN Project B2-2b on social vulnerability and urban residents' perceptions of flood risk
- Significance is to increase understanding of historical and present water inequities as understood by scientists, water managers, community advocates, and the public

PROJECT C3-1:
SOCIAL EQUITY AND ENVIRONMENTAL JUSTICE IN URBAN WATER SYSTEMS

PRODUCTS

Harlan, S.L., M. Sarango, E.A. Mack, T. Stephens. (2019) "A Survey-Based Assessment of Perceived Flood Risk in Urban Areas of the United States." *Anthropocene* 28 (December) 100217. https://doi.org/10.1016/j.ancene.2019.100217

Hondula, D.M., J.L. Sabo, R. Quay, M. Chester, M. Georgescu, N.B. Grimm, S.L. Harlan, A. Middel, S. Porter, C.L. Redman, B. Rittman, B.L. Ruddell, and D.D. White (2019) "Cities of the Southwest Are Testbeds for Urban Resilience." *Frontiers in Ecology and the Environment* 17(2): 79-80. https://doi.org/10.1002/fee.2005

Mack, E.A., S. Wrase, J. Dahme, M. Wright, S.M. Crosby, M. Davis, M. Wright, R. Muhammad. (2020) "An Experiment in Making Water Affordable: Philadelphia's Tiered Assistance Program (TAP)." *Journal of the American Water Resources Association (JAWRA)*. First published 16 March 2020. https://doi.org/10.1111/1752-1688.12830

Sarango, Mariana. (2020) *Keeping Our Heads above Water: Unaffordable Water, Public Health, and Equity in the United States*. Ph.D. Dissertation, Northeastern University, Boston, MA (April).

Four presentations at the American Geophysical Union, American Meteorological Association, Massachusetts Water Resources Authority Advisory Board, Massachusetts Council on Aging

PROJECT TEAM

Sharon L. Harlan, Professor
Department of Health Sciences and Department of Sociology & Anthropology, Northeastern University

Elizabeth Mack, Associate Professor
Department of Geography, Environment, and Spatial Sciences, Michigan State University

Northeastern University students: Mariana Sarango, Elisabeth Wilder, Kelsi Furman, Kiera O'Donnell, Liz Mariluz, Maggie O'Connor (URP student, Wellesley College)

Michigan State University students: Laura Medwid, Michelle Church

Tim Stephens, Georgia State University

PROJECT C4-1:
FIANCIAL MODELS AND STRATEGIES TO SUPPORT THE TRANSITION TO ONE WATER

National Science Foundation

MOTIVATION AND OBJECTIVES

According to stakeholders, financial constraints are a major barrier to implementation of One Water strategies. Objectives are:

- Discover the financial connectors and levers that control how services are offered and create strategies to integrate financial sources and decisions to promote One Water.
- Connect with relevant UWIN Projects that are evaluating institutional constraints to Sustainable Water Management including A1-2, C1-2 and C3-1.
- Identify where barriers exist in the current financial programs for "One Water" Projects.

PROGRESS

Conducting willingness-to-pay surveys for co-benefits in water infrastructure investments.

Reconducting a financial survey meant to gauge the integrated financial management and general financial outlook of utilities.

APPROACH

Surveys will be used to identified key barriers faced by each utility service (drinking water, wastewater, and stormwater). Surveys will also identify success stories and provide examples and case studies for other utilities.

Financial and legal solutions to the identified barriers will be proposed and included in a report to the water sector.

Surveys will be conducted to identify the customer willingness to pay for co-benefits in water investments.

ACHIEVEMENTS AND SIGNIFICANCE

Financial strategies will be central to accomplishment of UWIN goals for progress toward One Water.

Have created a better understanding of customers' preferences and willingness-to-pay for utility services.

PROJECT C4-1:
FIANCIAL MODELS AND STRATEGIES TO SUPPORT THE TRANSITION TO ONE WATER

PRODUCTS

- Drafted a policy report for Palouse Basin Aquifer Committee and the city councils of Moscow ID and Pullman WA. This work was presented at the annual water summit.
- Puri, R., & Maas, A. (2020). Evaluating the Sensitivity of Residential Water Demand Estimation to Model Specification and Instrument Choices. *Water Resources Research*.

PROJECT TEAM

- Neil Grigg, Professor of Civil and Environmental Engineering, Colorado State University
- Alex Maas, Assistant Professor, Agricultural Economics and Rural Sociology, University of Idaho
- Koroles Awad, Graduate Students, Agricultural Economics and Rural Sociology, University of Idaho

PROJECT D1-1:
MODELING PRESENT AND FUTURE VALUES FOR SUSTAINABLE WATER MANAGEMENT BLUEPRINT INDICATORS

National Science Foundation

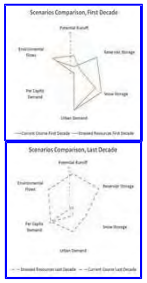
MOTIVATION AND OBJECTIVES

Motivation: To improve our understanding of how different water management strategies may help cities reduce their vulnerability to changing climate and population size by modeling present and future condition of urban water systems (UWS).

Objectives:
1. Assess the ability of different water management strategies to meet the challenges of population growth and climate change.
2. Pilot the use of Urban Water sustainability indicators to measure effectiveness of different water management solutions
3. Develop web services to quantify UW sustainability indicators

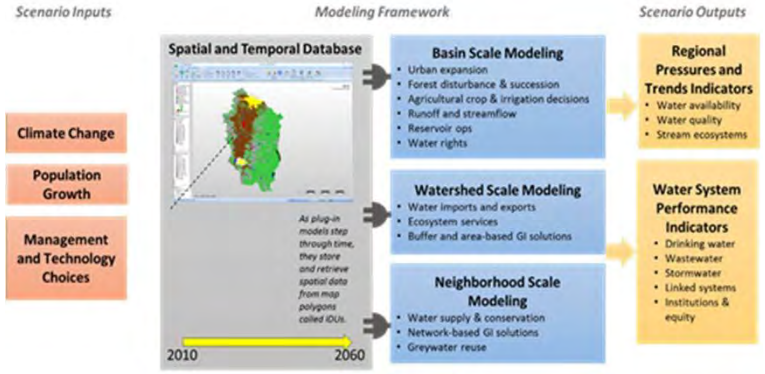
PROGRESS

- Developed a multi-scale modeling approach to evaluate future scenarios, using models selected to produce output at appropriate scales in space and time to calculate indicators identified by stakeholders as useful to decision-makers for design of future UWS.
- Produced representations of the existing landscape and future scenarios: Current Course, Integrated Water Future, and Stressed Resources at basin, watershed and neighborhood scales
- Guided graduate and undergraduate student research to produce publications, reports, and presentations.



APPROACH

Project D1-1 uses a transdisciplinary, stakeholder-driven approach to develop and evaluate three alternative future scenarios for urban water systems in the Portland, OR region.



ACHIEVEMENTS AND SIGNIFICANCE

Developed version of Stormwater Management Model (SWMM) and EPA-NET for use as web services
Developed UWINvision, a version of Envision model including a SWMM plug-in specifically for studying urban water systems (UWS) and the impacts of innovations designed to improve resilience and sustainability of UWS at multiple scales
Worked with regional stakeholders and water managers to develop three alternative future scenario descriptions
Published a paper and book contribution describing our multi-scale approach to design and evaluate innovative urban water systems in journals Urban Ecosystems, and two papers on the vegetation and management of urban parks in Frontiers in Ecology and Evolution and Ecological Applications.

PROJECT D1-1:
MODELING PRESENT AND FUTURE VALUES FOR SUSTAINABLE WATER MANAGEMENT BLUEPRINT INDICATORS

National Science Foundation

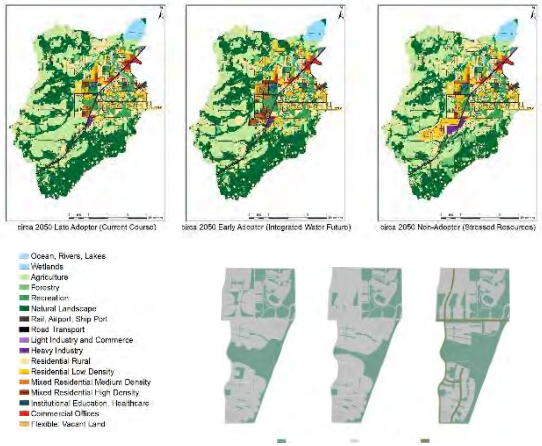
PRODUCTS

Papers

1. *Santelmann, M.V., D. Hulse, M. Wright, C. Enright, A. Branscomb, M. Tchintcharauli-Harrison, J. Bolson. 2019. Designing and modeling innovation across scales for urban water systems. Urban Ecosystems. https://doi.org/10.1007/s11252-019-00882-6*
2. *Santelmann, M. Hulse D., Wright M., Enright C., Branscomb A., Tchintcharauli-Harrison M., Talal, M. 2020. Innovation in Urban Water Systems. In: T. Fisher, B. Orland, and C. Steinitz (Eds.), The Intl. GeoDesign Collaborative: Changing Geography by Design; Redlands, California. ESRI Press.*
3. *Talal, M.L., M.V. Santelmann. 2019. Plant community composition and biodiversity patterns in urban parks of Portland, Oregon. Frontiers in Ecology and Evolution 04 June 2019 | https://doi.org/10.3389/fevo.2019.00201*
4. *Talal, M.L. and M.V. Santelmann. 2020. Vegetation management for urban park visitors: a mixed methods approach in Portland, Oregon. Ecological Applications https://doi.org/10.1002/eap.2079*
5. *Talal, M.L. and M.V. Santelmann. 2020. Vegetation management for urban park visitors: a mixed methods approach in Portland, Oregon. Bull. Ecol. Soc. Am.. 101(2):e01674. doi: 10.1002/bes2.1674.*

Presentations

1. *Talal and Santelmann. 2020. Urban Ecosystem Res. Consort. Symp., March 2, 2020, Portland, OR.*
2. *Oregon State University. 2020. Intl. GeoDesign Collab. Summit, Feb. 21-23, 2020, Redlands, CA.*
3. *Talal and Santelmann. 2020. Weizmann Inst. of Sci. Plant Ecol. Conf., Feb. 10-11 Rehovot, Israel.*
4. *Santelmann, M.V. 2019. Ecological Society of America, August 11-16, 2019, Louisville, KY.*
5. *Talal., M.L. 2019. Israeli Ministry of Ag. December 2019, Tel Aviv, Israel.*
6. *Talal, M.L. 2019. Hebrew University of Jerusalem Geography Dept., Nov.2019, Jerusalem, Israel.*
7. *Talal and Santelmann. 2019. Ecological Society of America August 11-16 2019, Louisville, KY.*
8. *Wright, Santelmann, and Conklin 2019. AGU Fall Meeting December 2019. San Francisco, CA.*
9. *Tchintcharauli-Harrison et al. 2019. AGU Fall Meeting, December 2019. San Francisco, CA.*



Models and Tools

UWINvision- Envision model with SWMM incorporated SWMM-LITE and EPANET-LITE packaged as web services Watershed-scale version of UWINvision

Designed alternative futures

Three alternative future scenario designs (Current Course, Stressed Resources and Integrated Water Futures) with spatially-specific representations of each at basin, watershed, and neighborhood scales

PROJECT TEAM

- Dr. M.V. Santelmann, Director Water Resources Graduate Program Oregon State University
- Dr. Roy Haggerty, Dean of the College of Science, Oregon State University
- Dr. David Hulse, Knight Professor of Landscape Architecture, University of Oregon
- Dr. David Conklin, Freshwater Simulations LLC, Portland Oregon (with Steve Drake, Brian Fulfrost and John Dalrymple) Faculty Research Associates: Alan Branscomb and Chris Enright, Univ. of Oregon; Maria Wright, Oregon State University,
- Graduate Students: Michael Harrison, Michelle Talal Undergraduate Students: Hattie Greydanus, Bijoux Schoner

PROJECT D1-2:
CROSS-SITE COMPARISONS AND CONTRASTS ACROSS ECO-HYDROLOGIC REGIONS

National Science Foundation

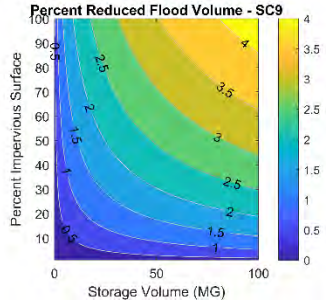
MOTIVATION AND OBJECTIVES

The overall goal of the study is to develop a unifying assessment framework and conduct case studies that demonstrate the benefits, co-benefits and system level effects of integrated urban water management solutions. Specifically, the objectives are to:

- Synthesize city water data and information from other projects.
- Identify optimal water management solutions under deep uncertainty about climate, land use, and population.
- Explore tradeoffs associated with water solutions for current and alternative future scenarios.
- Identify water management solutions that are most consistent with stakeholders' preferences.

PROGRESS

- Co-benefits of green infrastructure in UWIN cities were assessed using the iTree tool, including: air quality, carbon sequestration, cooling effects, and UV exposure.
- Monthly water use data from approximately 150 municipalities were analyzed to characterize indoor and outdoor residential, industrial, and temporal water use patterns in U.S. cities.
- The effects if grey and green stormwater infrastructure were assessed in the New York City for their impacts on flooding and combined sewer overflows over a range of climate change and sea level rise scenarios.



APPROACH

- An Urban Water Sustainability (“One Water”) Assessment Framework and Rating System is created to enable assessment of urban water systems at local, municipal, and regional scales.
- Assessment indicators are defined, characterized and quantified to provide a roadmap for the transition toward integrated management of urban water systems.
- The assessment framework incorporates multiple, and often conflicting, criteria in the decision-making process.
- The effects of One Water solutions are investigated at the municipal and CONUS levels, including: urban water demand reduction, resource recovery and water recycling systems, and green infrastructure.

ACHIEVEMENTS AND SIGNIFICANCE

- The comprehensive water sustainability study at the National Western Center (NWC) campus redevelopment project in Denver, CO created strategies for fit-for-purposes uses of alternative water sources.
- Green infrastructure can markedly change the hydrologic cycle in cities by influencing infiltration.
- Green infrastructure systems provided complimentary effects on flooding but would not substitute the effects of grey systems on combined sewer overflows in New York City.
- The study will reveal social viability, economic feasibility, and environmental sustainability and resiliency of the proposed technological, policy, and financial solutions.

PROJECT D1-2:
CROSS-SITE COMPARISONS AND CONTRASTS ACROSS ECO-HYDROLOGIC REGIONS

National Science Foundation

PRODUCTS

Recent Journal Papers

- Dozier, A., M. Arabi, C. Goemans, and D. Manning, 2020, Combating loss of agriculture in rapidly urbanizing semi-arid regions with institutional change, infrastructure, and conservation, *Environmental Modeling & Software*, in review.
- Ahmad, N., M. Chester, E. Bondank, M. Arabi, N. Johnson, and B. Ruddell, 2020, A Synthetic Water Distribution Network Model for Urban Resilience, *Sustainable and Resilient Infrastructure*, 1-15.
- Neale, M., S. Sharvelle, M. Arabi, A. Dozier, and C. Goemans, 2020, Assessing tradeoffs of urban water demand reduction strategies, *Journal of Hydrology*, 8: 100059.
- Olson, C., M. Arabi, T. Dell, and L. Roesner, 2020, Probabilistic Assessment of Extended Detention Basins: Role of Model Parameter Uncertainty, *ASCE Journal of Water Resources Planning and Management*, 146(8), 04020052.
- Daigger, G., S. Sharvelle, M. Arabi, and N. Love, 2019, Progress and Promise Transitioning to the One Water/Resource Recovery Integrated Urban Water Management Systems, *ASCE Journal of Environmental Engineering*, 145(10), 04019061.

Thesis/Dissertations

- Heiden, Chelsey (2019). Characterization of the vulnerability of urban streams to nutrient pollution under varying flow regimes . MS Thesis: Civil and Environmental Engineering, Colorado State University. Web: https://hdl.handle.net/10217/193176.
- Batista, Giovana das Gracas (2018). Characterization of urban water use and performance evaluation of conservation practices using the Integrated Urban Water Model in São Paulo, Brazil. MS Thesis: Civil and Environmental Engineering, Colorado State University. Web: https://hdl.handle.net/10217/193176.
- Dozier, Andre (2017). Towards integrated water resources management through modeling, optimization, and stakeholder engagement with a decision support game. Dissertation: Civil and Environmental Engineering, Colorado State University. Web: https://hdl.handle.net/10217/184012.
- Wostoupal, Benjamin (2018). Exploring water management tradeoffs in semiarid regions through conservation, institutions, and integrated modeling. M.S. Thesis, Civil and Environmental Engineering, Colorado State University, Fort Collins, Colorado. Web: https://hdl.handle.net/10217/191277.

PROJECT TEAM

- Mazdak Arabi, Professor, Colorado State University
- Benjamin Wostoupal, MS Student, Colorado State University
- Chelsey Heiden, MS Student, Colorado State University
- Alfy Joseph George, MS Student, Colorado State University
- Canon Furth, MS Student, Colorado State University
- William Rainey, MS Student, Colorado State University
- Omar Shebab, MS Student, Colorado State University
- Tyler Dell, Graduate Student, Colorado State University

PROJECT D1-3:
URBAN WATER DECISION INNOVATION SYSTEM

National Science Foundation

MOTIVATION AND OBJECTIVES

The overall goal of the study is to develop a unifying assessment framework and conduct case studies that demonstrate the benefits, co-benefits and system level effects of integrated urban water management solutions. Specifically, the objectives are to:

- Develop outcomes, indicators and metrics for urban water sustainability assessments.
- Develop a rating system to enable measuring the progress toward sustainable urban water systems.
- Create an expert system to guide identification of sustainable urban water solutions in a variety of context, including climate change, land use change, population growth, and ageing infrastructure.

PROGRESS

- An initial scalable and geospatially-enabled Water Connect website was created to upload, share, and disseminate geospatial or other scientific products from UWIN project teams.
- A comprehensive literature review was conducted to identify and summarize One Water goals, outcomes, indicators and metrics.
- The CLASIC lifecycle cost assessment tool to support to support stormwater infrastructure decisions on extent and combinations of green, hybrid green-gray and gray infrastructure practices.

APPROACH

- A data-sharing web tool is developed to host UWIN data.
- The data and modeling tools are deployed as web-services using the eRAMS Cloud Services Implementation Services (CSIP) and provides web interfaces using geospatial capabilities.
- An Urban Water Sustainability ("One Water") Assessment Framework and Rating System is created to enable assessment of urban water systems at local, municipal, regional and continental scales.
- Assessment indicators are defined, characterized and quantified to provide a roadmap for the transition toward integrated management of urban water systems.

ACHIEVEMENTS AND SIGNIFICANCE

- The One Water City assessment framework and rating system will enable cities identify technological and integrated planning and management solutions that enhance the reliability of water services, increase the resilience to changes in climate and land use, increase co-benefits, and ultimate enhance community livability.
- Leveraging urban water sustainability data from the research community is hampered by using customized and inconsistent data frameworks including formats, units of measurement, and storage mechanisms. The UWIN data and modeling platforms foster rapid collaborative interdisciplinary research.

PROJECT D1-3:
URBAN WATER DECISION INNOVATION SYSTEM

PRODUCTS

- Bolson, J., M. Sukop, M. Arabi, G. Pivo, and A. Lanier, 2018, A stakeholder-science based approach to analyzing the state of urban water sustainability in the U.S., *Water Resources Research*, 54 (5), 3453-3471.
- Sharvelle, S., A. Dozier, M. Arabi, and B. Reichel. 2017. A geospatially-enabled web tool for urban water demand forecasting and assessment of alternative urban water management strategies, *Environmental Modeling & Software*, 97: 213-228, 2017.
- Chinnasamy, C. V., Dozier, A., Furth, C. D., and Arabi, M. (2019). Characteristics of water use across 125 urban centers in the contiguous USA: What did we learn? *AGU Hydrology Days*, March 27 - 29, 2019, Fort Collins, Colorado.
- Chinnasamy, C. V., Dozier, A., Furth, C. D., Arabi, M., and Sharvelle, S. (2019). Characteristics of Municipal End Water Uses in the Contiguous USA. *16th Annual Rocky Mountain Student Conference*, May 13, 2019, Boulder, Colorado.
- Chinnasamy, C. V., Furth, C. D., Arabi, M., Sharvelle, S., and Dozier, A. (2019). Characteristics of Municipal End-Water Uses in the Contiguous USA. *4th Annual Meeting of the Urban Water Innovation Network*, July 30 – August 1, 2019, Fort Collins, Colorado.
- Joseph George, A., Arabi, M., Sharvelle, S., and Dell, T. (2019). Assess Performance of Urban Stormwater Control Measures (SCMs) under varying Maintenance Regimes. *39th Annual AGU Hydrology Days*, March 27 -29, 2019, Fort Collins, CO.
- Joseph George, A., Dell, T., and Sharvelle, S. (2018). Evaluating Uncertainty in Stormwater Control Measures (SCMs) using the EPA Storm Water Management Model linked with Markov Chain Monte-Carlo Uncertainty Technique. 9th International Congress on Environmental Modelling and Software, *Modelling for Sustainable Food-Energy-Water Systems*, June 24 - 28, 2018, Fort Collins, CO.
- [Software] Dell, T., S. Sharvelle, and M. Arabi, 2020, Community-Enabled Lifecycle Analysis of Stormwater Infrastructure Cost (CLASIC) Model, classic.erams.com/.
- [Software] Wible, T. and M. Arabi, 2020, River Discharge and Water Quality Analysis Tool, https://erams.com/catena/tools/water-quality/.
- [Software] Sharvelle, S. and M. Arabi, 2020, Urban Water Demand Forecasting Model, https://erams.com/catena/tools/urban-planning/urban-water-demand-forecasting/.
- [Software] Fontaine, D. and M. Arabi, 2020, Pipe Renewal Prioritization Model, https://erams.com/catena/tools/urban-planning/pipe-renewal-prioritization/.
- [Software] Wible, T., R. Morrison, and M. Arabi, 2020, River Hydraulics & Sediment Transport Model, https://erams.com/catena/tools/river-basin-planning/hydraulics/.
- [Software] Wible, T., R. Morrison, and M. Arabi, 2020, Watershed Rapid Assessment Program (WRAP) Model, https://erams.com/catena/tools/colorado-collaborative/watershed-assessment/.

PROJECT TEAM

- Mazdak Arabi, Professor, Colorado State University
- Andre Dozier, Research Scientist, Colorado State University
- Donya Dezfooli, PhD Student
- Galen MacPheson, MS Student
- Mahshid Mohammad-Zadeh, MS Student
- Kyle Traff, Software Developer, Colorado State University
- Tyler Wible, Research Scientist, Colorado State University

PROJECT E1-1:
UWIN STAKEHOLDER ENGAGEMENT

MOTIVATION AND OBJECTIVES

- "… train the next generation of researchers to meet the interdisciplinary research needs of the future"
- "… promote collaboration with resource managers, policymakers, end-users and other stakeholders in the private and public sectors…
- "… direct involvement - from the outset - of participants from federal, state and local agencies and tribal communities, non-governmental and international bodies and industry"
- Years 1 and 2: Build network, understand issues and decisions
- Year 3: Develop actionable science
- Year 4: Identify best management practices

PROGRESS

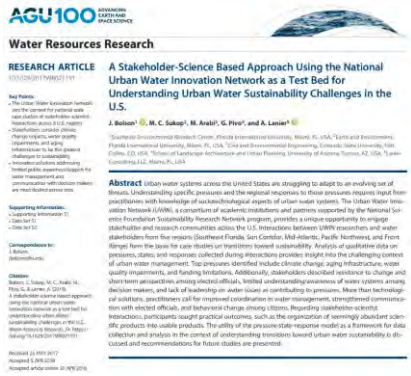
- Training:
  - 50% graduate students
  - 2016 cohort: 42 individuals
  - 2017 cohort: 32 individuals
- Engagement:
  - 2016/2017/2019 Stakeholder meetings summarized:
    - https://erams.com/UWIN/2016-meetings/
    - https://erams.com/UWIN/2017-meetings/
    - https://erams.com/UWIN/2019-philadelphia-workshop/
  - 2016 findings published

APPROACH

- Years 1 and 2:
  - Training & Stakeholder meetings and surveys in 5+ regions
  - Data gathering and synthesis
- Year 3:
  - Stakeholder-led Webinars (187 attendees)
- Year 4:
  - Stakeholder interviews to inform blueprint
  - Marketing strategies for water management
  - Case studies of successful urban water integration collaborations

ACHIEVEMENTS AND SIGNIFICANCE

- Top issues across country:
  - Climate change, aging infrastructure, water quality, and funding
  - Resistance to change and short-term perspectives among elected officials, limited understanding/awareness of water systems among decision makers, and lack of leadership on water
  - Practitioners call for improved coordination in water management, strengthened communication with elected officials, and behavioral change among citizens
  - Stakeholders want practical outcomes, such as the organization of seemingly abundant scientific products into usable products



PROJECT E1-1:
UWIN STAKEHOLDER ENGAGEMENT

PROUCTS

- Bolson, J., Sukop, M. C., Arabi, M., Pivo, G., & Lanier, A. (2018). A stakeholder-science based approach using the national urban water innovation network as a test bed for understanding urban Water sustainability challenges in the U.S.. Water Resources Research, 54. https://doi.org/10.1029/2017WR021191

PROJECT TEAM

- Michael Sukop
- Jessica Bolson
- Alicia Lanier

PROJECT E2-1:
UNDERGRADUATE RESEARCH PROGRAM

MOTIVATION AND OBJECTIVES

- Contribute to UWIN research
- Promote students' learning and increase their identity and confidence as scholars
- Promote diversity in UWIN
- Understand transdisciplinary problem-solving/learning

PROGRESS

- Nine undergraduate students participated in URP 2019.
- We recruited 10 students from a pool of 177 applicants as well as 17 mentors for an all-virtual URP 2020.
- We are currently running the all-virtual URP with students mentored by scientists at 11 host institutions involved in the 2020 program.

APPROACH

- Undergraduate students conduct independent research projects under the guidance of UWIN mentor scientists.
- Students participate in key enrichment activities providing them a deeper and broader understanding of urban water sustainability research and how transdisciplinary science is conducted.
- Students are connected to the broader UWIN community to build networks to support their continued professional development.

ACHIEVEMENTS AND SIGNIFICANCE

- All students (n=9) from the 2019 URP cohort successfully completed all the program requirements.
- The size of the 2019 applicant pool decreased compared to 2019 while the percentage of under-represented minorities applying to the program increased (from 24% to 33%)
- A highly diverse group of students, mentors, and project types participated in the 2020 program. For example, 40% of URP participants were from underrepresented minorities. The pool of mentors includes 13 faculty and 4 graduate students.

PROJECT E2-1:
UNDERGRADUATE RESEARCH PROGRAM

PRODUCTS

Chan, E., Papuga, S.A., Eklund, A. 2019. Developing tools to assess the long-term and multifunctional performance of green infrastructure: A case study in Detroit, Michigan. AGU Fall Meeting, San Francisco CA, 9-13 December 2019. Poster presentation.

PROJECT TEAM

- Alan Berkowitz
- Aude Lochet
- Kevin Burgio
- Shirley Vincent
- Sarah Millonig
- Ali Mostafavi
- Jessica Bolson

CITIZEN SCIENCE PROGRAM

OFF THE ROOF: EMPLOYING CITIZEN SCIENCE TO ENABLE CHARACTERIZATION OF MICROBIAL QUALITY OF ROOF RUNOFF

National Science Foundation

MOTIVATION AND OBJECTIVES

Roof runoff is a valuable source of water, but uncertainty remains in treatment targets for various end uses. Quantitative microbial risk assessment can be used to inform treatment targets and to characterize pathogens in roof runoff. *The overarching goal of this research is to engage citizens in roof runoff sampling that will inform the public on use of alternative water sources while also collecting data on microbial water quality to better inform treatment targets for roof runoff for various end uses.*

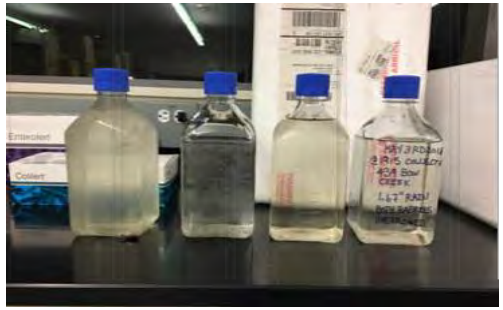
Characterize Pathogens in Source Water → Exposure (Based on End Use) → Select Acceptable Level of Risk → Set Log Reduction Target

APPROACH

Citizen participants are collecting samples of roof runoff using rain barrels. Those samples are analyzed for physical and chemical parameters, indicator organisms (*E. coli* and Entercocci) and pathogens (Campylobacter, Salmonella, Cryptosproidium, and Giardia)

PROGRESS

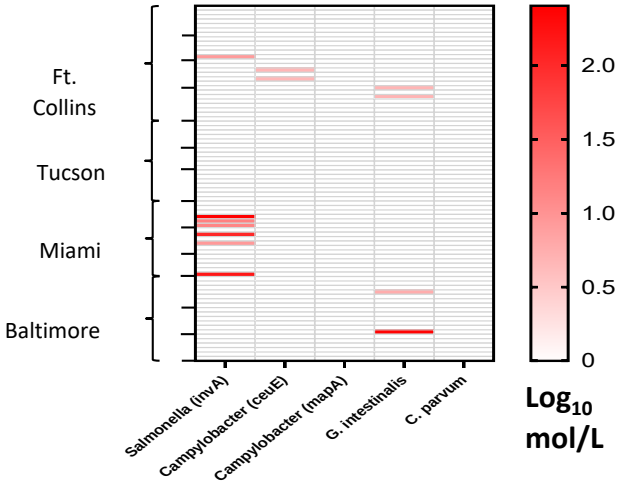
- Collected roof runoff from 7 households in each Fort Collin, CO (4 events), Tucson, AZ (3 events), Miami, FL (3 events), and Baltimore, MD (3 events)
- Samples analyzed for chemical water quality, fecal indicator bacteria, and pathogens



ACHIEVEMENTS AND SIGNIFICANCE

Chemical and microbial quality of roof runoff samples were highly variable across sampling locations and seasons

While potentially human-infectious pathogens were found to be present in roof runoff samples, the concentrations were not highly different from those in surface water



CITIZEN SCIENCE PROGRAM

OFF THE ROOF: EMPLOYING CITIZEN SCIENCE TO ENABLE CHARACTERIZATION OF MICROBIAL QUALITY OF ROOF RUNOFF

PRODUCTS

Website:
CitSci.org website

Presentations:
Alja'fari, J., Sharvelle, S., Crall, A., Newman, G. (2019) "Off the Roof: A Citizen Science Project to Measure the Microbial Characteristics of Roof Runoff", Hydrology Days, Fort Collins, CO.

PROJECT TEAM

Academic Team:
Sybil Sharvelle, Associate Professor, Colorado State University
Greg Newman, Research Scientist, Natural Resource Ecology Laboratory Alycia Crall, Paricipant Coordination
Alan Berkowitz, Plant Ecologist, Cary Institute of Ecosystem Studies Mike Sukop, Professor, Florida International University
Tom Meixner, Professor, University of Arizona
Claire Welty, Professor, University of Maryland Tom Meixner, Professor, University of Arizona

USEPA Collaborators:
Jay Garland, Division Director, USEPA National Exposure Research Laboratory Nichole Brinkman, USEPA National Exposure Research Laboratory
Scott Keely, USEPA National Exposure Research Laboratory
Michael Jahne, Environmental Engineer, USEPA National Exposure Research Laboratory

External Advisory Committee:
Robert Dunn, North Carolina State University Rebecca Jordan, Rutgers University
Audra Mohan, Research Scientist, Biological Sciences Curriculum Study