FINAL REPORT

(EPA grant 83556901)

Submitted by: James R. Mihelcic

University of South Florida

May 12, 2019

Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt)

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Final Project Summary

Period Covered by the Report: September 1, 2013 through August 31, 2018

Date of Final Report: November 21, 2018 (revised for May 12, 2019)

EPA Agreement Number: RD835569

Center Name: Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt)

Project Title: Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt)

Investigator(s): Mihelcic, James R. , Boyer, Treavor H. , Coney, Earnest , Cunningham, Jeffrey A. , Davis, Allen , Ergas, Sarina , Kuwayama, Yusuke , Olmstead, Sheila , Richardson, Nathan , Shih, Jhih-Shyang , Trotz, Maya , Yeh, Daniel H , Zhang, Qiong , Zimmerman, Julie B.

Institutions of PIs: University of South Florida, Resources for the Future, University of Florida, University of Maryland, Yale University

Research Category: Water and Watersheds, Water

Project Period: September 1, 2013 through August 31, 2018

Objective of Research: The mission of RAINmgt is to achieve sustainable and cost-effective health and environmental outcomes by re-imagining aging coastal urban infrastructure systems for nutrient recovery and management contributing to sustainable and healthy communities. The overall goal is to develop the science behind new technology and management innovations and a deep understanding of the integrated system while demonstrating and assessing these innovations to provide new knowledge for students, community members, and other stakeholders. Systems approaches allow us to evaluate and optimize an integrated system of technologies and management strategies.

Summary of Findings (Outputs/Outcomes)

To date, our Center researchers have published: 18 peer reviewed publications and 9 graduate student theses/dissertations. We also plan to have at least 11 additional peer reviewed journal articles and at least 3 additional student theses/dissertations published in 2019. Three patent applications have also been submitted for innovative technology developed by Center researchers.

Researchers completed science and demonstration of full-scale waterless urinals designed so that they minimize unwanted precipitation of urine-derived minerals and simultaneously maximize the potential for nutrient recovery from stored urine.

Researchers developed a decentralized wastewater resource recovery solution, based on the anaerobic membrane bioreactor technology, which can generate and sustain high quality product water containing nutrients suitable for irrigation. Demonstration is currently taking place with a full-scale machine with application to mine sewers to generate an effluent that will support a hydroponic green wall located on the side of the unit.

Researchers developed and demonstrated a nutrient management process applied to side stream nutrient recovery at a wastewater treatment plant that used anaerobic digestion, precipitation of struvite from the digester effluent, nitritation or nitrification of the liquid effluent from the struvite precipitation, and a microbial fuel cell with nitrite/nitrate serving as the electron acceptor in the cathode. The demonstration showed the microbial fuel cell can achieve complete removal of nitrate from samples of the sidestream generated at a Biosolids Management Facility, while simultaneously generating a low current of electricity.

Researchers completed a 1.5 year monitoring of the demonstration of a side-by-side conventional bioretention system and a modified bioretention system (developed in this research) to better manage nitrogen in stormwater runoff. Overall, the Total Nitrogen and NOx mass removal efficiency was significantly greater in the modified system than measured in the conventional system. Adding plants to both systems was shown to have a more significant impact for the conventional system in its nitrogen removing performance.

Researchers integrated nutrient and stormwater management research demonstrations with K-12 science education at local middle schools and at a community center, all located in under-represented neighborhoods of EPA Region 4.

Researchers developed and tested a new technology for removal of nitrogen in onsite wastewater treatment systems and operated a demonstration system. Results showed the system with recirculation consistently removed more ammonium nitrogen than the system without recirculation and high levels of inorganic nitrogen were removed from the system with complete denitrification observed in all systems. The demonstration also showed the developed technology could successfully handle transient loadings encountered in onsite systems.

Researchers completed Life Cycle Cost Analysis (LCCA) and Life Cycle Assessment (LCA) to assess the environmental sustainability of several nutrient management technologies for discharge and reuse scenarios developed and demonstrated by Center researchers: aerobic membrane bioreactors (AeMBR), anaerobic membrane bioreactors (AnMBR), an onsite wastewater treatment system, and stormwater bioretention systems.

Researchers completed development of an analytical model that provides a framework for quantifying the economic benefits of nutrient recovery and water reuse from point source nutrient management approaches.

Researchers have drafted a working paper on using hedonic models to estimate monetized values of nutrient pollution reductions in the Tampa Bay region.

Researchers continued development of a modeling framework to quantify watershed-scale water quality impacts of nutrient management technologies and strategies along with a decision support model to provide guidance on optimal location and capacity design of these nutrient management technologies.

Researchers have collected state and local regulations and guidelines relating to nutrient management. Identification of policy changes to spur adoption by households/businesses and integration into regulatory compliance.

Publications: (as of May 12, 2019):

Textbook

Mihelcic, J.R., J.B. Zimmerman, *Environmental Engineering: Fundamentals, Sustainability, Design*, 2nd Edition, John Wiley & Sons, 704 pages, 2014. ISBN: 978-1-118-74149-8

Patents

Cunningham J.A., Orner K.O., Mihelcic J.R. Struvite Precipitation and Microbial Fuel Cell for Recovery of Nutrients and Energy from Digester Effluent." United States Non-Provisional Patent Application No. 15/943,427 filed on April 2, 2018. https://patentimages.storage.googleapis.com/df/12/56/7548258b50a8b6/US20180282189A1.pdf

Yeh, D., O. Ozcan and R. Bair. Concentrically-baffled reactors and systems that incorporate them. U.S. Patent Application Publication. US 2017/0067005A1. March 9, 2017. https://patentimages.storage.googleapis.com/d0/99/21/e98b6c90909476/US20170067005A1.pdf

Yeh, D., G. Dick, R. Bair, O. Ozcan and J. Calabria. Systems and methods for treating dilute wastewater. International PCT Patent Application Publication. WO 2016/141369A1, September 9, 2016.
https://patentimages.storage.googleapis.com/9c/bd/f8/c59911dd630f02/US20180016171A1.pdf

Theses/Dissertations

Butcher M.R. (2014). Diffuse nutrient pollution from residential catchments. M.S.C.E. Thesis. Department of Civil and Environmental Engineering, University of South Florida, Tampa, FL, June 16, 2014 http://scholarcommons.usf.edu/etd/5194

Dick, G.H., (2015). Direct Membrane Filtration of Domestic Wastewater: Implications for Coupling with Anaerobic Membrane Bioreactor (DF-AnMBR) for Wastewater Resource Recovery. Graduate Theses and Dissertations. https://scholarcommons.usf.edu/etd/5829

Henderson, M.B. (2017). The Fate of Fecal Indicator Bacteria in Passive Nitrogen Reduction Systems. MS Thesis, Department of Civil & Environmental Engineering, University of South Florida, Tampa. https://scholarcommons.usf.edu/etd/6858

Igielski, S.J. (2016) Understanding Urban Stormwater Denitrification in Bioretention Internal Water Storage Zones. MS Thesis, Department of Civil & Environmental Engineering, University of Maryland College Park. http://hdl.handle.net/1903/18824

Miriyala, A. (2018). Impact of Recirculating Nitrified Effluent on the Performance of Passive Onsite Hybrid Adsorption and Biological Treatment Systems. MS Thesis, Department of Civil &

Environmental Engineering, University of South Florida, Tampa. (thesis will be made available in 2019).

Orner, K.D. (2019). Removal and Recovery of Nutrients from Wastewater in Urban and Rural Contexts, PhD Dissertation, Department of Civil & Environmental Engineering, University of South Florida, Tampa. (thesis will be made available in 2019).

Ozcan, O.Y. (2016). Development of an Anaerobic-Phototrophic Bioreactor System for Wastewater Treatment. Graduate Theses and Dissertations. http://scholarcommons.usf.edu/etd/6559

Payne, Karl (2018). Mathematical and Numerical Modeling of Hybrid Adsorption and Biological Treatment Systems for Enhanced Nitrogen Removal. PhD Dissertation, Department of Civil & Environmental Engineering, University of South Florida, Tampa. (dissertation will be made available in 2019).

Rodriguez-Gonzalez, L.C. (2017). Advanced Treatment Technologies for Mitigation of Nitrogen and Off-flavor Compounds in Onsite Wastewater Treatment and Recirculating Aquaculture Systems. PhD Dissertation, Department of Civil & Environmental Engineering, University of South Florida, Tampa. http://scholarcommons.usf.edu/etd/6941

Saetta, Daniella (2016). Urea Hydrolysis Inhibition in Waterless Urinals for Water Conservation and Nutrient Recovery. Master's Thesis, University of Florida, Gainesville, FL. http://ufdc.ufl.edu/UFE0050767/00001

Stocks, J. (2017) Enhancement of Two Passive Decentralized Biological Nitrogen Removal Systems. MS Thesis, Department of Civil & Environmental Engineering, University of South Florida, Tampa. http://scholarcommons.usf.edu/etd/7093

Peer Reviewed Journal Articles or Conference Proceedings

Cornejo, P.K., Zhang, Q., Mihelcic, J.R. (2016). How Does Scale of Implementation Impact the Environmental Sustainability of Wastewater Treatment Integrated with Resource Recovery? Environmental Science & Technology, 50(13), 6680-6689. doi:10.1021/acs.est.5b05055

Diaz-Elsayed, N., Xu, X., Balaguer-Barbosa, M., Zhang, Q. (2017). An Evaluation of the Sustainability of Onsite Wastewater Treatment Systems for Nutrient Management. Water Research, 121, 186-196. https://doi.org/10.1016/j.watres.2017.05.005

Diaz-Elsayed, N., Rezaei, N., Guo, T., Mohebbi, S., & Zhang, Q. (2019). Wastewater-based resource recovery technologies across scale: A review. Resources, Conservation and Recycling, 145, 94-112. https://doi.org/10.1016/j.resconrec.2018.12.035

Igielski, S., Kjellerup, B. V., & Davis, A. P. (2019). Understanding urban stormwater denitrification in bioretention internal water storage zones. Water Environment Research, 91(1), 32-44. https://doi.org/10.2175/106143017X15131012188024

Kuwayama, Y., Kamen, H. (2016). What drives the reuse of municipal wastewater? A county-level analysis of Florida. Land Economics, 92 (4), 679-702. doi:10.3368/le.92.4.679

Lopez, E., Lynn, T., Peterson, M., Ergas, S., Trotz, M., Mihelcic, J. (2016) Enhanced Nutrient Management of Stormwater through a Field Demonstration of Nitrogen Removal in a Modified Bioretention System. World Environmental and Water Resources Congress 2016, pp. 60-69. doi:10.1061/9780784479865.007

Lopez-Ponnada, E.V., Lynn, T.J., Peterson, M., Ergas, S.J., Mihelcic, J.R. (2017). Application of denitrifying wood chip bioreactors for management of residential non-point sources of nitrogen. Journal of Biological Engineering, 11(1), 16. doi:10.1186/s13036-017-0057-4

Lopez-Ponnada, E.V., Ergas, S.J., Trotz, M.A., Barton, F., Mihelcic, J.R. (2017). Enhanced Management of Nitrogen in Urban Stormwater Runoff through a Field Demonstration of a Modified Bioretention System. Proceedings of the Water Environment Federation, 2017(3), 156-160. doi:10.2175/193864717821494718

Lopez-Ponnada, E.V., Ergas, S.J., Nachabee, M., Payne, K.A., Mihelcic, J.R. Innovating Infrastructure for Management of Nitrogen Found in Stormwater: Long-Term Field Performance of a Full-Scale Modified Bioretention System. Proceedings of the Stormwater and Green Infrastructure Symposium 2019, May 8-10, 2019, Ft. Lauderdale, FL.

Lynn, T.J., Ergas, S.J., Nachabe, M.H. (2016). Effect of Hydrodynamic Dispersion in Denitrifying Wood-Chip Stormwater Biofilters. J. Sustainable Water in the Built Environment – ASCE, 2(4), 1-7. https://doi.org/10.1061/JSWBAY.0000812

Lynn, T.J., Nachabe, M.H., Ergas, S.J. (2017). Modeling Denitrifying Stormwater Biofilters Using SWMM5. Journal of Environmental Engineering, 143(7), 04017017. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001209

Orner, K. D., Ozcan, O. Y., Saetta, D., Boyer, T. H., Yeh, D. H., Anderson, D., & Cunningham, J. A. (2017). House of quality planning matrix for evaluating wastewater nutrient management technologies at three scales within a sewershed. Environmental Engineering Science, 34(11), 773-784. https://doi.org/10.1089/ees.2017.0016

Orner, K., Cools, C., Balaguer-Barbosa, M., Zalivina, N., Mihelcic, J.R., Chen, G., Cunningham, J.A. (2019). Energy Recovery and Nitrogen Management from Struvite Precipitation Effluent via Microbial Fuel Cells. Journal of Environmental Engineering, 145(3), 04018145. doi:10.1061/(ASCE)EE.1943-7870.0001500

Ray, H., Saetta, D., Boyer, T.H. (2018). Characterization of urea hydrolysis in fresh human urine and inhibition by chemical addition. Environmental Science: Water Research & Technology, 4, 87–98. http://dx.doi.org/10.1039/c7ew00271h

Rodriguez-Gonzalez, L., Payne, K., Trotz, M., Anderson, D. Ergas, S.J. (2015). Hybrid Adsorption Biological Treatment Systems (HABiTS) for Improved Nitrogen Removal in Onsite Wastewater Treatment. Proceedings of the Water Environment Federation, 11:4660-4672, dx.doi.org/10.2175/193864715819557632

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Rodriguez-Gonzalez, L.C., Miriyala, A., Rice, M., Delgado, D., Marshall, J., Henderson, M., Ghebremichael, K., Mihelcic, J.R., Ergas, S.J. (2019). "A Pilot-Scale Hybrid Adsorption Biological Treatment System (HABiTS) for Nitrogen Removal in Onsite Wastewater Treatment," *Journal of Sustainable Water in the Built Environment* (in press).

Saetta, D., & Boyer, T. H. (2017). Mimicking and inhibiting urea hydrolysis in nonwater urinals. Environmental Science & Technology, 51(23), 13850-13858. DOI: 10.1021/acs.est.7b03571

Tong, S., Stocks, J.L., Rodriguez-Gonzalez, L.C., Feng, C, Ergas, S.J. (2017). Effect of oyster shell medium and organic substrate on the performance of a particulate pyrite autotrophic denitrification (PPAD) process. Bioresource Technology, 244(2017): 296-303. doi:10.1016/j.biortech.2017.07.109

Tong, S., Rodriguez-Gonzalez, L.C., Feng, C., Ergas, S.J. (2017). Comparison of Particulate Pyrite Autotrophic Denitrification (PPAD) and Sulfur Oxidizing Denitrification (SOD) for Treatment of Nitrified Wastewater. Water Science & Technology, 75(1): 239-246. doi:10.2166/wst.2016.502

Tong, S., Rodriguez-Gonzalez, L.C., Payne, K.A., Stocks, J.L, Feng, C., Ergas, S.J. (2018). Effect of pyrite pretreatment, particle size, dose and biomass concentration on particulate pyrite autotrophic denitrification (PPAD) of nitrified domestic wastewater. Environmental Engineering Science, 35(8):875-886. https://doi.org/10.1089/ees.2017.0295

Xu, X., Diaz-Elsayed, N., & Zhang, Q. (2018). The Role of Location in Sustainable Nitrogen Removal for Onsite Wastewater Treatment Systems. Proceedings of the Water Environment Federation, 2018(5), 83-92.

Xu, X., Schreiber, D., Lu, Q., & Zhang, Q. (2018). A GIS-Based Framework Creating Green Stormwater Infrastructure Inventory Relevant to Surface Transportation Planning. Sustainability, 10(12), 4710. https://doi.org/10.3390/su10124710

Xu, X. Zhang, Q. (2019). Sustainable Configuration of Bioretention Systems for Nutrient Management through Life Cycle Assessment and Cost Analysis. Journal of Environmental Engineering. doi:10.1061/(ASCE)EE.1943-7870.0001526

Wang, R., Zimmerman, J.B. (2015) Economic and Environmental Assessment of Office Building Rainwater Harvesting Systems in Various U.S. Cities. Environmental Science and Technology, 49 (3): 1768-1778. doi:10.1021/es5046887

Supplemental Keywords: nutrient, phosphorus, nitrogen, infrastructure, sustainable, built environment, policy, resource recovery, LCA, LCCA

Relevant Web Sites: http://usf-reclaim.org/ Twitter: @USF_Reclaim

Table of Contents

1) Center Mission and Goals

The *mission* of the Center for Reinventing Aging Infrastructure for Nutrient Management[1] is to achieve sustainable and cost-effective health and environmental outcomes by re-imagining aging coastal urban infrastructure systems for nutrient recovery and management contributing to sustainable and healthy communities.

The *overall goal* of the Center for Reinventing Aging Infrastructure for Nutrient Management is to develop the science behind new technology and management innovations and a deep understanding of the integrated system while demonstrating and assessing these innovations to provide new knowledge for students and other community members, policy makers, regulators, design engineers, and regulated entities. This overall goal will be met by innovating sustainable, transdisciplinary, life cycle, and systems-based approaches applicable to the management of point and diffuse sources of nutrients, over different scales, and in urban coastal watersheds.

The three research thrusts and associated demonstration projects will: (1) address point and diffuse sources of nutrients, (2) consider different scales (i.e., household, building, community, city), (3) develop and assess management options that have different technological time frames for implementation (short- and long-term), and (4) focus on innovative technologies and strategies that prioritize source reduction and reuse/recycling and seek to minimize nutrient fluxes and greenhouse gas emissions (including carbon and nitrogen).

The Center Science Advisory Board consisted of: Ms. Jeanette Brown (Manhattan College), Dr. Richard Woodward (Texas A&M University), Dr. Charles Bott (Hampton Roads Sanitation District), Ms. Lindsay Cross (Tampa Bay Estuary Program), Mr. Lance Davis (Architecture/Sustainability U.S.), Dr. Sudhir Murthy (District of Colombia Water and Sewer Authority), Dr. Albert Robert Rubin (North Carolina State University), Ms. Jennette Seachrist (Southwest Florida Water Management District), Dr. Richard A. Smith (United States Geological Survey), and Dr. Kenneth Williamson (Clean Water Services).

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[1] The Center for Reinventing Aging Infrastructure for Nutrient Management (RAINmgt) was supported by USEPA grant 83556901. The Center for Reinventing Aging Infrastructure for Nutrient Management began its main activities in January 2014. The Center consists of faculty, research staff, and students from: The University of South Florida, the University of Texas-Austin, Resources for the Future, Yale University, University of Florida, University of Maryland, Corporation to Develop Communities of Tampa, and Hazen & Sawyer. James Mihelcic (University of South Florida) is the Director and Sheila Olmstead (University of Texas-Austin) is the Deputy Director. Other senior researchers are: Jeffrey Cunningham, Sarina Ergas, Maya Trotz, Daniel Yeh, Qiong Zhang (University of South Florida); Yusuke Kuwayama, Nathan Richardson, Jhih-Shyang Shih (Resources for the Future); Julie Zimmerman (Yale University); Treavor Boyer (University of Florida); Allen Davis (University of Maryland); and, Damann Anderson (Hazen & Sawyer).

2) **Summary of Major Products and Outputs**

1. To date, our Center researchers have published: 18 peer reviewed publications and 9 graduate student theses/dissertations. We also plan to have at least 11 additional peer reviewed journal articles and at least 3 additional student theses/dissertations published in 2019.

2. To date, three patent applications have been submitted for innovative technology developed by Center researchers.

3. Dr. Mihelcic (Center Director) is one of three guest editors for special issue of *Journal of Environmental Quality* for special collection of papers entitled "Nutrient Pollution Control Strategies." Papers are being submitted for review with a January 2019 deadline and special issue will be published in early 2019. Three individual research manuscripts led by our Center researchers will be submitted to the special issues and are titled: 1) Discharge or Reuse? Comparative Sustainability Assessment of Anaerobic and Aerobic Membrane Bioreactors, 2) Hydroeconomic Modeling of Resource Recovery from Wastewater: Implications for Water Quality and Quantity Management, 3) A Case Study for Analyzing Nutrient Management Technologies at Three Scales within a Sewershed.

4. Center Researchers (Dr. Sarina Ergas, Dr. Treavor Boyer) are serving as guest editors for "Special Collection on Onsite and Decentralized Wastewater Management Systems" that will appear in the J*ournal of Sustainable Water in the Built Environment* featuring research related to onsite and decentralized wastewater management to provide greater opportunities for sustainable urban water utilization. Papers are being submitted for review and special issue will be published in 2019. (Flyer attached in the Appendix A)

5. Center Researchers (Dr. Sarina Ergas, Dr. James Mihelcic, Mr. Damann Anderson, Ms. Josefin Hirst, Mr. Karl Payne, Dr. Laura Rodriguez-Gonzalez) organized a one-day Workshop titled "Onsite and Decentralized Nutrient Removal and Recovery Systems" at the 2017 Water Environment Federation (WEF) Nutrient Symposium. The workshop included 14 platform presentations, 4 posters, and a panel discussion. The workshop was attended by approximately 50 people, including consultants, installers, regulators, faculty and students (June 12, 2017).

6. Center Researchers (Dr. Colleen Naughton, Dr. Qiong Zhang and Dr. Treavor Boyer) organized and delivered an EPA SSWR Water Research Webinar (Wednesday, December 14, 2016) on the topic "Systems View of Nutrient Management – Nutrient Recovery from Human Urine" with participants from the WERF Center (see Appendix B for webinar details).

7. Center Researchers (Dr. Sarina Ergas, Dr. James Mihelcic) served on planning committee for the Water Environment Federation's Nutrient Symposium in 2015, 2016, 2017, and 2018.

8. Center researchers (Dr. Jeff Cunningham, Dr. Daniel Yeh) organized a workshop titled "Re-Thinking Wastewater Treatment at the Nexus of Energy, Climate Change, and Resource Recovery" at the 2015 Association of Environmental Engineering and Science Professors (AEESP) Research and Education Conference (June 2015, New Haven, CT).

9. Center researcher (Dr. Treavor Boyer) organized a technical session on "Nutrient Recovery: Source Separated Urine" at the 250th American Chemical Society National Meeting & Exposition (June 2015, Boston, MA).

10. Center Researcher (Dr. James Mihelcic) coauthored presentation titled "US EPA Nitrogen and Co-Pollutant Roadmap and the National Priorities Nutrient Management Centers" that was a keynote presentation by Mr. Ben Packard, U.S. Environmental Protection Agency at the WEF Nutrient Removal and Recovery Conference 2017 (other authors were Anne Rea, U.S. Environmental Protection Agency and Amit Pramanik, Water Environment & Reuse Foundation)

11. Center Researcher (Dr. James Mihelcic) co-organized with Amit Pramanik (WE&RF) a half-day session on output of demonstrations that was titled "EPA National Priorities Nutrient Management Centers: Practical Outcomes from Five Years of Water Research Nationwide" at the 2018 WEF Nutrient Conference (June, 2018) (details in Appendix C).

12. The topic of nutrient management was integrated into all 12 chapters of a college environmental engineering textbook that is currently adopted by over 100 U.S. universities (Mihelcic, J.R., J.B. Zimmerman, *Environmental Engineering: Fundamentals, Sustainability, Design*, 2nd Edition, John Wiley & Sons, 704 pages, 2014. ISBN: 978-1-118-74149-8

13. Center leadership (Dr. James Mihelcic) continues to work with officials from EPA, DOE, NSF, and WE&RF to advance significant opportunities to spur innovation and accelerate adoption of reliable technologies that enhance integrated resource recovery in the wastewater sector by creation of a National Test Bed Network (www.werf.org/testbednetwork).[2]

14. Center researcher (Dr. Colleen Naughton) developed a video to train Center researchers on how to properly engage the community throughout the research process for more

[2] Mihelcic, J.R., Ren, Z.J., Cornejo, P.K., Fisher, A., Simon, A.J., Snyder, S.W., Zhang, Q., Rosso, D., Huggins, T.M., Cooper, W., Moeller, J., Rose, B., Schottel, B.L., Turgeon, J. (2017). Accelerating Innovation that Enhances Resource Recovery in the Wastewater Sector: Advancing a National Testbed Network. *Environmental Science & Technology*, 51:7749-7758. DOI: 10.1021/acs.est.6b05917

Cornejo, P.K, Becker, J., Pagilla, K., Mo, W. Zhang, Q., Mihelcic, J.R., Chandran, K., Sturm, B., Yeh, D., Rosso, D. (2018). Sustainability Metrics for Assessing Water Resource Recovery Facilities of the Future. *Water Environment Research*. January, 2019. https://doi.org/10.2175/106143017X15131012187980 sustainable projects and technologies. (the 26-minute video is available at: https://www.youtube.com/watch?v=tFaiIYjkYjo)

15. Center partnered with the Corporation to Develop Communities of Tampa, Inc. (CDC) to train non-traditional and minority adult learners to implement green infrastructure. This training is incorporated into a 6-week adult workforce development program on construction that is offered through the CDC's Tampa Vocational Institute (TVI) (https://www.youtube.com/watch?v=usf8VHKQuUg).

3) Discussion of any Changes in Key Personnel

There were no changes in key personnel over the grant period. Dr. Sheila Olmstead (Deputy Director of the Center) accepted an offer to serve as the senior economist for energy and environment at the President's Council of Economic Advisers from summer 2016 to summer 2017. Dr. Yusuke Kuwayama assumed her duties as Deputy Director for this time period.

4) Discussion of Subaward Monitoring Activities

The PI (Dr. James Mihelcic) monitored the progress of Subrecipient's work scope by reviewing quarterly invoices and backup documentation. These technical progress reviews are documented by the PI's signature on the Subrecipient invoices. The PI's signature indicates that a review was completed and that the invoice adhered to the approved budget and received deliverables. Also, the PI received informal progress reports via phone conversations, e-mail communications, face-to-face discussions or other required deliverables.

5) Statement on how Quality Assurance Requirements in Center Quality Management Plan were met

Quality Assurance Project Plans (QAPP) were first developed for each of the three research thrusts by individual research groups working collectively. They were then approved by the Center Director and submitted to EPA and approved by USEPA in January-February 2014. Each QAPP had an investigator responsible for oversight. Dr. Yeh oversaw QA/QC activities for Research Thrust 1, Dr. Ergas oversaw QA/QC activities for Research Thrust 2, and Dr. Olmstead oversaw QA/QC activities for Research Thrust 3. That individual was responsible to direct or co-direct individual research that took place within a particular research thrust they were responsible for. Regular meetings then took place between the responsible individual and the other researchers in a particular research thrust area. This communication was supplemented by the responsible individuals meeting face-to-face with other researchers at annual meetings when the External Advisory Board was present and also in many instances serving on student graduate committees and coauthoring publications that were taking place within a particular research thrust.

6) Discussion of Expenditures Including Costs Significantly Higher/Lower than Expected

Initially when the budget was completed during the proposal stage, there were several areas that were either slightly under/overestimated mainly in the categories of travel, salaries, and supplies. The sponsor approved an NCE which allowed for additional supplies and salaries expenditures. The research supplies along with an optimal level of personnel was required to meet our research goals and objectives. Our budget revisions were reasonable and consistent with the University and sponsor policies/guidelines.

7) Statement of Whether Goals Changed Since Original Application and Research Misconduct Statement

Center goals did not change since the original application.

PIs under the grant abided by the research misconduct requirements for the grant.

8) Summary of Center Research

(Organized around 3 Research Thrusts)

8.1 Research Thrust 1: Sustainable Management of Point Sources of Nutrients

Overview: The three research projects in Research Thrust 1 addressed nutrient recovery opportunities and challenges across different scales (building, community, and city) and at the highest concentration and purity states when possible. The Thrust 1a Project examined strategies at the building scale through nutrient recovery from urine and Thrust 1ba Project examined community-level decentralized wastewater reuse and nutrient recovery through sewer mining with an anaerobic membrane bioreactor (AnMBR). The Thrust 1c Project developed a new wastewater sidestream technology to intercept and recover nutrients from sludge digestate because this wastewater contains significant portions of a treatment plant's nutrient budget. The social, economic, and environmental costs, benefits, and implementation potential of technologies innovated in Research Thrust 1 were evaluated using system-based approaches including life cycle environmental and cost assessment, an integrated modeling decision support framework, and socioeconomic analysis as described in Research Thrust 3.

8.1.1 Research Thrust 1a - Decentralized (Building-Scale) Nutrient Recovery from Urine Using Sorption-Precipitation

Motive: Develop and demonstrate a solution for building-level nutrient recovery through urea hydrolysis inhibition and precipitation technologies.

Science: Urea hydrolysis was mimicked in waterless urinals using synthetic urine and realistic bathroom conditions, specifically urine void volume and urine frequency. Acetic and citric acid treatment inhibited the urea hydrolysis reaction in situ by lowering the pH of the urine in the trapway. It was observed that conductivity, phosphate, and calcium concentrations were higher in the effluent urine when treated with the acids, further proving that urea hydrolysis was inhibited and subsequent precipitation reactions were reduced. Total phosphate recovery, via struvite precipitation, was higher in the synthetic urine treated with acetic acid than in the urine that received no treatment.

Demonstration: Urea hydrolysis was mimicked in full scale waterless urinals using real human urine (April - June, 2016, University of Florida, Gainesville, FL). Human urine was collected from volunteers 10 am – 4 pm on Monday – Friday for 3 weeks in a baseline demonstration and 3 weeks in a treatment demonstration system. Four random donors were asked to donate per day. After each donor anonymously logged the urine measurements in a dedicated notebook, they were asked to slowly pour the urine in the urinal doing their best to pour the urine for 15–20 seconds. All results agreed with the laboratory conclusions mentioned under the science section of this research thrust. When using real human urine, acetic acid treatment inhibited the urea hydrolysis reaction in the storage tanks. Phosphorus recovery via struvite precipitation as part of the demonstration study gave inconclusive results to its impact on inhibition of urea hydrolysis. Struvite precipitation was done twice using real human urine collected from the demonstration experiments. The struvite precipitation method followed the laboratory experiments (as mentioned in the science section) and used real human urine. The dose of magnesium chloride was determined using the phosphate concentration in the stored urine collected from the demonstration experiments immediately before the struvite precipitation was performed. The urine was mixed for 10 min and it was allowed to settle for 24 h before filtering. The filtered urine was collected and stored for 3 days before the struvite precipitation method was repeated.

Products Related to Science and Demonstration of Research Thrust 1a:

1. Saetta, Daniella (December 2016) *Urea Hydrolysis Inhibition in Waterless Urinals for Water Conservation and Nutrient Recovery*. Master's Thesis, University of Florida, Gainesville, FL. http://ufdc.ufl.edu/UFE0050767/00001
2. Saetta, D., & Boyer, T. H. (2017). Mimicking and inhibiting urea hydrolysis in nonwater urinals. *Environmental Science & Technology*, 51(23), 13850-13858. DOI: 10.1021/acs.est.7b03571
3. Ray, H., Saetta, D., Boyer, T.H. (2018). Characterization of urea hydrolysis in fresh human urine and inhibition by chemical addition. *Environmental Science: Water Research & Technology*, 4, 87–98. http://dx.doi.org/10.1039/c7ew00271h

Output Related to Science and Demonstration of Research Thrust 1a:

9) Center Researchers (Dr. Colleen Naughton, Dr. Qiong Zhang and Dr. Treavor Boyer) organized and delivered an EPA SSWR Water Research Webinar (Wednesday, December 14 2016) on the topic of "Systems View of Nutrient Management – Nutrient Recovery from Human Urine" (Appendix B).

8.1.2 Research Thrust 1b - Anaerobic Membrane Bioreactor (AnMBR)

Motive: Develop and demonstrate a decentralized wastewater resource recovery solution, based on the anaerobic membrane bioreactor technology, which can generate and sustain high quality product water (permeate) containing nutrients suitable for irrigation.

Science: Enhancing membrane performance is generally performed with extensive pretreatment methods before the feedwater is filtered by the membrane. With the utilization of direct membrane filtration (DF), no pretreatment is performed and the membrane is exposed to raw wastewater. A direct membrane filtration system was coupled with an anaerobic membrane bioreactor (AnMBR). By coupling the direct membrane filtration with an AnMBR, the DF-AnMBR can treat low COD strength domestic wastewater. The direct membrane filtration portion can handle the bulk of the liquid fraction, while the highly concentrated fraction of wastewater is treated by the AnMBR stage, thus improving the energy profile of the AnMBR and enhancing performance. In the science part of this research project, 1) flow and mass balance equations for the combined DF-AnMBR provided insight on design parameters relevant to this novel treatment process and (2) because membrane fouling occurs gradually over weeks or months, it is difficult to systematically determine how processes changes may affect membrane performance. A method to rapidly determine the fouling propensity of wastewater was developed by adapting the modified fouling index (MFI) to test the fouling propensity of various treatment streams in the direct membrane filtration -AnMBR system. Raw wastewater had a fouling potential of about 25% of the AnMBR MFI, and with the utilization of powdered activated carbon (PAC) the fouling potential was further decreased to nearly 50% of the original fouling potential. The direct membrane filtration concentrated stream had a higher MFI value than liquor from the AnMBR, but presumably some of organics contributing to fouling would be degraded in the AnMBR. This study suggests that direct membrane filtration of raw wastewater is feasible, and the combined use of direct membrane filtration and AnMBR is promising. In a parallel study, a concentrically-baffled reactor (CBR) was designed to reduce heat loss by transferring more of the heat between reactor zones than traditional baffled reactor designs. This should increase energy efficiency for heated systems. The processes which were conducted were: 1) A prototype CBR was operated abiotically under varying hydraulic retention times (HRTs) from 4h to 24 h, and achieved over 90% removal of total suspended solids (TSS) for all HRTs tested with feed particle sizes below 1.7 mm. 2) Phototrophic membrane bioreactors (PMBRs) were tested with low aeration conditions to decrease their energy demand, which resulted in nitrification-dominated systems. A phototrophic technology was developed for increasing the pH of waste streams to potentially aid pH-sensitive nutrient recovery processes. 3) The CBR was combined with a post-CBR membrane filtration process, and two PMBRs treating the effluent and permeate streams from the CBR in order to achieve complete organic matter and nutrient removal. Using the combined CBR-PMBR system, over 90% TN and TP removal were possible for 10 days HRT operation at high-strength feed conditions, with post-CBR membrane filtration. COD removal over 90% was possible for both high-strength and low-strength scenarios under all conditions tested.

Demonstration: The demonstration for research thrust 1b is currently being conducted. The demonstration is comparable to what was proposed in the original proposal to EPA. The changes are: 1) the location was changed to the University of South Florida (USF) campus because of administration changes and closure of the original science museum); 2) we will use simulated wastewater instead of actual wastewater because of permitting barriers and costs for sewer/plumbing connections; 3) an actual full-scale machine will be used, rather than an experimental set up.

The wastewater source will be simulated wastewater (e.g., originating from the USF FlexHouse). The idea is to present the concept of a mini-grid decentralized resource recovery system based on an AnMBR that mines wastewater from households and sewers. Our demonstration unit is a full-scale fully-functional system that operates completely on solar energy and can process up to 1,000 liters per day. However, to actually connect to sewer and mine the contents for the demonstration would have required permitting and exceptions with multiple jurisdictions and burdensome monitoring requirements, in addition to considerable costs for plumbing and sewer connections. The main message to be conveyed is that the AnMBR technology can treat wastewater onsite and recover water and nutrients for local fertilizer/irrigation, which the demonstration will be able to convey. The effluent from the demonstration will be used for fertigation to support a hydroponic green wall (flowers) on the side of the AnMBR unit. The connection with nutrient management is that fertigation is the most direct form of nutrient reuse/recovery, and utilizes nitrogen and phosphorus nutrient without additional processing steps (e.g., precipitation and drying) which necessitate storage and transportation.

Table. Modified Schedule for Research Thrust 1b Demonstration.

Month	Activity	Milestone
Nov 2018	Site prep, install concrete pad, walkways, signage	Site prep complete
Dec 2018	Install AnMBR system, Move system in place, commissioning, install plants	Installation and commissioning
Jan 2019	Demonstration	Stabilize operation, tours by appointment
Feb 2019	Demonstration	Open House event, tours and demonstrations
Mar 2019	Demonstration	Tours and demonstrations
Apr 2019	Demonstration	Tours and demonstrations
May 2019	Continued demonstration (or decommissioning)	Tours and demonstrations

The expected output is increased awareness of wastewater management, specifically a) AnMBR technology, and b) nutrient reuse/recovery towards beneficial uses, on the part of USF campus community, general public, and industry. We will create a webpage for further information and collating comments from visitors, via a QR code. The exterior of the unit will be openly accessible to the public to visit. We plan to host open house events and tours by appointment.

We have already conducted one engagement with approximately 70 visitors from the Portable Sanitation Association International (PSAI) on Nov 15, 2018. The visit occurred at a temporary location near the future demonstration site. PSAI is the trade organization that represents portable toilets in the U.S. and Canada. We were able to introduce them to the concept of onsite treatment and water recycling using an off-grid AnMBR, and assessed whether this is of value to the industry. The consensus from this interaction was yes, it would be of value, especially for remote areas (e.g., parks) where portable toilet emptying and replacement is difficult.

Products Related to Science and Demonstration of Research Thrust 1b:

1. Dick, G.H. (2015). *Direct Membrane Filtration of Domestic Wastewater: Implications for Coupling with Anaerobic Membrane Bioreactor (DF-AnMBR) for Wastewater Resource Recovery*. Graduate Theses and Dissertations. https://scholarcommons.usf.edu/etd/5829
2. Ozcan, O.Y. (2016). *Development of an Anaerobic-Phototrophic Bioreactor System for Wastewater Treatment*. Graduate Theses and Dissertations. http://scholarcommons.usf.edu/etd/6559
3. Orner, K. D., Ozcan, O. Y., Saetta, D., Boyer, T. H., Yeh, D. H., Anderson, D., & Cunningham, J. A. (2017). House of Quality Planning Matrix for Evaluating Wastewater Nutrient Management Technologies at Three Scales Within a Sewershed. *Environmental Engineering Scienc*e, 34(11), 773-784. https://doi.org/10.1089/ees.2017.0016
4. Yeh, D., O. Ozcan and R. Bair. Concentrically-baffled reactors and systems that incorporate them. U.S. Patent Application Publication. US 2017/0067005A1. March 9,

2017. https://patentimages.storage.googleapis.com/d0/99/21/e98b6c90909476/US20170067005A1.pdf

5. Yeh, D., G. Dick, R. Bair, O. Ozcan and J. Calabria. Systems and methods for treating dilute wastewater. International PCT Patent Application Publication. WO 2016/141369A1, September 9, 2016. https://patentimages.storage.googleapis.com/9c/bd/f8/c59911dd630f02/US20180016171A1.pdf

8.1.3 Research Thrust 1c - Centralized (City-Scale) Nutrient Removal and Recovery through Side stream Treatment of Anaerobic Digester Filtrate

Motive: Develop and demonstrate innovative nutrient recovery solutions at a large wastewater treatment plant, through side stream nutrient recovery using sorption-precipitation technologies.

Science: Engineered struvite precipitation is now a common procedure to recover phosphorus and nitrogen from waste streams such as wastewater treatment plant sidestreams, urine, landfill leachate, and agricultural waste. Depending on the waste stream, the liquid effluent from engineered struvite precipitation is likely to still contain either nitrogen or phosphorus. In the case of wastewater treatment plant sidestreams, the liquid recycled back to the head of the plant still contains high concentrations of nitrogen, which can cause instability in mainstream treatment processes and additional energy and chemical costs. A laboratory scale treatment system was developed in this research thrust that included anaerobic digestion, precipitation of struvite from the digester effluent, nitritation or nitrification of the liquid effluent from the struvite precipitation, and a microbial fuel cell (MFC) with nitrite/nitrate serving as the electron acceptor in the cathode. For this research, nitrogen removal and energy recovery was achieved using a proof-of-concept fixed-film nitrification and microbial fuel cell (MFC) process. Fixed-film nitrification and MFC together removed 52% of nitrogen from the liquid effluent of ESP, while the MFC generated 0.3 mW power per m^2 of anodic surface area. This process was not energy-neutral, as energy input for aeration was greater than the energy output from the MFC. However, the goal of energy neutrality may be advanced beyond this proof-of-concept study by reducing the energy input for aeration and increasing energy output through further improvement of MFC performance. This was the first study to our knowledge that demonstrated how fixed-film nitrification and MFCs can be used to treat the liquid effluent from engineered struvite precipitation to recover energy and remove nitrogen, while simultaneously reducing the undesirable recycling of nutrients from sidestreams back to mainstream treatment.

Demonstration: Deployment of a pilot-scale system at the Northwest Hillsborough Water Reclamation Testbed Facility (Tampa, FL) took place in 2018. The demonstration MFC is a revised version of a technology that was first developed in the USF laboratory as part of this project. The system was constructed in January and February 2018, was restarted in April 2018, and was operational through the end of 2018. The technology was modified based on engagement with, and input from the Hillsborough County Public Utilities. The microbial fuel cell demonstration configuration consists of two 500-mL chambers (anode and cathode) separated by a proton exchange membrane and connected by a wire. The electrodes inside the chambers were constructed of 0.5 mg/cm^2 60 % platinum on Vulcan-Carbon paper with a 12.5 cm^2 surface area. Anode and cathode were inoculated with pure culture of *Shewanella putrefaciens* and *Geobacter metallireducens* respectively and initially fed with synthetic wastewater and broth. Both the anode and cathode chambers are bubbled with nitrogen gas to flush out oxygen. Once, the system stabilized, synthetic wastewater was replaced with raw wastewater in the anode and aerobically digested sidestream in the cathode. Voltage and current are measured with Keithley 2701 digital multimeter. Samples from anode and cathode chambers are collected twice a week and tested for COD and nitrogen to assess nutrient removal in the MFC.

We successfully showed that a demonstration-scale microbial fuel cell can achieve 100% removal of nitrate from samples of the "sidestream" of the Biosolids Management Facility, while simultaneously generating a low current of electricity. If applied at full scale, this could prevent the recycle of nitrate from the Biosolids Management Facility to the mainstream treatment process of the Northwest Regional Water Reclamation Facility (NWRWRF), which is important for two reasons: (1) it decreases the overall nitrogen loading to NWRWRF and thereby decreases the associated costs of nitrogen removal, and (2) the presence of nitrate in the sidestream is believed to interfere with fermentation, a key step in biological phosphorus removal at NWRWRF, so removal of nitrate should improve biological phosphorus removal. These findings may apply to other wastewater treatment plants nationwide that use aerobic digestion for sludge stabilization.

Products Related to Science and Demonstration of Research Thrust 1c:

1. Orner, K. D., Ozcan, O. Y., Saetta, D., Boyer, T. H., Yeh, D. H., Anderson, D., & Cunningham, J. A. (2017). House of quality planning matrix for evaluating wastewater nutrient management technologies at three scales within a sewershed. Environmental Engineering Science, 34(11), 773-784. https://doi.org/10.1089/ees.2017.0016
2. Orner, K., Cools, C., Balaguer-Barbosa, M., Zalivina, N., Mihelcic, J.R., Chen, G., Cunningham, J.A. (2019). Energy Recovery and Nitrogen Management from Struvite Precipitation Effluent via Microbial Fuel Cells. *Journal of Environmental Engineering*, in press. (this manuscript was accepted on August 29, 2018 and will be published in 2019; doi:10.1061/(ASCE)EE.1943-7870.0001500
3. Orner, K.D. (2019). Removal and Recovery of Nutrients from Wastewater in Urban and Rural Contexts, PhD Dissertation, Department of Civil & Environmental Engineering, University of South Florida, Tampa. (thesis will be made available in 2019).
4. Cunningham J.A., Orner K.O., Mihelcic J.R. Struvite Precipitation and Microbial Fuel Cell for Recovery of Nutrients and Energy from Digester Effluent. United States Non-

Provisional Patent Application No. 15/943,427 filed on April 2, 2018. https://patentimages.storage.googleapis.com/df/12/56/7548258b50a8b6/US20180282189A1.pdf

5. One additional student dissertation will be published in 2019 that results from the science and demonstration (Helene Kassouf)

8.2 Research Thrust 2: Sustainable Management of Diffuse Sources of Nutrients

Overview: The fundamental research question for Research Thrust Area 2 was what innovative and sustainable non-point source nutrient management technologies and strategies could be developed, demonstrated, and evaluated to support low impact development technology for stormwater management and also for on-site wastewater treatment systems. Social, economic, and environmental costs, benefits, and implementation potential of the technologies and strategies innovated in Research Thrust 2 were evaluated using system-based approaches including life cycle environmental and cost assessment, an integrated modeling decision support framework, and socioeconomic analysis as described in Research Thrust 3.

8.2.1 Research Thrust 2a: Development of a Stormwater Management System that Maximizes Overall Nutrient Removal under Varying Hydraulic Antecedent Dry Conditions

Motive: Develop low impact development (LID) systems that maximize overall nutrient removal rates under varying hydraulic and pollutant loading conditions and antecedent dry conditions.

Science: Results from laboratory tracer and reactive column studies with gravel and wood chip medium revealed dispersivity values that are an order of magnitude larger than dispersivity values common to natural porous media such as sand filters. High dispersivity can result in significant nitrate mass bypass where solutes exit without spending sufficient time for nitrate removal. This information is useful for those who design the volume and depth of these systems by targeting average detention time. Free-draining bioretention systems commonly demonstrate poor nitrate removal. In this study, column tests verified the necessity of a permanently saturated zone to target nitrate removal via denitrification. Experiments determined a first-order denitrification rate constant of 0.0011/min specific to Willow Oak woodchip media. A 2.6-day retention time reduced 3.0 mg-N/L to below 0.05 mg-N/L since influent water has a longer contact time in IWSZ. During simulated storm events, hydraulic retention time may be used as a predictive measurement of nitrate fate and removal. A minimum 4.0hour retention time was necessary for in-storm denitrification defined by a minimum 20% nitrate removal. Additional environmental parameters, e.g., pH, temperature, oxidation-reduction potential, and dissolved oxygen, affect denitrification rate and response, but macroscale measurements may not be an accurate depiction of denitrifying biofilm conditions. A simple model was developed to predict annual bioretention nitrate performance. Novel bioretention design should incorporate bowl storage and large subsurface denitrifying zones to maximize treatment volume and contact time.

Demonstration: The demonstration was the result of a two-year study of two side-by-side full-scale bioretention designs located in Tampa (Florida) that were operated for two years before we began our demonstration study (January 2016 – December 2017). The demonstration takes place in the low-income community of East Tampa (FL). The two designs are a conventional bioretention system and a modified system designed specifically for nitrogen removal. Both systems evaluated here operate in a gravity flow hydraulic configuration. Both have an upper sand layer to support nitrification and the modified system has a permanently saturated layer located below the sand layer that is augmented with wood chips that supplies organic carbon into the aqueous phase to promote denitrification. This saturated layer is referred to as the internal water storage zone (IWSZ). We have also assessed both system in a planted and unplanted configuration and under different hydraulic loading rates and antecedent dry conditions (i.e., the amount of dry days in between rainfall events).

The results of individual nitrogen species and DOC influent and effluent concentrations from 20 storm events (14 in systems not planted and 6 in systems that were planted) are being summarized in a journal paper and dissertation. Overall, the NOx mass removal efficiency for the modified system (81±19%) was observed to be significantly higher than the conventional system (29±56%). Similarly, the TN mass removal efficiency (77±10%) for the modified system was observed to be significantly higher than the conventional system (44±15%). The performance of the full-scale modified bioretention system operated in the field is also better or equal to performance reported for bench-scale systems with similar media. For the planted and unplanted systems (Figure 2), in the modified system, the median NOx removal was determined to be the same (89%) for planted and unplanted system; however, the average removal was higher for the planted system at 88% compared to 78% for the unplanted system. For the conventional system, the median NOx removal increased from 36% to 59% after the system was planted, with the average NOx removal also increasing from 15% to 58%.

Modeling of the hydraulics and biochemical removal of nitrogen using HYDRUS 1D is also taking place and will be completed by the end of January, 2019. For that work, we have already calibrated our HYDRUS 1D model to a tracer study we performed in the field. We are currently calibrating our model to the nitrogen removal data and expect that to be completed by the end of 2018. After that we plan to use the model to present results from realistic scenarios that estimate the performance of our modified bioretention system design when considering variables such as size of the sand layer and the IWSZ of the reactor (which impact capital cost), intensity of precipitation events, and changing climate.

Activities with youth and adult programs from the Corporation to Develop Communities of Tampa, Inc. were conducted every year at the demonstration site. This included addition of signage related to inform the public about the bioretention system/rain garden, activities on the importance of treating urban stormwater runoff, the use of low impact development and green infrastructure for managing and treating stormwater runoff, and maintenance of the plants in the rain garden. The demonstration project is part of a larger effort of our group's effort in East Tampa. East Tampa is a 7.5 square mile majority African American community within the City of Tampa. The majority of the students enrolled in the K-12 schools we work with in East Tampa qualify for free school lunches. Center partners with the Corporation to Develop Communities of Tampa, Inc. (CDC) to train non-traditional adult learners to implement green infrastructure. This training is incorporated into a 6-week adult workforce development program on construction that is offered through the CDC's Tampa Vocational Institute (TVI) (https://www.youtube.com/watch?v=usf8VHKQuUg).

The demonstration and CDC training activities supported by the Center are part of a larger effort supported by other grants that has: 1) installed 9 raingardens in East Tampa (schools, homes, and community center). 6th and 7th grade students from Young Middle Magnet Science Summer Camp were seen installing a raingarden at their school here (http://ryanlocicero.com/rain-garden-installation-video/), 2) developed an educational kiosk for Young Middle Magnet school that provides information on the function of their rain garden and describes the benefits green infrastructure has on the overall health of the Tampa Bay watershed, 3) provided a structured research, education and professional development experience for over 24 middle and high school science and math teachers from the Hillsborough County Public Schools that was focused on sustainable management of water resources, 4) developed seven K-12 science/math curriculums around stormwater (e.g., https://www.teachengineering.org/lessons/view/usf_stormwater_lesson01), and 5) transferred this K-12 curriculum to student friendly e-learning suites that bring the science content to life on a computer screen (http://www.coedu.usf.edu/it/ware/WARE/story.html).

Products Related to Science and Demonstration of Research Thrust 2a:

1) Igielski, S.J. (2016). *Understanding Urban Stormwater Denitrification in Bioretention Internal Water Storage Zones.* MS Thesis, Department of Civil & Environmental Engineering, University of Maryland College Park. http://hdl.handle.net/1903/18824
2) Igielski, S., Kjellerup, B. V., & Davis, A. P. (2019). Understanding urban stormwater denitrification in bioretention internal water storage zones. Water Environment Research, 91(1), 32-44. https://doi.org/10.2175/106143017X15131012188024
3) Lopez-Ponnada, E.V., Lynn, T.J., Peterson, M., Ergas, S.J., Mihelcic, J.R. (2017). Application of denitrifying wood chip bioreactors for management of residential non-point sources of nitrogen. *Journal of Biological Engineering*, 11(1), 16. doi:10.1186/s13036-017-0057-4
4) Lopez-Ponnada, E.V., Ergas, S.J., Trotz, M.A., Barton, F., Mihelcic, J.R. (2017). Enhanced Management of Nitrogen in Urban Stormwater Runoff through a Field Demonstration of a Modified Bioretention System. *Proceedings of the Water Environment Federation*, 2017(3), 156-160. doi: 10.2175/193864717821494718

5) Lopez-Ponnada, E.V., Ergas, S.J., Nachabee, M., Payne, K.A., Mihelcic, J.R. Innovating Infrastructure for Management of Nitrogen Found in Stormwater: Long-Term Field Performance of a Full-Scale Modified Bioretention System. *Proceedings of the Stormwater and Green Infrastructure Symposium 2019*, May 8-10, 2019, Ft. Lauderdale, FL.Lopez, E.,
6) Lynn, T., Peterson, M., Ergas, S., Trotz, M., Mihelcic, J. (2016) Enhanced Nutrient Management of Stormwater through a Field Demonstration of Nitrogen Removal in a Modified Bioretention System. World Environmental and Water Resources Congress 2016, pp. 60-69. doi:10.1061/9780784479865.007
7) Lynn, T.J., Ergas, S.J., Nachabe, M.H. (2016). Effect of Hydrodynamic Dispersion in Denitrifying Wood-Chip Stormwater Biofilters. *J. Sustainable Water in the Built Environment – ASCE*, 2(4), 1-7. https://doi.org/10.1061/JSWBAY.0000812
8) Lynn, T.J., Nachabe, M.H., Ergas, S.J. (2017). Modeling Denitrifying Stormwater Biofilters Using SWMM5. *Journal of Environmental Engineering*, 143(7), 04017017. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001209
9) One student dissertations will be published in 2019 that results from the demonstration (Emma Lopez-Ponnada) and two additional journal publications will be submitted related to the demonstration.

8.2.2 Thrust 2b - Optimization of Onsite Wastewater Treatment Systems for Nutrient Removal

Motive: Develop onsite wastewater treatment systems that consider nutrient management and can withstand highly transient loading conditions and long idle periods using hybrid ion exchange-biological treatment processes.

Science: Conventional onsite wastewater treatment systems (i.e., septic systems) are often hindered by limited nitrogen removal and transient loadings. Hybrid Adsorption and Biological Treatment Systems (HABiTS) are an option for passive enhancement of these systems while keeping their simplicity, low maintenance and low chemical and energy inputs. HABiTS utilize an ion exchange (IX) medium that also serves as a biofilm carrier. During high loading rate periods, the medium adsorbs ionic N species (NH_4^+ or NO_3^-) in excess of the biodegradation capacity of the biomass. During low loading rate periods, the medium slowly releases substrate to support the microbial population. Two stage HABiTS were investigated in this research that provide: 1) nitrification in an aerobic trickling filter containing expanded clay particles and a natural zeolite material, clinoptilolite, which is used as an NH_4^+ IX medium followed by 2) denitrification in a submerged packed bed reactor containing scrap tire chips used as a NO_3^- IX medium with sulfur pellets and crushed oyster shells to promote sulfur oxidizing denitrification (SOD).

Side-by-side bench-scale column studies were conducted under transient loading conditions with 2-stage HABiTS reactors and packed bed reactors without IX materials. Batch IX kinetics and IX isotherm studies were used to determine adsorption rates and capacities of candidate IX materials. A mathematical model describing contaminant mass transport and mixotrophic denitrification for a tire-sulfur hybrid adsorption and denitrification (T-SHAD) reactor was developed and compared to experimental results. Additional batch and column studies were conducted with Particulate Pyrite Autotrophic Denitrification (PPAD) to reduce the sulfate production and alkalinity consumption observed due to SOD. Results of these studies showed that: 1) Enhanced NH_4^+-N removal (80%) was observed in a HABiTS laboratory column that combined expanded clay and clinoptilolite compared with a control column with only expanded clay (73%) during phases with high nitrogen loads, 2) During lower hydraulic loading rates nitrification becomes the predominant treatment resulting in equal performance of both treatments, 3) HABiTS reactors also had significantly faster start up times and recovery after an idle period (e.g. after a vacation) than controls without IX, 4) The integration of a denitrification stage resulted in significantly higher total nitrogen removal in HABiTS (53%) than the control treatment (39%), 5) The model developed captured the trend of the experimental data showing approximately 90% NO_3^- removal under varying flow conditions. Moreover, the model describes the effluent characteristics of the process showing a transient response in correspondence the changes in fluid velocity, 6) Batch and column studies showed that denitrification rates for PPAD were slower than for SOD. However, PPAD had lower alkalinity consumption and sulfur by-product formation (SO_4^{2-}, S^{2-} and SO_3^{2-} plus $S_2O_3^{2-}$) than SOD, and 7) Organic carbon addition improved PPAD denitrification performance, possibly by promoting mixotrophic metabolism. SEM images and biofilm protein measurements indicated that the presence of oyster shells enhanced biofilm growth in PPAD columns.

Demonstration: A pilot scale demonstration was used to assess the HABiTS technology in the field and test its effectiveness for nitrogen removal with and without stage 1 recirculation. The local test site was located at the Northwest Hillsborough County Advanced Wastewater Treatment Testbed Facility. Each system consisted of two stages: 1) Nitrification in an aerobic trickling filter containing expanded clay particles, crushed oyster shells and a natural zeolite material, clinoptilolite, which is used as an NH_4^+ IX medium followed by 2) 2) Denitrification in a submerged packed bed reactor containing scrap tire chips used as a NO_3^- IX medium with sulfur pellets and crushed oyster shells to promote sulfur oxidizing denitrification (SOD).

The systems were set up based on the bench and column studies described in the science section. Crushed oyster shells were added to both stages 1 and 2 to reduce alkalinity limitations encountered during the bench-scale studies. Prior research by others had demonstrated that effluent recirculation in the nitrification stage can improve system performance by: 1) promoting pre-denitrification, which reduces organic carbon loading on stage 1 and NO_3^- loading on stage 2,

(2) increasing the mass transfer rate of substrates (NH_4^+, oxygen) to the biofilm, and 3) maintaining the optimal biofilm thickness by shearing excess biofilm from the medium. However, Stage 1 effluent recirculation adds energy costs and complexity therefore pilot-scale HABiTS were tested with and without recirculation.

The systems were started in June 2017 and the demonstration was completed in October 2018. Preliminary results from the demonstration showed that: 1) The system with recirculation removed consistently more NH_4^+ (> 80%) than the system without recirculation (57%), 2) Recirculation ratios of 6:1, 1:1 and 3:1 (recirculation flow rate: influent flow rate) all improved total nitrogen removal compared to no recirculation, 3) An average of 81% of total inorganic nitrogen (TIN) removal from the system influent was seen in the recirculation system's final effluent when compared to an average of 55% in forward flow system's final effluent, 4) Complete denitrification was observed in both systems, NO_2^- and NO_3^- concentrations were consistently below method detection limits, 5) The effect of transient loadings were evaluated by collecting samples from all stages of the reactors each hour during the morning (high loading rate), afternoon (moderate loading rate) and evening (very high loading rate). The results showed that both systems had consistent low effluent nitrogen species concentrations, supporting our hypothesis that combining IX and BNR buffers transient loading on the system, 6) Backwashing studies showed that the system with recirculation had very low excess biomass production, supporting the hypothesis that Stage 1 effluent recirculation helps to maintain low biofilm thickness without backwashing, 7) Similar to the bench-scale studies, HABiTS reactors had fast start up and short recovery after an idle period, 8) High *E. coli* removals were observed with recirculation (1.5 log) than without recirculation (0.95 log). *E. coli* removal was higher in pilot-scale reactors than in bench scale studies. Currently effluent disinfection using simple tablet feeder chlorination systems are being evaluated to assess whether HABiTS effluent can consistently meet irrigation reuse standards.

Students working on this project attended workshops offered by the Florida Onsite Wastewater Association (FOWA) involving onsite system installation requirements, certifications and regulations. They followed up with septic tank installers, homeowners and regulators to gain input on the design and operation of OWTS. Dr. Ergas and students working on the project participated in the Kings Bay (FL) Springs Technical Working Group. This provided a forum for discussion with local stakeholders regarding the impacts of OWTS and potential applications of passive onsite nitrogen removal systems in Florida springsheds. Two onsite wastewater pilot tours were held at the demonstration on October 22, 2017 and November 6, 2017. The October 22nd tour was concurrent with a meeting of the Soil Science Society of America, which was held in Tampa Bay. Participants included engineering consultants, regulators, municipal utility staff, regulators, faculty and students.

Products Related to Science and Demonstration of Research Thrust 2b:

1) Tong, S., Stocks, J.L., Rodriguez-Gonzalez, L.C., Feng, C, Ergas, S.J. (2017). Effect of oyster shell medium and organic substrate on the performance of a particulate pyrite autotrophic denitrification (PPAD) process. *Bioresource Technology*, 244(2017): 296-303. doi:10.1016/j.biortech.2017.07.109

2) Tong, S., Rodriguez-Gonzalez, L.C., Feng, C., Ergas, S.J. (2017). Comparison of Particulate Pyrite Autotrophic Denitrification (PPAD) and Sulfur Oxidizing Denitrification (SOD) for Treatment of Nitrified Wastewater. *Water Science & Technology*, 75(1): 239-246. doi:10.2166/wst.2016.502

3) Tong, S., Rodriguez-Gonzalez, L.C., Payne, K.A., Stocks, J.L, Feng, C., Ergas, S.J. (2018). Effect of pyrite pretreatment, particle size, dose and biomass concentration on particulate pyrite autotrophic denitrification (PPAD) of nitrified domestic wastewater. *Environmental Engineering Science*, 35(8):875-886. https://doi.org/10.1089/ees.2017.0295

4) Rodriguez-Gonzalez, L., Payne, K., Trotz, M., Anderson, D. Ergas, S.J. (2015). Hybrid Adsorption Biological Treatment Systems (HABiTS) for Improved Nitrogen Removal in Onsite Wastewater Treatment. *Proceedings of the Water Environment Federation, 11:4660-4672*, dx.doi.org/10.2175/193864715819557632

5) Rodriguez-Gonzalez, L., Payne, K., Trotz, M., Anderson, D. Ergas, S.J. (2016). Hybrid Adsorption and Biological Treatment System (HABiTS) for Enhanced Nitrogen Removal in Onsite Wastewater Treatment Systems. *Proceedings of 13th IWA Specialized Conference on Small Water & Wastewater Systems*, Athens, Greece. https://pdfs.semanticscholar.org/82d1/75d08f451e6b1a793d398f3508ebf4131cd0.pdf

6) Henderson, M.B. (2017) *The Fate of Fecal Indicator Bacteria in Passive Nitrogen Reduction Systems*. MS Thesis, Department of Civil & Environmental Engineering, University of South Florida, Tampa. https://scholarcommons.usf.edu/etd/6858

7) Miriyala, A. (2018) *Impact of Recirculating Nitrified Effluent on the Performance of Passive Onsite Hybrid Adsorption and Biological Treatment Systems*. MS Thesis, Department of Civil & Environmental Engineering, University of South Florida, Tampa. (thesis will be made available in 2019).

8) Payne, Karl (2018) *Mathematical and Numerical Modeling of Hybrid Adsorption and Biological Treatment Systems for Enhanced Nitrogen Removal*. PhD Dissertation, Department of Civil & Environmental Engineering, University of South Florida, Tampa. (dissertation will be made available in 2019).

9) Rodriguez-Gonzalez, L.C. (2017) *Advanced Treatment Technologies for Mitigation of Nitrogen and Off-flavor Compounds in Onsite Wastewater Treatment and Recirculating Aquaculture Systems*. PhD Dissertation, Department of Civil & Environmental Engineering, University of South Florida, Tampa. http://scholarcommons.usf.edu/etd/6941

10) Stocks, J. (2017) *Enhancement of Two Passive Decentralized Biological Nitrogen Removal Systems*. MS Thesis, Department of Civil & Environmental Engineering, University of South Florida, Tampa. http://scholarcommons.usf.edu/etd/7093

11) Rodriguez-Gonzalez, L.C., Miriyala, A., Rice, M., Delgado, D., Marshall, J., Henderson, M., Ghebremichael, K., Mihelcic, J.R., Ergas, S.J. (2019). "A Pilot-Scale Hybrid Adsorption Biological Treatment System (HABiTS) for Nitrogen Removal in Onsite Wastewater Treatment," *Journal of Sustainable Water in the Built Environment*.

Output Related to Science and Demonstration of Research Thrust 2b:

1. Drs. Ergas and Mihelcic, Damann Anderson, Josefin Hirst, Karl Payne and Laura Rodriguez-Gonzalez organized a workshop on Onsite Nutrient Removal at the Water Environment Federation Nutrient Symposium in Ft. Lauderdale FL in 2017. The workshop included 14 platform presentations, 4 posters, and a panel discussion. The workshop was attended by approximately 50 people, including consultants, installers, regulators, faculty and students.
2. Center Researchers (Dr. Sarina Ergas, Dr. Treavor Boyer) are serving as guest editors for "Special Collection on Onsite and Decentralized Wastewater Management Systems" that will appear in the Journal of Sustainable Water in the Built Environment featuring research related to onsite and decentralized wastewater management to provide greater opportunities for sustainable urban water utilization. Papers are being submitted for review and special issue will be published in 2019. (Flyer attached in the Appendix A)

8.2.3 Thrust 2c - Nutrients in Stormwater from Residential Catchments

Motive: Quantify the release of nutrients from residential yards in a socio-economic and fertilizer policy context, with specific focus on using an ongoing study for the four counties near Tampa Bay. No funds were set aside in the Center budget for this activity.

Discussion: Identify how socio-economic factors influence fertilizer application and leaching rates. Ranges of nutrient concentration associated with residential stormwater were compiled from the literature and showed 0.33 to 6.67 mg TN/L and 0.02 to 0.92 mg TP/L. This review revealed several important knowledge gaps. No correlation was found between residential system nutrient loss reported in the literature and environment and social and demographic factors.

Products Related to Science and Demonstration of Research Thrust 2c:

Butcher M.R. (2014). *Diffuse Nutrient Pollution from Residential Catchments*. MS Thesis. Department of Civil and Environmental Engineering, University of South Florida, Tampa, FL, June 16, 2014 http://scholarcommons.usf.edu/etd/5194

8.3 Research Thrust 3 - Socioeconomic & Environmental Sustainability Analysis and Systems Integration

Overview: The two fundamental research questions for Research Thrust Area 3 were: 1) What are the social, environmental and economic benefits and costs of innovative point source and diffuse source nutrient management practices, and how do they compare with benefits and costs of nutrient removal at centralized treatment plants? 2) What do the benefits and costs of such nutrient management practices imply about the incentives for their adoption by households, businesses, and local and state public managers, and how can this information be used to develop innovative policies, pedagogical tools, and community outreach programs to encourage their use?

8.3.1 Thrust 3a - Life Cycle Environmental Impact and Cost Analysis for Nutrient Removal and Recovery Technologies

Motive: Estimate life cycle environmental impacts and costs associated with point source nutrient recovery systems considered in Research Thrust 1 and diffuse source nutrient management technologies considered in Research Thrust 2 at different scales. This research compared economic and environmental impacts for a variety of endpoints per pound of nitrogen and phosphorus recovered (for distributed-scale recovery systems) or reduced (for non-point source nutrient management systems) with the environmental and economic costs of recovery or reduction at the centralized treatment system.

Work completed to date: The following tasks have been completed including 1) LCA of urine separation using improved waterless urinals and no-mix toilets by Dr. Boyer's research group from Thrust 1, 2) LCA and LCCA of AeMBR and AnMBR for discharge and reuse scenarios, 3) LCA and LCCA of OWTS that compares conventional systems with advanced ones, 4) LCA and LCCA of alternative bioretention system configurations with various depths of denitrification zone and on-ground plant species, 5) model selection for spatial nutrient-loading evaluation in the Tampa Bay area, and 6) creation of current green infrastructure inventory in Tampa for further spatial optimization of green stormwater infrastructure.

The life cycle environmental impacts of decentralized nutrient management approach using urine separation and struvite precipitation was compared with a centralized wastewater treatment approach in Task 1. It was found that urine source separation with high P recovery in struvite precipitation with MgO addition has the lower environmental impact compared to the centralized wastewater treatment and the environmental benefit of P offsets is greater than that of N offsets. Task 2 compared life cycle environmental impacts and costs of AeMBR and AnMBR for discharge scenario and reuse scenarios of irrigation for different crops. It was found that in general AeMBR has better environmental and economic performance than AnMBR for discharge scenario and the performance of AnMBR in reuse scenarios highly depends on the nutrient requirement of crops. Designing a reuse scenario matching the nutrient requirement of a crop to the effluent nutrient concentration of AnMBR greatly reduced environmental and economic impacts of AnMBR. Task 3 evaluated the environmental and economic impacts of conventional OWTSs (with different septic tank and drainfield materials) and advanced OWTSs (with aerobic treatment units and passive nitrogen reduction systems) under different soil and temperature conditions. The results demonstrated a tradeoff between nutrient management (reduced freshwater and marine eutrophication) and life cycle costs and other environmental impact categories. The advanced system had lower impacts than conventional OWTSs when the TN removal in the drainfield was lower than 20%. Task 4 investigated the influence of the depth of internal water storage zone (IWSZ) and ground plant species on the life cycle environmental impacts and costs of bioretention systems. Similar as the study of OWTS, better nutrient management (lower effluent nutrient concentration and eutrophication potential) is achieved at the expense of higher life cycle costs and other environmental impact categories. It was also found that the depth of 45cm for IWSZ has the highest marginal benefits and the influence of ground plant species is insignificant in terms of bioretention's nutrient removal.

Two nutrient-loading evaluation models for the Tampa Bay area were evaluated in Task 5. SPARROW model as a statistical model was selected in the further optimization study due to its moderate computation time, complexity, and its application in Thrust 3b. Leveraging the funding from the Department of Transportation, a GIS-based framework was developed in Task 6 for creating green stormwater infrastructure relevant to surface transportation planning. The green infrastructure inventory for the Middle Hillsborough River-Spillway 20 subwatershed area (HUC12 code: 031002050503) was created. It was found that a limited number of green infrastructures were implemented along the major roads with most of the implemented green infrastructure as wet ponds.

Work in progress. Currently we are completing projects that: 1) conduct a spatial optimization for the implementation of bioretention systems that are selected as a technology example, and 2) conduct a literature review on the sustainability assessments and decision making of green infrastructure at the system level.

Products Related to Science and Demonstration of Research Thrust 3a:

1. Cornejo, P.K., Zhang, Q., Mihelcic, J.R. (2016). How Does Scale of Implementation Impact the Environmental Sustainability of Wastewater Treatment Integrated with Resource Recovery? *Environmental Science & Technology*, 50(13), 6680-6689. doi: 10.1021/acs.est.5b05055

2. Diaz-Elsayed, N., Xu, X., Balaguer-Barbosa, M., Zhang, Q. (2017). An Evaluation of the Sustainability of Onsite Wastewater Treatment Systems for Nutrient Management. *Water Research*, 121, 186-196. https://doi.org/10.1016/j.watres.2017.05.005
3. Wang, R., Zimmerman, J.B. (2015) Economic and Environmental Assessment of Office Building Rainwater Harvesting Systems in Various U.S. Cities. *Environmental Science and Technology*, 49 (3): 1768-1778. doi: 10.1021/es5046887
4. Xu, X., Schreiber, D., Lu, Q., & Zhang, Q. (2018). A GIS-Based Framework Creating Green Stormwater Infrastructure Inventory Relevant to Surface Transportation Planning. Sustainability, 10(12), 4710. https://doi.org/10.3390/su10124710
5. Xu, X. Zhang, Q. (2019). Sustainable Configuration of Bioretention Systems for Nutrient Management through Life Cycle Assessment and Cost Analysis. Journal of Environmental Engineering. doi:10.1061/(ASCE)EE.1943-7870.0001526
6. Xu, X., Dao, H., Bair, R., Uman, A., Yeh, D., Zhang Q. (2019) Discharge or Reuse? Comparative Sustainability Assessment of Anaerobic and Aerobic Membrane Bioreactors. submitted in January 2019 to *Journal of Environmental Quality* for special issue organized by EPA funded Nutrient Centers.
7. An additional one dissertation (X. Xu) and one publication will come from this research in 2019.

8.3.2 Thrust 3b - Integrated Analytical, Hydroeconomic Modeling Frameworks to Analyze the Cost Effectiveness of Nutrient Removal and Recovery Technologies

Thrust 3b.1 Motive: Develop an analytical model that provides a framework for quantifying the economic benefits of nutrient recovery and water reuse from point source nutrient management approaches. Apply this model to recover aggregate estimates of the market value of recovered N and P and the implicit value of water reuse (its "shadow price" to residential and other potential end users) for nutrient recovery technologies considered in Research Thrust 1.

Work completed: To date we have completed: 1) development of the analytical hydroeconomic model of an optimal "closed system" with a point source and 2) revised and published an econometric analysis of the determinants of water reuse adoption in Florida.

Thrust 3b.2 Motive:

Implement partial benefit-cost analysis (quantifying private benefits and costs to households, businesses, and other parties) for each nutrient recovery technology considered in Research Thrust 1, by pairing the benefit estimates for nutrient recovery and water reuse from the analytical model with life cycle cost estimates. Evaluate the private incentive structure suggested by benefit-cost analysis of point-source nutrient management technologies, considering likelihood of adoption by

Tampa-area homes, businesses, as well as likely participation in any resulting markets for recovered nutrients and water by agricultural entities

Products Related to Science and Demonstration of Research Thrust 3b:

1. Kuwayama, Y., Kamen, H. (2016). What drives the reuse of municipal wastewater? A county-level analysis of Florida. *Land Economics*, 92 (4), 679-702. doi: 10.3368/le.92.4.679
2. Kuwayama, Y., Olmstead, S. Hydroeconomic modeling of resource recovery from wastewater: Implications for water quality and quantity management. submitted in January 2019 to *Journal of Environmental Quality* for special issue organized by EPA funded Nutrient Centers.

8.3.3 Thrust 3c. Scaling up of integrated hydroeconomic modeling frameworks to nutrient management problems in Tampa Bay, FL

Thrust 3c.1 Motive: Develop a nested water quality modeling framework which combines catchment-scale modeling of impacts of nutrient management technologies in Research Thrust 2 (using SWMM5) with a watershed-scale model (SPAtially Referenced Regressions On Watershed attributes, SPARROW). Use the nested modeling framework to quantify the impact of non-point source nutrient management (such as reducing bioretention pond or on-site septic flows) on nutrient loading to Tampa Bay.

Work completed: To date we have: 1) collected sewer pipeline network data, including age information, from City of Tampa, Hillsborough County, and Manatee County. Pinellas County data request is pending, 2) collected multi-year (2005-2014) land parcel data for City of Tampa, Hillsborough County, Manatee County and Pinellas County, 3) collected block level Census population and housing unit data for years between 2000 to 2010 (extrapolated for 1999-2000 and 2010-2014), 4) estimated population connected to sewer pipeline for years between 1999 and 2014, and 5) estimated population adopted onsite wastewater treatment system (septic tank) for years between 1999 and 2014. These estimations will replace previous septic tank inventory data from Florida Department of Health as one of the RHS nutrient source variables in the dynamic SPARROW model.

Work in progress: Currently we are completing projects that: 1) verify the sewered population we estimated, 2) continue to request sewer pipeline network data from Pinellas County, 3) continue progress on developing dynamic SPARROW model with USGS. Working on model calibration using load estimates and sewer connected population data developed previously. (2) Continue to develop methods to include nutrient sources reduction from green infrastructure. This work will be ongoing through the end of 2018.

Thrust 3.c.2 Motive: Integrate cost and benefit information with the nested SWMM/SPARROW water quality modeling framework and develop a mathematical model for the optimal spatial allocation of investments in nutrient management across technologies (point source nutrient recovery, non-point source nutrient management, and recovery/treatment at the centralized WWTP). Model optimal allocation of nutrient management investments for multiple scenarios of reductions in nutrient loading to Tampa Bay.

Work in progress: To date we have: 1) collected nutrient control and management cost data across technologies, including point source recovery, non-point source nutrient management, recovery/treatment at the centralized WWTP and green infrastructure, to develop cost functions. The sources of cost data include results from Thrust 3a activities, state agencies, and existing economic and engineering literature, 2) incorporated benefit information developed in Thrust 3c4, 3) incorporated technology and management strategy impact on water quality information from Thrust 3c.2, and 4) developed a multi-objective optimization decision support system for optimal siting and allocation of nutrient management investments. This work will be on going through the spring 2019.

Thrust 3.c.3 Motive: Monetize the benefits of water quality improvements in Tampa Bay achievable through nutrient recovery technologies (Research Thrust 1), diffuse source nutrient management (Research Thrust 2), and nutrient recovery at the City of Tampa's centralized treatment plant, using benefit estimates from the economics literature.

Work completed: To date we have 1) reviewed literature on hedonic valuation of water quality, air quality, and natural resources, 2) as part of a hedonic analysis, we have collected residential property sale transaction data and GIS maps from property appraiser offices in Hillsborough, Pinellas, and Manatee counties, 3) collected water quality measurements in the Tampa Bay region from EPA STORET dataset, 3) obtained total nitrogen and total phosphorous data from USGS, public boat ramp location information from Florida Fish and Wildlife Conservation Commission, and seagrass transect data from the Tampa Bay Estuary Program (TBEP) for information on seagrass data, 5) used ArcGIS to link property sales and water quality measurements, 6) ran preliminary regressions on linked data using panel data methods, 7) estimated two-stage, repeat-sales hedonic housing models that incorporate both the recreational and amenity value of nutrient pollution reductions to households in the three counties, (8) Drafted a working paper using these hedonic models to estimate the monetized value of nutrient pollution reductions in the Tampa Bay region from 1998-2014.

Products Related to Science and Demonstration of Research Thrust 3c:

1. Kuwayama, Y., Olmstead, S. Hydroeconomic modeling of resource recovery from wastewater: Implications for water quality and quantity management. (planned to be submitted in 2019).
2. An additional one dissertation (Jiameng Zheng) will come from this research in 2019.

8.3.4 Thrust 3d. Reducing Social and Regulatory Barriers to Implementation of Innovative Nutrient Management Practices in Urban Coastal Watersheds.

Motive: Analyze local and state regulatory and other legal constraints to adoption of optimal allocation scenarios for nutrient management, identifying specific local and state policy changes that would be required in order to spur: 1) adoption by households and businesses; and 2) integration into regulatory compliance strategies by local, regional and state government institutions. We havey developed a framework for identifying the impact of federal, state, and local regulations and guidelines on specific nutrient management technologies and practices, accompanied by a case study for the Tampa Bay region. An RFF Working Paper describing the framework and case study is planned for publication in 2019.

Appendix A. Announcement for "Special Collection on Onsite and Decentralized Wastewater Management Systems" that will appear in the Journal of Sustainable Water in the Built Environment.

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Journal of Sustainable Water in the Built Environment
Special Collection on Onsite and Decentralized Wastewater Management Systems

Guest Editors: Sarina Ergas, University of South Florida, Tampa (sergas@usf.edu)
Eran Friedler, Technion Israel Institute of Technology (eranf@technion.ac.il)
Jose Amador, University of Rhode Island (jamador@uri.edu)
Treavor Boyer, Arizona State University (thboyer@asu.edu)

Submission Deadline: January 31, 2019

Aims and Scope

While sewerage systems are anticipated to expand over the next decades, it remains cost-prohibitive to connect many rural and suburban areas to centralized treatment facilities. Major benefits of on-site (e.g. septic) and decentralized systems include greater opportunities for groundwater recharge and recovery of water, energy and nutrients close to their source of generation. However, benefits must be balanced against risks to public health and water quality.

As a contribution to this important environmental and water resources engineering challenge, papers are invited for a special collection of the Journal of Sustainable Water in the Built Environment on sustainable on-site and decentralized wastewater management systems. Specific topics of interest include but are not limited to:

- Onsite and decentralized management of nutrients, pathogens and trace organics
- Evaluation of different scales and levels of treatment
- Management approaches for source separated urine, greywater and black water
- Recovery of nutrients, energy and water close to the source of generation
- Sewer mining approaches to water treatment and reuse
- Effects of climate change on onsite and decentralized systems
- Mechanistic, statistical and ecological modeling of onsite and decentralized systems
- Life cycle, economic and systems models of onsite and decentralized wastewater
- Regulatory approaches to onsite and decentralized wastewater management

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Appendix B. Details on EPA SSWR Water Research Webinar on Nutrient Recovery from Human Urine

EPA SSWR Water Research Webinar
Wednesday, December 14 (2-3 p.m. East Coast Time)

Systems View of Nutrient Management – Nutrient Recovery from Human Urine

Free registration link: (https://www.epa.gov/water-research/water-research-webinar-series).

Webinar Description. Urine is the primary source of phosphorus and nitrogen in municipal wastewater. Accordingly, it is important to consider for nutrient management. This webinar will cover new science on recovering nutrients from human urine. This includes issues of source separation in buildings, use at the farm, review of health issues, and factors influencing the environmental sustainability of nutrient management strategies. The webinar is an output of preliminary scientific research and demonstrations achieved from the EPA Science to Achieve Results (STAR) Centers for Water Research on National Priorities Related to a Systems View of Nutrient Management.

Agenda

1. **Introduction:** Dr. Colleen Naughton provides a brief introduction.
2. **Building:** Waterless urinals can serve a two-fold benefit of water conservation and implementation of urine source separation system. However, due to urine's composition and the presence of the urease enzyme that hydrolyzes urea, valuable nutrients readily precipitate in the urinal fixtures and pipes. This hinders both water conservation and nutrient recovery efforts because of maintenance problems. Dr. Treavor Boyer will review controlled laboratory experiments and a demonstration study that increases our understanding of the urea hydrolysis process in waterless urinals by mimicking and inhibiting urea hydrolysis so as to benefit water conservation and nutrient recovery.
3. **Environmental Sustainability:** Nutrients embedded in wastewater or stormwater can be managed via different technologies at different scales. Dr. Qiong Zhang will discuss the factors influencing environmental sustainability of nutrient management strategies including end applications, design configurations, implementation locations, and scale of implementations.
4. **Health:** Source separated urine typically contains pharmaceuticals and microorganisms. Dr. Krista Wigginton will review the occurrence of pharmaceuticals and microorganisms in source separated urine as it is transformed into fertilizer products. Her project team has studied the impact of storage, struvite precipitation, and pasteurization on the levels and types of contaminants in urine.
5. **Farm:** Source separated urine has been shown to work well as a crop fertilizer. Mr. Abraham Noe-Hays will discuss work on applying urine-derived fertilizer products to grow crops on a research farm in Vermont. Urine was collected from public toilets (>1,000 users) and turned into fertilizer. Lettuce and carrots were grown over two seasons in test field plots amended with urine, urine spiked with additional pharmaceuticals, urine-derived struvite, and synthetic fertilizer.
6. **Questions**

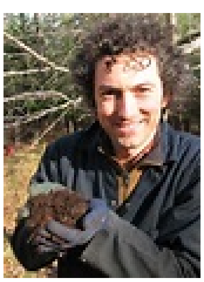
Presenters

Colleen Naughton, University of South Florida, National Center for Reinventing Aging Infrastructure for Nutrient Management. Dr. Naughton is a postdoctoral research associate in Civil and Environmental Engineering at the University of South Florida where she also serves as the administrative assistant for the National Center for Reinventing Aging Infrastructure for Nutrient Management. Her research is focused around the food-water-energy nexus and coupling natural and human systems, integrating environmental sustainability and ethnographic analyses with local and global issues of sustainable development.

Treavor Boyer, Arizona State University, National Center for Reinventing Aging Infrastructure for Nutrient Management. Dr. Boyer is an associate professor on the School of Sustainable Engineering and the Built Environment at Arizona State University. Before joining ASU, he was an Associate Professor in the Department of Environmental Engineering Sciences at the University of Florida. His research is broadly focused on water sustainability, and spans drinking water and wastewater treatment, and natural aquatic systems.

Qiong Zhang, University of South Florida, National Center for Reinventing Aging Infrastructure for Nutrient Management. Dr. Zhang is an associate professor of Civil and Environmental Engineering at the University of South Florida. Prior to joining USF, she worked as the operations manager for the Sustainable Futures Institute at Michigan Tech. She has sponsored research projects in the areas of green engineering and sustainability, life cycle assessment, waste-based resource recovery, system modeling of environmental technology adoption and critical infrastructures resiliency, and carbon footprint accounting of water and wastewater technologies and strategies.

Krista Wigginton, University of Michigan, WE&RF's National Research Center for Resource Recovery and Nutrient Management. Dr. Wigginton is an assistant professor of Civil and Environmental Engineering at the University of Michigan. Prior to joining the faculty at UM, she was an assistant professor at the University of Maryland, College Park. Her research focuses on applications of environmental biotechnology in drinking water and wastewater treatment. In particular, her research group develops new methods to detect and analyze the fate of emerging pollutants in the environment.



Abraham Noe-Hays, Rich Earth Institute, WE&RF's National Research Center for Resource Recovery and Nutrient Management. Mr. Noe-Hays is a founder of the Rich Earth Institute and has been working with dry sanitation systems since 1990. He holds a BA in Human Ecology with concentrations in agroecology and compost science from the College of the Atlantic, where his interest in recycling human manure led to an internship at Woods End Research Laboratory and his thesis project, “An Experiment in Thermophilic Composting.”

Appendix C. Details of Special Session Organized at 2018 WEF Nutrient Conference

Nutrient Removal and Recovery Conference 2018: Innovating, Optimizing, and Planning

June 18 – 21, 2018
Raleigh, North Carolina, USA
https://www.wef.org/nutrients

The following two EPA Center talks are already accepted for sessions on 1) Sustainability as a Driver for Planning and Decision Making, and 2) Reuse and Separation.

119	The Role of Location in Sustainable Nitrogen Removal for Onsite Wastewater Treatment Systems	Xiaofan	Xu (Qiong Zhang is PI)	University of South Florida
256	Advancing Nutrient Recovery through Urine-Derived Fertilizers (UDF) in the United States	Nancy	Love	University of Michigan

This is confirmed schedule for half-day session related to Center Research.

US EPA National Priorities Nutrient Management Centers:
Practical Outcomes from Five Years of Water Research Nationwide
(Co-Moderators Ben Packard, Amit Pramanik)
Thursday a.m. (June 21)

(5 mins) Ben Packard introduces Nutrient Center Concept to Audience

(20 mins) **Presentation title:** Smart nonwater urinals for improved water conservation and enhanced nutrient recovery

Presenter: Treavor Boyer, Associate Professor, Arizona State University

Co-authors: Daniella Saetta, Graduate student, Arizona State University; Hannah Ray, Graduate student, Arizona State University

Abstract: Urine diversion is the separate collection, storage, and treatment of human urine, typically with the goal of beneficially using the liquid urine or urine-derived products as fertilizer in agriculture. The benefits of urine diversion include water conservation because the urine is collected with minimal flush water, and resource recovery of nutrients because urine contains high concentrations of nitrogen (N) and phosphorus (P). Because the benefits of urine diversion are directly proportional to the volume of urine diverted and collected, the ideal location for implementing urine diversion is usually high-occupancy buildings such as apartments, schools, and office buildings. At the building-scale, urine can be separated at the point of generation using nonwater urinals and urine-diverting toilets. However, unforeseen problems can occur when nonwater urinals are installed in buildings. One of the biggest problems with nonwater urinals is their propensity to clog due to the spontaneous precipitation of undiluted urine salts. Due to the maintenance issues associated with urinal clogging, nonwater urinals have been replaced with water-flush urinals, ceasing their ability to function as part of a urine diversion system. Research has shown that acetic acid addition at the urinal decreases urine pH, creating unfavorable conditions for the urea hydrolysis, which is the process by which the urease enzyme hydrolyzes urea to form ammonia and bicarbonate, increasing urine pH from 6 to 9. Furthermore, by inhibiting urea hydrolysis the potential for nutrient recovery is enhanced because more P stays in solutions and N stays in the urea form. The goal of this project was to create a nonwater urinal testbed to evaluate the chemical addition technique that has proven to decrease precipitation-induced clogging of nonwater urinals. Specifically, (1) a cyber-physical system (CPS) with sensors and actuators was created to monitor urine chemistry in real-time, (2) actuator-controlled experiments were conducted to manipulate urine composition, (3) urine composition was tracked throughout the collection system to monitor urea hydrolysis and calculate losses within the urinal testbed, and (4) enhanced nutrient recovery potential was calculated and evaluated experimentally.

(25 mins) **Presentation title:** Management of Diffuse Nutrients from Stormwater and On-Site Wastewater: New Science and Community Engagement Informing Field Demonstrations of New Technologies

Presenter: Sarina Ergas, Professor, University of South Florida

Co-Authors: Maya A. Trotz[1], Qiong Zhang[1], James R. Mihelcic[1], Kebreab Ghebremichael[2], Damann Anderson[3], Laura Rodriguez-Gonzalez[1], Karl A. Payne[1], Michelle Henderson[1], Thomas Lynn[4], Amulya Miriyala[1], Justine Stocks[1], Emma Lopez-Ponnada[1]
[1]Civil & Environmental Engineering, University of South Florida, [2]Patel College of Global Sustainability, University of South Florida, [3]Hazen and Sawyer, [4]Department of Environmental Engineering, Texas A&M University-Kingsville

The National Center for Reinventing Aging Infrastructure for Nutrient Management has the mission to achieve sustainable and cost-effective health and environmental outcomes by re-imagining aging coastal urban infrastructure systems for nutrient recovery and management contributing to sustainable and healthy communities. The overall goal is to develop the science behind new technology and management innovations and a deeper understanding of the integrated systems, while demonstrating and assessing technological innovations to provide new knowledge for students, community members, practitioners, and other stakeholders. This talk will provide: a) science and bench-scale research that led to development of new technologies for nutrient management from diffuse sources, b) results from field demonstrations of two new technologies to manage nitrogen found in urban stormwater and on-site wastewater systems, and c) information how local and professional communities were engaged to inform the nutrient management technology and improve nutrient management. Hybrid Adsorption and Biological Treatment Systems (HABiTS) were developed to integrate treatment of nitrogen with septic tank performance through a combination of ion exchange and biological nitrogen removal. The performance of the technology has been demonstrated for the past nine months at the Northwest Regional Water Reclamation Facility (Hillsborough County, FL). The impact of extended idle periods and recirculation ratio on nitrogen removal will be presented. The demonstration has received input from stakeholders that make up the professional community of on-site wastewater managers. Concurrently, another new technology developed in our laboratory is being demonstrated to treat nitrogen found in urban stormwater. In that project, a conventional bioretention system is being compared to a modified bioretention system. The modified system includes an internal water storage zone that contains an electron donor (provided from wood chips) to enhance denitrification. The demonstration has been integrated with several outreach activities that take place in East Tampa (FL), a lower-income community. Our Center has partnered with the Corporation to Develop Communities of Tampa, Inc. (CDC) to incorporate our demonstration and other research findings into a 6-week adult workforce development program on green construction that is offered through the CDC's Tampa Vocational Institute. In addition, K-12 students enrolled in the CDC's Youth Leadership Movement out of school program also work with the research team on maintenance and community outreach associated with the bioretention system. Results from the field performance of the technology will be presented, including the impact of plants, hydraulic loading and antecedent dry days on nitrogen removal. The overall goal in both systems has led to more informed research that can develop new technologies and strategies to better manage urban, coastal nutrient pollution.

(20 mins) **Presentation title:** Assessing Efficacy of Nutrient Removal and Recovery Technologies at Wastewater Treatment Facilities

Presenter: Brock Hodgson

Authors: Brock Hodgson (Colorado State University), Sybil Sharvelle (Colorado State University)

Abstract: Many states are considering or have recently adopted nutrient regulations requiring wastewater treatment facilities (WWTFs) to improve existing treatment operations, and it is important for WWTF to be able to identify and evaluate factors that limit the effectiveness of nutrient removal efficiency. This is traditionally done using complex biological and chemical models of WWTF operations and requires a significant amount of data input, modeling experience, and time. The purpose of this research is to provide a more effective way of evaluating factors that impact nutrient removal effectiveness of different treatment technologies. To accomplish this, an empirical model was developed to generalize the nutrient removal efficiency of various process configurations and sidestream treatment technologies utilizing numerous developed BioWin process simulations from four calibrated and validated wastewater treatment process models. To develop this empirical model, a regression analysis was performed on the model outputs to characterize the estimated effluent quality based on explanatory model variables. The developed empirical model allows for facilities to estimate the achievable effluent nutrient water quality as well as characterizes impacts to mainstream aeration system and potential recovered nutrient products. This provides facilities with a decision making tool for ranking and comparing when adoption of a technology may provide sufficient treatment levels to meet the desired discharge requirements.

(20 min) **Discussion and Questions:** Ben and Amit Moderate Q+A from audience.