Message from the Director

As water researchers, we challenge ourselves to see water-related issues from a fresh perspective in our quest to find new and better solutions. Often this means either taking a much closer look or backing off to view things in a broader frame of reference. In this issue, we look at projects on both ends of the spectrum, from the microscopic to the regional.

In the first project, researchers seek to understand the interactions between plant roots and metal nanoparticles (NPs) in the soil by investigating the potential protective influence of the root zone bacterium Pseudomonas chlororaphis O6 (PcO6) in wheat roots. PcO6 shows some indirect influence in protecting against the negative effects of NPs on the plants, but it may also work with NPs in the soil to protect these same plants in drought conditions. The second project is developing a new methodology, based on the complementary methods, to accurately estimate evapostranspiration (ET) at a relatively fast pace and with limited resources, as well as predict and monitor drought over large semi-arid regions of the United States.

These projects represent only a fraction of the active research underway at the UCWRR aimed at solving water-related natural resources problems throughout Utah, the nation, and the world.

Mac McKee, Director

Welcome!

The Water bLog is the semi-annual newsletter of the Utah Center for Water Resources Research (UCWRR), housed at the Utah Water Research Laboratory.

The Center supports the development of applied research related to water resources problems in Utah and promotes instructional programs that will further the training of water resource scientists and engineers.

Each issue of The Water bLog reports on a small selection of current or recently completed research projects conducted at the center. More information is available online at:
http://uwrl.usu.edu/partnerships/ucwrr/

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Copper oxide nanoparticles (CuO NPs) present a conundrum. These NPs can contribute to metal pollution, negatively affecting environmental quality. In fact, intentional or accidental application of CuO NPs on crops or soil can be toxic to plants and can adversely affect both plants and their related beneficial soil microbial ecosystems.

At the same time, CuO NPs can be useful in various medical, food safety, personal care product, and even agricultural applications. For instance, CuO NPs can be used as a beneficial antimicrobial in fungicides for treating plants or as a slow release source of Cu, an essential micronutrient. Preliminary research has even shown potential agricultural benefits from the drought resistance-stimulating properties of NPs.

Understanding CuO NPs

For the past 10 years, UWRL researcher Joan McLean has been collaborating with other USU faculty and students to investigate the bioavailability and toxicity of CuO NPs to wheat plants. Their recent work looks at how properties of Utah’s agricultural soils specifically influence the bioavailability of CuO NPs to wheat plants.

A recently granted 3-year NSF project is extending this research to further explore the interplay of soil chemistry, root exudation, and foot biofilm exudation in relation to CuO NP bioactivity in the wheat rhizosphere. Additional USDA funding links past research and the NSF project to improve understanding of how rooting zone interactions between wheat seedling roots and soil with and without CuO nanoparticles

- No CuO nanoparticles
  1. Wheat releases exudates
  2. Exudates collect essential nutrients and shuttle nutrients back to roots, promote beneficial bacterial growth

- High-dose CuO nanoparticles
  1. Wheat releases exudates
  2. Exudates dissolve CuO nanoparticles
  3. Elevated copper stimulates release of further exudates as defense, worsening cycle
  4. Roots become stunted
  5. Nutrient deficiencies develop
ecosystems (with the addition of NPs) affect plant health during drought.

**Pore water effects**

Many factors present in soil or produced by plant roots and associated microbes, including soil pH, salt content, and organic matter content influence the behavior of NPs by altering their surface properties and solubility. In order to test these effects, the research team grew wheat plants for 10 days in sand watered with one of three soil pore waters. The pore waters were extracted from soils in Cache Valley under different agricultural management practices that affect the type and concentration of organic matter. Soil organic matter interacts with copper by forming complexes that will influence CuO NPs and the bioavailability of copper to the wheat plant.

The health of the wheat plant was evaluated by its root length. The presence of the CuO NPs decreased the root length compared to the control (plants grown in deionized water, while the addition of pore water provided protection to the plants.

The concentration of copper in solution increased with the concentration of dissolved organic matter in the soil pore water, but the increase in soluble copper did not alter the root. Copper complexes that formed with organic matter in soil pore water or were produced from plant root growth protected the plants from the adverse effects of CuO NPs.

**PcO6 colonization effects**

In this work, wheat roots were colonized with the bacterium *Pseudomonas chlororaphis* O6 (PcO6) to see if it could provide protection for roots in the presence of CuO NPs. Wheat roots colonized with PcO6 showed no significant difference in root length, but the bacterial produced biofilm offered other protective influences. PcO6 may stimulate and prime the defense pathways when the plant is stressed.

Colonized roots showed lower levels of copper uptake at some NP doses. The lower levels of soluble copper detected in the rhizosphere suggest that the bacteria may act as a physical shield limiting the impact of copper on the plant root. It is possible that the PcO6 may consume some metal chelators (citrate and malate) as nutrients, thereby reducing dissolution of copper from the CuO NPs.

Collectively, these data showed that the challenge to the plant imposed by CuO NPs remained dominant but can be modulated by the presence of the root-colonizing bacterial cells.

**What’s Next?**

Despite the recent progress, many questions remain:

- What is the solubility of CuO NPs in whole soils?
- How do wheat root exudates interact with metal-containing soil minerals?
- Do CuO NPs, ZnO NPs, or SiO$_2$ NPs reduce stress experienced by wheat under drought?
- How do NPs interact with wheat roots, PcO6, and root exudates under drought stress conditions?

Answering these questions will reveal some of the mysteries in the CuO NP conundrum, including the risk of using CuO NPs in soils, ways that root exudates interact with metal pollutions, and potential beneficial uses of metal NPs to improve crop performance under drought.

In the near future, these are the very things McLean and her colleagues intend to find out.

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*Bacterial colonization showed no overall protective effect on morphology, but may have reduced the extent of gene expression associated with plant responses to stress induced by root exposure to CuO NPs*
“Results showed that the drought patterns from the EWDI index were consistent with USDM and may even be more accurate and reliable.”

Improving water loss estimates: a new method to enhance drought monitoring

Given the importance of rural agriculture and rural livelihoods in Utah and other arid/semi-arid regions, water managers need accurate ways to estimate water loss and to monitor emerging drought conditions.

Researchers have been modeling evapotranspiration (ET) for decades, seeking more reliable water management data. Classical methods of computing ET from agricultural lands require detailed and complex data, and methods that use remote sensing data from satellites provide good estimates but require advanced knowledge and training. On the other hand, the complementary methods developed in the 1960s use only meteorological data and can be used to make highly valid regional estimates with limited data requirements. These methods each have benefits, but they also have vexing limitations, especially in contrasting climates.

Extending ET Estimates

UWRL researchers Jagath Kaluarachchi and Homin Kim have developed a simple, nearly universal methodology, based on the complementary methods, that can estimate ET at a relatively fast pace and with limited resources.

In previous efforts with F. Anayah, Dr. Kaluarachchi modified the GG model, extending the work of Granger and Gray from 1989, using only point data from meteorological stations:

- temperature,
- relative humidity,
- wind speed, and
- sunlight hours

The new model estimates regional water loss under a variety of physical and climatic conditions. The result showed vast improvements over other recent studies for most conditions except for arid conditions.

So the new team set to work to further improve the modified GG model using limited remote sensing information, consisting of primarily vegetation cover information (in the form of normalized difference vegetation index, or NDVI),
define a drought index. Instead, we used our updated Adjusted GG-NDVI model, along with a probabilistic approach, to develop a new drought index, called the Evapotranspiration Water Deficit Drought Index (EWDI).

To demonstrate its operational features, the team compared EWDI and two other common and well-respected drought indexes with the US Drought Monitor (USDM), the most widely used drought index, for the period of 2001 to 2015.

The Palmer Drought Severity Index (PDSI; Palmer 1965) incorporates precipitation, moisture supply, runoff, and ET at the surface level, but performs particularly poorly in the western US and has a fixed temporal scale that is difficult to use in rapidly evolving drought conditions.

The Standardized Precipitation Index (SPI; McKee et al. 1993) can be calculated at different time scales and considers groundwater, soil moisture, reservoir storage, snowpack, and streamflow, but it does not consider other meteorological variables that can influence droughts, such as temperature, ET, and wind speed.

The EWDI index considers both precipitation and vegetation data and includes accurate ET estimates under diverse climate conditions. Thus EWDI can capture the precursor signals of water stress developing over time and can uniquely describe drought conditions. EWDI also uses the same classification scheme as USDM.

**What’s Next?**

Results showed that the drought patterns from the EWDI index were consistent with USDM and may even be more accurate and reliable. Future work will address the applicability of using accurate ET within EWDI as an outlook to predict trends for areas experiencing drought up to 12 months in the future and to indicate areas where new droughts may develop.

**Adding In a Drought Index**

The next step for this work was to extend and develop the ET model for drought monitoring. Many operational drought indices depend on either precipitation or temperature, and a few use actual ET to develop a hybrid method with an emphasis on estimating total water loss from arid land regions. Model results showed significant improvements in accuracy over the original GG-NDVI model, and the new model can be applied to a wide range of climatic conditions, such as over an entire basin or region.
Jagath Kaluarachchi is the Interim Dean of the College of Engineering at Utah State University (USU) and Professor in the Department of Civil and Environmental Engineering. He has been active in the area of hydrology, water resources, and water quality for more than 25 years, having published ~80 journal publications and more than 100 conference proceedings and presentations. Dr. Kaluarachchi has conducted many international development projects related to water management in arid regions including Iraq, Ethiopia, Ghana, Sri Lanka, Palestine, and Jordan, among many other countries. He is an ASCE and EWRI Fellow and Diplomat in Water Resources Engineering from the American Academy of Water Resources Engineering. [https://jkalu.usu.edu/](https://jkalu.usu.edu/)

Joan McLean is a Research Professor in Civil and Environmental Engineering and at the Utah Water Research Laboratory at USU. For the past 30 years, her research has focused on the biogeochemistry of pollutants in soil/water environments, with emphasis on heavy metals and metalloids. Current research projects include evaluating sources of hexavalent chromium in drinking water, microbial reduction of iron containing minerals, microbial processes controlling arsenic release to groundwater, effects of metal nanoparticles on plant root-bacteria interactions, fate and behavior of metals in soil/subsurface systems, defining bioavailability of metals to soil organisms, phytoremediation of metal-contaminated soils, and metal-soil-plant interactions.

New faculty members

Belize Lane
Most recent post: University of California, Davis
Expertise: Hydrology and water resources management, improving river management for human and environmental objectives.
Recent research: Linking surface hydrology, fluvial geomorphology, and river ecology to improve basic scientific understanding of river systems while directly informing watershed management applications.

Alfonso Torres-Rua
Most recent post: Utah State University
Expertise: AggieAir analytics and research applications, water resources analysis, evapotranspiration, irrigation, remote sensing, soil moisture, use of high-resolution UAV and satellite imagery at all scales.
Recent research: Spatial crop status and water use estimation and monitoring for agricultural water management.

Tianfang Xu
Most recent post: Michigan State University
Expertise: Numerical simulation of groundwater flow and solute transport, uncertainty quantification, remote sensing, machine learning.
Recent research: Using remote sensing and machine learning for crop irrigation monitoring and yield prediction, and HPC-enabled uncertainty quantification for hydrologic models.

Ruijie Zeng
Most recent post: U. Illinois, Urbana-Champaign
Expertise: Water resources systems analysis, data mining techniques to provide better decision-making support for water resources planning and management.
Recent research: Understanding watersheds as coupled nature-human systems, hydroclimatic process changes due to irrigation development at watershed/regional scales.
In the News:

**USU to host the 2019 UCOWR annual conference**

We are pleased to announce that USU will be sponsoring the 2019 UCOWR Annual Conference at Snowbird, UT.

The Universities Council on Water Resources (UCOWR) is an association of universities and other organizations leading out in water resources education, research, and public service.

The eight UCOWR delegates at USU, Jeff Horsburgh, Jagath Kaluarachchi, Mac McKee, Laurie McNeill, Bethany Neilson, David Rosenberg, David Stevens, and Joe Wheaton, represent a wide range of water resources expertise and research. Seven of the eight delegates are UWRL/UCWRR faculty members.

**Randy Martin embarks on a Fulbright Fellowship**

In January 2018, Dr. Randy Martin will travel to Nablus, West Bank, Palestinian Territories to begin his Fulbright Fellowship there. In this combined teaching/research fellowship, Dr. Martin will work with Dr. Abdelhaleem Khader at An-Najah National University to develop an air pollutant monitoring program for the city and Governorate of Nablus, West Bank, Palestinian Territories and establish an active and sustainable air quality education and research program at the University in Nablus.

Dr. Khader is a former USU graduate student and visiting scholar.

**Major grants received**

David Tarboton and Jeff Horsburgh are leading a $4 million NSF-funded project that involves collaborators from nine other universities and US institutions to improve HydroShare, an online database system that simplifies the storage and sharing of hydrological data and models, and helps scientists share water research data. Read more.

Joan McLean, is part of a team of USU researchers to be recently awarded two grants for their projects: “CuO NP bioactivity in the wheat rhizosphere: Interplay of soil chemistry, root exudation, and biofilms” (NSF, over $300,000) and “Nanoparticles prime crop defenses to abiotic stress” (USDA, $500,000).

**Other News**

Bethany Neilson and graduate student Tyler King contributed to the U.S Department of State book, Our Arctic Nation, published from the U.S. Arctic Council Chairmanship Initiative Read blog.

Irene Garousi, UWRL PhD student, was honored to be selected for two prestigious summer programs: the UCGIS program at the National Center for Supercomputing Application, U. of Illinois at Urbana Champaign, and the CUAHSI National Water Center Innovators program in Tuscaloosa, Alabama.

**Future Issues**

“Tracking and transforming toxic algae blooms”

(AggieAir remote sensing and anaerobic digestion will help manage toxic algae blooms at Scofield Reservoir while the algae generates power)

“Transitioning from iUTAH to the Logan River Observatory”

(As the iUTAH projects ends, the Logan River Observatory will be established and expanded.)

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