MINERAL LEASE FUND REPORT
Utah Water Research Laboratory

Fiscal Year 2019

for

Office of the Legislative Fiscal Analyst
State Capitol Complex
House Building, Suite W310
Salt Lake City, UT 84114

by

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Foreword

Water is a precious and scarce resource in the State of Utah and ongoing research to understand and manage the many issues associated with providing safe water for drinking, ensuring sufficient water for irrigation and the environment, and enabling economic development is critical. This report describes the work funded by Mineral Lease funds (MLF) during fiscal year (FY18/FY19 at the Utah Water Research Laboratory (UWRL) in pursuit of its mission to generate the knowledge needed to solve water problems through research and help the State meet its water, food, and energy resource needs now and in the future. The projects described in this report focus on cutting-edge research to find practical solutions to some of the most pressing water related problems facing Utah. The types of research ongoing at the UWRL include work on innovative sensing to measure and manage flows and water use, and assess the conditions of wetlands and invasive species; work on computer models to improve flood forecasts and water quality, and research on the emerging threat of pharmaceutical and personal care products in water, and numerous innovative ways to reduce water contamination. Several projects focus on the Logan River as an observatory and microcosm for study and development of the understanding needed to solve problems throughout Utah, and beyond.

To support our mission, the UWRL receives 2¼% of deposits made to the Mineral Lease (ML) Account, "to be used for activities… having as a purpose the development… of water resources in the State of Utah." With this basic support, UWRL is able to leverage significant funding from other public and private sources to enhance the scope and impact of our projects. This past fiscal year we have over $4.3 million in project funding from other sources, thus providing additional opportunities for finding solutions to State water issues as well as contributing to economic growth. The UWRL also expands the benefits of its projects through collaborations and partnerships with local, state, and federal agencies. As one of the oldest, most respected and unique University-based water research facilities, UWRL's goals and mission remain the same: To provide data, tools, and solutions to better manage and use the limited water and land resources of the State. We look forward to many more decades of service to Utah's citizens.

In compliance with House Bill 103 passed during the 1993 Legislature General Session, this report provides a brief description of the UWRL's MLF-supported active research, training, and service projects this past fiscal year, along with an accounting of the ML funds for FY2019, budgeted expenditures for FY2020, and planned expenditures for 2021. The projects are organized into broad areas of activity that address a spectrum of high-priority water resources needs and issues in the State. Each project includes a statement of the project purpose, the specific benefits to the citizens of Utah, and areas benefited.

Events of this past year have shown that pressures on our water and environmental resources are continuing to increase, and the problems are becoming more complex. The UWRL brings together a world-class faculty whose work focuses on finding ways to provide for today's and tomorrow's water resource and environmental needs. We look forward with optimism to meeting this challenge. The UWRL is pleased to submit this year's report to the Legislature through the Office of the Legislative Fiscal Analyst, and to the Community and Economic Development Appropriation Subcommittee of the Legislature, which reviews this report as part of its normal budgetary process.

We welcome any comments or questions that result from these reviews.

David G. Tarboton, UWRL Director

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Introduction

History of the Utah Water Research Laboratory

The Utah legislature authorized the establishment of the UWRL at Utah State University in 1959 as an important component of the State of Utah's commitment to water resources research, assuring cutting-edge solutions to the State's water problems. Today, the UWRL continues its service as one of the oldest and most respected university-based facilities performing research and providing practical solutions to the most pressing problems facing Utah, and indeed our nation and the world.

Water is often referred to as the lifeblood of Utah. As we look to the future, it is important to recall how important water resources have always been to the prosperity and quality of life of Utah's citizens. This was evident in the vision of our State leaders when USU was established as the State's Land Grant University in 1888, and water, and particularly irrigation science and the engineering of water works, were of foremost importance as curricular and research components. During the next several decades, water resource education and research were mainly carried out by faculty and students in the relevant academic departments and by the Engineering and Ag Experiment Stations. In 1957, George Dewey Clyde, former Dean of Engineering at USU, was elected the 10th Governor of Utah, serving two terms until 1965. During his tenure, he strongly supported research on best practices for using and protecting Utah's precious water resources, including funding and breaking ground for construction of the Utah Water Research Laboratory in 1963. In the following year, 1964, Congress approved the Water Resources Research Act that created a water research institute in every state. The Utah institute, known as the Utah Center for Water Resources Research (UCWRR), was established at the UWRL as part of a national network of water research institutes.

As an acknowledged world leader in water engineering, the opening of the new Utah Water Research Laboratory building in 1965 provided the State and USU with a world-class research facility to support the work of faculty, students, and water professionals from across the state and around the world. The Laboratory's facilities include one of the best hydraulics laboratories in the United States and a unique erosion testing facility with a large rainfall simulator. In 1981, an extensive remodeling project added an environmental quality laboratory wing, significantly upgrading facilities and equipment needed for water quality testing and research. In 2009, the UWRL completed a hydraulics modeling and testing laboratory in order to support expanded hydraulics research activities associated with releases from dams (and related hydraulic phenomena, such as venting) and the design of hydraulic structures in Utah, such as the new irrigation lift stations on Utah Lake. Today, the UWRL has a total of more than 113,000 square feet of state-of-the-art laboratory, computer, and office space. This continued growth and productivity over the past 52 years have allowed the UWRL to have a greater state, national, and worldwide impact in water resources research and applications.

The table below summarizes the current high-level productivity of the Lab in terms of research, education, outreach, and training**.** The total research funding through the UWRL in FY2019 of over $8.6 million makes it one of the largest institutes in the nation.

UWRL Financial/Academic Summary (FY2019)

Number of Active Projects	239
Dollar Value of Active Projects	$8,611,764
Scholarly Publications in Peer-Reviewed Journals	86
Scholarly Presentations at Professional Conferences	152

Outreach Products (FY2019)

Short Courses and Field Training	14

Degrees Granted

PhD	4
MS	9
ME	10

In order to leverage the expertise of the UWRL, our faculty collaborate with colleagues from various USU departments, as well as faculty from other institutions and professionals from the private sector and government agencies in Utah and elsewhere. Several of our faculty members, including a former UWRL Director, have been awarded the Utah Governor's Medal for Science and Technology. In addition, our faculty have received many national honors and recognitions, and served on numerous state, national, and international engineering and science panels and committees.

Research Program Structure and Organization

The research programs of the Utah Water Research Laboratory (UWRL) directly address current and future water resources needs of the state, and most are relevant to national and worldwide issues as well. The State of Utah provides state-appropriated funds (SAF) and mineral lease funds (MLF) for research support at the UWRL. These funds directly target problems facing the State of Utah. In FY2019, MLF funding of just under $1.5 million accounted for 15% of total UWRL expenditures. With additional funding from federal, private, and other state sources (as shown in the pie chart), the total UWRL expenditures for FY2018 were over $ 8.6 million.
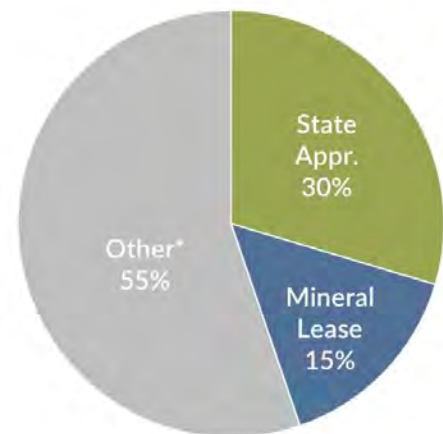
UWRL Funding FY18/FY19

The UWRL's MLF-funded projects are organized into six major research program areas:

- Drinking Water and Wastewater Treatment

- Environmental Quality Management and Remediation

- Surface and Groundwater Quality and Quantity

- Water Conveyance, Distribution and Control

- Water Education and Technology Transfer

- Water Resources Planning and Management

The individual projects are under the direction of engineers and scientists affiliated with the following departments within the College of Engineering:

- Civil and Environmental Engineering - (Environmental, Irrigation and Water Divisions).

- Electrical and Computer Engineering.

- Mechanical and Aerospace Engineering.

- Biological Engineering.

The overall UWRL research, education, and training activities related to ML funding are very diverse, as is indicated by the project summaries in this report. However, the totality of UWRL's programs, taking into account state funds and our external contracts and grants, is even broader. We continue to be involved in many field-scale soil and water remediation research projects. At several experimental watersheds, we are investigating hydro-climatological processes. Our hydraulics, erosion control, and environmental quality laboratories are involved with a range of experimental work and service projects that utilize our unique facilities. Computer models, remote sensing, geographic information systems, digital terrain models, expert systems, and many other modern technologies are developed and applied in the research projects, and are used to develop tools for use by water and environmental managers and professionals in Utah. The UWRL also prepares guidance materials for use by practitioners. Some projects are relatively small in scope while others involve interdisciplinary teams and collaboration with multiple agencies and with the private sector. Most of our projects also include an outreach component, so our staff is also engaged in public and professional service, technology and information transfer, and public education.

In addition to our research role, the UWRL is involved in university graduate and undergraduate education through hands-on projects, part-time employment, and research assistantships. In order to train future water professionals, almost all research and applied projects include graduate student involvements and result in masters or doctoral degrees. Undergraduate student involvement in UWRL projects for the purpose of student education and training is also integrated into the basic and applied research programs.

UWRL Student Involvement FY2019

Graduate Students Supported (FY19)	48
Undergraduate Students Supported (FY19)	66

As students graduate and are hired by Utah employers, they become effective means of technology transfer from the UWRL to Utah's water and environmental organizations. Technology and information are also transferred through collaborating and partnering with engineers, scientists, and managers of the Utah Department of Natural Resources, Water Resources Division, the Utah Department of Environmental Quality, the twelve Utah local health departments, and several large water user districts and associations.

Management of USGS 104 Program for State Benefit

The Water Resources Research Act of 1964 created a national network of Water Resources Research Institutes (WRRIs) in the United States and an allotment program providing funds for the institutes, called the Section 104 Program. The Utah Institute, known as the Utah Center for Water Resources Research (UCWRR), is located at the

Utah Water Research Laboratory (UWRL). In 2019, the Section 104 Program received federal funds of $92,335 through the U.S. Geological Survey (USGS). This grant, in combination with ML funds used as matching funds, directly benefits the State of Utah in the following areas:

1. Exploring the applicability of using UAVs to map subsurface drainage systems and identify the key parameters in order to enhance water quality monitoring and early-warning systems for non-point source pollution from agricultural practices.

2. Developing a hybrid model that integrates a physically-based, distributed snow model with a data-driven karst model based on machine learning to simulate stream discharge response to climate variables to improve understanding of streamflow under climate variability and change, which will inform water resources management and planning in mountainous, snow-charged karst regions.

3. Investigated the relationship between streamflow depletion and water temperature response over a dry summer in the Blacksmith Fork River in northern Utah showing the sensitivity of stream temperature patterns and dependent aquatic species to land and water management decisions, and identifying opportunities to enhance baseflow and maintain stream temperature through the summer low flow period.

4. Examining how beaver dams alter biogeochemical cycling in rivers and whether dams can be used as a mitigation strategy for non-point source pollution by conducting mass balances for phosphorus, nitrogen, and carbon, linking fluxes to both physical and biological processes.

5. Collecting optical (visual, near infrared) and thermal imagery along the San Rafael River, Utah, for the Division of Wildlife Resources to with compare historical information and identify changes to wetlands flow paths due to Tamarisk, a woody, non-native invasive vegetation species and evaluate its consumptive water use to inform restoration efforts.

In the future, the USGS 104 Program will continue to support applied research and accomplish information and technology transfer to address Utah's water quantity and quality problems and develop tools and programs for water resources management and protection across the State of Utah.

Relevancy and Benefits of the Mineral Lease Fund

As one of the driest states in the union, the LIFE BLOOD of Utah's economy and quality of life is WATER. Our average precipitation of only 13 inches of water a year, mostly in the form of winter snowfall, must meet the State's economic, social, and environmental water needs throughout hot, dry summer periods. As has often been emphasized by our state leaders over many the decades, water is indeed the essential resource needed to sustain Utah's quality of life and economic vitality. The State's investment in its water resources through the ML Fund is critically important to finding the best technologies and methods to protect, manage, and wisely use our precious water for the benefit of all Utah's citizens.

Research Program Planning and Project Selection

The goal of the UWRL research programs is to identify and develop projects that will help to assure that Utah will be able to meet the water needs of its citizens and economy in the future. This requires a broad and deep understanding of our surface and groundwater resources in the context of climate change and environmental variability, the complex physical and biological processes that affect water quantity and quality, and the dynamic interaction of human activity in the use of land and water in our arid environment.

In order to focus research on problems and needs that are both relevant and current, the UWRL engineers and scientists work closely with state and local government agencies and are actively involved with and serve on many state and local organizations, committees, and boards. The UWRL Director, Associate Directors and most of the faculty meet frequently with state and federal agency managers and personnel from local water organizations to discuss research needs and identify opportunities for the UWRL to respond to these needs. The UWRL has worked with the following State agencies and many other statewide and regional organizations over the past fiscal years.

Utah Department of Natural Resources	**Utah Department of Environmental Quality**
Division of Water Resources State Engineer – Division of Water Rights	Air Quality Drinking Water Water Quality Solid and Hazardous Waste
State Regulatory and Advisory Committees	**State Water Associations and Organizations**
DEQ Water Quality Board Utah Solid and Hazardous Waste Control DEQ Drinking Water Board Utah Governor's Unmanned Aerial Systems Test Site Advisory Board	Utah Center for Water Resources Research (UCWRR) Utah Division of Air Quality Utah Rural Water User's Association Water Environment Association of Utah Utah League of Cities and Towns Utah On-Site Wastewater Treatment Association
Professional Organizations and Associations	**Regional and National Research Alliances**
American Water Resources Association American Society of Civil Engineers American Water Works Association Water Environment Research Foundation (WERF)	Lake Powell Technical Advisory Committee Universities Council on Water resources (UCOWR) Inland Northwest Research Alliance (INRA) National Institutes for Water Resources (NIWR) Water Environment Research Foundation (WERF)

In addition, the Utah Center for Water Resources Research (UCWRR) at the UWRL participates as an active member of the National Institutes for Water Resources (NIWR). UWRL faculty members are also active in state sections of professional organizations and serve on state, local, and national committees. Participation in the national and international professional water and environmental organizations helps to bring recognition and external project funding to the state, and it provides opportunities to learn from other research and best practices worldwide. In return, this helps UWRL to identify current and future research needs that will affect our state, and further strengthens our research identification process to assure the relevancy of projects to Utah.

Mineral Lease Fund Expenditures

The table below summarizes the actual, budgeted, and planned expenditures of ML funds allocated to the UWRL for FY2019 through FY2021 for research projects in the six major **Program Areas.** UWRL administration and technology transfer expenditures account for approximately 22% of total MLF budgeted and planned expenditures.

Mineral Lease Fund Expenditures			
Research Program Area	**Actual FY2019**	**Budgeted FY2020**	**Planned FY2021**
UWRL Administration	$293,222	$334,454	$344,488
Drinking Water and Wastewater Treatment	$101,537	$164,596	$167,733
Environmental Quality Management and Remediation	$301,845	$367,976	$376,077
Water Conveyance, Distribution, and Control	$18,483	$23,700	$23,956
Surface and Groundwater Quantity and Quality	$216,413	$280,878	$287,946
Water Education and Technology Transfer	$111,676	$158,041	$176,950
Water Resources Planning and Management	$262,391	$416,155	$412,433

A detailed breakdown of the expenditures for each project within these **Research Program Areas** is presented in the **Research Project Summaries** section of this report.

Benefits to the State of Utah

ML funding is often used as leverage to acquire additional support from other sources, which allows us to perform even more research in the State. Every one of Utah's counties have benefited from one or more of the UWRL projects conducted during the past year.

The following gives a general overview of some of the recent and current benefits produced by ML funded projects by Program Research Area. The Research Project Summaries section of the report describes specific State benefits from each research project.

Drinking Water and Wastewater Treatment

The program develops engineering approaches for the treatment and production of drinking water and the treatment and reclamation, recycling, and reuse of municipal and industrial wastewater, and evaluates the effectiveness of various seepage treatment options in Utah environments. Research in this area also investigates methods to develop renewable energy from waste streams and creates new biological-based technologies for efficient, sustainable water treatment that utilize biosolids to produce methane gas for fuel, bioplastics, and other valuable bioproducts.

Environmental Quality Management and Remediation

This program emphasizes an integrated engineering and science approach to environmental quality of land, water, and air. It includes characterization and remedial design approaches for contaminated subsurface environments at laboratory scale along with one of the largest field scale research programs of any academic institution in the nation. Varied research in this area includes bioreactor processing of environmental materials, and engineering scale-up of biologically based waste treatment. These developments encompass diverse areas of specialization including composting, waste reuse, biosolids processing, management of environmental biotransformation, and engineering bioprocess-optimization of wetlands. In addition to the research on water and land processes, this area also includes work on contaminant uptake into plants and indoor and outdoor air quality problems in the state, including winter inversions and vehicle emissions.

Surface and Groundwater Quality and Quantity

This diverse program has strengths in both the theoretical and the applied aspects of surface and groundwater. Surface water research includes modern surface water hydrology, including climate modeling, rainfall processes, snow hydrology, floods, droughts, terminal lake analyses, soil erosion, stream water quality modeling, water-quality management, assessment and control of nonpoint source pollution and storm water, characterization and control of dissolved and particulate natural organic matter (NOM). Current projects in the groundwater research ranges from stochastic and numerical analysis of pollution transport of toxic contaminants in natural and engineered systems to the practical aspects of designing technologies to clean up and manage contaminated sites in Utah's aquifer systems. Other research focuses on surface/ground water interactions in streams, quantifying water losses in agriculture, and development of more accurate low-cost water quality sensors.

Water Conveyance, Distribution and Control

The UWRL uses numerical and scaled physical models to evaluate hydraulic structure design and performance and to test and improve hydraulic instrumentation. Projects involve spillways, such as labyrinth weirs to manage flood discharges from reservoirs, and bottom outlets, pump stations, and other hydraulic structures.

Water Education and Technology Transfer

Projects conducted by the UWRL in this program area, including many funded from sources other than Mineral Lease Funds, have substantial education, outreach, and training components. Resources provided by Mineral Lease moneys are sometimes used to enhance the development of technologies, training modules or educational materials, and are often used to provide technical support to Utah's state and local agencies on water-related issues.

Water Resources Planning and Management

Research areas include water conservation, river basin planning, reservoir operating policies, habitat monitoring and restoration, urban water issues, land use, hydrologic modeling, and many others. This program area also addresses various institutional and legal aspects of water, such as water rights transfers, distributed water demand and supply modeling using geographical information systems, and cost allocation and determination of user fees for multiple purpose water resources projects. To be effective, water and environmental managers must have real-time access to relevant data. UWRL is a leader in developing cyberinfrastructure for water related data and interfacing data with user-driven decision support systems for water and environmental planning and management. Another significant area of research focuses on the use of remote sensing technology and data to improve water, agricultural, and environmental resources management. This includes UWRL development of a unique unmanned aerial remote sensing system (AggieAir^{TM}). These small aircraft are programmed to fly over

research sites, such as farm fields, wetlands, river and riparian environments collecting multispectral high-resolution imagery. These data are then analyzed and used for better irrigation of crops and for improved water and environmental management.

Outreach

The mission of the UWRL also involves outreach activities related to public service, information dissemination, technology transfer, and short courses. These activities provide benefit to Utah's state and local agencies, elected officials, citizens, and the nation. Additionally, our UWRL associated faculty, staff, and students provide various other outreach functions as described on our website: http://uwrl.usu.edu.

Public Service

UWRL faculty members serve on state and local advisory panels to provide technical expertise, input, and review of water-related issues. Recent specific panels include:

State of Utah Drinking Water Board
State of Utah Water Operators Certification Council
Salt Lake Valley Solid Waste Management Council
Utah State Solid and Hazardous Waste Control Board
Cache County Solid Waste Advisory Board
Jordan River Water Quality Technical Advisory Committee (Utah DEQ)
Willard Spur Science Panel, a panel formed by the Utah Division of Water Quality
The Nutrient Criteria Development Core Advisory Team- Utah Division of Water Quality
Utah Division of Water Quality, Department of Environmental Quality, Task Force Member,
    R317-4 Onsite Wastewater Systems Stakeholders Workgroup
Water Environment Association of Utah, Board of Directors and Biosolids Committee
Logan City Air Quality Task Force
Logan City Renewable Energy and Conservation Advisory Board
Bear River Health Dept.'s Air Task Force
The Weber-Morgan Health Department Wastewater Advisory Committee

UWRL personnel are frequently invited to provide technical and informational presentations before state and national professional groups, such as the American Water Works Association, and national and international organizations engaged in financing water developments, such as the World Bank.

Information Dissemination and Technology Transfer

UWRL information dissemination, outreach, and technology transfer activities include the publication of research results in professional journals, distribution of information on various UWRL and UCWRR web pages and newsletters, presentations before various professional societies at organization and association meetings both in the state and around the country, and sponsorship and participation in numerous short courses and training programs.

The UWRL web page (http://uwrl.usu.edu) provides general information about the UWRL and its personnel and from time-to-time a feature article on different research projects, faculty, and students at the UWRL. The Utah On-Site Wastewater Treatment Training Program at the UWRL offers on-site wastewater training in support of the

State of Utah certification program for on-site wastewater treatment professionals. Additional information can be found at https://uwrl.usu.edu/research/owt. Undergraduate and graduate students also participate in projects that involve hands-on, real-world activities.

UWRL: Solving Today's Water Problems by Looking to the Future

Our planet is clearly experiencing staggering water problems driven by increased climatic variability and extreme climate driven events; an expanding population with growing demands for water, food, and energy; and the need to protect valuable environmental resources. The uncertainty about our water availability and quality in the face of these pressures underscores the need for forward thinking research that results in practical solutions. The UWRL has evolved into a diverse center of excellence for generating knowledge related to water challenges. It fills an important role in the US/global community of water research facilities, with the interdisciplinary expertise to develop better ways to measure, monitor, model, understand, and manage 21st century water resources. Good water management recognizes the value of information from many disciplines—from how a single water molecule behaves to the constraints and opportunities created by state or national water laws and policies. Through its support of the UWRL, Utah is investing both in the creation of new knowledge and in the next generation of water engineers and experts that are critical to our state and nation's ability to deal with these water challenges now and the future. As the UWRL looks forward to another year of service to Utah, we are proud to acknowledge all the dedicated people, past and present, who have contributed to the UWRL's achievements and its outstanding reputation for water research and education.

Administration, Advisory Support, and Special Equipment

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Administration

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Business Office	$156,159	$167,808	$172,842
Publications Office	$64,870	$110,785	$114,109
UWRL Administration	$72,193	$55,861	$57,537
Total	**$293,222**	**$334,454**	**$344,488**

Administration and Advisory Support, and Special Equipment

The Administrative Officers of the UWRL are responsible for managing the facilities and budget of the lab and overseeing the diverse projects conducted by faculty and their students. The Director and Associate Directors of the UWRL also work to maintain liaison with water planning and management officials across the state. Frequently, faculty from the UWRL are requested for technical or advisory support on water problems by various state or local agencies and, to the extent that it lies within the mission of the UWRL to provide such input, ML funds are sometimes used to cover expenses required to support these activities until other funding opportunities can be developed. Finally, when a number of Utah-based research needs arise that require specialized equipment that cannot be made available through other means, MLF resources are sometimes used to acquire these critical equipment items.

Administration of the MLF Program

The costs of administering the MLF program at the Utah Water Research Laboratory are conscientiously held as low as possible, consistent with the needs of evaluating the productivity of the research supported by ML funds. Collaboration with water managers and policy makers in state and local agencies identifies where applied research can contribute toward the solution of critical water resources problems. MLF money spent on administration at the UWRL provides minimal salary support for the UWRL Director and Associate Directors and supports the administration of the USGS 104(b) program funding that comes to the state. FY2019 administrative costs represented approximately 5% of total UWRL MLF expenditures.

Outreach and Business Support

Overall, annual research expenditures for the UWRL have generally fluctuated between $ 8 and $ 12 million, and at any point in time more than 200 active research contracts are administered at the UWRL. These projects require significant support from the UWRL Business Office in the form of accounting and financial oversight. Further, the UWRL Publications Office provides support for outreach activities (such as the production of presentations, maintenance of the UWRL and UCWRR web pages, etc.). MLF expenditures in FY2019 on these support activities accounted for 17% of total MLF funding.

Advisory Support on Water Problems

The UWRL received many requests in FY2019 for advice and collaborative help on various water problems in the state. The UWRL provided support from MLF sources to defray travel costs so UWRL faculty could participate in meetings in the State to coordinate UWRL activities with ongoing water problems, to identify and seek funding for new applied research in the state, and to provide expert advice relative to current water issues faced by various state and local agencies. These activities are enumerated in the Project Reports section of this document.

Special Equipment

Numerous communities in Utah face problems with the management of soils and aquifers that have been contaminated by hazardous materials. The UWRL is active in providing state-of-the-art scientific input to understand these problems. Similarly, the UWRL is engaged in applied research on the management of contaminants of concern for various municipalities that supply potable water to communities in the state. The

Administration

UWRL also maintains an active program of coordination with state agencies such as the Utah Division of Water Rights on problems associated with the operation and safety of dams. ML funds are occasionally used to invest in state-of-the-art equipment to support these activities and provide long-term, sustainable capability to continue these efforts. The Project Reports sections describes any new equipment acquisition and their integration into research.

Research Project Summary Categories

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Summary by Research Projects

	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
UWRL Administration	$ 293,222	$ 334,454	$ 344,488
Drinking Water and Wastewater Treatment	$ 101,537	$ 164,596	$ 167,733
Environmental Quality Management and Remediation	$ 301,845	$ 367,976	$ 376,077
Surface and Groundwater Quality and Quantity	$ 216,413	$ 280,878	$ 287,496
Water Conveyance, Distribution, and Control	$ 18,483	$ 23,700	$ 23,956
Water Education and Technology Transfer	$ 111,676	$ 158,041	$ 176,950
Water Resources Planning and Management	$ 262,391	$ 416,155	$ 412,433
Totals	**$ 1,305,567**	**$ 1,745,800**	**$ 1,789,133**

Research Project Summary Categories

This section of the report provides a summary of each project and its benefits to the state and areas benefited. The projects are organized into the previously noted program areas as follows:

Drinking Water and Wastewater Treatment

Environmental Quality Management and Remediation

Surface and Groundwater Quality and Quantity

Water Conveyance, Distribution, and Control

Water Education and Technology Transfer

Water Resources Planning and Management

Research Project Summary Categories

Drinking Water and Wastewater Treatment

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Drinking Water and Wastewater Treatment

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Mitigation of Methane Emissions from Septic Systems	$47,590	$49,018	$50,489
Treatment and Bioenergy Recovery from Beverage Wastewater	$24,318	$25,048	$25,799
Use of Magnetite to Improve Settling and Effluent Quality in Wastewater Treatment Plants	$29,629	$30,518	$31,433
Designated Projects		$20,000	$20,000
Undesignated research projects in program area		$40,013	$40,013
Total	**$101,537**	**$164,596**	**$167,733**

Mitigation of Methane Emissions from Septic Systems

Principal Investigators:
Judith L. Sims
Charles Miller
Ronald C. Sims
Katelyn Ellis (student)
Jace Parkinson (student)
Jacob Watkins (student)

Partners/Collaborators:
- *None*

Project Description

- **Need and Purpose:**

Concerns about climate change have led to efforts to reduce greenhouse gas emissions (GHGs). Methane has been identified as a GHG that is over twenty times more effective at trapping heat in the atmosphere than carbon dioxide. Using assumptions developed by the Intergovernmental Panel on Climate Change (IPCC), the U.S. Environmental Protection Agency GHG inventory (2009) estimated that 76 percent of wastewater sector methane emissions in the United States are from onsite (septic) systems. This is due to the large number of individual septic systems in use and the anaerobic conditions present in septic tanks.
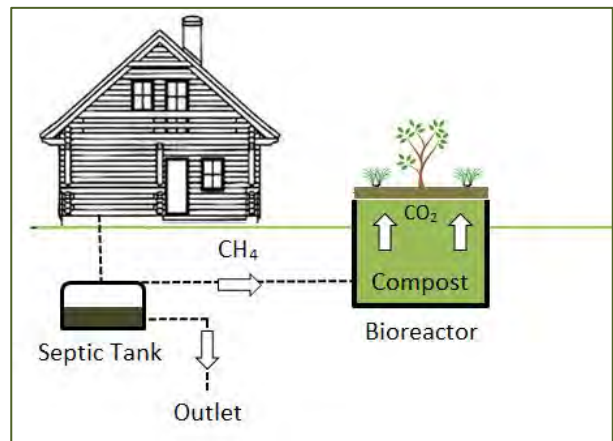
Figure 1. A schematic showing the process of mitigating methane at a local residence.

In addition, methane contributes to the formation of NH_4NO_3, which is a major component of particulate matter less than 2.5 microns ($PM_{2.5}$). $PM_{2.5}$ is an important air contaminant that contributes to the poor air quality that occurs in Cache Valley and in other areas of Utah during winter inversions.

In this project we are investigating the potential effectiveness of a method to mitigate the impacts of methane produced in septic tanks that collects the methane and treats it in a compost biofilter system. The methane is converted to carbon dioxide, which can be used by plants growing on the compost (Figure 1).

- **Benefits to the State:**

The project will provide direct benefit to the State of Utah, especially the Cache Valley area, by targeting an environmental source of methane for reduction. This can potentially reduce the amount of methane that is a precursor for the formation of $PM_{2.5}$, as well as GHG.

- **Geographic Areas:**

Study Area: Cache County.
Areas Benefited: Areas of Utah where air quality problems exist and septic systems are commonly used for on-site wastewater treatment.

Drinking Water and Wastewater Treatment

- **Accomplishments:**

  Findings: Of three methanotroph bacteria species considered for use in mitigation of methane in septic systems, *Methylomicrobium alcaliphilum* was selected because of its robustness and fast growth rate. Additionally, *M. alcaliphilum* naturally secretes a valuable biproduct called ectoine, which is used in cosmetics. In its refined form, its value has been reported to be upwards of $450/lb.

  Results: A growth curve for *Methylomicrobium alcaliphilum* has been characterized. Experimental procedures for maintaining pure cultures, evaluating growth, and optimizing culture robustness have been developed and improved iteratively. Dependence of *M. alcaliphilum* on methane as a carbon source, energy source, and electron donor has been demonstrated. The growth rate of *M. alcaliphilum* was experimentally determined to have a doubling time of approximately five hours, which is similar to values that have been reported in the literature. Using gas chromatography of samples over a ten-day period, *M. alcaliphilum* has been shown to degrade methane, although a methane degradation rate has yet to be verified.

Work Plan FY19/FY20

During FY19/FY20, we will focus on investigating the capability of *M. alcaliphilum* to grow and to degrade methane in low methane environments such as those found in septic tank environments (less than 10% methane by volume in gas phase). We will also investigate the potential of *M. alcaliphilum* to remove methane from other waste sources such as landfills and wastewater anaerobic digesters. We will also investigate if *M. alcaliphilum* is producing the valuable by-product ectoine.
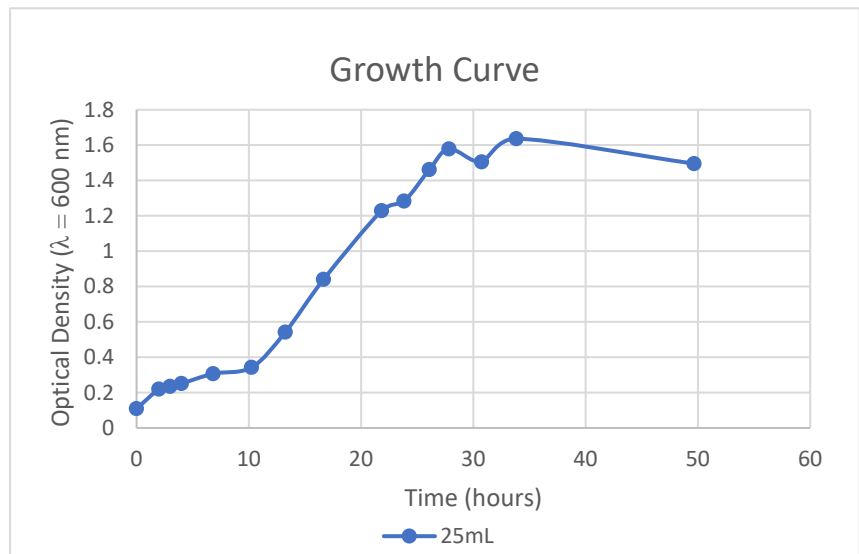
Figure 2. The experimental growth curve of M. alcaliphilum is shown from the time of inoculation to 50 hours.

Informational Resources

Contact: Ms. Judith L. Sims, Telephone: (435) 797-3230, E-mail: judith.sims@usu.edu.

Poster Presentations:

Hodges, Alan, C. Hancock, R.C. Sims, and J. Sims (2016). Reduction of Greenhouse Gas Emissions from Septic Tanks via Compost Biofiltration. *Annual Conference, Institute of Biological Engineering*, Greenville, SC, April 7-9.

Parkinson, J.C. and K. Ellis (2018). Mitigation of Methane Emissions from Septic Tanks via Compost Biofiltration. *Utah State University Student Research Symposium*, Logan, UT, April 12.

Parkinson, J.C. and K. Ellis (2019). Methane Emission Mitigation Using *Methylomicrobium alcaliphilum*. *Utah State University Student Research Symposium*, Logan, UT, April 12.

Drinking Water and Wastewater Treatment

Treatment and Bioenergy Recovery from Beverage Wastewater

Principle Investigators:
Ronald C. Sims
Charles Miller
Legor Pererva (PhD student)

Partners/ Collaborators:
Local: WesTech-Inc., Logan, Utah
Business/Industry: WesTech, Inc. Engineering, Salt Lake
City, Utah

Project Description

- **Need and Purpose:**

The environmental firm of WesTech-Inc., located in Logan, Utah, and with its national center in Salt Lake City, is interested in introducing a new technology for both the treatment of waste and the recovery of energy in the form of biomethane for the expanding beverage industry in Utah. The technology is referred to as Upflow Anaerobic Sludge Blanket (UASB). Advantages include lower electricity requirement, less cost for treatment, and recovery of sustainable bioenergy that can be utilized in powering the technology. The UASB technology does not require oxygen and uses the biogas produced (methane and carbon dioxide) to mix the contents of the UASB reactor. The purpose of this project is to test and evaluate the UASB technology for the management of distillery waste, specifically to determine the "bio-methane potential" (BMP).

Benefits to the State:

The UASB technology for treating wastewater would benefit the state of Utah by providing an alternative low cost, environmentally protective, and sustainable energy recovery-based management option for the expanding beverage industry in Utah. The technology is also potentially advantageous for other types of industry wastes currently being produced in Utah. Implementing the UASB technology could boost economic growth through creation of new engineering jobs and services in Utah.

- **Geographic Areas:**

Study Area: The State of Utah and, most immediately, the Salt Lake City area.

Areas Benefited: All areas of the state of Utah that must meet strict wastewater treatment plant nutrient limits, including mechanical plants and ponds or lagoons.

- **Accomplishments:**

Findings: (1) The beverage wastewater (distillery) has a high potential for treating the wastewater constituents without the need for more expensive additions (i.e., oxygen and mechanical mixing). The microorganisms can be cultivated successfully as a "blanket" within the biological reactor and can remove contaminating organic chemicals from the wastewater, (2) The technology can generate bioenergy in the form of bio-methane and bio-hydrogen that can serve as electricity, heat, and power generation sources for reuse by the industry.

Results: The bio-gas produced in the Bio-methane Potential (BMP) tests is shown in Figure 1. Three of the four wastes produced significant amounts of biogas (methane and carbon dioxide) over a short period of time (14 days). The fourth wastewater (JD #4) started producing biogas later than the other three; however, it only needed a longer acclimating time before generating biogas. Carbon dioxide can serve as a food source for microalgae that can be cultivated and used for fertilizer, as well as recycled back as feed

for the UASB technology to produce more bioenergy. These results demonstrated the success of mixed culture anaerobic microorganisms for treating industry wastewaters and producing valuable bioenergy.

Work Plan FY19/FY20

The results from this test and evaluation for Bio-methane Potential (BMP) will be used in Upflow Anaerobic Sludge Blanket (UASB) reactors to determine operating and control conditions, as well as monitoring strategies. UASB reactors will be designed, constructed, and operated to treat the test wastewaters over several months of operation to determine more long-term performance.
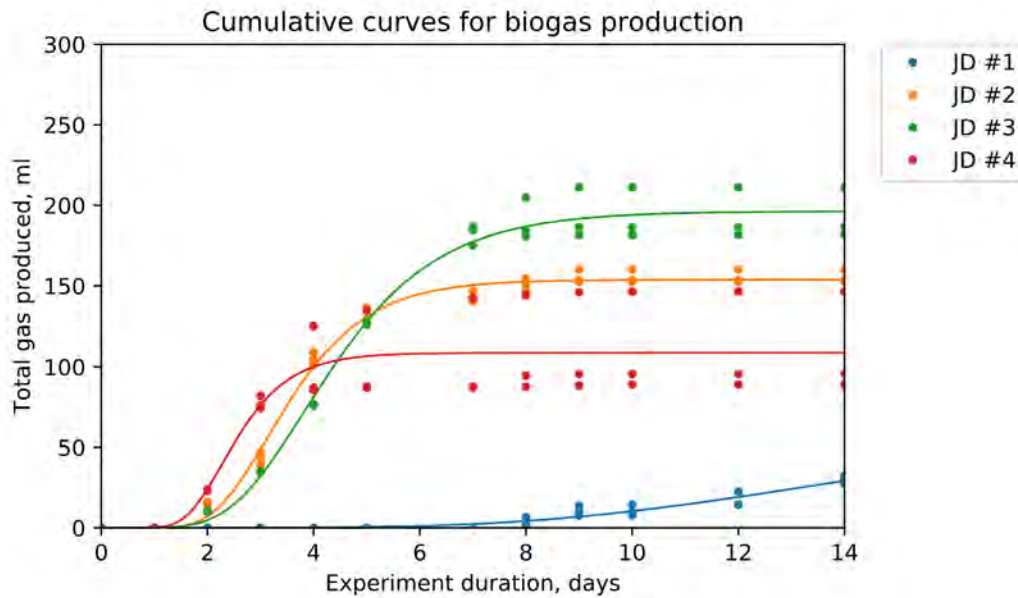
Figure 1. Biogas (methane and carbon dioxide) production for four different beverage (distillery) wastes as measured in Bio-Methane Potential (BMP) tests.

Informational Resources

Contact: Dr. Ronald C. Sims, Telephone: (435) 797 3156, E-mail: ron.sims@usu.edu.
Mr. Keith Albresten, Biological Engineer, WesTech-Inc., Logan, UT. kalbretsen@westech-inc.com.
Mr. Tyler Garr, Environmental Engineer, WesTech-Inc., Salt Lake City, UT. tgarr@westech-inc.com.
Mr. Rex Plaizier, President and CEO, WesTech, Inc. Engineering, (801) 856-5323, rplaizier@westech-inc.com.

Use of Magnetite to Improve Settling and Effluent Quality in Wastewater Treatment Plants

Principal Investigators:
Michael J. McFarland
Patricia Ayaa (graduate student)

Partners/Collaborators:
- **Local**: Holly Daines, Mayor, Logan City; Issa Hamud, Environmental Director, Logan City; Tom Jensen, Sewer and Water Board, Logan City

Project Description:

- **Need and Purpose:**

  The City of Logan is in the process of upgrading its wastewater treatment facility from a lagoon system to a mechanical facility in order to meet its new phosphorous and ammonia effluent limits imposed by the Utah Division of Water Quality. The new treatment plant will use the 3-Stage Bardenpho process with BioMag® Technology, which adds magnetite to the secondary treatment process. BioMag® was chosen because it would enable Logan City to build a facility with a much smaller footprint than a conventional 3-Stage Bardenpho wastewater treatment facility since the soils in the area where the new plant will stand would not be able to support the size of a conventional facility. Magnetite is an iron ore mineral with a specific gravity of about 5.2, which is much higher than the specific gravity of water and of individual biological floc particles. The high specific gravity of magnetite is expected to increase the settling velocity of the biological floc in the settling tanks, thereby improving their efficiency and enabling smaller sized tanks to be used. Magnetite is also said to improve the quality of effluent from wastewater treatment facilities.

  This research is aimed at investigating the effectiveness of magnetite in wastewater treatment in terms of biological nutrient removal (BNR), and the use of the wasted solids containing magnetite in processes such as anaerobic digestion and land application. The information obtained should help the City of Logan to have a clearer picture of what to expect with the new treatment plant.

- **Benefits to the State:**

  o Savings on the initial capital cost of erecting larger new facilities to meet more stringent effluent quality standards, as well as savings on operation and maintenance costs.

  o Improvement in the capacity of existing wastewater treatment facilities, thus eliminating the need to erect entirely new facilities to meet effluent quality requirements.

  o Improvement in effluent quality from wastewater treatment facilities to meet requirements imposed by the Division of Water Quality.

- **Geographic Areas:**

  Study Areas: City of Logan, Utah.
  Areas Benefited: Could benefit any similar wastewater treatment plant in the state.

- **Accomplishments:**

  Findings/Results: So far, findings from the research have shown that the technology has helped improve nitrogen and phosphorus removal at the Marlay-Taylor Water Reclamation Facility, and that the facility is

effectively treating peak flows and is in compliance with their effluent discharge regulations. Therefore, Logan City and any other facilities that are struggling with nutrient (nitrogen and phosphorus) removal at their wastewater treatment facilities may benefit from this technology. A paper has been written and is in the submission process for review and eventual publication.

Work Plan FY19/FY20

Plans for the next fiscal year include:

1. Investigating the effect of magnetite in anaerobic digesters for facilities that plan to produce biogas from their waste.

2. Investigating the effect of land application of solids containing magnetite from a wastewater treatment facility.

3. Investigating any other issues that may arise as a result of magnetite use in wastewater treatment during the course of this research.

Informational Resources

Contact: Dr. Michael J. McFarland, Telephone: (435) 994 0905, E-mail: farlandm1@outlook.com.

Environmental Quality Management and Remediation

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Environmental Quality, Management, and Remediation

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Impact of Biochar Additions to Soil on Contaminant Mobility and Fate for Groundwater Protection	$33,737	$0	$0
Impact of Metals and Metal Ions on Soils and Plants	$66,171	$68,156	$70,201
Northrop Grumman Static Rocket Test Environmental Assessment	$53,213	$54,810	$56,454
Understanding the Potential Impacts of Onsite Wastewater Systems on Groundwater Quality in Monroe City, Utah	$5,926	$0	$0
Using Duckweed as a Treatment Technology for Nutrients and Pharmaceutical Contaminants in Municipal Wastewater Systems	$57,924	$59,662	$61,452
Vehicle Dynamometer and On-Road Ammonia Emissions	$84,873	$87,419	$90,041
Designated Projects		$30,000	$30,000
Undesignated Projects		$67,929	$67,929
Total	**$301,845**	**$367,976**	**$376,077**

Environmental Quality Management and Remediation

Impact of Biochar Additions to Soil on Contaminant Mobility and Fate for Groundwater Protection

Principal Investigator:
William J. Doucette
Jeff Flashinski (graduate student)

Partners/Collaborators:
- **Local:** *Darren McAvoy, USU extension program and Utah Biomass Resources Group (UBRG)*

Project Description

- **Need and Purpose:**

  Reclaimed water is being used increasingly in arid and semi-arid regions for non-potable purposes (irrigation, industrial processes, toilet flushing, groundwater recharge, etc.). When used for irrigation, any contaminants in the reclaimed water, such as pharmaceuticals and personal care products (PPCPs) and other compounds, can accumulate in exposed crops. Biochar is biological material (often a plant material) that has partly or fully undergone pyrolysis (decomposition at high temperatures with no oxygen). Biochar is a potentially cost-effective soil amendment and contaminant sorbent that could reduce plant exposure to the contaminants in reclaimed water.

  The main objective of this study is to investigate the impact of wood biochar on the crop bioavailability of selected PPCPs often found in reclaimed water and biomass production. A secondary objective is to quantify the contaminant sorption-desorption characteristics in the amended soils and to determine if there is a relationship between sorption-desorption behavior and plant bioavailability. Development of sorption-desorption and plant bioavailability relationships could help determine the quantity and type of biochar needed as an effective soil amendment. PPCPs were selected as target contaminants because of their widespread occurrence in reclaimed water and their potential impact on animals feeding on the irrigated crops (Ferrari et al., 2003). Target PPCPs were selected for this study based on chemical properties, widespread use, frequent detection in WWTP effluent, and potential risk to the environment. The target PPCPs represent a range of therapeutic uses: (1) antibiotics linked to antibiotic resistance in bacteria (sulfamethoxazole (SMZ) and triclosan (TRI)), (2) an anticonvulsant that prevents seizures and relieves nerve pain (carbamazepine), and (3) an antidepressant (fluoxetine (FLX)). Atrazine (ATZ) was also selected because it is an herbicide commonly used on corn and has been used in a number of sorption studies with biochar. Pinyon Juniper and Lodgepole Pine derived biochars were chosen based on their abundance and need for removal in the local region. Corn was used as the test plant because of its commercial value and because it has been grown with reclaimed water.

- **Benefits to the State:**

  Research showing the successful use of biochar generated from waste biomass as a soil amendment would potential benefit the state in a variety of ways. It could minimize biomass waste associated with forest and agricultural industries, improve reclamation of contaminated mine sites, and enhance groundwater protection associated with septic tank use.

- **Geographic Areas:**

  Study Area: Logan, Utah (Greenhouse and laboratory facilities).

Environmental Quality Management and Remediation

Areas Benefited: All counties in the state could benefit from this resource available in most areas of the state.

- **Accomplishments**: Corn plants were grown in PVC columns filled with sandy loam soil, sand, biochar-amended soil, or perlite amended soil under greenhouse conditions (14 hrs. light—sunlight supplemented with mercury vapor lights; 10 hrs. dark. Estimated light levels in the greenhouse were 500 μmol m s^{-1}, relative humidity 50±25%, and temperature 20±2 ˚C). See Figure 1. Treated plants were watered with reclaimed wastewater spiked with the target compounds (1 mg/L), whereas the control plants received no spike. All treatments were conducted in triplicate, along with two additional plants that were used to determine growth rates, resulting in a total of 50 plants. At 28 days, the corn leaves, stems, and roots were collected and dried in a desiccator.

Dried plant tissue samples were placed into centrifuge tubes and extracted three times with methanol using a vortex shaker. Phenomenex roQ QuEChERs were used to clean up the combined extract prior to analysis using an Agilent 1290 Infinity LC and Agilent 6490 Triple Quadrupole MS system. An Agilent Eclipse Plus C18 column (2.1 x 50 mm, 1.8 μm I.D, 0.45 mL/min flow rate, 10 min. run time, 3 μL injections) was used for chromatograph separations.
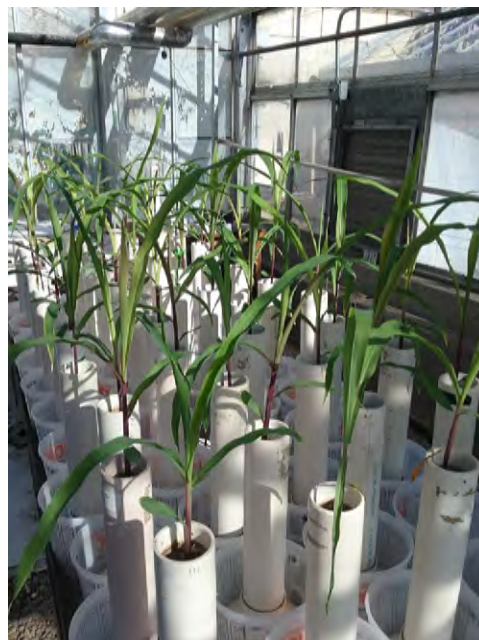
Figure 1: Corn grown in columns containing sand, soil, or soil amended with biochar.

- **Findings:** Results from the corn experiment showed that corn leaves grown in biochar amended soils had significantly lower concentrations ($p < 0.05$) than those grown in non-amended soil for 4 out of the 5 compounds of interest (Figure 2). The corn grown in pinyon juniper (PJ) biochar amended sand had significantly lower leaf concentrations compared to the control corn leaves grown in only sand for 4 of the 5 compounds of interest; however, the lodgepole pine (LP) biochar amended sand reduced leaf concentrations for only 1 of the 5 compounds. The biochar amendments did not negatively impact plant growth.
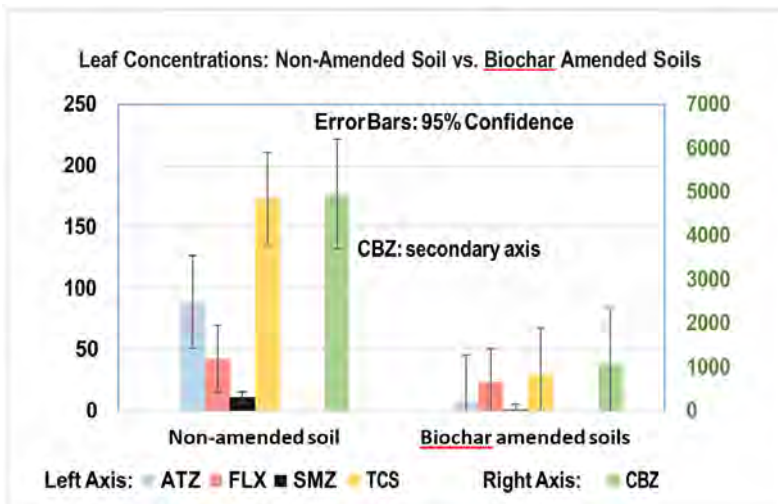
Figure 2: Leaf concentrations (ng/g) for corn grown in non-amended soil vs. biochar amended soil. Carbamazepine concentrations are listed on the secondary axis.

Work Plan FY19/FY20
The project has been completed.

Informational Resources
Contact: Dr. William J. Doucette, Telephone: (435) 797-3178, E-mail: william.doucette@usu.edu.

Environmental Quality Management and Remediation

Impact of Metals and Metal Ions on Soils and Plants

Principal Investigators:
Joan E. McLean
Anne Anderson (Biology)
David Britt (Biological Engineering)
Astrid Jacobson (Plants, Soils, and Climate)
Joshua Hortin ((Researcher I)
Jessica Cooper and Dakota Sparks (Undergraduate students)

Partners/Collaborators:
- **Federal**: *In support of NSF and USDA funding*

Project Description

- **Need and Purpose:**
  Copper oxide nanoparticles (CuO NPs) may be used in agriculture as an antifungal or antimicrobial, as a fertilizer, or as a drought resistance treatment. However, application of CuO NPs in or near soils for any purpose may have unintended consequences to plant and microbial life as the NPs dissolve, transform, or move. Plants need copper (Cu) as a micronutrient, but elevated levels of bioavailable Cu are highly toxic to plants and their associated bacteria. Soils are exceedingly complex and many properties influence the behavior of Cu in the soil. Plant roots and bacteria add to the complexity as

Figure 1. Wheat plants grown with 15 mg Cu/kg CuO NPs under well-watered (A) and drought (B) conditions.

they exude chemicals (exudates) that frequently bind to Cu in solution, promoting dissolution of the CuO NPs and altering plant uptake of Cu. The focus of this year's effort was to evaluate how drought conditions during wheat growth alter the biogeochemistry of the rooting environment and thus CuO NP interaction with plants.

  Benefits to the State:

  Although the research focuses on CuO NPs, it is also relevant to metal pollution and other NPs in general. Results directly benefit Utah counties with current metal contamination from abandoned and active hard rock mining and related industrial operations by protecting environmental quality and human health related to metal exposure. CuO NPs may benefit counties with agricultural operations as more research is conducted on the pesticidal and drought resistance-stimulating properties of the NPs, particularly as drought and opportunistic pathogens increase in frequency.

- **Geographic Areas:**

  Study Areas: Counties with abandoned and active mining operations, counties with industrial operations, and counties with agricultural operations—all counties in Utah.
  Areas Benefited: All counties in Utah.

Environmental Quality Management and Remediation

- **Accomplishments:**

Findings: Plants under drought stress produce higher concentrations of root exudates, increasing solution concentration of Cu, but not Cu uptake by the wheat. These Cu-exudate complexes alter the bioavailability of Cu, but the plant tightly regulates Cu uptake.

Results: Wheat was grown in the presence of a beneficial soil bacterium in sand. The dose of CuO NPs ranged from 0 to 30 mg Cu/kg sand. After 10 days of growth, half of the wheat samples were droughted. Wheat was grown for an additional 8 days (Fig. 1). The pore water in the rooting zone of wheat plants contained higher concentrations of exduates when grown under drought conditions compare to well-watered conditions. These exudates complex with Cu, increasing the solubility of the CuO NPs (Fig 2A). The increase in solution concentration is not, however, reflected in an increase in Cu concentration in the above ground tissue of the plant (Fig 2B); wheat plants control the concentration of this essential nutrient to avoid toxic levels of this element being taken up. We have previously published evidence with collaborators that CuO NPs increase lignin in wheat shoots, which may decrease collapse of wheat during drought. We are presently evaluating other plant response factors, such as photosynthetic activity, to determine whether the NPs at the tested doses also aid metabolic aspects of the drought-tolerance of wheat.

Work Plan FY19/FY20

We have been conducting our research under controlled conditions using sand as the growth media. We will now conduct studies using three soils from Northern Utah under different soil management practices that alter soil organic matter and microbial population and composition. We will also expand our work to include additional NPs—zinc oxide and silica dioxide—to evaluate the efficacy of these NPs in aiding wheat's resistance to drought.

Informational Resources

Contact: Ms. Joan E. McLean, Telephone: (435) 797-3199, E-Mail: joan.mclean@usu.edu.
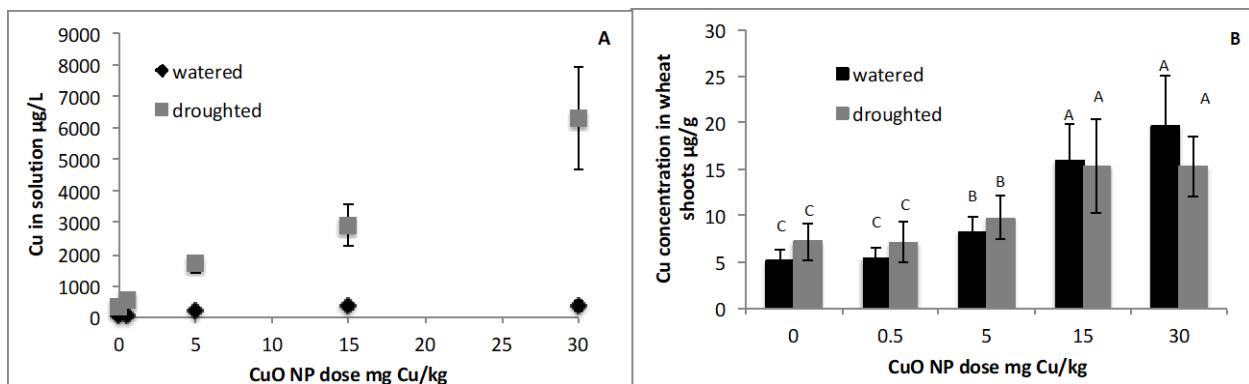

Figure 2. Copper concentration in solution increased with dosing of NPs and drought conditions (A). The increased dosing of CuO NPs results in increased plant uptake of Cu into shoot tissue, but the plant restricts continued uptake of Cu under drought conditions (B). Error bars are 95% confidence intervals; letters in (B) designate no difference among treatments.

Environmental Quality Management and Remediation

Northrop Grumman Static Rocket Test Environmental Assessment

Principal Investigators:
William Doucette
Laurie McNeill
Autumn Slade (MS student)
Jeff Wight (BS research assistant)

Partners/Collaborators:
- **Business/Industry:** Northrup Grumman

Project Description

- **Need and Purpose:**

  Tests of horizontally restrained rocket motors at the Northrup Grummon facility in Promontory, UT, USA, results in the deposition of entrained soil and combustion products (largely aluminum oxide, gaseous hydrogen chloride, and water) on the surrounding area. The deposition is referred to as test fire soil (TFS). Local residents and farmers observing TFS deposited on their property and crops have expressed concerns regarding the potential impact of this material.

  The focus of this study was to collect, quantify, and analyze TFS deposition samples in the surrounding area resulting from a rocket motor test at the site. Specific study objectives were: (1) collect samples of TFS within the deposition-affected areas and (2) analyze the TFS samples for chloride, aluminum and other metals.

Figure 1. Laurie McNeill preparing to collect TFS samples from overhead plume.

- **Benefits to the State:**

  This research will help Northrup Grumman (a leading employer in the State of Utah) to better understand the environmental effects of their static motor tests. Results will also help to address the concerns of local residents about the effects of material deposited during the static tests.

- **Geographic Areas:**

  Study Area: Northrup Grummon Promontory facility in Box Elder County

  Areas Benefited: Box Elder County, including Thatcher, Tremonton, Corrine, and Penrose

- **Accomplishments:**

  Findings/Results: The four sample collection sites (Figure 2) were selected based on the plume path predictions made by Northrup Grumman meteorologists just before the static test. The static test started at 1:05 PM, May 30, 2019. TFS deposition was first observed at between 1:32 and 1:33 PM at Sites 1, 2, and 3, with no TFS deposition observed at Site 4 (Maple Bluff). The duration of the TSF deposition period was approximately 23 minutes. Deposition of the TFS at the three impacted sites during the May 30, 2019 test ranged from 0.4 to 12 g/m^2 as compared to a historical average of 70 g/m^2. Chemical characterization

of the collected TFS determined that chloride (average = 46600 mg/kg) and aluminum (average = 45300 mg/kg) levels were similar to those found in previous events.

Work Plan FY19/FY20

Similar sampling and analysis is planned for future rocket motor tests in FY19/FY20.

Informational Resources

Contact: Dr. William J. Doucette, Telephone: (435) 797 3178, E-mail: william.doucette@usu.edu.
Dr. Laurie McNeill, Telephone: (435) 797-1522, Email: laurie.mcneill@usu.edu.

*Figure 2. Sampling locations for the OmegA™
First Stage Rocket Motor static test.*

Environmental Quality Management and Remediation

Understanding the Potential Impacts of Onsite Wastewater Systems on Groundwater Quality in Monroe City, Utah

Principal Investigators:
William J. Doucette
Autumn Slade (graduate student)

Partners/Collaborators:
- **State/National**: John L. Chartier, PE, District Engineer, Central Utah District

Project Description:

- **Need and Purpose:**

  The purpose of this analysis project was to assist the Utah State District Engineer and Monroe City, Utah, in understanding the potential impacts of onsite wastewater systems on groundwater quality. Well water samples were collected by the District Engineer and sent to the Utah Water Research Laboratory (UWRL) for the analysis of caffeine and sucralose via solid phase extraction (SPE) and liquid chromatography mass spectrometry (LCMS). Caffeine and sucralose, a food additive and an artificial sweetener, respectively, were used as anthropogenic markers to track discharges from onsite wastewater treatment systems.

- **Benefits to the State:**

  Understanding potential sources of groundwater contamination is critical to protecting the quality of drinking water wells. Results from the study were used by the State District Engineer and Monroe City to determine if onsite wastewater treatment systems were contributing to groundwater contamination in that area. The same approach could be used throughout the state of Utah.

- **Geographic Areas:**

  Study Areas: Monroe, UT.

  Areas Benefited: The entire state could benefit from this approach.

- **Accomplishments:**

  Findings/Results: The four water samples collected from wells located near Monroe, Utah, were analyzed for caffeine and sucralose using SPE and LCMS. Results were sent to the District Engineer to assist in the determining potential sources of groundwater contamination. Caffeine and sucralose were detected in very low concentrations (low ng/L) in several of the well water samples.

Work Plan FY19/FY20

The project ended in May 2019.

Environmental Quality Management and Remediation

Informational Resources

Contact: Dr. William J. Doucette, Telephone: (435) 797 3178, E-mail: william.doucette@usu.edu.

Environmental Quality Management and Remediation

Using Duckweed as a Treatment Technology for Nutrients and Pharmaceutical Contaminants in Municipal Wastewater Systems

Principal Investigators:
R. Ryan Dupont
Joan E. McLean
Kwame Duodu Cristal (MS student)
Carolina Collins (Undergraduate student)
Lucy Campos (Undergraduate student)

Partners/Collaborators:
- **Local:** Scott Wells, City Manager, Wellsville City; Issa Hamud, Director, Environmental Department, Logan City; Kevin Maughn, Manager, Hyrum City Wastewater Treatment Plant

Project Description

- **Need and Purpose:**

Nutrients, particularly phosphorous, along with other contaminants such as personal care products and pharmaceuticals (PCPP) in municipal wastewater systems are of increasing concern due to their effects on aquatic ecosystems. Conventional wastewater treatment systems are not effective in the removal of these contaminants. Chemical or advanced biological treatment alternatives that do provide contaminant removal are often prohibitively expensive to implement, particularly for small, rural communities. This study is determining the effectiveness of a duckweed-based system (*Lemna turionifera* and *Wolffia borealis*) for treatment of nutrients and PCPP contaminants in municipal wastewater, especially in communities like Wellsville City and

Figure 1. Bank view of duckweed covering the Wellsville lagoons, May 2017

Logan City, which currently have lagoon wastewater treatment systems. In addition, the work is quantifying the energy recovery potential of harvested duckweed biomass using anaerobic digestion and determining the fate of PCPPs exposed to anaerobic digestion and the growth of heterotrophic algae on the digester supernatant.

- **Benefits to the State:**

Protecting surface water quality from nutrient enrichment and PCPPs is a concern in many watersheds in the State. This project is developing effective, low-cost treatment methods to remove nutrients and PCPPs from wastewater with a net positive energy and environmental footprint.

- **Geographic Areas:**

Study Area: Cache County, UT.

Figure 2. Schematic of the batch-fed anaerobic digesters.

Areas Benefited: Utah locations with actual/potential nutrient and PCPP impacted surface water that require low-cost, sustainable nutrient management systems for water quality improvements.

- **Accomplishments**:

Findings: Studies at the Wellsville lagoons (Figure 1) showed significant duckweed growth rates, high nutrient concentrations accumulated in the duckweed biomass, and high PCPP removal rates. This demonstrates that a duckweed-based wastewater treatment system can be feasibly implemented. However, the effectiveness of the system is dependent on efficient cost-effective harvesting, stabilization,
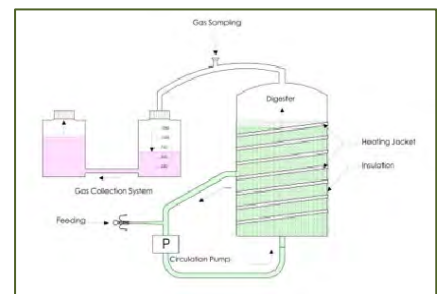
and processing of the biomass. Freshly grown duckweed and field-harvested biomass have been used as feedstock for lab-scale anaerobic digesters (Figure 2) that stabilize harvested biomass and generate methane (Fig.3). We have evaluated the digesters' methane production and reactor stability, and explored the use of digester effluent to grow heterotrophic algae for use in producing valuable biofuels. We have also developed methods to extract and analyze PCPPs from duckweed biomass and anaerobic digester effluent so we can predict PCPP concentrations in treatment plant effluent.
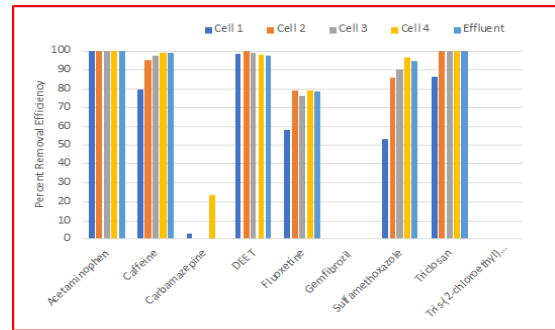
Figure 3. PPCP removal efficiency in the Wellsville wastewater treatment plant, 2019.

Results: Wastewater and duckweed associated PPCP concentrations along the Wellsville Lagoon system flow path were analyzed to evaluate PPCP uptake and transformation in duckweed under field conditions. Figure 3 shows the removal efficiency for PPCPs measured in the liquid phase through the Wellsville lagoons, with Figures 4a and 4b showing the PCPP concentrations in the lagoon duckweed and bottom sludge, respectively. Acetaminophen, Caffeine, DEET, Sulfamethoxazole, and Triclosan are removed with greater than 90% efficiency, while Carbamazepine, Gemfibrozil and Tris-(2-choloroethyl) Phosphate are not removed to any significant extent through the four cell, duckweed populated lagoon system. Carbamazepine and Tris-(2-choloroethyl) Phosphate are also seen to accumulate in both duckweed and sludge solids, while all other compounds are found to degrade in both solids through the treatment process.

The Duckweed technology is clearly a feasible low-cost alternative to much more expensive advanced biological/chemical treatment processes. In addition, it produces a potentially valuable end product in the form of harvested duckweed biomass.

a.

b.
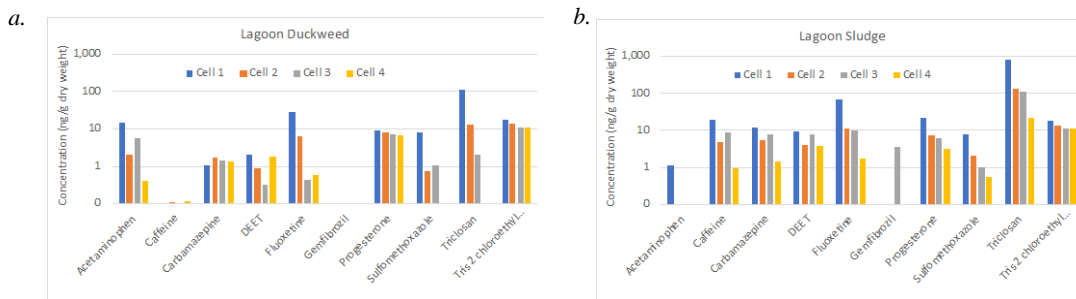
Figure 4. PPCP concentrations (ng/g dry weight) in a. duckweed, and b. lagoon cell bottom sludge measured in the Wellsville lagoon system, 2019.

Work Plan FY19/FY20

We will (1) complete laboratory anaerobic digester studies and aerobic composting studies to evaluate PCPP transformation in duckweed biomass solids handling systems to quantify their fate during anaerobic digestion and composting and (2) develop guidelines and recommendations for duckweed harvesting and stabilization to maximize PPCP degradation and minimize the risk relative to processing and reusing duckweed biomass.

Informational Resources

Contact: Dr. R. Ryan Dupont, Telephone : (435) 797 3227, E-mail : ryan.dupont@usu.edu.
Website: http://duckweedresearch.blogspot.com/2012/05/duckweed-research-presentations-and.html.

Environmental Quality Management and Remediation

Vehicle Dynamometer and On-Road Ammonia Emissions

Principal Investigators:
Randal S. Martin
Joe Thomas (UDAQ/WSU NACST)
John Sohl (UDAQ/NACST)
Nancy Daher (UDAQ)
Motasem Abualquomboz (graduate student)

Partners/Collaborators:
- **Local**: City of Logan, Cache County
- **State/National**: Utah Division of Air Quality (UDAQ)

Project Description:

- **Need and Purpose:**

  Preventative and protective strategies are needed to address Utah's $PM_{2.5}$ (particulate matter) and O_3 (ozone) air pollution health issues in the Cache Valley, along the Wasatch Front, and even out into the Uintah Basin. This is especially true during the wintertime inversion conditions typical of northern and northeastern Utah. Previous research and regulatory work has shown that vehicle emissions are the dominant emission sources of Utah's direct and precursor pollutants. However, it has become apparent that current air pollutant emission inventories underestimate available ambient ammonia (NH_3), a key component of our local/regional $PM_{2.5}$ (ammonium nitrate). State-wide photochemical modeling attempts must be artificially enriched by two to six times to adequately predict observed ambient concentrations. Literature searches have shown little available data on raw NH_3 emissions from mobile sources, although many infer that the mobile sector may be a significant source of these underestimations. This project combines Mineral Lease funds and funds from the Utah State Division of Air Quality (UDAQ) to expand the overall scope of this research topic.

- **Benefits to the State:**

  Accurately assessing the NH_3 and other pollutant emissions from sources relevant to the fleets and conditions of the Cache Valley and Wasatch Front will help to identify the significance of these sources, particularly under wintertime conditions. This will also facilitate the development of information that can be provided to the general public through local and statewide outreach programs for both gasoline and diesel engine types.

- **Geographic Areas:**

  Study Areas: The majority of the automobile emissions testing has been and will be conducted at the Utah Water Research Laboratory (UWRL) and at Weber State University's National Center for Automotive Science and Technology (WSU/NCAST). Laboratory characterization and on-road studies take place at UWRL and dynamometer studies at WSU/NCAST.

  Areas Benefited: The populations of the Cache Valley and the Wasatch Front will see the most direct and immediate benefit of these and future studies. The results will also be of use to UDAQ in planning future mitigation and modeling strategies. Air quality research partnerships have also been established among UDAQ/AMC, USU/UWRL, WSU, the U of U and BYU.

- **Accomplishments:**

  Findings: In cooperation with two other projects funded through the UDAQ, various state-of-the-art instrumentation have been obtained. These include a Picarro 2103 real-time ambient ammonia (NH3)

monitor and an ECM NH3/Oxides of Nitrogen (NOx) mobile source tailpipe emissions monitor. In-house laboratory studies have found that the Picarro instrument is highly sensitive and remarkably stable, but care must be used in tailpipe measurement due to excess moisture. An optimal configuration of the more portable ECM unit was developed and calibrated. This proved challenging as separate configurations were found to be needed for gasoline versus diesel vehicles due to different states of oxygen depletion in the different exhausts. Following these findings, approximately half a dozen gasoline vehicles have been tested on the WSU/NCAST dynamometer and about a dozen mixed gasoline/diesel vehicles have been tested, some in triplicate, over the on-road transect developed at the UWRL.

Results: Analysis, compilation, and validation of dynamometer and on-road test data is ongoing. However, as shown in the figure below, the NH_3 emissions (green) for the on-road test of a 2007 Dodge Ram 1500 gasoline pickup were very transient and seemed to be anti-correlated with vehicle speed (grey). The mechanism for this variability is uncertain, but under investigation.

Additionally, during the past winter and summer, airshed NH_3 studies in the Salt Lake Valley used near-road ambient NH_3 levels, coupled with nearby meteorological measurements, with a Gaussian inverse modeling protocol to derive whole-fleet, comparative NH_3 emission rates. Despite great apparent variability, the average NH_3 emission rate was found to be 207 mg NH4/km/vehicle, which compares favorably to literature values (2-250 mg NH4/km/vehicle).
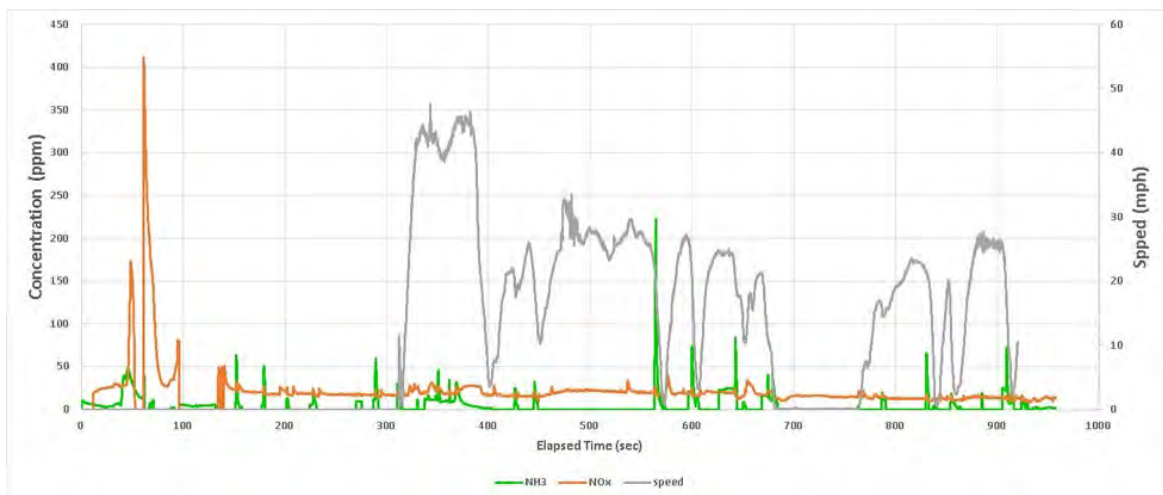
Work Plan FY19/FY20

Instrument comparisons and characterizations will continue through the next fiscal year on a periodic, as required, basis. Both on-road and dynamometer tailpipe emission studies on gasoline and diesel vehicles that are population proportionally representative will continue, as will software development for the most effective data analysis, compilation, and comparison. A poster presentation has been accepted for the CRC 30th Real World Emissions Workshop in San Diego, CA, March 15–18, 2020. In addition, the to-date results will be presented at the Utah-centric Science for Solutions Conference in Provo, UT, March 26, 2020.

Informational Resources

Contact: Dr. Randal S. Martin, Telephone: (435) 797 1585, E-mail: randy.martin@usu.edu.

Surface and Groundwater Quality and Quantity

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Surface and Groundwater Quality and Quantity

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Characterizing Streamflow and Temperature Patterns to Determine Impacts of Summer Dewatering on the Blacksmith Fork River	$28,094	$28,937	$29,805
Impacts of Beaver Dams on Stream Hydrology, Temperature, and Geomorphology	$21,131	$0	$0
Integrated Model of Water Quality in Streams and Reservoirs in Highly Managed Watersheds	$19,684	$20,274	$20,882
Logan City Stormwater Monitoring	$17,929	$18,467	$19,021
Optimizing Stormwater BMP Performance through Vegetation Selection and Harvesting Strategies	$55,818	$57,492	$59,217
Quantification of Groundwater Influences in High Gradient Utah Streams and Rivers	$17,929	$18,467	$19,021
Release of Arsenic from Aquifer Solids under Anaerobic Conditions	$55,828	$0	$0
Designated Projects		$50,000	$60,000
Undesignated Projects		$87,241	$80,000
Total	**$216,413**	**$280,878**	**$287,946**

Surface and Groundwater Quality and Quantity

Characterizing Streamflow and Temperature Patterns to Determine Impacts of Summer Dewatering on the Blacksmith Fork River

Principal Investigators:
Belize Lane
Bethany Neilson

Partners/Collaborators:
- **Federal:** *Trout Unlimited*
- **State:** *Division of Natural Resources*
- **Local:** *City of Nibley*

Project Description:

- **Need and Purpose:**

As one of the driest and fastest growing states, Utah faces a critical challenge to identify how limited and increasingly uncertain water resources can be more efficiently allocated to meet human and environmental water needs. In dry summers in northern Utah, irrigation diversions dewater lowland river reaches, from which native trout populations take years to recover. Understanding how stream temperature and flow are altered by distributed irrigation diversions and seepage return flows is fundamental to predicting temperature changes under different water management practices and the ecological consequences of these changes.

- **Benefits to the State:**

The overall focus of this research is to improve coupled human-environmental water management in Utah, particularly in lowland agricultural regions downstream from mountain canyons. We are monitoring trends in streamflow, groundwater exchange, and water temperature over the summer low flow period to improve understanding of the consequences of water management decisions for river ecosystems. This in turn will allow us to more accurately assess tradeoffs between water uses and propose solutions that benefit both irrigators and fish.

- **Geographic Areas:**

Study Areas: Lower Blacksmith Fork River, Nibley, UT.

Areas Benefited: This research will directly benefit Nibley, but the information gained and methods developed may be applicable to all of Utah's lowland irrigated streams and rivers.

- **Accomplishments:**

Findings: Based on discharge, water temperature, and irrigation seepage patterns recorded along the study reach, are characterizing the impact of streamflow diversions and water efficiency projects (e.g., lining or piping canals) on stream flow and temperature. The schematic below illustrates the depletion occurring over summer in many streams across the state. Aerial and thermal imagery were also collected using the UWRL's AggieAir remote sensing platform, along with field-based temperature sensors, to assess spatial patterns of water temperature.

Results: The information gained in this field-intensive project will help identify limiting streamflow and temperature conditions and locations for native and recreational trout fisheries in the Blacksmith Fork River. These thresholds will help us determine how much water needs to be kept in the river to maintain river ecosystems through the hot summer months, particularly in dry years, and will also improve

understanding of the unintended impacts of irrigation seepage losses and potential consequences of increasing irrigation efficiency for instream flows.

Work Plan FY19/FY20

The physical river parameters monitored in summer 2019 will be compared with parameters monitored in the much drier summer 2018 to assess climate influences. Graduate student Madison Alger is continuing to work with Trout Unlimited and Nibley City to implement a proposed solution to keep minimum instream flows in the Blacksmith Fork River based on the outcomes of this research project. This information is also being used to inform a larger research proposal to improve understanding of stream temperature patterns in irrigated western landscapes.

Informational Resources

Contact: Dr. Belize Lane, Telephone: (435) 797 4145, E-mail: belize.lane@usu.edu.

Publication:

Alger, M., B.T., Neilson., and B. Lane (In preparation). Stream temperature and flow patterns in an irrigated western landscape. *Journal of Hydrology*.
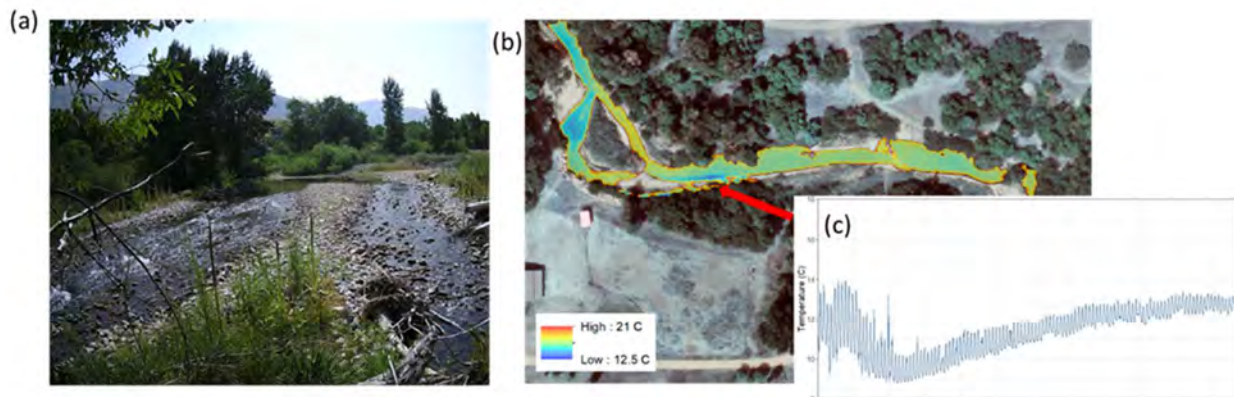

Figure 1. (a) Depleted section of river from streamflow diversions, (b) water temperature patterns remotely sensed using AggieAir indicate locations of cool water inputs, and (c) daily water temperature at a seep over the summer.

Impacts of Beaver Dams on Stream Hydrology, Temperature, and Geomorphology

Principal Investigators:
Bethany T. Neilson

Partners/Collaborators:
- **Local:** *Brad Hunt, Hardware Ranch*
- **State:** *UDFW, UDWR*
- **Federal:** *Brett Roper, USFS*

Project Description

- **Need and Purpose:**

  Conditions within Curtis Creek changed significantly in 2007 when a 2-km section was colonized by beaver. Beaver dams alter channel hydraulics, which in turn change the geomorphic templates of streams. Variability in geomorphic units, the building blocks of stream systems, and water temperature, critical to stream ecological function, define habitat heterogeneity and availability. While prior research has shown the impact of beaver dams on stream hydraulics, geomorphic template, or temperature, the connections or feedbacks between these habitat measures are not well understood. This has left questions regarding relationships between temperature variability at different spatial scales to hydraulic properties such as flow depth and velocity that are dependent on the geomorphology.

- **Benefits to the State:**

  This research provides a method for understanding the influences of beaver dams on instream processes. This is critical to the state of Utah as debate continues regarding the pros and cons of beaver dams on stream function and what this means in terms of implementing the current State of Utah Beaver Management Plan.

- **Geographic Areas:**

  Study Area: Curtis Creek, Hardware Ranch, Cache County

  Areas Benefited: Because of the broad application of our findings, the entire State of Utah could potentially benefit.

- **Accomplishments:**

  Findings: As detailed within Majerova et al. (2019), we combined detailed predicted hydraulic properties, field-based maps with an additional classification scheme of geomorphic units, and detailed water temperature observations throughout a study reach to demonstrate the relationship between these factors at different spatial scales (reach, beaver dam complexes, and geomorphic units). Over a three-week low flow period we found temperature to vary 2 °C between the upstream and downstream extents of the reach, with a net warming of 1 °C during the day and a net cooling of 0.5 °C at night. At the beaver dam complex scale, net warming of 1.15 °C occurred during the day, with variable cooling at night. Regardless of limited temperature changes at these larger scales, the temperature variability within a beaver dam complex reached up to 10.5 °C due to the diversity of geomorphic units.

  Results: At the geomorphic unit scale, the highly altered flow velocity and depth distributions within primary geomorphic units provide an explanation of the temperature variability within the dam complex and insight regarding increases in habitat heterogeneity (see figure below).

Surface and Groundwater Quality and Quantity

Work Plan FY19/FY20: This project is now complete.
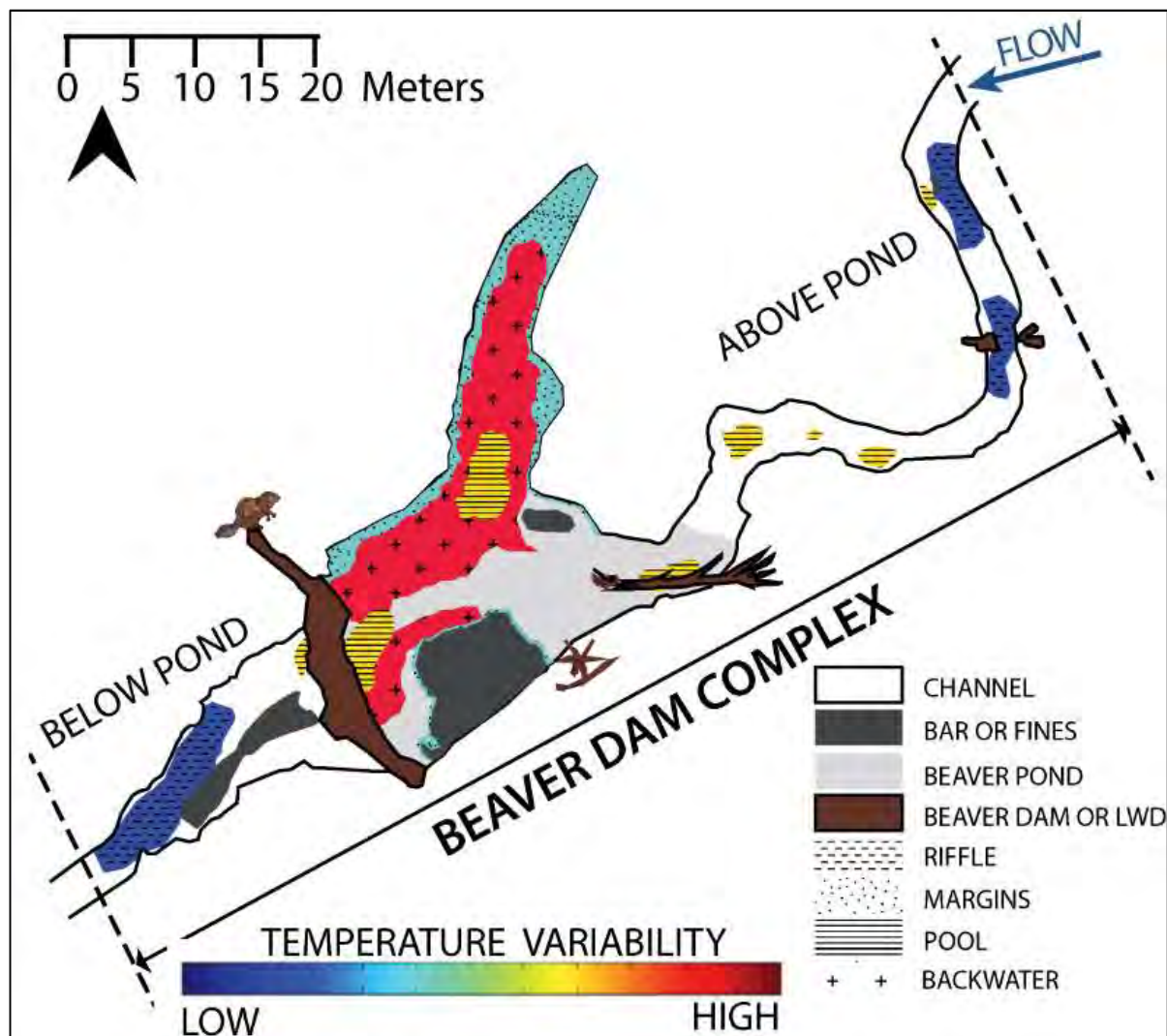
Informational Resources

Contact: Dr. Bethany T. Neilson, Telephone: (435) 797 7369, E-mail: bethany.neilson@usu.edu.

Representative Publications: *where *=Post-Doctoral Researcher, ** = Graduate Student, *** = Undergraduate Student*

Majerova[*], M., B.T. Neilson, N.M. Schmadel[**], C. Snow[**], J. Wheaton (2015). Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream. *Hydrology and Earth System Sciences*, 19:1–16, doi:10.5194/hess-19-1-2015.

Stout[**], T.L., M. Majerova[*], B.T. Neilson (2017). Impacts of beaver dams on channel hydraulics and substrate characteristics in a mountain stream. *Ecohydrology*. 10:1 *(e1767).* doi: 10.1002/eco.1767.

Majerova[*], M., B.T. Neilson, B. Roper (2019). Beaver dam influences on streamflow hydraulic properties and thermal regimes. *Science of the Total Environment*. In press.

Surface and Groundwater Quality and Quantity

Integrated Model of Water Quality in Streams and Reservoirs in Highly Managed Watersheds

Principal Investigators:
David K. Stevens

Partners/Collaborators:
None

Project Description:

- **Need and Purpose:**

  Utah's waters are intensively used and highly regulated. Increasing population pressure makes every drop more valuable every year, while water quality criteria remain stringent. A number of water quality models for rivers, streams, lakes, and reservoir generally have been developed in recent years, but none are directly applicable to systems in which the major diversions and return flows are from agriculture in a montane, snowmelt driven hydrologic system. The work carried out in this project is designed to produce a number of modeling and data analysis tools tailored to Utah's unique terrain, weather, and water use.

- **Benefits to the State:**

  Successful completion of this project will result in a computer-based toolbox that will facilitate the response of water bodies to the addition of pollutants and pollution reduction efforts, accounting explicitly for in-, inter-, and out-of-basin diversions, point and non-point loads, and other processes that affect water quality. The final version will include prediction of most constituents regulated under the Clean Water Act under a variety of flow conditions.

- **Geographic Areas:**

  Study Areas: Bear River basin in Cache County.

  Areas Benefited: All Utah river basins will benefit from this work.

- **Accomplishments:**

  Findings: Development is ongoing. The suite of tools is being implemented in HTML form using the R language and the Shiny web interface. The model currently predicts water quality changes in oxygen, organic matter, nutrients, conservative substances, temperature, and the carbonate system. Visualization and reporting capabilities are being developed alongside the model.

  Results: A series of white papers has been prepared describing the conceptual model, mathematical details, and expected results. Development of the model and visualization is advancing. A unique feature of the model, which is solved using finite differences, is the variable grid spacing. It is designed to provide accurate prediction where concentrations are varying rapidly with a fine grid, while saving execution time by using large grids where changes are slow.

  A model interface where inputs can be defined and outputs viewed is also under development.

Surface and Groundwater Quality and Quantity

Work Plan FY19/FY20

Work will continue in developing this toolkit.

Informational Resources

Contact: Dr. David K. Stevens, Telephone: (435) 797 3229, E-mail: david.stevens@usu.edu.

Logan City Stormwater Monitoring

Principal Investigators:
Bethany T. Neilson
Jeff S. Horsburgh

Partners/Collaborators:
- **Local:** Logan City, Paul Lindhart, Bill Young

Project Description

- **Need and Purpose:**

  As part of Logan City's regular stormwater sampling program and USU's ongoing water quality research in urban stormwater systems within Logan City, USU will assist Logan City in collecting and interpreting flow and water quality monitoring data within the Logan River and related stormwater conveyances. Because of the historical role of agriculture in this area, stormwater is collected within irrigation canals throughout Logan City and requires monitoring of combined irrigation and stormwater.

- **Benefits to the State:**

  Continued expansion of Logan River Observatory monitoring efforts will increase understanding of the urbanizing of agricultural areas. The cyberinfrastructure and data dissemination protocols can be adapted as needed to ensure these approaches can be transferred to other small cities across Utah.

- **Geographic Areas:**

  Study Area: Logan City Canals.

  Areas Benefited: Logan City and Cache County.

- **Accomplishments:**

  Findings:
  To date we have assisted Logan City in the design, purchase, and installation of continuous flow and water quality monitoring stations in the Northwest Field and Benson Canals. We coordinated with Logan City's flow structure installation at these locations and have installed continuous monitoring equipment and telemetry. We have also installed storm monitoring equipment at these locations and at the Utah Water Research Laboratory (UWRL) Logan River Observatory station. We have collaborated with Logan City to develop a coordinated sampling and analysis plan for both continuous sensor data and discrete water quality samples (baseline and storm event sampling).

  We are currently working collaboratively with Logan City to analyze monitoring results and will seek to determine complementary research projects that will develop advanced understanding of hydrologic and water quality processes within Logan and other urban water systems.

Work Plan FY19/FY20

Continued work with Logan City to develop routine monitoring protocols, interpret data, and establish new monitoring sites as needed.

Surface and Groundwater Quality and Quantity

Surface and Groundwater Quality and Quantity

Optimizing Stormwater BMP Performance through Vegetation Selection and Harvesting Strategies

Principal Investigators:
R. Ryan Dupont, Joan E. McLean
Trixie Rife (PhD student)
Rosa Fernandez (MS student)
Kaisa Petersen (MS student
Avery Holyoak (Undergraduate student)

Partners/Collaborators:

- **Local:** Bill Young, Logan City Public Works Department. Salt Lake City Public Utilities, Salt Lake County Public Works.

Project Description

- **Need and Purpose:**

The EPA National Pollutant Discharge Elimination System (NPDES) water pollution control program mandates that municipalities across Utah install structural stormwater best management practices (BMP) as a means of reducing polluted runoff from major industrial facilities, city storm sewers, and construction sites that disturb one or more acres of land. Stormwater detention basins are often

Figure 1: Stormwater BMP site, 300 E Logan.

Figure 2: Stormwater BMP site, USU Campus.

Figure 3: Sample collection at a stormwater BMP site, Salt Lake City Public Utilities building.

used in response to this federal mandate. Objectives of this work are to: (1) minimize discharge volumes and pollutant loadings from urbanized areas flowing into receiving water bodies, and (2) address increased flooding and decreased water quality from urban and rural non-point stormwater sources.

To address stormwater quality and quantity issues effectively, Utah municipalities need locally generated quantitative research to accurately characterize the effectiveness of vegetated storm water management systems. This study measured biomass production and water quality improvement in a controlled greenhouse environment, validated by findings at a field demonstration study site at the Green Meadows subdivision in Logan, Utah. Water and pollutant uptake for seven plant species were quantified in the laboratory under simulated (frequency and duration) rainfall events. The field demonstration site used three of these plant species, along with naturally propagated plant species and non-vegetated control plots. Plant growth was quantified, and contaminant (nutrients and metals) removal was measured in response to periodic plant harvesting. We also evaluated the effectiveness of stormwater BMPs for storms under real environmental conditions by studying green infrastructure performance in capturing and treating storm water and storing it via groundwater at recharge sites in Logan (Figs. 1–2), and Salt Lake City (Fig. 3).

- **Benefits to the State:**

This study is investigating the effectiveness of local plant species that Utah municipalities might use to remove stormwater nutrients and metals and optimize stormwater BMP systems. These data are specific to Utah's climate and geologic conditions. In addition, these quantitative results will prove critical to Utah municipalities and counties that are responsible to meet new MS4 storm water management permit requirement by the State and US EPA.

- **Geographic Areas:**
Study Area: <u>Field demonstration sites in Logan</u>: Green Meadows Subdivision detention basin, 600 S and 1600 W; curb cut/bio-swale, 300 E between 900 and 1000 N; parking lot vegetative strip, Early Education

Building, USU campus; roof drain/dry well, Engineering Building, USU campus; Green roof on Early Education Building, USU campus. <u>Field demonstration site in Salt Lake City</u>: SLC Public Utilities Complex bioretention system.

Areas Benefited: All counties in Utah would potentially benefit.

- **Accomplishments**:

Findings: The species differences in nutrient and metal concentrations accumulated in the harvestable, above-ground biomass evident at both greenhouse and field-scale suggest that sedges are optimal plants to improve water quality of storm water in arid northern Utah. Total containment of stormwater generated at all of the field sites continues to result in 100% pollutant removal from surface water discharge.

Results: New studies are investigating the effectiveness of other green infrastructure systems, such as curb cut modifications to conventional curb and gutter, and bio-swales that completely eliminate storm water discharge into the collection system for storms up to 2 in. in depth (24-hr, 25-year storm in Logan, UT). Soil pore water lysimeter data collected at the 300 E bioswale site (Fig. 4) vegetated with turf grass indicated that the BMP improved pollutant removal compared to 2017 results, with greater >50% removal for most pollutants monitored. Significant increases in EC and mobilization of arsenic (>300% increase from bay influent As concentrations) are evident below this bioretention area, although the pore water arsenic concentration (2.9 µg/L) is significantly below its drinking water standard of 10 µg/L.

Results from the field studies conducted in the summer of 2018 at the field demonstration site at Green Meadows in Logan have confirmed the variability of pollutant removal and protection of groundwater as a function of species planted within a bioretention area. Groundwater concentration for all pollutants evaluated were lower below planted bays than non-vegetated test bays. In addition, sedge has proven the most effective species in removing many pollutants (total nitrogen, total phosphorous, nitrate + nitrite, copper) and concentrating nutrients (total nitrogen, total phosphorous) in above ground tissue (Figure 5) for easy harvesting and removal from a bioretention area compared to other species being evaluated (rush, cattail).

Work Plan FY19/FY20

At the green Meadows site, a final field-scale vegetation study and final field sampling was conducted to specifically focus on quantifying pollutant loading to groundwater measured below the soil rooting zone as a function of pollutant loading to the bioretention systems to determine if groundwater protection can be enhanced by plant selection in stormwater BMPs. Complete results of these sampling excursions and final recommendations regarding plant selection and expected BMP performance will be concluded.
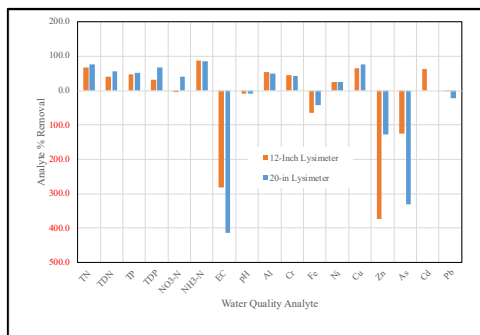
Figure 4: Stormwater BMP site pollutant removal performance 2017-2018 sampling season at 300 E Bioswale, 12 and 20 in depth, Logan.
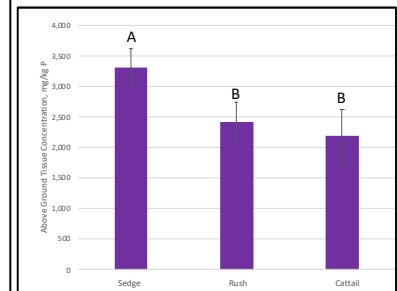

Figure 5: Above ground tissue concentrations of phosphorous in plants harvested from the Green Meadows field site. Letters indicate samples significantly different from one another.

Informational Resources

Contact: Dr. R. Ryan Dupont, Telephone: (435) 797 3227, E-mail: ryan.dupont@usu.edu.

Surface and Groundwater Quality and Quantity

Quantification of Groundwater Influences in High Gradient Utah Streams and Rivers

Principal Investigators:
Bethany T. Neilson
Tianfang Xu
Belize Lane

Partners/Collaborators:
- **Local:** *Logan River Observatory, Cache Water District, Logan City*
- **State:** *USGS Utah Water Science Center, Utah Division of Water Resources*
- **Federal:** *National Science Foundation, USGS*

Project Description

- **Need and Purpose:**

  Characterizing groundwater gains and losses in stream and river systems is critical because of their effect on in-stream water quantity and quality. Some modeling approaches indirectly estimate the influence of groundwater sources and sinks on heat and solute transport in rivers. A wide range of data-centric methods are also used to estimate groundwater exchanges. Recent groundwater exchange studies in northern Utah have focused efforts on smaller scale reaches using a wide variety of data types, but a broader, variable scale investigation of groundwater gains and losses along fast flowing high-gradient streams and river systems is also needed.

- **Benefits to the State:**

  The overall focus of this research is to analyze existing flow and chemical data collected from streams in northern Utah. The study aims to quantify groundwater influences in both pristine mountainous and human impacted urban portions of each watershed. Detailed flow, temperature, and chemistry data have been gathered in the Logan River starting in 2014 and in the Blacksmith Fork River starting in 2018 over various spatial scales during different flow conditions. These data are available along the main-stem as well as tributary inflows and diversions. In the Logan River, many sampling efforts have collected both chemical and flow data to combine flow and chemical mass balances and estimate groundwater contributions to surface water. Time series data from a subset of locations in each watershed also provide fundamental information regarding temporal variability of exchanges. The results of this research will contribute to better management of local water quantity and quality.

- **Geographic Areas:**

  Study Area: Logan River, Logan, UT and Blacksmith Fork, UT.
  Areas Benefited: This research will directly benefit the most populated portions of Utah, but the information gained and methods developed should be applicable to the entire state of Utah.

- **Accomplishments:**

  Findings: Based on flow and mass balances, we have developed a series of assumptions and equations that allow for the quantification of karst and matrix groundwater in gaining, losing, and simultaneously gaining/losing reaches within the upper portion of the Logan River watershed (see Neilson et al. 2018 for details). To further our understanding of karst mountain recharge and discharge, we are investigating the variability of groundwater recharge and stream discharge due to variability in precipitation and snow accumulation throughout the Logan River watershed. We are using a combination of different process based models, machine learning approaches, and field sampling methods to understand linkages between snow and river baseflow.

Surface and Groundwater Quality and Quantity

In summer 2018 and 2019, additional detailed data (flow, chemistry and temperature) were collected in the urban portion of the Logan River watershed, and multiple modeling and analysis approaches have been used to estimate groundwater and other lateral inflows in this portion of the river. Buahin et al. (2019) used a component based temperature modeling approach to back out lateral inflow quantities and temperatures. The calibrated temperature of these lateral inflows provided insight regarding the source of this water (e.g., cold groundwater or warm irrigation returns). Another effort is combining the detailed flow and chemistry data, similar to the upper portion of the basin, to estimate lateral inflows (i.e., agricultural return flows, urban drainage, and groundwater) in the urban area. In the Blacksmith Fork River, we have collected flow, temperature, and isotope data to determine how irrigation canals influence groundwater recharge to dewatered sections of rivers below diversions.

Results: These unique approaches and data sets provide multiple methods for understanding complicated groundwater interactions in karst mountain watersheds, complex urban areas, and irrigation impacted portions of rivers. Twenty conference and seminar presentations about these findings have also been given. Over the last year, 1 Post-Doc, 1 PhD, 3 MS, and 3 BS students have been working on various aspects of these projects.

Work Plan FY19/FY20

We are in the process of developing two NSF proposals, and these efforts are integrated into and dependent on data from the Logan River Observatory.

Informational Resources

Contact: Dr. Bethany T. Neilson, Telephone: (435) 797 7369, E-mail: bethany.neilson@usu.edu.

Representative Publications: *where *=Post-Doctoral Researcher, ** = Graduate Student, *** = Undergraduate Student*

Buahin* C.A., J.S. Horsburgh, B.T. Neilson (2019). Parallel multi-objective calibration of a component-based river temperature model. *Environmental Modelling & Software*, 116:57-71. https://doi.org/10.1016/j.envsoft.2019.02.012.

Neilson, B.T., H. Tennant***, T.L. Stout**, Miller, M., Gabor+, R.S., Y. Jameel++, M. Millington++, A. Gelderloos++, G.J. Bowen, P.D. Brooks (2018). Stream-centric methods for determining groundwater contributions in karst mountain watersheds. *Water Resources Research*, 54:6708-6724. https://doi.org/10.1029/2018WR022664.

Surface and Groundwater Quality and Quantity

Release of Arsenic from Aquifer Solids under Anaerobic Conditions

Principal Investigators:
Joan E. McLean
R. Ryan Dupont
Kaisa Patterson and Jeremy Jensen (MS students)

Partners/Collaborators:
- **Local**: Issa Hamud, Director, Environmental Department, City of Logan

Project Description:

- **Need and Purpose:**

Arsenic (As) is one of the most frequently detected contaminants in private wells used for household drinking water and public water supplies in the U.S., and local geology is often the source. Geologic formations throughout Utah contain As. Many of these formations are stable and pose no threat to humans or the environment, while others respond to altering hydrologic conditions by leaching As into groundwater. Our research on aquifers in Cache Valley, UT, has emphasized the importance of not only oxidation-reduction controlled dissolution from iron containing minerals, but also the role of dissolution and precipitation of carbonate minerals affecting As solubility. Carbonate minerals are common in the geology of the semi-arid west and contribute significantly to As biogeochemistry in soils and groundwater in this region. This year we have been evaluating the effect of wetting and drying cycles on the solubility of As since these cycles control oxidation-reduction and dissolution-precipitation reactions. We are presently studying these cycles in (1) a laboratory columns study simulating a rising and lowering groundwater table and (2) a stormwater bioretention area. Arsenic is not a pollutant associated with stormwater runoff, but some bioretention systems provide environments conducive to As solubilization and leaching to groundwater.

- **Benefits to the State:**

All counties in Utah will benefit from an improved understanding of the biogeochemistry governing the behavior of As in surface and subsurface environments as they are exposed to wetting-drying and oxidizing-reducing conditions that can lead to groundwater contamination.

- **Geographic Areas:**

Study Areas: Cache County.
Areas Benefited: Arsenic in groundwater is a worldwide problem. The entire state can benefit.

- **Accomplishments:**

1. Simulated cycling of wet-dry conditions in a laboratory column study using As-bearing aquifer material from Cache Valley demonstrated the leaching of As under wet-reducing environments. Iron (Fe) oxides undergo reduction and dissolution, releasing associated As. Carbonate minerals were a sink for As, providing retention sites to stabilize As concentration that are unaffected by wet-dry cycles.
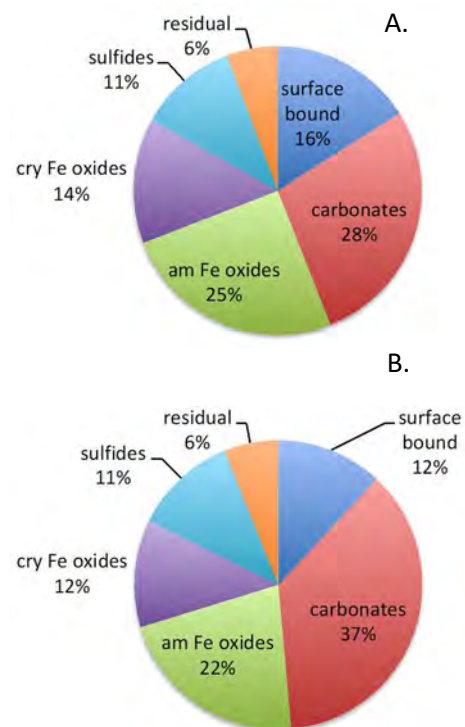

Figure 1. Arsenic is removed from surface bound sites and from Fe oxide minerals over the six-month laboratory column study.

2. Two of the plant species tested in the bioretention basin increased the solubility of As compared to the unplanted control. Various rooting zone processes, including root and bacterial exudates, aided in this solubilization. Locating bioretention basins in areas with leachable As should be avoided, and te selection of plant type is important for effective management of stormwater operations without As contamination of groundwater.

Findings/Results:

Laboratory column studies: Laboratory column experiments were set-up to replicate the effects of groundwater fluctuation on As-rich and carbonate-rich aquifer material collected from Cache Valley. Over the six-month study, As was leached out of the columns at concentration that exceeded the drinking water limit. Arsenic was leached from Fe oxides under reducing conditions (Figure 1 A,B); As associated with carbonate minerals was stable across alternating wet/dry cycles and redox conditions. Carbonate minerals therefore provide a sink for As that does not alter with changing environmental conditions.

Stormwater biorention basin studies: A designed stormwater detention basin collects water from a housing development located in Logan, UT (Figure 2). The retention basin has been divided into cells and planted with four species of plants and an unplanted control. The cells received artificial stormwater events and pollutant loads over the summer of 2018. Arsenic was not added as a pollutant, but occurs naturally in the soil. Pore water was sampled over the summer and analyzed for As. Sedge and sunflowers mobilized more As than the unplanted control (Figure 3). Selection of plant type is critical in As containing environments to minimize leaching of As to groundwater.

Work Plan FY19/FY20
This project is now completed.

Informational Resources

Contact: Ms. Joan E. McLean,
Telephone: (435) 797 3199, E-mail:
joan.mclean@usu.edu

Publications: Two theses have resulted from this funding.

Figure 2. Sampling soil from a bioretention basin planted with sunflowers and field analysis of water samples.
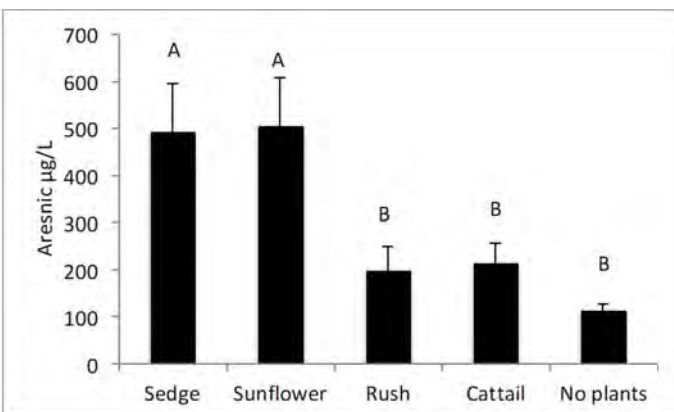
Figure 3. Arsenic was released to solution in a stormwater bioretention basin in Cache Valley when planted with sedge or sunflower compared to the unplanted control. Systems plants with Baltic rush or cattail did not increase solubility

Water Conveyance, Distribution, and Control

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Water Conveyance, Distribution, and Control

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Hydraulic and Water Research on Flow Measurement	$10,201	$0	$0
Labyrinth Weir Research	$8,282	$8,530	$8,786
Designated Projects		$5,000	$5,000
Undesignated Projects		$10,169	$10,169
Total	**$18,483**	**$23,700**	**$23,956**

Water Conveyance, Distribution, and Control

Hydraulic and Water Research on Flow Measurement

Principal Investigators:
Michael Johnson
Taylor Stauffer (graduate student)

Partners/Collaborators:
- **Local**: Central Valley Machine
- **Business/Industry:** Primary Flow Signal

Project Description:

- **Need and Purpose:**

  With increasing populations in the state, country and world, the need to measure water resources also continues to increase. The research conducted for this project assists in improving flow measurement.

- **Benefits to the State:**

  The funding supported a student research project that focused on resource management and monitoring. In cases where flow measurement accuracy is important, for example in water distribution systems, flow meter performance is critical to accurate measurement. Some cases require installation of a flow meter in piping that is not ideal. Research was conducted to demonstrate how flow measurement could be improved in spite of adverse piping installation. The student has now accepted employment within the State of Utah and is a contributing citizen. He is using his expertise to provide benefit to the citizens of the state through the various projects he is working on and can employ the findings of his research where applicable.

- **Geographic Areas:**

  Study Areas: Cache County, Utah
  Areas Benefited: Any distribution system in the State of Utah may benefit from this work.

- **Accomplishments:**

Findings: The research determined ways to connect the sensing tubing for adverse piping installations that may improve Venturi meter performance. Work was presented in a thesis and peer-reviewed journal article.

Results: The results showed that that improved performance may be achieved by properly considering the pressure distribution at the inlet of the Venturi.
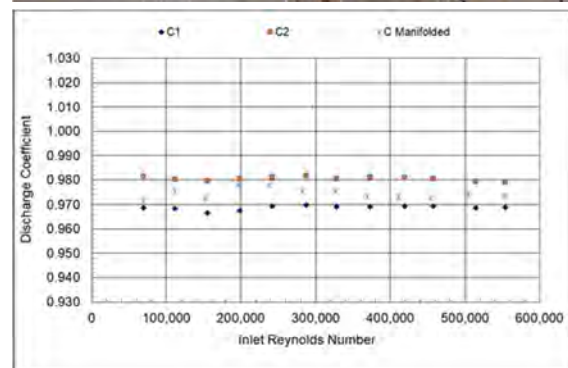
Work Plan FY19/FY20

This project is complete.

Informational Resources

Contact: Dr. Michael C. Johnson, Telephone: (435) 797-3176, E-mail: michael.johnson@usu.edu.

Thesis and Journal:

Stauffer, T. (2019). *Hydraulic Average of Multiple Tap Sets to Improve Performance of Venturi Flow Meters with Upstream Disturbance*. Utah State University, Logan, UT.

Stauffer, T., M.C. Johnson, Z.B. Sharp, and S.L. Barfuss (2019). *Multiple tap sets to improve Venturi flowmeters performance characteristics with disturbed flow*.
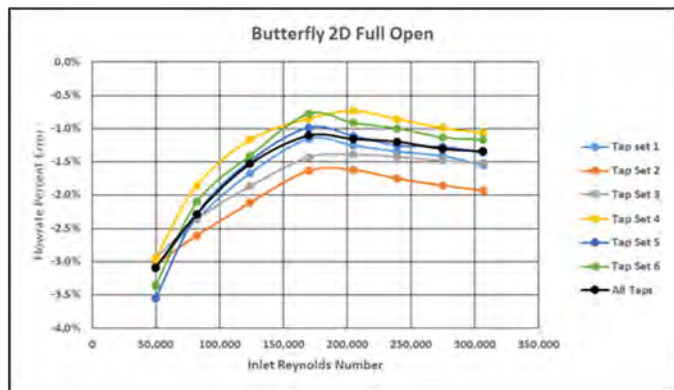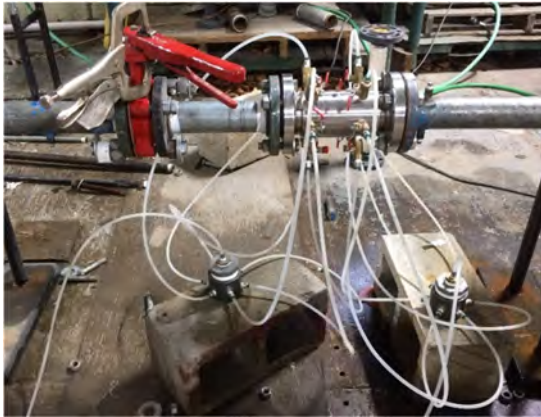
Labyrinth Weir Research

Principal Investigator:
Blake P. Tullis
Seth Thompson (MS Student)

Partners/Collaborators:
- **Local**: *Everett Taylor, DNR-Water Rights*

Project Description

- **Need and Purpose**:

  With the revisions of probable maximum flood flows and greater emphasis on dam safety, many spillways are found to require rehabilitation or replacement. Labyrinth weirs are often a favorable design option because these 'folded linear weirs' facilitate flood routing and increase base-flow reservoir storage capacity. However, the many geometric design parameters and the distinct hydraulic behaviors of these structures can make it difficult to engineer an optimal weir design. In-reservoir applications benefit from the opportunity to use arced labyrinth weirs that project into the reservoir. The hydraulic efficiency increases, relative to traditional (straight) labyrinth weirs, because the inlet cycles are better aligned with the radially converging approach flow vectors. In an effort to provide additional design guidance for engineers, this study evaluated the hydraulic performance of a 5-cycle, 16-degree sidewall angle arced labyrinth in the laboratory. Previous UWRL studies evaluated 6-, 12-, and 20-degree arced labyrinth weirs. Because most prototype applications will likely fall within the 6- to 20-degree range, it was important to provide an intermediate data set as well as provide insights into the practicality of linear interpolation between datasets.

- **Benefits to the State:**

  The results of this arced labyrinth study will help spillway designers in the State of Utah and elsewhere with better information for evaluating prototype weir designs and performance in reservation applications. The Utah Division of Water Resources is currently designing/building an arced labyrinth weir for Millsite Reservoir (UT) and the results of this study will benefit similar projects.

Figure 1. Arced labyrinth weir geometry.

- **Geographic Areas**:

  Study Area: All work was completed in the Hydraulics Lab at the Utah Water Research Laboratory (UWRL) at Utah State University.

  Areas Benefited: Spillway structures are common to nearly all dams, so the application of the study results could extend globally.

██████████████████████████████████████

- **Accomplishments:**

  (a) A 5-cycle, 16-degree arced labyrinth weir was tested in the laboratory, rating curve data was generated, and the results were compared with the results from previous studies of 12- and 20-degree arced labyrinth weirs.
  (b) In an effort to support future design efforts for arced labyrinth weirs with sidewall angles differing from the data in the literature, the 5-cycle, 16-degree labyrinth weir was also evaluated using computational fluid dynamics (cfd) modeling. The results compared well and suggest that cfd is a viable tool option for design.
  (c) A conference paper was published and presented at the 2019 Annual Conference of the Association of State Dam Safety Officials (Orlando).
  (d) An MS Thesis was produced at Utah State University.

Work Plan FY19/FY20

Because of the similarity between the 16- and 20-degree arced labyrinth weir performance, in FY 20 we plan to use cfd to further evaluate the hydraulic performance of the 20-degree weir. If the results are not consistent with the experimental data, a new physical study will be conducted.

Informational Resources

Contact: Dr. Blake P. Tullis, Telephone: (435) 797 3194, E-mail: blake.tullis@usu.edu.
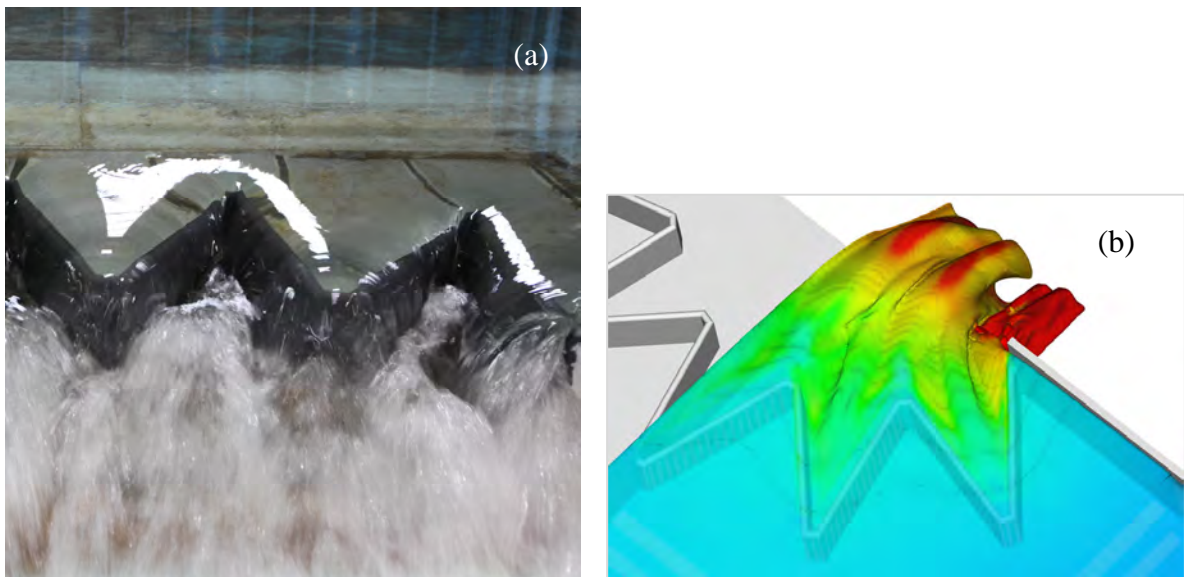
Figure 2. (a) Physical model (b) and cfd model testing.

Water Education and Technology Transfer

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Water Education and Technology Transfer

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Development of an On-Site Demonstration Site at the Ash Creek Special Service District	$40,838	$42,063	$43,325
Logan City Renewable Energy and Conservation Advisory Board (RECAB)	$10,000	$10,000	$10,300
State of Utah Drinking Water Board	$10,000	$10,000	$10,000
State of Utah Operators Certification Commission	$10,000	$10,000	$10,000
Utah On-Site Wastewater Treatment Training Program	$40,838	$42,063	$43,325
Designated Projects		$30,000	$30,000
Undesignated Projects		$13,915	$30,000
Total	**$111,676**	**$158,041**	**$176,950**

Water Education and Technology Transfer

Development of an On-Site Demonstration Site at the Ash Creek Special Service District

Principal Investigators:
Judith L. Sims
Brian Cowan
Richard Jex
Kyle Hillman (student)

Partners/Collaborators:
- **Local:** Mike Chandler, Ash Creek Special Service District; Utah's 13 Local Health Departments;
- **State:** Division of Water Quality, Utah Department of Environmental Quality); Utah On-Site Wastewater Association (UOWA)

Project Description

- **Need and Purpose:**

  The Huntsman On-Site Wastewater Treatment Training and Demonstration Site on the campus of Utah State University (USU) in northern Utah is used for State of Utah certification workshops for on-site wastewater professionals as well as occasional tours for outside groups and for university classes. The site is an integral part of the USU On-Site Wastewater Treatment Training Program (https://uwrl.usu.edu/research/owt). However, because the USU demonstration site is located in northern Utah, there is a need to have a similar demonstration site in the southern part of the state to serve on-site professionals in that area. Therefore a second demonstration site is being constructed at the Ash Creek Special Service District (Ash Creek) site in Hurricane, Utah. Ash Creek also has classroom facilities for on-site certification workshops that will utilize the demonstration site. This southern demonstration site at Ash Creek will facilitate the ability of instructors and regulatory staff from the area to participate in the certification training program as well as provide tours and other educational activities concerning septic systems and non-point source pollution (NPS) to their clients and the public.

- **Benefits to the State:**

  Continued population growth results in an increase in housing developments as well. This creates an increased need for accurate and thorough information regarding on-site wastewater treatment technologies. Enhanced educational opportunities available at the Ash Creek demonstration site will benefit the on-site professionals active in the oversight of septic system siting, design, inspection, and monitoring and maintenance, especially for professionals located in central and southern Utah.

- **Geographic Areas:**

  Study Area: Entire State of Utah.

  Areas Benefited: The development of the on-site wastewater demonstration site at Ash Creek will be especially beneficial to persons in southern and central Utah, but use of the site will be open to all on-site professionals and other interested parties from all parts of Utah.

- **Accomplishments:**

  Findings: The approach to the development of the project is design/build. Demonstration displays will include displays of: (a) septic tanks; (b) distribution devices for septic tank effluents in absorption systems; (c) absorption systems (in-ground), including standard trenches (pipe and gravel, chambers, bundled synthetic aggregates), deep wall trenches, pressurized drain fields, and absorption beds; (d) alternative systems, including at-grade systems, mound systems, packed bed systems (intermittent sand

filter, recirculating sand and gravel filters, textile system, peat system, and synthetic polystyrene media filter), and sand-lined trenches; (e) pump systems, tanks, and vaults; (f) control panels; (g) effluent filters for septic tanks; (h) valves for alternating drain fields; (i) dosing tanks; and (j) drip irrigation systems.

Results: In the first stage of the project, we are developing a plot plan of the site and designing the various demonstration displays. We also began the process of procuring the materials for building the various displays, developing posters and signs, and producing videos.

Work Plan FY19/FY20

We will continue to procure materials and demonstration materials and begin installation of the educational models at the Ash Creek demonstration site.

Informational Resources

Contact: Ms. Judith L. Sims, Telephone (435) 797-3230, E-mail: judith.sims@usu.edu.

Website: http://uwrl.usu.edu/partnerships/training.

Water Education and Technology Transfer

Logan City Renewable Energy and Conservation Advisory Board (RECAB)

Investigators:
R. Ryan Dupont

Partners/Collaborators:
- **Local:** Emily Malik, Logan City Environmental Department; Amy Anderson, Tom Jensen, Logan City Council

Project Description

- **Need and Purpose:**

The mission of the Logan City Renewable Energy and Conservation Advisory Board (RECAB) is to provide advice and technical assistance related to the conservation and efficient use of resources, to assist in transitioning the City of Logan toward a renewable energy portfolio that is secure, diverse, and cost-effective and promotes security of the environment. Utah Water Research Laboratory faculty member Ryan Dupont served on the Board during FY 18-19.

RECAB's goals include:

(1) Reduction of residential energy consumption (per capita) over the next 10 years.
(2) Improved energy efficiency of commercial and public customers.
(3) Implementation of demand-side management (DSM) programs with residential, commercial and public customers.
(4) Identify and research potential sources of renewable energy for Logan City.
(5) Identifying and promote green building standards.
(6) Identify and promote alternative forms of public transportation.
(7) Promote public education on issues of energy supply security, energy cost security, and environmental security.
(8) Reduce carbon emissions and assist with Logan City's carbon emission study.

- **Benefits to the State:**

The RECAB mission is to provide Logan City with technical expertise and experience relative to the potential of new renewable energy sources, carbon emission estimates, and public education. The PI attends monthly meetings of the Logan RECAB, provides comments and input on renewable energy and waste management issues that arise, and responds to special requests from RECAB regarding technical issues related to alternative renewable energy sources. Recent examples of special project requests during the reporting period include: (1) an in-depth analysis of the renewable energy potential of landfill methane gas recovery and power generation at the closed municipal landfill, and (2) additional evaluation of the potential for energy use reduction at the planned mechanical wastewater treatment plant through process modification and installation of anaerobic digesters for secondary treatment load reduction and energy production. The PI is a member of the Community Solar subcommittee of RECAB that is evaluating program options for increasing participation in the existing Logan City solar farm, and considering options to expand the current program and facilities to include a commercial customer base.

- **Geographic Areas:**

Study Area: Logan City and Cache County.

Areas Benefited: Logan City and Cache County.

- **Accomplishments:**

  Findings/Results: The PI attended all regularly scheduled Logan RECAB meetings throughout FY18–19 and provided review and comment on all RECAB items relevant to his area of expertise. Topics included the following: (1) analysis of current and future resource mix to meet a 50% renewables component in Logan City's power portfolio by 2030, (2) input on the long-term Renewable Energy Road Map and 50% renewable resolution for Logan City that was passed by the Logan City Council in 2018, and (3) participation on the Community Solar program analysis RECAB subcommittee.

Work Plan FY19/FY20

Involvement of the PI with the Logan RECAB will continue, as will his response to special project requests as they arise, to support Logan City RECAB's mission and goals.

Figure 1. Solar array installed adjacent to the Logan City Wastewater Treatment Lagoons.

Informational Resources

Contact: Dr. R. Ryan Dupont, Telephone: (435) 797 3227, E-mail: ryan.dupont@usu.edu.

Website:
https://www.loganutah.org/government/departments/light_and_power/energy_conservation_solar/recab.php.

Water Education and Technology Transfer

State of Utah Drinking Water Board

Principal Investigators:
David K Stevens

Partners/Collaborators:
- **State:** Marie Owens, Director, Division of Drinking Water

Project Description

- **Need and Purpose:**

  Under the Utah Drinking Water Act (the Act), responsibility for overseeing drinking water treatment and distribution rests with DEQ and the Utah Drinking Water Board (the Board). The Board has the authority to issue orders implementing the Act and to ensure compliance with the Act's provisions. Jurisdiction of the Board covers public and private community drinking water systems, including the various federal facilities. Utah Water Research Laboratory faculty member Dr. Stevens served on the State of Utah Drinking Water Board during FY2018/FY19.

- **Benefits to the State:**

  Membership on the Drinking Water Board provides service to the citizens of the State of Utah, the Utah DEQ, and the regulated community by providing technical overview and expertise for drinking water management, as well as oversight of state and federal revolving loan funds, to the Division of Drinking Water in their rulemaking, facility inspections and reviews, policy implementation, and conflict resolution. The PI attends ~monthly meetings of the Drinking Water Board held throughout the State and provides comments and input on drinking water treatment and distribution issues that arise during the course of the Division's implementation of federal and state drinking water laws.

- **Geographic Areas:**

  Study Area: State of Utah.

  Areas Benefited: State of Utah.

- **Accomplishments:**

  Findings/Results: The PI attended all regularly scheduled Drinking Water Board meetings and facility tours from July 1, 2018 to June 30, 2019, and provided review and comment on all Board items relevant to his area of expertise. The PI also serves on the Drinking Water Board Finance Committee previewing projects and making recommendations to the full board concerning action or tabling of proposals. The Finance Committee holds teleconference meetings 6–7 times per year and the PI participated in each of them.

Work Plan FY19/FY20

The PIs term on the board expired May 1, 2019. Dr. Blake Tullis from the UWRL has been appointed to the board from 2019 to 2023.

Water Education and Technology Transfer

Informational Resources

Contact: Dr. David K Stevens, Telephone (435) 797-3229, E-mail: david.stevens@usu.edu.
               Dr. Blake Tullis, Telephone (435) 797-3194, Email : blake.tullis@usu.edu.

Website: https://deq.utah.gov/boards/utah-drinking-water-board.

Water Education and Technology Transfer

State of Utah Operators Certification Commission

Principal Investigators:
David K. Stevens

Partners/Collaborators:
- ***State:*** *Marie Owens, Director, Division of Drinking Water*

Project Description

- **Need and Purpose:**

  Dr. Stevens serves on the Utah Department of Environmental Quality Water Treatment Operators Certification Commission. Under the Utah Drinking Water Act (the Act), responsibility for overseeing drinking water treatment and distribution rests with Utah Department of Environmental Quality and the Utah Drinking Water Board (the Board). The Board has the authority to issue orders implementing the Act and to ensure compliance with the Act's provisions. Jurisdiction of the Board covers public and private community drinking water systems, including the various federal facilities. The Board created the Water Treatment Operators Certification Commission in 1984 and Dr. Stevens has been a member of that commission since 1987.

- **Benefits to the State:**

  Membership on the Operators Certification Commission provides service to the citizens of the State of Utah, the Utah DEQ, and the regulated community by managing training for water treatment plant operators. This includes setting policy, administering examinations, and making decisions on appeals. The PI attends yearly meetings of the Commission held in Salt Lake City and provides comments and inputs policies and procedures regarding the certification of water treatment and distribution system operators in accordance with federal and state drinking water laws.

- **Geographic Areas:**

  Study Area: State of Utah.

  Areas Benefited: State of Utah.

- **Accomplishments:**

  Findings/Results: The PI attended all scheduled Operators Certification Commission meetings July 1, 2018 to June 30, 2019, and provided review and comment on all Commission items relevant to his area of expertise. The PI also served on the Drinking Water Board and its Finance Committee, reviewing projects and making recommendation to the full board concerning action on proposals.

Work Plan FY19/FY20

Involvement on the Board will continue through 2020

Water Education and Technology Transfer

Informational Resources

Contact: Dr. David K. Stevens, Telephone (435) 797-3229, E-mail: david.stevens@usu.edu.

Website: https://deq.utah.gov/drinking-water/operator-certification.

Water Education and Technology Transfer

Utah On-Site Wastewater Treatment Training Program

Principal Investigators:
Judith L. Sims
Margaret Cashell
Brian Cowan
Richard Jex
Kyle Hillman (student)
Ivonne Harris

Partners/Collaborators:
- **Local:** *Utah's 13 Local Health Departments; Utah On-Site Wastewater Association (UOWA)*
- **State:** *Division of Water Quality, Utah Department of Environmental Quality; Council of Local Environmental Health Directors (CLEHA)*

Project Description

- **Need and Purpose:**

  The Utah On-Site Wastewater Treatment Training Program was established in January 1998 in cooperation with the Utah Department of Environmental Quality (DEQ) and the thirteen Utah local health departments. It provides classroom and field (hands-on) training to Utah homeowners, regulators, designers, installers, pumpers, and other stakeholders in on-site wastewater treatment systems.

  Adequately protecting environmental health and enhancing user satisfaction are achieved through knowledgeable selection, competent design, correct installation, and proper operation of on-site systems. Applying the right technology in the right place requires accurate information and up-to-date training. Landowners, homeowners, developers, lenders, installers, regulators, planners, municipal authorities, and elected authorities are all stakeholders in Utah on-site issues and must have current information and training to address these matters responsibly.

  Utah will continue to grow, and as housing developments continue to expand into current open space, such developments may include areas of groundwater recharge, shallow soils, or shallow ground water. Current Utah rules allow the use of conventional septic tank systems, as well as eight alternative treatment systems that may be installed in areas where soils are unsuitable for conventional systems. Training those involved in the use of both conventional and alternative systems will ensure that these systems will work correctly.

- **Benefits to the State:**

  Continued population growth, along with associated housing developments, creates an increased need for accurate and thorough information regarding on-site wastewater treatment technologies. The Utah On-Site Wastewater Treatment Training Program addresses these challenges through such means as workshops and participation in educational conferences. Many of Utah's soils are marginal or unacceptable for the use of conventional soil absorption systems due to high or fluctuating water tables, slowly permeable or highly permeable soil horizons, and extreme slopes, thus requiring the use of more advanced alternative systems. The On-Site Training Program provides the necessary education to utilize conventional and alternative systems in an effective manner that will protect both public health and the environment.

- **Geographic Areas:**

  Study Area: Entire State of Utah.
  Areas Benefited: The entire state (29 counties and 13 local health departments).

Water Education and Technology Transfer

- **Accomplishments:**

  Findings: A state legislative initiative introduced and passed as House Bill 14s during the 2001 Legislative Session mandated a certification program for persons involved in siting, designing, operating, and maintaining both conventional and alternative on-site systems. The certification program, administered by the Division of Water Quality in the Utah DEQ, involves mandatory training provided by the Utah On-Site Wastewater Treatment Training Program.

  The certification program includes three levels, each of which requires workshops and testing provided through the Utah Training Program: (1) Level 1—Soil Evaluation and Percolation Testing; (2) Level 2—Design, Inspection, and Maintenance of Conventional Systems; and (3) Level 3—Design, Operation, and Maintenance of Alternative Systems.

  Because Level 1, Level 2, and Level 3 certifications expire after 3 years, workshops are also provided for renewal of certifications.

  Results: During FY 2018–19, two Level 1 workshops, two Level 2 workshops, two Level 3 workshops, three Level 1 & 2 recertification, and two Level 3 recertification workshops were taught at various locations around the State of Utah, including Richfield, Vernal, Ogden, and Logan.

Work Plan FY19/FY20

We will continue to provide workshops in support of the mandatory State of Utah certification program for on-site wastewater professionals (through FY 2019–20). Fall workshops in 2019 will be held in Park City and Logan. Spring 2020 workshops will be held in Logan and other locations yet to be determined.

Informational Resources

Contact: Ms. Judith L. Sims, Telephone (435) 797-3230, E-mail: judith.sims@usu.edu.
Website: http://uwrl.usu.edu/partnerships/training.

Publications:

Sims, J.L., M. Cashell, B. Cowan, and R. Jex (2018, 2019). *Course Manuals for Levels 1, 2, and 3 Original Certification and Recertification Workshops*. Utah Water Research Laboratory, Utah State University, Logan, UT.

Water Resources Planning and Management

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Water Resources Planning and Management

Project Name	FY2019 Actual Expenditures	FY2020 Budgeted Expenditures	FY2021 Planned Expenditures
Aggieair Research and Service Center	$25,444	$15,000	$15,000
Automated Quality Control for In-situ Water Temperature Sensors	$25,408	$0	$0
Logan River Observatory	$33,868	$34,884	$35,931
Making Water Research Results More Reproducible	$11,993	$12,352	$12,721
Mapping Subsurface Tile Drainage Systems with Unmanned Aerial Vehicles	$14,047	$6,000	$0
Metering Non-Residential Water Users to Identify Conservation Opportunities	$17,348	$17,869	$18,405
Organizing and Synthesizing Water Management Data to Support Modeling	$17,105	$17,618	$18,146
Terrain Analysis Using Digital Elevation Models	$19,686	$20,276	$20,884
Use of sUAS for Mapping Wetland Flow Paths and Consumptive Use on the San Rafael River, Utah	$25,408	$26,170	$26,955
Using High-Resolution Aerial Imagery of a Wetland near the Lower San Rafael River in South Central Utah to Understand the Hydraulic and Thermal Characteristics of Complex Habitat Structures	$25,529	$15,000	$15,000
Using the Utah Energy Balance Snowmelt Model to Improve Water Supply Forecasts	$19,686	$20,276	$20,884
Water Management in the Event of Recurring Long-Term Historical Droughts	$14,876	$15,323	$15,782
Weber Basin Drought Vulnerability Study	$11,993	$12,352	$12,723
Designated Projects		$60,000	$70,000
Undesignated Projects		$143,034	$130,000
Total	**$262,391**	**$416,155**	**$412,433**

Water Resources Planning and Management

AggieAir Research and Service Center

Principal Investigators:
Calvin Coopmans
Mac McKee
Scott Budge,
Baron Wesemann

Partners/Collaborators:
- **Business/Industry**: *Deseret UAS*

Project Description:

- **Need and Purpose:**

  Remote sensing data sources are necessary for the critical monitoring of natural and civil resources, such as those related to water use and invasive species management. Many current sources of remote sensing (e.g., manned aircraft and satellite platforms) are too expensive, have low spatial resolution, or are not updated frequently enough to be practical for many applications. A low-cost, small unmanned aerial system (sUAS) called AggieAir can fill this need by providing low-cost, multispectral aerial imagery and other scientific data quickly and frequently. In addition, the AggieAir platform design is not dependent on a runway for takeoff and landing, which enables it to be launched almost anywhere. AggieAir has benefitted a wide range of applications, including agriculture, riparian habitat mapping, road and highway surface monitoring, wetland mapping, and fish and wildlife tracking, among others.
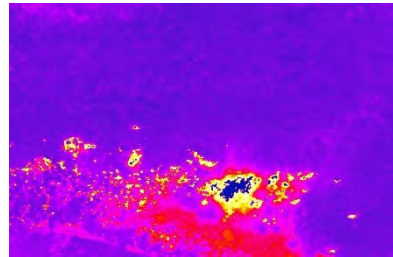
  Benefits to the State:

  The data produced by AggieAir have the potential to facilitate better water and natural resources management in Utah by offering farmers and scientists a low-cost solution to mapping the soil moisture of their crops and other crop health indicators for more efficient irrigation and fertilizer application. This data can also help canal operators to manage water more effectively or wetland managers to manage invasive plant species. If invasive plant species are left unchecked, they can outcompete native plant species, destroy bird habitat, and use excessive amounts of water. AggieAir can also provide new jobs and economic growth to the state of Utah. The long-term goal of the AggieAir system is to eventually create a business and market this technology within the state of Utah. AggieAir's technology also adds a focus to the State's standing in aerospace, unmanned systems, and civil uses for technologies such as remote sensing for agriculture.

Figure 1: Thermal Infrared aerial data from controlled burn in Logan Canyon.

Figure 2: AggieAir flying downtown Reno, NV, live on CNBC national TV.

- **Geographic Areas:**

  Study Areas: Most AggieAir test flights took place at our test site near Cache Junction, UT, where AggieAir has official approval from the FAA to conduct flights (FAA Form 7711-1 2013-WSA-63). In the past year, AggieAir has conducted authorized flights at sites throughout the state of Utah, as well as California.

  Areas Benefited: All counties in the state can benefit.

Water Resources Planning and Management

- **Accomplishments:**

  Findings: To accomplish the work created by AggieAir, the USU UWRL AggieAir Service Center has deployed the systems more frequently in the past year than ever before and used the platform for many applications. Continued platform development has enhanced the reliability and performance of the aircraft, payloads, and data pipeline. Continued upgrades to hardware and software allow the AggieAir system to deliver higher quality and more consistent data than ever before. For example, BluJay has attained 180 minutes of all-electric flight, allowing the AggieAir data payload to reliably map over 15,000 acres in a single 2-hour flight and delivering actionable information at unprecedented scales for small unmanned aerial vehicles. Work has progressed on increasing the speed of the AggieAir data pipeline, including the study of Big Data solutions such as High-Performance Computing (HPC) and Deep Learning (DL) techniques for processing a high volume of data into actionable information in a short period of time (Figure 1). This includes work on the structure of the data processing, focusing on high-quality scientific information. Due to AggieAir's flight heritage and reputation with the Federal Aviation Administration and NASA, AggieAir was invited to participate in prestigious large-scale airspace access demonstration tests in Reno and Las Vegas, NV, during the summer of 2019 (Figure 2).

Work Plan FY19/FY20

In the coming year, AggieAir will continue to innovate in the areas of civil scientific remote sensing, autonomous flight, and airspace access. This includes possible collaborations with private industry such as L3 communications, along with NASA and the FAA, to further innovate and bring cutting-edge aviation and aerial data systems to Utah. AggieAir will continue to study autonomous aerial flight and data pipeline improvements that will deliver higher-speed actionable scientific-quality data for farm managers, natural resources scientists, and water research and applications to benefit the state of Utah.

Informational Resources

Contact: Dr. Calvin Coopmans, Telephone: (435) 764 4579, E-mail: cal.coopmans@usu.edu
Website: http://aggieair.usu.edu/

Published academic work from this FY (out of 14+ total publications):

Abdel-Motaleb, S.A., J.D. Taylor, D.F. Hunsaker, and C. Coopmans (2019). Comparison of Induced and Parasitic Drag on Wings with Minimum Induced Drag. In *AIAA Scitech 2019 Forum* (p. 2120).

Coopmans, C., J. Humble, and M. Givens (2019). Software requirements, architecture, design, and results of a modular, multispectral, scientific quality unmanned aerial system payload for civilian remote sensing. In *Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping IV* (Vol. 11008, p. 1100809).

Givens, M., C. Coopmans, and R. Christensen (2019). An estimation-domain approach to MEMS Multi-IMU fusion for sUAS. In *2019 International Conference on Unmanned Aircraft Systems, ICUAS 2019* (pp. 1048–1053). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ICUAS.2019.8797886.

Water Resources Planning and Management

Automated Quality Control for In-situ Water Temperature Sensors
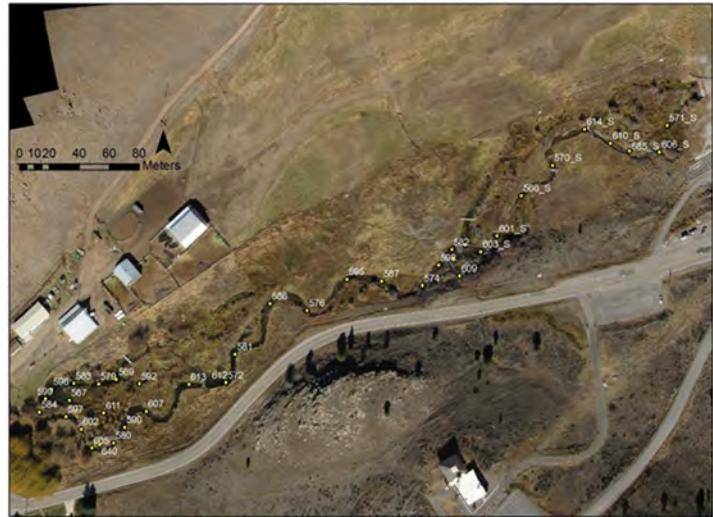
Principal Investigators:
Mac McKee
Leah Richardson

Partners/Collaborators:
- **None**

Project Description:

- **Need and Purpose:**

The growing use of real-time environmental monitoring equipment for data collection in river basins and agricultural areas has produced a growing problem related processing of the staggering volume of data that are collected, including control of data quality. The topic of identifying bad data collected by in-situ sensors has been explored in the past. Many of the tools developed in these studies have succeeded in providing an end user with correct identification of outliers over 95% of the time. However, with the continuous increase in the use of automated data collection, a simple

Lower section water temperature sensor placement at Curtis Creek (aerial imagery provided by USU's AggieAir platform).

indication of which data are likely to be bad may no longer be enough. While these techniques (consisting largely of machine learning regression approaches) can be quite good at identifying and flagging potentially erroneous values, they do not excel at choosing and applying appropriate data corrections to resolve the error for which the data were flagged, steps that generally require the attention and expertise of field or data technicians. This adds cost to data collection and storage operations that might be avoided if better automated procedures can be developed for data quality control. The purpose of this research is to devise and test a data assimilation technique capable of determining when and why water quality data (provided by in-situ water temperature sensors) are incorrect in an environment that experiences seasonal and daily fluctuations. This should reduce or eliminate the need for manual quality control in a large-volume data system where the range of good data is wide and changes often. Further, this research adds a classification component to help the end-user determine how to correct anomalous data based on why it is identified as being bad.

- **Benefits to the State:**

As more real-time monitoring stations are installed across the state to acquire stream flow, water quality, diversion and water use, air quality, and other environmental data, a greater emphasis on automated methods for data quality control will be necessary to control costs and ensure a desired level of data quality. Methods such as those developed in this study could provide answers to these quality control issues.

Water Resources Planning and Management

- **Geographic Areas:**

  Study Areas: Curtis Creek, Cache County, Utah.
  Areas Benefited: Any location in Utah with installed real-time monitoring stations.

- **Accomplishments:**

  Findings: The project used data from approximately four years of temperature measurements taken at 10-minute intervals by 47 different sensors located along Curtis Creek, a tributary of the Blacksmith Fork of the Little Bear River, in Cache Valley. For the type of sensors used and for the stream flow regimen at that location, sensor error occurred when sensors became exposed to the air (as water levels declined) or became buried in sediment. These bad data are typically a small portion of the total data set collected, but their manual identification is costly and time-consuming. The project developed and tested a multiclass relevance vector machine (MCRVM) to detect bad sensor readings and to classify bad readings by source of error (i.e., sensors exposed to the air or buried in sediment).

  Results: The modeling results indicated that analysis of the quality of the data with the learning machines used in the study is best done at a coarser time scale than the 10-minute data recording frequency. Best results were obtained using 12-hour averages. The MCRVM was able to obtain correct classification of data errors approximately 85% to 95% of the time. These results could be improved through more thorough training of the MCRVM with a data set having a larger number of erroneous data points. The MCRVM seems to have difficulty with false negatives. This might also be improved through training with larger data sets.

Work Plan FY19/FY20

This project is complete.

Informational Resources

Contact: Dr. David Tarboton
Telephone: (435) 797 3172,
E-mail: david.tarboton@usu.edu.
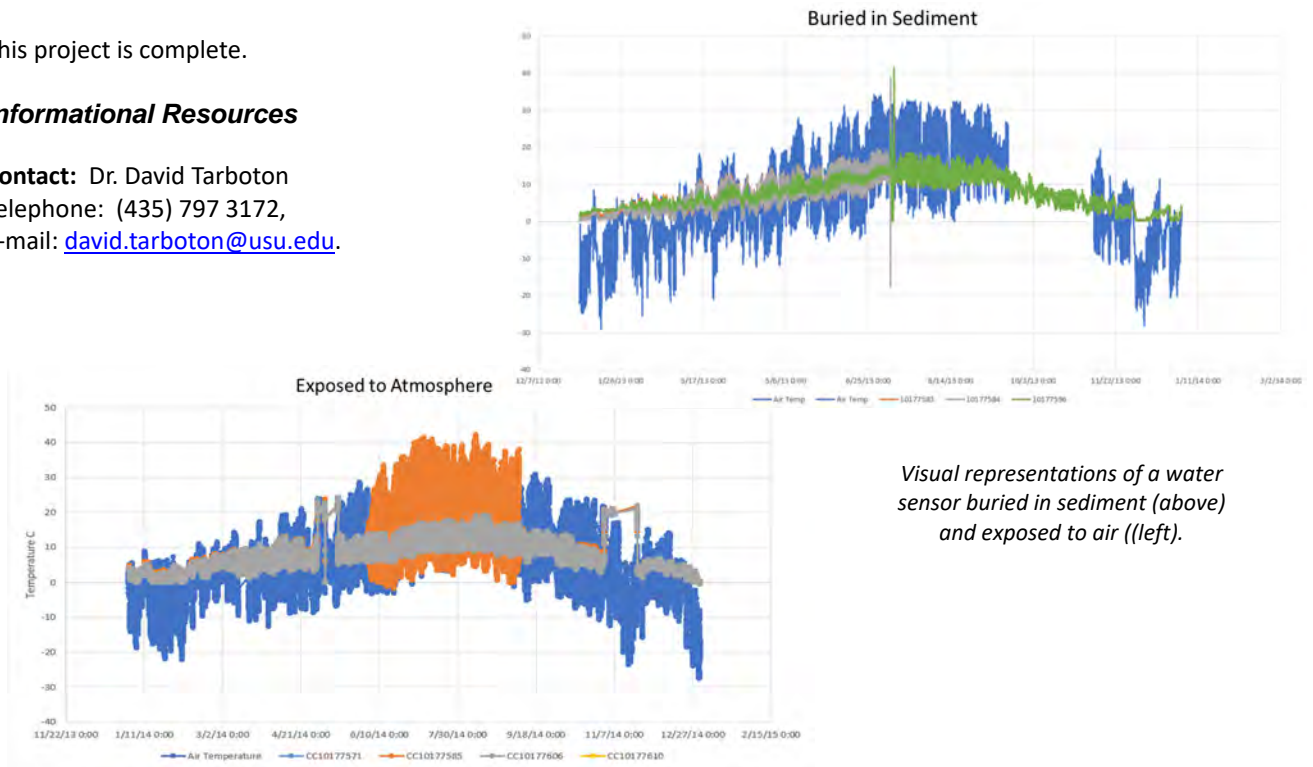
Visual representations of a water sensor buried in sediment (above) and exposed to air ((left).

Logan River Observatory

Principal Investigators:
Bethany T. Neilson
Jeffery S. Horsburgh
Patrick Strong
Caleb Buahin (student)
Hyrum Tennant(student)

Partners/Collaborators:
- **Local**: Logan City, Cache Water District
- **State:** Utah Division of Water Resources, Utah Division of Water Quality
- **Federal:** USGS Utah Water Science Center

Project Description

- **Need and Purpose:**

In 2012, the National Science Foundation (NSF) awarded funding of $20 million to Utah State University in an infrastructure grant to establish a monitoring network in the Logan River and two other watersheds in Utah. Ongoing support for maintenance and operations of these stations by NSF was discontinued when the state of Utah became ineligible for NSF's EPSCoR funding. At that point, the Logan River Observatory was established and expanded the Logan River monitoring network to include 21 river flow stations, 8 real-time water quality stations, and 6 weather stations, making it one of the most highly instrumented watersheds in the U.S. This infrastructure, along with the associated data, provide an opportunity for Utah to lead the country in water related research and development of innovative water management approaches in water-scarce regions. Through integration of research, teaching, and involvement of community members and local and state government entities, this infrastructure can support the critical water management decision making that we are now facing across Utah.

- **Benefits to the State:**

The ongoing operation and maintenance of these stations and the data that they provide are critical to water supply and water quality monitoring in northern Utah. Given that the Logan River Watershed spans wilderness areas, Forest Service land, urban areas, and agricultural areas, the lessons learned, and methods developed for integrating efforts by various levels of government, citizen-led organizations, and management entities, are highly transferrable to watersheds spanning pristine to rural to urban areas throughout Utah and the Western US.

The Utah Division of Water Resources plans to use the flow and water quality data collected by these stations for water management and evaluation of potential water development projects within the Logan River basin. These data are also critical for quantifying the water entering the Bear River and eventually the Great Salt Lake. The Utah Division of Water Quality plans to use the data to assess compliance with state water quality standards, determine the need for additional funding for stream restoration projects, and identify and address other water quality related problems. Cache County Water Conservancy District and the City of Logan are using data from these installations to gather information about drinking water source status and protection. The data also inform Logan City's stormwater management efforts. These data provide information necessary for the Cache County Water Conservancy District to meet their mission to protect and manage water resources in Cache County. Utah State University installed these stations and operates them for uses such as teaching, research, and K-12 outreach. The data gathered in the Logan River Observatory are available to the public online at no cost.

- **Geographic Areas:**

Study Area: Logan River watershed.

Water Resources Planning and Management

Areas Benefited: This research will directly benefit Utah's most populated areas that depend on mountain precipitation as their primary water source. However, the information gained and methods developed will be applicable to the entire state of Utah.

- **Accomplishments:**

Over the last year we were successful in establishing long-term funding from the Utah Legislature and received some additional funds from Logan City and the Cache County Water Conservancy District. We have also maintained the sites established by the iUTAH project, added many additional monitoring sites to help answer research questions raised by various project working within the watershed, and have relocated sites that were originally placed in unrepresentative locations. A website was developed for the Logan River Observatory (lro.usu.edu). The website provides real-time flow data within the time series analyst (http://lrodata.usu.edu/). We have refined quality assurance and quality control procedures to provide quality data with only a short lag time.

1. Numerous faculty (https://uwrl.usu.edu/lro/lropeople/faculty).
2. Staff (https://uwrl.usu.edu/lro/lropeople/research-staff).
3. Students (https://uwrl.usu.edu/lro/lropeople/students), along with a growing network of collaborators, are involved in the Logan River Observatory.

Many different conference presentations and outreach presentations have been given over the past year (see https://uwrl.usu.edu/lro/research for details).

Work Plan FY19/FY20

During the coming year, we will continue to collect and disseminate data and refine data collection methods. We will also continue to support development of various proposals that will focus research efforts in the Logan River watershed and will utilize the Logan River Observatory data.

Informational Resources

Contacts: Dr. Bethany Neilson, Telephone: (435) 797-7369, E-mail: bethany.neilson@usu.edu.
Dr. Jeffery S. Horsburgh, Telephone: (435) 797-2946, E-mail: jeff.horsburgh@usu.edu.

Website: https://lro.usu.edu.

Water Resources Planning and Management

Making Water Research Results More Reproducible

Investigators:
David E. Rosenberg
James Stagge (Ohio State University)
Adel Abdallah, Ryan James,
Hadia Akbar, and Nour Atallah (students)

Partners/Collaborators:
- **Business/Commercial/Not-for-Profit:** Dave Watkins, Dana Compton, American Society of Civil Engineers

Project Description

- **Need and Purpose:**

  Science and engineering communities are expressing broad interest in making research results reproducible, even though, currently, few published results are reproducible. This contradiction exists because of several perceived and real challenges: (1) More author effort is needed to reproduce article figures, tables, and other results as they must prepare and share their data, models, code, and directions; (2) Authors must learn new skills to organize and share materials online; (3) Authors may not share proprietary or sensitive materials; (4) Some workflows use stochastic, high performance computing, big data, or methods with long run times that are too big to share or reproduce bit for bit; (5) Reproducing others' results takes time and expertise; (6) Funders, universities, and institutions value publication of novel, peer-reviewed journal articles rather than datasets, documentation, or reproducing others' efforts; and (7) Promoting and rewarding reproducibility may unintentionally encourage researchers to pursue easily reproduced methods rather than complex methods that offer bigger contributions but cannot be reproduced with today's tools. The authors, journals, funders, and institutions that produce, publish, and support research must better coordinate to overcome these challenges. Here we share practices that encourage the research community to make research data, models, code, and directions more available and results more reproducible (Figure 1).

- **Benefits to the State:**

  Making research results more reproducible will allow more Utahns to access research. Improved access will also allow Utah researchers and businesses to use and extend research produced in Utah, the U.S., and the world. Making research results more reproducible will also improve public trust in research, data, and models and help organize materials in perpetuity for future users. Making research results more reproducible will also help narrow the gap between academics and professionals in practice.

- **Geographic Areas:**

  Study Area: This project has no specific study area. Research is conducted across Utah and other states. **Areas Benefited:** Areas throughout Utah.

- **Accomplishments:**

  Findings and Results:

  o   360 articles published in six top water journals in 2017 were assessed for the availability of data, models, code, and directions and for whether results in the article figures, tables, and text could be reproduced. The study team more readily reproduced results in articles that provided directions for materials use.

- A data, model, and code availability policy was implemented for the *Journal of Water Resources Planning and Management* published by the American Society of Civil Engineers (ASCE). This data availability policy was subsequently adopted by the 30 other journals ASCE publishes.
- Authors, journals, funders, institutions, and agencies all have important roles to play in making research results more reproducible.
- Writing is underway for an editorial with 10 co-authors from Utah, other U.S. states, and two countries for the *Journal of Water Resources Planning and Management* that presents 40 best practices to make research results more reproducible. A very important practice is to build reproducibility into the project from the start by budgeting the time, personnel, storage, and other resources to make results reproducible, and to set up licensing agreements to allow data sharing later.
- We are leading an effort to develop a new journal reproducibility policy that will allow authors to optionally request that the journal verify that their research results are reproducible. If verified, the journal would recognize that accomplishment.

Work Plan FY19/FY20

- Publish an editorial with 40 best practices to make results more reproducible.
- Work with the publisher to adopt the new journal policy to allow authors to optionally submit articles with reproducible results.

Informational Resources

Contact: Dr. David E. Rosenberg, Telephone (435) 797 8689, E-mail: david.rosenberg@usu.edu.

Website: https://doi.org/10.1038/sdata.2019.30. Article by Stagge et al (2019) titled "Assessing data availability and research reproducibility in hydrology and water resources."
Website: Editor's Note by Rosenberg and Watkins (2017) titled "New Policy to Specify Availability of Data, Models, and Code."
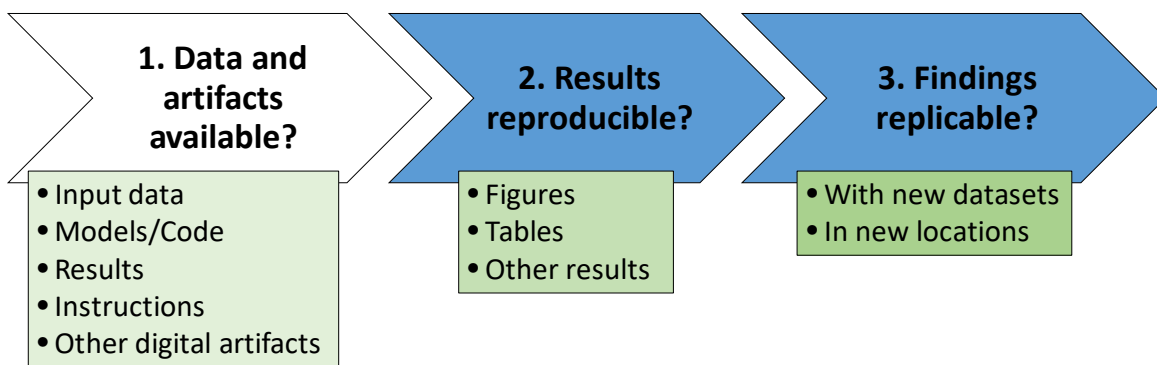

Figure 1. Reproducibility is a continuum. The goal is to push research up the continuum to be more reproducible. Definitions for available, reproducible, and replicable follow definitions by U.S. National Science Foundation, U.S. Department of Education, and the National Academy of Sciences

Mapping Subsurface Tile Drainage Systems with Unmanned Aerial Vehicles

Principal Investigators:
Ruijie Zeng
Rui Gao (graduate student)

Partners/Collaborators:

- **Local**: Natural Resources Conservation Service, North Logan Office

Project Description:

- **Need and Purpose:**

  Subsurface tile drainage systems are commonly implemented in areas with a high groundwater table in order to remove excess water from the soil. Subsurface tile drains lower the water table below the crop root systems. In addition to increasing crop yields and reducing yield variability, tile drainage systems also change the hydrologic surface and subsurface characteristics at the site, leading to higher levels of nonpoint source pollutant concentration due to nitrate leaching at the outlet and causing water quality degradation downstream. However, the location of subsurface drainage systems is generally unavailable, making the hydrologic prediction and water quality management of farmland difficult. The goal of this research is to map the location of subsurface tile drainage systems using unmanned aerial vehicles (UAVs). To accomplish this, we are quantifying the impact of subsurface tile drains on land surface signatures, such as temperature, soil moisture, and surface reflectivity captured by ultra-high-resolution visible- and invisible-band images from unmanned aerial vehicles.

- **Benefits to the State:**

  The subsurface drainage detection method developed in this study provides a remote sensing approach to locate the drainage pipe by capturing the land surface features. This cost-effective method can be implemented to detect subsurface drainage over large areas. For regions with existing subsurface drainage pipes, the method can detect pipes that are clogged and not functioning. An improved understanding of subsurface drainage provides guidelines for better management of irrigation practices and agricultural water quality conservation.

- **Geographic Areas:**

  Study Areas: Agricultural fields located near Bear River City, Box Elder County, Utah. A variety of vegetables are planted at different plots. All fields are flood irrigated through irrigation canals and laterally drained into the Malad River, which joins to Bear River and finally drains to Great Salt Lake.

  Areas Benefited: Box Elder County, Great Salt Lake.

- **Accomplishments:**

  Records of subsurface drainage pipes were obtained from the Natural Resources Conservation Service North Logan office. The records included the exact location of subsurface drainage pipes recently installed within Bear River City and serve as ground truth to validate the remote sensing results. A successful UAV flight campaign was launched to scan the study area. Due to the maximum 400-ft flight height allowed by FAA regulation, one UAV flight covers approximately 2 square miles. The image resolution is about 5 cm for RGB band and 15 cm for the thermal band. A flight time 3 days after a >2in storm event was chosen to ensure that the soil was drained from saturation.

Findings: Ten subsurface drainage pipes were successfully detected using the remote sensing thermal band in two plots, as shown in figure below. The northeast field is fallow, and crops (i.e., onions) in the southwest field are harvested. This indicates that the top soil heterogeneity caused by drainage pipes can be detected by UAV, while fields covered by vegetation do not show the heterogeneity.

Results: The proposed method can detect subsurface drainage pipes by capturing the bare soil surface heterogeneity caused by a drainage system. The 2 or 3 days after a heavy storm event would be good timing for the UAVs to capture the land surface heterogeneity. The spatial resolution in the test flight was very high. If the resolution is reduced to 1 m, more area could be covered.

Work Plan FY19/FY20
We plan to launch another flight in spring 2020 to test a coarser resolution. A journal paper is in preparation and will be submitted in early 2020.

Informational Resources

Contact: Dr. Ruijie Zeng, Telephone: (435) 797 3194, E-mail: ruijie.zeng@usu.edu.

Legend:
— Detected subsurface drainage pipes
• Recorded drainage pipes outlets
— Irrigation canal
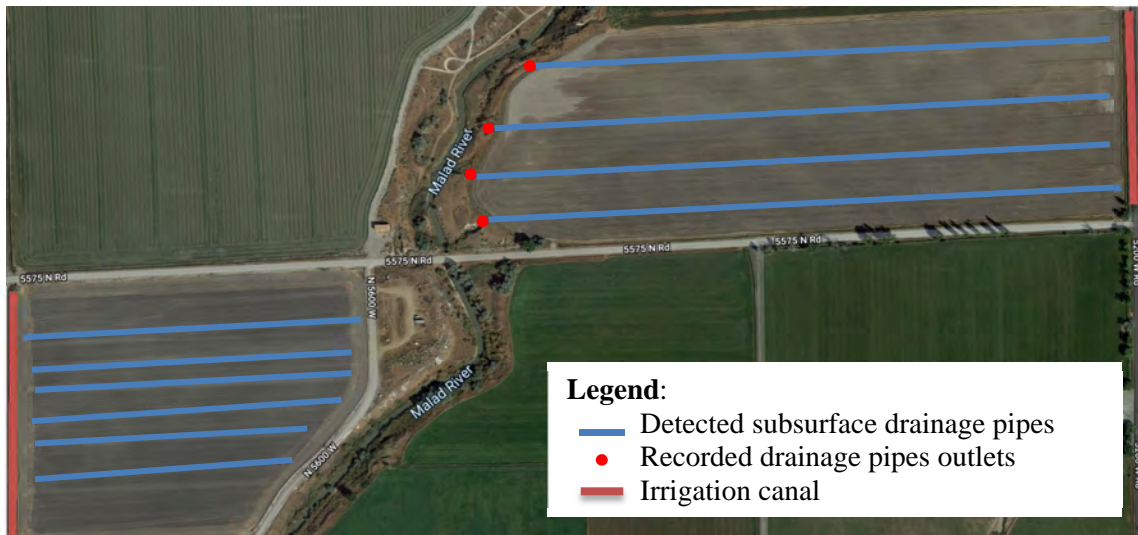
Water Resources Planning and Management

Metering Non-Residential Water Users to Identify Conservation Opportunities

Investigators:
David E. Rosenberg
Jeffery Horsburgh
Nour Atallah (student)

Partners/Collaborators:
- **Local:** Jed Olson, Logan City; Cameron Draney, Logan City; Paul Lindhardt, Logan City; Mark Nielsen, Logan City; Tyson Griffin, Logan City; James Geier, Logan City

Project Description

- **Need and Purpose:**

  Nearly all urban water use monitoring, modeling, and conservation research has focused on a large but relatively homogenous group of residential water users. Non-residential business and commercial establishments, industries, and institutions also use significant volumes of water. However, the diversity of non-residential uses has made them difficult to monitor and study due to their varying types of water uses in terms of the amount, timing, location and other factors. Newer "smart" meters can now measure and record water use at very high temporal frequency. In this project, we are using smart meters to determine total water use, timing, and component end uses to better understand current water use practices in non-residential user groups. With these better data records, we can identify water-saving opportunities that will help meet Utah's water conservation goals.

- **Benefits to the State:**

  The principal benefits to the state are to (1) expand current water metering methods, enhance existing monitoring data, and estimate peak demands and timing of demands for commercial/industrial users, (2) demonstrate and test methods for identifying opportunities for conservation, and (3) quantify the effects of any conservation activities undertaken by our partners in their efforts to help the State meet its overall water conservation goals. In addition, the data collected could help the Utah Division of Drinking Water update its Minimum Sizing Requirements for public water systems (R309-510) for any of the non-residential establishments considered.

- **Geographic Areas:**

  Study Area: Logan City, Cache County, Utah.
  Areas Benefited: Logan City and other municipal water providers throughout Utah.

- **Accomplishments:**

  Findings and Results:

  o We have published the findings and results reported last year as a Master's Student's thesis (Attaallah 2018).
  o We have published anonymized results in an open data repository (Atallah and Rosenberg 2019).
  o We have also submitted the work for publication in the peer-reviewed *Journal of Water Resources Planning and Management* published by the American Society of Civil Engineers.

Water Resources Planning and Management

Work Plan FY19/FY20

- Work on this project will switch from recording high-frequency water use for a small number of nonresidential users in Logan, Utah, to analyzing multiple existing household water use datasets for a national set of users. The analysis will focus on characterizing the skewness in water use across the large populations of households and using the skewness to characterize households with potential to save large amounts of water, energy, and money by adopting conservation actions. We will also analyze skewness in water use over time to see how the trends are changing.

Informational Resources

Contact: Dr. David E. Rosenberg, Telephone (435) 797 8689, E-mail: david.rosenberg@usu.edu.

Publications:

Attaallah, N.A.M. (2018). *Demand Disaggregation for Non-Residential Water Users in the City of Logan, Utah, USA*. MS Thesis. Utah State University, Logan, Utah. https://digitalcommons.usu.edu/etd/7401.

Data Repository:

Atallah, N. and D.E. Rosenberg (2019). Water Demand Disaggregation for Non-Residential Users of the City of Logan. *Hydroshare*. http://www.hydroshare.org/resource/2081d6098f3e4569bce119174a78f10e.

Water Resources Planning and Management

Organizing and Synthesizing Water Management Data to Support Modeling

Investigators:
David E. Rosenberg
Adel Abdallah (student)

Partners/Collaborators:
- *State:* Craig Miller, Utah Division of Water Resources
- *Business/Commercial:* Sarah Larsen, Western States Water Council; Jack Sieber, Stockholm Environment Institute
- *U.S.:* David Rheinheimer, University of Massachusetts, Amherst
- *International:* Julien Harou, Stephen Knox, University of Manchester

Project Description

- **Need and Purpose:**

  Modeling of complex water systems requires multi-disciplinary hydrologic, ecologic, economic, operational, engineered infrastructure, network connectivity, and other data. These data reside in different places, are managed by different entities, vary in space and time, and use different formats (e.g., shapefiles, text files), data types (e.g., time series, parameters, text), and terminology (e.g., dam vs. reservoir). Water managers and scientists, therefore, spend considerable time gathering and organizing data before they can run a model or conduct an analysis. Thus, a persistent informatics method is needed to organize and integrate diverse water resources data. After a persistent informatics method is developed, users can more readily re-use analysis methods across river basins. They can also leverage existing software to interact with models and data through a web interface, store model data in a HydroShare repository, and use the Jupyter Notebooks web platform to reproduce results.

- **Benefits to the State:**

  This project develops an easy-to-use informatics tool to organize, compare, and synthesize diverse water resources data. Use of the tool will decrease the time water managers, scientists, and engineers spend gathering and interpreting water management data and increase the time they spend modeling, analyzing, and managing their water systems. The tool will also allow managers and engineers to (1) more quickly interpret water resources data correctly, (2) use the same data to develop and run multiple models in the same or different study areas and compare results, (3) store data, models, and results, and (4) reproduce results. All these features are needed to model the integrated effects of coupled human-hydrologic components of our water systems.

- **Geographic Areas:**

  Study Area: Bear and Weber River basins; Rich, Cache, Weber, Morgan, Summit, Davis, and Box Elder Counties, Utah.
  Areas Benefited: Water managers and researchers statewide in all counties.

- **Accomplishments:**

  Findings and Results: We connected the Water Management Data Management system (WaMDaM), its controlled vocabulary, and supporting software tools to Hydra Platform and OpenAgua to allow users to view, modify, and run models online through a web portal (Figure 1).

Water Resources Planning and Management

- o We connected the WaMDaM model to Hydroshare and Jupyter notebooks to allow users to more easily store models and data in an online repository and reproduce results (Figure 1).
- o We used the connected software tools to quantify demand reliability for separate Water Evaluation and Planning (WEAP) simulation models of the Bear River and Weber River basins under supply, demand, and reservoir scenarios (Figure 2).
- o The coupled software tools identify similarities and differences in the networks (reservoirs, demand sites, river reaches, and diversions) used by different models for the same river basin.
- o We used the coupled software tools to visualize and compare model data from models of different river basins (agricultural water demand in Monterrey, Mexico and in Logan, Utah).
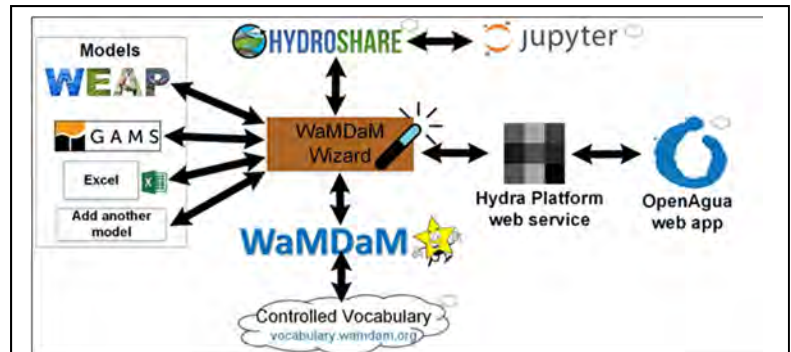
Work Plan FY19/FY20

- Finalize Adel Abdallah's PhD dissertation.
- Submit two chapters from the dissertation for publication in peer-reviewed journals.

Figure 1. Connecting WaMDaM with its controlled vocabulary and software tools to Hyda Platform and OpenAgua allows users to interact with models and data through a web portal. Connecting WaMDaM to Hydroshare and Jupyter notebooks allows users to store models and data and reproduce analyses.
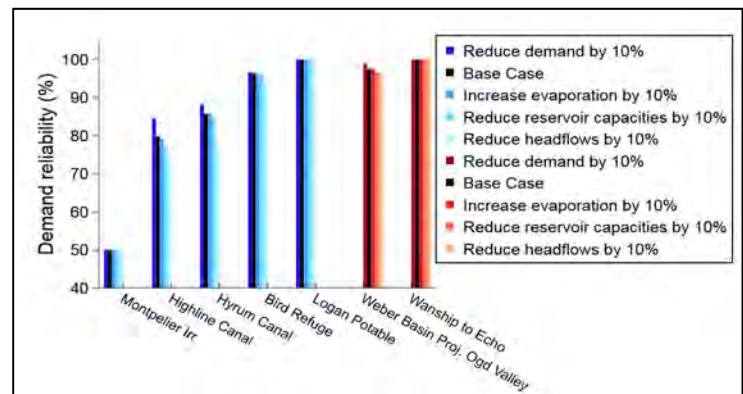

Figure 2. Modeled reliability of water deliveries to select sites in the Bear and Weber basins across supply, demand, and reservoir scenarios. WaMDaM permits the same analysis with two Water Evaluation and Planning (WEAP) models for the Bear and Weber basins

Informational Resources

Contact: Dr. David E. Rosenberg, Telephone (435) 797 8689, E-mail: david.rosenberg@usu.edu.

Website: https://wamdam.org
Website: https://github.com/WamdamProject/ WaMDaM_JupyterNotebooks.

Peer-Reviewed Journal Article:

Abdallah, A.M. and D.E. Rosenberg (2019). A data model to manage data for water resources systems modeling. *Environmental Modelling and Software*, 115:113-127. https://doi.org/10.1016/j.envsoft.2019.02.005.

Water Resources Planning and Management

Terrain Analysis Using Digital Elevation Models

Principal Investigators:
David G. Tarboton
Alfonso Torres-Rua
Irene Garousi-Nejad (graduate student)
Mahyar Aboutalebi (graduate student)

Partners/Collaborators:
- **National**: National Water Center flood mapping teams
- **Federal**: USGS

Project Description:

- **Need and Purpose:**

  Terrain Analysis involving the extraction of hydrologic information from digital elevation models (DEMs) is an important component of hydrologic modeling. It enables models to take advantage of the detailed information represented by a DEM and enriches the information content of a DEM from a simple grid of elevation values into a data structure that represents the terrain flow field and supports quantification of contributing area and a host of other derived quantities useful for hydrologic analysis. Over several years the UWRL has advanced the Terrain Analysis Using Digital Elevation Models (TauDEM) software for hydrologic terrain analysis. This year TauDEM methods and tools were advanced to improve the calculation of height above nearest drainage (HAND) used in the modeling of flood inundation and determination of river hydraulic geometry properties.

- **Benefits to the State:**

  While considered a dry state, Utah is not immune to flooding. Rapid snowmelt in 2017 resulted in a record flood on the Bear River in northern Utah that was not anticipated or well predicted, and it resulted in notable property damage. The National Water Model operated by the National Water Center in Tuscaloosa Alabama, provides discharge forecasts for each stream reach in the National Hydrography Dataset. HAND, calculated using TauDEM, is used to convert these discharges into flood heights to forecast inundation. However, complex topography and limitations in the currently used continental scale flood inundation mapping methods diminish the accuracy and utility of these forecasts. This work strives to improve the calculation of HAND and its use in National Water Model inundation forecasting.

- **Geographic Areas:**

  Study Areas: The National Water Model applies to the entire US. This project focused on inundation in a reach of the Bear River in northern Utah that experienced flooding in 2017. This case study was used to improve and advance methods that could be applied nationally.

  Areas Benefited: All areas of Utah and the US with the potential for flooding.

- **Accomplishments:**

  Findings: Comparing flood inundation mapped using Height Above Nearest Drainage (HAND) to inundation observed using high-resolution Planet RapidEye satellite imagery was shown to improve forecasts by incrementally adding better discharge values, using uniform stream segment lengths in the HAND procedure, conditioning the underlying digital elevation model using high-resolution hydrography, and using a higher resolution DEM. The standard continental scale flood inundation mapping procedure uses a 10-m DEM, but the 3-m DEM available for the study river reach was able to produce an

improvement. We also found that hydraulic roughness parameters could be estimated from calibration using observed inundation.

Results: This work has resulted in a new tool that is now part of the TauDEM software distributed by the UWRL for flow direction conditioning. This tool conditions a digital elevation model to have non-increasing elevation along the downstream direction of input stream flowlines. This work has been reported in a Water Resources Research paper, with data and procedures used in the paper publicly available in HydroShare.

Work Plan FY19/FY20

Ongoing work is continuing to refine terrain analysis methods to enhance their applicability and use in hydrologic analysis. This year we anticipate contributing to the development of a refined national HAND layer that uses the methods reported and can be implemented in National Water Model inundation forecasting procedures.

Informational Resources

Contact: Dr. David G. Tarboton, Telephone: (435) 797-3172, Email: david.tarboton@usu.edu.

TauDEM Website: http://hydrology.usu.edu/taudem.

Publications:

Garousi-Nejad, I., D.G. Tarboton, M. Aboutalebi, and A. Torres-Rua (2019). Terrain analysis enhancements to the height above nearest drainage flood inundation mapping method. *Water Resources Research*, 55. https://doi.org/10.1029/2019WR024837.

Water Resources Planning and Management

Use of sUAS for Mapping Wetland Flow Paths and Consumptive Use on the San Rafael River, Utah

Principal Investigators:
Alfonso Torres-Rua
Ian Gowing
Ayman Nassar (graduate student)
Mahyar Aboutalebi (graduate student)

Partners/Collaborators:
- **State**: Daniel Keller, Division of Wildlife Resources

Project Description:

- **Need and Purpose:**

One of the main invasive vegetation species in Utah riversides and wetlands is Tamarisk, a vegetation that has colonized river floodplains throughout the western US. Tamarisk colonized the San Rafael, Utah in the 1950s, and efforts for eradication have been quite successful; however, Tamarisk has proven to be resilient because time periods between eradication activities (2 to 3 years) allow Tamarisk to develop again (Fig. 1). Current questions from water managers in Utah are related to riverbank morphological (flow paths) changes and consumptive water use. This is because river restoration is needed if changes in flow paths are drastic due to Tamarisk eradication, along with bank erosion and soil displacement. On the water use side, limited information exists on the actual water use (daily and seasonal) within Utah by these invasive plants. Current unmanned aerial technologies can help to achieve both purposes.

Figure 1. Student Ayman Nassar collecting Tamarisk measurements in the San Rafael River.

- **Benefits to the State:**

By providing detailed information of vegetation distribution, flow paths and consumptive use from current unmanned aerial technologies, Utah water related agencies can take immediate, effective action on river restoration activities, monitoring flow paths and invasive vegetation along with water use impact. Furthermore, the project informs state officials of advances in unmanned technologies and modeling efforts for their water management activities.

- **Geographic Areas:**

Study Areas: The proposed project is implemented downstream of Highway 24 towards Cottonwood Wash, along the San Rafael River, Emery County, Utah (Fig 2).

Areas Benefited: Utah's Colorado Upper River Basin.

Figure 2. Area of study in Utah.

Water Resources Planning and Management

- **Accomplishments:**

Findings: An example of thermal information in the area of study is presented in Fig.3. One UAV data collection efforts was completed by June with two more scheduled for August and September. Intensive data collection of leaf area index by student Ayman Nassar during UAV flights provides an indication of biomass differences between Tamarisk and native vegetation. Once UAV and ground data collection are completed, data analysis, including spatial estimation of biomass (for Tamarisk and native vegetation) and assessment of vegetation water use, will be completed in the following months.

Results: Data collection activities are still ongoing in this project. Orthomosaics of optical images will be delivered to Utah DWR for the wetlands flow path analysis to determine changes in wetlands flow paths due to Tamarisk by comparing against historical information. Students associated with the project will evaluate consumptive water use in the second component in this task using surface energy balance models (SEB) for high-resolution information.

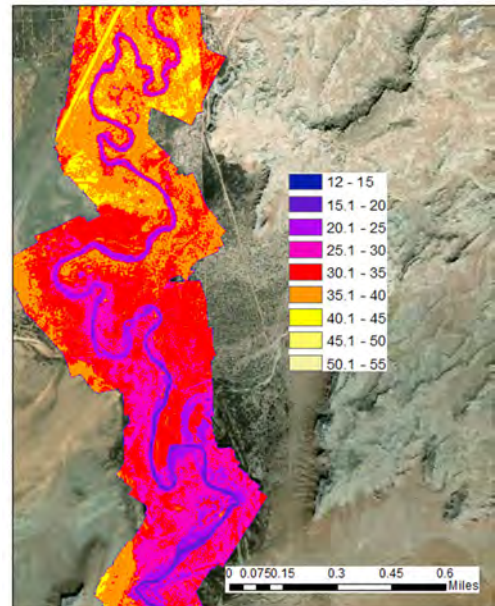*Figure 3. Example of thermal information (Celsius) for the area of study in the San Rafael River.*

Work Plan FY19/FY20

The work plan involves completion of ground information and data collection in August and September along with the Tamarisk water consumption analysis.

Informational Resources

Contact: Dr. Alfonso Torres-Rua, Telephone: (435) 797 0397, E-mail: alfonso.torres@usu.edu.

Water Resources Planning and Management

Using High-Resolution Aerial Imagery of a Wetland near the Lower San Rafael River in South Central Utah to Understand the Hydraulic and Thermal Characteristics of Complex Habitat Structures

Principal Investigators:
Ian Gowing
Bethany Neilson

Partners/Collaborators:
- **State**: Dan Keller, Utah Division of Wildlife; Paul Birdsey, Utah Division of Wildlife
- **Federal**: Justin Jimenez, Bureau of Land Management

Project Description:

- **Need and Purpose:**

The purpose of this research is to investigate the effectiveness of Beaver Dam Assist Structures (BDAs) in terms of providing good quality fish habitat for native fish populations throughout the San Rafael. Fish habitat within the lower San Rafael is known to be severely depleted/limited, and these BDA structures could potentially enhance native fish abundance by providing more high quality habitat. Previous research (fish-surveys) conducted by the Division of Wildlife Resources have related these structures with high fish abundance levels when compared to other habitat types within the San Rafael.

Figure 1. A beaver Dam Assist structure on the San Rafael River.

This study aims to examine what makes these structures preferred and/or more suitable habitat locations with respect to temperature and hydraulic variables including depth, mean column velocity, and substrate/cover. Such variables will be investigated and analyzed during fish surveys conducted by the Division of Wildlife Resources. Temperature sensors will be positioned throughout these structures to examine how temperature varies spatially and temporally, especially during critical periods of low flow. Temperature data from these sites will be analyzed alongside longitudinal temperature data being simultaneously collected along 55 miles of the San Rafael to establish if these locations provide more favorable thermal conditions. The Division of Wildlife Resources has also contracted with the AggieAir™ Service Center, to capture high-resolution aerial imagery of a wetland complex just upstream of Cottonwood Wash that may act as a fish barrier and prevent fish migration.

- **Benefits to the State:**

With the implementation of this river restoration scheme we anticipate that the river will be restored to a more ecologically acceptable state, providing more comprehensive complex habitat to the native fish, encouraging changes in channel morphology through removal of Tamarisk, more native riparian species planted along the river corridor, removal of man- made barriers to enhance and encourage fish movement/passage throughout the entire drainage.

- **Geographic Areas:**

Study Areas: San Rafael River, Emery County, Utah.

Areas Benefited: Emery County and statewide where river restoration projects are being implemented.

Water Resources Planning and Management

- **Accomplishments:**

  Findings: Fieldwork and monitoring in and around the Beaver dam structures were completed April/May 2017. Analysis on the data will continue through to December 2019 when a final report will be produced. The first UAV flight over the San Rafael wetland complex took place June 2017.

  Results: Preliminary data analysis on data collected in and around the beaver dam structures continued through the end of 2018, and imagery from the first AggieAir™ UAV flight is being processed and orthorectified.

Work Plan FY19/FY20

Data analysis will continue through the end 2019. A second flight to capture imagery will occur during fall of 2019. It is anticipated that this imagery will be used by DWR to assess the effects of high spring flows on the main channel and to assess fish habitat.

Informational Resources

Contact: Mr. Ian Gowing, Telephone: (435) 797 3159, E-mail: ian.gowing@usu.edu.
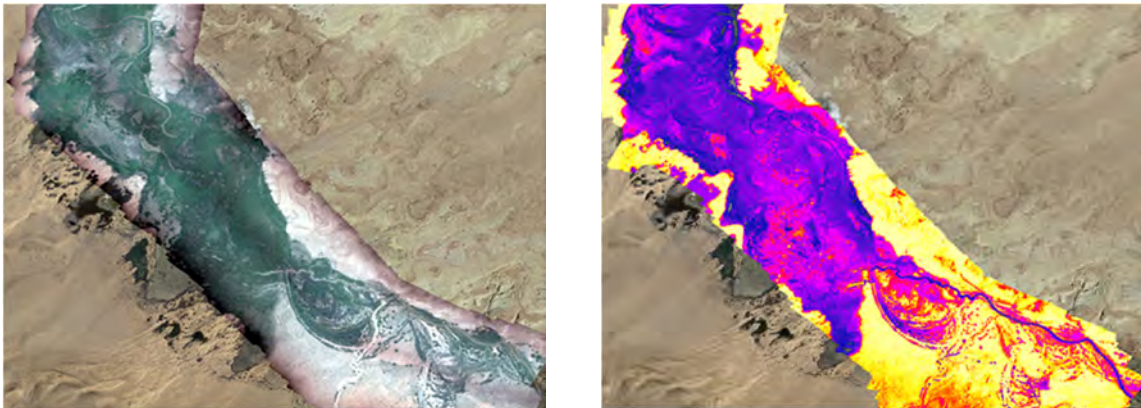
Figure 2. Visual and thermal imagery over the San Rafael captured 2017.

Water Resources Planning and Management

Using the Utah Energy Balance Snowmelt Model to Improve Water Supply Forecasts

Principal Investigators:
David G. Tarboton
Tian Gan (graduate student)
Tseganeh Gichamo (graduate student)

Partners/Collaborators:
- **Regional**: Colorado Basin River Forecast Center; Gerald Day, RTI, Fort Collins, CO

Project Description:

- **Need and Purpose:**

In many parts of the world, including Utah, snow is a significant water resources component. Currently many operational streamflow forecasting systems use temperature index snowmelt models that have limited predictive capability for weather and land cover conditions that are different from those for which the models were calibrated. This study advances streamflow forecasting through the use of a physically based model, assimilation of observed data, and use of High-Performance Computing (HPC).

- **Benefits to the State:**

Water is a critical resource in Utah. The Colorado Basin River Forecast Center provides water supply forecasts for the Colorado River and Great Salt Lake Basin encompassing the majority of Utah. Managers rely on water supply forecasts for irrigation and water resources planning. This work is improving our capability to model snowmelt, the major source of water in the state. It is also improving our ability to simulate streamflow for flood forecasting, water supply, and stream ecosystems. Better streamflow forecasts also advance our understanding of the impacts of water resources development activities around the Great Salt Lake. Planning for potential growth and development in the state requires information on water availability and on the effects of growth on our water resources.

- **Geographic Areas:**

Study Areas: The study area is the semi-arid Western U.S., particularly Utah, the Great Salt Lake and its drainage basins, and the areas of the Colorado River Basin served by the National Weather Service Colorado Basin River Forecast Center (CBRFC) in Salt Lake City.

Areas Benefited: Water resources in watersheds throughout Utah will be subject to impacts from changes in land use and climate, so all counties in the state stand to benefit from a better understanding of these impacts.

- **Accomplishments:**

Findings: (1) Graduate student Tian Gan compared the Utah Energy Balance (UEB) snowmelt model, a physically based energy balance model developed at the UWRL with the empirical temperature index model currently in use in Colorado Basin River Forecast Center systems. She found that while both models, when coupled to a runoff model and calibrated, provide reasonable basin snow and discharge simulations, the physically based model was better able to quantify evaporative water balance components (sublimation from snow) and sensitivity to land cover change with fewer calibrated parameters, thus offering better transferability potential to remain valid for different climate and terrain conditions.

(2) Graduate student Tseganeh Gichamo has developed a novel approach based on a statistical technique referred to as an Ensemble Kalman Filter, to use information on snow accumulation and melt measured at SNOTEL stations to adjust gridded snow accumulation and melt across a watershed and improve water supply forecasts. He also improved the efficiency of the UEB by refactoring its computer code to take advantage of parallel high-performance computing.

Results: This work was performed in collaboration with RTI (Research Triangle Institute Fort Collins Office) and the CBRFC responsible for water supply forecasting over the Colorado River and Great Salt Lake Basins. Code for the models developed has been provided to the CBRFC which are evaluating its use within their forecast systems. The Utah Energy Balance (UEB) snowmelt model was integrated into the National Weather Service Research Distributed Hydrologic Model (RDHM) framework used by the CBRFC. This work has been reported in the PhD dissertations of Tian Gan and Tseganeh Gichamo listed below, as well as in one paper published in Water Resources Research, with others under review or in preparation.

Work Plan FY19/FY20

The project in partnership with RTI and CBRFC to address improved water supply forecasts has ended. We plan in the next year to finish writing and revising the papers reporting this work and assist CBRFC with any questions related to implementation of the UEB in their systems.

Informational Resources

Contact: Dr. David G. Tarboton, Telephone: (435) 797 3172, E-mail: david.tarboton@usu.edu.

Publications:

Gan, T. (2019). *Advancing Cyberinfrastructure for Collaborative Data Sharing and Modeling in Hydrology*. Ph.D. Thesis, Civil and Environmental Engineering, Utah State University, Logan, UT. https://digitalcommons.usu.edu/etd/7618/.

Gichamo, T. (2019). *Advancing Streamflow Forecasts through the Application of a Physically Based Energy Balance Snowmelt Model with Data Assimilation and Cyberinfrastructure Resources*. Ph.D. Thesis, Civil and Environmental Engineering, Utah State University, Logan, UT. https://digitalcommons.usu.edu/etd/7463/.

Gichamo, T. Z. and D.G. Tarboton (2019). Ensemble Streamflow Forecasting using an Energy Balance Snowmelt Model Coupled to a Distributed Hydrologic Model with Assimilation of Snow and Streamflow Observations. *Water Resources Research*, 55. https://doi.org/10.1029/2019WR025472.

Water Resources Planning and Management

Water Management in the Event of Recurring Long-Term Historical Droughts

Investigators:
David E. Rosenberg
Tammy Rittenour
Justin DeRose
James Stagge (Ohio State University)

Partners/Collaborators:
- **Local:** Derek Johnson, Weber Basin Water Conservancy District; Darren Hess, Weber Basin Water Conservancy District; Chris Slater, JUB Engineers, Josh King,
- **State:** Candice Hasenyager, Utah Division of Water Resources; Scott McGettigan, Utah Division of Water Resources
- **Federal:**, U.S. Forest Service
- **Business/Commercial:** Eve Davies, PacifiCorp; Con Baldwin, PacifiCorp; Greg Hansen, Hansen and Associates; Seth Arens, Western Water Assessment

Project Description

- **Need and Purpose:**

  New data for annual climate and streamflow series dating back 1,200 years have been reconstructed from tree rings. These data provide water managers with a sense of the   magnitude, frequency, and duration of extreme events that we face today or may face in the future. At present, reconstructed time series of annual flows have limited spatial coverage and only one stream flow value per year. They are also not well integrated into water systems models or drought planning efforts, specifically because of the spatial and time limitations. To make use of these long, valuable records, water managers need streamflow estimates at higher spatial and temporal resolutions. This project has produced monthly flow reconstructions from existing annual reconstructions derived from tree ring data that date back to the year 1605 on the Logan River, 1430 AD on Weber River at Oakley, and 800 AD at the uppermost Bear River gage on the Utah-Wyoming border. We have incorporated these flows into a Utah Division of Water Resources (UDWR) model for the Weber Basin Water Conservancy District (WBWCD) to identify impacts of paleo, observed, and future droughts should they re-occur in the near future. Results are shared on the open repository http://paleoflow.org.

- **Benefits to the State:**

  The project is benefitting Utah in several ways: (1) Better quantifying historic droughts, (2) Comparing drought susceptibility under historic, observed, and future forecasted climate, and (3) Extending an existing water simulation model for the Lower Bear River (Utah) to include Idaho and Bear Lake.

- **Geographic Areas:**

  Study Area: Bear and Weber River basins; Rich, Cache, Weber, Morgan, Summit, Davis, and Box Elder Counties, Utah.
  Areas Benefited: Weber and Bear River basins and other basins throughout Utah for which tree ring, reconstructed flow, and water system data are available.

- **Findings and Results:**

  o We simulated reservoir levels and deliveries through droughts during the paleo, observed, and future climate periods and found that total reservoir storage dropped lowest during warm-dry and hot-dry climate projections for the next century (Figure 1).

- o Different future temperature-precipitation changes have different impacts on future drought duration and severity. Future warm-dry and hot dry climates can lead to droughts with longer severity and intensity (Figure 2).
- o This work led to a new drought vulnerability project with the Weber Basin Water Conservancy.
- o Additionally, we shared modeling work on Bear River that extended the existing Water Evaluation and Planning (WEAP) simulation model for the Bear River to include more diversions in Cache County, Utah; Idaho; and Bear Lake with the UDWR. The UDWR is currently building a new model for the Bear River.
- o We are writing a paper that describes the simulation results with reconstructed stream flows. We intend to submit the paper to the *Journal of the American Water Resources Association*.
- o We are revising a paper submitted to the journal *SoftwareX* that describes the online repository of reconstructed streamflows (http://paleoflow.org).

Work Plan FY19/FY20

- Revise paper to *SoftwareX* in response to reviewer comments.
- Submit paper to *Journal of the American Water Resources Association.*
- Continue drought vulnerability work.

Figure 1. Frequency of reservoir storage triggers (% of months) across the paleo reconstructed (1429 AD to 1903 AD), observed (1904 AD to 2016 AD), and projected future climate change (2034 AD to 2064 AD) periods.
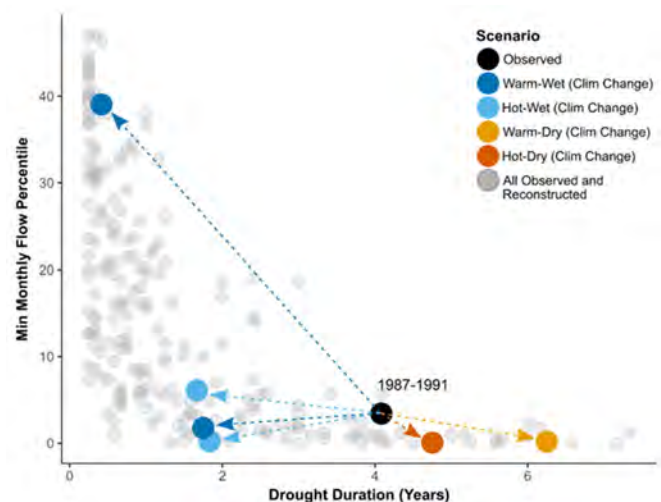
Figure 2. Effect of temperature-precipitation climate perturbations on drought duration and intensity.

Informational Resources

Contact: Dr. David E. Rosenberg, Telephone (435) 797 8689, E-mail: david.rosenberg@usu.edu.

Website: http://www.paleoflow.org.
Software: paleoAPR package. https://github.com/jstagge/paleoAPR.

Water Resources Planning and Management

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Weber Basin Drought Vulnerability Study

Investigators:
David E. Rosenberg
Jacob Everitt (graduate student)

Partners/Collaborators:
- ***Local:*** *Jon Parry, Ashley Nay, Derek Johnson, Darren Hess, Weber Basin Water Conservancy District*
- ***State:*** *Candice Hasenyager, Scott McGettigan, Utah Division of Water Resources*
- ***Business/Commercial/Institutions:*** *Seth Arens, Western Water Assessment; Court Strong, Paul Brooks, University of Utah*

Project Description

- **Need and Purpose:**

  Climate, streamflow, demographic, operational, and other factors affect the ability of the Weber Basin Water Conservancy District (WBWCD) to store and deliver water to agricultural and municipal customers. The Utah Water Research Laboratory is using a bottom-up approach to identify the individual factors and combinations of factors where the water system succeeds and fails to meet delivery criteria. The bottom-up approach is identifying key thresholds that tip the system from more vulnerable to less vulnerable states.

  The bottom up approach works as follows: (1) Identify factors that affect system success, ranges of values, and intermediary levels to test for each factor. Factors can include stream flow (influenced by climate, historical, and paleo droughts available at http://paleoflow.org identified in prior work for the District's drought contingency plan), urban and agricultural demands (population growth, per-capita water use, landscape evapotranspiration, potential evaporation, agricultural to urban water transfers), net reservoir evaporation, and reservoir sedimentation. (2) Develop scenarios that represent combinations of factors and factor levels then define the input data files for the Utah Division of Water Resources (UDWR) Riverware model for the Weber basin system. (3) Run the UDWR Riverware model for each scenario and generate stream flow, reservoir storage, water deliveries, and shortage outputs. (4) Identify storage and water delivery criteria that describe when the water system is performing satisfactorily. (5) Show the water supply, demand, and reservoir conditions when the system transitions from performing satisfactorily to unsatisfactorily.

- **Benefits to the State:**

  The project is benefitting Utah by identifying how a major state water system is vulnerable to climate, stream flow, demand, reservoir, operations, and other factors.

- **Geographic Areas:**

  Study Area: Bear and Weber River basins; Rich, Cache, Weber, Morgan, Summit, Davis, and Box Elder Counties, Utah.
  Areas Benefited: Weber Basin. Methods can also be applied to other basins throughout Utah that are served by large water systems.

Water Resources Planning and Management

- **Findings and Results:**

  o We have identified 4 major factors, subfactors, ranges of values, and levels for the vulnerability analysis (Table 1). We have generated the input data files to run combinations of factors in the UDWR Riverware model for the Weber Basin.

  o We have defined system performance criteria to be the (1) fraction of months within the ~30 year monthly simulation period when total system reservoir storage stays above WBWCD's yellow, orange, and red drought contingency reservoir targets (> 64%, > 53%, and < 53% of total system storage), and (2) fraction of months when water deliveries to demand sites meet delivery targets.

Work Plan FY19/FY20

- Run all scenarios.
- Show conditions of satisfactory and unsatisfactory system performance including relationships to key climate, stream flow, demand, and other factors.
- Share and discuss results with WBWCD staff.
- Write up results as a report, master's thesis, and data repository.

Informational Resources

Contact: Dr. David E. Rosenberg, Telephone (435) 797-8689, E-mail: david.rosenberg@usu.edu.

Website: http://www.paleoflow.org.

Table 1. Factors, subfactors, and ranges for vulnerability analysis

Factors	Subfactors	Description	Range of Values (USU)
Inflows			
Weber River Flow at Oakley, UT	Paleo Flows (1429 AD to 1903 AD)	Reconstructed from tree ring chronologies and regional climate indicators	20,000 - 264,000 Acre-Feet/year
	Observed Flows (1904 AD to 2016 AD)	Recorded gage flows by U.S. Geological Survey	56,000 - 300,000 Acre-Feet/year
	Climate Flows (2034 AD to 2064 AD)	Downscaled, estimated frows from Western Water Assessment Study	52,000 - 165,000 Acre-Feet/year
Urban Demand			
Indoor Water Use	Summit County Indoor Per-Capita Water Use (gallons per person per day; GCPD)	Declining per-capita water for three scenarios that represent base case, Utah 25% reduction goal, and a drastic case	Base: 145 GPCD Utah Goal: 96 GPCD Drastic: 81 GPCD
	Weber County Outdoor Per Capita Water Use (gallons per person per day)	Declining per-capita water for three scenarios that represent base case, Utah 25% reduction goal, and a drastic case	Base: 256 GPCD Utah Goal: 230 GPCD Drastic: 205 GPCD
	District Population (persons)	Inclines of Population within the District	Base: 623,960 people Median: 1,295,000 people Maximum: 1,913,000 people
Outdoor Use	Evapotranspiration	The Evaporation and transpiration rate from the landscape area.	(+/-) 5% to the Demand
	Precipitation	Rain on Landscape area. Will be affected by Climate Change	(+/-) 5% to the Demand
Agricultural Demand			
Field Irrigation	Arrgricultural to Urban Volumetric Conversaion Rate (%)	Fraction of agricultural water use that is transferred to urban use as defined from Utah Division of Water Rights water rights transfer data	68% to 73%
	Evapotranspiration	The evaporation and transpiration rate from the crop and crop area. Typically a rate.	-5% to +5% of Demand
Storage			
Reservoirs	Net Evaporation (ft/year)	For Willard Bay Compiled from existing model and University of Utah projections for Historical (1995-2005) and Late Century (2085-2095)	Riverware: 3.2 feet/year Historial: 3.7 feet/year Late: 4.0 feet/year
	Sediment Buildup (% of capacity)	The buildup of sediment in all district reservoirs either gradually over time or suddenly do to floods.	0% 10% 30%

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Research Faculty, Professional, and Support Staff

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