MINERAL LEASE FUND REPORT

Utah Water Research Laboratory
Utah State University

Fiscal Year 2016

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

Last year as we celebrated 50 years of service and achievements at the Utah Water Research Laboratory, our world-class faculty was hard at work on the water, food, and energy resources challenges that we are facing now and in the next 50 years. The role water resources play in meeting our needs for food, fiber, and energy, while maintaining a healthy sustainable environment continue to expand in both in scope and complexity as we face extreme variability in climatic conditions and a growing population.

Today, with a world-class research facility and a dedicated faculty and staff, we look forward to continuing our cutting edge research and providing practical solutions to the most pressing water problems facing Utah, our nation and the world. To help accomplish its 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." In compliance with House Bill 103 passed during the 1993 Legislature General Session, this report provides a brief description of the UWRL's 263 active research, training, and service projects this past fiscal year, along with an accounting of the ML funds for FY 2016, budgeted expenditures for FY 2017, and planned expenditures for 2018.

As one of the oldest and most respected University-based facilities, the UWRL's goals and mission remain the same, as reflected in this Annual MLF Report on current projects. 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. The UWRL also leverages and expands the benefits of these projects through collaborations and partnerships with local, state, and federal agencies. This past FY we have worked with most of Utah's water related agencies and organizations, as well as undertaken some $4 million in project funding from other sources, thus providing additional opportunities for solutions to State water issues as well as substantial economic benefits.

This "Introduction" to our report provides a general description of the role and history of the UWRL, and an overview of UWRL's research activities, including sources of funding, program structure, collaborating organizations, training, and outreach, followed by a short overview of UWRL Administration. The final section of the report details the UWRL's contributions to addressing high-priority water resources problems and issues in the state. Each individual project is summarized, including a statement of the need and purpose, and the benefits to specific areas in the State and the citizens of Utah. The local, state, and federal agencies and other organizations partnering in the project research and potential applications are also noted.

As today's water resources management problems become more complex, our internationally renowned faculty and their students are meeting current challenges and finding solutions to tomorrow's water and environmental problems now. We look forward with optimism to helping Utah solve its water resources needs and challenges throughout its next 50 years of service. The UWRL is pleased to submit this year's report 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.

The UWRL welcomes any comments or questions that result from these reviews.

Mac McKee
UWRL Director

Foreword

Table of Contents

Table of Contents

Table of Contents

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. More recently in 2009, the UWRL completed a new 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 50 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 FY 2016 of more than $9 million makes it one of the largest institutes in the nation.

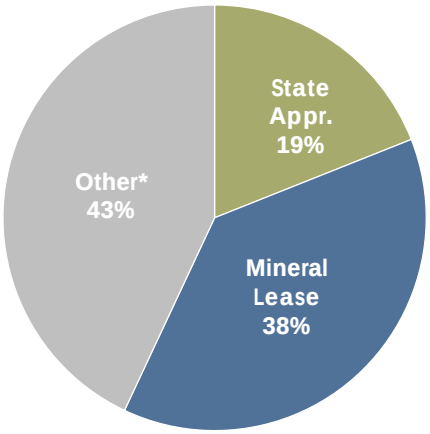
UWRL Financial/Academic Summary (FY 2016)

Number of Active Projects	263
Dollar Value of Active Projects	$9,277,880
Scholarly Publications in Peer-Reviewed Journals	81
Scholarly Presentations at Professional Conferences	138
Outreach Products (FY 16)	
Short Courses and Field Training	6
Degrees Granted	
PhD	9
MS	15
ME	22

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 many 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 FY 2016, MLF funding of over $3 million accounted for 36% 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 FY 2016 were over $ 9 million.



UWRL Funding FY 2016

The UWRL's 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
- Computer Science

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 hydroclimatological 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 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.

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, as well as public and professional service, technology and information transfer, and public education. 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 FY 2016

Graduate Students Supported (FY 16)	51
Undergraduate Students Supported (FY 16)	122

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). Currently, the Section 104 Program is funded at an annual level of approximately $92,000 of federal funds through the U.S. Geological Survey (USGS). This year, the base grant, in combination with ML funds, directly benefits the State of Utah in areas of

1. Developing a framework for estimating crop water use using remote sensing through a standardized approach, thus providing guidelines and specifications for applying certain evapotranspiration (ET) models and producing ET products that are acceptable to the USGS WaterSmart program and the scientific and user community.

2. Using an inexpensive unmanned aerial vehicle (UAV) to provide high resolution, up to date aerial imagery in support of restoration schemes ongoing in the San Rafael River in South Central Utah and determining the accuracy and limitation of this platform for providing digital elevation and terrain models in place of more conventional, and more expensive, approaches.

3. Identifying key opportunities and challenges faced by irrigation companies as they adapt to changes in land use and urban pressure and helping them understand and adapt to changes associated with the urbanization of an irrigated agricultural landscape.

4. Developing methods for analyzing historical water billing data to assist cities, counties, and state agencies in reducing municipal water demand throughout the State of Utah.

5. Evaluating biofiltration as an effective way to reduce organic matter and potential disinfection by-product production in Utah drinking water.

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

Relevancy and Benefits of the Mineral Lease Fund

As the second driest state 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

Hence, 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 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 agencies and are actively involved with and serve on many state and local organizations, committees, and boards. The UWRL Director, Associate Director 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 network of organizations over the past fiscal years.

Utah Department of Natural Resources Division of Water Resources State Engineer – Division of Water Rights	**Utah Department of Environmental Quality** Air Quality Drinking Water Water Quality Solid and Hazardous Waste
State Regulatory and Advisory Committees DEQ Water Quality Board Utah Solid and Hazardous Waste Control DEQ Drinking Water Board Utah Governor's Unmanned Aerial Systems Test Site Advisory Board	**State Water Associations and Organizations** 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 American Water Resources Association American Society of Civil Engineers American Water Works Association Water Environment Research Foundation (WERF)	**Regional and National Research Alliances** 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 FY 2016 through FY 2018 for research projects in the six major **Program Areas.** UWRL administration and technology transfer expenditures account for approximately 13% of total MLF budgeted and planned expenditures.

MINERAL LEASE FUND EXPENDITURES			
Research Program Area	**Actual FY15**	**Budgeted FY16**	**Planned FY17**
Drinking Water and Wastewater Treatment	$379,877.66	$225,959.88	$251,183.85
Environmental Quality Management and Remediation	$526,269.31	$289,119.58	$289,923.18
Surface and Groundwater Quality and Quantity	$455,934.79	$269,111.00	$254,359.33
Water Conveyance, Distribution and Control	$56,049.40	$31,000.00	$31,082.06
Water Education and Technology Transfer	$79,829.29	$57,092.50	$61,080.28
Water Resources Planning and Management	$1,438,278.78	$527,289.54	$500,121.19

A detailed breakdown of the expenditures for each project within these **Research Program Areas** can be found 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 among the 263 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 is developing engineering approaches for the treatment and production of drinking water and the treatment

and reclamation, recycling, and reuse of municipal and industrial wastewater, as well as evaluating the effectiveness of various seepage treatment options in Utah environments. Research in this area is also investigating methods to develop renewable energy from waste streams and creating 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 are being developed in 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

This program utilizes UWRL's unique hydraulics laboratories for physical and numerical (CFD) modeling of hydraulic structures, including optimal designs for weir structures, hydraulic structures for flood control and flood bypass, testing and evaluating hydraulic machinery and piping systems, flow meter calibration, and erosion control. Analytical aspects of the program include pipe network designs for water supply, sediment transport, non-contact flow measurement, open channel flow, low-head dam effects, energy dissipations, and fish passage, among others.

Water Education and Technology Transfer

Projects conducted by the UWRL in this program area, including many that are 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 systems (AggieAir). 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 are provided for the benefit of Utah's state and local agencies, elected officials, citizens, and the nation. Outreach is provided by our faculty, staff, and students associated with the UWRL. Additional outreach is available 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. Specific panels include:

State of Utah Drinking Water Board
Water Treatment Operators Certification Commission
Salt Lake County 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
Bear River Health Dept.'s Air Task Force
The Weber-Morgan Health Department Wastewater Advisory Committee

In addition, 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: http://uwrl.usu.edu/partnerships/training/. 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 in the form of increased climatic variability; 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. 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 dealing with these water challenges now and the future. As the UWRL begins its next half-century of service to Utah, we are proud to acknowledge all the dedicated people, past and present, who have contributed to the Lab's achievements and its world-class reputation for water research and education.

Administration, Advisory Support, and Special Equipment

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

Project Name	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
Business Office	$ 171,239.59	$ 176,376.78	$ 181,668.08
Laboratory Infrastructure Support, Travel, and Special Request	$ 95,374.12	$ 78,235.34	$ 80,582.40
Publications Office	$ 67,625.69	$ 69,654.46	$ 71,744.09
UWRL Administration	$ 85,263.02	$ 87,820.91	$ 90,455.54
Total	**$ 419,502.42**	**$ 412,087.50**	**$ 424,450.12**

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 deliberately 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 important 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. FY 2016 administrative costs represented approximately 2.5% of total UWRL MLF expenditures.

Outreach and Business Support

Overall, annual research expenditures for the UWRL fluctuate between $ 8 and $ 12 million, and at any point in time there will be around 250 active research contracts administered at the UWRL. These projects require significant support from the UWRL Business Office in the form of accounting and financial oversight. Further, they benefit from assistance that comes from the UWRL Publications Office, which provides support for outreach activities (such as the production of presentations, maintenance of the UWRL and UCWRR web pages, etc.). MLF expenditures in FY 2016 on these support activities accounted for 10% of total MLF funding.

Advisory Support on Water Problems

The UWRL received many requests in FY 2016 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 management 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, as is the case for current research on metals and pharmaceuticals for Park City water supplies and wastewater. The 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. Investments in state-of-the-art equipment are sometimes made from MLF resources to support these activities and to provide long-term, sustainable capability to continue these efforts in the state. New equipment acquisition and their integration into research are described in specific Project Reports.

Research Project Summary Categories

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

Drinking Water and Wastewater Treatment

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

Project Name	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
Biofiltration of Utah Municipal Drinking Water	$ 50,051.99	$ 20,069.00	$ 20,671.07
Biological Phosphorus and Nitrogen Removal from Lagoon Wastewater using Rotating Algae Biofilm Bioreactors (RABR)	$ 42,418.56	$ -	$ -
Enhancing Methane Production at Water Reclamation Facilities	$ 77,398.53	$ 79,720.49	$ 82,112.10
Low Level Hexavalent Chromium (Cr-6) in Drinking Water	$ 38,124.72	$ 16,000.00	$ 16,480.00
Managing Drinking Water Quality in Park City	$ 76,176.11	$ 30,000.00	$ 30,900.00
Mitigation of Methane Emissions from Septic Systems	$ 46,755.42	$ 35,000.00	$ 36,050.00
Solar Disinfection of Drinking Water by Point-of-Use Inactivation of Intestinal Pathogens	$ 33,398.56	$ 7,000.00	$ 7,210.00
Treatment of Wastewater Algae for Bioenergy	$ 6,353.77	$ -	$ -
Wastewater Operator Certification Council	$ 1,500.00	$ 1,545.39	$ 1,591.75
Designated Projects		$ 16,694.00	$ 33,000.00
Undesignated research projects in program area		$ 12,000.00	$ 15,000.00
Total	**$ 372,177.66**	**$ 218,028.88**	**$ 243,014.92**

Biofiltration of Utah Municipal Drinking Water

Principal Investigators:
David K. Stevens
Darwin L. Sorensen
Stetson Bassett (Student)

Partners/Collaborators:
- ***State:*** *Eva Nieminski, DDW*
- ***Business/Industry:*** *David Pitcher, Monica Hoyt, Joe Crawford, Mike Rau (CUWCD)*

Project Description

- **Need and Purpose:**

  Biofiltration of drinking water supplies is a promising method for reducing the potential for unwanted disinfection byproducts and for minimizing the regrowth of microorganisms in water distribution systems. Because of the site-specific implementation of this technology, the project studied and will study, at pilot scale, the potential for using biofiltration to reduce and modify the organic matter content of drinking water at two Utah water utilities and develop preliminary information pertaining to the design and operation of such utilities.

  The primary objective of the project is the assessment and optimization of biofiltration in selected Utah Drinking Water Treatment plants at pilot scale. The research seeks to answer the following questions: (1) Is biofiltration an effective way to reduce organic matter from Utah source waters? (2) Can biofiltration be used to reduce the potential for production of disinfection byproducts? and, (3) Can ATP measurements be correlated with the more definitive measure of biofiltration performance, CBXA, as a surrogate measure of biological activity and organic compound treatment efficiency?

  A series of designed experiments to examine these questions are being carried out at two Utah water treatment plants, one at Duchesne and the other at Hurricane. The plants were chosen in consultation with project partners from the Utah Division of Drinking Water and the Utah Water Quality Alliance: operators of larger water treatment facilities in Utah.

  At Duchesne, pilot-scale biofilters were designed and fabricated for each plant in triplicate, then operation and data collection at the plants were be carried out over the next twelve months from April 2015–April 2016. Influent, intermediate, and effluent water triplicate samples were collected weekly during this period and assayed for general water chemistry, heterotrophic plate count (HPC), dissolved and total organic carbon, UV254, ATP, nutrients (N and P), and other measures. Regular weekly samples of the biofiltration media were collected during the study to assess the development of the biological consortia through microbiological analyses.

  The study at Hurricane, focuses on the Washington County Water Conservancy District's Quail Creek water treatment plant. The test is being done at full scale for a one-year duration with half of the plant converted to biofiltration in a way that does not compromise the quality of the drinking water delivered to the WCWCD's customers. The plant operation in this configuration began in July 2016 and will continue through the year.

- **Benefits to the State:**

  Biofiltration is long overdue as a method of water treatment in Utah. This project is helping to fill the knowledge gap currently make water utilities reluctant to promote its use.

- **Geographic Areas:**

  Study Area: Duchesne, UT, Hurricane, UT (site of Washington County Quail Creek WTP).

  Areas Benefited: Statewide.

- **Accomplishments**:

  Findings/Results: Monitoring at the Duchesne water treatment plant pilot system began in April 2015. Samples were collected by CUWCD and USU personnel for on-site analysis and also sent to the State lab in Salt Lake County for further testing. These samples were assayed for a variety of chemical constituents.

  Results: Results showed that the pilot plant using biofiltration produced water of a quality suitable for drinking, and with lower levels of organic matter that may cause harmful disinfection by-products.

Work Plan FY16/FY17

During the period from July 1 2016 to June 20 2017, we will continue data collection and database construction for the Quail Creek trials, and complete data analysis for the Duchesne segment of the project. MLF funding will continue to support data analysis. We will also seek additional sources of funding to continue the project for at least an additional year.

Informational Resources

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

Biological Phosphorus and Nitrogen Removal from Lagoon Wastewater using Rotating Algae Biofilm Bioreactors (RABR)

Principle Investigators:
Ronald C. Sims
Charles Miller
Anna Doloman (PhD student)
Sahand Iman Shayan (MS student0
Alan Hodges (MS student)
Celeste Hancock (BS student)
Tyler Marlar (BS student)

Partners/ Collaborators:
Local: *Mr. Issa Hamud, Director, Logan City Environmental Department*
Business/Industry: *WesTech, Inc. Engineering, Salt Lake City, Utah*

Project Description

- **Need and Purpose:**

  Logan City is currently required to remove phosphorus to low levels (1 mg/L) and was recently required to remove nitrogen from wastewater in order to meet water quality criteria established by the State of Utah in 2015. The biological-based technology, the Rotating Algae Biofilm Reactor (RABR), was tested for phosphorus removal at the City Lagoons Wastewater Treatment Plant. The RABR technology treats wastewater to higher quality (nitrogen removal to less than 5 mg/L) and utilizes the biosolids produced to make valuable bioproducts.

- **Benefits to the State:**

  The RABR method for treating wastewater captures carbon dioxide, a greenhouse gas (GHG), in the form of microalgae, thereby providing "CO2 credits" as part of a life cycle analysis of wastewater treatment impacts on the environment. The method also provides a way to avoid landfill disposal of biosolids generated in wastewater treatment by fractionating the algae into several streams that can be used as a feedstock to make valuable bioproducts. The method developed is applicable to other wastewater systems in Utah that depend on lagoons or open ponds for treatment and also to mechanical plants that treat lower volumes of highly concentrated nutrient streams. Implementing RABR microalgae wastewater treatment technology can boost economic growth through creation of new engineering jobs and services in Utah.

- **Geographic Areas:**

  Study Area: The Salt Lake City area and Northern Utah, including the cities of Logan, Hyde Park, Smithfield, North Logan, River Heights, Providence, Nibley, and Utah State University.

  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 microalgae can be cultivated successfully as a biofilm and can remove both nitrogen and phosphorus from wastewater, (2) The harvested algae can be fractionated into streams that are used to produce several products. One stream serves as feed for a digester to generate biogas to heat and power the treatment plant. Another stream has a high protein content and omega fatty acids that can serve as feed for aquaculture and animals.

Results: We successfully removed nutrients, including phosphorus and nitrogen, from Logan Lagoon wastewater using the RABR technology (Publication 1); developed and tested an improved method for processing the wet harvested algae (Publication 2); and treated Logan Lagoon microalgae in an Upflow Anaerobic Sludge Blanket Reactor (UASB) to produce bioenergy at 90% methane (Publication 3). These results demonstrated the success of mixed culture microalgae for treating municipal wastewater and producing valuable bioenergy and products utilizing all fractions of the algae biomass. As an added benefit, this technology keeps the biomass from wastewater treatment out of the landfill.

Work Plan FY16/FY17

We will apply the technology developed in this project to the largest municipal wastewater treatment plant in the State of Utah, Central Valley Water Reclamation Facility, Salt Lake City, to test nutrient removal and produce bioenergy.

Informational Resources

Contact: Mr. Tom Holstrom, Manager, Central Valley Water Reclamation Facility, Salt Lake City, UT.; Telephone: (801)973-9198; E-mail: holstromt@cvwrf.org.

Mr. Issa Hamud, Director, Logan City Environmental Dept., Telephone: (435) 716-9752, E-mail: issa.hamud@loganutah.org.

Mr. Rex Plaizier, President and CEO, WesTech, Inc. Engineering, Telephone: (801) 856-5323, E-mail: rplaizier@westech-inc.com.

Publications from this project:

Sathish, A., Marlar, T., and Sims, R.C. (2015). Optimization of a Wet Microalgal Lipid Extraction Procedure for Improved Lipid Recovery for Biofuel and Bioproduct Production. *Bioresource Technology*. **193:**15–24.

Shayan, S.I., Foster A. Agblevor, L.B., and Sims, R.C. (2016). Hydraulic Retention Time Effects on Wastewater Nutrient Removal and Bioproduct Production via Rotating Algae Biofilm Reactor. *Bioresource Technology,* 211:527-533.

Soboh, Y.M., Sorensen, D.L., and Sims, R.C. (2016). Upflow Anaerobic Sludge Blanket Reactor Co-Digestion of Algae and Acetate to Produce Methane. *Water Environment Research*. **DOI:** http://dx.doi.org/10.2175/106143016X14504669767490.

Figure 1. Logan City Wastewater Reclamation Plant. Rotating Algae Biofilm Reactor (RABR) for algae treatment of wastewater. Left to Right: students Celeste Hancock, Alan Hodges, Dr. Ron Sims, student Ben Peterson, USTAR Associate Director Tyson Todd, USTAR Director Andrew Sweeney, and student Jason Peterson

Enhancing Methane Production at Water Reclamation Facilities

Principal Investigators:
Michael J. McFarland
Morris Demitry

Partners/Collaborators:
Local: *Lance Wood, Central Weber Sewer Improvement District, Kevin Hall, Central Weber Sewer Improvement District*
State*: Dan Griffin, Utah Division of Water Quality; Jeff Barrett, Utah Governor's Office – Renewable Energy Initiative*

Project Description

- **Need and Purpose:**

  Enhancing methane gas from the anaerobic digesters with stable performance is a challenge for reclamation facilities. Recent studies show promising results when bakery waste (BW) obtained from CMS factory, Ogden, UT was co-digested with municipal sludge (MS) at the Central Weber facility using fully-mixed reactors. However, investigating the process of co-digesting MS and BW using other kinds of reactors, specifically the induced bed reactors (IBR), can potentially increase the production of methane gas and increase the organic loading rate. This potentially can be applied to full-scale facilities digesters if stable performance is achieved. Additionally, the Anaerobic Digestion Model Number 1 (ADM1) was modified and optimized to simulate the process accurately, reducing risk and uncertainty inherent within the process.

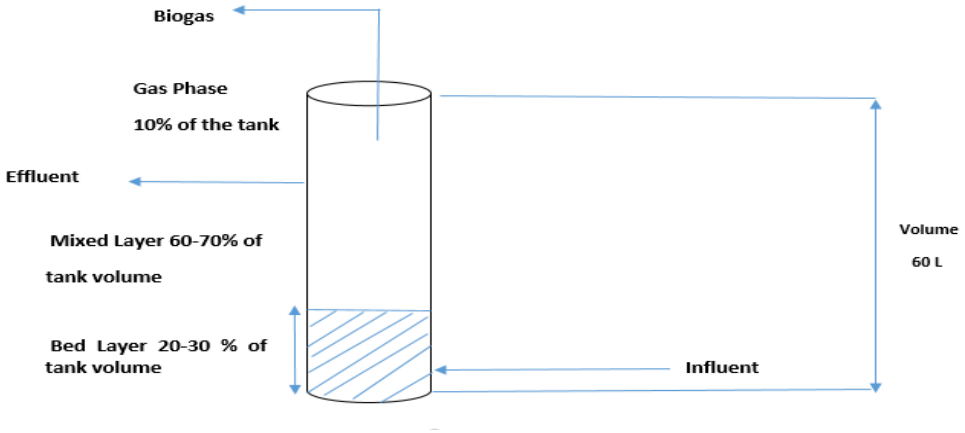


Figure 1: Cross section of an Induced Bed Reactor

- **Benefits to the State:**

  These results will generate a number of benefits for the state of Utah including the following:
  - Open up new markets for food and other organic wastes
  - Expand generation and use of renewable energy
  - Reduce organic waste quantities through recycling activities
  - Develop new energy production for Utah's water reclamation facilities
  - Transfer of IBR technology to Utah's' water reclamation facilities
  - Develop a computer model (ADM1) that can be used accurately in full-scale simulations

- **Geographic Areas:**

  Study Area: Weber County, Utah
  Areas Benefited: The State of Utah

- **Accomplishments:**

  Findings/Results: The results of this study show that co-digestion of (BW) and (MS) using IBR is possible and has great potential to allow wastewater treatment plants to reduce their need for external fossil fuels and safely remove BW pollutants. Results of this study will be published in the Journal of Environment and Pollution, October 2016.

Work Plan FY16/FY17

The Utah State University team will continue to work in close collaboration with the technical staff at the Central Weber Sewer Improvement District and the State Department of Water Quality in the next phase of this project. The technical work for this fiscal year will focus on the following five tasks:

1. Study the feasibility of using the techniques of the IBR in full-scale applications at Central Weber Sewer Improvement District to enhance the production of methane gas.
2. Increase the organic loading rate to determine upper limits to co-digestion using IBR.
3. Develop best management practices for the collection, transport, and management of food wastes by the facility.
4. Test the accuracy of the ADM1 model when used for full-scale applications at Central Weber Sewer Improvement District.
5. Study the possibility of producing hydrogen gas from the co-digestion of MS with BW at the facility.

Informational Resources

Contact: Dr. Michael J. McFarland, PE, BCEE; Telephone: (435) 994-0905, Email: farlandm1@outlook.com.

Publication:

Demitry, M., Hansen, C., Stevens, D., and McFarland, M. (2016). *Extending the Applications of the ADM1 to Predict Performance of the Induced Bed Reactor (IBR) Co-Digesting Municipal Sludge with Bakery Waste*. Vol 2, 2016.

Low Level Hexavalent Chromium (Cr-6) in Drinking Water

Principal Investigators:
Laurie S. McNeill
Joan E. McLean
Nate Rogers (Graduate student)
Adam Jones, Kailey Jorgensen,
Katie Henderson (Undergraduate students)

Partners/Collaborators:

- ***Local**: Salt Lake City Public Utilities*
  Logan City
  Park City

Project Description

- **Need and Purpose:**

  In December 2010, the Environmental Working Group (EWG) issued a public report about hexavalent chromium (Cr6) occurrence at very low levels in US drinking water sources. In that report, Salt Lake City, UT, was targeted as a system of concern due to a detection of 0.3 parts per billion (ppb) of Cr6, which was the 11th highest level of the 35 cities tested. SLC easily complies with the current Maximum Contaminant Level (MCL) for Total Cr, which includes both trivalent chromium-3 (Cr3, a trace nutrient) and hexavalent chromium (Cr6, a likely human carcinogen). Nevertheless, this report generated a lot of concern within the SLC Department of Public Utilities, other drinking water systems in Utah, and the public they serve. The US Environmental Protection Agency (USEPA) is currently reviewing toxicology data for Cr6, and may establish a new MCL specifically for Cr6. A new federal MCL for Cr6 is likely to be substantially lower than the current MCL for Total Cr, which will have an enormous impact on drinking water systems across the US. The State of California recently established their own MCL for Cr6 at 10 ppb.

  In order for drinking water utilities to understand the chromium chemistry within their water and comply with a Cr6 MCL, they must be able to measure Cr6 at those low levels. A second issue is that with these very low levels of Cr6 being of concern, any Cr6 that leaches from water plant infrastructure or is added as a trace contaminant within treatment chemicals may now produce a significant level of contamination, causing utilities to potentially exceed the MCL, even if there is no Cr6 contamination in their source water. Any Cr3 present can also be oxidized to Cr6 by chemical disinfectants present in water distribution systems.

- **Benefits to the State:**

  If USEPA sets an MCL for Cr6, every public water system in Utah must comply. This project has provided a thorough evaluation of preservation and analysis techniques for Cr6 and the oxidation kinetics of chromium by common treatment chemicals. Several UT treatment plants will be sampled to determine the sources of chromium to drinking water and possible treatment techniques for removing Cr6. This will help water utilities understand sources and behavior of Cr6 and evaluate the best way to comply with regulations related to chromium.

- **Geographic Areas:**

  Study Area: Salt Lake City (Salt Lake County), Logan (Cache County), Park City (Summit County).

  Areas Benefited: All drinking water treatment utilities in the State of Utah.

- **Accomplishments**:

  Findings/Results: Bench-scale testing investigated the oxidation of harmless Cr3 into the potentially-carcinogenic Cr6 by two commonly used treatment chemicals: chlorine dioxide (Figure 1) and potassium permanganate (Figure 2). Results indicate that both chemicals are strong enough to oxidize Cr3 to Cr6 within a water treatment plant. Measured data points were modeled by a first order kinetics model.

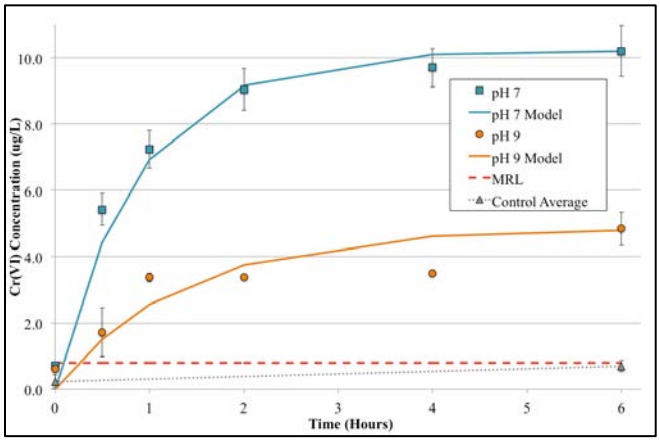


Figure 1. Effect of 0.8 mg/L chlorine dioxide. Initial conditions: Cr3 = 10 ppb, temperature = 16C. Error bars represent standard deviation of triplicate experiments. Nearly complete oxidation to Cr6 is observed within 4 hours at pH 7 but less oxidation is observed at pH 9.

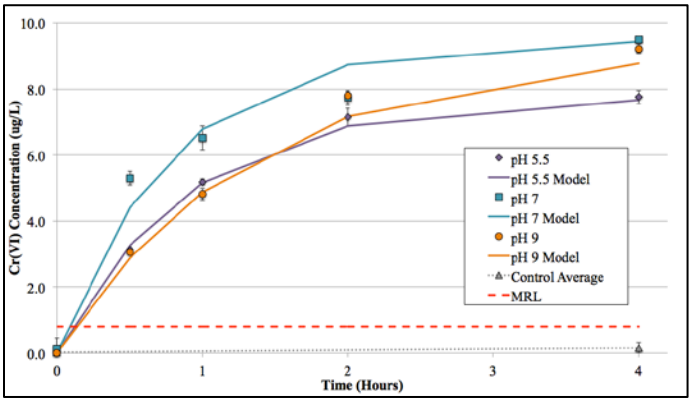


Figure 2. Effect of 1 mg/L potassium permanganate. Initial conditions: Cr3 = 10 ppb, temperature = 16C. Essentially all Cr3 is oxidized to Cr6 within 4 hours. Error bars represent standard deviation of triplicate experiments

Work Plan FY16/FY17

Collect additional samples from water treatment plants across UT to look at sources and treatment of Cr6, with a focus on systems that use different oxidants.

Informational Resources

Contact: Dr. Laurie S. McNeill, Telephone : (435) 797-1522, Email: Laurie.McNeill@usu.edu.
Ms. Joan E. McLean, Telephone: (435) 797-3663, Email: Joan.McLean@usu.edu.

Publications: Results from this project were presented at the American Water Works Association's Water Quality Technology Conference in Salt Lake City in November 2015 and will be published in a forthcoming peer-reviewed journal article.

Managing Drinking Water Quality in Park City

Principal Investigators:
Laurie S. McNeill
Joan E. McLean
David K. Stevens
William Kent, Tiana Hammer, Erin Andersen
(Graduate students)

Partners/Collaborators:

- ***Local**: Park City, UT*
- ***National**: Water Research Foundation*
- ***Business/Industry**: Confluence Engineering*

Project Description

- **Need and Purpose:**

  Park City is one of Utah's most famous cities due to its ski resorts and the Sundance Film Festival. It was named "The Best Town in America" by *Outside* magazine in 2013. However, Park City is also becoming infamous due to its drinking water quality. In 2007 and 2010, Park City experienced adverse water quality events with discolored water and high levels of arsenic, thallium, manganese, iron, and mercury in their water distribution system. Park City has an incredibly complex water system, with various sources (including groundwater, surface water, and water passing through old mine tunnels), several treatment plants, unique water demand patterns, and a complicated water distribution system with more than 50 pressure zones.

  The goal of this project is to assess the causes of these adverse water quality events, evaluate monitoring techniques that can be used to predict future events, and recommend strategies to prevent contaminant release. Tasks include the following:

  1. Evaluate historic water quality data as a preliminary assessment of causes of water quality events. Park City's current data management practices will also be assessed.
  2. Evaluate techniques to minimize deposition and/or subsequent release of corrosion scale, sediments, and biofilms in the distribution system. This will include sampling at water sources and in the distribution system, as well as bench-scale experiments.
  3. Develop a monitoring strategy for the Park City water system, along with tools to manage and interpret collected data. The ultimate goal is to produce a guidance document to help the water utility respond to changes in their distribution system and avoid adverse water quality events.

- **Benefits to the State:**

  This project will help Park City manage their complex water system to provide high quality water to their citizens and visitors. The understanding gained about chemical and biological processes in the water distribution system, as well as strategies developed for real-time monitoring and assessment of these systems, will be applicable to many other water utilities in Utah and across the US.

- **Geographic Areas:**

  Study Area: Park City (Summit County).

  Areas Benefited: All drinking water treatment utilities in the State of Utah.

- **Accomplishments**:

  Findings/Results: Analysis of more than 1,000 monitoring samples showed that despite PCMC's known inventory of legacy pipe deposits, the distribution system is under good control. Only 22 metal releases (defined as measured bulk water metal concentration ≥ 100% of background concentration) were identified during the year-long monitoring program. Of the 22 metal releases, 15 were in suspended form while seven were soluble. Eleven of the suspended releases were associated with Fe and/or Mn release, indicating metal co-occurrence with these substrate metals. Of the seven soluble releases, all were associated with one or more shifts in water chemistry. Soluble thallium release was correlated with a drop in chlorine residual below 0.2 mg/L. Thallium was also shown to be highly mobile in laboratory-scale desorption and biofilm experiments, and significant suspended thallium was observed during a hydrant flushing trial (Figure 1).

Work Plan FY16/FY17

Conduct additional lab experiments to investigate the role of sorption/desorption on release of thallium and other metals from distribution solids.

Informational Resources

Contact:

Dr. Laurie S. McNeill, Telephone : (435) 797-1522,
Email: Laurie.McNeill@usu.edu.

Ms. Joan E. McLean,Telephone: (435) 797-3663,
Email: Joan.McLean@usu.edu.

Dr. David K. Stevens, Telephone: (435) 797-3229,
Email: David.Stevens@usu.edu.

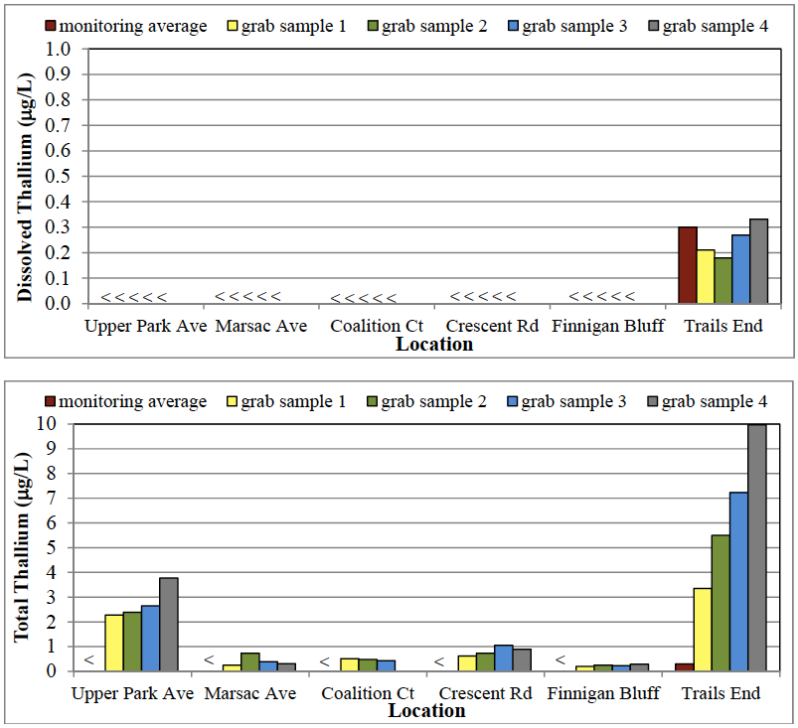


Figure 1. Total and dissolved thallium in grab samples during a hydrant flushing event. "<" = below the minimum reporting level of 0.2 ug/L. The MCL for thallium in drinking water is 2 ug/L

Publications:

This project was the focus of an entire special session at the American Water Works Association's Water Quality Technology Conference in Salt Lake City in Nov 2015.

A report is available from the Water Research Foundation: www.waterrf.org/Pages/Projects.aspx?PID=4509. Results will also be published in multiple peer-reviewed journal articles.

Mitigation of Methane Emissions from Septic Systems

Principal Investigators:
Judith L. Sims
Charles Miller
Ronald C. Sims
Alan Hodges (Student)
Celeste Hancock (Student)
Jason Peterson (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.

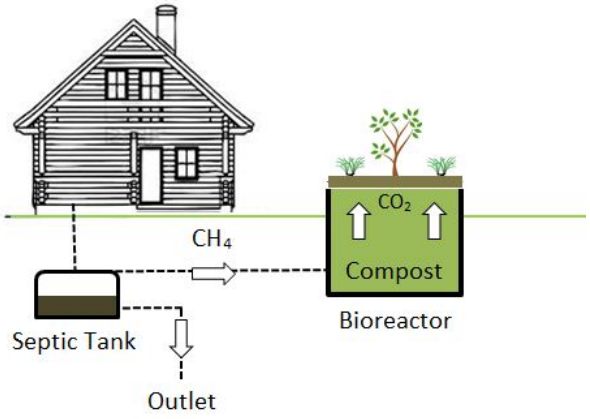


Figure 1. A schematic showing the process of mitigating methane at a local residence

  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.

  A project funded by the Water Environment Research Foundation (*Evaluation of Greenhouse Gas Emissions from Septic Systems*, 2010) concluded that study is needed to develop technologies for the control of GHG emissions from on-site wastewater systems. In this project we are investigating the potential effectiveness of mitigating the impacts of methane produced in septic tanks by collecting the methane and treating it in a compost biofilter system where the methane can be converted to carbon dioxide, which can then 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.

Figure 2. Bench Scale System

- **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.

- **Accomplishments:**

Findings: After preliminary methane degradation feasibility was observed, in FY15/16 we focused on developing a model of temperature effects on methane degradation. Bench-scale, batch-operated (Figure 2) systems were temperature controlled and the effect of temperature on methane degradation was measured. These data were then used to create an Arrhenius rate correction for temperature change (Figure 3). Additionally, a commercially sized septic system was identified to explore the feasibility of applying a compost biofiltration system for the reduction of methane at high methane loadings.

Results: Methane removal was observed in both continuous flow and batch operated reactors. Continuously fed reactors showed an average methane removal rate of 142 g CH_4 m^{-3} d^{-1}. A predictive model for methane reduction in Logan City was developed (Figure 4) that will be tested with field scale monitoring in FY16/17.

Work Plan FY16/FY17

The work plan for FY16/17 will focus on two objectives. The first objective will be testing the temperature based methane reduction model developed in FY15/16 in the field. Field scale biofilters will be built and monitored for methane removal and ambient temperature at both a residential and commercial septic system. The second objective will use metagenomic analysis to determine the change in methanotroph populations through time while under methane-enriched conditions.

Informational Resources

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

Conference Poster Presentation:

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

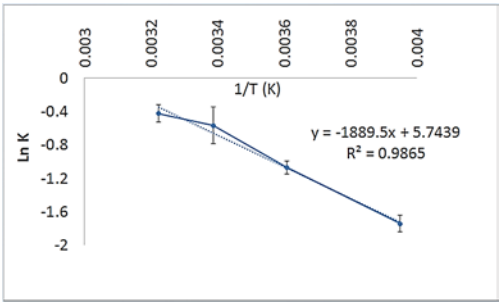


Figure 3. Arrhenius Plot for temperature correction of methane removal rate

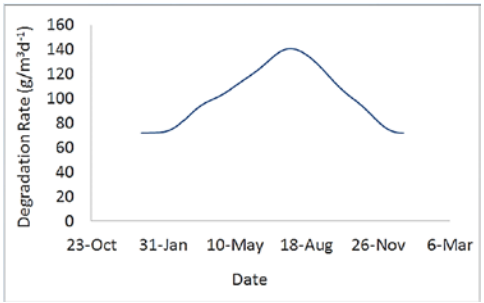


Figure 4. Logan City compost based methane removal model

Solar Disinfection of Drinking Water by Point-of-Use Inactivation of Intestinal Pathogens

Principal Investigators:
David K. Stevens
Darwin L. Sorensen
Maryana Azmi (Student)

Partners/Collaborators:
- *None*

Project Description

- **Need and Purpose:**

  This study is furthering the development of simple point-of-use methods of solar disinfection to decontaminate household drinking water sources. The project is developing and assessing low cost methods of water disinfection for use in low income urban households without access to treated drinking water and for emergency situations in which municipal water treatment systems have been compromised (e.g. in Trenton, UT, in 2014 where water supply springs were found to be in direct contact with surface water contaminated by harmful bacteria). One large-scale example of the need for this technology is the approximately 2 million or so persons using untreated water from the Nile River near Khartoum, Sudan, for culinary purposes.

- **Benefits to the State:**

  Specific benefits to the State of Utah from the point-of-use disinfection process include:

  - Guidance for using point-of-use emergency water treatment systems when municipal water systems are compromised, e.g., after an earthquake or other natural disaster.
  - Preliminary data collection regarding use of solar radiation, abundant in Utah, as a primary disinfectant alternative to chlorine, ozone, or mechanical ultraviolet disinfection systems.
  - Information concerning the effect of solar radiation on the disease-causing protozoans cryptosporidium parvum and giardia that are common in Utah water supplies.

- **Geographic Areas:**

  Study Area: This project is being carried out in Logan, UT, Cache County.

  Areas Benefited: Statewide.

- **Accomplishments**:

  Findings/Results: The following project elements have been completed:

  - A review of the literature.
  - Development of procedures.
  - Identification of specific organisms to be used for the assessment.

  Experiments began in FY15/FY16 and will continue through the end of 2016. The first phase studied the impact of POU filtration on turbidity removal. It was found to be effective in reducing high turbidity levels to near U.S. drinking water standards. The second phase, the impact of filtration and solar disinfection on

microbial concentrations is currently underway. It is being carried out in collaboration with the USU Animal Sciences Laboratory.

Work Plan FY16/FY17

The major outcome of the project will be a modern database for managing information relating to the combined point-of-use filtration/solar disinfection system. Results will be integrated with previous studies. The final results of the project will be presented at the USU Spring Runoff conference and, potentially, at annual Intermountain AWWA or AWRA chapter conferences.

Informational Resources

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

Treatment of Wastewater Algae for Bioenergy

Principal Investigators:
Ronald C. Sims
Charles Miller
Anna Doloman (PhD student)
Jason Peterson (MS student)
Zack Fica (MS Srtudent)
Michael Flores (BS student)

Partners/Collaborators:

- ***Local:*** *Dr. Jong-Su Eun, Cain Dairy, Utah State University*
- ***Business/Industry:*** *WesTech_Inc, SLC*

Project Description

Figure 1. Rotating Algae Biofilm reactor at the Caine Dairy Farm using biofilm algae for wastewater treatment and bioenergy recovery through anaerobic digestion of algae biomass

- **Need and Purpose:**

  The USU Caine Dairy Center cannot apply water from the waste treatment lagoons to the land because of the high concentrations of nutrients. Hence, this project is evaluating the use of algae to take up nutrients from dairy wastewater and the transformation of the algae into biogas energy. Dairy wastewater cultivated algae represents a promising substrate for bioenergy production that can be used as a source of combined heat and power (CHP) for the dairy industry. This project uses anaerobic treatment for the transformation of algae cultivated on dairy wastewater into methane. Algae was cultivated on dairy wastewater at the USU Caine Dairy in the form of a biofilm that could be alternately exposed to the wastewater and then to the sunlight. While algae do not normally grow in turbid and colored wastewater due to lack of light penetration, this approach treats the turbid and colored wastewater with microalgae. The harvested microalgae are then used in anaerobic systems to produce bioenergy as methane. The anaerobic digester shown in Figure 1 is available and can be used for transforming algae into biogas.

- **Benefits to the State:**

  Alternative energy sources based on local treatment system wastewaters provide a path from waste to valuable biofuels and result in greater energy independence and a positive economic impact for rural communities in Utah. Utilizing microalgae that are cultivated as a biofilm in turbid and colored wastewater to remediate the nutrients provides an important path to producing bioenergy from wastewater treatment products in the State.

- **Geographic Areas:**

  Study Area: Areas in rural Utah treating animal waste in open ponds and lagoons. Such wastes may be derived from dairy, cattle, swine, poultry, and aquaculture (fish) industries.

  Areas Benefited: All areas of the state of Utah, especially rural agricultural communities where wastes can be utilized as sources of nutrients to grow algae, which can then be transformed into bioenergy for heat and power. Animal waste managers often face a challenge in dealing with nonpoint source runoff. Farm and industrial use of the rotating algae biofilm reactor (RABR) technology provides a way to both treat the waste and recovery bioenergy for their use.

- **Accomplishments:**

  Findings: The algae biomass was cultivated on dairy wastewater at temperatures ranging from 7–27 ºC, representing the seasonal changes in North Utah, and concentrations ranging from 200-1,200 mg/L of Total Organic Carbon, representing a range of dairy wastewater strengths. Biofilm growth rates were a direct function of the temperature. Statistical analysis of the results indicated that both temperature and organic carbon concentration significantly affected the rate of microalgae biomass growth. Quantitative relationships developed in this project can be used for the design of treatment and bioenergy recovery systems for other animal waste sites.

  Bioenergy in the form of methane was successfully produced in anaerobic bioreactors at laboratory scale using algae that was cultivated on the dairy wastewater. When harvested, biofilm microalgae were augmented with an inoculum of algalytic microbes from the sediments in the Logan Lagoons wastewater treatment plant. The methane content was 80–90% of the total biogas. These results indicate a significant energy level in the biogas compared to conventional anaerobic digestion (only 50% methane production). Anaerobic treatment also reduced the concentration of organic chemicals in the wastewater, as well as nitrogen, phosphorus, and other nutrients. Figure 1 shows the 1,000-gallon pilot bioreactor that is available for testing the system at larger scale.

  Results: Treatment of dairy wastewater was successful using the novel bioreactor (RABR), in which the nutrients are taken up into microalgae grown as a biofilm. The waste-cultivated algae were used as a feedstock for anaerobic bioreactors to recover energy in the form of methane gas.

Work Plan FY16/FY17

We will expand the scale of the wastewater treatment system and the anaerobic digestion of microalgae for bioenergy recovery. We will also evaluate the quality of the protein extracted from the harvested microalgae as a possible source of feed for the dairy cows. We will also optimize the process and utilize algae that are cultivated on agricultural wastes to test bioenergy production.

Informational Resources

Contact: Dr. Jong-Su Eun, College of Agriculture, Telephone: (435) 797-2497, E-mail: jseun@usu.edu.
Mr. Floyd Griffiths, WesTech-Inc., Salt Lake City, Industry partner.
Dr. Ronald C Sims, Telephone: (435) 797-3156, E-mail: ron.sims@usu.edu.

Publications:

Fica, Z. and Sims, R.C. (2016). Algae-Based Biofilm Productivity and Treatment of Dairy Wastewater. 2016. Under peer review by the *Journal of Biological Engineering*.

Fica, Z. and Sims, R.C. (2016). Effects of Temperature and Organic Carbon Concentration on Algae-Based Biofilm Biomass Productivity and Treatment of Dairy Wastewater. *Presentation at the Institute of Biological Engineering Annual Meeting*, South Carolina, March.

Peterson, J. (2016). *Anaerobic Digestion of Wastewater for Treatment and Bioenergy Recovery*. M.S. Thesis. Biological Engineering Department, Utah State University.

Wastewater Operator Certification Council

Principal Investigators:
Michael J. McFarland

Partners/Collaborators:

- ***Local:*** *North Davis County Sewer District, Central David County Sewer District, Salt Lake Water Reclamation Facility, Kearns Improvement District, Central Valley Water Reclamation, South Valley Water Reclamation Facility, Timpanogos Special Services District, Orem Metropolitan Water District, Snyderville Basin Water Reclamation District*

Project Description

- **Need and Purpose:**

  The goal of the Wastewater Operator Certification Council (The Council) is to provide environmental stewardship, financial integrity, safety, and quality service to benefit the environment, residents, businesses, and employees of the State of Utah. The Council comprises representatives from various water reclamation facilities within the State of Utah as well as equipment vendors, university researchers, and environmental regulators.

- **Benefits to the State:**

  The Council is dedicated to the professional growth of its members and the preservation and enhancement of the water environment in the State of Utah. The Council specifically benefits the state by facilitating:

  1. Opportunities for interaction and professional growth of WEAU members.
  2. Greater understanding of the value of water quality and water resources to Utah citizens.
  3. Educational information for State of Utah law makers to form environmental policy.
  4. Alliances and information exchange with State of Utah residents.
  5. A focus on diverse water quality issues within the State.

- **Geographic Areas:**

  Study Area: State of Utah.

  Areas Benefited: State of Utah.

- **Accomplishments:**

  Findings/Results: The PI attended all regularly scheduled Council meetings throughout FY15/FY16 and provided review and comment on all items relevant to his area of expertise. The PI also proctored semi-annual certification exams.

Figure 1. Anaerobic Digesters - Central Valley Wastewater Treatment Plant – Salt Lake City, Utah

Work Plan FY16/FY17

Continued involvement in decision-making through attendance at quarterly Council Meetings. Continued proctoring of semi-annual wastewater operator certification exams.

Informational Resources

Contact: Dr. Michael J. McFarland, PE, BCEE; 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	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
Biogeochemistry in TCE Contaminated Aquifers in Northern Utah	$ 118,619.65	$ 27,000.00	$ 27,810.00
Cache Valley's Pollutant Profiles and Application to Additional Areas in Utah	$ 25,865.94	$ 15,150.00	$ 15,604.50
Impact of Biochar additions to Soil on Contaminant Mobility and Fate for Groundwater Protection	$ 44,656.08	$ 6,500.00	$ 6,695.00
Impact of Metals and Metal Ions on Soils and Plants	$ 27,841.66	$ 28,676.91	$ 29,537.22
Nitrogen Cycling, Oxygen Demand, and Nitrate Reduction to Ammonia in Silver Creek, Below a Water Reclamation Facility	$ 72,407.63	$ 23,000.00	$ 23,690.00
Pharmaceuticals and Personal Care Products (PPCPs) in the Sediments, Organisms and Plants in East Canyon Creek, Utah	$ 62,124.47	$ 16,000.00	$ 16,480.00
Phytoremediation Evaluation Site for Quantifying the Fate of Trichloroethylene (TCE) Taken Up by Trees	$ 16,615.44	$ 17,113.90	$ 17,627.32
Real-Time Polymerase Chain Reaction (RT-PCR) Instrumentation	$ 22,866.47	$ 23,552.46	$ 24,259.04
Using Duckweed as a Treatment Technology for Nutrients and Pharmaceutical Contaminants in Municipal Wastewater Systems	$ 73,984.29	$ 40,000.00	$ 41,200.00
Vehicle Cold Start and Hot Start Emissions	$ 61,287.68	$ 63,126.31	$ 65,020.10
Designated Projects		$ 14,000.00	$ 17,000.00
Undesignated Projects		$ 15,000.00	$ 5,000.00
Total	**$ 526,269.31**	**$ 289,119.59**	**$ 289,923.18**

Biogeochemistry in TCE Contaminated Aquifers in Northern Utah

Principal Investigators:
Joan E. McLean
R. Ryan Dupont
Darwin L. Sorensen
Babur Mirza (Research biologist))
Sarah Kissel (MS student)

Partners/Collaborators:

- ***Federal:*** *Hill AFB*

Project Description

- **Need and Purpose:**

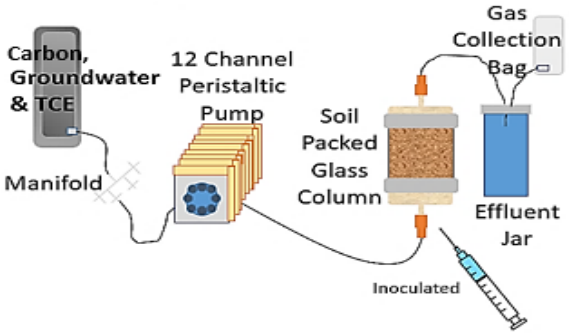


Figure 1. Set-up of small column study for testing sequential microbial processing of TCE under different conditions of biostimulation

Trichloroethene (TCE), a widely used industrial solvent, is frequently encountered as an environmental contaminant and a potential carcinogen. TCE is denser than water and very slow to degrade, especially in oxygenated aquifer environments where labile organic matter concentrations are low. Extensive areas of groundwater contamination exist in the industrialized world and in Utah. TCE contaminates aquifers at Hill Air Force Base (AFB), Dugway Proving Ground (DPG), and other industrial sites along the Wasatch Front. Both private and Department of Defense industrial complexes are required to remediate this contamination.

Biostimulation remediation of TCE includes adding organic materials to the aquifer. Microbial respiration removes oxygen from the aquifer and creates a reducing biogeochemical environment. Bacteria able to use TCE as a respiratory electron acceptor (dechlororespiration) in this environment may reduce TCE to less chlorinated compounds. The desired, completely dechlorinated product is ethene, a common non-toxic gas. This research studied biostimulation of contaminated aquifer material from Hill AFB in microcosms with no observed dechlororespiration. Column (15 x 200 cm) studies conducted over a period of 7.5 years with the same aquifer material showed complete dehalogenation or partial dehalogenation to cis-dichloroethene depending on the type of organic carbon added. Some investigators have suggested that complete dechlororespiration in biostimulated aquifers is ubiquitous, but the microbial ecology and biogeochemistry for dechlororespiration remains incompletely described, so successful engineering of biostimulation treatment technologies is tenuous.

To understand the sequence of processes that occur in the large columns over time, small columns (7.6 cm x 7.6 cm) were assembled with the same aquifer material used previously. The Columns were treated with either whey or lactate as the carbon source Then, the columns were analyzed at specified times to observe biogeochemical and microbial progression leading to complete dechlorination as compared to a no carbon control.

- **Benefits to the State:**

All counties in Utah would benefit from improved understanding and the development of remediation strategies for dechlorination of TCE and other chlorinated solvents that contaminate groundwater resources.

- **Geographic Areas:**

  Study Area: Hill Air Force Base, Davis County, and Weber County.

  Areas Benefited: In addition to the specific areas noted above, this project will contribute to groundwater protection throughout the state.

- **Accomplishments:**
  Findings/Results: The aquifer solids collected from Hill Air Force Base were packed into small glass columns (7.6 cm diameter and 7.6 cm in height) (Figure 1) and were fed with TCE containing groundwater from the site. The treatments included whey and lactate. Columns with no added carbon were used as a control. All columns were bioaugmented with a culture containing known dechlorinating bacteria. One set of columns (in triplicate) was sacrificed for analysis when the effluent from the columns displayed conditions defining (1) iron reduction, (2) dechlorination to cis-DCE, (3) dechlorination to vinyl chloride, and (4) production of ethene.

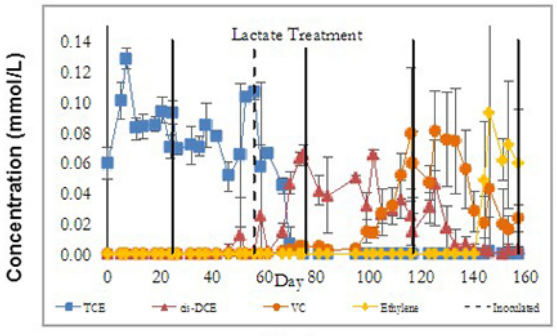


Figure 2. TCE dehalogenation in the Lactate amended column

The aquifer solids and the pore water were analyzed for TCE degradation products, water quality, and geochemical properties. Each carbon source produced reducing conditions and complete reductive dechlorination was observed in both biostimulated treatments by day 160 (Figure 2). The lactate biostimulated columns showed the accumulation of VC from day 100 to 140 (Figure 2); whereas, in the whey amended columns, VC accumulation was non-significant and systems progressed from *cis*-DCE to ethene production. Overall, three distinctive microbial communities were developed, one for each treatment (Figure 3). Within the control columns, the microbial community did not vary over time. In the biostimulated treatments the microbial community evolved from one sacrifice point to another as the system progressed from partial to complete TCE dehalogenation stages. Among the different bacterial phyla *Firmicutes* were the most abundant bacterial group in the whey treated columns containing up to 70% of total sequences. In the lactate amended columns, the abundance of *Proteobacteria* related sequences was significantly higher as compared to the whey amended columns. This research has resulted in one published paper and one paper submitted for review.

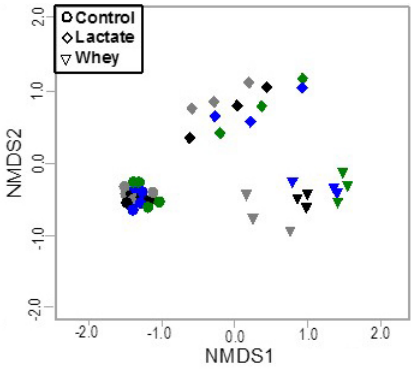


Figure 3. Bacterial community composition across different treatments over a period of 160 Days. Color represents the column sacrifice time; grey (first sacrifice), black (2nd sacrifice), blue (3rd sacrifice), green (4th sacrifice)

Work Plan FY16/FY17

Sediments samples from these small columns will be sequenced using Illumina paired end sequencing and analyzed for the 16S rRNA both from general bacteria and *Dehaloccoides*. We are also developing a NSF proposal to get additional funds for RNA based studies.

Informational Resources

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

Cache Valley's Pollutant Profiles and Application to Additional Areas in Utah

Principal Investigators:
Dr. Randal S. Martin

Partners/Collaborators:

- ***Local:*** *Utah State University*
- ***State:*** *Utah Division of Air Quality (UDAQ), Air Monitoring Center (AMC), University of Utah, Weber State University, Brigham Young University*

Project Description:

- **Need and Purpose:**

  The more densely populated areas in Utah, including most of the Wasatch Front and Cache Valley, are known to violate winter-time standards for $PM_{2.5}$ (Particulate Matter), which is a serious, well-known threat to human health. These regions in Utah have been categorized by the USEPA as $PM_{2.5}$ "non-attainment" areas since 2009. Furthermore, it is anticipated that the Cache Valley will be re-designated as "serious non-attainment" area. This means that more stringent controls and remediation scenarios will have to be implemented. In order to address some of the uncertainties in the particle precursor sources and the $PM_{2.5}$ formation behaviors, additional research is needed. Specifically, temporal chemical composition of $PM_{2.5}$ collected during inversion events along the Wasatch Front and the distribution of available gas-phase ammonia (NH_3) needs to be determined.

- **Benefits to the State:**

  Understanding the composition of $PM_{2.5}$ and its temporal changes will contribute to improved modeling of the current $PM_{2.5}$ behaviors and understanding the effectiveness of implementing remediation proposals and strategies. Additionally, since this and other studies have shown that gas-phase NH_3 is an integral part of the $PM_{2.5}$ formation process, knowing the abundance and distribution of NH_3 along the Wasatch Front and in Cache Valley can give local scientists, modelers, and regulators tools to directly benefit the affected populations.

- **Geographic Areas:**

  Study Areas: During the winter of 2016 (and late 2015), $PM_{2.5}$ samples were collected in the Salt Lake Valley (on the campus of the University of Utah at the William B. Brown building) and arrayed networks of NH_3 samplers were deployed along the Wasatch Front and in Cache Valley.

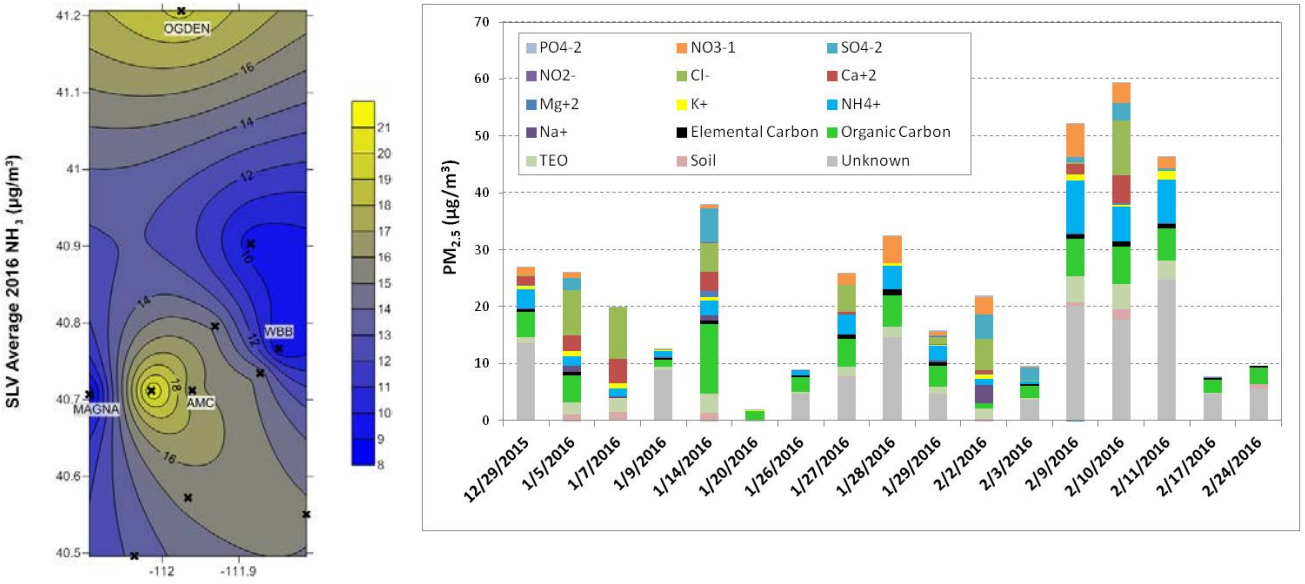
  Areas Benefited: This year's studies directly examined areas along the Wasatch Front and the Cache Valley. However, the methodologies employed by this project are directly applicable to other state regions with air pollutant issues.

- **Accomplishments:**

  Findings: A diverse team of university scientists, engineers, and agency personnel, from Utah State University, University of Utah, Brigham Young University, Weber State University, and the Utah Division of Air Quality worked cooperatively to successfully complete this year's work. Aside from its scientific findings, this study presented the first major opportunity to develop collaborative air pollutant studies among the major Utah academic institutions.

Results: The figure below on the left shows the average NH_3 concentrations measured across the Wasatch Front (Ogden to South Jordon) for the 2016 winter season. The average concentration was 14.2 µg/m^3. In comparison, the Cache Valley's average observed NH_3 concentration was around 107 µg/m^3. This reflects the abundance of agricultural sources and limited atmospheric mixing volume due to the valley topography. In both regions, the gas-phase NH_3 was found to be in excess of that balanced by the nitrate component for $PM_{2.5}$ formation. This indicates that NH_3 control would have minimal effect on ultimate $PM_{2.5}$ formation. These NH_3 studies have been presented at two nationally-recognized professional conventions.

The figure below on the right shows the variability and temporal changes of the $PM_{2.5}$ chemical speciation as measured at the University of Utah sampling location. Additional analysis is still in progress in order to assess the "unknown" components during the late February events. We suspect that these are related to evaporative losses, most likely of ammonium nitrate type compounds.



Work Plan FY16/FY17

The work for FY15/FY16, supported by Mineral Lease and additional funding sources, has provided the Utah Division of Air Quality with data relevant to addressing northern Utah $PM_{2.5}$ issues. These studies have led to the planning and implementation of an additional study for the winter of 2017. This work will involve most of the same Utah investigators, and also include other scientists from NOAA, the EPA, and out-of-state universities. A key component of the new study will be manned-flights to collect of atmospheric air quality samples (both vertical and horizontal profiles) over the region stretching from Provo to Cache Valley and above the Great Salt Lake.

Informational Resources

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

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

Principal Investigator:
William J. Doucette
Jeff Flashinski (Student)

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

Project Description

- **Need and Purpose:**

  Biochar refers to the solid residue remaining after the pyrolytic decomposition (i.e., heating under a limited supply of oxygen) of biomass materials. It is often a byproduct formed during the production of bio-oil and syngas. Potential feedstocks include low-value forest and crop residues.

  Because of its long-term stability, biochar has the potential to be used for carbon sequestration applications. Its sorptive properties have also made it a candidate as a source of soil fertility improvement and moisture holding capacity, as a type of "filter" for contaminant removal, and as a soil amendment for bioavailability and leachability reduction.

  The Utah Biomass Resources Group (UBRG) is trying to help build a sustainable biomass utilization industry in Utah. The development of woody biomass for energy would help Utah develop a local renewable source of energy and potentially reduce the cost of many forest management projects. Using woody biomass for energy can substantially reduce open burning and air pollution.

  The focus of this project is to investigate the potential use of biochar as a soil amendment to improve plant growth conditions while limiting contaminant leachability (metals and organics) to groundwater and bioavailability to plants. Potential applications of biochar soil amendments would be in agriculture, mine reclamation, and septic tank effluent drain fields.

- **Benefits to the State:**

  Research showing the successful use of biochar generated from waste biomass as soil amendments would potential benefit the state in a variety of ways including: the minimization of biomass waste associated with forest and agricultural industries, improved reclamation of contaminated mine sites, and enhanced groundwater protection associated with septic tank use.

- **Geographic Areas:**

  Study Area: Logan, Utah (Greenhouse and laboratory facilities).
  Areas Benefited: Biochar is a resource available throughout much of the state and its use as a soil amendment could potentially benefit all counties in the state.

- **Accomplishments**: Experiments conducted with tomato, corn and cabbage are being used to examine the impact of biochar on nutrient and contaminant availability to plants. Plants are grown hydroponically in various soil/biochar mixtures. Depending on the outcome of the plant availability studies, batch and column sorption studies may also be conducted in order to determine whether adding biochar to soils limits contaminant and nutrient leaching into groundwater. Pharmaceutical and personal care products

(PPCPs) such as DEET, diphenhydramine, and tris-(2-chloroethyl) phosphate have been found in the wastewater effluents from treatment plants. With the increased use or reclaimed wastewater for irrigation, it is important, for public health reasons, to know the effect of biochar on these contaminants.

- **Findings:** Hydroponic experiments have been conducted to look at the impact of biochar on nutrient availability to plants.

Work Plan FY16/FY17

Continue plant uptake and sorption studies to examine the impact of biochar amendments on the mobility of nutrients and contaminants.

Informational Resources

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

Greenhouse uptake studies

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)
Paul McManus (Graduate student)
Joshua Hortin (Graduate student)

Partners/Collaborators:
None

Project Description

- **Need and Purpose:**

Figure 1. Wheat plants were grown in sand with and without the addition of CuO NPs

Copper oxide nanoparticles (CuO NPs) are manufactured for use in a variety of applications in medicine, food safety, personal care products, and agriculture. One beneficial use of CuO NPs is as an antimicrobial. The accidental or intentional application of CuO NPs on agricultural crops, such as wheat, however, may lead to adverse effects on plants and beneficial soil microbial ecosystems. Plants need Cu as a micronutrient, but elevated levels of bioavailable Cu is highly toxic to plants and their associated bacteria. This project investigates the bioavailability and toxicity of CuO NPs on wheat. Many factors present either in the soil or produced by the plant roots, such as soil pH, salt content, organic matter content, and Cu complexing ligands, influence the behavior of NPs by altering their surface properties and solubility. This study looks at how properties of agricultural soils in Utah specifically influence the bioavailability of CuO NPs to wheat plants.

- **Benefits to the State:**

  Although the research focuses on CuO NPs, it is also relevant to metal pollution in general. Results will directly benefit the counties in Utah with current metal contamination from abandoned and active hard rock mining and counties planning to expand industrial development by protecting environmental quality and human health as related to metal exposure.

- **Geographic Areas:**

  Study Areas: Counties with abandoned and active mining operations and counties with industrial operation—all counties in Utah.

  Areas Benefited: All counties in Utah.

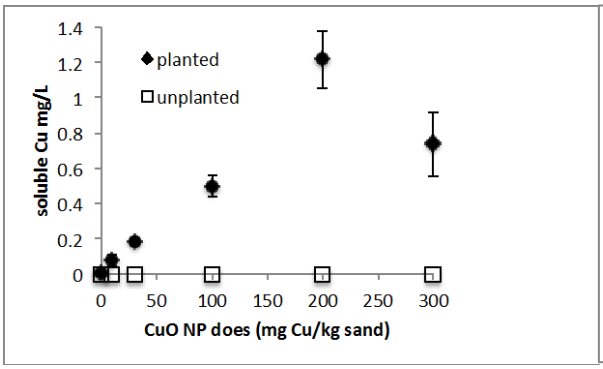


Figure 2. Copper solubility increased with dosing of the CuO NPs in the presence of wheat plants. CuO NPs were insoluble without the plants

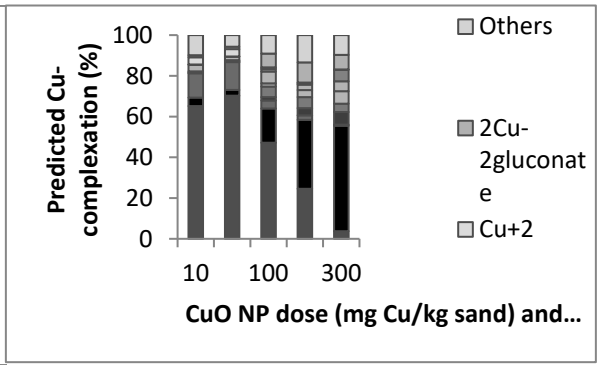


Figure 3. The increased solubility of copper observed in Figure 1 was due to the formation of copper-complexes with citrate, malate and DMA

Accomplishments:

Findings: Copper solubility increased with dosing of CuO NPs in wheat planted systems. The NPs were not soluble in systems without plants. The plants produced exudates that increased the solubility of the NPs.

Results: Wheat plants were grown in sand with and without the addition of CuO NPs for 10 days (Figure 1). At harvesting the sand was extracted with water for the determination of soluble copper and root exudates. The copper concentration in solution increased with increased dosing of the NPs (Figure 2). The NPs were insoluble in systems without plants. Geochemical analysis and modeling showed the increased solubility was due to complexation of copper with the root exudates, including citrate, malate and deoxymugeinic acid (DMA) (Figure 3. Plant roots were damaged by the high doses of NPs (Figure 4). Whether the damage was due to increased uptake of copper-complexes into the plant or a direct effect of the NPs is under investigation.

Work Plan FY16/FY17

We will address the following questions over the next year: What is the influence on dissolution/aggregation of CuO ENPs of phosphate, organic matter, alkalinity, and other soluble components in the soil pore water? Can components of soil pore water and microbial interactions (*Pseudomonas chlororaphis* O6, *PcO6*) protect wheat from the toxicity of CuO ENPs in sand (surrogate for soil), as predicted by the BLM? Is the bioavailability of CuO ENPs decreased by sorption to sand, or increased by sorption to roots?

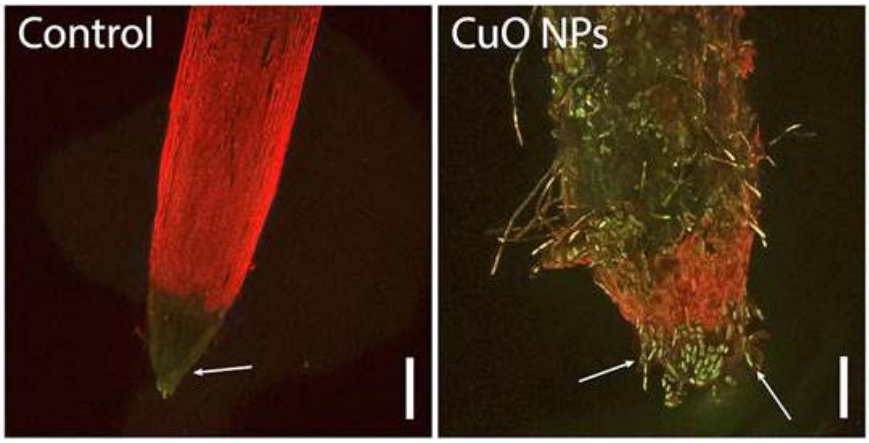


Figure 4. Higher dosing of the CuO NPs led to root damage. Green staining reveals lipid peroxidation (cell membrane damage), red shows healthy membranes

Informational Resources

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

Nitrogen Cycling, Oxygen Demand, and Nitrate Reduction to Ammonia in Silver Creek, Below a Water Reclamation Facility

Principal Investigators:
R. Ryan Dupont
Darwin L. Sorensen
Chelsea Stewardson (MS student)
Jared Richins (MS student)
Makenzie Beltran (MS student)

Partners/Collaborators:
State: *Nicholas von Stackelberg, Environmental Scientist, and Erica Gaddis, Section Manager, Water Quality Management Section, Division of Water Quality, Utah Department of Environmental Quality*

Project Description

- **Need and Purpose:**

On March 16, 2011, the US Environmental Protection Agency launched a "Working Partnership with States to Address Phosphorus and Nitrogen Pollution through Use of a Framework for State Nutrient Reductions." Part of the state framework ensures the effectiveness of point source permits for municipal and industrial wastewater treatment facilities in reducing the impact of nutrients on effluent receiving waters. The Utah Division of Water Quality (UDWQ) has established a nutrient reduction program (http://www.nutrients.utah.gov/). UDWQ is drafting rules for implementing the state's nutrient control strategy. Technology-based limits for total phosphorus are currently being developed, with limits for nitrogen following soon thereafter. Many of Utah's wastewater treatment facilities may need to demonstrate through monitoring and modeling that their effluents will not lead to impairment of receiving waters. Potential negative impacts on streams of nitrogen discharged from treatments plants is a reduction in oxygen due to the nitrification process in which ammonia-nitrogen (NH_4^+-N) is oxidized to nitrate-nitrogen (NO_3^--N). Oxygen is also used up by decomposing plant material in streams that has grown in the nutrient rich wastewater of treatment plant effluents. Dissolved oxygen modeling below the Silver Creek Water Reclamation Facility (SCWRF) indicated an oxygen use that is inconsistent with decomposition of known organic matter loads and nitrification oxygen demand.

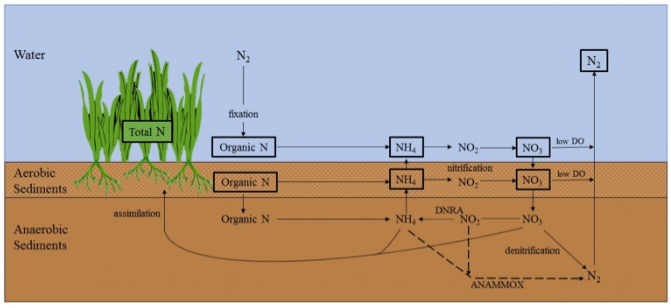


Figure 1. Nitrogen cycle within water, plant, and sediment compartments in streams

Based on observations of relatively high amounts of peat-like decomposing plant material on the bottom of Silver Creek and some high sediment oxygen demand measurements, it appears that nitrate reduction to ammonium (DNRA) and re-nitrification of this stream-generated ammonia (Figure 1) may occur in the sediment and water column of Silver Creek below the SCWRF. These processes could exist in combination with denitrification, nitrogen fixation, and nitrogen assimilation. This project is testing each component of the nitrogen cycle under at least two seasonal conditions (including low-flow, when the effect of the effluent is anticipated to be at a maximum), using in-stream chambers and water quality measurements to determine their impact on observed oxygen depletion. Findings from Silver Creek aided in formulating recommendations to UDWQ regarding modeling and monitoring necessary to accurately determine impacts to Utah streams from nitrogen discharges from wastewater treatment plants.

- **Benefits to the State:**

  As Utah begins regulating nitrogen loading to streams, deeper insights into the in-stream processing of nitrogen from wastewater treatment plants and validated methods to improve the detection of significant nitrogen transformation processes and measurement of nitrogen transformation rates will help set water quality standards and guide the design and operation of wastewater treatment plants in the state.

- **Geographic Areas:**

  Study Area: Park City, Summit County, UT.
  Areas Benefited: All locations in the state with actual or potential nutrient impacted surface water where nitrogen transformation processes and rates are required for development of rational nutrient discharge limits from wastewater treatment plants.

Figure 2. In Situ Benthic Chambers and Piezometers at the Silver Creek Field Site

- **Accomplishments:**

  Findings: Benthic in-situ chamber studies (Figure 2) conducted below the SCWRF treated wastewater effluent discharge point between August 2014 and June 2015 showed that wastewater effluent dominated conditions within Silver Creek over a wide range of seasonal conditions. Piezometers were installed in June 2015 to monitor vertical groundwater flow (Figure 1). Chambers were designed so that isotope (^{15}N) dilution and pairing methods could be used to track the transport and transformation of nitrogen through the system. Sampling procedures were evaluated and modified as needed to quantify the amount of nitrate, ammonium, total nitrogen, and dissolved nitrogen gas within the water, plant, and sediment compartments. A collection of laboratory methods was established and modifications made in order to process the collected field samples.

  Results: Not all nitrogen transformation rates from the benthic chambers could be generated due to loss of spiked nitrogen isotope due to groundwater/surface water exchange at the sampling locations. The study identified chamber design improvements and placement to increase mass recovery during sampling, and revised the field design to optimize data generated from the study. The study found limited denitrification rates that were comparable to rates reported in the literature (Table 1). Results showed that dissolved oxygen variability in Silver Creek is driven by aquatic plant activity and sediment oxygen demand rather than microbial metabolism of carbon and transformation of nitrogen.

Work Plan FY16/FY17

Results of this study are being used to update both field and laboratory transformation rate measurement approaches for Utah streams. These will be implemented in a Utah DWQ-funded follow up study conducted at two additional stream sites impacted by wastewater treatment plant discharges.

Table 1. Denitrification Rate Comparison for Silver Creek

Min. Rate	Max. Rate	^{15}N based	units	Reference	Technique
0.002	1	no	day^{-1}	Bowie et al., 1985	Model
0.05	2	no	day^{-1}	Neilson et al., 2013	Model
0.3	0.41	no	day^{-1}	Silver Creek Non-Labeled Data	Chamber
1.8*		yes	day^{-1}	Silver Creek Chamber 1[1]	Chamber
0.032*		yes	$mg\ L^{-1}\ d^{-1}$	Silver Creek Chamber 1	Chamber
0.012	0.084	yes	$mg\ L^{-1}\ d^{-1}$	O'Brien et al., 2012[2]	Chamber
0.28*		yes	$mg\ L^{-1}\ d^{-1}$	Smith et al., 2009[2]	Chamber

Informational Resources

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

Pharmaceuticals and Personal Care Products (PPCPs) in the Sediments, Organisms and Plants in East Canyon Creek, Utah

Principal Investigator(s):
William J. Doucette
Brad Buswell (Student)

Partners/Collaborators:
- ***Local:*** *Michael Luers, Snyderville Basin Water Reclamation District*

Project Description

- **Need and Purpose:**

  The occurrence of pharmaceuticals and personal care products (PPCPs) in surface waters is a growing concern. In addition to prescription drugs, over-the-counter medications, lotions, fragrances, and soaps, the term PPCPs represents a wide variety of chemicals used in consumer products, including plasticizers and fire retardants. Wastewater effluents have been shown to be a major source of PPCPs in surface waters since most PPCPs are directly or indirectly disposed into domestic sewage systems that are not designed to treat them.

  The Synderville WWTP effluent discharges directly into East Canyon Creek, Utah, and during the late summer, the effluent can be the major component of the total stream flow. Several PPCPs were identified in fish collected from East Canyon Creek, Utah, downstream of the Synderville wastewater treatment plant (WWTP) in November and December 2008 (Baylor University).

  To better evaluate the potential impact of PPCPs originating from the Synderville WWTP, the main objectives of this proposed research are to determine the seasonal variation in PPCP loading to East Canyon creek from the Synderville WWTP and determine the extent of PPCP concentrations in the sediments and aquatic plants downstream from WWTP.

- **Benefits to the State:**

  Results from this study will contribute to our overall understanding of the environmental fate and impact of PPCPs originating from WWTPs. It will also provide important information on the seasonal variability of PPCP loading to the East Canyon Creek. The sediment and plant concentration data will help delineate potential routes of exposure to East Canyon Creek fish. This project will have a direct impact on Utah citizens because WWTPs are located throughout the state. An improved understanding of the fate of PPCP in surface waters by regulatory agencies such as the Utah DEQ will also enable a more efficient expenditure of public funds based on risk management prioritization that will be made possible by this information.

- **Geographic Areas:**

  Study Area: East Canyon Creek, Utah.
  Areas Benefited: PCPPs in wastewater effluents is a statewide issue, so all counties in the state would potentially benefit.

- **Accomplishments**: Water, sediment, and plant samples have been collected from the point where the WWTP discharges into East Canyon Creek and at upstream and downstream locations (Figure 1).

- **Findings:** As shown in Figure 2, several PPCPs were identified in water and sediments samples collected below the WWTP. However, as expected, the extent of sorption to sediments varied between compounds. Additional sediment and plant samples are currently being extracted and analyzed to see if the trends change seasonally.

Work Plan FY16/FY17

Continue additional sampling of water, sediments and plants. Examine the relationship between PPCP concentrations in water; sediment, and plants to better understand the fate of these compounds in effluent dominated rivers.

Informational Resources

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

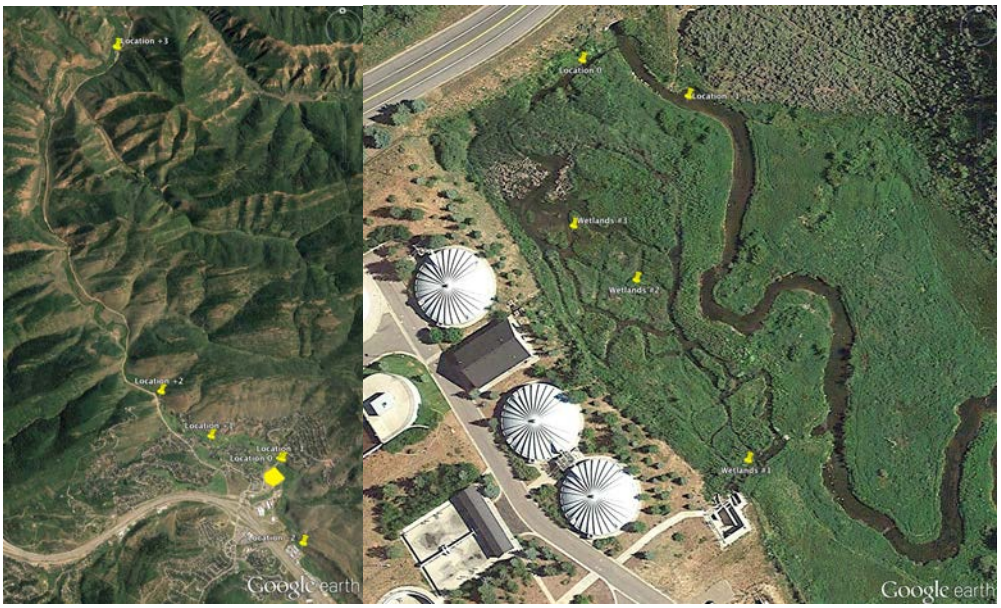


Figure 1. East Canyon Creek, Utah sampling locations

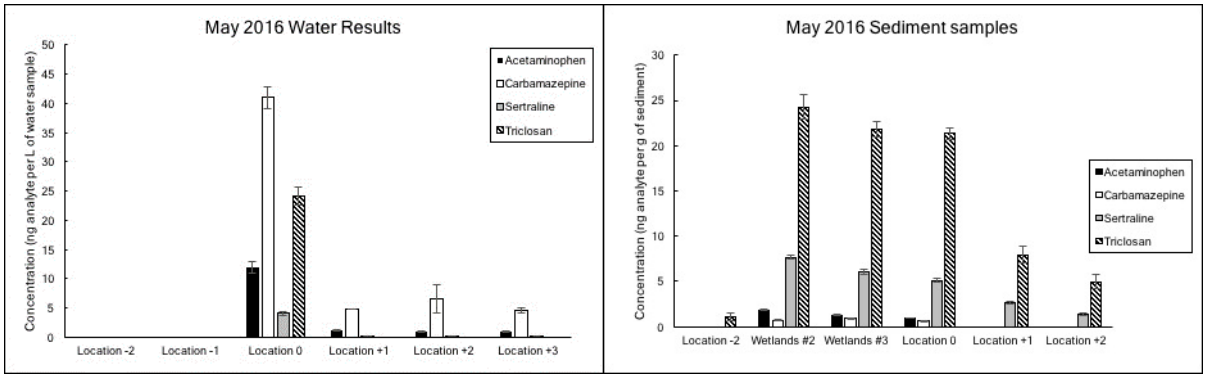


Figure 2. Concentrations of four selected PPCPs in East Canyon Creek water and sediment

Phytoremediation Evaluation Site for Quantifying the Fate of Trichloroethylene (TCE) Taken Up by Trees

Principal Investigators:
William J. Doucette
J. Oliver Diamond (Student)

Partners/Collaborators:
- ***Local:*** *Kyle Gorder, Hill AFB, UT*
- *Ivan Ray, Weber Canal Company*

Project Description

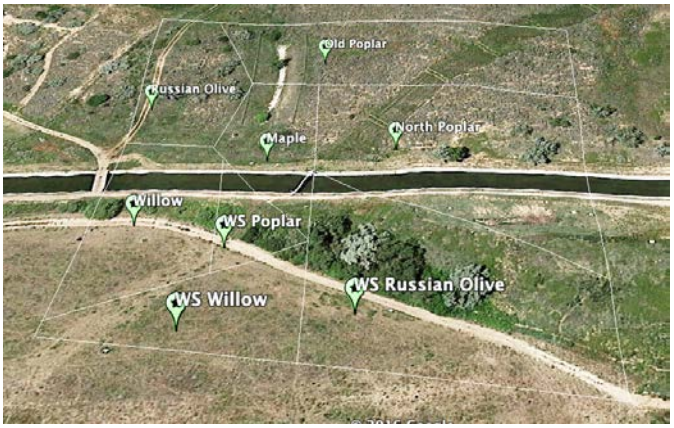
- **Need and Purpose:**

  Chlorinated volatile organic compounds (CVOCs) are found at many locations in the State of Utah, including several communities surrounding Hill Air Force Base. Phytoremediation using fast growing trees is promoted as a low cost, sustainable remediation alternative for the clean-up of shallow groundwater contaminated with CVOCs like trichloroethylene (TCE). The uptake by trees and the subsequent volatilization from leaves into the atmosphere is thought to be a significant removal mechanism for TCE. Once in the atmosphere hydroxyl radicals rapidly degrade TCE. Trees also can metabolize TCE into less problematic compounds. In addition, tree core sampling has been used to inexpensively delineate groundwater plumes. One of the main limitations preventing the implementation of phytoremediation is the lack of acceptance by the regulatory community. This is often due to a limited understanding of the removal mechanisms and the scarcity of data quantifying the removal.

  The goal of this study is to establish a small phytoremediation evaluation site just outside Hill Air Force Base Operable Unit 2 (OU2) that can be used to refine measurement and scaling approaches for estimating the total mass of TCE and other CVOCs removed annually from shallow groundwater aquifers by trees through volatilization and metabolism.

- **Benefits to the State:**

  Results from this study will contribute to our basic understanding of phytoremediation and the potential to use trees to monitor and improve groundwater quality. An improved understanding of the phytoremediation removal mechanisms and kinetics will provide regulatory agencies such as Utah DEQ with the necessary information to determine the potential for using phytoremediation as an alternative to more costly remediation approaches.



Tree Core polygons used to estimate current TCE removal from existing and sampled trees

- **Geographic Areas:**

  Study Area: Weber County.

  Areas Benefited: Phytoremediation can be used statewide, so all counties in the state could benefit.

- **Accomplishments:**

  Approximately 60 poplar poles were obtained from the Utah State University (USU) research farm and planted on a seep area between the Hill AFB boundary and the Weber Canal within OU2 during April 2013 and 2014. To minimize the risk of erosion on the steep hillside, the poles were planted in holes near the depth of shallow groundwater (4 feet), and only limited watering of the poplar was applied. However, with the hot, dry spring only 25% of the trees survived after two years.

  Findings: Flow through or recirculating chambers were used to quantify the amount of TCE removed by volatilization through leaf, trunk, and soil surfaces. Tenax™ sorbent tubes, used to collect TCE from the chambers, were analyzed by thermal desorption gas chromatography/mass spectrometry. Tree cores were collected using an incremental borer and analyzed by headspace GC/MS to quantify the TCE mass contained in the trees.

- **Results:** Field measured transpiration stream concentrations (TSC) and groundwater data were used to calculate transpiration stream concentration factors (TSCF) for TCE. Compared to current and historical data, it was found that trees reach a steady state TSCF value of 0.26 after about 15 years. Using this information, it was predicted that a phytoremediation plot containing 40 poplar trees located in a seep area within HAFB OU2 would remove 4.82 kg of TCE annually. A larger plot covering the entire hillside above this seep (160 trees) could remove up to 19.28 kg of TCE annually, once trees reach a steady state TSCF.

Work Plan FY16/FY17

This project has been completed and the results are summarized in J. Oliver Diamond's MS thesis titled: *Predicting the Removal of Trichloroethylene via Phytoremediation at Hill Air Force Base, Using Recent and Historical Data,* (http://digitalcommons.usu.edu/etd/4743/).

Informational Resources

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

Poplar pole being planted

Poplar pole one month after planting

Volatilization flux measurement

Real-Time Polymerase Chain Reaction (RT-PCR) Instrumentation

Principal Investigators:
R. Ryan Dupont
Joan E. McLean
Darwin L. Sorensen
Babur Mirza

Partners/Collaborators:

- ***Local:*** *Issa Hamud, Logan City Environmental Department; Michelle DeHaan, Water Quality Program Manager, Park City Municipal Corporation*
- ***State****: Eva Naminski, Division of Drinking Water, Utah Department of Environmental Quality*
- ***Federal:*** *Kyle Gorder, Mark Roginski, Environmental Management Directorate, Hill AFB*

Project Description

- **Need and Purpose:**

  Molecular biology tools for use in environmental engineering have been growing in importance over the past decade. Qualitative tools that determine the presence or absence of particular microorganisms or functional genes have been the predominant means of investigating contaminated sites and evaluating performance of bioremediation systems. RT-PCR provides a means to quantitatively describe microbial community and function and has become a standard technique for engineering applications of molecular biology concepts to bioremediation.

  This project used RT_PCR instrumentation to facilitate development and implementation of routine quantitative molecular biology capabilities of the Utah Water Research Laboratory's Environmental Quality Lab (EQL). This research is needed to support advanced molecular biology research that generates information regarding the numbers of organisms and functional gene copies in a wide range of environmental soil and groundwater samples. This instrumentation is being utilized by a number of researchers to carry out quantitative analyses of DNA from field and laboratory generated soil, groundwater, plant, and reservoir samples. These RT-PCR tools are being used in conjunction with other microbial community analysis techniques, primarily 454 pyrosequencing. With these tools, the make-up of impacted microbial communities and their interactions in natural systems and the response of microbial communities to engineered modification of contaminated environments can be explored.

- **Benefits to the State:**

  RT-PCR instrumentation provides quantitative capabilities for the low-level detection of specific microorganisms and functional genes in environmental samples. Applications of RT-PCR techniques directly benefit the State of Utah in the following ways:

  1. Provide quantitative analysis of specific organism numbers, gene copies, and/or gene expression using messenger RNA probes so that environmental responses to engineered perturbations (carbon donor addition, electron acceptor addition) can be quantitatively analyzed for improved contaminated site management throughout Utah.
  2. Provide quantitative analysis of microbial community composition in Utah reservoirs to investigate microbial sources of taste, odor, and eutrophication problems.
  3. Evaluate the presence and abundance of arsenic reducing bacteria in soil and groundwater surrounding the Logan City Landfill to isolate the landfill's influence on groundwater quality impairment.
  4. Analyze the community composition and function associated with biofilms accumulating within the potable water distribution system in Park City.

- **Geographic Areas:**

  Study Area: Counties throughout Utah where soil, groundwater, reservoir, drinking water biofilm, and plant samples have been collected for analysis, including Cache, Davis, Morgan, Salt Lake, Summit, Tooele, and Weber Counties.

  Areas Benefited: All counties in the state would potentially benefit from microbial community analysis using these molecular tools on samples from natural, contaminated, or engineered sites.

- **Accomplishments**:

  Findings: Three separate studies are currently underway using this equipment to evaluate system performance and guide remedial design. These quantitative molecular tools are useful in studies that (1) evaluate the presence, abundance, and expression of *Dehalococcoides mccartyi* and functional genes associated with TCE transformation in soil and groundwater contamination of OU5 at Hill AFB; (2) evaluate the presence and abundance of arsenic reducing bacteria in soil and groundwater surrounding the Logan City Landfill, (3) evaluate groundwater throughout Cache Valley to isolate the landfill's influence on groundwater quality impairment, (4) investigate the distribution and diversity of arsenic reducing organisms in the Cache Valley's geologic setting; and (5) conduct screening level analysis of the microbial community of biofilms that periodically grow and then are released into the Park City potable water distribution system.

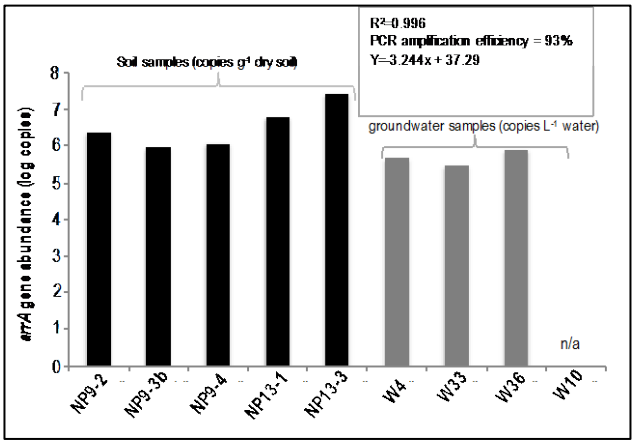


Figure 1. arrA gene copies quantified by qPCR from soil and groundwater samples of the Cache Valley Basin using newly developed arrA gene primers. The gene copy numbers are given on a log scale. n/a = not analyzed

  Results: Use of this equipment to study how these chemical reactions impact water quality is yielding information that will help protect and improve water quality around the State.

Work Plan FY16/FY17

The identification and analysis of arsenic reducing microorganisms isolated from shallow and deep groundwater samples collected throughout Cache Valley and northern Utah, added to earlier findings of the uniqueness and diversity of arsenic reducing species endemic to this region, will create a bigger picture and better understanding of bioremediation as a means of treating contaminated soils and water.

Informational Resources

Contact: Dr. R. Ryan Dupont, Telephone: (435) 797 3227, E-mail: ryan.dupont@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
Leila Ahmadi (Post-Doc)

Partners/Collaborators:
- ***Local:*** *Don Hartle, City Manager, Wellsville City; Issa Hamud, Director, Environmental Department, Logan City*

Project Description

- **Need and Purpose:**

  Nutrients, particularly phosphorous, and 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 the uptake and transformation of nutrients and PCPP contaminants from municipal wastewater, especially in communities like Wellsville City and Logan City, which have lagoon wastewater treatment systems currently in place. In addition, work is ongoing to quantify the energy recovery potential of harvested duckweed biomass via 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/PCPPs from wastewater with a net positive energy and environmental footprint.

Figure 1. Bank view of duckweed covering the Wellsville lagoons, 2015

- **Geographic Areas:**

  Study Area: Cache County, UT.
  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 showed significant duckweed growth rates, high nutrient concentrations that accumulate in the duckweed biomass, and high duckweed PCPP removal rates. This demonstrates that a duckweed-based wastewater treatment system can be feasibly implemented, compared to more expensive mechanical treatment systems. The effectiveness of such a system is dependent, however, on efficient and cost-effective harvesting and stabilization/processing of the generated biomass. Freshly grown duckweek and field-harvested biomass are powering lab-scale anaerobic digesters to stabilize harvested biomass and generate methane. We are evaluating methane production capacity and reactor stability associated with the harvested biomass within anaerobic

digestion systems and exploring the use of digester effluent to grow heterotrophic algae and the production/harvesting of potentially valuable biofuel materials.

Results: The 56-acre Wellsville lagoons could harvest more than 250,000 lbs. of dried duckweed material annually, with ~2,500 lbs. of phosphorus recovered in the harvested material. Duckweed pharmaceutical compound removal rates for Acetaminophin were 56-99%, Sulfamethxazole 45-86%, Fluoxetine 82-93%, Carbamazepine 0-38%, and Progesterone 82-98%, which are comparable to values reported in the literature for more expensive complex physical/chemical treatment systems. Bi-weekly harvesting of duckweed biomass alone would provide sufficient P removal for Wellsville to meet its permit limits until approximately 2017. This technology is clearly a low cost alternative to replace much more expensive advanced biological/chemical treatment processes. In addition, it produces a valuable end product in the form of harvested duckweed biomass.

Two 5-L lab-scale anaerobic digesters were fed 100% duckweed solids feedstock for more than 2 years. Results show stable operating pH despite significant increases in reactor feeding rates (Figure 2), while average gas production has stabilized at approximately 290 mL/g dried duckweed (Figure 3). With methane composition at ≥ 65%, the digesters yielded ≥ 189 mL CH4/g dried duckweed feed, corresponding to 50% of the theoretical maximum methane yield from this biomass feed.

During the experiment, feed concentration was increased in order to increase the amount of residual organic carbon in the digester's effluent that could serve as a substitute carbon source for heterotrophic algae growth. However, increases in duckweed concentration have been limited due to maximum solids concentrations that can feasibly be added to the digesters. The high carbon removal efficiency of the duckweed-fed digesters and a physical maximum limit of feed concentration has made a high residual organic carbon content in the duckweed digester effluent unachievable. Therefore, one of the digesters has been converted to whey powder feed containing significantly higher amounts of carbon. Currently, one digester is operating fully on duckweed, while the other is operating fully on whey powder. Studies are on-going to increase the feed of whey powder, while keeping pH stable to produce a carbon enriched effluent that supports heterotrophic algae growth. Production of heterotrophic algae to average concentrations of approximately 8.9 g/L (peak concentrations > 25 g/L) has been achieved on pure glucose substrate.

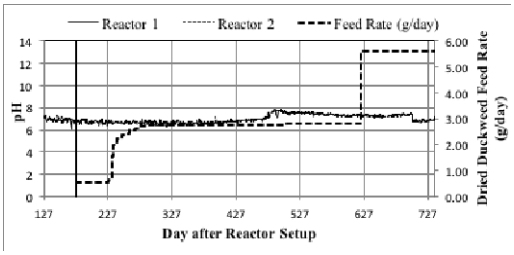


Figure 2. Reactor pH as a function of time and duckweed feed rate

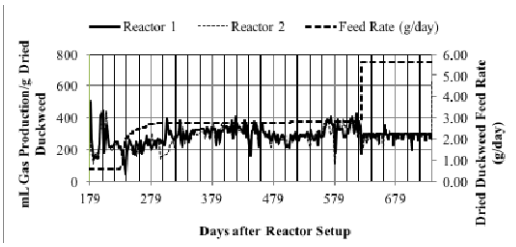


Figure 3. Reactor gas production as a function of time and duckweed feed rate

Work Plan FY16/FY17

Continue to evaluate whey-based anaerobic digester effluent for production of heterotrophic algae during FY17, and analyze the whey solution used directly to grow heterotrophic algae. Complete a comprehensive analysis of solids destruction, nutrient uptake, energy transformation efficiency, and final effluent quality for both duckweed-fed and whey-fed digesters. Evaluate the growth rate and lipid content in the heterotrophic algae grown with different feedstocks (glucose/whey).

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 Cold Start and Hot Start Emissions

Principal Investigators:
Dr. Randal S. Martin
Clay Woods (PhD student)

Partners/Collaborators:

- ***Local:*** *The City of Logan, USU, as well as several private and commercial facilities*
- ***State:*** *Utah Division of Air Quality (UDAQ) & Air Monitoring (AMC), Weber State University's National Center for Automotive Service and Technology (NCAST)*

Project Description

- **Need and Purpose:**

  Preventative and protective strategies are needed to address the $PM_{2.5}$ (Particulate Matter) and O_3 (Ozone) air pollution health issues in the Cache Valley and along the Wasatch Front, especially during the wintertime conditions of northern Utah. Strategies to limit exposure include staying indoors, and automotive anti-idling programs. A related issue is the effect of hot vs. cold vehicle engine starts. Unfortunately, limited data are available to evaluate the benefit of these types of measures, particularly as they apply to the vehicle fleet representative of Cache Valley and the Wasatch Front. This project combines Mineral Lease and funds from the Utah State Division of Air Quality (UDAQ) to expand the overall scope of the research.

- **Benefits to the State:**

  Ultimately, accurately assessing the pollutant emissions from sources relevant to the Cache Valley and Wasatch Front will help to identify the most effective remediation scenarios. This will also facilitate the development of information that can be provided to the general public through local and statewide outreach programs. The results from this project have been presented to several local and state communities, and a number of educational and governmental entities.

- **Geographic Areas:**

  Study Area: The setup for the majority of the automobile emissions testing took place at the UWRL, with some additional comparative testing at WSU's National Center for Automobile Science and Technology.

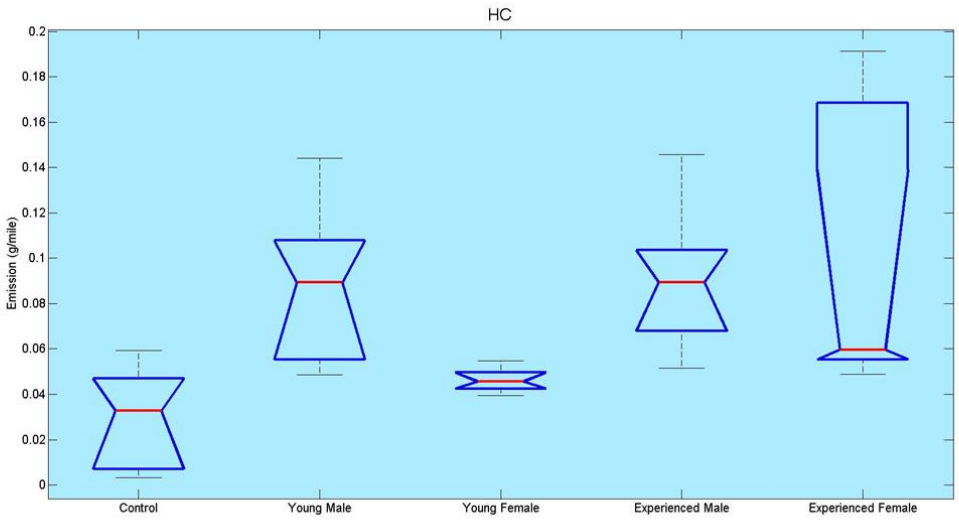
  Areas Benefited: The populations of the Cache Valley and the Wasatch Front will see the most direct and immediate benefit of these and future studies. However, the results will also be of use to UDAQ in planning future mitigation strategies. Air quality research partnerships have also been established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

- **Accomplishments:**

  Findings: The total number of vehicles examined was extended beyond the originally planned number from 50 to 67. In addition, a few vehicles were tested multiple times. The results were not significantly different from the previous year's work but added a higher degree of confidence to the findings. Strong differences between cold (≈95%) and hot starts (≈5%) showed that idling generally results in higher emissions than going through a hot start protocol. The capabilities developed during this project also allowed for expansion of the study into the effect of driver behavior on emissions, as related to years of driver experience and gender. This study was conducted with the assistance of a self-funded, visiting scholar, Dr. Abdelhallem Khader from An-Najah University, Nablus, Palestinian Territories.

Results: As noted above, the additional vehicle testing this year reinforced the evidence that idling a vehicle during a short stop produces more emissions than shutting off and restarting the engine, and that vehicles do not require an extensive (> 3minute) warm-up period. The results from single vehicle tests at varying atmospheric temperatures (early winter below 20°F and summer above 90°F) showed that the temperature dependency of the USEPA's current MOBILE6 emissions algorithm appears reasonable for the northern Utah vehicle fleet.

The figure below shows an example of on-road air pollutant emissions from the driver behavior study. The box and whisker plots of pollutants shows that although there is considerable variability among the driver segments, with the young (<5 years driving experience) female driving behavior averaging the lowest pollutant emissions, while the older males (>10 years driving experience) tend to average the highest pollutant emissions. These trends remained similar across all of the pollutants examined (hydrocarbons, oxides of nitrogen, and carbon monoxide).



Work Plan FY16/FY17

The work accomplished in FY15-16 continued to fill some critical gaps in knowledge and expanded the scope of the project's research fields. This year's work is underway on further analysis into the relationship between the various engine-start scenarios and carbon dioxide emissions (greenhouse gas concerns), and work also is planned to examine the effects of catalyst replacement as a function of different types of available after-market catalysts (OEM, EPA-certified, CARB-certified, non-certified).

Informational Resources

The results of the study were presented at the International Conference of the Air & Waste Management Association in June 2016, and final report and multiple manuscripts are in preparation. Of particular importance is the development of an informational flyer in cooperation with UDAQ. The flyer has been made publically available in the Cache Valley but could benefit all areas along the Wasatch Front.

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	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
Assessment of Utah 319 Projects for Controlling Non-point Source Water Pollution	$ 6,550.84	$ 6,747.37	$ 6,949.79
Estimating Water Loss from Rural Lands Using Remote Sensing and Complementary Methods	$ 66,158.58	$ 12,000.00	$ 12,360.00
Incorporation of Heat into Solute Models	$ 61,587.80	$ 36,000.00	$ 37,080.00
"Lab-on-a-Chip" – Miniaturized Salinity Sensor Arrays for Water Quality Monitoring	$ 97,061.45	$ 43,000.00	$ 44,290.00
Optimizing Storm Water BMP Performance through Vegetation Selection and Harvesting Strategies	$ 82,144.54	$ 25,000.00	$ 25,750.00
Quantification of Groundwater Influences in High Gradient Utah Streams and Rivers	$ 55,854.97	$ 36,000.00	$ 37,080.00
Release of Arsenic from Aquifer Solids Under Anaerobic Conditions	$ 54,670.17	$ 40,000.00	$ 35,000.00
Source Water Protection for Potential Phosphorus Mining Impacts in the Uintah Basin	$ 31,906.44	$ 32,863.63	$ 33,849.54
Designated Projects		$ 22,500.00	$ 14,000.00
Undesignated Projects		$ 15,000.00	$ 8,000.00
Total	**$ 455,934.79**	**$ 269,111.00**	**$ 254,359.33**

Assessment of Utah 319 Projects for Controlling Non-point Source Water Pollution

Principal Investigators:
David K. Stevens
Nancy Mesner
Douglas Jackson-Smith
Phaedra Budy,
Darwin L Sorensen
Lorien Belton
JInsu Choi (Student)

Partners/Collaborators:
- ***Local:*** *e.g. Bear River Canal Company*
- ***State:*** *Utah Department of Environmental Quality*

Project Description

- **Need and Purpose:**

  Nonpoint source (NPS) pollution remains a significant public policy concern in the State of Utah. Unlike point-source pollution (e.g., factories or sewage treatment plants), NPS pollution is diffuse, originating from a wide range of small sources dispersed across the landscape. In Utah, the most common agents of NPS pollution are sediments, nutrients, heavy metals, salts, and pathogens (UDEQ 2010).

  The dispersed character of NPS pollution presents challenges in efforts to address pollution problems because many actors are involved and each individual change may not noticeably improve environmental conditions. A major focus of NPS pollution control is the development of public programs to encourage voluntary changes at the landscape scale in individual behaviors thought to contribute to documented water quality problems.

  Most of the agricultural watersheds in Utah have supported non-point source pollution mitigation projects under EPA's 319 program or other federal and state programs. Since 1990, the state NPS program has expended almost $30 million to address water quality problems (UDEQ 2009). Much of this funding has gone to watershed projects that involve cost-sharing, technical assistance, and educational programs that encourage landowners to implement appropriate best management practices (BMPs) to reduce pollution loadings to impaired waterways. This project is assessing the efficacy of these projects.

- **Benefits to the State:**

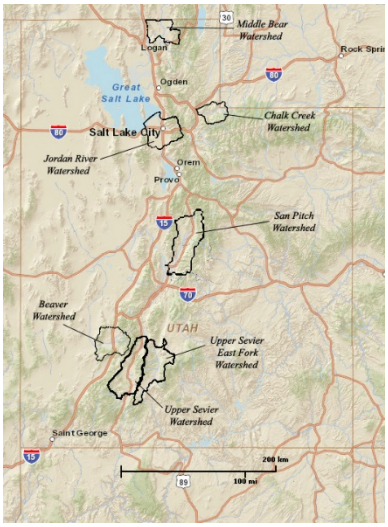
  Some evidence indicates that public efforts to reduce NPS water pollution in Utah have been successful. A comprehensive water quality monitoring program tracks current conditions and water quality trends for all of the 14,250 miles of rivers and streams and for the nearly 3,000 lakes and reservoirs in Utah (UDEQ 2009). State agency assessments suggest that 30% of Utah's waters have impairments that prevent them from meeting their expected uses (UDEQ 2006). This detailed assessment is helping to determine the impact of public 319-funded projects on measured water quality in the state.

- **Geographic Areas:**

  Study Area: Beaver River (Beaver, Piute Counties), Chalk Creek (Summit County), San Pitch River (San Pitch County), Upper Sevier River (including East Fork Sevier River, Garfield County), and Middle Bear River (Cache County). See the map below.

  Areas Benefited: Most agricultural watersheds in Utah.

- **Accomplishments:**



Findings: Most respondents had a good basic understanding of the state's NPS program goals and the state's most significant pollutant concerns. However, several challenges to efficiency were identified, including concerns that the allocation of 319 funding was too heavily tilted to staff support rather than actual implementation of projects, poor coordination between the land management programs promoted by different state agencies, poor record keeping on project outcomes and impacts, a convoluted system of contract management, a perception that the program has focused too heavily on agricultural sources, monitoring approaches that limited the ability to adequately document program impacts, and a failure of the program to "tell the 319 story" to Utah citizens and decision makers.

Suggestions for improving program administration and support were submitted to the Utah Department of Environmental Quality. The suggestions included improvements to (1) program administration and implementation, (2) partnership coordination and permit application processes, (3) monitoring and reporting, and (4) communication and outreach.

Results: Overall, the study found that most 319-funded projects are still in place, still functional, and are appreciated by the landowner. Only a small minority of BMPs experienced implementation problems. The qualitative assessment—based on interviews and field assessments—suggested that ~60% of BMPs likely or definitely produced positive impacts on water quality, while 15% were in situations that were difficult to clearly evaluate net water quality impacts. About 25% of rural watershed BMPs were considered unlikely to have improved water quality, generally due to placement of the BMPs and/or designs that mostly accommodated other goals (such as improving irrigation efficiency). Watershed hydrologic models suggested that the full suite of 319-funded BMPs likely improved nutrient loadings and concentrations by very modest amounts (P declined 0.1– 3% and N declined 0.1–0.2% over a 15-year period of simulations). The small changes in total nutrient loadings were associated with two factors: (1) the relatively small proportion of the watershed that was affected by 319 BMP implementations, and (2) the high background levels of nutrient flows in the affected waterways. Water quality improvements were more significant at the subbasin scale—particularly in the winter and spring when hydrologic conditions generated higher total nutrient loads.

Taken as a whole, assessment of BMP impacts was constrained by poor record keeping, a lack of pre-project data, and the absence of systematic and ongoing monitoring of BMPs and water quality conditions. Improved monitoring efforts and data management for future BMP projects will be necessary to ensure that program evaluations can provide more detailed, project-specific information on key parameters for NPS source reduction.

Work Plan FY16/FY17

Completion of student report and publications.

Informational Resources

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

Estimating Water Loss from Rural Lands Using Remote Sensing and Complementary Methods

Principal Investigators:
Jagath J. Kaluarachchi
Homin Kim (PhD student)

Partners/Collaborators:

- ***State:*** *Utah Department of Water Resources*

Project Description

- **Need and Purpose:**

  In previous efforts we developed a novel method to estimate total water loss from agricultural and non-agricultural lands using the complementary methods. Classical methods of estimating evapotranspiration (ET) are valid for water loss estimates from crop-covered lands; however, water loss also occurs from others surfaces, such as bare land, open water surfaces, etc. The promising results of our earlier study developing the modified GG model, along with the complementary methods, used only point data from meteorological stations. The modified GG model is an extension of the earlier work of Granger and Gray (1989) who developed one form of the complementary methods. The data required include temperature, relative humidity, wind speed, and sunlight hours. The estimates provide regional water loss from lands under a variety of physical and climatic conditions. The result showed vast improvements over other recent studies for most conditions except for arid conditions, for which they were similar or only slightly better than previous studies. The focus of this work is to further improve the modified GG model using limited remote sensing information, primarily vegetation cover information, to develop a hybrid method with an emphasis on estimating total water loss from arid land regions.

- **Benefits to the State:**

  Given the importance of rural agriculture and rural livelihoods in Utah, where water is typically limited, accurate water loss estimates from both agricultural and non-agricultural lands are important in water resources management. Classical methods of computing ET from agricultural lands are available, but the data needs are detailed and complex. Remote sensing data from satellites and corresponding methods require advanced knowledge and trained personnel to provide good estimates of ET. On the other hand, the complementary methods, which use only meteorological data, have high validity in making regional estimates with limited data requirements. The methodology derived from this work is useful for Utah, where good estimates can be obtained at a relatively fast pace and with limited resources.

- **Geographic Areas:**

  Study Area: The Sevier Basin, occupying approximately 12.5 percent of the land area of Utah.

  Areas Benefited: Areas with limited water supply and rural agricultural economies.

- **Accomplishments:**

  Findings: A previously developed modified GG model, GG-NDVI, has been validated by comparing its results with 75 Eddy Covariance (EC) flux tower observations, and other complementary methods with 60 EC flux tower observations. These findings are good within the realm of ground-based ET methods, but remote sensing-based ET methods provide another opportunity to estimate ET at a variety of spatial and temporal scales. The Operational Simplified Surface Energy Balance (SSEBop) is one of the most widely used models to estimate ET from satellite imagery and is now available free through USGS Geo Data Portal. To be

accepted as an operational model, the GG-NDVI will be validated by comparing it with the SSEBop model at 60 EC AmeriFlux sites. Potential improvements of GG-NDVI will be identified based on this work.

Results: The Root Mean Square Error (RMSE) for GG-NDVI ranged 15–20 mm/month, which is lower than for SSEBop. Also, RMSE less than 20 mm/month with GG-NDVI occurred more frequent than with SSEBop, as shown in Figure 1. These results further support GG-NDVI as a reliable approach to estimate ET. The GG-NDVI model assumes a symmetric complementary relationship between ET and ETP with respect to ETW (the ET rate for a wet surface with unlimited moisture). This may produce poor results under certain conditions, for example when the RMSE from GG-NDVI increases slightly with moisture availability. With the symmetric complementary relationship, increasing moisture availability means ET is closer to ETW. However, natural surfaces even in the wettest regions may not approach complete saturation. Consequently, the magnitude of difference between ET and ETW is important for estimating ET.

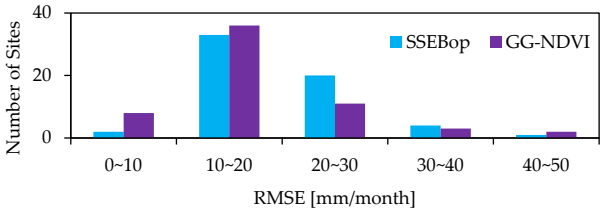


Figure 1. Histogram of RMSE values of SSEBop and GG-NDVI for 60 AmeriFlux sites

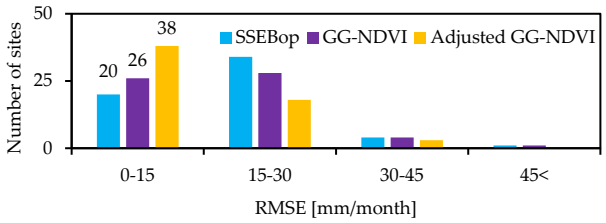


Figure 2. Comparison of histogram of RMSE values

To examine the relationships affecting model accuracy, a nonlinear correction function was incorporated into GG-NDVI. We expected the correction function to be an exponential function and fitted 2772 data points using multiple regression analyses. The GG-NDVI model with the correction function is called the Adjusted GG-NDVI model in Figure 2. According to Figure 2, 68% of Adjusted GG-NDVI sites had RMSE less than 15 mm/month compared 43% with GG-NDVI.

This work strengthens the idea that the use of vegeatation cover information in the complementary relationship increased the ET estimation power. An important result of this work is that the lastest verion of the GG model, Adjusted GG-NDVI, overcomes limitations of both the symmetric complementray relationship from Bouchet (1963) and the relative evaporation proposed by Granger and Gray (1989). Consequently, Adjusted GG-NDVI can lead to siginificantly increased accuracy of ET estimates under diverse climate conditions.

Work Plan FY16/FY17

Future work will develop a drought index using ET. Many operational drought indices focus on precipitation, soil moisture, and air temperature. However, other climate factors such as solar radiation, wind speed, and humidity can be important drivers in drought monitoring. Taking this into account, the actual ET and ETP derived from climate factors may serve as a drought index and detect drought driven by meteorological changes when there is no substantive change in precipitation. We will evaluate the potential use of ET as a drought index using the U. S. Drought Monitor (USDM).

Informational Resources

Contact: Dr. Jagath J. Kaluarachchi, Telephone: (435) 797-3918, E-Mail: jagath.kaluarachchi@usu.edu.

Incorporation of Heat into Solute Models

Principal Investigators:
Bethany T. Neilson

Partners/Collaborators:
- ***Local:*** *Corey Cram, Washington County Water Conservancy District*
- ***State:*** *Brad Hunt/UDWR; Steve Meismer, Virgin River Program*
- ***Federal:*** *Rick Friedell, US Fish and Wildlife Service*

Project Description

- **Need and Purpose:**

  In many watersheds, exchanges between surface water and groundwater play an important role in understanding solute transport and transformations. Quantifying the relative magnitude and direction of these exchanges is important for understanding both the energy and the mass balances within streams and rivers. A number of different methods have been developed to assist in quantifying these interactions, including data collection techniques that use a variety of sensors and sampling procedures and a combination of data collection and modeling techniques. There are questions, however, as to the appropriateness and accuracy of these methods for different systems. This project analyzes the data resulting from the combination of several different data collection techniques as multiple lines of evidence toward quantifying the magnitude and direction of fluxes between surface water and groundwater using various modeling approaches. Further, because conditions within Curtis Creek have changed significantly over the past few years due to beaver colonization, significant efforts have been focused on understanding the influence of beaver dam complexes on groundwater/surface water interactions and heat and solute transport.

- **Benefits to the State:**

  This area of research provides for a more complete understanding of the impacts of transient storage and surface water-groundwater interactions on streams in Utah and the Intermountain West. It also provides a platform to understand the influences of beaver dams on instream processes. As methods are developed to measure and predict the fate and transport of constituents in streams and rivers, while simultaneously considering the impacts of surface water-groundwater interactions, the state of Utah will have the tools and methods necessary to complete these types of studies and better manage limited water sources. This effort will also assist the state in understanding the implications of the recently passed State of Utah Beaver Management Plan.

- **Geographic Areas:**

  Study Area: Curtis Creek, Hardware Ranch, Cache County, Utah; Silver Creek, Summit County, Utah; and Virgin River, Washington County, Utah.

  Areas Benefited: The current applications of the modeling approach span desert and mountain watersheds. Therefore, the entire State of Utah could potentially benefit.

- **Accomplishments:**

  Findings: Data collection strategies and new model development approaches have provided more accurate heat and solute fate and transport predictions through the main channel, dead zones, and surface-groundwater interface of rivers and streams (referred to as two-zone transport models). Analytical solutions have been developed to describe these transport processes better than more

traditional methods using numerical solutions (e.g., Schmadel at el. 2016). New techniques have also been developed to account for spatial variability in system characteristics using information extracted from aerial high-resolution multispectral and thermal infrared imagery gathered by AggieAir.

Results: Analytical solutions of two-zone solute transport, as well as temporal moments, have been developed and have been tested against observed solute data within various systems. Imagery has been found to be critical in estimating parameters and in capturing the longitudinal and lateral spatial variability present within desert and mountain streams in Utah. Four papers have been published from this focus area, and a PhD dissertation was completed. In 2014, an MS thesis was completed that focused on the heat transport processes within beaver dams. Another MS student graduated Spring 2016 and a chapter of his thesis, now in press in Ecohydraulics (Stout et al. 2016), begins quantifying the influence of beaver dams on hydraulics (see Figure 1). A post-doctoral student also published an article investigating the influences of beaver dams on local hydrology and thermal regimes. Additionally, 29 presentations of results have been delivered by faculty and students.

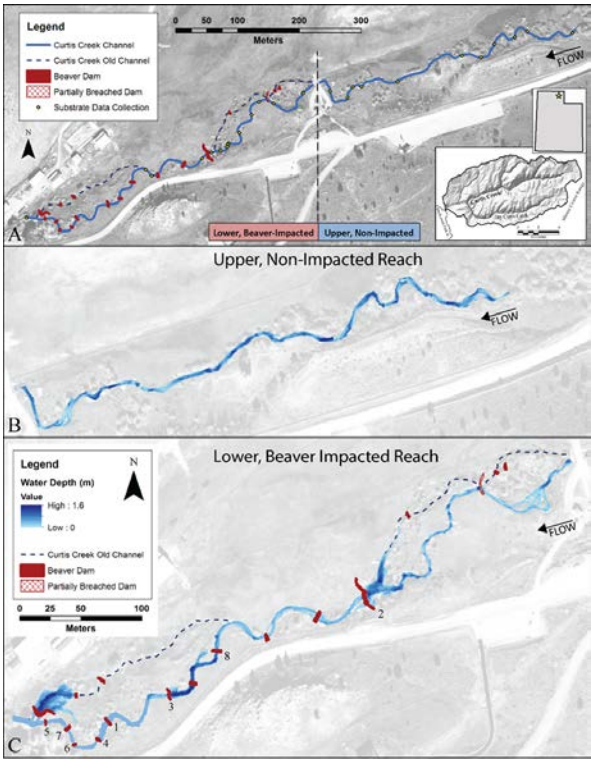


Figure 1. Taken from Stout et al. 2016. Site map of the study reach at Curtis Creek near Hardware Ranch, UT. The beaver impacted reach is indicated in red, while the non-impacted reach is in blue (Figure 1A). Flow is from right to left. The main channel is indicated with blue line (Figure 1A) and different shades of blue representing water depth ranging from 0 to 1.6 meters (Figure 1B, 1C). The location of the old channel is indicated with dashed blue line. Substrate data locations are shown as yellow circles along both reaches (Figure 1A). Beaver dams present in the lower reach are numbered in the same order as they were constructed by the beaver (Figure 1C)

Work Plan FY16/FY17

We continue to analyze data in different study reaches to quantify the influences of beaver dams on heat and solute transport. Currently a 1- and 2-dimensional hydraulic model has been applied to the study reach where 10 beaver dams are present. A paper is being developed using these results to quantify the influences of beaver dams on temperature, geomorphic change, and fish habitat.

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***

Schmadel**, N.M., Heavilin, J., Neilson, B.T., and Wörman, A. (2016). Isolating parameter sensitivity in reach scale transient storage modeling. *Advances in Water Resources*. 89, 24-31, doi:10.1016/j.advwatres.2015.12.020.

Stout**, T.L., Majerova*, M., and Neilson, B.T. (2016). Impacts of beaver dams on channel hydraulics and substrate characteristics in a mountain stream. *Ecohydrology*. In press, doi:10.1002/eco.1767.

"Lab-on-a-Chip"—Miniaturized Salinity Sensor Arrays for Water Quality Monitoring

Principal Investigators:
Anhong Zhou

Partners/Collaborators:
- *None*

Project Description

- **Need and Purpose:**

  Utah is one of seven western states in the United States (Arizona, New Mexico, California, Utah, Colorado, Wyoming, and Nevada) that make up the Colorado River Basin Salinity Control Forum. The forum manages the problem of elevated salinity levels in the Colorado River. Salt in the Colorado River, aside from the natural sources, generally results from activities in support of irrigated agriculture in the Upper Colorado River, especially in drainages such as the Price and San Rafael Rivers in Utah. However, substantial uncertainty exists about the efficacy of salinity management in the basin due to the lack of a commercially available detection device to adequately measure salinity levels in the river. This project is developing a portable, reliable, affordable chemical sensor device capable of measuring the concentrations of individual salt ions in the field.

- **Benefits to the State:**

  The ability to detect a majority of salinity ions will help Utah to better manage and control contributions to the Colorado River salinity problem. Benefits of this project include (1) producing ion sensor arrays that can measure salt loading in critical Utah rivers, (2) making available a portable detector for measuring the most significant ions contributing to salinity from sources in Utah and other states, and (3) helping water managers improve the timing and efficiency of water quality monitoring to track salinity sources in the water system.

- **Geographic Areas:**

  Study Area: Logan, Price and San Rafael Rivers, Cache County in Utah.
  Areas Benefited: Salinity concerns are statewide, so all counties in the state could benefit.

- **Accomplishments:**

  Findings: In the past year, we designed and fabricated a microfluidic, low-cost, paper-based chip that uses colorimetric analysis via smartphone for detection of ions in a water sample. This device successfully detected the heavy metal ion (Pb^{2+}) in a standard ion solution, as well as calcium (Ca^{2+}), one of major ions contributing to the salinity problem in Utah. These results show that our paper-based smartphone sensor device was able to detect concentrations in the range needed to meet the water quality monitoring classification defined by the U.S. Department of Interior and the Water Quality Association for water hardness classifications (slightly hard 17.1-60 mg/l (or ppm), moderately hard: 60-120 mg/l, hard: 120-180 mg/l. very hard: > 180 mg/l.)

  Results:

  1) We optimized the sensor design, fabrication, and the ionophores for developing paper-based microfluidic Ca^{2+} ion sensor (also via smartphone colorimetric analysis). Our sensor was able to detect Ca^{2+} ions in a concentration range of 10~1000 ppm (Figure 1).

2) Our paper- based sensor was fabricated and tested with smartphone colorimetric analysis of 20–800 mg/L Ca^{2+} ions (R^2=0.92) in standard water solutions (Figure 2). The selection of Calcium ionophore, chromoionophore, ion-exchanger, plasticizer was optimized.

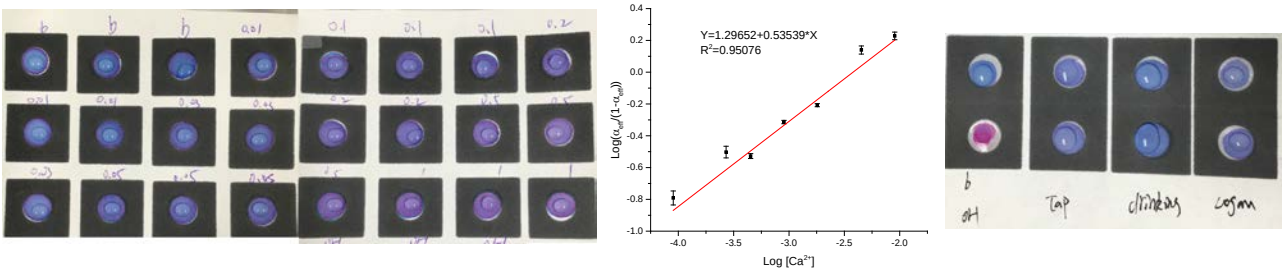


Figure 1. Paper-based colorimetric analysis of Ca^{2+} ion a linear range of 10 ~ 1000 ppm in the standard ion solutions (R^2=0.95) and the real water samples (right photo) from tap water, drinking bottle water, and Logan river. The concentration of Ca^{2+} are detected as 1.15 mM (moderately hard), 0.002 mM (soft), 0.28 mM (soft), respectively

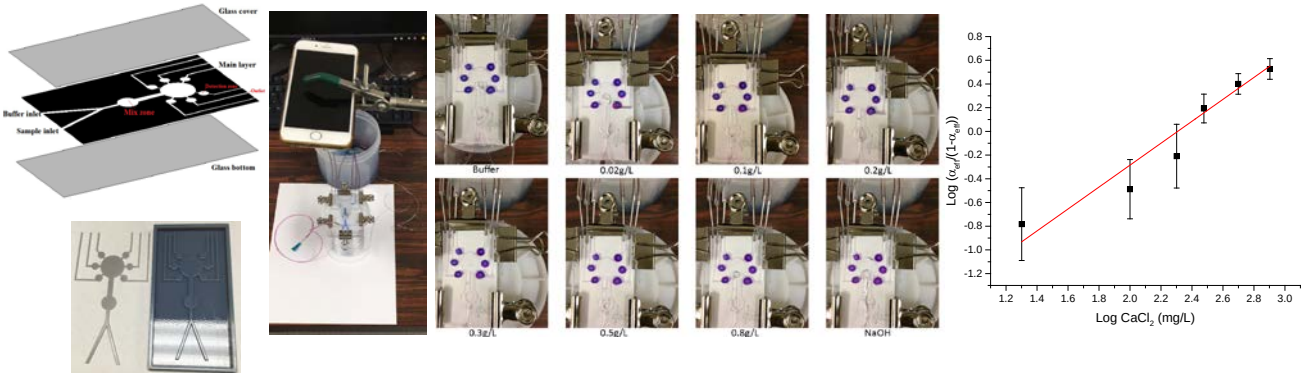


Figure 2. 3D printed, microfabricated on-chip device integrates with paper-based microfluidics allowing continuous detection of Ca^{2+} ion concentration in a linear range of 20~800 ppm in standard ion solutions (R^2=0.92)

Work Plan FY16/FY17

- Design and fabricate paper-based sensor for Magnesium (Mg^{2+}) detection.
- Find resources to develop iOS and/or Android App to control smartphones for data acquisition.
- Explore the integration of Ca^{2+} and Mg^{2+} sensors in one chip for multiplex ion detection capability.

Informational Resources

Contact: Dr. Anhong Zhou, Telephone: (435) 797 2863, E-mail: Anhong.Zhou@usu.edu.
Website: Dr. Zhou at Dept. of Biological Engineering, USU: http://www.be.usu.edu.
Salinity probe project at UWRL, USU: http://uwrl.usu.edu/researchareas/waterquality/labonachip.html.

Publications/Products:

Ilkhani, H., Zhang, H., Zhang, W., and Zhou, A. (2016). An ultra-selective single base mismatch DNA biosensor on configurable chip device for detection of human genotype of *Cryptosporidium* DNA. *2016 Annual Institute of Biological Engineering Meeting*, Greenville, SC, April 7-9, 2016.

Zhang, H., Ilkhani, H., Zhang, W., Williams, S., and Zhou, A. (2016). Comparison of designs of various PDMS based microfluidic devices for water quality monitoring. *2016 America Chemical Society Northwest Regional Meeting (NORM)*, Anchorage, Alaska, June 26-29, 2016.

Optimizing Storm Water BMP Performance through Vegetation Selection and Harvesting Strategies

Principal Investigators:
R. Ryan Dupont
Joan E. McLean
Trixie Rife (PhD student)
Sarah Guzman (MS student)
Darriane Willey (Undergrad student)
Joydino Beyale (Undergrad student)
Holly Flan (Undergrad student)
Mitch Steele (Undergrad student)

Partners/Collaborators:

- ***Local:*** *Bill Young, Logan City Public Works Department iUTAH Research Coalition. Cache County Storm Water Coalition. Salt Lake City Public Utilities*

Project Description

Figure 1. Curb flow meter installed at the 300 E site, Logan

- **Need and Purpose:**

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

  Logan City and surrounding municipalities are beginning to address storm water quality and quantity issues. To do this effectively, they need locally generated quantitative research to accurately characterize the effectiveness of vegetative species within storm water management facilities. This study measured biomass production and water quality improvement in a controlled laboratory environment and validated findings at a field demonstration study site. The lab scale study provided controlled replicates of storm water retention basins to measure plant biomass production and total nutrient and metal removal. Water and pollutant uptake for seven vegetative species was quantified in the laboratory under simulated (frequency and duration) rainfall events. The field demonstration site using three plant species produced quantitative water quality improvement data for plant growth and contaminant removal in response to periodic plant harvesting. Pollutant uptake by these three species was compared to naturally propagated weed species and non-vegetated control plots. We also evaluated the potential for increasing plant metal uptake through addition of citric acid, a metal chelator. Additional studies evaluating green infrastructure performance for stormwater capture and treatment have been initiated.

- **Benefits to the State:**

  This study is providing storm water nutrient and metal removal effectiveness of local species that Utah municipalities can use to optimize stormwater BMP systems. The data are specific to Utah's climate and geologic conditions. Logan City officials intend to utilize this information in the upcoming TMDL regulations that target reductions in the nutrient loading (particularly phosphorous) of discharges into Cutler Reservoir. Additionally, the quantitative results will prove critical to Utah's BMP designers and managers

who are responsible for species selection under local/regional site conditions and nutrient and metal removal requirements.

- **Geographic Areas:**

  Study Area: Laboratory study at Utah State University Research Greenhouse. Field demonstration site: Green Meadows Subdivision detention basin, 600 S and 1600 W, Logan, Utah.
  Areas Benefited: All counties in Utah would potentially benefit from quantitative data that can be utilized within storm water management systems.

- **Accomplishments**:

  Findings: Analysis and reporting of nutrient and metal removal data from the lab greenhouse study are complete. Lab-scale evidence of species differences in nutrient and metal concentrations accumulated in the harvestable, above-ground biomass suggests that the common reed and sedges are optimal plants to improve water quality of stormwater in arid, northern Utah.

  The Green Meadows field demonstration site provided contaminant removal performance data for 2015 in response to citric acid addition. These data continue to indicate significant storm water retention and infiltration capacity within the collection system. Total containment of stormwater generated at the demonstration site continues to result in 100% pollutant removal from surface water discharge. All data collected were added to the database.

  Results: Plant biomass production (sedge, sunflower, cattail, naturally seeded plots), and nutrient and metal mass recovery from the treatment areas, as a function of seasonal harvesting (mid- and end-season versus only end-season), was evaluated and complete for FY11–15 growing seasons. No surface discharge from the planted areas results in maximum nutrient and metal removal. Biomass significantly increased over the first 2–3 years for sedge, sunflower, and cattail but then reached steady-state levels. The naturally seeded, mixed plant community initially provided significantly higher biomass than other single test species but showed no difference by FY15.

  The citric acid added to the site to investigate potential increases in metal and nutrient uptake into the harvestable plant tissue showed increased metal solubility in the soil-water but did not significantly increase uptake into the aboveground tissue. However, the sedge treatment took up significantly more Cu and Zn in the aboveground plant tissue than sunflower and cattail in 2014, indicating that species selection can have a significant impact on metal uptake, and on-going control of metal accumulation in storm water treatments systems. A study investigating effectiveness of green infrastructure modifications to conventional curb and gutter stormwater systems to intercept/treat first flush contaminants began in FY15. Curb flow meters (Figure 1) were designed, tested, calibrated and installed to evaluate the curb cut system's hydraulic efficiency. Soil pore water lysimeters will monitor nutrient uptake by grasses in the bioswale, and soil samples below the bioswale will be analyzed for metal uptake and transport.

Work Plan FY16/FY17

Field plant harvesting and soil sampling from late fall 2016 at Green Meadows will be added to the database of nutrient and metal uptake and harvesting performance for this site. Results of the green infrastructure study at the 300 East site will be collected and reported during FY16.

Informational Resources

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

Quantification of Groundwater Influences in High Gradient Utah Streams and Rivers

Principal Investigators:
Bethany T. Neilson

Partners/Collaborators:

- ***Local:*** *Many within the greater iUTAH project*
- ***State:*** *USGS Utah Water Science Center and many others in the greater iUTAH project*
- ***Federal:*** *National Science Foundation, USGS*

Project Description

- **Need and Purpose:**

  Groundwater gains and losses in stream and river systems are critical to characterize 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 is 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 there is also a need for a broader, variable scale investigation of groundwater gains and losses along fast flowing high-gradient streams and river systems.

- **Benefits to the State:**

  The overall focus of this research is to analyze existing flow and chemical data collected throughout two northern Utah streams. The study aims to quantify groundwater influences in pristine, mountainous, and urban portions of each watershed. Detailed flow data were gathered in 2014-2015 at small spatial scales during different flow conditions in Logan River (five sampling events) and Red Butte Creek (four sampling events). These data are available along the main-stem as well as tributary inflows and diversions. For two sampling events in each watershed, chemical data were also gathered at all discharge locations. These chemical and flow data can be used to determine the role of groundwater on surface water throughout each watershed. Time series data from a subset of locations in each watershed may also provide fundamental information regarding temporal variability of exchanges. The results of this research will contribute to better management of the water quantity and quality of our pristine mountain streams.

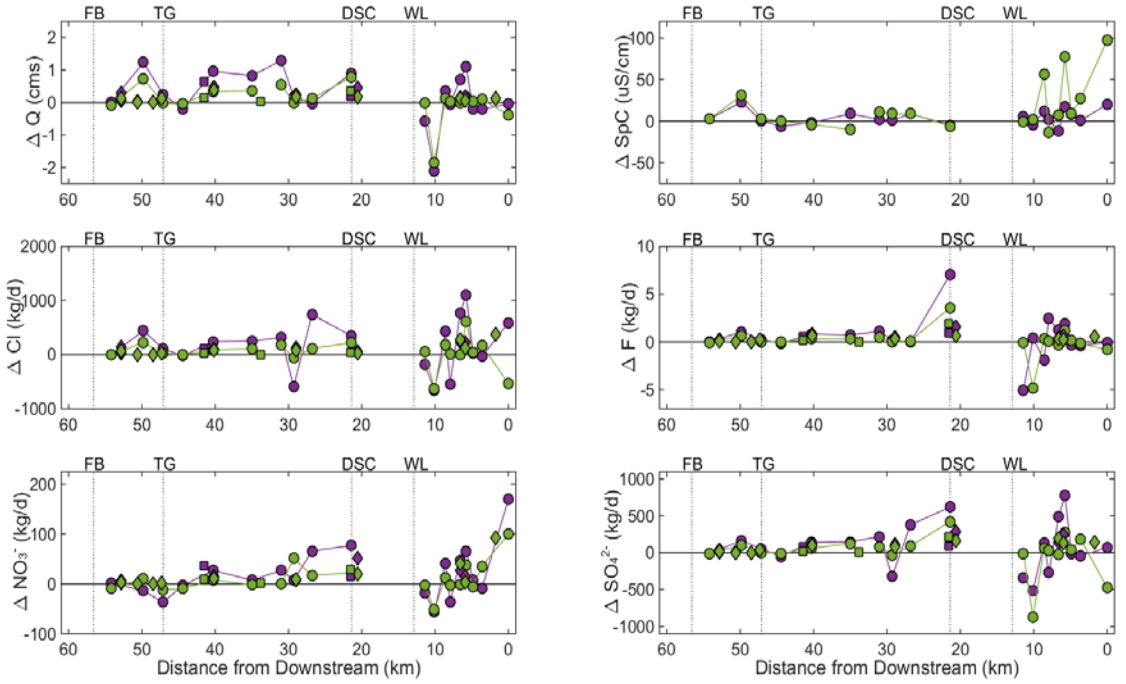
- **Geographic Areas:**

  Study Area: Logan River, Logan, UT and Red Butte Creek, Salt Lake City, 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 balance information, principle component analyses, and mass balances, we have developed a series of assumptions and equations that allow for the quantification of deep and shallow groundwater in gaining, losing, and simultaneously gaining/losing reaches. The figure below illustrates the ΔQ or total groundwater gained or lost over reaches starting at Franklin Basin (FB, ~55 km) and ending at Mendon Road (0 km) based on flow balances. It also shows the change in load of individual ions over each reach.



Results: This unique approach and data set provides a simple method for understanding complicated groundwater interactions in mountain watersheds. An undergraduate (BS) and two graduate (PhD and MS) students have assisted on this project, and we have joined with some collaborators at the University of Utah that have primarily focused on analyzing data from Red Butte Creek. A draft manuscript has been developed describing the groundwater interactions in the urban portion of Red Butte Creek. The Logan River manuscript is in development.

Work Plan FY16/FY17

We will continue analyses of existing and new data sets to support the development of peer reviewed journal articles.

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***

Gabor, R.*, Brooks, P., Neilson, B.T., Barnes**, M.L., Stout**, T.L., Millington**, M., Gelderloos**, A., Tennant***, H., and Eiriksson, D. (2015). Assessing Changes in Water Chemistry along the Mountain to Urban Gradient. *24th National NSF EPSCoR Conference*. November 2015. Portsmouth, NH.

Gabor, R.*, Brooks, P., Neilson, B.T., Barnes**, M.L., Stout**, T.L., Millington**, M., Gelderloos**, A., Tennant***, H., and Eiriksson, D. (2015). Assessing Changes in Water Chemistry along the Mountain to Urban Gradient. *2015 Fall Meeting, American Geophysical Union*, December 14-18, 2015. Abstract B41B-0418. San Francisco, CA.

Tennant***, H, Barnes**, M.L., Stout**, T., and Neilson, B.T. (2015). Methods and Techniques for Measuring Discharge in Three Utah Watersheds. *iUTAH Summer Symposium*, July 2015. Midway, UT.

Release of Arsenic from Aquifer Solids under Anaerobic Conditions

Principal Investigators:
Joan E. McLean
Darwin L. Sorensen
Babur Mirza
Kelsey Wagner (MS student)
Kaisa Forsyth (MS student)
William Fullmer (BS student)

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

Project Description

- **Need and Purpose:**

  Arsenic is one of the most frequently detected individual contaminants in domestic private wells used for household drinking water and public water supplies in the U.S. Of the domestic wells tested that had arsenic in excess of the drinking water limit (10 µg/L), 10% were located in the basin-fill aquifers of California, Nevada, New Mexico, Arizona, and Utah. Seventeen percent of the well water in Cache County, as reported by the Utah Geological Survey, contained levels of arsenic that exceeded the drinking water limit. Elevated concentrations of arsenic are also present in the well water of Salt Lake and Utah counties. Geologic formations throughout Utah contain arsenic; however, many of these formations are stable and pose no threat to humans or the environment. Our past research 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 arsenic solubility. Carbonate minerals are common in the geology of the semi-arid west and, thus, could contribute significantly to arsenic biogeochemistry in soils and groundwater in this region.

- **Benefits to the State:**

  All counties in Utah will benefit from an improved understanding of the biogeochemistry governing the behavior of arsenic 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: City of Logan Landfill, Cache County; Hill AFB, Weber-Davis County.

Figure 1. Collecting samples in the Cache Valley Basin

Areas Benefited: In addition to the specific areas above, this project will contribute to protection of groundwater resources throughout the state. Arsenic in groundwater is a worldwide problem.

- **Accomplishments:**

  Findings: We conducted a survey of arsenic concentrations in surface soils across the Cache Valley Basin (Figure 1 and 2). We have previously evaluated arsenic-geochemistry in aquifer solids associated with the groundwater. Here we investigated the contribution of arsenic in surface soils as a continuous source of arsenic contamination of groundwater.

  Results: The concentration of arsenic in the surface soils was within the range reported for U.S. soils (1-50 mg/kg). However the arsenic in these soils, in particular the RS soil, is extractable with mild chemical reagents that remove arsenic from soil surfaces associated with potentially soluble carbonate and amorphous oxide minerals. This loosely held arsenic is susceptible to leaching with input of rain, stormwater or irrigation water and end up contaminating groundwater. We have previously reported on arsenic geochemistry in soil profiles, from the soil surface to depth of groundwater, at NP13 (Figure 2). The present results show that surface soils across Cache Valley are potential sources for arsenic in groundwater. Land management becomes a consideration in preventing leaching of arsenic from the surface to groundwater.

Work Plan FY16/FY17

We are investigating the impacts of a rising and lowering water table on arsenic solubility using field and laboratory studies. This cycling between wet, anaerobic and dry, aerobic conditions will drive the association of arsenic with iron oxides and carbonate minerals. Research this year in northern Utah will focus on which process is most important and under what conditions?

Informational Resources

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

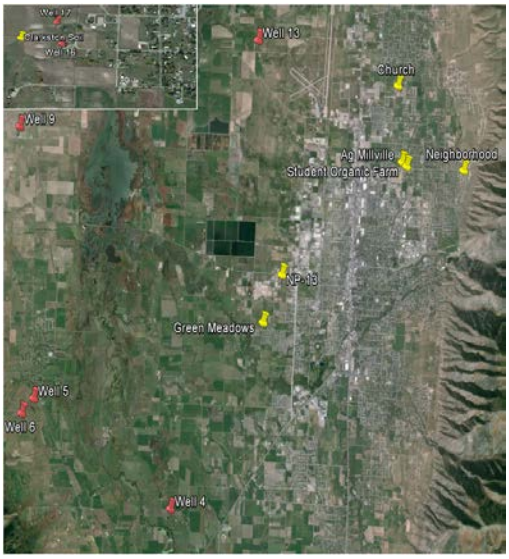


Figure 2. Location of surface soils collected for this study indicated by the yellow pins

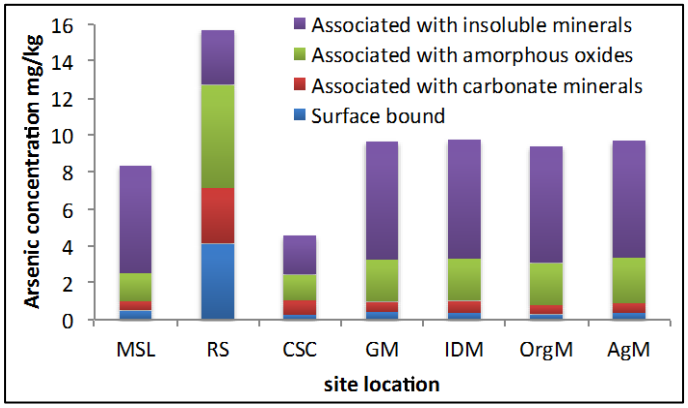


Figure 3. Arsenic concentrations per site location

Source Water Protection from Potential Phosphorus Mining Impacts in the Uintah Basin

Principal Investigators:
David K. Stevens
Joan E. McLean
Ahmed Bitar (graduate student)

Partners/Collaborators:

- ***Local:*** *City of Vernal and Uintah County*

Project Description

- **Need and Purpose:**

  Source water protection for drinking water systems remains a significant public policy concern in the State of Utah. A proposed phosphate mine in the Uintah Basin, Utah, near the city of Vernal on Ashley Creek, may threaten the city's water supply at Ashley Springs with (1) non-point source runoff that could contaminate the water supply with sediment and inorganic pollutants and (2) modifications to flow regimes that could disrupt discharge from those springs. Discussion with city and county officials has highlighted concerns regarding threats to the water supply. The proposed phosphate mining operation is on the ridges surrounding Ashley Creek. Removal of ~20 meters of overburden cap rock and the phosphorus-bearing ore will expose buried materials to weathering. This will create a significant risk for release of sediment and toxic anions such as selenium and arsenic and other anions such as sulfate. All of these materials would threaten the quality of the water supply at Vernal's Ashley Springs and could impact the spring discharge and force the city to seek alternative sources. This project is collecting and assessing data to provide the City of Vernal and Uintah County with resources and tools to deal with this possible threat to Ashley Springs.

- **Benefits to the State:**

  The data and information from this project will provide:

  - An assessment of the current situation and the potential for changes in hydrology and contaminant transport that may threaten drinking water supplies.
  - Resources and tools for the City of Vernal and Uintah County to plan for the possibility of this threat to Ashley Springs as a drinking water source.
  - Data and reporting activities that will help city and county decision makers to understand potential threats and act to protect this drinking water source, including: field measurements of physical parameters (e.g. channel configuration) needed for analytical models; collection of water quality data near source water protection zones where such data are not available; incorporating data in a database system to produce data summaries and reports; and public meetings with stakeholders.

- **Geographic Areas:**

  Study Area: All project related work is being performed in Uintah County and at the UWRL.

  Areas Benefited: Watersheds statewide.

- **Accomplishments**: The following elements have been completed:

Findings/Results:

Assess Data Needs—Existing data have been collected, reviewed, and warehoused in spreadsheets for assessment purposes. An existing database that includes hydrologic and water quality data in Ashley Creek and Dry Fork through 2003 has been updated through 2012. Additional land use, topography, weather, and other data have been collected. Once existing data are compiled, we will determine their suitability for source water assessment, and recommend any additional data collection.

Delineate/Assess Source Water Protection Zones—A Source Water Protection plan was developed by the Central Utah Water Conservancy District for Ashley Springs based on land use in effect in 2009. The Zone 1 protection area (the most critical) is shown shaded in red on the map below, extending 1/2 mile on either side of Dry Fork 15 miles west into Dry Fork and 1/2 miles on either side of Ashley Creek 15 miles north, including all tributaries to each stream.

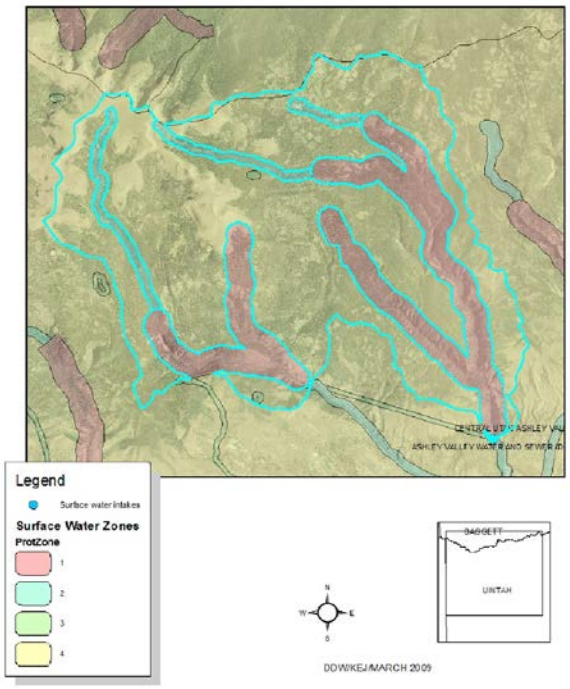
Assess potential for release of toxic inorganic compounds due to exposure of ore bodies—One important threat to drinking water from mining is exposure of the subsurface rock to oxygen, carbon dioxide, and water. Geological formations in the region have historically released selenium and arsenic when exposed to water and air, threatening viability of the water supply. A preliminary study of the geology of the proposed mining region will inform the City of Vernal of these potential concerns. This will also inform plans for sampling and analysis of subsurface materials and the effects of their exposure to weathering.

Work Plan FY16/FY17

- Complete and deploy the model for the effect of P mining on Ashely Spring. Apply SWAT/ APEX rainfall/runoff/contaminant transport model to the source protection zone.
- Complete development of modified source water protection zones for Ashley Springs and assess their suitability in light of potential phosphate mining activities within and adjacent to the Zone 1 protection area.
- Complete analysis of hydrologic, geological, and water quality date, following source protection protocols to add this fifth source and determine suitable plan changes.
- Recommend a source water protection zone.
- Complete student thesis based on project results.

Informational Resources

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



View of potential project area for Ashley Gap phosphate mining (CUWCD 2009)

Water Conveyance, Distribution, and Control

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

Project Name	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
Irrigation Field Flow Measurement, Maintenance and Upgrade for the State of Utah	$ 4,208.32	$ 8,000.00	$ 8,282.06
Labyrinth Weir Research	$ 50,163.08	$ 3,000.00	$ -
Designated Projects		$ 12,500.00	$ 15,000.00
Undesignated Projects		$ 7,500.00	$ 7,800.00
Total	**$ 54,371.40**	**$ 31,000.00**	**$ 31,082.06**

Irrigation Field Flow Measurement, Maintenance and Upgrade for the State of Utah

Principal Investigators:
Steven L. Barfuss

Partners/Collaborators:
- ***State:*** *James Greer, Utah DWR*
  Gertrudys Adkins, Utah DWR

Project Description

- **Need and Purpose:**

  Limited and depleted water resources have become an issue of increased concern, especially in Utah where the arid land requires irrigation to produce ample crops. As a result, water distribution system managers have realized the importance of accurately measuring water used in their systems. Understanding the available methods and measurement devices and their specified accuracies is vital to ensuring that the best achievable distribution and use of water is occurring.

  Initial investigations showed that a large number of flow measurement devices throughout the State of Utah were not measuring flow at the accuracy that design manufacturer specifications claim. The purpose of this project has been to determine major contributors to flow measurement errors and to assess the devices that exhibit these errors in an attempt to provide direction for reducing these measurement errors. Another purpose is to provide a resource to irrigation companies for evaluating the accuracy of their flow measurement devices and to provide suggestions on how to improve the accuracy of their devices.

- **Benefits to the State:**

  Improved accuracy of flow measurements throughout the State of Utah will ultimately improve the allocation of water rights. Over time, small errors in flow measurement can add up to very large errors in the allocation of water rights. This project is generating a database of information to determine which flow measurement structures have the greatest need for remediation, repair, or recalibration. The project directly benefits water companies in the State as a result of the in-field calibrations that are performed.

- **Geographic Areas:**

  Study Area: Entire State of Utah.

  Areas Benefited: All irrigated areas of Utah.

- **Accomplishments**:

  Findings: A total of 259 flow measurement device assessments have been performed as of August 24, 2016. These devices include 153 Parshall flumes, 23 ramp flumes, 4 cutthroat flume, 29 weirs, 27 rated sections, 6 sluice gates, 12 ultrasonic meters and 5 magnetic meters. Only 31.3% of the tested devices measured flow within manufacturer design specifications. The remaining 68.7% exhibited flow measurement errors in excess of the design specifications. Some of the major contributing factors to inaccuracies were uneven settlement, sediment and moss buildup in and around the structure, corrosion or damage to the device, uneven flow where head measurements are taken, and improper construction

of the device. These factors create incorrect measurements that prevent water users from receiving their true water allocations.

Results:

- A list has been generated that details all visited sites and their locations, measurement device types, accuracies, and problems.
- Verification certificates for each site visited were created and sent to the measurement device operator, the Utah Division of Water Rights, and any other interested party.

Work Plan FY16/FY17

- Continue to locate flow measurement devices throughout the State of Utah.
- Visit flow measurement device sites, perform verification tests to determine the accuracy of the flow measurement devices, and document concerns about the error associated with each structure.
- Continue to report findings to the Utah Division of Water Rights and encourage the improvement and maintenance of degraded or inaccurate flow measurement devices.

Informational Resources

Contact: Mr. Steven. L. Barfuss, Telephone: (435) 797 3214, Email: steve.barfuss@usu.edu.

Examples of Flow Measurement Devices Tested in Utah

Labyrinth Weir Research

Principal Investigator:
Blake P. Tullis
Mohanad Khodier (Post Doc Student)

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

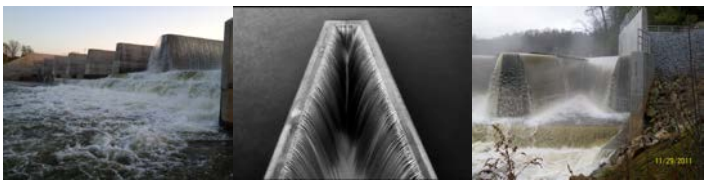


Figure 1. (a) staged labyrinth weir, (b) labyrinth weir apex

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. This study included work on the following topics: (a) controlling peak reservoir flood discharges through the use of staged labyrinth weirs, (b) influence of labyrinth weir apex design on hydraulic efficiency, and (c) weir flow nappe vibration/instabilities.

(a) In many cases, the goal with reservoir flood routing is to maximize the outflow discharge, using highly efficient flow control structures such as labyrinth weirs, to maximize dam safety and minimize upstream flooding. In other cases, the maximum outflow through the spillway should be limited during more frequent lower-magnitude flood events to minimize downstream flooding impacts.

(b) Labyrinth weir hydraulic inefficiencies have been attributed to the colliding flows at the upstream apex (typically a trapezoidal weir wall geometry in plan view). The apex width should be made sufficiently wide to be "constructible" (allow sufficient room for concrete form work) while mitigating the negative effect of overall weir length reduction that comes with wider apexes. Laboratory tests were conducted to evaluate the influence of apex geometry variation on hydraulic efficiency.

(c) Under certain conditions, the jet of water (nappe) flowing over a weir wall can become unstable and begin to vibrate. Nappe vibration can create significant acoustic energy that may pose structural response risks as well as negative environmental impacts. Laboratory tests were conducted to develop a better understanding of nappe vibration behavior and methods of mitigation.

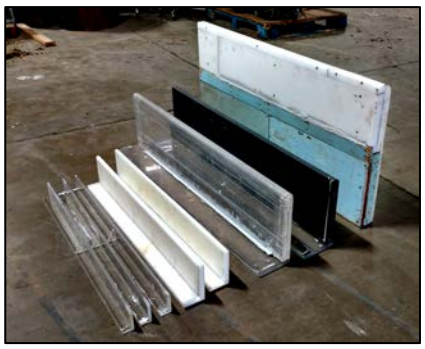


Figure 2. Linear weir models for size scale test

- **Benefits to the State:**

The results of this labyrinth weir study may provide a spillway upgrade alternative and may prove useful in increasing the sustainability of existing dams with undersized spillways. Labyrinth weirs are a commonly used alternative to linear weirs for increasing the spillway capacity without increasing the width of the spillway apron. Insufficient data are currently available for the range of labyrinth weir design alternatives. The Utah Division of Water Resources is currently designing an arced labyrinth weir for Millsite Reservoir (UT) based on this research.

- **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 statewide and globally.

Figure 3. Large-scale piano key and labyrinth weirs

- **Accomplishments:**

(a) Using previous research results, which established hydraulic discharge relationships for staged labyrinth weirs (staged labyrinth weirs feature weir wall segments with varied crest elevations), the effects of weir type (linear ogee crest weir, labyrinth weir, staged labyrinth weir) on peak reservoir outflow discharges were evaluated using a numerical flood routing computer model and a fictitious reservoir. Results showed that, by varying the hydraulic characteristics of the spillway control structure (i.e., weir), the peak reservoir outflow discharge can be manipulated based on how the reservoir flood storage volume is utilized during a flood routing event. This paper was submitted in 2014 and resubmitted to a different journal in 2015 for review.

(b) A peer reviewed journal paper examining the effect on labyrinth weir apex width with respect to discharge efficiency will be completed and submitted in 2016-17.

(c) Research on unstable nappe flow behavior was completed in 2015. A paper will be submitted in 2016-17 for review.

(d) New research on unstable nappe flow behavior was performed in 2015-16. Using the Particle Image Velcometry system, the air flow patterns in the air cavity behind the nappe were investigated, specifically near the crest. Velocity profiling inside the nappe was also conducted in a unique test set up where the free water surface acted as a reflective boundary and projected the laser light and data collection beyond the direct line of sight of the laser. One peer reviewed journal paper has been submitted on this topic, and two additional papers are in progress.

(e) A study of size scale effect on linear suppressed weirs with flat top, quarter-round, and half-round crest shapes was completed. Four different geometrically similar weir sizes were tested with weir heights of 36, 12, 6, and 3 inches. Results showed that viscous and surface tension-driven size scale effects do indeed exist with smaller weir sizes, and the corresponding uncertainty was quantified.

Work Plan FY16/FY17

In FY17, we will primarily focus on evaluating size-scale effects for non-linear weirs. As the size scale decreases, the relative influence of surface tension and viscous effects become more significant, relative to the usually dominant gravitational and inertial forces that drive free-surface flow problems. We hope to identify the effects of model scale on head-discharge relationships, nappe trajectory, and air entrainment for a variety of laboratory scale models. The largest weir models will be 3 ft. tall and will represent the prototype scale. All other weirs will be geometrically similar at smaller scales. We plan to submit three conference papers on these topics and 3 to 4 peer reviewed journal papers.

Informational Resources

Contact: Dr. Blake P. Tullis, Telephone: (435) 797 3194, E-mail: blake.tullis@usu.edu.

Water Education and Technology Transfer

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

Project Name	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
Ad hoc Advisor to the Utah Legislature Transportation Interim Committee	$ 3,008.00	$ 3,098.24	$ 3,191.19
Education Program for Homeowners and Other Users of Septic Systems in Utah	$ 16,724.55	$ 17,226.29	$ 17,743.08
Intermountain Section American Water Works Association (IMS-AWWA) Scholarship and Student Outreach Committee	$ 1,096.00	$ 1,128.88	$ 1,162.75
Manuals for On-Site Wastewater Treatment Best Practices	$ 5,574.85	$ 5,742.10	$ 5,914.36
Salt Lake Valley Solid Waste Management Council	$ 2,276.81	$ 2,345.11	$ 2,415.47
State of Utah Drinking Water Board	$ 1,778.00	$ 1,831.34	$ 1,886.28
State of Utah Operators Certification Commission	$ 1,185.00	$ 1,220.55	$ 1,257.17
Statewide Nutrient Criteria Development: Core Advisory Team	$ 3,500.00	$ 3,605.00	$ 3,713.15
Utah On-Site Wastewater Treatment Training Program	$ 48,186.08	$ 17,000.00	$ 17,510.00
Virgin River Gorge Fish Barrier Physical and Numerical Hydraulic Model Study	$ 1,678.00		$ -
Weber-Morgan Health Department Wastewater Advisory Committee	$ 4,200.00	$ 4,326.00	$ 4,455.78
Designated Projects			
Undesignated Projects		$ 7,500.00	$ 10,000.00
Total	**$ 89,207.29**	**$ 65,023.51**	**$ 69,249.21**

Ad hoc Advisor to the Utah Legislature Transportation Interim Committee

Principal Investigators:
Mac McKee

Partners/Collaborators:

- ***State:*** *Utah Legislature Transportation Interim Committee, Utah Governor's Office of Economic Development, Marshall Wright*
- ***Private:*** *Various representatives from the private sector interested in and knowledgeable of the commercial and research opportunities attached to unmanned aerial systems*

Project Description

- **Need and Purpose:**

  Unmanned aerial systems (UAS) technology is rapidly developing and is expected to become a disruptive influence in the US economy over the next 20 years. Utah is well positioned to become a leader in this area. However, the regulatory environment surrounding the commercialization of the technology is ill-informed and in a state of flux. Unfortunately, for the most part, this has retarded technological advances and the economic returns that the use of UASs can bring. Regulation of this developing industry is important in order to protect privacy and safety, as well as to encourage possible economic development.

- **Benefits to the State:**

  The UAS industry in the US is in a fledgling state. It is a new technology that has not previously seen domestic applications. Domestic applications of UASs in agriculture, natural resources management, surveillance, and a host of others uses are forecast to be an $82 billion per year industry by 2025. Utah is well situated to participate in the economic and job growth that UASs will bring, but the state must be prepared with regulations that foster economic growth and protect privacy and safety. Over the course of the past year, Dr. McKee has provided official testimony before hearings of the Transportation Interim Committee and, at the request of Committee Leadership, he has attended several meetings as an informal advisor. He has offered analyses of UAS legislation that has been adopted in other states, and has provided comments and suggestions for regulatory legislation that might be considered for Utah. For more than 10 years, the UWRL has driven the development, testing, and deployment of UASs for use as scientific-grade remote sensing devices in support of research in water, agriculture, and natural resources management problems. Personnel from the UWRL have extensive scientific, engineering, and management expertise in this newly emerging area that is of great economic potential for the State.

- **Geographic Areas:**

  Study Area: Statewide.

  Areas Benefited: Potential economic benefits could be felt state-wide.

- **Accomplishments:**

  Findings/Results: The UWRL has played a key role in educating state officials on UAS-related research and development activities that are ongoing and on the economic potential of UAS applications in the areas of agriculture and natural resources management. The UWRL continues to support the State's effort to

benefit from UAS development and use by offering expert advice to the Transportation Interim Committee and in other settings as needed.

Work Plan FY16/FY17

The UWRL will continue to provide information and guidance as requested by the Lt. Governor.

Informational Resources

Contact: Dr. Mac McKee, Telephone: (435) 797-3188, E-mail: mac.mckee@usu.edu.

Education Program for Homeowners and Other Users of Septic Systems in Utah

Principal Investigators:
Judith L. Sims

Partners/Collaborators:

- ***Local:*** *Utah Local Health Departments*
- ***State:*** *Utah Division of Water Quality, Utah Department of Environmental Quality*

Project Description

- **Need and Purpose:**

  The goal of the project is to develop and deliver an educational approach to improve owner/user stewardship of on-site wastewater treatment systems. Many brochures and flyers list "dos" and "do nots" for the users of septic systems, but such simple guidelines can be easily forgotten and not incorporated into everyday personal habits. Effective educational tools for ensuring that septic systems are adequately operated and maintained would help the users to better understand their role in protecting public health and the environment. If septic system users had information focusing on their responsibilities for their septic systems as personal wastewater treatment plants, they would be better prepared to fulfill their roles as environmental stewards, and the effectiveness of homeowner on-site septic systems would be enhanced.

- **Benefits to the State:**

  Expected benefits to Utah watersheds include water supplies protected from the harmful effects of excessive organic materials, nitrogen, phosphorus, suspended solids, and pathogens that may occur from runoff of wastewater from surfacing failing on-site systems. The flow of contaminants (especially pathogens and nitrogen) carried by subsurface transport of wastewater from failing, overloaded, or improperly maintained systems to ground water or through watershed base-flow to surface waters can be reduced by proper management of septic systems by homeowners or system users.

- **Geographic Areas:**

  Study Area: Statewide.

  Areas Benefited: Presentation of educational workshops will be targeted for areas in Utah with impaired water bodies that may be affected adversely by septic systems or in areas were improperly managed septic systems could potentially impact water bodies or ground water. However, educational materials developed in this project will also be made available to all thirteen Utah local health departments for dissemination to homeowners and other septic system users.

- **Accomplishments:**

  Findings: We have investigated approaches to educational programs using social marketing techniques. Social marketing is the use of marketing principles to influence human behavior in order to improve health or benefit society. Social marketing includes: (1) focusing on a key issue; (2) developing a key objective to define the issue; and (3) focusing on reaching the key audience with messages that work. We also have developed and administered a survey to Utah on-site professionals to help us define topics that are essential for homeowners to know regarding the use (and abuse) and maintenance of their septic systems.

Results: Based on our investigations, we identified the following topics as essential for our educational program:

Ins and Outs of Septic Systems:

- What Type of System Do You Have?
- What Do You Need to Know About Your Septic System?
- Do You Know the Location of Your Septic System and Replacement Area?
- Is Your Septic System Working Okay?
- What Maintenance Has Been Done?
- What Maintenance Do You Need to Do? Day-to-Day Management of Your Septic System.
- Don't Use Too Much Water.
- Don't Use Your Septic System as a Trash Can.
- Protect Your System from Physical Damage.
- Dispose of All Wastewater into Your Septic System: Periodic Maintenance and Repair.
- Home and Yard, Including Drain Field.
- Septic Tank.
- Regulations.
- Signs of Septic System Problems.

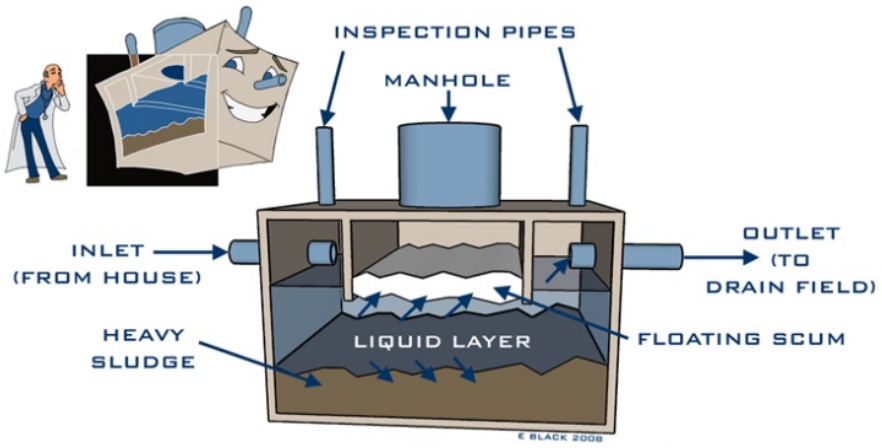
During FY15/FY16 we continued to develop and prepare the documents and presentations associated with the topics identified as being critical.

Work Plan FY16/FY17

During FY 16/17, we will finalize the educational program materials, which will include homeowner/system user handouts and workshop presentations. We will provide homeowner workshops at various locations around the state and will work with local health department staff who might want to present workshops themselves. We will also provide fact sheets to local health departments for distribution to homeowners and systems users and to real estate groups.

Informational Resources

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



Intermountain Section American Water Works Association (IMS-AWWA) Scholarship and Student Outreach Committee

Principal Investigator:
Laurie S. McNeill

Partners/Collaborators:

- ***State**: Intermountain Section American Water Works Association*

Project Description

- **Need and Purpose:**

  The drinking water industry is facing a wave of retirements and needs to recruit new engineers to join the field. This is particularly true in Utah.

- **Benefits to the State:**

  This committee provides scholarships to students who will contribute to the field of water quality, supply, and treatment in the Intermountain West (Utah and southern Idaho). There are currently four scholarships: one undergraduate ($1,000), two graduate ($1,500 each), and one diversity ($1,000). The committee also organizes the "Fresh Ideas Poster Contest" at the Intermountain Section's Annual Conference, with the winner competing at the national AWWA Annual Conference and Exhibition.

- **Geographic Areas:**

  Study Area: Statewide.

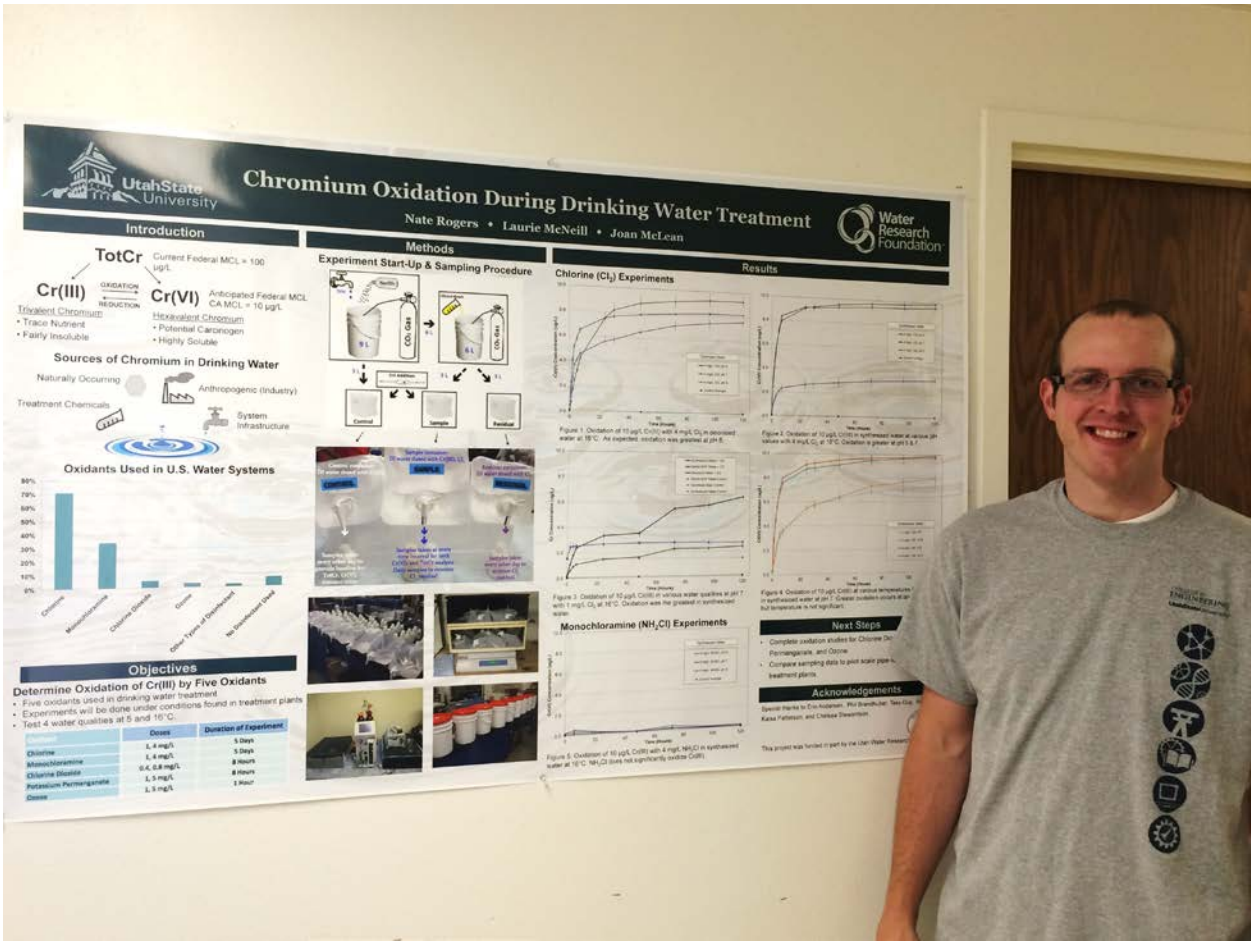
  Areas Benefited: Statewide—students at any college or university in Utah or southern Idaho are eligible.

- **Accomplishments:**

  Findings/Results: Four students (one undergraduate and three graduate) were awarded scholarships totaling $5,000 to study water quality and treatment during the Fall 2015 semester. Three students are studying at Utah State University and one at University of Utah. A total of 14 applications were received this year. The Fresh Ideas poster contest was also a great success. The winner (a USU Graduate Student) received funding to present his poster at the national AWWA conference in Chicago, IL in June 2016.

Work Plan FY16/FY17

Participation in IMS-AWWA meetings and activities will continue. At least four scholarships will be awarded in Fall Semester 2016, and the Fresh Ideas Poster Contest will take place on September 14-16, 2016 in St. George, UT.



Nate Rogers, Winner of the 2015 Fresh Ideas Poster Contest

Informational Resources

Contact: Dr. Laurie S. McNeill, Telephone: (435) 797-1522, E-mail: Laurie.McNeill@usu.edu.

Website: http://ims-awwa.site-ym.com/group/Scholarship.

Manuals for On-Site Wastewater Treatment Best Practices

Principal Investigators:
Judith L. Sims

Partners/Collaborators:
- ***State:*** *Engineering Section, Utah Division of Water Quality, Utah Department of Environmental Quality*

Project Description

- **Need and Purpose:**

  In this project, we are developing best practice manuals for various aspects of on-site wastewater treatment methods and technologies. These manuals will enhance training workshops presented by the Utah On-Site Wastewater Treatment Training Program at Utah State University in support of the Utah mandatory certification program for on-site wastewater professionals (R317-11: *Certification Required to Design, Inspect and Maintain Underground Wastewater Disposal Systems, or Conduct Soil Evaluations or Percolation Tests for Underground Wastewater Disposal Systems*). These manuals will also serve as stand-alone guidance and educational tools.

- **Benefits to the State:**

  Expected benefits to Utah include protection of water supplies from the harmful effects of excessive organic materials, nitrogen, phosphorus, suspended solids, and pathogens that may occur from runoff of wastewater from surfacing failing on-site systems. Subsurface transport of wastewater from overloaded systems may carry contaminants (especially pathogens, nitrogen, and phosphorus) to ground water or through watershed base-flow to surface waters. High-quality and thorough educational materials will help Utah on-site professionals to develop and implement tools to reduce the flow of contaminants to water bodies from on-site systems.

- **Geographic Areas:**

  Study Area: Statewide.

  Areas Benefited: Entire State of Utah.

- **Accomplishments:**

  Findings: Three manuals, which reflect Levels 1, 2, and 3 of the certification program, are being prepared:

  1. Best Practices: Site and Soil Evaluation Procedures and Evaluation Techniques—Topics include soil evaluation procedures, identification of other critical site features and requirements, assessment of site feasibility, and guidance on the appropriate use of percolation testing in selected situations.
  2. Best Practices: Design, Installation, Inspection, and Operation & Maintenance of Conventional On-Site Wastewater Treatment Systems—Topics include septic tank selection, installation, and maintenance, absorption field distribution options (including pros and cons of each type), design and installation of absorption systems (standard trenches, chambered trenches, bundled synthetic aggregates), absorption beds, deep wall trenches, and seepage pits, sizing and layout of systems, inspection of systems, and operation and maintenance of systems.

3. Best Practices: Design, Installation, Inspection, and Operation & Maintenance of Alternative On-Site Wastewater Treatment Systems—Topics include selection of the appropriate alternative system with regards to site and soil limitations, design guidance, installation, and maintenance considerations, inspection of systems, and operation and maintenance of systems.

Best practices are being developed from Utah regulatory materials, present Utah Training Program educational materials and tools, U.S. Environmental Protection Agency guidance materials, and educational materials developed by the Consortium of Institutes for Decentralized Wastewater Treatment. The manuals developed through this project will focus on Utah regulations, practices, and needs.

Results: During FY15/FY16, we continued to develop design worksheets, recording sheets for site and soil information, installation and inspection checklists, and operation & maintenance checklists. These worksheets and forms are being prepared specifically to address Utah guidelines and practices.

We also began writing the text of the manuals.

Work Plan FY16/FY17

During FY16/FY17, we will complete the manuals of best practice and submit drafts of the manuals to the Utah Division of Water Quality(DWQ) staff for review. After revisions have been accepted by the DWQ, the completed manuals will be distributed to each of the thirteen Utah health departments and to the Utah Division of Water Quality on-site program. The documents will also be made available on-line through the USU Training Program web site.

Informational Resources

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

Salt Lake Valley Solid Waste Management Council

Principal Investigators:
R. Ryan Dupont

Partners/Collaborators:

- ***Local:*** *Scot Baird, Salt Lake County Public Works; Debbie Lyons, Vicki Bennett, Salt Lake City Public Works; Dorothy Adams, Salt Lake County Health Department; Russ Willardson, Council of Governments; Staff, Salt Lake County Solid Waste Management Facility; Mark Hooyer , Trans Jordan Landfill*
- ***State:*** *Scott T. Anderson, Director, Division of Solid and Hazardous Waste*

Project Description

- **Need and Purpose:**

  The goal of the Salt Lake Valley Solid Waste Management Facility (SLVSWMF) is to provide long-term environmental stewardship, financial integrity, safety, recycling education, and quality service to benefit the environment, residents, businesses, and employees of Salt Lake County.

  The SLVSWMF operates a transfer station and landfill and is involved with the collection, transportation, and disposal of municipal and commercial solid waste within the Salt Lake City and Salt Lake County boundaries. The landfill facility operates a citizen's unloading facility, provides recycling for various commodities, including household hazardous waste, collects landfill-generated methane for electricity production, runs a green waste compost production operation, and is involved in land reclamation. The facility is also proactively involved in educating the public about waste reduction, recycling, composting, and other sustainability practices, and provides informational tours of the landfill and transfer station facility and their operations.

  The SLVSWMF operates on the financial principle of an enterprise fund and is supported by gate fees rather than tax revenues. The SLVSWMF Council is tasked with oversight of operations at the facility and makes recommendations to the owners of the facility (Salt Lake City and Salt Lake County) regarding operational issues and policies, fee structure for services provided to the public, and other regulatory and management issues that arise in the running of the enterprise.

- **Benefits to the State:**

  Membership on the SLVSWMF Council provides service to the citizens of Salt Lake City and Salt Lake County, the Utah DEQ, and the regulated community by providing technical overview and expertise in solid waste management to the operating staff of the facility. The PI attends monthly meetings of the SLVSWMF Council, provides comments and input on solid and hazardous waste issues that arise, and has responded to special requests from the Council or facility staff regarding technical issues affecting operation at the facility. Recent examples of special project requests include review of food waste composting proposals; investigation of the impact on the SLVSWMF carbon and energy footprint of expanding green waste recycling on a county-wide basis, implementing food waste composting in Salt Lake City, and an analysis of the connection between curbside green waste collection and water quality impacts to the Jordan River from urban stormwater from Salt Lake City.

Figure 1. Windrow composting at the Salt Lake Valley Solid Waste Management Facility

- **Geographic Areas:**

  Study Area: Salt Lake City, West Valley City, and Salt Lake County.

  Areas Benefited: Salt Lake City, West Valley City, and Salt Lake County.

- **Accomplishments:**

  Findings/Results: The PI attended all regularly scheduled SLVSWMF Council meetings throughout FY15/FY16 and provided review and comment on all Council items relevant to his area of expertise, being heavily involved in analysis and development of recommendations regarding implementation of mandatory green waste recycling, food waste recycling, and increased municipal solid waste recycling throughout Salt Lake City, West Valley City, and Salt Lake County, as well as composting system and shredder analyses, gas collection system updates, green waste collection/stormwater impacts, and cost of services analyses.

Work Plan FY16/FY17

Continue involvement in decision-making through attendance at monthly SLVSWMF Council meetings and respond to special project requests as they arise to support the SLVSWMF's mission and goals. Continue the evaluation of food waste composting and urban stormwater pollutant generation and development of stormwater pollutant loading data to support analysis of curbside green waste program operations.

Informational Resources

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

Website: http://www.slvlandfill.slco.org/.

State of Utah Drinking Water Board

Principal Investigators:
David K. Stevens

Partners/Collaborators:
- ***State:*** *Kenneth Bousfield, 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.

- **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, 2015 to June 30, 2016 except one, due to a scheduling conflict, 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.

Work Plan FY16/FY17

Continued involvement on the Board through 2018—this year through comments during Sabbatical Leave.

Informational Resources

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

Website: http://www.drinkingwater.utah.gov/Board/board.html.

State of Utah Operators Certification Commission

Principal Investigators:
David K. Stevens

Partners/Collaborators:
- ***State:*** *Kenneth Bousfield, 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 the Department of Environmental Quality (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. 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, 2015 to June 30, 2016, and provided review and comment on all Commission items relevant to his area of expertise. The PI also serves on the Drinking Water Board and its Finance Committee, reviewing projects and making recommendation to the full board concerning action on proposals.

Work Plan FY16/FY17

Involvement on the Board will continue through 2018

Informational Resources

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

Website: http://www.deq.utah.gov/Certification/certification/drinkingwater/certsysoperator.htm.

Statewide Nutrient Criteria Development: Core Advisory Team

Investigator:
Darwin L. Sorensen

Partners/Collaborators:

- ***State:*** *Walter Baker, Director, Utah Division of Water Quality*

Project Description

- **Need and Purpose:**

  Many states, including Utah, are in the process of developing water quality nutrient criteria for the waters of their states (http://www.nutrients.utah.gov/index.htm). The policy and procedures developed with this process must be informed by the best available science because of the environmental, economic, and social impacts they will have on the communities and citizens of the state.

  The Nutrient Criteria Development Core Advisory Team advises the director and staff of the Utah Division of Water Quality. Members of the team include representatives from the Utah Department of Agriculture and Food, the Division of State Parks, the Division of Wildlife Resources, drinking water utilities, the US Environmental Protection Agency, environmental interests, the USDA Natural Resource Conservation Service, the USDA Forest Service, the Utah League of Cities and Towns, publicly owned wastewater treatment plant managers, storm water and ground water managers, agricultural producers, and scientific experts.

- **Benefits to the State:**

  Water quality nutrient criteria adopted by the Division of Water Quality will be applied throughout Utah. Dr. Sorensen has worked with the other members of the team and the staff of the division to formulate general and site specific standards.

- **Geographic Areas:**

  Study Area: Statewide.

  Areas Benefited: Statewide.

- **Accomplishments:**

  Findings/Results: A technology-based rule for phosphorus in wastewater treatment plant effluents became effective in January of 2015 and was amended in February 2016. The Division of Water Quality is in the process of formalizing numeric nutrient criteria for Utah's headwater streams.

Work Plan FY16/FY17

The team will continue to work into the coming fiscal year. It is anticipated that Dr. Sorensen will continue to serve as member of the team in FY17.

Informational Resources

Contact: Dr. Darwin L. Sorensen, Telephone: (435) 797-3207, E-mail: darwin.sorensen@usu.edu.

Utah On-Site Wastewater Treatment Training Program

Principal Investigators:
Judith L. Sims
Margaret Cashell
Brian Cowan
Richard Jex

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 the soils in Utah 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).

- **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 2015–2016, two Level 1 workshops, two Level 2 workshops, and two Level 3 workshops were taught at various locations around the State of Utah, including Ogden, Vernal, and Logan, as well as three Level 1 renewal workshops, three Level 2 renewal workshops, and two Level 3 renewal workshops.

Work Plan FY16/FY17

We will continue to provide workshops in support of the mandatory State of Utah certification program for on-site wastewater professionals (through FY2019/FY2020).

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., Cashell, M., Cowan, B., and Jex, R. (2015, 2016). *Course Manuals for Levels 1, 2, and 3 Certification*. Utah Water Research Laboratory, Utah State University, Logan, UT.



Virgin River Gorge Fish Barrier Physical and Numerical Hydraulic Model Study

Principal Investigators:
Steven L. Barfuss
Zac Sharp
Jordan Jarrett
Brad Clawson
Jared Justensen

Partners/Collaborators:

- ***State:*** *Steve Meismer, Washington County Water Conservancy District, St. George, Utah*

Project Description

- **Need and Purpose:**

  The physical and numerical model studies of the Virgin River Gorge Fish Barrier were performed at the Utah Water Research Laboratory in Logan, Utah. The purpose was to determine the hydraulic conditions where it becomes possible for fish to migrate upstream past the barrier. Local biologists reported that the fish barrier functioned as intended for several years. However, after the large flood event of September 2014, Red Shiner were located once again upstream of the barrier. This indicates that at high flow rates the barrier is not performing as intended. Recognizing that low velocity zones near and through the fish barrier provide hydraulic conditions for upstream passage, the study focused on searching for low-velocity regions during each specific modeling run. Accordingly, once any low-velocity locations were found, physical and numerical models were used to test trial structural modifications to the barrier that would eliminate the low velocity zones.

- **Benefits to the State:**

  The model studies were effective in developing a "fix" to prevent the upstream migration of the Red Shiner. A cutoff wall was designed and tested in the model and found to be effective in eliminating dead and low velocity regions near the fish barrier where the fish could move upstream. Construction is currently underway to install the wall, which will prevent this invasive fish species from migrating upstream into Utah within the Virgin River.

- **Geographic Areas:**

  Study Area: Virgin River.

  Areas Benefited: Washington County Water Conservancy District.

- **Accomplishments**:

  Findings: The model study showed that there were, in fact, low velocity regions under some flood conditions in which the Red Shiner could move upstream past the fish barrier. The model studies allowed researchers to determine hydraulically efficient and cost effective ways to block upstream fish passage over a wider range of Virgin River flow rates.

Results:

- Members of the WCWCD observed the operating physical model, which provided them with an opportunity to specifically observe the conditions under which upstream fish passage was possible and to make suggestions about potential remedies.
- A test report was provided to the WCWCD documenting model study results.

Work Plan FY15/FY16

The study has been completed and a report was submitted October 2015.

Informational Resources

Contact: Mr. Steven. L. Barfuss, Telephone: (435) 797 3214, Email: steve.barfuss@usu.edu.

Physical model study of Virgin River Gorge Fish Barrier

Virgin River Gorge Fish Barrier

Weber-Morgan Health Department Wastewater Advisory Committee

Principal Investigator:
Darwin L. Sorensen

Partners/Collaborators:
- ***Local:*** *Louis K. Cooper, Environmental Health Director*

Project Description

- **Need and Purpose:**

  The committee's purpose is to provide (1) scientific, technical, and socioeconomic information to the Health Department staff that will inform their decisions, and (2) counsel to the Board of Health relative to the use of on-site (e.g., septic system) wastewater treatment and disposal. Staff members of the Weber-Morgan Health Department who deal with on-site wastewater issues bring technical and technically-related policy issues to the wastewater advisory committee for advice. The committee comprises representatives from local government, land developers, consulting engineers, the Central Weber Sewer Improvement District, the Utah Geological Survey, and academia (Utah State University). The committee meets on an as-needed basis. Resolving conflicts between environmental protection policies, technical practice, and/or costs and benefits in the face of scientific uncertainty can be challenging for decision makers. The committee's multidisciplinary evaluation of the issues and possible solutions helps to inform decisions about site specific applications of policy and technology.

- **Benefits to the State:**

  The Weber-Morgan Health Department serves all of Weber and Morgan Counties. The wastewater advisory committee was formed to provide technical advice to the staff of the Department and to the Board of Health. Some actions of the committee may be used as guidance by other local health departments.

- **Geographic Areas:**

  Study Area: Weber and Morgan Counties.

  Areas Benefited: Weber and Morgan Counties.

- **Accomplishments:**

  Findings/Results: Historically, most issues addressed by the committee have been related to variance requests by citizens seeking to develop privately owned land that is not considered suitable for development under current Health Department rules. In these cases, the committee considers the scientific and public health protection principles underlying the rule and seeks to find ways for the land to be used without jeopardizing public health and environmental quality. This may be possible in some situations when more detailed site information is made available and appropriate treatment technologies can be employed. In situations where this is not possible, the committee advises against allowing a variance. Over its history the committee has considered a broad range of water quality protection issues including septic system densities in western Weber County and the development of steeply sloped properties high in the Ogden River watershed.

Work Plan FY16/FY17

It is anticipated that a Utah State University faculty member will continue to serve as a member of the committee in FY17.

Informational Resources

Contact: Dr. Darwin L. Sorensen, Telephone: (435) 797-3207, E-mail: darwin.sorensen@usu.edu.

Water Resources Planning and Management

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

Project Name	FY2016 Actual Expenditures	FY2017 Budgeted Expenditures	FY2018 Planned Expenditures
A Low Cost Vertical Take Off and Landing (VTOL) System for Remote Sensing of Water and Land Resources	$ 234,674.85	$ 20,000.00	$ 25,000.00
Advancing Hydrologic Modeling	$ 38,366.98	$ 39,517.99	$ 40,703.53
Aggie Air Imagery Information Pipeline Improvements	$ 81,568.57		
Allocating Scarce Water for Utah Wetland, Riverine and Riparian Areas with Ecological Uncertainties	$ 38,447.41	$ 39,600.83	$ 40,788.86
ASR Optimization Protocol and Decision Support: Jordan River Valley	$ 17,567.40	$ 13,193.00	$ 5,000.00
Bear River Basin Water Management in the Event of Recurring Long-Term Historical Droughts	$ 36,146.55	$ 19,500.00	$ 20,085.00
Bird Nest Aquifer Saline Injection Simulation, Optimization, and Economic Impact	$ 26,122.48	$ 10,000.00	$ 10,300.00
Crop Water Demand Monitoring and Forecasting	$ 20,754.03	$ 10,000.00	$ 10,300.00
Development of an Inexpensive UAV for Remote Sensing in Water Management and Natural Resources Management	$ 278,002.65	$ 135,000.00	$ 139,050.00
Evaluating Restoration Efforts Using Imagery from an Unmanned Aerial Vehicle (UAV)	$ 116,225.23	$ 50,000.00	$ 51,500.00
Gain-Loss Study on the San Rafael River, South Central Utah	$ 5,835.85	$ -	$ -
High Frequency Data and Cyber-infrastructure Tools for High Resolution Modeling in Snowmelt Dominated Watersheds	$ 44,489.61	$ -	$ -
Hydraulic and Thermal Characteristics of Complex Habitat Structures in the Lower San Rafael River	$ 33,219.79	$ -	$ -
Impact of Urban Irrigated Agriculture on Utah's Per Capita Water Use	$ 23,420.78	$ 4,950.00	$ -
Improving Stream Flow Forecasting	$ 52,098.48	$ 25,000.00	$ -
Irrigation System Water Use Efficiency Using Field Evaluations and Remotely Sensed Evapotranspiration Estimates	$ 11,190.45	$ -	$ -
iUTAH – Innovative Urban Transitions and Arid Region Water-Sustainability	$ 63,606.95	$ -	$ -
Metering Non-Residential Water Users to Identify Conservation Opportunities	$ 8,587.36	$ 8,844.98	$ 9,110.33
Near-Real-Time Orthorectification and Mosaicking of UAV Images	$ 59,846.13	$ 21,365.00	$ -
Organizing and Synthesizing Water Management Data to Speed Modeling	$ 22,647.92	$ 23,327.36	$ 24,027.18
Quantifying the Flow Field in Baffled Fish Culverts	$ 7,311.05	$ 7,530.38	$ 7,756.29
Real-Time Management of Irrigation Systems in the Sevier River Basin	$ 185,398.00	$ 50,000.00	$ 51,500.00
UAV Remote Sensing Service Center	$ 32,750.26	$ -	$ -
Designated Projects		$ 40,000.00	$ 50,000.00
Undesignated Projects		$ 10,000.00	$ 15,000.00
Total	**$ 1,438,278.78**	**$ 527,829.54**	**$ 500,121.19**

A Low Cost Vertical Take Off and Landing (VTOL) System for Remote Sensing of Water and Land Resources

Principal Investigators:
Calvin Coopmans
Mac McKee

Partners/Collaborators:
- ***Federal:*** *Roger Hansen, USBR*

Project Description

- **Need and Purpose:**

  Better management of water and other natural resources, such as farmland, wetlands, and floodplains, requires timely knowledge of the conditions on the ground surface and in the vegetation. Data obtained from high-resolution aerial imagery provides this essential knowledge. The Utah Water Research Laboratory (UWRL) is actively developing small Unmanned Arial Vehicle (UAV) platforms known as AggieAir for capturing high-resolution aerial imagery more frequently and at a lower cost than conventional platforms (e.g. manned aircraft and satellite). AggieAir's fixed wing platform is being used successfully for many applications. However, there is also a need for a rotary wing aircraft with the ability to take off and land vertically and to hover. Hence, this project's purpose is to develop a small rotary wing aircraft, known as a Vertical Takeoff and Landing (VTOL) platform, as part of the AggieAir system. The VTOL platform is able to launch and land in constrained areas and hover over areas to make close "point measurements." It can be used for applications such as detailed vegetation mapping and for more detailed images of water infrastructure, such as dams and canals, in order to monitor their condition and operation. The VTOL will complement the current fixed wing aircraft for applications in water resources and land management.

- **Benefits to the State:**

  AggieAir's fixed-wing UAVs have proven highly successful in collecting the detailed aerial imagery needed for managing natural resources in the State of Utah. For example, the ability to acquire decision-relevant data on soil moisture and evapotranspiration in a timely fashion and at a low cost gives canal companies and irrigation districts in the state the ability to (1) provide farmers with highly detailed information about soil moisture conditions in individual fields, enabling them to better manage scarce irrigation resources; and (2) manage complex irrigation delivery systems more efficiently, thereby saving water that could be used to increase agricultural output or allocate to growing needs of other users. The water savings could be as much as 5 or 10 percent of current deliveries.

  AggieAir's VTOL platform will also benefit the State of Utah in many similar and complementary ways to the fixed wing platform. In addition, the VTOL platform enables many new and emerging applications.

- **Geographic Areas:**

  Study Area: Most of the test flights took place at the AggieAir test site near Cache Junction, UT. We have official approval from the FAA to conduct flights there.

  Areas Benefited: All counties in the state could benefit.

- **Accomplishments**:

  Findings: AggieAir's VTOL craft engineering is finished, and the project is now in the final stages of testing and refining its operation. The AggieAir scientific payload has been integrated into the VTOL architecture

and is also undergoing final flight proofing. The RT-Paparazzi autopilot and hardware-in-the-loop simulation environment have been completed as well.

Work Plan FY16/FY17

Having accomplished all of the major goals, the new VTOL platform (named Ark) is slated to be included in the AggieAir data collection fleet in the summer of 2017 following final flight testing and proofing.

Informational Resources

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

Website: http://aggieair.usu.edu/
AggieVTOL bookchapter: http://www.igi-global.com/bookstore/titledetails.aspx?TitleId=58292.

Figure 1: New VTOL Ark Finished Airframe and payload

Figure 2: Color, Near-Infrared, Thermal Infrared foliage image data collected from AggieAir Ark Platform

Advancing Hydrologic Modeling

Investigators:
David G. Tarboton
Avirup Sen Gupta (Former student)
Sulochan Dhungel (Former student)
Nazmus Sazib (Student)
Madeline Merck (Student)

Partners/Collaborators:
Michelle Stokes, Colorado Basin River Forecast Center
Gerald Day, Riverside Technology, Ft Collins
Jeff Denbleyker, Armin Munevar, CH2M, Salt Lake City
Sarah Null, Watershed Sciences, Utah State University

Project Description

- **Need and Purpose:**

  Much of Utah's water originates as snowmelt, and, along the Wasatch Front; water that is not consumptively used ends up in the Great Salt Lake. More advanced hydrologic models are needed to predict the availability of water and to quantify changes in streamflow from watersheds within Utah and the Western US where water is scarce. The models are needed to quantify the impacts due to changes in land cover and land use in agriculture, urbanization, forest management, and climate variability. The impacts of changes are also needed in order to quantify what is going to happen to the Great Salt Lake.

- **Benefits to the State:**

  Water is a critical resource in Utah, and this project will provide a better understanding and an improved ability to predict water availability in the future as a result of land use and climate changes. It will also advance 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, as well as on the effects of growth on our water resources. This work is improving our capability to model snowmelt, which is a major source of water in the state. It is also improving our ability to simulate streamflow for flood forecasting, water supply, and stream ecosystems.

- **Geographic Areas:**

  Study Area: The study area is the semi-arid Western U.S., particularly Utah, the Great Salt Lake, and its drainage basins. Model evaluation uses data from the USU TW Daniels Experimental Forest, and SNOTEL and USGS stream gages across Utah and the Western US.

  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: This work focuses on (1) improvement of the Utah Energy Balance (UEB) Snowmelt model, (2) streamflow modeling to evaluate the potential effects of climate change on ecologically relevant aspects of streamflow regime, and (3) development of an integrated water resources management model for the Great Salt Lake.

  Results: A downscaling tool was developed to interpolate coarse scale weather data to the fine spatial scale needed for forecasting snowmelt by the Utah Energy Balance (UEB) Snowmelt

Model (Sen Gupta and Tarboton, 2016). UEB is being used in studies of flood and water supply forecasting in partnership with the Colorado Basin River Forecast Center in Salt Lake City and Riverside Technology in Ft. Collins. Besides snowmelt, research included a statistical study on the potential effects of climate change on streamflow regimes of importance to stream ecosystems (Dhungel et al., 2016) and a review of physically based modeling (Fatichi et al., 2016). We also contributed to the development of an integrated water resource management model for the Great Salt Lake, in partnership with CH2M and with the support of the State of Utah. Our work identified interesting patterns in the change of salinity with depth and time in the Lake and its deep brine layer (Figure 1). Efforts are underway to incorporate modeling of flow through the Great Salt Lake Causeway (White et al., 2015) into the GSL integrated water resources management model. This will allow the model to quantify the effects of changing lake inflows and causeway flow controls on lake levels and salinity patterns.

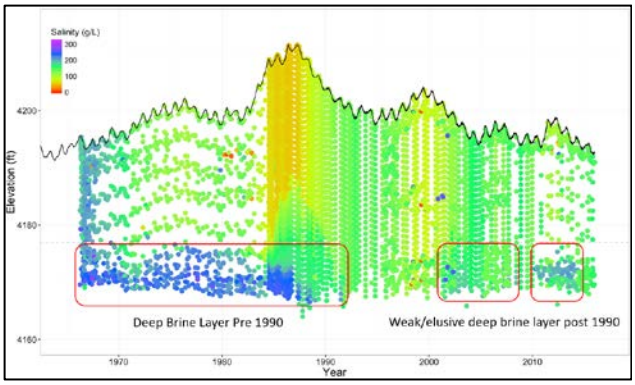


Figure 1. Great Salt Lake South Arm Salinity over time and depth indicating intermittency in deep brine layer. Based on integration of data from Utah Geological Survey and USGS.

Work Plan FY16/FY17

In the coming year we will continue the work on improving the UEB snowmelt model, and on integrating it with hydrologic models used for streamflow and water supply forecasting in the Great Salt Lake Basin and Colorado River Basin. We will also continue work on the integrated water resource management model for the Great Salt Lake.

Informational Resources

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

Publications:

Dhungel, S., Tarboton, D.G., Jin, J. and Hawkins, C.P. (2016). Potential Effects of Climate Change on Ecologically Relevant Streamflow Regimes. *River Research and Applications.* http://dx.doi.org/10.1002/rra.3029.

Fatichi, S., Vivoni, E.R., Ogden, F.L., Ivanov, V.Y., Mirus, B., Gochis, D., Downer, C.W., Camporese, M., Davison, J.H., Ebel,B., Jones, N., Kim, J., Mascaro, G., Niswonger, R., Restrepo, P., Rigon, R., Shen, C., Sulis, M., and Tarboton, G. (2016). An overview of current applications, challenges, and future trends in distributed process-based models in hydrology. *Journal of Hydrology.* http://dx.doi.org/10.1016/j.jhydrol.2016.03.026.

Sen Gupta, A. and Tarboton, D.G. (2016). A tool for downscaling weather data from large-grid reanalysis products to finer spatial scales for distributed hydrological applications. *Environmental Modelling & Software*, 84:50-69, http://dx.doi.org/10.1016/j.envsoft.2016.06.014

White, J.S., Null S.E., and Tarboton, D.G. (2015). How Do Changes to the Railroad Causeway in Utah's Great Salt Lake Affect Water and Salt Flow?. *PLoS ONE*, 10(12):e0144111. http://dx.doi.org/10.1371/journal.pone.0144111.

AggieAir Imagery Information Pipeline Improvements

Principal Investigators:
Todd Moon
Calvin Coopmans, Post-doctoral Researcher

Partners/Collaborators:
- ***Local**: Utah State University, Utah Water Research Laboratory*
- ***State**: Utah Department of Environmental Quality*

Project Description

- **Need and Purpose**

  Since 2006, the AggieAir group at the Utah Water Research Laboratory has been developing unmanned, aerial remote sensing systems for natural and water resources management. These small aircraft are programmed to fly over areas such as farming fields or natural environments to collect scientific data (imagery), which can then be used for better crop care, early detection of poor plant health, or conservation of wildlife habitat.

  The process of converting the aircraft imagery into scientific-grade data includes steps such as orthorectification to place the images on a global map and "stitching" to make the images into a completed map for data processing. Current approaches require experienced human operators to assemble the imagery and process it into the science data. This can take anywhere from 12 to 48 hours of post-flight work, creating delays of one to several days in delivery of data to farmers or to water and environmental managers.

  Many important applications for the AggieAir technology (such as day-to-day high-value agriculture) require data in near real time. If AggieAir were to deliver actionable data in a 4- to 10-hour timeframe, many of these important management applications could be implemented and improved. Hence, the goal of this project is to determine the best way to reduce the image-to-data processing time.

  This project is analyzing the flight and data collection processes and the ways these complex operations could be modified or augmented to improve the raw imagery data collected by the aircraft, which will provide a better starting point for transforming the data into actionable information needed by the users.

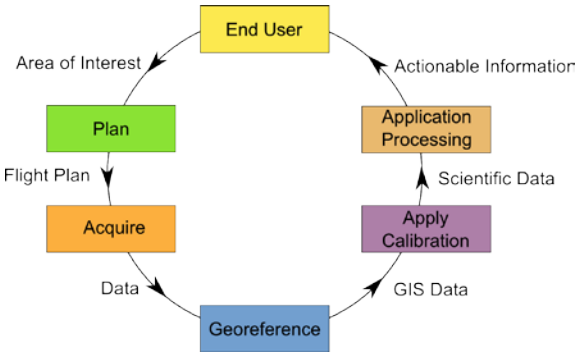


Figure 1. The circle of airborne scientific information gathering

- **Benefits to the State:**

  Utah is part of the high desert Intermountain West, and water is a critical part of agriculture, business, natural habitat, and other resource management in the state. The AggieAir group within the UWRL addresses difficult aerial remote sensing problems and applies real world solutions to water and environmental management.

  The Federal Aviation Administration quotes the Teal group (an intelligence and aerospace research group), who predicts the unmanned aerial vehicle spending worldwide at $89.1 billion in the next 10 years. In

addition to the important agricultural and water-saving benefits, this project will help position Utah to become part of this large, cutting-edge, emerging market.

This work can provide substantial benefits to the state of Utah by promoting innovative techniques for more optimal resource monitoring and management and by keeping these technologies in the state to strengthen our industry and promote job creation.

- **Geographic Areas:**
  Study Area: Statewide.

  Areas Benefited: Statewide.

- **Accomplishments**

  Results:

  The current project has been completed, resulting in a greatly improved scientific payload (Figure 2). The AggieAir payload camera speed has been increased to nearly 6 frames per second (fps), while at the same time also upping the speed of the imagery pipeline. This provides much more imagery for improved data quality and faster delivery of data to the users. However, the USB 3 data bus speeds required for the fast operation cause radio frequency problems with the navigational and safety override systems of the aircraft. Thus, more work on integration is required before actual flight is possible.

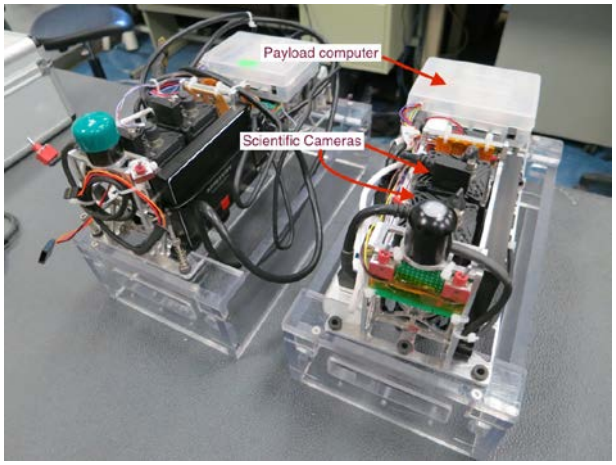


Figure 2. The AggieAir scientific payload with upgraded cameras and USB3 interface

  Other parts of the imagery pipeline were also evaluated and improved. Higher-performance computing hardware has replaced the slower network-based data transfer. This can reduce image conversion and preparation time by as much as 2–3 hours, so scientific data processing can begin more quickly. Also, the image processing tools used to produce data have been modified to work with the new imagery. This means that the existing software is ready to work on higher-framerate data sets, a big improvement over the old image collection and processing rate of 1 frame per second.

  The applicability of the real-time kinematic GPS system was also evaluated. Spatial location improvements were found to improve the imagery in the pipeline. An inertial navigation system onboard the aircraft is now used to estimate the position and orientation of the camera system. This system has its own GPS, which would need to be replaced with a RTK GPS system to get the improvements. However, analysis showed that a stand-alone RTK GPS would not add enough value to the imagery pipeline on its own to justify its use.

Work Plan FY16/FY17

This project is complete.

Informational Resources

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

Allocating Scarce Water for Utah Wetland, Riverine and Riparian Areas with Ecological Uncertainties

Principal Investigators:

David E. Rosenberg
Karin M. Kettenring
Omar Alminagorta (Student)
Ayman Alafifi (Student)
Todd Keniry (Student)
Dahlia Curiel (Student)
Kellie Ann Shawn (Student)
Todd Brown (Student)
Dylan Anderson (Student)
Russell Babb (Student)

Partners/Collaborators:

- ***Local:*** *Joan Degiorgio, The Nature Conservancy; Bryan Dixon, Bear River Land Conservancy; Bob Fotheringham, Cache County, Jim DeRito, Trout Unlimited*
- ***State:*** *Toby Hooker, Utah Geologic Survey; Pam Kramer, Division of Wildlife Resources; Paul Thompson, Utah Division of Wildlife Resources*
- ***Federal:*** *Bob Barrett, Howard Browers, Karl Fleming, U.S. Fish and Wildlife Service*
- ***Business/Commercial:*** *Eve Davies, PacifiCorp; Con Baldwin, PacifiCorp*

Project Description

- **Need and Purpose:**

  Wetlands, particularly along the Great Salt Lake, provide critical wildlife habitat, resting grounds for migratory birds, and social and economic services including water purification, storm water retention, and recreation for hunters. Wetlands need water, but in Utah and the western U.S., water is often scarce and not available to flood and maintain wetland habitats and functions. Scarce water challenges wetland managers on how to best allocate limited water to and within wetlands to improve ecosystem functions and services. Water allocation decisions are further complicated because responses by bird populations and native plant species are often uncertain. Riverine and riparian areas also have water needs and require vegetation management.

  This project extends systems modeling underway at the Bear River Migratory Bird Refuge, Utah (the Refuge). Part I is using a wetland systems (optimization) model (SWAMPS) to identify water and vegetation management actions Refuge mangers can take to improve wetland performance under existing water, vegetation response, budget, staff time, and other constraints. Part II is a federally-funded National Science Foundation (NSF) effort to develop a Watershed Area of Suitable Habitat (WASH) model for the lower Bear River Basin. The objective is to identify numerous near-optimal water allocation strategies to improve wetland, riparian, and riverine performance.

- **Benefits to the State:**

  The project benefits Utah in several ways. First, the project is helping Utah wetland managers better manage and allocate scarce water, personnel, and budget resources to achieve their wetland objectives. The project is showing how water levels encourage and discourage *Phragmites* spread and how to manage water to reduce *Phragmites* spread. The project is also helping Utah environmental managers allocate scarce water to environmentally important areas across a watershed. These benefits help managers promote hunting, birding, and recreation that are vital to the Utah communities that border the Great Salt Lake and the State's rivers and protect critical species. Finally, the project is integrating systems modeling, ecology, and stakeholder input and showcases a new Utah-based approach to environmental management.

- **Geographic Areas:**

  Study Area: Bear River Migratory Bird Refuge, north shore of the Great Salt Lake, Box Elder County, Utah; Bear River, Cache and Box Elder Counties, Utah.

Areas Benefited: Wetland, riparian, and riverine areas throughout Utah.

- **Accomplishments:**

  Findings and Results:

  - Held SWAMPS modeling workshop with Bear River Migratory Bird Refuge staff and ongoing discussions to use the model to help develop annual Refuge management plans.
  - Developed interactive web map to share WASH model recommendations to better manage water for aquatic, riparian, and impounded wetlands ecosystems (Figures 1 and 2).
  - Presented preliminary WASH model results and solicited feedback on model-recommended reservoir releases from five stakeholder groups.
  - Made a third multi-day river trip in August 2015 with five incoming freshmen Bear River Fellows and worked with Fellows over the academic year to analyze collected data and present three posters at the iUTAH Summer Symposium and USU Spring Runoff Conferences.
  - Published article "Systems modeling to improve the hydroecological performance of diked wetlands" in Water Resources Research, DOI: 10.1002/2015wr018105.

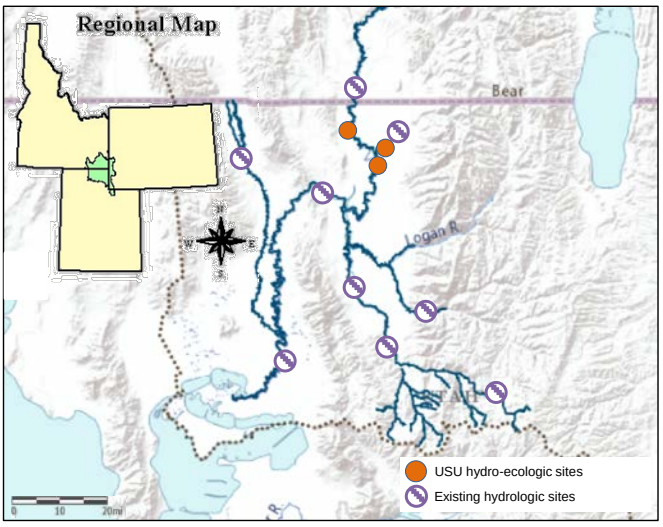


Figure 1. Map of USU hydro-ecologic and existing monitoring sites in the lower Bear River basin used to provide data for aquatic and riparian areas in the WASH model

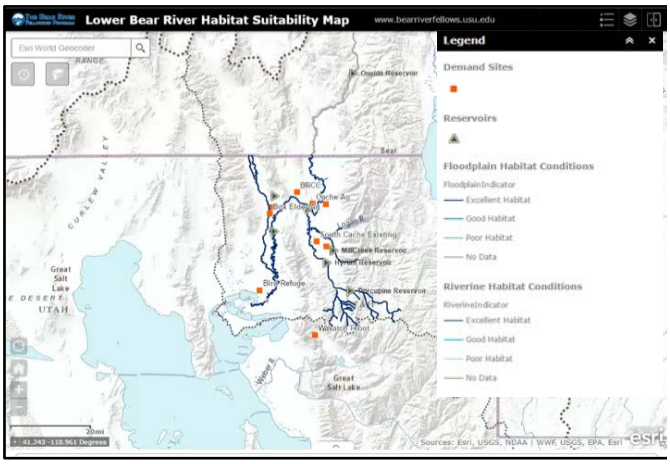


Figure 2. Interactive webmap showing preliminary WASH model results of floodplain and riverine habitat conditions

Work Plan FY16/FY17

- Use stakeholder feedback to update WASH model, again share results, and publish results.
- Extend WASH model to include systematic uncertainties in inputs and near-optimal alternatives.
- Work with select Bear River Fellows to continue data and model analysis for another year.

Informational Resources

Contact: Dr. David E. Rosenberg, Telephone: (435) 797 8689, E-mail: david.rosenberg@usu.edu.
Website: SWAMPS model and data repository.
Website: https://github.com/dzeke/Blended-Near-Optimal-Tools.
Website: http://bearriverfellows.usu.edu/.

ASR Optimization Protocol and Decision Support: Jordan River Valley

Principal Investigators:
Richard C. Peralta
Ali Forghani (MS student)

Partners/Collaborators:
Local: *Richard Bay, Jordan Valley Water Conservancy District*

Project Description:

- **Need and Purpose:**

  The Jordan Valley Water Conservancy District (JVWCD) began operating a full-scale Aquifer Storage and Recovery (ASR) system in 2002. The JVWCD wishes to optimize management of the current system of 18 extraction/injection-wells. Optimal management depends on the economic value of credit the State Engineer grants for the amount of water the JVWCD injects (injectate). The State Engineer allows multiple-year carryover credit of injectate, subject to the condition that 10% of the carryover storage is lost after 12 months from the time of injection. This loss supposedly represents an escape of groundwater that is not extracted by ASR wells. JVWCD believes it recovers more injectate than it receives credit for, but it needs accurate recovery estimates to verify the amount. To manage efficiently, JVWCD also needs to know the best time to inject and extract water. The ARS Optimization Protocol can more accurately quantify the amount of recovered injectate, and provided optimal injection/extraction timing, subject to varying water availability, need, and cost.

  Benefits to the State:

  To best integrate available water resource use, Utah water managers increasingly employ aquifer recharge (AR) and aquifer storage and recovery (ASR). Often, treated river water is injected into aquifers during the Spring. Groundwater is extracted later when surface flow is low. ASR needs to be optimized with respect to cost, reliability, and related issues. Considerations are (1) how much injectate the recharging organization can physically recover, (2) how much credit the State.

  Engineer gives an organization for the recharge, and (3) cost and timing of water needs and availability. Optimal ASR strategies are situation-specific, but the development procedure is transferable. This project will aid JVWCD ASR use and promote ASR use by other entities.

- **Geographic Areas:**

  Study Areas: Jordan River Valley (part of Salt Lake County and parts of Utah cities of Bluffdale, Draper, Herriman, Kearns, Magna, Midvale, Riverton, South Jordan, South Salt Lake, Taylorsville-Bennion, West Jordan, White City).

  Areas Benefited: The above Utah cities, parts of Holladay, Sandy, unincorporated county areas, Granger-Hunter Improvement District, Willow Creek Country Club, and the Metropolitan Water District of SL and Sandy. The project aids entities worldwide that want to use wells to recharge aquifers for later extraction, especially if timing of surface water availability does not coincide with water need.

- **Accomplishments:**

  Findings: The project accomplished the following key aspects of ARS optimization:

- Defined Recovery Effectiveness (REN) as the proportion of the injected water that the same ASR well can capture during subsequent extraction.
- Employed TMR and LGR techniques to prepare horizontally and vertically refined models for accurate REN estimation for well SLCWCD8.
- Prepared 5-year model beginning with Jan-2009 heads and simulated all ASR wells with monthly stresses for sequential average, dry, dry, wet, and average hydrologic years.
- Used parallel processing to develop a data base containing the inputs and results (RENs) from 10,000 systematic Modflow-Mt3dms simulations.
- Trained Artificial Neural Network models using 10,000 data points to predict REN using all the important factors affecting REN in JVWCD ASR system.
- Designed graphical interface (GUI) to facilitate ANN model use and sensitivity analysis of different factors on REN.

Results: Employing the ARS Protocol demonstrated the following:

- Increase in injectate volume improves REN.
- For well SLCWCD-8 and with 12 months of injectate storage, REN is 95% by the end of cycle 1 extraction, and 99.2% by the end of cycle 4 extraction. Each extraction cycle is usually 3 months, from July to September.
- Based on evaluations using TMR and LGR models, the final valley model used 38-ft square cell size.
- Modeling results suggest that installing only a screen in lower permeability strata increases REN, and this benefit increases as background hydraulic conductivity increases.
- Except SLCWCD3, 22, and 28, ASR wells that inject and extract can recover over 98% of year 1 injectate during next 5 years. (Goal 1 accomplishment).
- SLCWCD 3, 22, and 28 (located in eastern margin of the valley with steep gradient), should not be used for annual storage of water. Hence, extraction must start within a couple of months after injection ceases.
- Extracting 3 times the injectate volume as soon as possible will recover more than 95% of recoverable injectate.
- The GUI and ANN models predict REN within about 3 percent, and computes REN sensitivity (Goal 4 accomplishment).
- GUI shows that gradient most strongly impacts REN.
- The developed GUI can evaluate REN sensitivity to all assumed physical system parameters. (Goal 2 accomplishment).

Work Plan FY16/FY17

Perform optimizations using previously developed objective functions and constraints (To accomplish Goal 3). Submit manuscripts to journals for publication. Report results and meet with Jordan Valley Conservancy District.

Informational Resources

Contact: Dr. Richard C. Peralta, Telephone: (435) 797 2786, E-mail: peralta.rc@gmail.com.

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

Investigators:
David E. Rosenberg
Tammy Rittenour
Jim Stagge (Postdoctoral Researcher)

Partners/Collaborators:

- ***Local:*** *Bob Fotheringham, Cache County;*
- ***State:*** *Dave Cole, Utah Division of Water Resources; Candice Hasenyager, Utah Division of Water Resources; Todd Adams, Utah Division of Water Resources;*
- ***Federal:*** *Justin DeRose, 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 are giving water managers a sense of the magnitude, frequency, and duration of extreme events that we face today. This reconstructed data, coupled with observations from the most recent century of instrumented records, can help expand our understanding of the magnitude and duration of future extreme events. At present, the reconstructed time series of annual flows have limited spatial coverage and only one stream flow value per year at a given location. Also, at this time, they are not integrated into water system models, operations, or drought planning efforts. To make better use of reconstructed stream flow information in drought planning and management, water managers need streamflow estimates at higher spatial and temporal resolution within engineered storage and conveyance infrastructure and natural systems. This project is using two time-series of reconstructed annual stream flows derived from tree ring data dating back to the year 1605 on the Logan River and to 800 AD at the uppermost Bear River gage on the UT-WY border to identify likely impacts of droughts such as those experienced before the collection of instrumented data re-occurring in the near future.

- **Benefits to the State:**

  The project will benefit Utah in several direct and indirect ways. First, the project will develop an integrated simulation model of the entire Bear River basin and expand coverage beyond the lower, Utah-portion of the basin. A second major benefit to Utah is a better understanding and quantification of susceptibility to historic drought risk. As a third benefit, the project will suggest reservoir, diversion, and demand management operations to reduce identified risks.

- **Geographic Areas:**

  Study Area: Bear River basin, Rich, Cache, and Box Elder Counties, Utah.

  Areas Benefited: Bear River basin and other basins throughout Utah for which tree ring, reconstructed flows, and water systems data are available.

- **Accomplishments:**

  Findings and Results:

  - Held an initial workshop with approximately 30 water managers in April at Weber Basin Water Conservancy District. Presented the initial project concepts and solicited feedback.

- Developed method to downscale annual reconstructed stream flows to monthly values and tested on the Logan River, Utah (Figure 1). The method uses average monthly flow apportionment observed in the historical record, regional tree chronologies, and the Pacific Decadal Oscillation (PDO) and El Nino Southern Oscillation (ENSO) climate indicators.

- Met with stakeholders to present initial results for the temporal downscaling method.

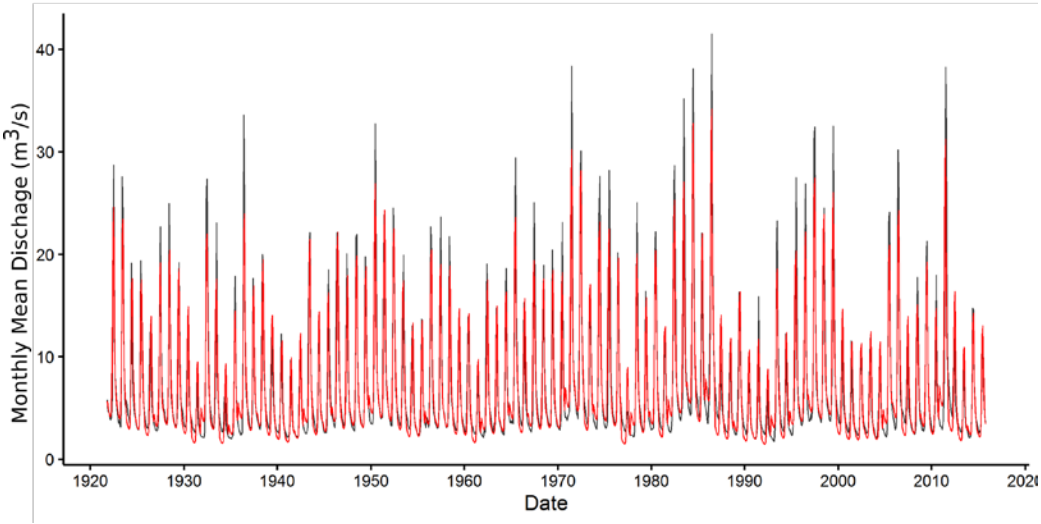


Figure 1. Comparison of model estimated (red) and observed (black) flows on the Logan River at First Dam

Work Plan FY16/FY17

- Expand spatial coverage of the systems model from the lower Bear River in Utah to include Idaho, Wyoming, Bear Lake, and associated inflows, users, and return flows.
- Extend spatial coverage of chronologies of reconstructed stream flows to other important locations in the basin (Figure 2).
- Identify key droughts in the reconstructed paleoclimate record.
- Simulate performance of existing water system and demands through droughts identified in the paleo-climatic record.
- Recommend reservoir, diversion, and water conservation operations to reduce impacts of paleodroughts.

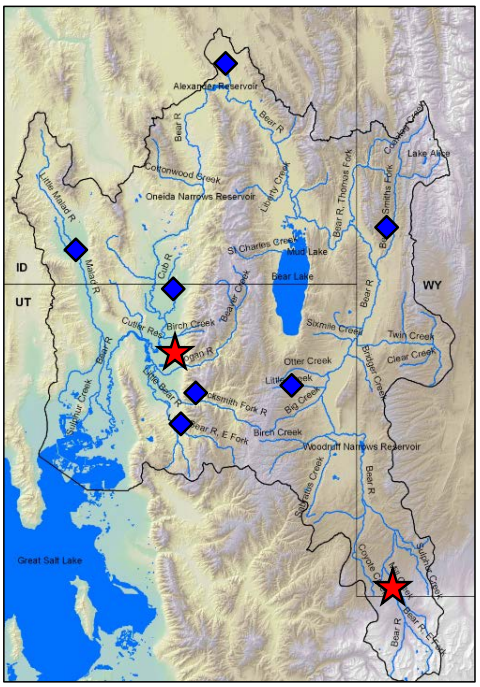


Figure 2. Locations requiring reconstructed stream flows to evaluate effects of paleo droughts. Red stars show sites with existing reconstructions (from tree rings) and blue diamonds indicate additional sites for which we will develop reconstructions

Informational Resources

Contact: Dr. David E. Rosenberg,
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E-mail: david.rosenberg@usu.edu.

Bird Nest Aquifer Saline Injection Simulation, Optimization, and Economic Impact

Principal Investigators:
Richard C. Peralta
Rick Lyons (MS student)

Partners/Collaborators:
State: *Michael D. Vanden Berg, P.G., Utah Geological Survey*

Project Description:

- **Need and Purpose:**

  Agencies are concerned about possible impacts of dramatic Uintah Basin petroleum production increases. Oil and gas production also produce saline water. From 2001 to 2011, natural gas, crude oil, and saline water production increased 208%, 160%, and 86%, respectively. In the future, the 25,000 proposed new petroleum wells would produce a huge volume of saline water requiring disposal. For environmental reasons, the preferred Uintah basin disposal method is subsurface injection. Gas producers plan to increase saline water injection into the Birds Nest Aquifer (BNA), which exists within the oil shale horizon. This aquifer has veins of solid hydrocarbon Gilsonite that can affect groundwater flow, and its effect on horizontal or vertical groundwater flow are not well known. The northwestern part of the BNA is eligible for saline water injection because its salt concentration already exceeds 10,000 mg/L total dissolved solids (TDS). Southeastern aquifer water which has less than 10,000 mg/L TDS is protected from injection.

  The Utah Geological Survey (UGS) and US Bureau of Land Management (BLM) have identified possible negative injection consequences. Horizontally flowing injectate could harm existing groundwater supply wells, increase fresh water spring discharge, and cause saline springs that might contaminate surface waters. Injection could also economically harm Gilsonite mining. Water could also flow downward through Gilsonite veins into fractures in fracked oil-shale strata and flood future petroleum-harvesting activities. Clearly, the physical setting is complex, and guidance is needed. Unfortunately, no good groundwater flow and contaminant transport models exist of the impacted area. To address the range of concerns agencies have expressed about the effects of saline water injection on the aquifer and the fractures resulting from lower stratum fracking, two appropriately discretized calibrated flow models are needed. First, a calibrated transport flow model is needed to predict salinity concentrations at target locations in the BNA and associated higher and lower strata. Second, a porous media flow simulation is needed to represent fracture-flow through BNA vertical fractures caused by hydro-fracking.

- **Benefits to the State:**

  The project will provide critically needed guidance for Utah energy-development decisions that have significant economic, environmental, social, and political ramifications. Hence, the Utah Division of Oil, Gas, and Mining (UDOGM), of the Utah Geological Survey (UGS), needs safe optimal saline injection strategies in order to develop viable management scenarios. Each strategy requires a spatial/temporal distribution of injected saline water. The strategies are obtained using a simulation-optimization (BNA S-O) model, i.e. a model that couples the BNA simulation model with mathematical optimization algorithms. Results of the simulation will also help project the economic consequences and impacts of management scenarios. For example, a sample scenario would optimize saline injection at candidate wells over a 20-year period, without causing excessive fresh water spring discharges, saline discharge at springs feeding surface waters, the southward movement of 10,000 TDS fresh-saline water interface, or harmful domestic well impacts. Collaboration with Agencies and industry will help assure practical utility of the project results, and will aid the sustainable safe development of Uintah Basin water and energy resources.

- **Geographic Areas:**

  Study Areas: Uintah Basin (Uintah, Duchesne, Carbon, Grand, Emery, and Wasatch Counties, and the cities of Vernal and Duchesne.

  Areas Benefited: The project provides strategies for safely disposing of saline water resulting from oil and gas production in the Uintah Basin. Methods developed are applicable worldwide.

- **Accomplishments:**

  Findings: Geographic and other information needed for the BNA S-O model was gathered from the UGS, UDOGM, Utah Department of Natural Resources (UDNR), and the Utah Division of Water Rights (DWR). Using data from a modeling report by Glover (1996), a preliminary steady-state MODFLOW groundwater flow model was formulated for the Uinta/Duchesne layer of the Uintah Basin. The model computes flow directions and heads similar to those of Glover (1996). At many observation wells, the head levels are much closer to observed values than those calculated by Glover.

  A 1 layer, 22 row, and 50 column grid groundwater flow simulation model was used to represent the top stratum of the Uintah Basin subsurface. Previous models assumed uniform thickness and elevation. Well water elevations and aquifer thickness for the model were primarily derived from well logs and records of well construction. The model was populated with estimated hydraulic parameters and some boundary conditions (hydraulic head, deep percolation from precipitation, and recharge into and discharge out of the various rivers that traverse the Uintah basin)

  Findings: Instead of assuming a flat aquifer of uniform thickness, the use of ground surface and stratum elevation data allows for the creation of a more representative model. However, this approach also creates the need for more specific system parameter values, many of which are not readily available. These values can be estimated from related information such as soil type, rock type, visible fractures, rock outcrops, etc.

Work Plan FY16/FY17

- Finish steady-state flow calibration of the Uintah basin flow model.
- Populate the basin model with transient data and calibrate it.
- Create saline injection models for steady-state and transient 20-year situations.

Informational Resources

Contact: Dr. Richard C. Peralta, Telephone: (435) 797 2786, E-mail: peralta.rc@gmail.com.

Crop Water Demand Monitoring and Forecasting

Principal Investigators:
Alfonso Torres-Rua
Andres M. Ticlavilca
Mac McKee
Wynn Walker

Partners/Collaborators:
Federal: *USGS Earth Resources Observation and Science (EROS) Center; US Bureau of Reclamation, Provo Office*

Project Description:

- **Need and Purpose:**

  Current Utah agricultural water management at farm, irrigation district, and state levels is restricted to referential, delayed, and often inadequate data that do not represent actual water use. This situation leads to misguided water related decision-making activities (e.g. over-irrigation and issues in irrigation scheduling, water shares). Current research using satellite technology (Landsat) allows for near real-time and historical estimation of actual water use at different levels (field, irrigation district, state). This water use information, integrated with automation mechanisms, will help to improve decision-making activities when made available to stakeholders (producers, water managers, and policy makers).

  This project is developing a practical, cost-effective, and straightforward actionable information platform, the Crop and Water Monitoring and Information System (CWMIS), to provide near real-time records of crop status (water, yield, and irrigation management). The information can be directly used by policy makers, water managers, and producers in the State of Utah. The CWMIS incorporates recent advances in crop water and status models, continuous NASA Landsat satellite information for Utah, and web mapping technologies made available to users for immediate access.

- **Benefits to the State:**

  At field scale, information on historical and near real-time crop water consumption can be used by producers to enhance irrigation water efficiency and minimize over-irrigation. At the irrigation district scale, water managers can use total actual crop water use to identify issues in the system such as losses due to scheduling, water irrigation, storage and conveyance. At the basin scale, availability of historical records of accurate actual crop water use can support better management of all water uses (agricultural, urban, ecological, and industrial) and water sources (surface, rainfall, and groundwater).

- **Geographic Areas:**

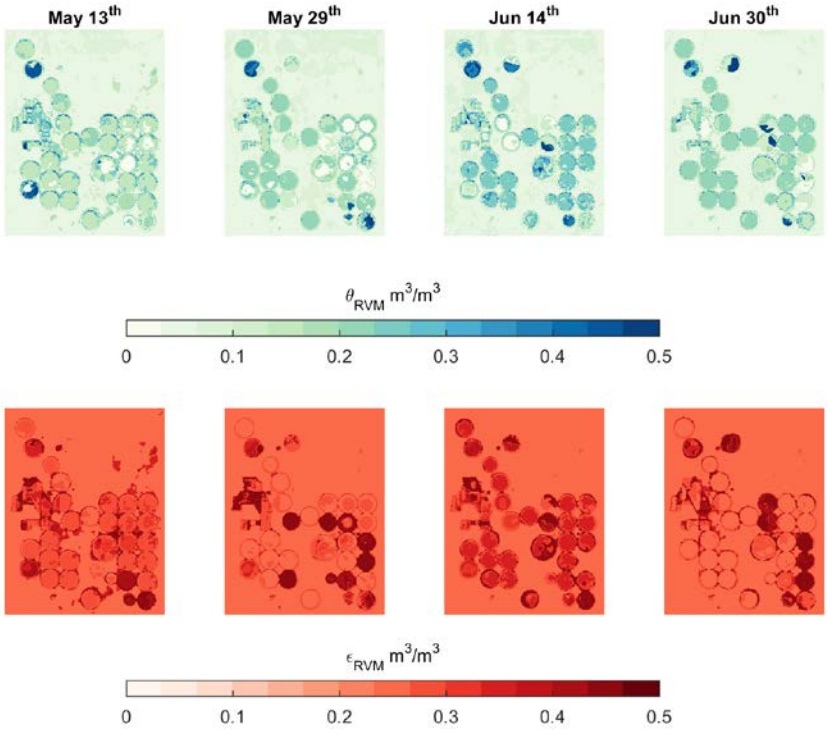
  Study Area: Central Utah, Millard County.

  Areas Benefited: Lower Sevier River Basin, Central Utah, Millard County.

- **Accomplishments:**

  Findings: Surface soil moisture was estimated using a data-mining model with satellite imagery. Results of the work were published in a peer-reviewed journal. The model can also provide a reasonably accurate estimation of soil moisture for non-agricultural areas (rangeland, wetlands), although no ground data was collected as input to the model. This finding opens opportunities for research on monitoring changes in soil water availability in natural and agricultural areas due to drought events. Further work to determine the accuracy and degree of uncertainty in soil moisture estimations is in progress (See Results figure and explanation).

In addition, an understanding of rainfall estimation using satellite information vs local weather stations is currently underway. The insight gained can help with better meeting the irrigation water needs at crop field level, especially for fields located away from weather stations.



Results:

The figure (top row) shows the estimation of satellite-based soil moisture in cubic meters of water per cubic meters of soil from dry conditions (light green color) to fully irrigated (blue) for the center pivots located in Hayden, UT for the year 2013. The bottom row of figures indicates the uncertainty related to the soil moisture estimations (+/- cubic meter of water per cubic meter of soil). The uncertainty varies by center pivot and date. Center pivots with lower uncertainty (light red color) indicates more accurate soil moisture estimation, while large uncertainty (red color) indicates need for additional moisture measurements in that location.

Work Plan FY16/FY17

For FY16/FY17, models that can describe soil water content at different depths will be developed. The resulting models will be incorporated into CWMIS workflow of information available to users.

Informational Resources

Contact: Dr. Alfonso Torres-Rua, Telephone: (435) 797-3149, E-mail: a.torres@aggiemail.usu.edu.

Crop and Water Monitoring and Information System – Project Website:
https://sites.google.com/a/aggiemail.usu.edu/cwmis_sevierriver/

Peer-Reviewed Paper:

Torres-Rua, A.F., Ticlavilca, A.M., Bachour,R., and McKee, M. (2016). Estimation of Surface Soil Moisture in Irrigated Lands by Assimilation of Landsat Vegetation Indices, Surface Energy Balance Products, and Relevance Vector Machines. *Water*.

Development of an Inexpensive UAV for Remote Sensing in Water and Natural Resources Management

Principal Investigators:
Calvin Coopmans
Mac McKee

Partners/Collaborators:
- *None*

Project Description

- **Need and Purpose:**

  Many current platforms for 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 (UAS) called AggieAir can fill this need by providing low-cost, multispectral aerial imagery quickly and frequently. In addition, AggieAir is not dependent on a runway for takeoff and landing, which enables it to be launched almost anywhere. Some examples of applications that could benefit from AggieAir include agriculture, riparian habitat mapping, road and highway surface monitoring, wetland mapping, and fish and wildlife tracking.

- **Benefits to the State:**

  The data produced by AggieAir have the potential to help save water in Utah by offering farmers a low-cost solution to mapping the soil moisture of their crops for more efficient irrigation. These data will also help canal operators to manage water deliveries more effectively. The data will also assist wetland managers to control invasive plant species. If these invasive plant species are left unchecked, they can take over native plants, destroy bird habitat, and use excessive amounts of water.

  Aggieair also has the potential to 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.

- **Geographic Areas:**

  Study Area: Most of the test flights took place at our test site near Cache Junction, UT. We have official approval from the FAA to conduct flights here (FAA Form 7711-1 2013-WSA-63).

  Areas Benefited: All counties in the state would benefit.

- **Accomplishments**:

  Findings: In the past year, the upgraded Minion UAV platform and payload was used in multiple data collection campaigns, and the new scientific payload was used successfully to deliver high-quality imagery to many different applications in Utah. The AggieAir 3.0 development was completed, and the improved aircraft has been named “BluJay” (See Figures 1 and 2). In addition, a new power system and avionics were developed and are now in the process of flight testing. The BluJay platform also includes an upgraded launcher and support equipment. The ground control (mission planning and data processing software) has also been upgraded and streamlined. With these significant improvements, AggieAir’s BluJay can carry an upgraded payload with a flight time of up to 200 minutes, and map up to an impressive 20,000 acres with scientific clarity.

Informational Resources

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

Figure 1: The final BluJay model ready for first flight

Figure 2. BluJay prototype ground system with launcher and control equipment, ready for takeoff

Evaluating Restoration Efforts Using Imagery from an Unmanned Aerial Vehicle (UAV)

Principal Investigators:
Mac McKee
Bethany Neilson
Ian Gowing

Partners/Collaborators:

- ***State**: Dan Keller – Utah Division of Wildlife*
- ***Federal**: Justin Jimenez – Bureau of Land Management*
- ***State**: Paul Birdsey – Utah Division of Wildlife*

Project Description

- **Need and Purpose:**

  The AggieAir Flying Circus, a service center at the Utah Water Research Water Laboratory that provides high-resolution multispectral aerial imagery using UAVs, was contracted by the Utah Division of Wildlife Resources to fly the lower 50 miles of the San Rafael River to provide high-resolution aerial imagery after a high river flow event. The San Rafael Restoration Committee intends to integrate the AggieAir imagery, along with the analysis of the data contained in the imagery, as an integral component in the San Rafael restoration effort. It is expected that the data and analyses provided will significantly improve the information content of the entire data collection effort for the San Rafael restoration process, and help to answer significant questions about the effects of tamarisk control on river morphology.

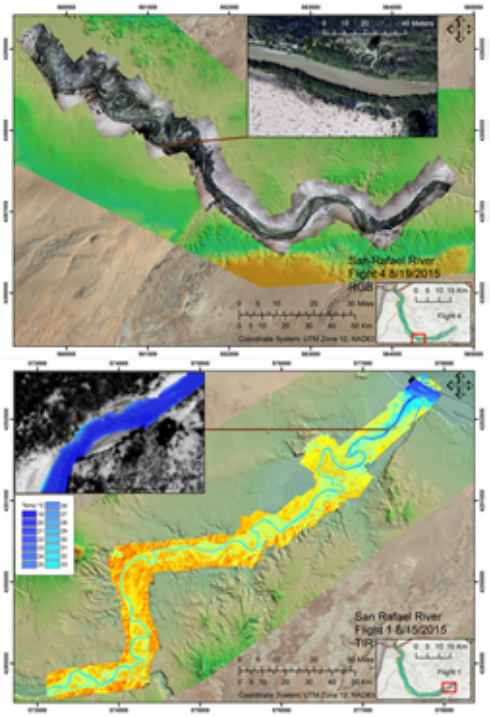
  The project also provides insight on the accuracy and limitations of inexpensive UAV platforms in providing data, such as digital elevation and terrain models, as opposed to more conventional and much more expensive approaches, such as LiDAR. Temperature sensors were positioned within the entire 50-mile study reach to help calibrate thermal imagery captured by Aggie Air in order to address the issue of thermal regime within the San Rafael River.

- **Benefits to the State:**

  The San Rafael River is recognized as being in a severely degraded state and is on the 303D list of degraded waters in the state of Utah. With the implementation of this river restoration scheme, we anticipate restoring the river to a more ecologically acceptable state by encouraging a change in channel morphology thus providing more and better habitat for the native fish. This will be accomplished by removing Tamarisk, planting more native riparian species along the river corridor, and removing man-made barriers. These measures are expected to enhance and encourage fish passage and movement throughout the entire drainage.

- **Geographic Areas:** San Rafael River, Emery County, Utah.

  Study Area: Emery County.



Calibrated thermal imagery for Flight 1 and calibrated RGB imagery for Flight 4 on the San Rafael River, 2015

Areas Benefited: Emery County and state-wide in river restoration areas.

Accomplishments:

Findings: Image processing and data analysis occurred September 2015 through June 2016. The aerial images from nine flights were processed in three stages: (1) orthomosaic generation, (2) digital surface model extraction, and (3) thermal imagery calibration. Fully orthorectified mosaics for 55 river miles along the San Rafael are now available to UDWR and the San Rafael Restoration committee. The imagery is being used as an integral component in evaluating the effects of tamarisk control on river morphology. It is also being used to quantify riffle/gravel, in relation to fish habitat, and lateral channel change of the river, particularly due to bank scour and channel widening or narrowing.

Results: Data analysis examined the vertical and horizontal accuracies of the RGB and NIR Digital Surface Models (DSMs) created using AggieAir imagery, as compared to LIDAR surface data produced by WSI (2013).

Overall, points with the highest vertical accuracies were typically found in areas with hard surfaces and low relief in images near selected ground control points. Points with low vertical accuracies were positioned closer to vegetation, near areas of high relief, or nearer the margins of the imagery in the DSM. The results indicate vertical accuracy is enhanced with airphoto targets and additional ground control points. Analysis indicates the difference between the Bare Earth 2013 San Rafael LIDAR surface (1-m resolution) and the AggieAir DSMs is on the negative side. This indicates that the DSM is much more likely to be above the surface of the Bare Earth LIDAR surface. This happens to occur in the vegetated areas that were not excluded.

Using the American Society of Photogrammetry & Remote Sensing (ASPRS) vertical data accuracy classes (Class I through Class X), and using only the level of points that most nearly represent LIDAR (all points >0.05 m), all of the AggieAir DSM data for non-vegetated surfaces meet the Class VI level of vertical accuracy, which is equivalent to 2-foot contour accuracy. Horizontal accuracies varied between flights but were much higher when Ground Control points were preselected interactively, rather than randomly selected.

It is recommended that Additional efforts using image classification to assign vegetation classes, areas of scour or deposition, impervious surfaces, etc. could be used to further assess accuracy within each class. Eliminating unacceptable or low confidence areas with additional GIS analyses could improve the vertical accuracy assessment.

Work Plan FY16/FY17

The work outlined for this project is now complete.

Informational Resources

Contact: Mr. Ian Gowing, Telephone: (435) 797-3159, E-mail: ian.gowing@usu.edu.

Gain-Loss Study on the San Rafael River, South Central Utah

Principal Investigators:
Ian Gowing
Mac McKee

Partners/Collaborators:

- ***State**: Dan Keller and Paul Birdsey, Utah Division of Wildlife Resources*
- ***Federal**: Justin Jimenez – Bureau of Land Management*

Project Description:

- **Need and Purpose:**

  Information relating to seepage gains and losses in rivers is required by water managers in order to understand how and where best to allocate this limited resource. The lower San Rafael River, south central Utah, is impacted by fragmentation, dewatering, non-native species, and channelization. Dewatering is sometimes severe and resulted in a complete lack of flow for two months during the summer of 2007.

  An initial gain-loss study was conduct on behalf of Emery Water Conservancy District during late 2011 early 2012. The study examined gains/losses within the San Rafael River during the winter months and data analysis indicated that both net gains and net losses were relatively small in magnitude and in contrasts to actual flow rates when data was collected. However, findings from recent studies have illustrated that river flows during the summer months could be critical to providing sufficient river levels and continuous river connectivity needed for spawning habitat of native fish species.

  This study further investigated the gains and/or losses that potentially affect the Lower San Rafael River from Highway I-70 to the confluence with the Green River. This was done by re-establishing discharge measurement transects used in the original study along the San Rafael River and collecting flow data once/twice a month from March through August 2014. Data were collected bi-monthly during critically low periods of river flow to monitor/assess net gains/losses and to investigate river connectivity.

- **Benefits to the State:**

  The San Rafael River is recognized as being in a severely degraded state and is on the 303D list of degraded waters in the state of Utah. Implementing the river restoration scheme would bring the river back to a more ecologically acceptable state by encouraging a change in channel morphology, thus providing more and better habitat for the native fish. This will be accomplished by removing Tamarisk, planting more native riparian species along the river corridor, and removing man-made barriers. These measures are expected to enhance and encourage fish passage and movement 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.

Measuring discharge on the San Rafael River, 2014

- **Accomplishments:**

  Findings: All data on the lower San Rafael were collected from May through August 2014, and instrumentation was removed from the river at the end of data collection. Data analysis was completed by April 2016. Major discrepancies between USU data collection results and USGS published gaged data were resolved. This resulted in the USGS establishing a new discharge rating relation (#34) for USGS Gage 09328500. A final report was delivered to the San Rafael restoration committee in July 2016.

  Results: Data analysis illustrates a combination of groundwater gains and losses, both spatially (between consecutive measurement stations and within reaches) and temporally. In particular, data analysis for the lower two reaches (B and C) illustrates some significant groundwater interaction between May and September 2014, with some significant loss in river flow below Hatt Ranch diversion, especially during July 2014. There was no significant identifiable groundwater surface water interaction in the upper most reach (A). Results from Reach B data show a loss of approximately 9% in May 2014, and gains from groundwater of 1185% and 303% during two periods in July 2014. Analysis of data for Reach C indicates a trend of groundwater gains through May, July and September 2014.

  Operations at Hatt Ranch diversion, the only significant diversion structure on the lower San Rafael, had significant effects on river flow, especially during the summer months. In July 2014, from 66% up to 93% of the river flow was diverted to provide irrigation water to Hatt Ranch. The dewatering of the river immediately downstream of the diversion structure has serious implications to aquatic wildlife and habitat both within the channel and along the riparian zone.

Work Plan FY16/FY17

All research efforts are now complete. Findings from this research may lead to a larger scale research study at the catchment scale in collaboration with DWR and BLM.

Informational Resources

Contact: Mr. Ian Gowing, Telephone: (435) 797 3159, E-mail: ian.gowing@usu.edu.

High Frequency Data and Cyber-infrastructure Tools for High Resolution Modeling in Snowmelt Dominated Watersheds

Principal Investigators:
Jeffery S. Horsburgh
Amber Spackman Jones
Stephanie Reeder
Tony Melcher and Bryce Mihalevich (Students)

Partners/Collaborators:
***Local**: Logan City, Northwest Field Irrigation Company*

Project Description

Figure 1. Continuous data collected at monitoring sites in Cache Valley provide high frequency observations that are challenging the assumptions and process representations in our current suite of hydrologic models

- **Need and Purpose:**

  This project is advancing the capabilities of water data collection cyber-infrastructure for watersheds within the state of Utah to (1) better understand hydrologic and water quality processes through instrumentation and data collection; (2) use high-frequency data to inform hydrologic and water quality modeling; and (3) educate next generation engineers and scientists in data collection and management techniques. A better understanding of hydrologic and water quality constituent behavior are important to water managers within the snowmelt dominated watersheds of the western United States. In particular, our high-frequency data collection in Cache Valley watersheds is improving our understanding of the spatial and temporal dynamics of important pollutants like nutrients (nitrogen and phosphorus) and dissolved organic matter. It is also extending capabilities to better estimate pollutant loading and timing, quantify storm water inputs in urban water systems, and test and implement hydrologic/water quality models. These tools aid in evaluating current and emerging water monitoring systems and the role of cyber-infrastructure in supporting day-to-day data collection, management, and sharing to support the next generation of environmental models.

- **Benefits to the State:**

  The ability to predict hydrologic and water quality responses within arid watersheds stressed by growing population, changing land use, and uncertain climate is essential to the State of Utah. This is difficult given high uncertainty in the driving forces and the human-impacted, heavily managed nature of these systems. The monitoring and modeling techniques we are developing provide better information about the timing, magnitude, sources, and flow paths associated with water and important pollutants. Results are already benefitting the Utah Division of Water Quality, local canal companies, municipalities, and in general, any utility providing drinking water from surface water sources. It is also of use to managers responsible for storm water and other water infrastructure throughout the state. This work is valuable in improving monitoring programs as to critical periods for pollutant transport and the necessary sampling frequency to obtain accurate data needed for load determination or watershed parameters needed by users. Finally, the cyber-infrastructure and tools developed as part of this project are essential to researchers across disciplines and managers in the state who need enhanced capabilities to work with increasingly complex water resources problems.

- **Geographic Areas:**

  Study Area: Watersheds in Cache County.

  Areas Benefited: River systems statewide.

- **Accomplishments:**

Figure 2. A mobile water quality monitoring platform enables us to examine spatial patterns in water quality that we cannot observe with grab sampling or fixed sensors

Findings: Combined urban/agricultural water conveyances (canals) show significant storm water impacts in both hydrology and water quality. Canal managers must reduce diversion flows to accommodate storm water inflow and avoid flooding. However, reductions in water diverted from the river lead to canal flows predominantly made up of storm runoff from streets, gutters, and parking lots. This reduced water quality can negatively impact downstream canal water users and receiving waters. Current urban storm water models generally lack mechanisms to accurately represent these types of water management activities, but accounting for them is critical to understanding and predicting system hydrology and water quality. Monitoring results show that major pollutant loading occurs during very brief periods during the year, e.g., river systems during spring snowmelt and urban water conveyance systems during storm water events. This underscores the need for high frequency, continuous data collection.

Results: We have developed new methods to quantify episodic events such as storm water runoff in urban water systems. We have also developed a mobile water quality monitoring platform that enables us to make new measurements of the spatial distribution of water quality variables (e.g., how water quality changes along the length of a stream or canal) instead of a limited number of fixed sensor measurement locations. We have used our monitoring network within the Northwest Field Canal system in Logan, UT to investigate storm water impacts to combined agricultural/urban water conveyances. Using this first-of-a-kind canal monitoring system, we have examined the impacts to flow and water quality from both storm events and system management. Our work has led to an ongoing relationship with both Logan City and the Northwest Field Irrigation Company as collaborators, and we are now working to expand the network of monitoring sites in collaboration with Logan City.

Work Plan FY16/FY17

Our data collection and sampling efforts have matured in the past year. They now provide the rich dataset we need to more closely examine flow and water quality impacts of storm water runoff, and the performance of the methods we are developing to better quantify those impacts. We will continue to monitor stream flow and water quality via our collaborations with Logan City and the Northwest Field Irrigation Company, operate our monitoring sites within the Logan River/Northwest Field canal system, and expand the data on quantity and quality of canal flows and storm water outfalls. We now have nearly two full years of high frequency data for these urban water quality sites, which we will use to test, calibrate, and increase the resolution of an existing storm water model for Logan City and investigate the benefits of these data for improving the accuracy and usefulness of modeling within other urban water systems. Finally, we plan to continue our work on open-source software tools for managing streaming data from environmental sensing sites.

Informational Resources

Contact: Dr. Jeffery S. Horsburgh, Telephone: (435) 797-2946, E-mail: jeff.horsburgh@usu.edu.
Websites: http://littlebearriver.usu.edu; http://gamut.iutahepscor.org.

Hydraulic and Thermal Characteristics of Complex Habitat Structures in the Lower San Rafael River

Principal Investigators:
Ian Gowing
Bethany Neilson

Partners/Collaborators:

- ***State**: Dan Keller – Utah Division of Wildlife*
- ***Federal**: Justin Jimenez – Bureau of Land Management*
- ***State**: Paul Birdsey – Utah Division of Wildlife*

Project Description

- **Need and Purpose:**

  The purpose of this work is to investigate Beaver Dam Assist Structures (BDA's) as a way of providing good quality fish habitat for native fish populations throughout the San Rafael River. Fish habitat within the lower San Rafael is limited or severely depleted, and these BDA structures could potentially enhance native fish abundance by providing additional high-quality habitat. Previous research (fish-surveys) conducted by the Division of Wildlife Resources related these structures with an abundance of fish when compared to other habitat types within the San Rafael.

  This study is examining what makes these structures more suitable locations with respect to habitat variables such as temperature, stream hydraulics (depth and mean velocity), and substrate/cover. These variables are being measured and analyzed during fish surveys conducted by the Division of Wildlife Resources. Temperature sensors are being positioned throughout these structures to examine how temperature varies spatially and temporally, especially during critical periods of low flow. Temperature data from these sites are being analyzed with longitudinal temperature data simultaneously collected along 55 miles of the San Rafael to see if these locations provide more favorable thermal conditions. Data are also being collected to see whether these structures reduce the overall incised nature of the river channel.

- **Benefits to the State:**

  The San Rafael River is recognized as being in a severely degraded state and is on the 303D list of degraded waters in the state of Utah. With the implementation of this river restoration approach, we anticipate restoring the river to a more ecologically acceptable state, providing more comprehensive complex habitat to native fish, encouraging change in channel morphology through removal of Tamarisk, planting more native riparian species along the river corridor, and removing man-made barriers to encourage fish movement and passage throughout the entire drainage.

- **Geographic Areas:** San Rafael River, Emery County, Utah.

  Study Area: Emery County.

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

- **Accomplishments**:

  Findings: Fieldwork commenced in May 2016 at the two existing sites on Moonshine Wash in the San Rafael River. A full topographic survey was completed at both sites using GPS. Instruments, including temperature sensors and pressure transducers, were positioned within the river and BDA structures.

Additional groundwater wells were established, and two existing groundwater wells were repaired due to infill. Fish surveys were completed in collaboration with UDWR at both sites during the summer and fall of 2016. Benthic samples were collected and sent to the lab for processing. A new intensive site was identified at Highway 24 where groundwater wells have been established. Monitoring will continue April/May 2017.

Results: Preliminary data analysis is on-going and will continue through the end 2017.

Instrumentation in and around the BDA structures, the San Rafael River

Measuring groundwater levels

Work Plan FY16/FY17

The groundwater wells at all three sites will be intensively monitored through 2017. Fish surveys will be completed at all three sites. Temperature sensors and pressure transducers will be installed at the new site near highway 24 in the summer 2017.

Informational Resources

Contact: Mr. Ian Gowing, Telephone: (435) 797-3159, E-mail: ian.gowing@usu.edu.

Impact of Urban Irrigated Agriculture on Utah's Per Capita Water Use

Principal Investigators:
L. Niel Allen
Arthur Tyler Pratt (Student)

Partners/Collaborators:
Local: *24 irrigators of urban agriculture in Cache County*
State: *Todd Adams, Utah Division of Water Resources*

Project Description:

- **Need and Purpose:**

  About 80% of Utah's total diverted water is for agriculture irrigation. The other 20% is for municipal, domestic, commercial, and industrial water uses, of which it is estimated that over 60% is for urban irrigation. Many of Utah's communities and cities have unmetered secondary water systems that deliver to both agriculture and urban water users. Additionally, in urban areas, private water systems from canals provide irrigation water for lawns, gardens, small pastures, and agriculture. These water uses complicate the water accounting process. Hence, a better understanding of the water use in unmetered urban irrigated agriculture is needed. A significant amount of water conservation may come from better accounting and management of urban agricultural irrigation. This research project aims to create a clearer picture of urban agricultural irrigation by determining typical quantities of water used, and evaluating efficiency of irrigation systems to determine areas for potential improvements.

- **Benefits to the State:**

  The results of this study can be used to better understand water use in Utah, particularly the portion of water that is used for irrigation in urban agriculture or undefined irrigation water use. A better understanding of urban irrigation water use will help the Utah Division of Water Resources better manage the State's water and provide direction for accounting and reporting of water use. The results identified management practices to better utilize Utah's water supply.

- **Geographic Areas:**

  Study Areas: Utah urban/small farm irrigated areas in Logan, North Logan, Smithfield, Hyde Park, Mendon, Nibley, Richmond, Benson, Paradise, and Levan.

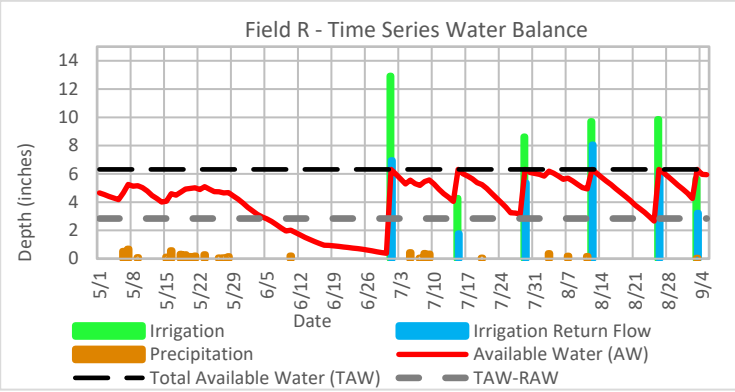
  Areas Benefited: State-wide.

- **Accomplishments:**

  Findings: During summer 2015, field measurements of irrigation deliveries, irrigation uniformity, and irrigation efficiencies were made for 24 urban irrigated agriculture sites including community gardens, small acreage commercial farms, backyard pastures, gardens, orchards, and small alfalfa fields. The following findings were observed:

  - A wide variation of water use exists across the fields and crop types in the study, with the majority of sites over-irrigated but seven of the 24 under-irrigated.
  - Small farms tended to over-irrigate more than large farms, and had worse uniformities.
  - Surface irrigated fields tended to be over-irrigated more than sprinkle and drip irrigated fields.

- Orchard crops received the most water, followed by pasture, alfalfa, and gardens. All of the crop types received less water than landscapes in a 2009 Division of Water Resources (DWRe) study of residential water use.
- The method of irrigation scheduling played a large role in the efficiency of each field, with fields relying on a fixed interval over-irrigate more than fields that irrigated based on a flexible schedule.



Results: The results from this study are summarized as follows:

- Generally, the DWRe agricultural water use estimation methods over-estimate the amount of secondary water used on urban and small farms.
- There is considerable room for improvement in urban and small farm irrigation operations. Conservation programs targeting reduced municipal and industrial water should incorporate urban and small farm water conservation in their approaches. Because gardens use less water than landscapes, alfalfa, and pastures, encouraging urban gardens may help the state meet its municipal and industrial water conservation goals.
- Conservation needs to emphasize proper water measurement, good irrigation uniformity, and irrigation scheduling. Technological improvements alone may not result in water savings if irrigation scheduling is ignored.
- Flexible irrigation water delivery schedules improve irrigation efficiency.
- Extension should target their efforts toward helping small and urban farmers improve irrigation by water measurement, improved irrigation uniformity, and irrigation scheduling, as well as promoting the benefits of good irrigation management.

Work Plan FY16/FY17

After submitting a paper for publication the work is complete.

Informational Resources

Contact: Dr. L. Niel Allen, Telephone: (435) 797 3926, E-mail: n.allen@usu.edu.

Website: http://extension.usu.edu/irrigation/.

Publications:

Pratt, T. (2016). *Urban Agriculture and Small Farm Irrigation: Case Studies from Cache Valley, Utah*. *All Graduate Theses and Dissertations.* Paper 4995.http://digitalcommons.usu.edu/etd/4995.

Improving Stream Flow Forecasting

Principal Investigators:
Andres Ticlavilca
Mac McKee

Partners/Collaborators:
- ***None***

Project Description:

- **Need and Purpose:**

  Climate change and extreme climatic events will require adaptations in behavior and decision-making, either in response to or in anticipation of new conditions. Appropriate responses to change will be more effective if better information about future water resources conditions are available, including information about future stream flow quantities and timing. Since irrigated agriculture in the state of Utah depends heavily on adequate water supplies and related water rights administration, accurate and timely knowledge is critical to effective adaptation to climate variability in order to preserve resilient, vital rural economies. Hence, accurate long-term forecasts of precipitation and stream flow quantities can be of great potential economic value in Utah, especially to the agriculture industry. Work in previous years tested short- and long-term streamflow forecasting based on statistical methods and advanced modeling approaches such as machine learning models and wavelet decomposition. A multi-resolution cross-correlation analysis connecting Pacific Ocean climate variability and seasonal stream flow in Utah was done as the next step of the project (FY15/FY16). The main goal was to analyze hydro-climatic relationships to gain a better understanding of the large-scale climate effects on the stream flow. The knowledge gained in this study can be used to improve forecasting models for different regions in Utah.

- **Benefits to the State:**

  Effectively adapting to climate variability and change in Utah will heavily depend on accurate and timely water supply forecasts on timescales ranging from days to decades. Improved water supply forecasts can enhance the economic value of agricultural decisions for both crop and livestock management and take into account the effects on water rights administration. This will, in turn, highlight institutional barriers to efficient water management and use and lead to improved planning and management of water resources systems in the state of Utah.

- **Geographic Areas:**

  Study Areas: Uinta Basin, Virgin River Basin.

  Areas Benefited: Irrigated agriculture is statewide, so all counties in the state would potentially benefit.

- **Accomplishments:**

  Findings: The results revealed stronger associations for tropical Pacific Ocean variables than for the North Pacific Ocean variables on stream flow in the State. In addition, results indicate that strong influences on the Southwestern Utah stream of the tropical Pacific Ocean variables start approximately 3 years earlier than the influences that affect Northeastern Utah. This seasonally staggered climate influence of the tropical climate variables on streamflow in Utah is potentially useful in prediction. A set of lead-lag

associations derived from the lifecycles of Pacific climate variations provide means for long-term prediction of streamflow at sites in Utah.
Results: Products generated by the project this year include:

- A wavelet-based, multi-resolution, cross-correlation methodology that has been used to identify the empirical relationships between Pacific Ocean climate variables and streamflow in various Utah regions.
- An article is nearing completion and it will be submitted to a peer reviewed journal.

Work Plan FY16/FY17

The methodology applied in this study will be used to improve the forecasting models developed for different regions in Utah. Proposals for external funding will be submitted to extend the methodology in order to make it of greater benefit to the state.

Informational Resources

Contact: Dr. Andres M. Ticlavilca, Telephone: (435) 757 0851, Email: andres.ticlavilca@usu.edu.

Irrigation System Water Use Efficiency Using Field Evaluations and Remotely Sensed Evapotranspiration Estimates

Principal Investigators:
Christopher M.U. Neale
Hatim Geli (Post-doc)
Jonna van Opstal (Graduate student)

Partners/Collaborators:

- ***Local:*** *Bear River Canal Company*
- ***State:*** *Utah Agricultural Experiment Station*
- ***Federal:*** *USDA-NRCS*

Project Description

- **Need and Purpose:**

  The growing demand for fresh water for municipal use in urban areas along the Wasatch Front and in Cache Valley has led to water quality and quantity pressures on existing water resources. The Bear River basin is one of the few systems in the US West that still has unallocated water. Additional dams would need to be built within the system to tap these water resources, even as the system is adjusting to changing runoff due to climate change. Solutions for improved management of the water resources in the Bear River basin must involve multiple stakeholders and will likely require policy adjustments to the existing water laws. Improving water management in large surface irrigated areas will be one of the elements important to the solution due to the high consumptive water use of irrigation and its large diversions from the river. This study has provided the information that system managers need in order to make future operational management decisions in adapting to changing conditions. The results will be relevant and applicable to other similar systems in Utah.

- **Benefits to the State:**

  Improved water management in irrigated agricultural areas can lead to water savings and, potentially, to improved water quality. Decreases in diversions for irrigation can be stored for future use during drought years and can guarantee minimum flows for healthy river systems and other uses. The methodology being developed can be used in other irrigated areas of the state.

- **Geographic Areas:**

  Study Area: Bear River Canal Company in Box Elder County.

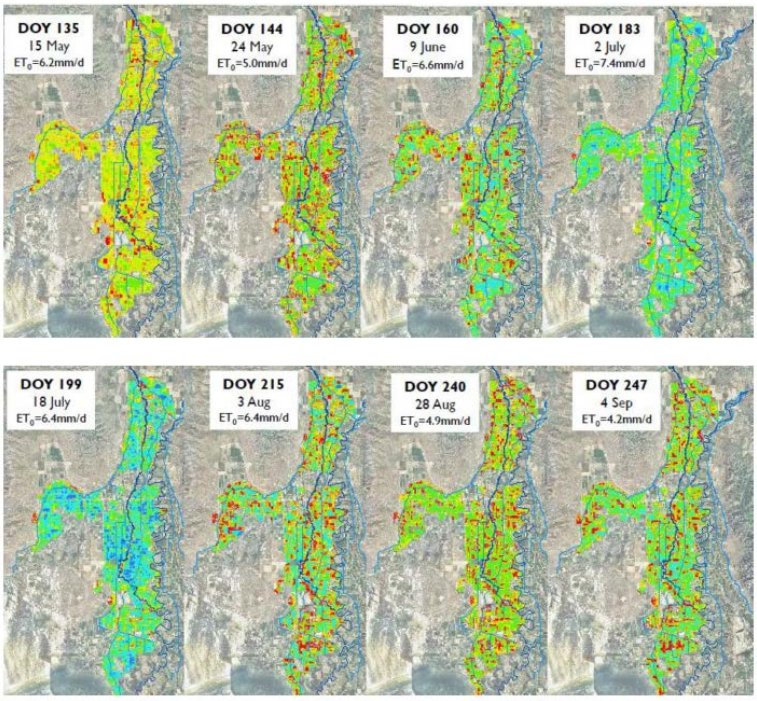
  Areas Benefited: Irrigated agricultural areas and systems in all 29 Utah counties.

- **Accomplishments:**

  Findings: Spatial evapotranspiration (ET) was estimated from a series of satellite images acquired over a growing season, and the data were used to establish seasonal crop water use in a large irrigated system. Crop water use was then used to establish the water balance and efficiency of the system at different levels. Additionally, the spatial ET data was used to calibrate the Ador irrigation system simulation and scheduling model. Continuous water depth and electrical conductivity measurements were conducted at 2 points in the Malad River and in an agricultural drainage ditch. These findings help determine the influence of irrigation strategies on outflow water quality. Field evaluations of irrigation events were conducted on 4 different soil types to determine infiltration parameters. Results from the field evaluations aided the Ador simulations.

Results: Evapotranspiration estimates were calculated with the METRIC surface energy balance model and applied to multi-temporal satellite imagery from Landsat 5 TM and Landsat 8 products. Weather station and irrigation diversion data were used to compute the water use and system efficiency in the years from 2003 to 2014. These results indicate the difference in irrigation system management for dry, normal, and wet years. Seasonal ET estimates were only impacted in a dry year when it was preceded by a dry year.

Field irrigation management was analyzed using the Ador model, which simulates water flow in the irrigation system infrastructure and on-field irrigation events. The field evaluation data collected on different soil types were used as inputs in the model to characterize the infiltration. Spatial ET from remote sensing was a valuable dataset to calibrate the model and include the spatial variability of the irrigation system. Results from current scenario simulations were discussed with local farmers and canal company managers. Findings were presented at the Bear River Canal Company annual shareholders meeting. Alternative water delivery scenarios were simulated with Ador, and that suggested potentially less water could be diverted for irrigation, whilst increasing yield if farmers irrigate more frequently for shorter periods during peak growing season. The performance of farms and headgates were analyzed by application efficiency, distribution uniformity, water productivity, and water delivery. Results have been published in a PhD dissertation defended in 2015. Scientific publications are underway.



Results from spatial ET estimates during the 2013 growing season using remote sensing data for the Bear River Canal company

Work Plan FY16/FY17

This project is now complete.

Informational Resources

Contact: Dr. Christopher Neale,
E-mail: cneale@nebraska.edu.
Ms. Jonna van Opstal, E-mail: j.vanopstal@unesco-ihe.org.

Publications:

van Opstal, J.D., Neale, C.M.U. and Lecina, S. (2014). Improvements in irrigation system modelling when using remotely sensed ET for calibration. *Proceedings SPIE 9239*, Remote Sensing for Agriculture, Ecosystems, and Hydrology XVI.

American Geophysical Union, San Francisco CA (Oral presentation) (2014). *Irrigation dynamics and tactics: Developing a sustainable and profitable irrigation strategy for agricultural areas*.

iUTAH – Innovative Urban Transitions and Arid Region Water-Sustainability

Principal Investigators:
Jeffery S. Horsburgh
Bethany T. Neilson
David Rosenberg
Caleb Buahin (Student)

Partners/Collaborators:

- ***Local****: Logan City and Many Others*
- ***State:*** *Utah State EPSCoR Office, University of Utah, Brigham Young University, Weber State University, Utah Education Network*
- ***Federal:*** *National Science Foundation, USGS Utah Water Science Center*

Project Description

- **Need and Purpose:**

  Water is critical to sustainable economic development in Utah and to the sustainability of urban and natural ecosystems. Freshwater resources face immediate and long-term challenges due to population pressure and predicted changes in the amount and timing of precipitation. Utah's population will at least double in the next two decades, with the most growth occurring along the narrow Wasatch Range Metropolitan Area (WRMA). Growth is expected to significantly increase the demand for high quality water, requiring water transfers, infrastructure investments, and efficiency programs. Sources, sinks, and residence times of heat and solute mass (e.g., pollutants) within stream networks are critical to identify and quantify because of their role in biogeochemical processes and water quality. A key process in mountain streams and rivers is the spatially and temporally variable groundwater exchanges. However, groundwater exchanges are not clearly defined and are widely recognized as being complex. Yet, they are important as they affect both water quality and quantity as well as our ability to deliver high quality water to meet Utah's growing demands. The interactions between stream flow and subsurface flow can occur in the hyporheic zone, deeper groundwater, parafluvial zone, riparian zone, and alluvial plain. Ongoing work on this project has focused on utilizing and combining flow and mass balances to build a spatial and temporal understanding of groundwater sources and exchanges.

- **Benefits to the State:**

  The innovative and transformational activities in this project include (1) the development of fully integrated hydrologic and social sciences observatories that encompass whole watersheds along an urbanizing land use gradient; (2) strategic activities designed to build a community of scholars across the state of Utah capable of addressing hydro-sustainability as a coupled human-natural system; and (3) integrated education and outreach activities such as participatory and collaborative modeling efforts to ensure that our research directly addresses societal needs and will translate and communicate the scientific findings to stakeholders, policy makers, and the general public. More specifically, recent groundwater exchange studies in Northern Utah have focused efforts on stream reach scales by using a wide variety of data types, but the need exists for a variable scale investigation on the importance of groundwater gains and losses within high gradient streams in the region. We are combing real time data being collected as part of the Utah EPSCoR Track 1 National Science Foundation project (iUTAH - innovative Urban Transitions and Aridregion Hydro-Sustainability) with synoptic sampling events to provide the foundational information needed to better quantify existing water sources and possible changes due to climate variability and change.

- **Geographic Areas:**

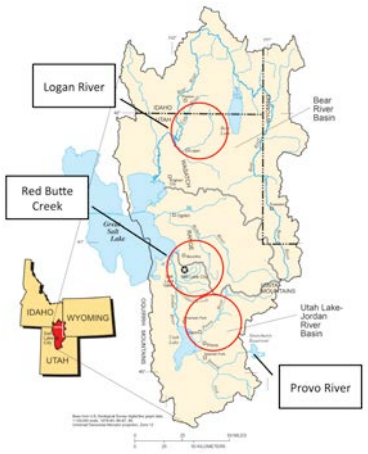
  Study Area: Logan River, Red Butte Creek, Provo River, WRMA.

Areas Benefited: This research will directly benefit Utah's most populated areas, but the information gained and methods developed should be applicable to the entire state of Utah.

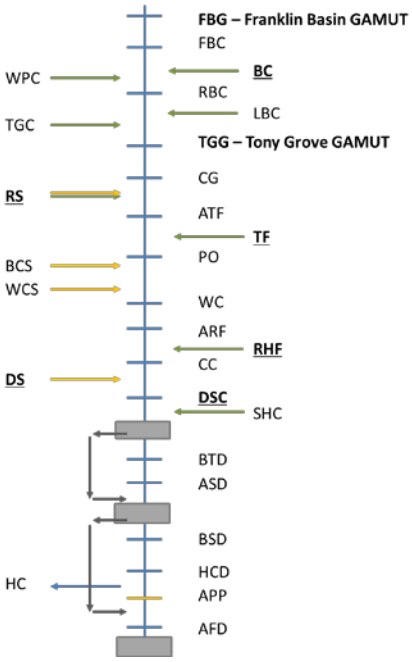
- **Accomplishments:**

Findings: Data have been gathered at many sites for five different time periods in the Logan River (see figure to right showing sampling locations) and Red Butte Creek over the last two years. During synoptic events, detailed flow information is collected at each sampling site, along with chemistry samples. These data are combined and analyzed to provide insight regarding groundwater sources and quantities during the critical low flow, groundwater dominated periods. We have additionally collected time series flow information at key tributaries and springs. These data have been combined to provide insight regarding reach scale net groundwater exchanges over 2 years.

Results: The data collection supports iUTAH efforts to (1) interpret the biochemical data collected longitudinally within the iUTAH study watersheds and (2) conduct other variable scale water balance modeling efforts within iUTAH to understand the implications of climate change on hydrology within the state of Utah. One undergraduate (BS) and four graduate (2 PhD and 2 MS) students are working on this project, and we have joined with a number of collaborators at the University of Utah to complete these efforts.



The iUTAH EPSCoR project is building new observing and data collection capabilities along a gradient of urbanization in three northern Utah watersheds



High resolution data collection enables us to better quantify inputs and sinks of both surface and ground water along the longitudinal profile of rivers like the Logan River

Work Plan FY16/FY17

During the coming year, we will collect additional data sets, complete analyses of existing and new data sets, and continue work on the cyber-infrastructure aspects of the iUTAH project, focusing on software systems to enable iUTAH scientists and partners to share and collaborate on water resources data and next-generation, linked models of the state's hydrologic systems. The data collection activities described above provide the essential inputs to these models. Ongoing research will use collected data (including continuous datasets from stream and terrestrial monitoring sites) to develop a new generation of interdisciplinary coupled models of human mediated hydrology for watersheds like the Logan River, Red Butte Creek, and Provo River.

Informational Resources

Contacts:

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

Website: http://www.iutahepscor.org, http://data.iutahepscor.org, http://gamut.iutahepscor.org.

Metering Non-Residential Water Users to Identify Conservation Opportunities

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

Partners/Collaborators:

- ***Local:*** *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 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 and sub-meters can now measure and record water use at very high temporal frequency. We are using smart meters to determine total water use, as well as the component end uses, and assess 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 demand and the 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:

  - Entered into a data sharing agreement with Logan City and took delivery of city data describing the monthly billed water use of all non-residential customers in the city, business licensing data, and the permeable and impermeable areas of each property.
  - Linked the multiple data sets, completed a preliminary analysis, and identified the largest users by water use, business category (using the North American Industry Classification System), and other factors that contribute to water use (Figure 1). This analysis provides important information about the most significant non-residential water users in the Logan City system. This analysis of existing data is a first view into the operation of Logan City's water system operation with respect to non-residential

users and provides information that the City could not have created given their existing resources. We will now use this analysis to select a set of non-residential users for installation of high frequency data collection.

- Presented the preliminary analysis to our Logan City collaborators, solicited feedback, and refined the analysis in response to feedback.

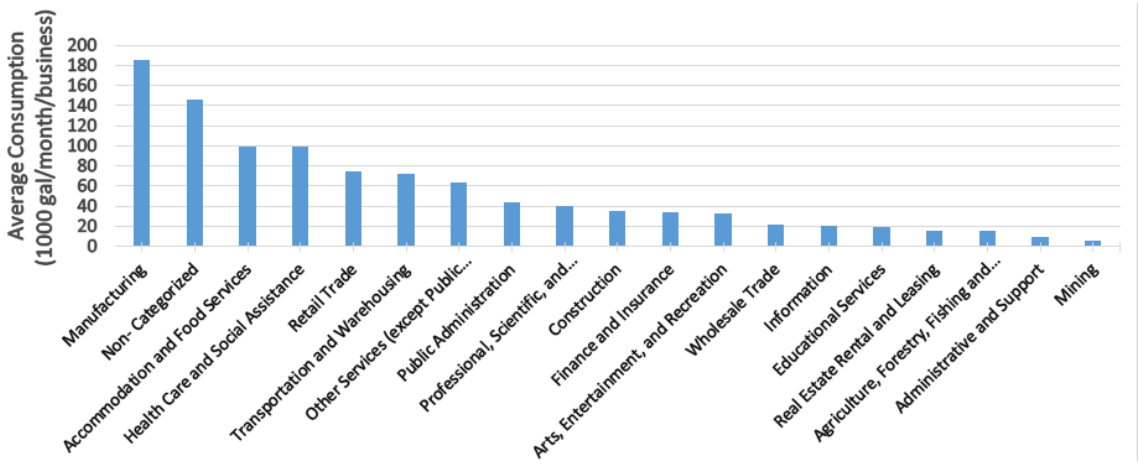

Figure 1. Average water use by business category in Logan, Utah from October 2014 to June 2016. Businesses are categorized and grouped by the North American Industry Classification System (NAICS).
Source: Monthly water billing and business licensing data provided by Logan City.

Work Plan FY16/FY17

- Select 10-20 non-residential users to meter and monitor at higher temporal frequency and work with them more intensively for the duration of the study.
- Approach users and request their consent to participate.
- With the consent of participants, conduct walk-throughs of the properties to identify current water use practices, piping, and the best location(s) to install a primary meter and, if needed, any secondary meters.
- Begin active metering and monitoring at high frequency.

Informational Resources

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

Near-Real-Time Orthorectification and Mosaicking of UAV Images

Principal Investigators:
Xiaojun Qi
Mohammad Reza Faraji (Post Doctor)
Amir Hossein Farzaneh (Ph.D. student)

Partners/Collaborators:
- *None*

Project Description

- **Need and Purpose:**

  Acquiring an accurate orthorectified RGB and NIR mosaic map from the images captured by a UAV (Unmanned Aerial Vehicle) system is a time-consuming and expensive process. Partly due to delays in the acquisition process, it is difficult to provide Utah water managers and farmers with timely and useful information. Resources of money and manpower are also wasted because the delayed maps cannot be used to their full potential. Hence, there is an urgent need for a more efficient process to generate accurate orthorectified RGB and NIR mosaic maps in near real-time or real-time.

- **Benefits to the State:**

  The project applies novel computer vision techniques to generate near real-time or real-time orthorectified RGB and NIR mosaic maps using images from a UAV system. This project will mainly benefit the State in the following two ways: (1) provide Utah farmers with a detailed picture of the variations that exist within a given agriculture field so they can implement management policies to maximize yield while minimizing inputs, and (2) provide researchers in Utah with the spatial or temporal view of water quality needed to accurately assess water bodies.

- **Geographic Areas:**

  Study Area: Utah area at UTM, NAD83, Zone 12N; California area at UTM, NAD83, Zone 10N.

  Areas Benefited: Precision agriculture, vegetation mapping, and stream and river applications to benefit Utah/California farmers and water managers statewide.

- **Accomplishments**:

  Findings: We transferred the Matlab code for direct and indirect geo-referencing methods to Java and were able to run a demo version of our application on NUC. The average computational time to orthorectify and georeference one resized RGB image is about 1.5 seconds when using the Min-Eigen feature detector. We designed a new image registration method (phase congruency based registration using a log-Gabor histogram descriptor PC+LGHD) to register NIR and RGB image pairs. Then, we can generate the mosaic map for the NIR images and use a transformation matrix to produce the RGB mosaic map.

  Results: Figure 1 shows the experimental results generated from the Gallo aerial image set using the proposed geo-referencing algorithm and three different base maps as the references. We produced each of the three mosaic maps in about 30 minutes, which is significantly less than the current running time of the other software (e.g., about one to two weeks). Figure 2 presents four generated NIR Gallo mosaic maps based on the registration results obtained from the PC+LGHD method using different values of

$norient$ (e.g., 6, 5, 4, and 3). It clearly shows that the NIR Gallo mosaic maps generated by the PC+LGHD method with $norient$=4 and $norient$=3 have fewer blank spots and yield better registration results. The experimental results demonstrate that better registration will help in generating better NIR Gallo mosaic maps.

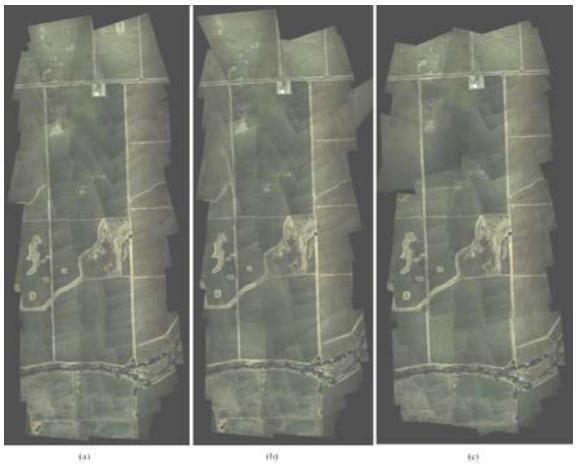

Figure 1. The generated mosaic maps of the Gallo aerial image set captured on the noon flight of July 10, 2015 using the reference image from: (a) the same date and time, (b) the afternoon flight of the same date, and (c) the noon session flight of June 2, 2015

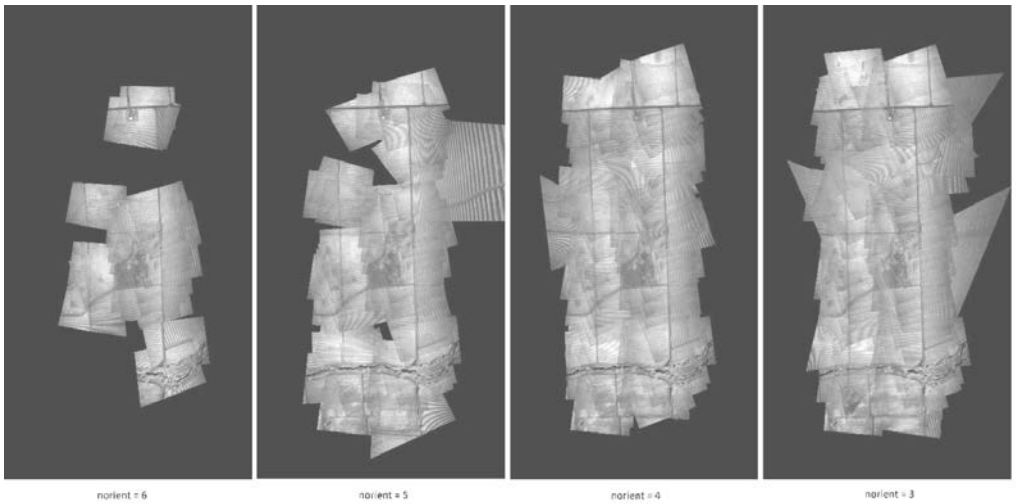

Figure 2. Generated NIR Gallo mosaic maps based on the registration results from the PC+LGHD method with a different number of orientations

Work Plan FY16/FY17

Further improve the image registration method and generate a better NIR mosaic map.

Informational Resources

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Organizing and Synthesizing Water Management Data to Speed Modeling

Investigators:
David E. Rosenberg
Adel Abdallah (Student)

Partners/Collaborators:

- ***Local:*** *Stephanie Duer, Salt Lake City Public Utilities*
- ***State:*** *Craig Miller, Utah Division of Water Resources*
- ***Business/Commercial:*** *Sarah Larsen, Western States Water Council; Jack Sieber, Stockholm Environment Institute*

Project Description

- **Need and Purpose:**

  Modeling of complex water systems requires multi-disciplinary data such as hydrologic, ecologic, economic, operation, engineered infrastructure, network connectivity, and scenarios whose data currently reside at different places and are managed by different entities. These data vary in space in time and use different formats (e.g., shapefile, text files), data types (e.g., time series, parameters, text), terminology (e.g., dam vs reservoir), and domains (e.g., water supply, storm water management). Water managers and scientists, therefore, spend considerable time gathering and organizing data before they can run a model or conduct an analysis. Thus, there is a need for a persistent informatics method to organize and integrate diverse water resources data.

- **Benefits to the State:**

  This project develops a persistent 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 thus 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 study area and compare results, and (3) archive results from one model for reuse as input to other models to identify the integrated effects of coupled human-hydrologic components of our water systems.

- **Geographic Areas:**

  Study Area: Lower Bear River and Salt Lake City Public Utilities service area; Cache, Box Elder, and Salt Lake Counties, Utah.

  Areas Benefited: Water managers and researchers statewide in all counties.

- **Accomplishments:**

  Findings and Results:

  - Designed the Water Management Data Model (WaM-DaM) as a flexible, modular, relational, location-independent tool that can store the data and metadata for different models, networks, scenarios, and the attributes that describe those data constructs. When importing data into the tool, users can either (i) use existing constructs or (ii) define new constructs and use controlled vocabulary to relate new constructs to existing ones.

- Used the WaM-DaM tool to organize 7 national and regional datasets with approximately 2.3 million data values spanning the years 1800 to 2015 (Figure 1).
- Refined the design of WaM-DaM to allow archiving model results.
- Presented work at an informal water management workshop held in Davis, CA in December, 2015.

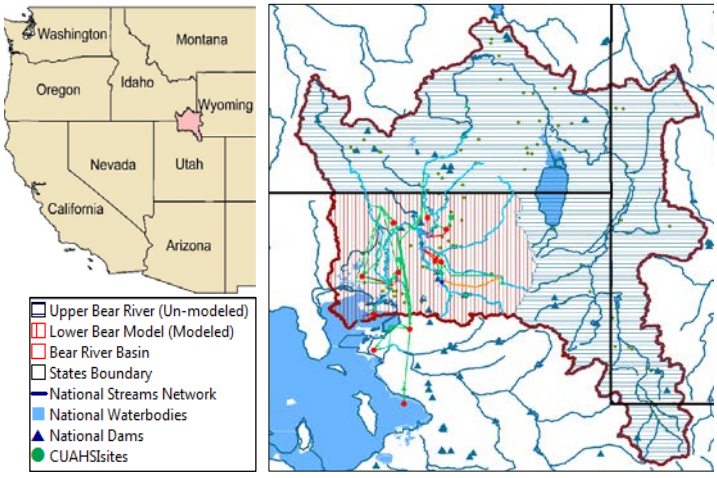


Figure 1. Map of data sets for the Bear River basin in Utah, Idaho, and Wyoming showing data available (blue lines, blue triangles, and green circles) to extend an existing model for the lower Bear (vertical red stripes) to the entire basin (horizontal blue stripes)

Work Plan FY16/FY17

- Develop a wizard to load data to speed the time to add new datasets to WaM-DaM.
- Submit the first article on WaM-DaM data system design and use to the peer-reviewed journal, *Environmental Modelling & Software*.
- Develop a wizard to export data already organized in WaM-DaM to run one or multiple models. Demonstrate capability to input the same Bear River basin data to a Water Evaluation and Planning (WEAP) model that allocates water by water priority and a Watershed Area of Suitable Habitat (WASH) model that allocates water to increase the area of suitable riverine, floodplain, and wetland habitat. This capability will allow comparisons of water operations for the two purposes.
- Develop the capability to load results from a first model into WaM-DaM, then export results in the format needed to run a second model. Demonstrate this model coupling capability by feeding results to the WEAP and WASH models from a household model that identifies individual water and energy use and savings for households along the Wasatch Front. Use the modeling and data sequence to identify the effects of conservation by individual households on water deliveries and flows throughout the lower Bear River basin.

Informational Resources

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

Website: http://ci-water.org/water_modeling/presentations/WaM-DaM_UWUG.pdf.
Website: https://github.com/amabdallah/WaM-DaM.

Quantifying the Flow Field in Baffled Fish Culverts

Principal Investigators:
Blake P. Tullis
Mohanad Khodier (Post Doc)

Partners/Collaborators:
State: *Tim Ularich, Utah Department of Transportation*

Project Description:

- **Need and Purpose:**

  Many culverts are approaching or are past their original design lives and need to be repaired, rehabilitated, or replaced. Due to the expense and impact of traffic disruption associated with culvert replacement, alternate measures to extend the culvert project life are growing increasingly popular. One such method is slip lining, where a 'sleeve' is installed within an existing culvert barrel and stabilized. Plastic pipe sleeves are very popular for slip lining, but the reduced flow resistance, relative to corrugated pipe, can result in increased flow velocities and reduced flow depths in the culvert, creating a potential fish barrier. Hence, mitigation of the increased velocities should go hand-in-hand with slip-lined projects where fish passage (present or future) is to be considered. Experience has been very limited in providing for fish passage through slip-lined culverts.

  Baffles installed in culvert liners have been recommended as a possible solution for culvert relining when fish passage is a concern, but very limited data are available in the literature regarding baffle performance in circular culverts in relation to fish passage, as well as discharge capacity. Consequently, the evaluation the flow dynamics (turbulence) and the corresponding swimming behavior of fish to that flow environment will be evaluated in this study. As the single largest owner of culverts in the State of Utah, the Utah Department of Transportation (UDOT) has a keen interest in fish passage through rehabilitated culverts. As such, UDOT provided the initial funding for this study and MLF funds have been used to expand the research and contribution. The objective of the currently proposed study is to incorporate a flow dynamics component by determining mean flow velocities and flow depths and, perhaps more importantly, fluid acceleration data for turbulence quantification. Flow dynamics will be compared with fish behavioral results from the UDOT-funded study in an effort to better predict the likelihood of successful fish passage in baffled culvert designs not included in this study (i.e., improve the general applicability of the fish passage data).

  The scope of work for the project is summarized as follows:

  - Develop a technique for evaluating the 3-dimensional flow field in the free-surface flow, baffled culvert using a particle image velocimeter. Some complications may include the presence of entrained air bubbles and equipment access to the pipe (light sheet generating laser and imaging camera).
  - Collect high-frequency, 3-dimensional velocity data for a range of discharges and culvert slopes using the PIV system and an acoustic doppler velocimeter system for comparison.
  - Process the velocity data to calculate local flow accelerations and representative turbulence parameters.
  - Correlate the turbulence values with the fish behavior, relative to their ability to negotiate the baffled culvert.
  - Use computational fluid dynamics (CFD) to further analyze the flow field and calibrate using the PIV velocity data.

- Determine hydraulic roughness coefficient data for the baffled culvert using laboratory and CFD data.
- Write a peer-reviewed journal article summarizing the result of the study

- **Benefits to the State:**

  UDOT does not currently have a design standard for baffled slip-lined culverts. The results of this study will be used to aid UDOT in developing a baffled culvert protocol for rehabilitated culverts where fish passage is a concern. The results of the study should have nation-wide application and perhaps even international application.

- **Geographic Areas:**

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

  Areas Benefited: Culvert rehabilitation projects statewide and nationwide where fish passage issues may be of concern.

- **Accomplishments:**

  Findings/Results: The fish experiments were completed in FY14. The CFD work was completed in FY15. Two papers were written and submitted to a journal in 2015. The journal requested some modifications that the authors felt were unnecessary so the papers were resubmitted in early FY 16 to a different journal (Journal of Hydraulic Research). A conference paper on the topic was presented at the 6th International Symposium on Hydraulic Structures, held in Portand, OR (June 2016).

Work Plan FY16/FY17

Efforts will continue with the two journal papers, both of which are currently in their second review.

Informational Resources

Contact: Dr. Blake P. Tullis, Telephone: (435) 797 3194,
E-mail: blake.tullis@usu.edu.

Publications:

Khodier, M.A. and Tullis, B.P. (2014). Fish Passage Behavior for Severe Hydraulic Conditions in Baffled Culverts. *J. Hydraul. Eng*., 140(3):322-327.

Olsen, A.H. and Tullis, B.P. (2013). Laboratory Study of Fish Passage and Discharge Capacity in Slip-Lined, Baffled Culverts. *J. Hydraul. Eng*., 139(4):424-432.

Real-Time Management of Irrigation Systems in the Sevier River Basin

Principal Investigators:
Mac McKee
Alfonso Torres
Andres Ticlavilca
Leila Hassan Esfahani
Manal Al Arab

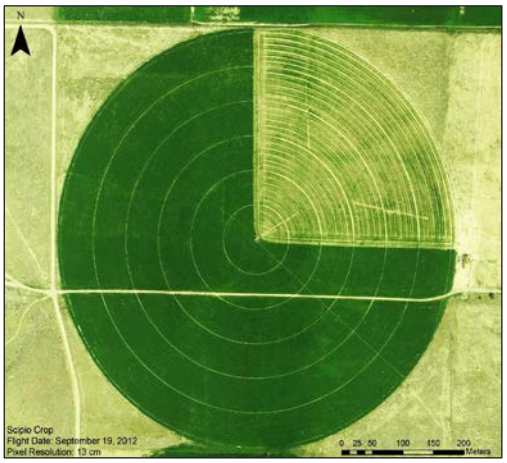
Partners/Collaborators:

- ***Local:*** *Jim Walker, Sevier River Water Users Association (SRWUA)*
- *Ivan Robins, Ex-President Scipio Irrigation Company*

Project Description

- **Need and Purpose:**

  As water demands increase in the western states, concerns for endangered species and water quality will have a greater impact on the allocation of water resources. Emphasis will have to be placed on more efficient water management if existing water rights are to be met in the future. Improvements in water management and efficient water use require a low-cost means for obtaining and distributing information about the state of the water supply system. This project is developing and adding significant data analysis capability to support real-time and long-term water management information needs of the Sevier River Water Users Association (SRWUA).



Aerial imagery of the center pivot system in Scipio obtained from UAV flights used to estimate soil moisture, evapotranspiration rates, and plant nitrogen content

- **Benefits to the State:**

  The data analysis, management and forecasting technologies applied in the Sevier River Basin in the past several years have significantly improved the decision-relevant information available to system managers. This information directly supports their efforts to increase the efficiency of basin-wide water management. Similar results could be achieved in virtually every river basin in Utah, especially those with substantial irrigated agriculture. The forecasting techniques developed by this project can provide valuable information to farmers/ranchers for making better long-term decisions on investments in crops and livestock, especially in years where drought might be likely. Similarly, the methods developed for short-term forecasting and remote sensing can provide system managers with information necessary to more precisely control the operation of large irrigation systems, such as those found in the Sevier Basin, thereby saving water and increasing the overall system productivity.

- **Geographic Areas:**

  Study Area: Sevier River Basin, including Sevier and Millard Counties,

  Areas Benefited: Irrigated agriculture is statewide, potentially benefiting all counties in the state.

- **Accomplishments**:

  Findings: The remote sensing tools and data-driven models developed in this project are able to improve real-time reservoir, canal, and on-farm operations in the Sevier River Basin by several percent.

  Results: Accomplishments of the project this year include the following:

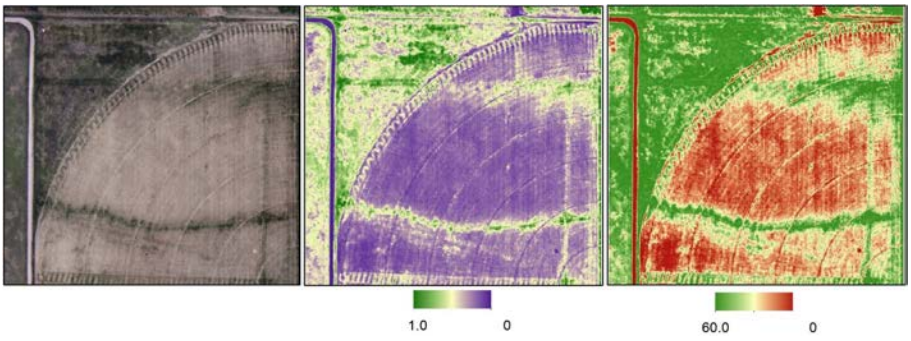
  - Used satellite data to develop a dynamic model for optimizing the irrigation operation of a center pivot system, with application demonstrated for a system in Scipio, UT.
  - Developed and published a model for use of UAV-based remote sensing capabilities to estimate surface soil moisture at high spatial resolution over irrigated land. This was demonstrated for a center pivot farm plot in Scipio, UT.
  - Developed and published a model for use of UAV- or satellite-based remote sensing of root-zone soil moisture on irrigated land. This was demonstrated for a center pivot farm in Scipio, UT.
  - Began exploring questions of downscaling satellite data to generate higher-resolution information for on-farm irrigation operational decisions.
  - Participated in discussions with the Utah Division of Water Resources to implement state-wide satellite-based spatial evapotranspiration models for agricultural water management.

Work Plan FY16/FY17

- Continue integration of current and completed algorithms to improve farm irrigation operations within the Sevier River Basin. This work will place greater emphasis on the use of remotely sensed data acquired from Landsat.
- Continue assessment of remote sensing and related tools for estimating the water requirements, evapotranspiration rates, and present and future soil moisture levels that are needed for better management of center pivot irrigation systems in the Scipio and Lower Sevier River areas.

Informational Resources

Contact: Dr. Mac McKee, Telephone: (435) 797 3188, E-mail: mac.mckee@usu.edu.



True color image of flight in Scipio, UT (left), LAI map (middle), estimated chlorophyll content map (µg.cm-2) (right)

UAV Remote Sensing Service Center

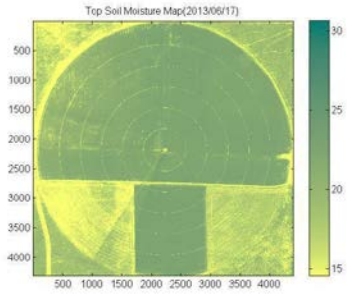
Principal Investigators:
Austin Jensen
Cal Coopmans
Nathan Hoffer
Mac McKee

Partners/Collaborators:
Various end-users in Utah

Project Description

- **Need and Purpose:**

Many current sources of remote sensing data, such as manned aircraft and satellite platforms, are too expensive, have low spatial resolution, or are not updated frequently enough to be useful for many applications. A low-cost, small unmanned aerial vehicle (UAV) called AggieAir™ fills these gaps by providing inexpensive multispectral aerial imagery, and also other types of remote sensing data, much more quickly and frequently. AggieAir now has stable and robust platforms available for use on a regular basis. A great advantage of AggieAir platforms is that they do not need a runway for takeoff and landing so they can be deployed almost anywhere. The payload sensor systems collect valuable data for research and support a variety of applications in agriculture, riparian habitat mapping, road and highway surface monitoring, wetland mapping, fish and wildlife tracking, air quality monitoring, and many others.



Surface soil moisture estimates developed from AggieAir imagery

The funds generated from these applications will support continued AggieAir development and research. A service center has been established to handle the operational and maintenance needs so R&D work can continue to progress effectively and efficiently. The service center also provides feedback to help steer future AggieAir activities in directions that are most beneficial.

- **Benefits to the State:**

The data provided by the service center can help Utah save water and better manage environmental resources. The service center is a low-cost solution for mapping soil moisture so farmers can irrigate their crops more efficiently and getting the necessary data for canal operators to manage water diversions more effectively. The UAV's can also survey roads before, during, and after construction, monitor the quality of the asphalt, and update road inventory information such as number of lanes, signs, culvert crossings, etc. Wetlands managers can obtain current data on the distribution of plant species and monitor the success of management practices to control invasive plants. Resources managers responsible for monitoring and managing water quality can obtain accurate, high-resolution thermal images showing temperature distributions along all reaches of a stream or river.

Long term, the service center is the first step toward a new business that will be based around the AggieAir UAV platform, and allows us to test business models and gain the experience required to make the transition to a viable industry. As such, the service center will directly and indirectly provide new jobs and economic growth to Utah.

- **Geographic Areas:**
Study Area: Statewide.

Areas Benefited: Statewide.

- **Accomplishments:**

Findings/Results: This project has developed and fully equipped the service center at the Utah Water Research Laboratory called the AggieAir Flying Circus (AAFC) (see http://AggieAir.usu.edu). As planned, the AAFC uses AggieAir UAV platforms and sensors on a regular basis to provide aerial images for applications that benefit from remote sensing data. The images shown are examples of the maps generated by the AAFC, and the analysis of the imagery is used to address water, environmental, and infrastructure management problems in a variety of applications.

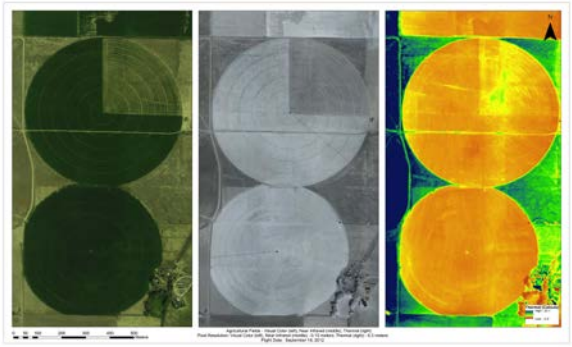
The AggieAir service center has completed manuals to train customers who have purchased the UAVs from USU. Aircraft have been sold to organizations that wish to use AggieAir for their own remote sensing purposes, including Oklahoma State University, University of California at Merced, and Texas State University. Licensing agreements are in place with private companies in Utah to manufacture AggieAir aircraft and avionics. Additional field crews have been trained to fly the UAVs and process collected imagery.

This year, the AAFC has provided support for a very large number of flights conducted on a wide array of resources management problems in Utah and has serviced research contracts in several states. These include flights and remote sensing work on the San Rafael River, air quality remote sensing over the Great Salt Lake at Promontory Point, river corridor mapping in support of endangered species management on Yellow Creek on the Utah-Wyoming border, and many others. The AAFC has supported work to improve monitoring of watershed recovery investments, to increase our understanding of ozone production along the Wasatch Front and how it is influenced by the Great Salt Lake, and to benefit many other important projects around the State. Personnel from the AAFC also worked in collaboration with Box Elder County, ATK, and the Governor's Office of Economic Development to submit a proposal to build a UAV test facility in Box Elder County at a site that will have airspace that is controlled by the US Federal Aviation Administration (FAA), and is supporting the team's work to improve access to the site.

The AAFC obtained several Certificates of Authorization (COA) from the FAA in the past year that certify the AggieAir platform is airworthy and authorize its use subject to FAA rules. AggieAir personnel helped Box Elder County obtain a COA for the new UAV test site. Negotiations are underway to create a spinoff company that will market some AggieAir technology. New payloads developed this year include a wider array of sensors. A new airframe was designed and tested, and it is now being integrated into the AggieAir fleet that provides better capability than all other small UAVs now being sold anywhere in the world.

Work Plan FY16/FY17

Expand the AAFC business base through acquisition of more research contracts, further develop and license a spinoff company to market AggieAir technology, and complete the development and deployment of new aircraft and payloads.



Daily evapotranspiration rates developed from AggieAir imagery, near Scipio, Utah

Informational Resources

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Research Faculty, Professional, and Support Staff

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