MINERAL LEASE FUND REPORT

Utah Water Research Laboratory

Fiscal Year 2006

for

Office of the Legislative Fiscal Analyst
Room 425
State Capitol
Salt Lake City, UT 84114

by

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March 2007

Foreword

The Utah Water Research Laboratory (UWRL) at Utah State University (USU) receives 2-1/4% of all deposits made to the Mineral Lease Account, "to be used for activities carried out by the UWRL having as a purpose the development and exploitation of water resources in the State of Utah."

This report is being submitted to the Legislature by the UWRL in compliance with House Bill 103 which was passed during the 1993 General Session. This legislation requires the UWRL to "provide the Legislature, through the Office of the Legislative Fiscal Analyst, with a complete accounting of the use of that money (MLF) on an annual basis." Following the requirements of the legislation, this report includes the following:

1) Actual expenditures for FY 2006
2) Budgeted expenditures for FY 2007
3) Planned expenditures for FY 2008

The report is divided into an introduction and the summaries of each MLF research project. The introduction describes the role of the UWRL, summarizes the requested MLF expenditure information, describes the history of the UWRL, and discusses how the UWRL maintains the relevancy of its research programs to Utah water problems. Project summary reports are grouped into eight program areas. A table summarizing actual, budgeted, and planned expenditures for FY 2006, FY 2007, and FY 2008, respectively, is presented at the beginning of each program area section.

Each project summary report begins with a project description that includes a statement of the problem addressed and research objectives. Accomplishments for FY 2006 are then described. A statement of the benefits to the State of Utah is also provided.

This report will be reviewed by the Community and Economic Development Appropriation Subcommittee of the Legislature as part of its normal budgetary process under Title 63, Chapter 38, Budgetary Procedures Act. The UWRL welcomes any comments or questions that result from this review.

Mac McKee
UWRL Director

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Introduction

Role of the Utah Water Research Laboratory

Research programs at the Utah Water Research Laboratory (UWRL) directly address current and future needs of the state, the nation, and the world. State appropriation funds (SAF) and mineral lease funds (MLF) are used to address problems facing the State of Utah. In FY 2006, SAF and MLF accounted for 36% of total UWRL expenditures with the balance coming from federal, private, and other state sources. MLF funds are presently used to match externally funded projects, thereby leveraging significant additional funding for solving important Utah water problems. Total UWRL expenditures for FY 2006 were $8.6 million.

The UWRL is organized into eight major research programs supported by the Environmental Division, the Water Division, and the International Office for Water and Science Education (IOWSE). Brief summaries of these major research programs under these three divisions are presented at the end of this Introduction section.

The UWRL research program related to MLF is very diverse as indicated by the project summaries in this report. The overall research program, funded by both state funds and 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 our 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, we continue to be involved in university graduate and undergraduate education through hands-on projects, part-time employment, and research assistantships. We are also involved in public and professional service, technology and information transfer, and public education. Almost all research and applied projects include student involvement, and result in masters or doctoral degrees. Seventy-eight graduate students were supported in FY 2006. Undergraduate student involvement in UWRL projects is significant, as student education and training are integrated with our basic and applied research programs. The UWRL employed approximately 34 undergraduate students in FY 2006 through leveraging of MLF and SAF support to build the larger total UWRL program. As they are hired by Utah employers, our students become effective means of technology transfer from the UWRL to the Utah water and environmental communities to assist with wise water use within drought conditions. Technology and information transfer are focused on public education, and on working with 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 users organizations.

History of 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. Construction was completed in December 1965, and included one of the best hydraulics laboratories in the United States and a unique erosion testing facility with a large rainfall simulator. Sixteen years later, an extensive remodeling project, including the addition of an environmental quality laboratory, was completed. In addition to the physical facilities, the State of Utah provides state-appropriated funds (SAF) and mineral lease funds (MLF) for research support at the UWRL.

In 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 a part of the national network of water research institutes. Total research funding through the UWRL was more than 8.6 million in FY 06, making it one of the largest institutes in the nation. It is also one of the most productive in terms of research publications and graduate student education.

Introduction

There are 24 faculty and 38 support staff at the UWRL. During FY 2006, 43 master's students and 35 doctoral students received support from UWRL projects. An additional 34 undergraduate students assisted with UWRL research. UWRL faculty collaborate with colleagues from other USU departments, faculty from other institutions, professionals from the private sector, and government agencies in Utah, and elsewhere. Several of our faculty, including the 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 recognition, and served on national and international engineering and science panels and committees.

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 for providing funds to 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 $90,000 of federal funds. This year, we used the base grant from the U.S. Geological Survey (USGS) in combination with MLF support to directly benefit the State of Utah in areas of: (1) large irrigation system management, with applications specifically aimed at the Sevier River Basin, (2) aquatic and riparian habitat management in the Virgin River Basin, and (3) aquatic management and endangered species recovery in the Provo River Basin. In the future, we will continue to use the USGS 104 Program support to develop applied research tools and accomplish information and technology transfer to address Utah's water quantity and quality problems.

We will continue to use the USGS 104 Program support to develop applied research information and to accomplish technology transfer for source water protection strategies, tools development, and programs across the State of Utah.

Mineral Lease Fund Expenditures

The table at the end of this Introduction section summarizes the actual, budgeted, and planned expenditures of MLF allocated to the UWRL for FY 2006, FY 2007, and FY 2008 by the eight major research program areas. A breakdown of these expenditures by individual projects is contained in tables presented at the beginning of each research program area section of this report. UWRL administration and technology transfer expenditures accounted for approximately 4% of total MLF budgeted and planned expenditures in FY 2006.

Relevancy and Benefits of the Mineral Lease Fund

Research Identification

In FY 2006, UWRL faculty kept current on state and national water research needs through professional and service activities and through research on improving efficiency during drought conditions. The Utah Center for Water Resources Research (UCWRR) participated as an active member of the National Institutes for Water Resources (NIWR). In addition, UWRL faculty participated as a member of the Lake Powell Technical Advisory Committee activities to identify research needs and arrange collaborative research efforts. The current Director represented the UWRL to the Universities Council on Water Resources (UCOWR). The UWRL also participated in the U.S. DOE-sponsored Inland Northwest Research Alliance (INRA). The former UWRL Director served as the University Programs Coordinator (UPC) for INRA, and the current UWRL director served on the INRA Coordinating Committee, which is charged with securing expanded funding support for the INRA universities. The UWRL Director, Associate Director, and many faculties met frequently with state and federal agency managers and personnel from local water organizations to discuss research needs and opportunities for the UWRL to respond to these needs. UWRL faculty were also active in state sections of professional organizations, such as the American Water Resources Association, the American Society of Civil Engineers, the American Water Works Association, and served on state, local, and national committees.

All these activities provided opportunities to identify current and future research needs that will affect our state and the nation.

We continually seek to strengthen the UWRL research identification process to maintain relevancy of our research programs to Utah. We do this through participation on state committees. The former UWRL Director serves on the DEQ Water Quality Board, UWRL Faculty member Dr. William J. Doucette serves on the Board of the Utah Solid and Hazardous Waste Control, and Dr. Laurie McNeill serves on the DEQ Drinking Water Board. Dr. Darwin L. Sorensen is a member of the Lake Powell Technical Advisory Committee. The UWRL also encourages faculty participation in meetings attended by the Utah water community, such as the Utah Water User's Association Annual Meeting, the Utah Rural Water User's Association, the Water Environment Association of Utah, the Annual Uinta Basin Water Conference, the Utah Annual Water Summit, the Utah League of Cities and Towns, and the recently formed Utah On-Site Wastewater Treatment Association (UOWA).

Outreach

The mission of the UWRL includes outreach activities related to public service, information dissemination, technology transfer, and short courses. These activities are provided for the benefit of Utah state and local agencies, elected officials, Utah citizens, and the nation. Outreach is provided by faculty, staff, and students associated with the UWRL. Additional outreach is provided through our World Wide Web (WWW) site: http://www.engineering.usu.edu/uwrl.

Public Service

UWRL faculty serve on state and local advisory panels to provide technical expertise, input, and review of water-related issues. Specific panels include: Utah Water Quality Board, Utah Solid and Hazardous Waste Control Board, Lake Powell Technical Advisory Committee, Salt Lake County Solid Waste Management Council, the State of Utah Wastewater Treatment Plant Operator Certification Committee, and the Utah Drinking Water Board. 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.

Information Dissemination and Technology Transfer

UWRL information dissemination, outreach, and technology transfer activities include the publication of research results in professional journals (listed in the Publications section of this report), distribution of information on various UWRL and UCWRR web pages, presentations before various professional societies and interest groups at meetings in the state and around the country, and sponsorship and participation in numerous short courses and training programs.

The UWRL web page (http://www.engineering.usu.edu/uwrl) provides general information about the UWRL and its personnel, and from time-to-time provides a feature article on different research projects, faculty, students, and groups from the UWRL. The Utah On-Site Wastewater Treatment Training Program at the UWRL provides on-site wastewater training in support of the State of Utah certification program for on-site wastewater treatment professionals. Undergraduate and graduate students participate through projects that involve hands-on, real-world activities. Additional information can be found at: http://www.engineering.usu.edu/uwrl/training.

The UWRL has provided donations to the Society of Women Engineers (SWE), Utah State University Chapter, enabling 12 members to attend the annual SWE conference in Salt Lake City, UT. The UWRL has hosted meetings of the Utah Solid and Hazardous Waste Control Board, including lunch and tour of the UWRL. The UWRL has also hosted meetings of the Utah Association of Local Boards of Health.

Outreach and service support provided by faculty of the UWRL have been recognized by the Girl Scouts of Utah for assistance in providing math, science, and engineering experience to girls in Cache Valley, aged 5-15, for the 2003-2006 years.

In the course of a year the UWRL hosts numerous delegations from other countries that have interest in the research conducted at the UWRL and in the capabilities that UWRL professionals could offer to the solution of their water problems. In the past year, these have included visits by delegations from Palestine, Pakistan, India, Spain, Iran, and Iraq.

Some examples of UWRL staff involvement in conducting technology transfer to audiences external to USU include:

- UWRL faculty have developed an internet-based viewer for Utah's native fish species. This has provided an Internet-based software tool that 4th and 9th grade students throughout the State of Utah can use to learn more about fish in Utah, which is a topic in their regular science curriculum. Teachers throughout the state can use this software in their lesson plans for teaching students about Utah's native fish species.

- Results of both laboratory and field investigations conducted by faculty and students of the UWRL provide cost-saving methods for improving the operations of dams in Utah and can be expected to play an important role in the management of the water stored in these facilities. For example, work this year on the flow measurement weir downstream of Piute Dam in the Sevier River Basin will improve the accuracy of the existing calibration for the facility and enable the dam operators to more accurately manage the releases from the reservoir. The results of this study have been shared with the Sevier River Water Users Association and the river commissioner responsible for operation of Piute Reservoir.

- Researchers at the UWRL frequently work in close collaboration with state and local agency personnel and members of the public to understand and seek solutions for resource management problems. One example is the work of UWRL faculty and students on Cache Valley's air pollution problem. These collaborations have produced not only a better scientific understanding of the seasonal ambient ammonia distributions in the valley, but also a more informed set of managers in Utah's Division of Air Quality, the Idaho Department of Environmental Quality, the Bear River Health Department, and numerous officials in local city and county government.

- As population growth and associated housing developments continue to threaten the preservation of agricultural lands in Utah, there is an increased need for accurate and thorough information on on-site wastewater treatment technologies. The Utah On-Site Wastewater Treatment Training Program at the UWRL helps address these challenges through such means as newsletters, educational brochures, and numerous workshops and training programs conducted annually throughout the state.

- The UWRL is actively engaged in the development of cost-effective approaches to acquire and display data that are important for water resource management in the state. Numerous projects supported at the UWRL in part with MLF funding have been instrumental in implementing streamflow and water quality monitoring stations in the Logan and Little Bear Rivers. Further, the UWRL maintains a website where the data from these monitoring stations are archived in real time and displayed to various water users, including canal operators and personnel at the Utah Division of Water Rights.

- Researchers at the UWRL have worked closely with canal managers to implement monitoring technology that will better quantify flow rates (greater accuracy and more frequent measurements) at key locations in irrigation and drainage canals, and improve operation and maintenance practices by the canal companies. These improvements, which are strongly supported through the involvement of canal operators with UWRL staff, are expected to result in the sustainable conservation of water for irrigated agriculture, municipalities, and industry, as well as ameliorate technical and legal problems associated with the excessive stormwater runoff into the canals during rainstorms.

Benefits to the State of Utah

Specific state benefits resulting from MLF research projects are listed at the end of each project summary in the following sections of this report. Projects conducted by the UWRL in the past year have produced activities in every county of the state. (Refer to Figure 1 for a tally of UWRL projects by county.) A few examples of recent and current benefits produced by MLF funding are:

- As water supply pipes age after installation, they can develop corrosion or deposits that increase friction loss, degrade system performance, and increase operation costs. Until now, the magnitude of pipe head loss due to pipe aging has been unknown due to lack of experimental data. Studies conducted this year at the UWRL, in collaboration with the Weber Basin Water Conservancy District and the City of Centerville will greatly improve our understanding of the effect of pipe aging on pipe roughness and help the State of Utah municipal water systems do a better job planning and managing water system operations.

- Inundation maps are a useful decision-making tool for emergency management, flood warning, and evacuation. Unsteady flow models such as DAMBRK, FLDWAV, and HEC-RAS are available for dam breach analysis. Advanced GIS tools are also available for processing the terrain data and displaying the results of breach analysis to develop inundation maps. Despite these technological advancements, their application seems to lag in practice due to laborious and time consuming steps involved in their use. Researchers at the UWRL have worked with personnel from the Utah Division of Water Rights on a project to address these shortcomings. The State of Utah will benefit from this work by having a tool to develop consistent and efficient GIS-based inundation maps for its dams. This will be especially helpful to the state's overall emergency management preparedness.

- Chlorinated solvents, fuel related compounds, and explosives have contaminated shallow groundwater at many locations in the State of Utah, including many communities surrounding Hill Air Force Base. Previous research conducted by the UWRL has documented the uptake of some of these organic compounds into plants but little experimental information is available regarding the potential transfer of these compounds into fruits and vegetables. The Environmental Directorate at Hill Air Force Base (HAFB), the Utah Department of Environmental Quality, and community citizen groups are interested in the potential contamination of fruits and vegetables growing in areas of contaminated groundwater. The results of research done at the UWRL on uptake of these chemicals by fruits and vegetables will directly benefit the Environmental Management at HAFB and the citizen advisory groups that monitor the groundwater pollution around HAFB and other contaminated groundwater sites.

- Understanding the potential impact that plants have on shallow soil/groundwater systems contaminated with chlorinated solvents, such as trichloroethylene (TCE), is critical in evaluating the potential effectiveness of phytoremediation and quantifying the relative impact of plants on the overall natural attenuation processes involved with these hazardous chemicals. Information regarding the fate of TCE taken up into plants is also necessary to assess the potential risk associated with the consumption of these plants by humans and animals. Tree sampling for chlorinated solvents such as TCE could also be used to supplement the groundwater monitoring efforts used for plume delineation. Ongoing research at the UWRL on plant uptake and phytoremediation of these chemicals will directly benefit the federal and state agencies charged with managing these contaminated groundwater sources.

- A GIS-based computer data management and modeling system was completed this year to help the Utah Department of Environmental Quality prioritize actions needed at sites to protect groundwater supplies from contamination by chlorinated solvents. This project will have a direct and positive impact on citizens throughout the state as chlorinated solvent impacted groundwater sites have been identified throughout the Salt Lake Valley as well as in Bountiful, Delta, Logan, Ogden, Price, Tooele, Tremonton, Vernal, and Woods Cross. All citizens will benefit from an improved understanding by the Utah DEQ of potential groundwater resource contamination represented by current and historic chlorinated solvent users, by their more efficient expenditure of public dollars based on risk-management prioritization that will be made possible by this tool, and by the preservation of groundwater resources in the state through proactive control of high risk sites.

- The UWRL has supported water management research in the Virgin River Basin for more than 25 years. Faculty and students at the UWRL are currently engaged in field based and associated technical assessments to allow the Virgin River Program to conduct cost-benefit assessments of

various proposed strategic watershed restoration actions. This effort will provide critical field data, analyses, and modeling results for use in strategic watershed planning in the Virgin River Basin under constraints imposed by endangered aquatic species. Related research at the UWRL will produce a decision support system (DSS) to provide watershed managers in the Virgin River Basin with data manipulation and visualization tools that assist them in better managing the Virgin River where water supply and endangered fish species are of concern.

- June sucker fry on their out-migration from the Provo River to Utah Lake face intense competition and predation from introduced species. Increasing the survival of this limiting life stage is key to the long-term restoration and delisting of the species. A project currently underway at the UWRL will provide the preliminary feasibility design and proof of concept for a specific restoration project on the Provo River that will ultimately lead to improvement in endangered fish habitat and recruitment.

- The rural parts of the State of Utah are still actively involved in agricultural activities, from crop cultivation to dairy farming and ranching. However, most parts of these agriculturally dominated regions of the state have moderate to severe water deficits that often hinder the full implementation of their desired agricultural goals. In these uncertain times of water deficit conditions, farmers cannot plan for the optimal land area/crop combinations to cultivate in a given season to maximize their annual profits. Most Midwestern states have sophisticated analytical tools available to the farming community to address these concerns so that they can rotate their land use patterns every season based on the water deficit and local market conditions. Current research at the UWRL will develop a web-oriented agricultural water management system for the State of Utah such that farming communities can use the system to determine the optimal land area/crop combination to cultivate in any given season knowing the water deficit and local market conditions such that agricultural profits can be maximized. This research is being conducted in coordination with the Utah Division of Water Resources and the USDA office in Salt Lake City.

- Research has been underway in recent years at the UWRL to better understand Cache Valley's air pollution problem. Identification of the seasonal ambient ammonia distributions will aide in locating areas of significant sources which may, in turn, be targeted for reductions, and verify the degree of excess methane (NH_3) in the local area. Vertical ozone (O_3) profile information provides information on to what extent downward vertical mixing is responsible for the seemingly anomalously high wintertime O_3 concentrations. Additionally, these data will then be available for use by local and state regulators. The ultimate products of this study will be significant contributions to the database and final report used by local and state regulators to help manage the air quality within the Cache Valley airshed.

- With the increasing costs and regulatory burdens associated with achieving new and proposed wastewater treatment standards, establishing scientifically defensible options for the beneficial use of biosolids generated within the State of Utah has become an urgent need for the Utah Department of Environmental Quality (UDEQ). Beyond the challenges associated with biosolids management, the UDEQ as well as the Utah Department of Natural resources are developing best management practices aimed at restoring disturbed rangelands in order to reduce soil erosion and to improve forage productivity. The Utah ranching community is also an important stakeholder in the development of sustainable practices for utilizing biosolids on rangelands. Biosolids land application improves rangeland forage productivity while reducing the need (and hence the costs) of utilizing chemical fertilizers and soil amendments/conditioners to increase vegetative yields on Utah rangelands. The information generated from a current project conducted by faculty and students of the UWRL will be important to rangeland managers as well as the Utah ranching community in identifying sustainable methods for utilizing biosolids to restore the vegetative vigor of disturbed Utah rangelands. It is anticipated that the results of the research will lead to rangeland management practices that will improve the forage value of Utah rangelands while minimizing any adverse environmental impacts of biosolids disposal. Land application of biosolids on disturbed rangelands represents a potentially cost-effective approach for beneficially using the solid residues from treated municipal wastewater. By demonstrating

that the biosolids land application leads to increases in both biomass yields and nutritional quality of rangeland vegetation, biosolids land application will be recommended to Utah agricultural/ranching specialists as a rangeland management practice that supports sustainable ranching in the State of Utah.

- As water demands increase in the western states and as concerns for endangered species and water quality begin to affect the allocation of water resources, greater emphasis will have to be placed on efficient water management if existing water rights are to continue to be met. Improvements in efficiency of water management require a low-cost mechanism for obtaining and distributing information about the state of the water supply system. The object of one ongoing research project at the UWRL is to develop and add significant data analysis functionality to the existing Sevier River Water Users Association (SRWUA) web site to support real-time and long-term water management information needs. Recent work on this project has focused on developing accurate short-term forecasts of irrigation water demand. This has involved the use of a combination of on-ground, real-time soil moisture measurements, weather data, and satellite imagery. Application of these and related technologies in the Sevier River Basin in the past several years have already shown a dramatic increase in 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. These forecasting techniques could supply system managers with information necessary to more precisely control the operation of large irrigation systems, thereby saving water and increasing the overall productivity of the system.

- Heavy rains in 2005, coupled with high groundwater levels and other unfavorable hydrologic and drainage conditions, caused severe flooding conditions and substantial property damage in numerous locations in northeast Box Elder County. This flooding problem is in part to the rate of urbanization of the area and the limited ability of local institutions and the tax base of unincorporated areas to provide flood protection services, especially in periods of exceedingly heavy rainfall. A project was developed at the UWRL in response to requests for help from Box Elder County officials. The purpose of the project is to assist the county in developing a database for flood control planning and to help them acquire state and federal funding to conduct such planning. In FY 2006, preliminary data were gathered (e.g., land use, stream and canal locations, topographic information, roads and highways, etc.) and placed in a GIS format. Numerous meetings were attended involving representatives of Box Elder County and the UWRL. Most significantly, staff from the UWRL wrote a proposal to obtain funding for a $10,000 planning grant from the state. This money is now available to the County to support more detailed flood planning and flood plane mapping.

- Utah regulations on the concentration of toxic heavy metals in water and soils are based on total contaminant concentration. This assessment does not provide information on potential bioavailability of the metal. The bioavailability of a metal is related to the association of the metal with solution and solid phase components, not necessarily the total concentration. Methods presently used for the analysis of metals cannot distinguish the bioavailable fraction. Research currently underway at the UWRL is examining the use of bacterial biosensors as a direct measurement of bioavailability. Results from this research effort will be used to develop technical management strategies with regards to risks for soils, sediments, and surface and groundwater contamination based on more accurate measurements of bioavailability, and to develop an approach to reduce risk to groundwater and surface water posed by metal contaminated waters and soils in Utah. Results will be useful to the Utah Department of Environmental Quality, various municipalities in the State of Utah, the State Division of Oil, Gas, and Mining, and county agencies for developing effective water quality management programs for heavy metal contaminated sites.

- Faculty and students at the UWRL are conducting research to identify, select, and design groundwater and sediment remediation systems and monitoring systems for gasoline sites contaminated with the additive MTBE (methyl-tertiary-butyl-ether). This project benefits the State of Utah Department of Environmental Quality, Division of Environmental Response and Remediation.

- High levels of salinity in the Great Salt Lake (GSL) play a strong role in the lake's ecosystem. In particular, brine shrimp are one of the few species that lives within the lake, and play an important role in keeping the lake's water clean through algae consumption. The brine shrimp also support an industry in which brine shrimp eggs are harvested and sold worldwide as fish food. Other important industries involve the extraction of minerals such as common salt, magnesium metal, sodium and potassium sulfate, and magnesium chloride. Recreational uses of the lake have been hampered due to long-term fluctuations in water levels, leading to large changes in the surface area. Given the importance of the lake to the region, long-term efforts have been underway by the United States Geological Survey and the Utah Department of Natural Resources to define physical characteristics of the GSL, and to understand how humans are affecting the lake. Currently, there is no consensus as to the general circulation patterns that exist within the GSL, nor does consensus exist regarding the dominant (forcing) mechanisms that cause the circulation. A hydrodynamics model was developed this year at the UWRL and applied to the south arm of the Great Salt Lake. Model inputs allow users to examine the influences of a wide range of forcing functions on the hydrodynamic behavior of the lake. Consequently, the transport of pollutants and influxes of fresh water into the lake may be predicted, aiding in management of this water resource.

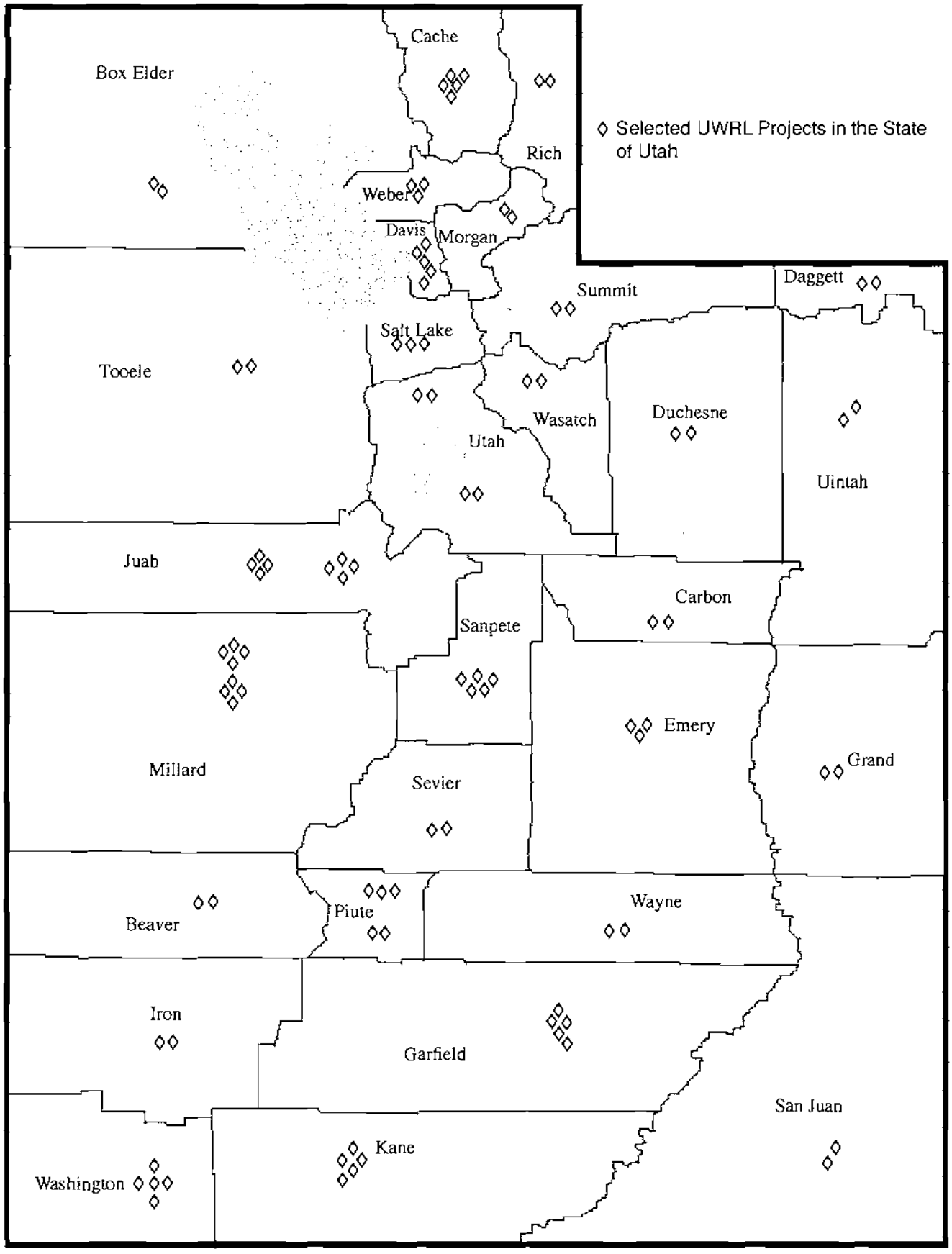

Figure 1. Projects conducted by the UWRL in the State of Utah.

Actual, Budgeted, and Planned Expenditures ef Mineral Lease Funds
Tetal Pregram Areas

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
UWRL Administration	$30,547.72	$31,567.10	$32,514.13
Projeot Management of USGS 104	$16,510.38	$17,005.69	$17,515.86
Publications Offioe	$21,079.93	$21,712.33	$22,363.75
Business Offioe	$121,367.94	$125,003.98	$128,759.25
Travel, Equipment, Student Support and Speoial Projeots	$235,762.40	$304,193.50	$245,164.17
Undesignated for Travel, Equipment, Student Support and Speoial Projects	$0.00	$15,000.00	$75,000.00
Water Eduoation and Teohnolgy Transfer	$69,265.15	$91,761.45	$105,442.11
Bioprooess Engineering	$59,659.26	$90,492.29	$93,219.06
Hazardous and Texio Waste Management	$204,961.49	$668,490.06	$795,690.53
Water Ouality Engineering	$279,664.26	$1,065,944.03	$1,071,607.16
Fluid Meohanios and Hydraulios	$100,901.29	$458,934.35	$477,332.63
Ground Water	$69,046.54	$139,217.30	$130,795.22
Hydrology	$130,971.23	$206,630.82	$201,904.40
Water Resouroes Planning and Management	$253,063.74	$1,355,839.91	$1,325,305.44
Totals	**$1,592,911.38**	**$4,591,848.36**	**$4,729,603.81**
Administration makes up	0.03	0.01	
Undesignated Amount for FY 07/03 Speoial Projects		$15,000.00	$75,000.00
Designated Amount for FY06/FY07 Researoh Projects		$2,336,013.90	$2,506,807.11
Undesignated amount for future FY06/07 Research Projeots		$125,000.00	$436,000.00
Budgeted Research		$4,451,343.36	$4,163,603.31

Summaries of Major Utah Water Research Laboratory Research Programs

Bioprocess Engineering

Bioreactor processing of environmental materials and engineering scale-up of biologically-based environmental reactions are being explored. Areas of specialization include: composting, waste reuse, biosolids processing, management of environmental biotransformations, and engineering optimization of wetlands.

Hazardous and Toxic Waste Management

This program emphasizes an integrated engineering and science approach for characterization and remedial design approaches for contaminated subsurface environments. In addition to laboratory scale work, the program has the largest field scale research dimension of any similar academic program in the nation. In addition to the research in hazardous and toxic waste, this component also includes the work conducted by the Utah Water Research Laboratory (UWRL) on air quality problems in the state.

Water Quality Engineering

The program focuses on the development of engineering approaches for production of drinking water; treatment, reclamation, recycling, and reuse of municipal and industrial wastewater; and modeling of water quality. Areas of specialization include: low technology and advanced treatment processes for potable water treatment, characterization and control of dissolved and particulate natural organic matter (NOM), modeling conventional and toxic contaminants in natural and engineered systems, water reuse engineering, water-quality management, and assessment and control of nonpoint source pollution and storm water.

Water Education and Technology Transfer

Several projects conducted by the UWRL, 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 training modules or educational materials, sometimes to provide technical support to Utah state agencies on water-related issues (such as the State Attorney General's Office in litigation involving liability assessment in hazardous waste problems), and development of curricular materials for use in K-12 education programs in the state

Fluid Mechanics and Hydraulics

This program utilizes the UWRL hydraulics laboratory for physical modeling of hydraulic structures, including evaluation of scour below spillways and other structures, testing and evaluation of hydraulic machinery and piping systems, flow meter calibration, and testing of erosion control systems for slopes and channels. Analytical aspects of the program include design of pipe networks for water supply, porous media flow, sediment transport, and open channel flow.

Ground Water

Current research activities cover topics from theoretical developments in the stochastic and numerical analysis of transport in ground water to practical aspects of the design of clean-up technologies for fuel-contaminated sites and management of Utah aquifer systems.

Hydrology

This diverse program has strengths in both the theoretical and applied aspects of modern hydrology, including climate modeling, rainfall processes, snow hydrology, floods, droughts, terminal lake analyses, soil erosion, and stream water quality modeling.

Water Resources Planning and Management

This program addresses institutional and legal aspects of 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. Additional areas include reservoir operating policies, water conservation, river basin planning, user-driven decision support systems for water planning, terminal lake water level management, and dam safety risk assessment.

Administration, Advisory Support, and Special Equipment

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

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
UWRL Administration	$30,647.72	$31,567.10	$32,514.13
Project Management of USGS 104	$16,510.38	$17,005.69	$17,515.86
Publications Office	$21,079.98	$21,712.33	$22,363.75
Business Office	$121,357.94	$125,003.98	$128,759.25
Travel, Equipment, Student Support and Special Projects	$235,752.40	$304,193.50	$246,184.17
Undesignated for Travel, Equipment, Student Support and Special Projects	$0.00	$15,000.00	$75,000.00
Total	**$425,368.42**	**$514,487.65**	**$522,317.16**

Administration, Advisory Support, and Special Equipment

The numerous projects conducted by faculty and students at the Utah Water Research Laboratory (UWRL) with financial support from the MLF program are administered by the officers of the UWRL. The Director and Associate Director 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 in the mission of the UWRL to provide such input, MLF funds are sometimes used to cover travel expenses of the faculty that become involved 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 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 MLF funds and, in collaboration with water managers and policy makers in state and local agencies, identifying opportunities in the state where applied research could 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 Director and supports the administration of the USGS 104-B program that comes to the state. FY 2006 administrative costs represented only 0.3 percent of total UWRL MLF expenditures.

Outreach and Business Support

Overall, annual research expenditures for the UWRL typically range between $8 and $10 million, and at any point in time there will be approximately 200 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 2006 on these support activities accounted for 0.9 percent of total MLF funding.

Advisory Support on Water Problems

The UWRL received several requests in FY 2006 for advice and collaborative help on various water problems in the state. In FY 2006, the UWRL provided support to defray travel costs from MLF sources so UWRL faculty could participate in meetings in the state to coordinate UWRL activities on ongoing water problems, to work to identify and seek funding for new applied research in the state, and to provide expert advice relative to current water management issues that various state and local agencies face. Examples of this type of activity in FY 2006 include:

- Box Elder County officials requested help from the UWRL on flood control problems, and MLF support was provided so UWRL personnel could attend preliminary meetings on these issues.
- Faculty from the UWRL were sent on one trip to Washington County using MLF funds to provide recommendations for future data collection and analysis work relative to the Virgin River management and recovery program.
- Travel support was given so UWRL faculty could attend a meeting of the team of state and federal agencies charged with devising a recovery program for the Provo River.

- Requests for assistance from the UWRL for technical help related to flooding and sediment management problems on the Dry Fork of Ashley Creek near Vernal, Utah, were honored by sending UWRL faculty to the Uintah Basin to advise in the initiation of a watershed planning program.

- The UWRL has provided travel support from MLF resources so that faculty could meet with representatives of the Weber-Morgan Health Department Wastewater Advisory Committee.

- Faculty from the UWRL received travel funds to participate in meetings of the Lake Powell Technical Advisory Committee to inform decisions relative to monitoring water quality in Lake Powell, to recommend policy for closing and opening beaches for recreational use, etc.

Special Equipment

Numerous communities in Utah face problems with the management of soils and aquifers that have been contaminated by hazardous materials, and the UWRL has been tremendously active in providing state-of-the-art scientific input into understanding these problems. Similarly, the UWRL tries to maintain an active program of coordination with such agencies as the Utah Division of Water Rights on problems associated with the operation and safety of dams in the state.

Investments in state-of-the-art equipment were made from MLF resources in FY 2006 to acquire real-time polymerase chain reaction (RT-PCR) instrumentation. The RT-PCR equipment provides quantitative capabilities for the low level detection of specific microorganisms and functional genes in environmental samples, and is becoming the standard PCR technique, replacing many applications of conventional PCR procedures we have routinely carried out at the UWRL environmental quality laboratory (EQL) in the past. This instrumentation gives the UWRL the capability to continue to support applied research on chlorinated solvent contaminated sites throughout Hill AFB and the surrounding area, at a contaminated site in Bountiful/Woods Cross, and at several sites at Dugway Proving Ground in Utah. RT-PCR capabilities at the UWRL has enhanced our ability to support these activities, and should improve our technical assistance to the Hill AFB Environmental Management (EM) Directorate, the Bureau of Reclamation and EPA (responsible for the Bountiful/Woods Cross site), and to the Dugway Environmental Management group/State of Utah Division of Solid and Hazardous Waste, and adjacent communities impacted by these contaminated sites.

To support hydraulics research activities associated with releases from dams in Utah (and related hydraulic phenomena, such as venting), the UWRL used MLF resources in FY 2006 to acquire a particle image velocimeter (PIV) system. This purchase will facilitate better investigation of variations in flow field velocities, and it will do so at very high spatial and temporal resolutions. In addition to furthering the general engineering knowledge in the area of boundary shear stress for open channel flow conditions, the results of the project should shed some light on the appropriateness of using shear stress performance limits on channel lining erosion control materials. Shear stress is a parameter commonly used by the Utah Departments of Transportation (UDOT) when qualifying erosion control products (blankets primarily) for state projects. The accuracy with which shear stress can be estimated in the field (or laboratory) has a significant impact on holding vendors accountable for the quality of their products, should a premature failure occur. Although standards are in place for minimum shear stress requirements, verification of performance (or failure) in the field is currently not a practical option. Acquisition of the PIV system will enable the UWRL to improve its ability to provide state-of-the-art science to state agencies engaged in the management or regulation of various kinds of hydraulic structures.

Bioprocess Engineering

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Bioprocess Engineering

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
Land Application of Biosolids and Animal Manure to Reclaim Disturbed Utah Rangelands	$29,040.27	$30,492.29	$31,407.05
Use of Anaerobically Digested and Composted Biosolids to Reclaim Arid Rangelands	$30,623.99	$37,000.00	$38,768.46
Designated Projects		$15,000.00	$16,043.55
Undesignated research projects in program area		$3,000.00	$17,000.00
Total	**$59,669.26**	**$90,492.29**	**$98,219.06**

Land Application of Biosolids and Animal Manure to Reclaim Disturbed Utah Rangelands

Principal Investigator(s):

Michael J. McFarland
Dharmin Desai
Mai AnhVutran
Issaak Romero

Project Description:

With the increasing costs and regulatory burdens associated with achieving new and proposed wastewater treatment standards, establishing scientifically defensible options for the beneficial use of biosolids generated within the State of Utah has become an urgent need for the Utah Department of Environmental Quality (UDEQ). Beyond the challenges associated with biosolids management, the UDEQ as well as the Utah Department of Natural resources are developing best management practices aimed at restoring disturbed rangelands in order to reduce soil erosion and to improve forage productivity. The Utah ranching community is also an important stakeholder in the development of sustainable practices for utilizing biosolids on rangelands. Biosolids land application improves rangeland forage productivity while reducing the need (and hence the costs) of utilizing chemical fertilizers and soil amendments/conditioners to increase vegetative yields on Utah rangelands.

The objective of this study is to determine the potential environmental, ecological and economic benefits of land applying lime-stabilized biosolids, aerobically digested biosolids and animal manures to alkaline rangelands located in Skull Valley, UT (an area located approximately 80 miles southwest of Salt Lake City, UT). To address this goal, the following six (6) research tasks were developed.

TASK 1: Based on an estimate of the nitrogen requirements of native rangeland vegetation in Skull Valley, UT and the plant available nitrogen (PAN) associated with lime-stabilized biosolids, aerobically digested biosolids and animal manures determine defensible agronomic rates (ton/acre) suitable for sustaining adequate vegetative production. Biosolids and animal manures will be applied in separately managed field plots at rates equivalent to 1, 5, 10 and 20 times the estimated agronomic rate.

TASK 2: Evaluate the potential impact of large application rates on nitrate mobility through conducting deep soil monitoring (up to five feet below ground surface) of biosolids and manure land application sites.

TASK 3: Quantify and statistically evaluate the effects of biosolids and animal manure land application on vegetative production (growth rate, plant diversity and density) as well as soil chemical and physical characteristics within rangeland field plots.

TASK 4: Based on the field plot's salinity, pH and sodium adsorption ratio (SAR) measured before and after land application of biosolids, characterize the rangeland soils as normal, saline, sodic or saline-sodic.

TASK 5: Monitor the changes in salinity, pH and sodium adsorption ratio (SAR) of the rangeland field plots over the two-year study period.

TASK 6: Based on the vegetative production results generated from rangeland field plots, develop a series of technical recommendations focused on improving rangeland management practices using biosolids and animal manure.

Accomplishments:

Biomass Results

Land application of both biosolids types occurred in December, 2004. In June 2006, the biosolids test plots were sampled for biomass (i.e. vegetative) yield as well as soil nutrient levels taken at depths ranging up to five (5) feet below the ground surface. Results from the biomass (i.e. vegetative) yield sampling are summarized in Table 1. Figure 1 provides photographs of the biosolids land application site taken during the June 2006 field sampling activity.

Table 1. Biomass Yields of Biosolids and Manure Applied to Disturbed Rangelands

Biosolids Type	Application Rate (Multiple of Agronomic Rate)	Ave. Biomass Yield (n = 6) (lbs/acre – wet weight)
Control	N/A	181.5
Aerobically Digested	1X	1669.8
Aerobically Digested	5X	1089.0
Aerobically Digested	10X	1415.7
Aerobically Digested	20X	1815.0
Lime Stabilized	1X	1197.9
Lime Stabilized	5X	689.7
Lime Stabilized	10X	526.4
Manure	1X	1016.4
Manure	5X	344.9
Manure	10X	1325.0
Manure	20X	962.0

Biosolids application was observed to increase vegetative biomass production above that which was recorded for the control plots in all cases. Although there was considerable variability found in the biomass data, initial inspections suggested that test plots that received aerobically digested biosolids, in general, had a greater vegetative response than those sites that had received lime stabilized biosolids. Preliminary ecological analysis indicated that the dominant plant species found on the control test plots was *Bromus tectorum* (cheat grass) while the dominant vegetative species found on the sites amended with biosolids was *Hordeum marinum gussoneanum* (seaside barley).

Work Plan FY 07/FY 08:

Aerobically digested and lime stabilized biosolids as well as beef cattle manure were surface applied at various rates on 1/3-acre test plots separated by buffer strips on private rangeland located in Skull Valley, UT. A control plot, which served as a treatment performance baseline, was also established and received no organic amendments. The agronomic rate (tons/acre) for the surface application of biosolids was determined based on the assumption that a healthy rangeland would exhibit a nitrogen demand of 150 lbs of nitrogen per acre. This nitrogen demand estimate was based on the assumption that a healthy rangeland would be dominated by perennial grass species.

To evaluate the long term benefit of applying organic amendments for rangeland restoration, lime-stabilized biosolids, aerobically digested biosolids and beef cattle manure were initially scheduled to be land applied on test plots at 20X, 10X, 5X and 1X the estimated agronomic rate. However, due to the low nitrogen content measured in the lime-stabilized biosolids, an unacceptably large biosolids application rate was found to be necessary for meeting the estimated rangeland nitrogen demand. To avoid the practical problems associated with applying a relatively thick layer of applied biosolids, the land application rates for the lime-stabilized biosolids were limited to 10X, 5X and 1X the estimated agronomic rate.

To draw defensible conclusions regarding the benefit of land applying biosolids to restore disturbed rangelands, a statistical inference approach was utilized. To facilitate the selection of random subplots to sample, each of the 1/3-acre test plots (14,520 ft^2) was divided into thirty-six (36) sections (or test plots) having physical dimensions of 20 feet by 20 feet. The exact boundaries of each of the 400 ft^2 test plots were established using a global positioning system (GPS).

Benefits to the State:

The information generated from this project will be important to rangeland managers as well as the Utah ranching community in identifying sustainable methods for utilizing biosolids to restore the vegetative vigor of disturbed Utah rangelands. It is anticipated that the results of the research will lead to rangeland management practices that will result in improving the forage value of Utah rangelands while minimizing any adverse environmental impacts.

Control Plot (June 2006)

Aerobically Digested Biosolids Site (1X – June 2006)

Lime Stabilized Biosolids (1X – June 2006)

Figure 1. Photographs of Biosolids Land Application Site During the June 2006 Field Sampling Activity

Use of Anaerobically Digested and Composted Biosolids to Reclaim Arid Rangelands

Principal Investigator(s):

Michael J. McFarland
Dharmin Desai
Mai Anh Vutran
Issaak Romero
Amy Davis

Project Description:

Utah rangelands provide forage for livestock production, habitat for native flora and fauna and watersheds for rural agriculture. However, because of past practices, these rangelands are in a variety of conditions ranging from severely degraded landscapes to fully functional ecosystems. Continued excessive defoliation, which is the major cause of range deterioration in Utah rangelands, has led to increased moisture runoff and soil erosion.

Wastewater biosolids represent a valuable and inexhaustible resource that can be utilized to restore the vegetative vigor of Utah rangelands. Biosolids contain significant amounts of plant nutrients as well as organic matter that support sustainable vegetative growth and forage productivity of rangelands. Land application of biosolids not only increases the economic value of Utah rangelands by increasing their forage value but collection of land leasing fees from municipal wastewater treatment plants can be a significant source of financial revenue for Utah ranchers who support the beneficial recycling of biosolids.

The objective of this work is to collect scientific data that support the sustainable use of biosolids on rangelands and to increase the environmental stewardship as well as the profitability of ranching activities in the State of Utah. The specific focus of this study is to document the impact of biosolids land application on the moisture infiltration properties and forage quality of disturbed rangelands.

Accomplishments:

The effect of biosolids land application on soil moisture infiltration was evaluated by estimating the soil's unsaturated hydraulic conductivity tests using a series of minidisk infiltrometers. The minidisk infiltrometer is constructed using two water chambers that maintain hydraulic communication during the test. A moisture level from 0 to 100 milliliters (ml) is maintained in the lower chamber while suction is controlled by the upper chamber. Moisture is drawn into the soil through a porous stainless steel sintered disk that is placed at the bottom of the minidisk infiltrometer (Figure 1).

To estimate an average moisture infiltration rate, four (4) minidisks were operated simultaneously for each subplot at the biosolids land application site (Figure 2). The hydraulic conductivity results from each minidisk are used to generate an average moisture infiltration rate (inches of water/hour).

Forage quality is important because it directly affects a rangeland's ability to support the nutritional needs of animal herds. Tests conducted to determine the forage quality of vegetation from vegetation collected at the biosolids land application site included: Crude Protein (CP), Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) determinations.

Work Plan FY 07/FY 08:

Table 1 summarizes the impact of biosolids land application on biomass yields and crude protein of rangeland vegetation. While vegetation from the control plots had approximately 8.5 lbs of crude protein per acre, on sites receiving anaerobically digested biosolids, aerobically digested biosolids, lime stabilized biosolids and beef cattle manure reported crude protein values of 93.4, 82.1, 56.6 and 45.09 lbs/acre, respectively. These preliminary data suggest that not only does biosolids land application result in more vegetation with increased nutritional value compared to background rangeland, but that biosolids land application is also superior to beef cattle manure land application with respect to biomass yields and vegetative nutritional value.

Table 1. Preliminary Results of Biosolids Land Application Results on Forage Value

Treatment	Application Rate	Biomass Wet (lbs/acre)	Biomass Dry (lbs/acre)	Crude Protein %	Crude Protein (lbs/acre)
Control	not applicable	308.6	84.10	10.15	8.54
Anaerobically Digested	1X	1688.0	612.25	15.26	93.42
Aerobically Digested	1X	1669.8	423.40	19.40	82.12
Lime Stabilized	1X	1197.9	395.64	14.30	56.58
Manure	1X	1016.4	362.15	12.45	45.09

Figure 3 provides photographs of the control, anaerobically digested, aerobically digested, lime stabilized and beef cattle manure field plots taken during the August 2006 field data collection activity. It should be noted that the composted biosolids land application site was not sampled for biomass during these field activities since the material had been placed on soil for less than four months. The composted plots will be part of next year's field sampling activities.

Benefits to the State:

Biosolids generation within the State of Utah will continue to increase significantly for the foreseeable future due to steady increases in population and public demand for improved water quality. Management of biosolids represents a significant technical and economic challenge for both the Utah Division of Water Quality and the Utah Department of Natural Resources. Land application of biosolids on disturbed rangelands represents a potentially cost-effective approach for beneficially using the solid residues from treated municipal wastewater. By demonstrating that the biosolids land application leads to increases in both biomass yields and nutritional quality of rangeland vegetation, biosolids land application will be recommended to Utah agricultural/ranching specialists as a rangeland management practice that supports sustainable ranching in the State of Utah.

Figure 1. Minidisk Infiltrometer (a) Photograph and (b) Schematic.

Figure 2. Four (4) Minidisks Operating Simultaneously at Biosolids Land Application Site.

(Control plot – August 2006)

(Plot Receiving 1X Anaerobically Digested Biosolids – August 2006)

(Plot Receiving 1X Aerobically Digested Biosolids – August 2006)

Figure 3. Photographs of Biosolids Land Application Plots on Utah Rangelands.

(Plot Receiving 1X Lime Stabilized Biosolids – August 2006)

(Plot Receiving 1X Beef Cattle Manure – August 2006)

Figure 3. Photographs of Biosolids (Continued).

Hazardous and Toxic Waste Management

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Hazardous & Toxic Waste Management

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
Ambient Particulate (PM2.5 and PM10), Gaseous Ammonia, and Other Particulate Precursors in Cache Valley, Utah	$39,803.55	$51,000.00	$52,530.00
Analysis of Microbial Diversity and Dechlorinating Potential at Solvent Contaminated Sites Throughout Utah	$14,660.37	$35,000.00	$35,050.00
Applications of Gene Probes to Utah Sites for Remediation	$5,215.07	$0.00	$0.00
Components of the Alternative Electron Acceptor-Using Bacterial Community in TCE Contaminated Aquifers in Northern Utah: Phases I and II	$55,182.39	$75,000.00	$77,250.00
Defining the Bioavailability of Toxic Trace Elements Using Microbial Biosensors	$34,275.25	$35,990.05	$37,069.75
Gasoline Additives (MTBE and TBA) Natural Attenuation	$5,704.13	$0.00	$0.00
Gene Probes for PAHs and Wastewater Treatment	$5,215.07	$0.00	$0.00
Phytovolatilization Measurements at Hill Air Force Base, Utah Operable Unit 2, August–September 2005	$13,948.19	$0.00	$0.00
Soil Bioremediation and Beneficial Reuse	$5,215.07	$0.00	$0.00
Uptake of Chlorinated Solvents, Fuels, and Related Compounds into Fruits and Vegetables	$24,741.40	$55,000.00	$55,950.00
Designated Projects	$0.00	$386,500.00	$431,840.62
Undesignated Projects	$0.00	$20,000.00	$95,000.00
Total	**$204,961.49**	**$666,490.06**	**$796,690.58**

Ambient Particulate ($PM_{2.5}$ and PM_{10}), Gaseous Ammonia, and Other Particulate Precursors in Cache Valley, Utah

Principal Investigator(s):

Randal S. Martin
Philip Silva
Mike Petersen
Kori Moore
Vishal Doshi

Project Description:

Northern Utah's Cache Valley is very close to becoming a non-attainment area for the air pollutant $PM_{2.5}$, particulate matter less than or equal to two and one-half micrometers in diameter. The levels of particulate matter less than 2.5 microns ($PM_{2.5}$) in Cache Valley's ambient air has exceeded the 24-hr National Ambient Air Quality Standard (formerly 65 μg/m3, readjusted to 35 μg/m3 in September, 2006) in most of the last few winters. The Logan site consistently records the highest wintertime concentrations in the state, with the Utah record value being recorded in February 2002 (138 μg/m3). Federal declaration of non-attainment status has not yet been achieved; however, with the proposed lowering of the standard, there is little chance that Cache Valley, as well as other areas in Utah, will be able to avoid non-attainment designation.

Understanding the causes of the elevated levels of the $PM_{2.5}$ will help regulators identify appropriate remediation and minimization scenarios. As such, Dr. Randal Martin has been involved in numerous projects to identify the sources, extent, and atmospheric behavior of Cache Valley's ambient particulate matter. Past research has found that the PM2.5 is essentially a wintertime problem, the $PM_{2.5}$ is statistically homogeneous throughout the Valley, the particles are compositionally dominated by NH_4NO_3, the valley airshed is NH_3-rich by a factor of approximately two in regards to NH_4NO_3 formation, approximately 5 to 10 percent of the local automobiles would fail an inspection program, and at least one rural area (Amalga) seems to contain 4 to 5 times as much ambient ammonia as the urban area (Logan). Even with the success of these studies, a few important questions remain.

The latest phases of the investigations were designed to examine two important parameters of the pollutant's lifecycle: the disparity between the rural and urban gas-phase ammonia (NH_3) concentrations and the likely driving forces for the photochemical formation of particulate-phase ammonium nitrate (NH_4NO_3), specifically what are the sources of wintertime ozone (O_3). The work within this project has been coupled with work separately funded from UDAQ and USU/CURI. Under these other grants, studies were conducted to examine how volatile organic compounds (VOCs) contributed to the local photochemistry and how NH_3 emissions from agricultural operations contribute to ambient NH_3 levels under local winter conditions.

Accomplishments:

The results have shown that the NH_3 is not homogeneous and is strongly tied to local sources, primarily those associated with the agricultural industry. The spatial trends, but not necessarily the absolute NH_3 concentrations, were similar between the winter (January and February) and summer (June, July, and August) study periods. Figures 1 and 2 show the average winter and summer NH_3 distributions observed in Cache Valley, respectively. Figure 3 shows the location-by-location seasonal average ambient ammonia concentrations measured throughout the Cache Valley. It is of interest to note that the overall averages are very nearly equal, even though differences in temperature-related NH_3 emissions and seasonal atmospheric dispersion conditions should theoretically result in different seasonal values.

The results showed unexpectedly high O_3 levels (50-60 ppb) within the upper troposphere (≈6000 -10000 ft asl) and have elicited enough interest that plans are being discussed for a more intensive O_3 profile study in the near future, although this study gives strong indication that free tropospheric ozone may supply sufficient O_3 concentrations to initiate local photochemistry. Figure 4 shows the afternoon (February 9) and morning vertical ozone and temperature profiles. Figures 5 and 6 show isoplethic concentration O_3 profiles as a function of elevation and the north-south transect position for the February 9 and 11 flights, respectively. As can be seen, both "O_3 maps" show consistent highest levels of O_3 at the higher observed elevations, while near-ground ozone levels varied somewhat by time of day (morning lowest) and valley location (the mid-to-southern end of valley seemed to titrate out more O_3). Finally, Ms. Crystal Viator presented a student paper/poster at the June 2006 meeting of the Air & Waste Management Association and received the 1st place award for the Undergraduate competition.

Work Plan FY 07/FY 08:

The work described herein was (and continues to be) conducted entirely within Cache Valley, including measurements within portions of Utah and Idaho. Under the NH_3 valley-wide studies of this project, approximately 25 Ogawa passive ammonia samplers were deployed for six separate one-week periods during January, February, June, July, and August of 2006. After each sampling period, the samplers were recovered and analyzed for collected NH_3 at the Utah Water Research Laboratory (UWRL) Environmental Quality Laboratory using ion chromatography.

The second part of this work will be coupled with the separately funded VOC studies previously mentioned. The impetus for this work is to identify the limiting reaction pathways for the conversion of nitric oxide (NO) to nitric acid (HNO_3). The focus of the work funded via the UWRL was to attempt delineation of possible sources of the main atmospheric oxidant compound, ozone (O_3), which is often uncharacteristically high in the Cache Valley wintertime air. Dr. Martin, Dr. Ed Redd (of the Bear River Health Department), and Ms. Viator installed an O_3 monitor in a private airplane (Mr. Bill Francis) during inversion/$PM_{2.5}$ episodes and measured the vertical O_3 and temperature profile during an early morning period (Feb. 11, 2006) and late afternoon period (Feb. 9, 2006).

Benefits to the State:

The project will provide direct benefit to the State of Utah, especially the Cache Valley area, by fitting more pieces into the puzzle representing Cache Valley's air pollution problem. Identification of the seasonal ambient ammonia distributions will aid in locating areas of significant sources which may, in turn, be targeted for reductions, and verify the degree of excess methane (NH_3) in the local area. Vertical ozone (O_3) profile information provides information on to what extent downward vertical mixing is responsible for the seemingly anomalously high wintertime O_3 concentrations. Additionally, these data will then be available for use by the aforementioned local and state regulators. The ultimate products of this study will be significant contributions to the database and final report used by local and state regulators to help manage the air quality within the Cache Valley airshed.

Utah State University would benefit not only through the establishment of a successful research program (especially beneficial if the cooperative proposal is funded), but also through the support of both graduate and undergraduate students. Utah State University has reaped indirect benefits associated with this project via contacts established with Utah's Division of Air Quality, the Idaho Department of Environmental Quality, and the Bear River Health Department in the form of donated research and teaching equipment, contacts for future employment of students, and presentations of graduate seminars by state personnel. Furthermore, continuing our student participation at international professional conferences, Ms. Viator presented a student paper/poster concerning some of the above work at the June 2006 meeting of the Air & Waste Management Association and received the 1st place award for the Undergraduate competition.

▲

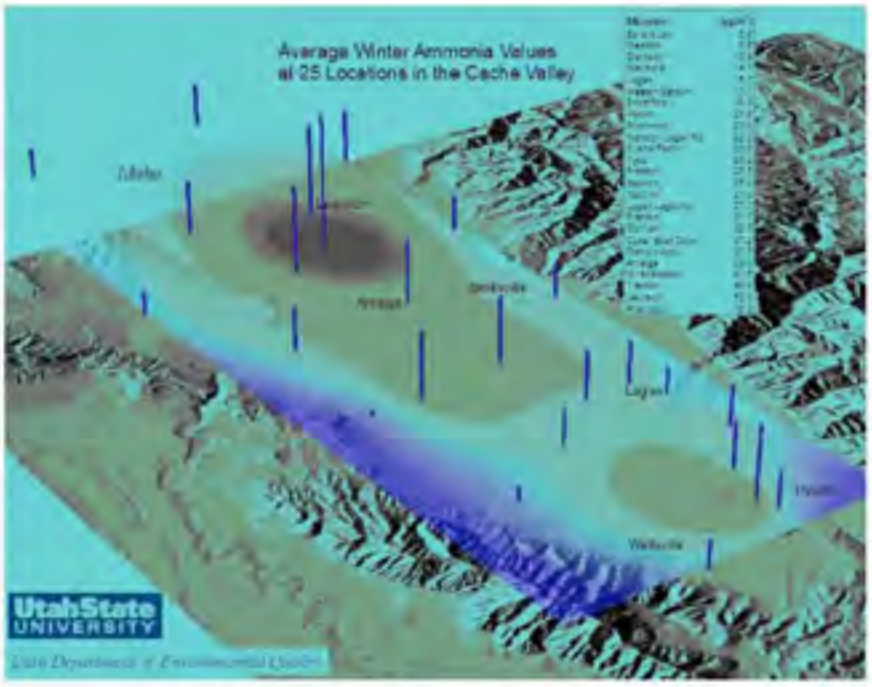

Figure 1. Wintertime (Jan., Feb.; 2006) Cache Valley ambient NH_3 distribution.

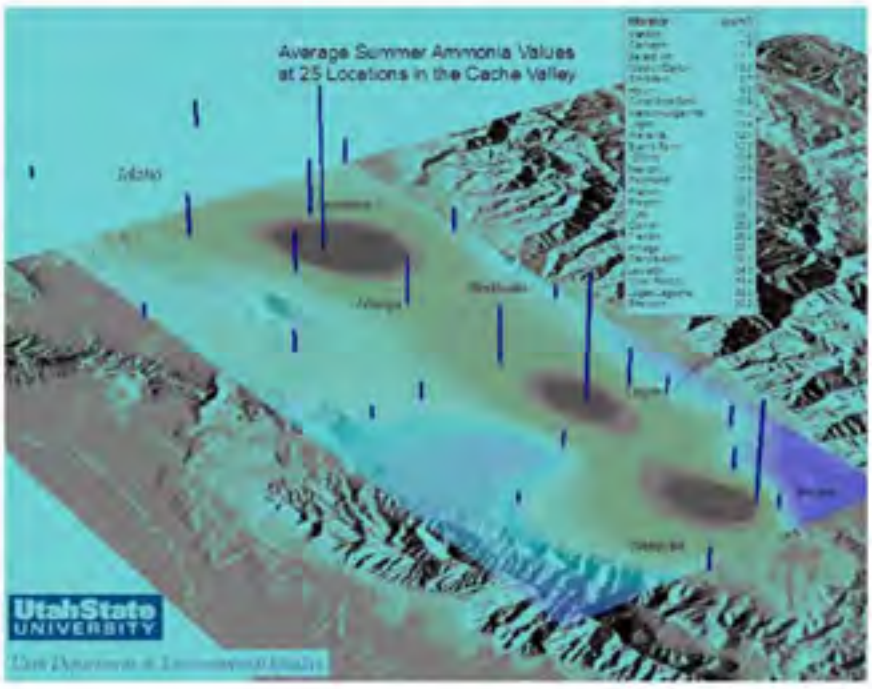

Figure 2. Summertime (Jun., Jul., Aug.; 2006) Cache Valley ambient NH_3 distribution.

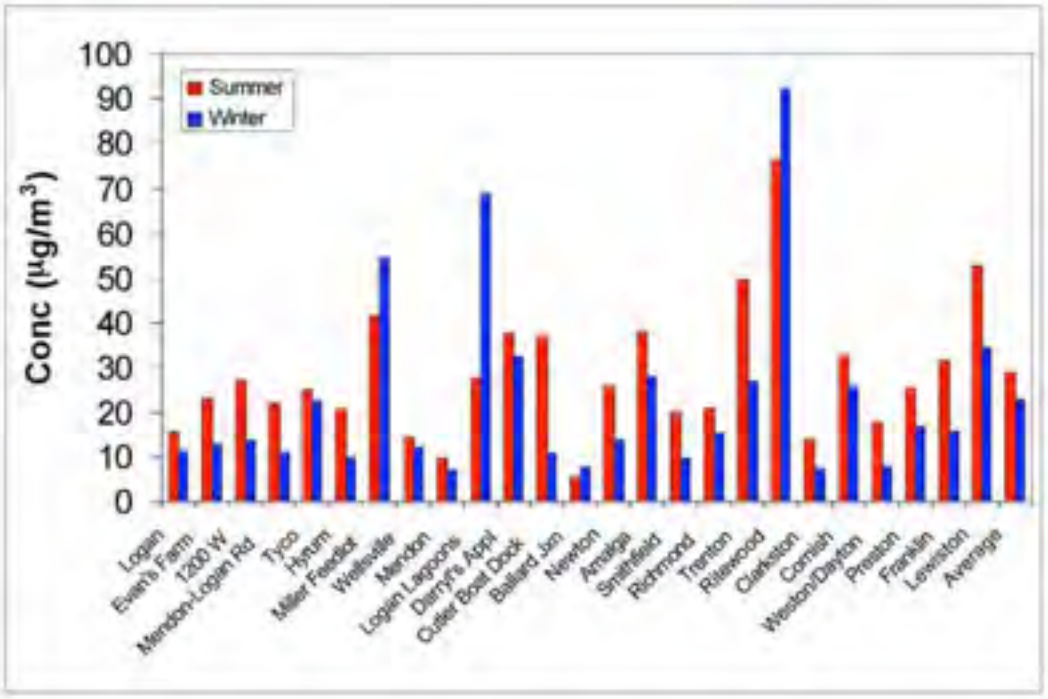

Figure 3. Seasonally-averaged Cache Valley NH_3 concentrations ($\mu g / m^3$) by receptor location .

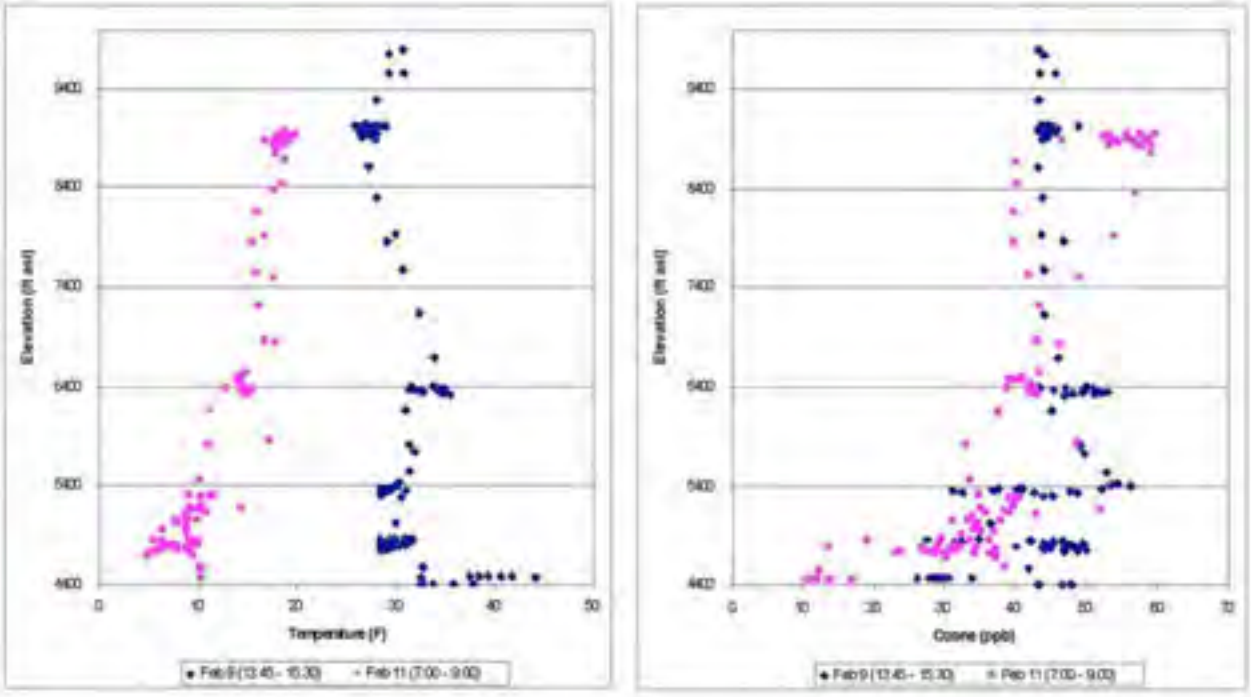

Figure 4. Cache Valley O_3 and temperature vertical profiles (Feb. 9 & 11, 2006).

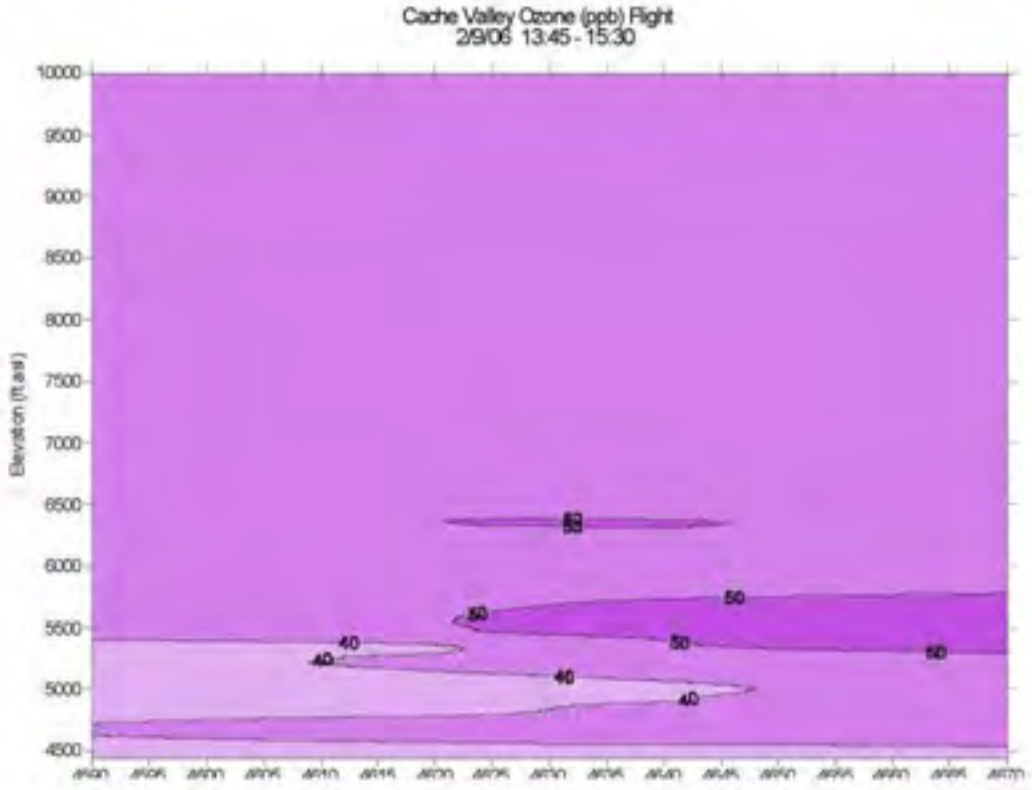

Figure 5. Cache Valley O_3 and temperature vertical profiles (Feb. 9 & 11, 2006).

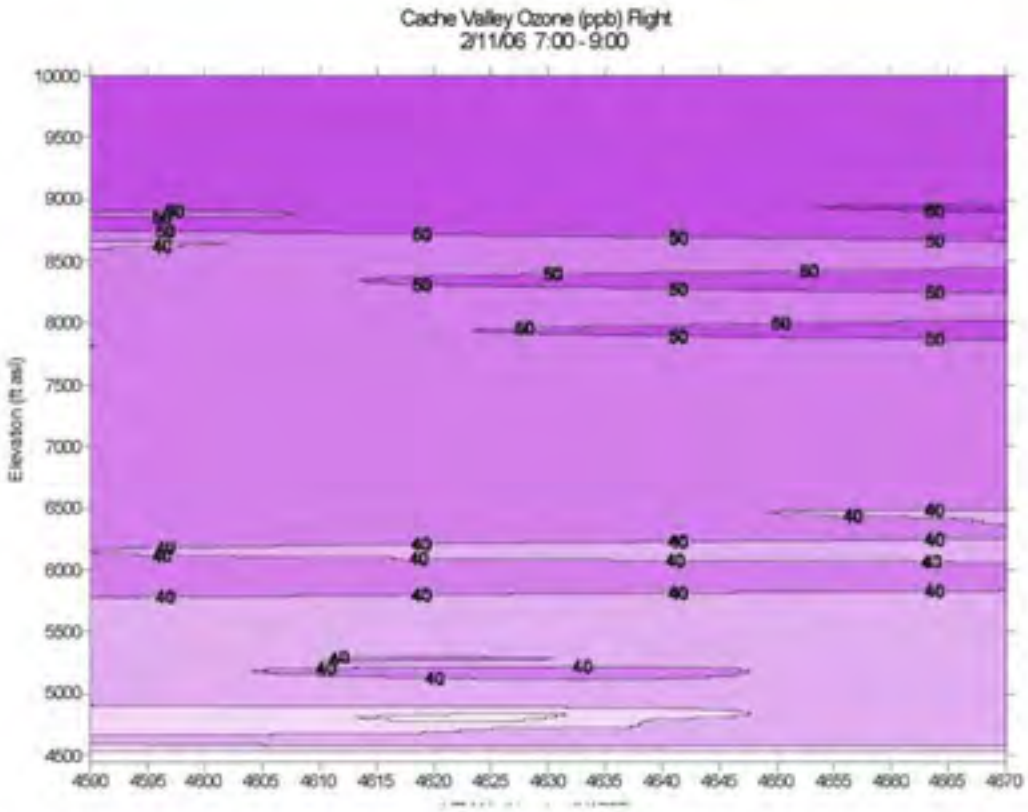

Figure 6. Cache Valley O_3 and temperature vertical profiles (Feb. 9 & 11, 2006).

Analysis of Microbial Diversity and Dechlorinating Potential at Solvent Contaminated Sites Throughout Utah

Principal Investigator(s):

R. Ryan Dupont
Jing Zhou
Jared Ervin
Allison Neptune

Project Description:

This study is designed to identify and quantify the predominant microorganisms responsible for various competing microbial degradation processes at sites throughout northern Utah using molecular biology techniques, and to correlate this description of the nature and distribution of these microbial communities and their activity with laboratory and field-scale observations of solvent degradation based on chemical analysis results from these sites, some of which are undergoing active remediation, and some which are only being monitored. The ultimate objective of the work is to develop an understanding of the microbial players that are responsible for affecting the transformation and fate of chlorinated solvents under natural and engineered conditions so that molecular screening tools can be used for future site assessment activities to aid in rapid and cost effective selection of optimal remedial designs under a given set of specific site constraints.

Accomplishments:

Field sites. Detection of specific microbial species and/or functional genes using standard PCR techniques was carried out at seven (7) field sites throughout northern Utah. These seven sites included: 1) OU5 (Hill AFB, no solvent dechlorination) where site monitoring is on-going, and where laboratory site manipulation and bioaugmentation studies have taken place; 2) OU2 (Hill AFB, partial solvent dechlorination) where site monitoring following active site source area remediation has taken place, and where site manipulation and bioaugmentation laboratory studies have been completed and field-scale site manipulation and bioaugmentation took place during the winter of 2005; 3) Little Mountain (Hill AFB, active solvent dechlorination) where site monitoring is on-going and where site manipulation activities are being contemplated; 4) OU10 (Hill AFB, partial solvent dechlorination) where site investigation efforts are currently underway; 5) SMWU-97 (Dugway Proving Ground, potential solvent dechlorination) where site manipulation activities are on-going; 6) Bountiful/Woods Cross (no solvent dechlorination) where a biostimulation and bioaugmentation study is currently underway; and 7) the Sugar House Park Plume site (no solvent dechlorination, where a Salt Lake City drinking water well has been impacted from a suspected chlorinated solvent release from a dry cleaning facility) where site monitoring is on-going.

Molecular probes used. Soil and groundwater samples were collected from these sites, DNA was extracted, and was amplified using standard PCR techniques as initially proposed in this study. As experience with the molecular probes was developed with these site samples during the study period, a subset of the full range of probes originally proposed at the beginning of the study was actually used on all of the field samples. Table 1 summarizes the final list of probes used in developing the results summarized below, and indicates that this final molecular probe list included: four *Dehalococcoides* species-specific primers for organisms capable of both partial and complete TCE transformation; three other dehalogenating species primers for organisms responsible for partial TCE transformation; one vinyl chloride reductase functional gene probe (vcrAB); a probe for the family Geobacteracea containing suspected competitors for electron donor with Dehalococcoides of the species Geobacter and Desulfuromonas; and three specific species of iron reducing bacteria (Geobacter, Schewanella, and

Rhodoferrax) that are again suspected of competing with Dehalococcoides for electron donor supply. The later organism is of particular interest at sites throughout Utah as it rather than the more commonly observed Geobacter appears to be a predominant species at contaminated sites in the area of Hill AFB.

This short list of molecular probes contains the two primary groups of organisms of most interest in this study, the dechlorinators and the iron reducing bacteria, but does not include members of three other groups of organisms that are also be targeted in this study, i.e., the nitrate reducers the sulfate reducers, and the methanogens. Work is continuing to develop and verify the effectiveness of molecular probes for these three groups, and on-going work is directed at collecting quantitative data for these organisms as well as the dechlorinators, iron reducers, and total bacterial numbers using a general Eubacterial primer. Table 2 shows the molecular probes used in the quantitative RT-PCR analyses currently underway for these field samples. The RT-PCR probes include a subset of the probes used in conventional PCR analyses for dechlorinators, iron reduction and vinyl chloride reductcion (vcrAB), along with a total Eubacterial probe and functional genes targeting sulfate reduction (dsrA) and methanogenic activity (mcrA). Results for RT-PCR analyses are being completed for the samples collected in this study, but primer optimal annealing temperatures and estimated detection limits are presented in the Results Section below.

Results. *Standard PCR analyses* results are summarized in Figure 1 in terms of the Frequency of Occurrence of a positive detection of the microbial species or functional gene of interest. These results indicate that soil samples produced more consistent and elevated detections of all PCR products of interest than did the water samples, and that *Dehalococcoides sp.* and other dechlorinators appear widely distributed, being detected at relatively high abundance at all of these Utah sites. Less widely distributed is the functional gene vcrAB that has been identified as key to the complete dehalogenation of TCE, through the critical vinyl chloride reduction step, to innocuous end products of ethene and carbon dioxide. This functional vinyl chloride reductase gene was only detected in background soil samples from Hill AFB OU5, and Dugway site SMWU-97, and infrequently in water samples from the Bountiful-Woods Cross site. The additional detection in Post-Treatment water at Hill's OU2 site is confirmation of the continued dechlorination activity of the Bachman Road culture with known vcrAB activity that was added during site remediation activities.

Figure 2 shows the relative abundance of iron reducing to dechlorinating species in the form of the ratio of iron reducers to *Dehalococcoides sp.* and iron reducers to total dechlorinators detected in these field samples. These ratios ranged from 0.8 to over 2.3 for iron/DHC species and 0.3 to 0.96 for iron/total dechlorinators for all sites and samples except for the water from Hill AFB OU5 where no iron reducing species were detected in three replicate samples analyzed in this study.

To investigate a more quantitative relationship between the abundance of iron reducing organisms and dechlorinators, and the affect of this relative abundance on dechlorination activity, the ratio data shown in Figure 2 were regressed against an indicator variable related to the observed dechlorination activity at these field sites. The data used in this quantitative regression analysis are shown in Table 2, with the results of the regression analysis shown graphically in Figures 3 through 6 and in tabulated form in Table 3. These results indicate that the dechlorination activity is not a simple function of the presence or absence of the iron reducing and dechlorinating species, but is more complicated than that. The simple relative abundance of iron reducers versus dechlorinators in terms of a determination of presence or absence does not appear to be sufficient to reliably predict the potential for partial or complete TCE dechlorination, at least across the range of site and soil conditions represented by the field sites in this study. The predictability of this simple ratio approach is increased through the analysis of *Dehalococcoides sp.* rather than Total Dechlorinators as indicated by both increased r2 values and reduced p values for the regression relationships. In addition, analysis of soil samples are seen in Table 4 to also increase the predictability of the developed relationships based on the negative slope of the regression equation, the increased r2 values, and the equivalent p values for far fewer number of samples included in the regression analysis.

While the conventional PCR analyses conducted in this study are not as quantitatively predictable as desired, the results do indicate the functional relationship between high iron reducing populations, low dechlorinator populations, and the lack of complete TCE transformation observed under field conditions at TCE contaminated sites throughout northern Utah. The functional relationship suggested by these qualitative standard PCR results lead to the need for more quantitative analysis of community composition through the use of RT-PCR techniques. It is hoped that with a more quantitative determination of not only the presence/absence, but the number of specific cells of a given species or with specific functional gene activity within these northern Utah field sites that a more reliable and statistically significant dechlorination activity predictor can be developed. In addition, it is hoped that a threshold number of members of the community can be identified to help more effectively design remediation approaches (biostimulation versus bioaugmentation) at these and other solvent contaminated sites throughout Utah. The follow-on UWRL funded effort to generate RT-PCR data from these field site soil and groundwater samples is currently underway, and method QA/QC results are presented below.

RT-PCR results are still being generated for the field samples collected in this study, but sample handling and analysis procedures have been finalized, and optimal primer annealing temperatures and method quantitative reporting limits for the probes have been generated. The results of these QA/QC activities are summarized in Table 5 for the primers used in RT-PCR analysis of these field samples. Quantitative results for these RT-PCR analyses are anticipated to be completed by the end of the calendar year for preparation of a final report, an additional Seed Grant to SERDP, and a manuscript for submission to the Journal of Environmental Engineering of ASCE in the Spring of 2007.

Work Plan FY 07/FY 08:

The project research approach is as follows: Groundwater (and soil samples when available) have been collected from known chlorinated solvent impacted sites from throughout northern Utah that have historical water chemistry data available for them. DNA from these samples has been extracted and analyzed for specific organisms and a range of functional metabolic capability using 16s rDNA and functional gene molecular probes using standard polymerase chain reaction (PCR) techniques. Specific organisms of interest include: four *Dehalococcoides* species responsible for PCE, TCE, DCE, VC and TCA/DCA degradation; five other dehalogenating species responsible for partial PCE/TCE degradation; four species of iron reducing bacteria (*Geobacter, Geothrix, Rhodoferrax,* and *Schewanella*) and the family Geobacteracea, all suspected of competing with the dechlorinators during site manipulation; two species of sulfate reducing organisms; and one species of methanogenic bacteria. Functional gene probes that were used included: probes designed to detect cprA, pceA/pceB, tceA, and vcrA in dechlorinating organisms; and functional probes designed to detect iron reductase genes in iron reducers, nitrate reductase in nitrate reducers, and one functional probe for genes coding for methane production in methanogenic bacteria.

Using these molecular probe results for the detection of specific microorganisms and their functional capabilities, relationships are being explored between the abundance of specific microorganisms, competing functional activity and the observation of the nature and extent of dechlorination activity in samples throughout these field sites.

Recently funded work includes the use of a subset of these 16s rDNA and functional gene probes with real time PCR (RT-PCR) instrumentation to generate quantitative information regarding the numbers of organisms and functional gene copies in environmental samples to improve the reliability and confidence in relationships among cell numbers and function and dechlorination capacity at impacted sites. The RT-PCR instrumentation is highlighted in an associated MLF report.

Benefits to the State:

The use of chlorinated solvents has been historically widespread throughout Utah resulting in a legacy of contaminated groundwater sites at both former and currently operating industrial facilities. This chlorinated solvent impacted groundwater poses a significant threat to public health and the environment when exposure pathways are completed as seen from the recent detection of TCE and is degradation

products in fruit trees and fruit growing above groundwater plumes leaving the west side of Hill Air Force Base (HAFB). Chlorinated solvents can also compromise drinking water supplies as is the case with the Sugar House Park Plume site, making chlorinated solvent contamination a growing concern as pressure increases to continue to develop groundwater supplies to meet increasing demands for municipal and industrial water demands. Remediation of this impacted groundwater is possible through the manipulation of site conditions or through the addition of acclimated organisms capable of solvent degradation. An a priori determination of which remedial option (site manipulation or bioaugmentation) will be effective at a give site is not easily done without expensive lab-scale treatability determinations even with extensive site water quality monitoring data, and previous work at HAFB by the Utah Water Research Laboratory (UWRL) has indicated that competition between native iron reducing bacteria and chlorinated solvent degraders can completely inhibit solvent remediation at locations thought to be amenable to inexpensive site manipulation strategies. With an improved understanding of the composition of microbial communities and functional metabolic capabilities that control the fate of chlorinated solvent degradation at contaminated sites, more rapid, reliable and cost-effective decisions regarding site remediation can be made, and sites can begin to be recovered so that groundwater resources are not permanently lost in the future.

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Table 1. Molecular probes used to generate microbial community information from field sites investigated in this study using standard PCR techniques.

Target	Probe Name	Species/Strain	Product Size (bp)
Dehalococcoides	2	*ethanogenes*/195, BAV1; *sp.* CBDB1, FL2	104
Dehalococcoides	3	*ethanogenes*/BAV1; *sp.* CBDB1, FL2	137
Dehalococcoides	9	*ethanogenes*/195, BAV1; *sp.* CBDB1, FL2	1377
Dehalococcoides	10	*ethanogenes*/195, BAV1; *sp.* CBDB1, FL2	307
Dechlorinator	4	*Desulfuromonas michiganensis* BB1	254
Dechlorinator	6	*Dehalobacter restrictus*	215
Dechlorinator	7	*Dehalospirillum multivorans*	218
Functional Gene	V2	vcrAB (vinyl chloride reductase gene)	442
Geobacteraceae	Ge	Family-level primer for competing electron accepting process community	276
Iron Reducer	G	*Geobacter sulfureducens*	264
Iron Reducer	Sw	*Schewanella sp.*	462
Iron Reducer	Rh	*Rhodoferrax ferrireducens*	207

Table 2. Molecular probes used to generate microbial community information from field sites investigated in this study using quantitative RT-PCR techniques.

Target	Probe Name	Species/Strain	Product Size (bp)
Dechlorinator	4	*Desulfuromonas michiganensis* BB1	254
Dechlorinator	10	*Dehalococcoides ethanogenes*/195, BAV1; *sp.* CBDB1, FL2	307
Iron Reducer	G	*Geobacter sulfureducens*	264
Iron Reducer	Sw	*Schewanella sp.*	462
Iron Reducer	Rh	*Rhodoferrax ferrireducens*	207
Functional Gene	V2	vcrAB (vinyl chloride reductase gene)	442
Functional Gene	dsr	dsrA (dissimilatory sulfate reductase gene)	243
Functional Gene	mcr	mcrA gene in methanogens	258
Eubacteria	Eu	General Eubacterial DNA	180

Table 3. Ratio of Frequency of Occurrence of positive PCR detections of Iron Reducing Organisms to *Dehalococcoides sp.* and Iron Reducing Organisms to Total Dechlorinators and value of site dechlorinating activity Indicator Variable from field sites investigated in this study.

Site	Status of Dechlorination Activity	Dechlorination Activity Indicator Variable	Iron Reducers/DHC	Iron Reducers/Total Dechlorinators
OU5-Water	No Dechlorination	0	0.00	0.00
OU5-Soil	No Dechlorination	0	1.34	0.56
OU2-Pre	Partial Dechlorination	0.5	1.67	0.67
OU2-Post	Partial Dechlorination	0.5	1.34	0.57
Little Mtn.	Full Dechlorination	1	0.78	0.35
OU10-Water	Partial Dechlorination	0.5	1.00	0.43
OU10-Soil	Partial Dechlorination	0.5	0.83	0.28
Dugway-Water	Full Dechlorination	1	2.29	0.96
Dugway-Soil	Full Dechlorination	1	1.13	0.59
Bountiful/WC-Water	No Dechlorination	0	1.38	0.78
Bountiful/WC-Soil	No Dechlorination	0	2.00	0.83
SLC Wells	No Dechlorination	0	1.50	0.64

Table 4. Regression results for Dechlorination Activity versus Ratio of Frequency of Occurrence of positive PCR detections of Iron Reducing Organisms to *Dehalococcoides sp.* and Iron Reducing Organisms to Total Dechlorinators from field sites investigated in this study.

Relationship, Dechlorination Activity versus	Slope	r^2	p Value	n	Statistically Significant
Iron Reducing Organisms to *Dehalococcoides sp.* - Water	0.59	0.1324	0.3756	8	No
Iron Reducing Organisms to *Dehalococcoides sp.* -Soil	-0.64	0.3854	0.3792	4	No
Iron Reducing Organisms to Total Dechlorinators - Water	0.18	0.0661	0.5388	8	No
Iron Reducing Organisms to Total Dechlorinators - Soil	-0.17	0.1320	0.6366	4	No

Table 5. QA/QC results for molecular probes used to generate microbial community information from field sites investigated in this study using quantitative RT-PCR techniques.

Target/Probe Name	Optimal Annealing Temperature, °C	QRL, Copies/mL
Desulfuromonas michiganensis BB1, Probe 4	61	322
Dehalococcoides ethanogenes/195, BAV1; *sp.* CBDB1, FL2, Probe 10	55	23.5
Geobacter sulfureducens, Probe G	56	214
Schewanella sp., Probe Sw	59	220
Rhodoferrax ferrireducens, Probe Rh	60	715
vcrAB (vinyl chloride reductase gene), Probe V2	60	1.2
dsrA (dissimilatory sulfate reductase gene), Probe dsr	60.6	450
mcrA gene in methanogens, Probe mcr	58	2,500
General Eubacterial DNA, Probe Eu	60	24.3

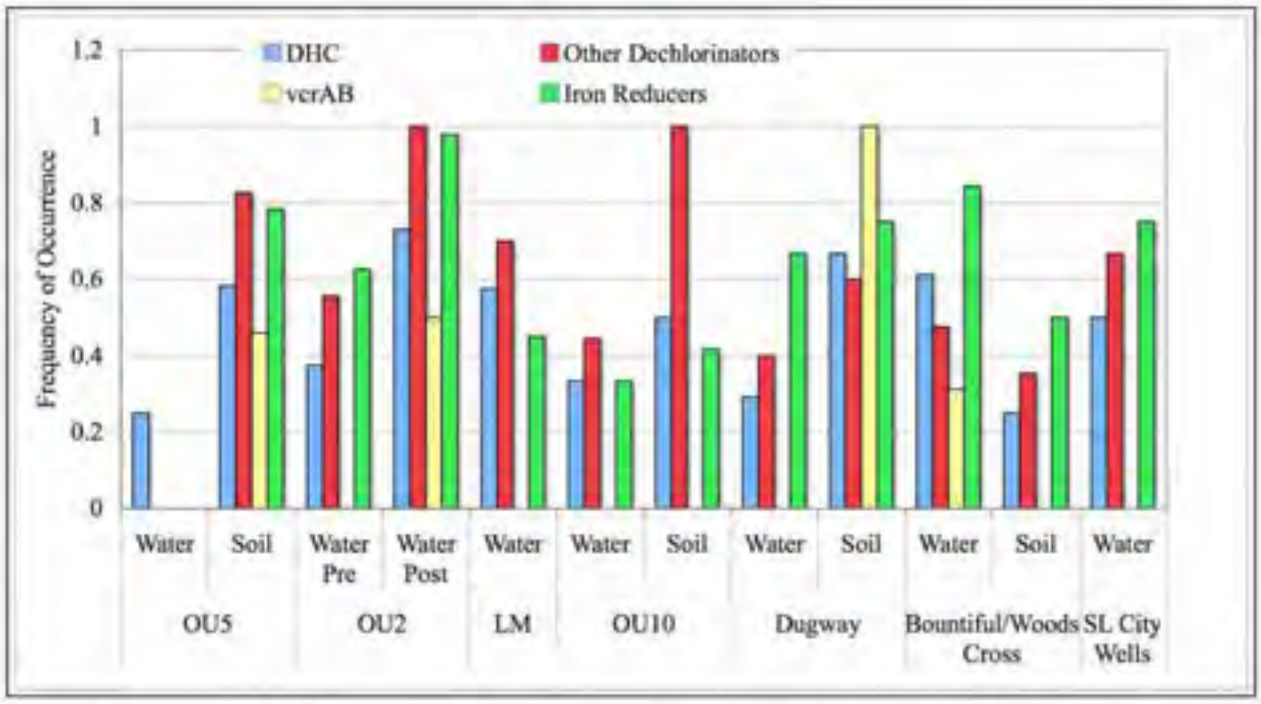

Figure 1. Frequency of Occurrence of positive PCR detections of *Dehalococcoides sp.*, Other Dechlorinators, Iron Reducing bacteria, and the functional gene vcrAB in field samples collected from throughout northern Utah in 2005.

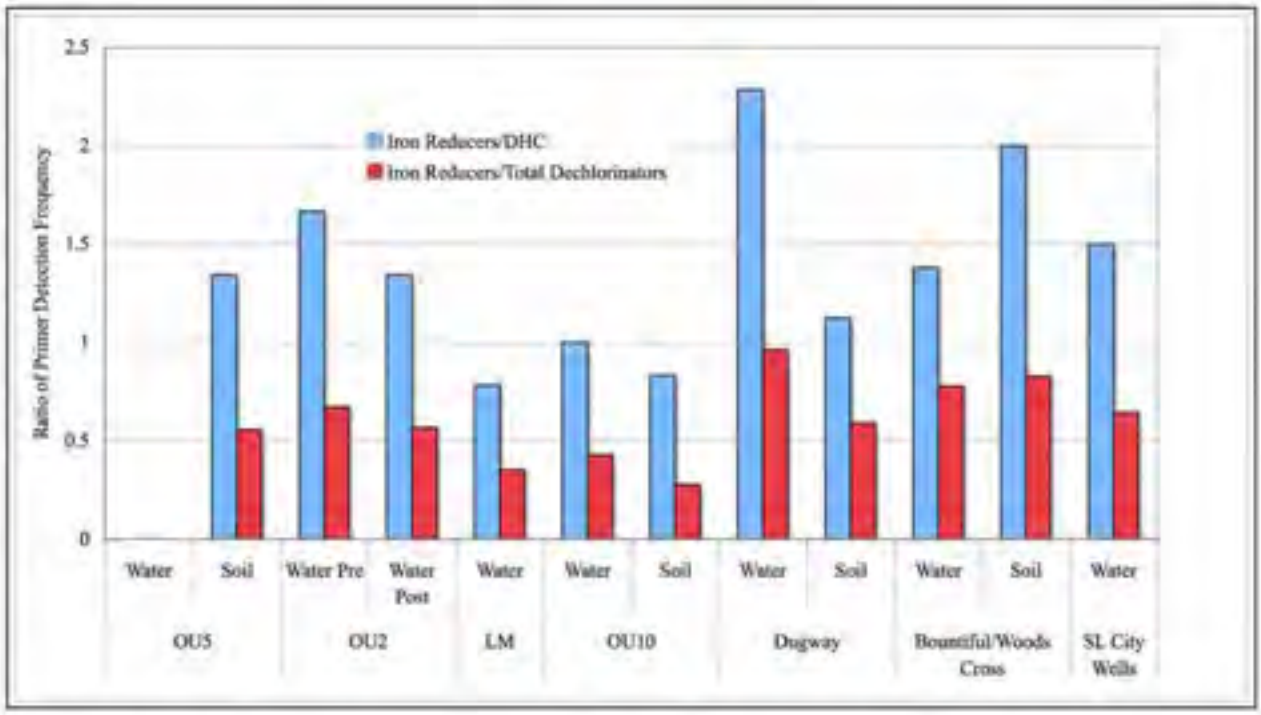

Figure 2. Ratio of Frequency of Occurrence of positive PCR detections of Iron Reducing Organisms to *Dehalococcoides sp.* and Iron Reducing Organisms to Total Dechlorinators in field samples collected from throughout northern Utah in 2005.

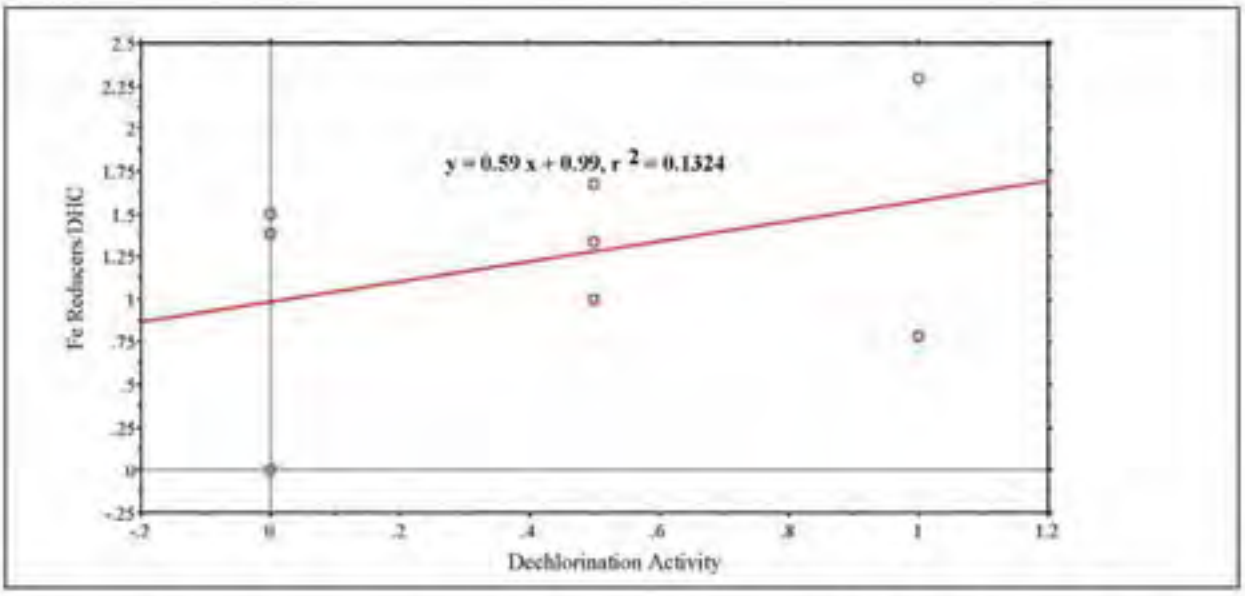

Figure 3. Linear regression analysis of the ratio of the frequency of detection of iron reducing to *Dehalococcoides* bacteria in water samples collected from field sites throughout northern Utah in 2005.

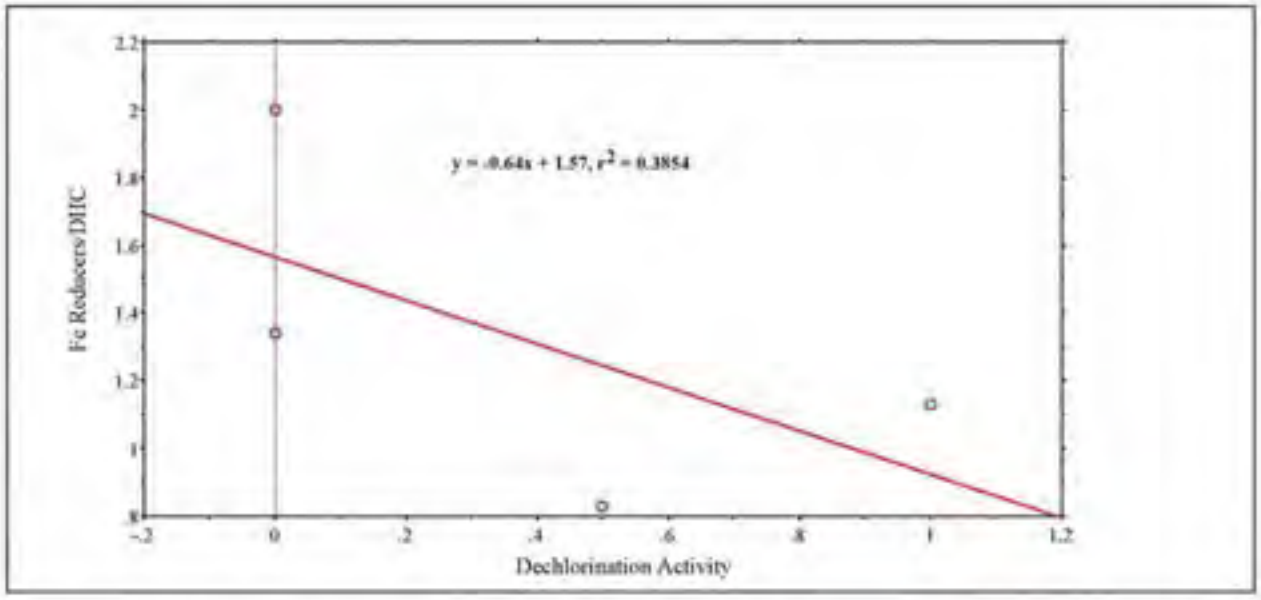

Figure 4. Linear regression analysis of the ratio of the frequency of detection of iron reducing to *Dehalococcoides* bacteria in soil samples collected from field sites throughout northern Utah in 2005.

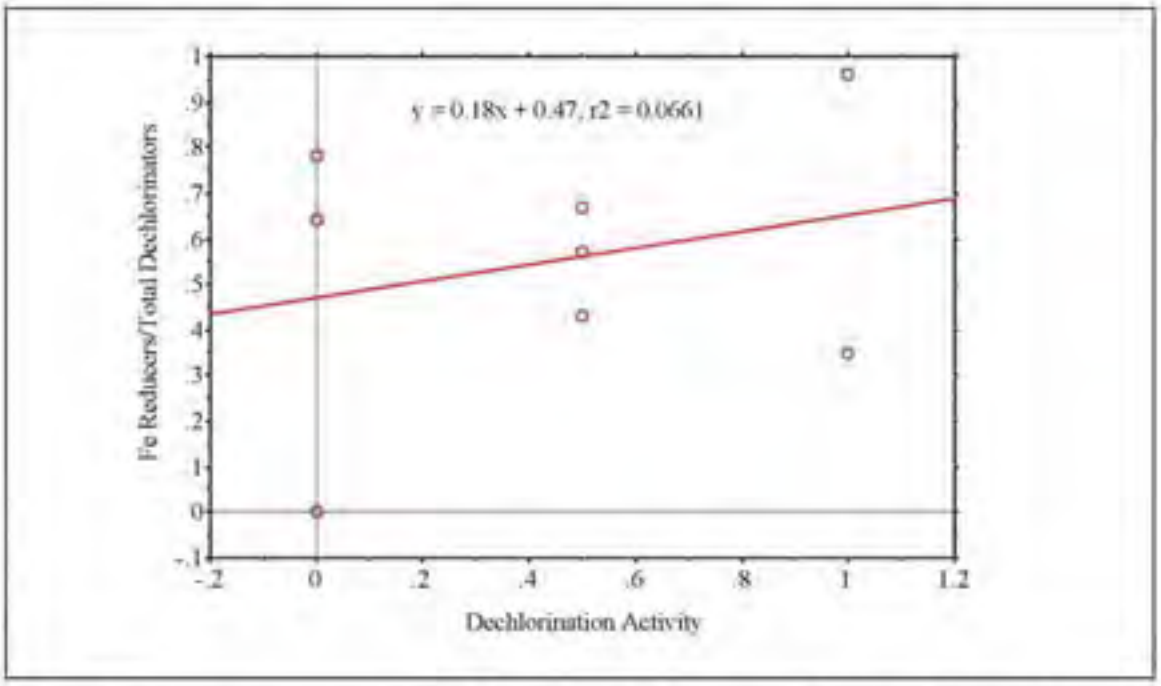

Figure 5. Linear regression analysis of the ratio of the frequency of detection of iron reducing to total dechlorinating bacteria in water samples collected from field sites throughout northern Utah in 2005.

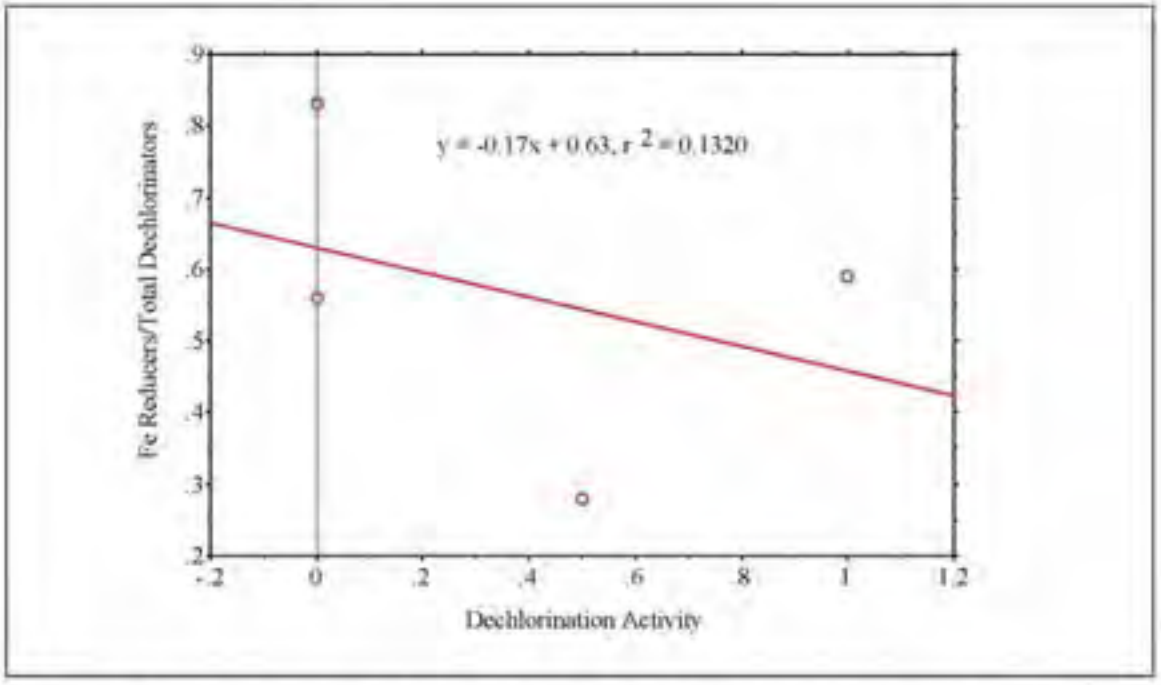

Figure 6. Linear regression analysis of the ratio of the frequency of detection of iron reducing to total dechlorinating bacteria in soil samples collected from field sites throughout northern Utah in 2005.

Applications of Gene Probes to Utah Sites for Remediation

Principal Investigator(s):

Ronald C. Sims
Charles Miller
Yanna Liang

Project Description:

Toxic and carcinogenic chemicals can enter Utah soils and groundwater from a variety of sources, including industrial chemical plants, used oils, disposal of wood preservatives, and accidental spills of chemical products. Incineration of contaminated soil or excavation and removal are expensive solutions. Biological treatment with naturally occurring microbes offers an inexpensive solution, and if there is no need to add microbes sold by vendors then the soil can be restored utilizing naturally occurring microbes at least cost to the property owner and/or the state (landowner).

Accomplishments:

New findings are that the microbes that can destroy chemical carcinogens also have the ability to degrade the toxic wood preservative pentachlorophenol (PCP). New information on the biology and biochemistry of the microbes has been developed to better understand how the microbes operate in a soil environment.

Work Plan FY 07/FY 08:

Microbes were discovered through research conducted at the Utah Water Research Laboratory that can degrade carcinogenic chemicals present in petroleum and wood preserving mixtures. A genetic probe tool was engineered to identify these organisms quickly and inexpensively in soil systems contaminated with toxic and carcinogenic chemicals. Soil samples from Northern and Southern Utah were taken and tested for the presence of these useful microbes.

Benefits to the State:

This year the practical tool (gene probe) that was created last year was applied to Utah sites to determine if microbes are naturally present in Utah soils that have the capability to transform carcinogens present in wastes or chemicals spilled onto soil into products that are harmless to humans and the environment. Samples from Northern and Southern Utah were tested and found to contain these helpful microbes. We also tested the microbes for their ability to destroy another pollutant used to preserve wood (Pentachlorophenol or PCP), and the results were successful. The information that was developed is helpful to the State of Utah for beneficial reuse and sustainability of soil for treatment of organic wastes in land treatment systems. In the State of Utah many rural municipalities and industries use land treatment for waste management, and the sustainable and safe long-term use are of concern.

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Components of the Alternative Electron Acceptor-Using Bacterial Community in TCE Contaminated Aquifers in Northern Utah: Phases I and II

Principal Investigator(s):

Darwin L. Sorensen
R. Ryan Dupont
Joan E. McLean
Jeanette M. Norton
Carmen Yupanqui Zaa

Project Description:

Knowing the distribution of chlorinated ethene solvent degrading bacteria and potentially competing iron reducing in contaminated aquifer plumes west of Hill Air Force Base (HAFB) may be critical to appropriately choosing to apply biostimulation and/or bioaugmentation treatment. The project is directed at describing the microbial ecology of TCE-contaminated aquifers at HAFB in terms that can be used in treatment system evaluation and design. The objective is to describe the distribution of populations of bacteria that are believed to be critical to the success of biostimulation treatment in solvent contaminated aquifers. These critical bacterial populations are, principally, bacteria that are capable of respiratory metabolism using chlorinated solvents such as TCE and bacteria that respire by reducing iron.

Accomplishments:

Soil cores were collected in a TCE-contaminated plume at OU5 on and near Hill AFB. These cores were assayed for a vinyl chloride reductase (*vcr*AB) gene as an indicator for the potential of the bacterial community to reduce vinyl chloride, a carcinogenic product of dehalorespiration of TCE. Assays were also done for the 16s rDNA gene for *Dehalococcoides*, an organism capable of reductive dehalogenation of TCE. Both the *vcr*AB gene and *Dehalococcoides* were detected in some of the samples. This implies that the capability for reductive dehalogenation exists at this contaminated site. The fact that dehalogenation is not being observed at this site suggests that environmental conditions, probably including the lack of reducing conditions and the lack of sufficient electron donor, are limiting the development of this process.

Quantitative polymerase chain reaction assays demonstrated that the capability for reductive dehalogenation exists at the contaminated site west of HAFB. The fact that dehalogenation is not being observed at this site suggests that environmental conditions, probably including the lack of sufficient electron donor and anaerobic/reducing conditions, are limiting the development of this process. Enrichment cultures for poorly-crystalline-iron reducing bacteria were initiated including a dilution-to-extinction enrichment for these kinds of bacteria to isolate the culturable iron-reducing bacteria that are in the samples in the highest numbers. Some iron reducing bacteria were isolated from the more dilute enrichments that showed iron reduction on solid growth media containing chelated, oxidized iron or poorly crystalline iron oxide or the iron oxide mineral, goethite. These bacteria are being characterized.

Work Plan FY 07/FY 08:

Culture-independent methods of identifying and quantifying bacteria, including real-time, quantitative PCR (qPCR), from aquifer material are being used. Cores of the uppermost, contaminated aquifer material in Sunset, Utah, were collected with the very generous sponsorship of the Environmental Restoration directorate of HAFB. Enrichment culture methods including a dilution-to-extinction procedure, are also being used to help isolate and estimate the population density of the iron

reducing bacteria in selected samples. The presence and approximate concentration of iron reducing bacteria including members of the *Geobacteriaceae* have been determined in unamended samples of aquifer material from operating units (OUs) 5 and 9 at HAFB. Research proposals were prepared and submitted to the Department of Defense, Department of Energy and Environmental Protection Agency Strategic Environmental Research and Development Program (SERDP) and to the Department of Energy's Environmental Remediation Science Program.

Benefits to the State:

Chlorinated solvents in ground water environments represent a threat to public health. Environmental regulations demand the cleanup of this kind of contamination. Evaluating the probability of success of cleanup technology represents an opportunity for improvement of the Utah environment and protection to the health of the citizens of the state. Avoiding the misuse of technology can hasten cleanup and avoid the wasteful expenditure of limited cleanup funds. The project has been focused on Hill Air Force Base but will have application to trichloroethene (TCE), and other chlorinated ethene, contamination at several locations within Utah.

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Defining the Bioavailability of Toxic Trace Elements Using Microbial Biosensors

Principal Investigator(s):

Joan E. McLean
Anne Anderson
Charles Miller
Mindy Wouden Pabst

Project Description:

This project has focused on the investigation of how bacterial cells interact with toxic metals in aqueous samples. It is well known that only a portion of the total metal concentration in solution is taken up by an organism and causes a biological response. The general theory is that only the free metal ion, e.g., Cd^{2+}, is bioavailable. Presently the total amount of dissolved metals in solution is analyzed and geochemical modeling is used to estimate the assumed bioavailable fraction, the free metal ion. We have developed metal detecting bioluminescent methods using a root-colonizing bacterium *Pseudomonas putida*. The bacterium produces light until there is oxidative stress in the cell on exposure to bioavailable metals. The sensitivity and selectively of response has been tested. Also we are using these bacteria to better understand the relationship among solution chemistry, metal adsorption onto and into the cell wall, and metal absorption into the cell and the corresponding bioresponse.

Accomplishments:

The three developed mutants of *Pseudomonas putida* Corvallis, Bfr, CatA, and FeSOD, have been tested for sensitivity and selectivity to copper and cadmium. There was significant decrease in light output when cells were exposed to 0.1 mg/L Cu and 1.0 mg/L Cd, initial solution concentration. Cadmium and copper differentially affect metabolism although both cause oxidative stress in the bacteria.

Adsorption of the metal to the cell surface is a pre-request for the absorption of the metal into the cell. Most studies of metal sorption by cells only analyze the total amount of metal removed from solution, but do not report on the actual amount of metal that is internalized by the organism causing a bioresponse. In this study we have attempted to define the specific location of copper and cadmium on or in the cell using chemical extractants. For copper, overall sorption was extensive, with a Kd value of 2700 L/kg (Kd =amount of metal associated with the cell/amount of metal remaining in solution). The partitioning of copper among surface bound, membrane bound and absorbed into the cell was concentration dependent. As the solution concentration of copper increased, from 0.5 to 2 mg/L, the cells shifted the partitioning of copper from membrane bound to being held on the cell surface. Over this concentration range the proportion of copper internalized was constant, with 20% of the total copper removed from solution being transported into the cell. At solution concentrations from 4 to 10 mg/L, the relative proportion of copper among surface bound (49%), membrane bound (41%) and internalized (10%) was independent of concentration. Copper is an essential nutrient and microbes have specific mechanisms to obtain sufficient copper, but at higher concentrations, above 4 mg/L, copper uptake into the cell was restricted.

The overall Kd for cadmium was 132 L/kg, significantly lower than that observed for copper. Cadmium has no known nutrient function in microbes; cells do not actively sequester cadmium from solution. Also unlike copper, the distribution of cadmium among surface bound, membrane bound and internalized was independent of concentration, with 80% of the total amount of cadmium associated with the cell bound to the surface and only 1% entering the cell.

The presence of ligands (sulfate, chloride, citrate and acetate) did affect the relative distribution of metals among surface bound, membrane bound and internalized. Specific interactions and effects of ligands on bioavailability of copper and cadmium are presently being investigated.

Work Plan FY 07/FY 08:

The approach to this study is to evaluate each step of the bacterial response of a bioluminescent *P. putida* to copper and cadmium. The solution chemistry was defined by preparing solutions of specific free metal ion activities and specific metal-ligand activities. Metal-ligand pairs of varying strength were selected for study. Common inorganic ligands (sulfate and chloride) and an organic ligand, citrate (a dicarboxylic acid present in root exudates and which plays a vital role in bioremediation of metal contaminated soils) were utilized to complex the copper and cadmium in these bioassays. The biosensor cells were exposed to these solutions and the amount of metal that was sorbed to the cell, as affected by solution chemistry, was determined. The metal sorbed by the cell may be bound to the surface or transported into the cell. We determined the partitioning of the metals between external and internal sites using chemical extractions. The bioresponse to the amount of metal internalized was determined by measuring the change in light output from these biosensors.

The objectives of this proposed study are to:

1. Determine optimal conditions for maximum responses of *Pseudomonas putida* Corvallis mutants Bfr, CatA, and FeSOD biosensors to copper and cadmium considering growth phase, exposure time, concentration of free metal ions, competition with background cations (Ca and K), and mutant type.

2. Determine how the free copper and cadmium ions interact with a mutant of the *Pseudomonas putida,* as defined by adsorption/absorption of the ions onto or into the cell and by the corresponding metabolic responses induced by the increase or decrease in light output from this luminescent sensor.

3. Determine how different metal complexes found in the environment affect the bioresponse of copper and cadmium.

Benefits to the State:

Utah regulations on the concentration of toxic heavy metals in water and soils are based on total contaminant concentration. This assessment does not provide information on potential bioavailability of the metal. The bioavailability of a metal is related to the association of the metal with solution and solid phase components, not necessarily the total concentration. Methods presently used for the analysis of metals cannot distinguish the bioavailable fraction. The use of bacterial biosensors will allow for a direct measurement of bioavailability.

Results from this research effort will be used to develop technical management strategies with regards to risks for soils, sediments, and surface and groundwater contamination based on more accurate measurements of bioavailability, and to develop an approach to reduce risk to groundwater and surface water posed by metal contaminated waters and soils in Utah. Results will be useful to the Utah Department of Environmental Quality, various municipalities in the State of Utah, the State Division of Oil, Gas, and Mining, and county agencies for developing effective water quality management programs for heavy metal contaminated sites.

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Gasoline Additives (MTBE and TBA) Natural Attenuation

Principal Investigator(s):

Ronald C. Sims
William J. Doucette
Joan E. McLean
Mark Greenwood

Project Description:

The Division of Environmental Response and Remediation, Utah Department of Environmental Quality, must oversee the remedial investigation, feasibility study, and remediation actions at all Utah sites contaminated by leaking underground fuel tanks (LUFTs). The division is currently lacking in procedures and tools that can be used to assist in site characterization and assessment of the extent of the problem and fate of MTBE.

Accomplishments:

1. Test procedures have been developed for developing quantitative information on the ability of sediments to absorb MTBE so that the chemical does not enter a drinking water system, and the ability of sediments of biodegrade MTBE.

2. MTBE can be biodegraded by naturally occurring microbes in groundwater systems in the presence of oxygen.

3. MTBE can be sorbed (absorbed) by sediment and soil materials such that little or no MTBE enters drinking water systems.

4. The ability of the sediment to absorb MTBE depends upon the organic matter content of the sediment, with more organic matter accomplishing more absorption and less organic matter content accomplishing less absorption of MTBE.

Work Plan FY 07/FY 08:

This project is designed to measure properties of groundwater sediments contaminated with gasoline containing the additive chemical MTBE for improved remediation at Utah Sites. The goals of the project are to: (1) sample sites identified by the Utah Department of Environmental Quality (UDEQ) for MTBE contaminated sediments, (2) conduct sediment tests to determine physical and biological properties, and (3) provide the test results to the Underground Fuel Tank (UFT) division of UDEQ for the design and monitoring of a remediation system. Locations of contaminated sites are in the Salt Lake City area in Salt Lake County.

Benefits to the State:

This project benefits the State of Utah Department of Environmental Quality, Division of Environmental Response and Remediation, in identifying, selecting, and designing ground water and sediment remediation systems and monitoring systems for gasoline sites contaminated with the additive MTBE (methyl-tertiary-butyl-ether). TBA (tertiary butyl alcohol) is a transformation product of MTBE and is a known carcinogen. MTBE is a suspected carcinogen that is soluble in water, and has been reported to be difficult to biodegrade within a ground water and sediment environment.

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Gene Probes for PAHs and Wastewater Treatment

Principal Investigator(s):

Ronald C. Sims
Charles Miller
Anne Anderson
Darwin L. Sorensen

Project Description:

Municipal wastewater is a product of every town and city in the State of Utah. The majority of cities, towns, and municipalities have a centralized wastewater treatment system that must meet increasingly stringent regulations with regard to treatment. Phosphorus is a pollutant produced by every central wastewater treatment plant in Utah, and treatment standards have been set by state and federal agencies (UDEQ and U.S. EPA) and TMDLs are being developed in Utah. An inexpensive and effective process of removal of Phosphorus from wastewater is needed.

Accomplishments:

Wastewater samples were analyzed by the genetic probe for PHB (Bio-plastic) and results indicated the presence of microbes with the capability to produce PHB.

Samples of wastewater and biosolids from the Logan and Hyrum municipal wastewater treatment plants (Figure 1) were taken and analyzed using a genetic probe to determine the presence of microbes that transform organic chemicals and the pollutant phosphorus into bio-plastic polymers. Laboratory experiments were conducted in fermentors to determine the bio-plastic production amount and rate.

Bio-plastic production (Figure 2) occurs during growth of the organism and is accumulated within the microbe cell as an energy reserve. The entire operation can be completed within days.

Work Plan FY 07/FY 08:

This project was undertaken to help the Cities of Logan and Hyrum, Utah. The objectives of the project include: (1) test wastewaters of Logan and Hyrum for the presence of microorganisms that produce bio-plastic materials, (2) optimize conditions for the microorganisms to manufacture bio-plastics, and (3) evaluate economical and safe procedures for removing and concentrating the bio-plastic materials from the microorganisms.

Benefits to the State:

This project will benefit the State of Utah by providing an effective and inexpensive process for the removal of the pollutant phosphorus from wastewater and the conversion of wastewater chemicals into bio-plastic materials that can be substituted for petroleum-based plastics. The design and development of an economical system for conversion of wastewater chemicals into bio-plastics will provide a more sustainable source of plastic materials and less reliance on petroleum-based plastics, and will also provide an economical benefit for the cities and citizens involved. The systems developed will have applications to other cities in the State of Utah.

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Figure 1. Utah State University Biological Engineering students take samples of Biosolids from the Hyrum Utah Wastewater Treatment Plant for evaluation of microbes that transform waste chemicals into bio-plastic polymers that are biodegradable and can be used to replace petroleum plastics.

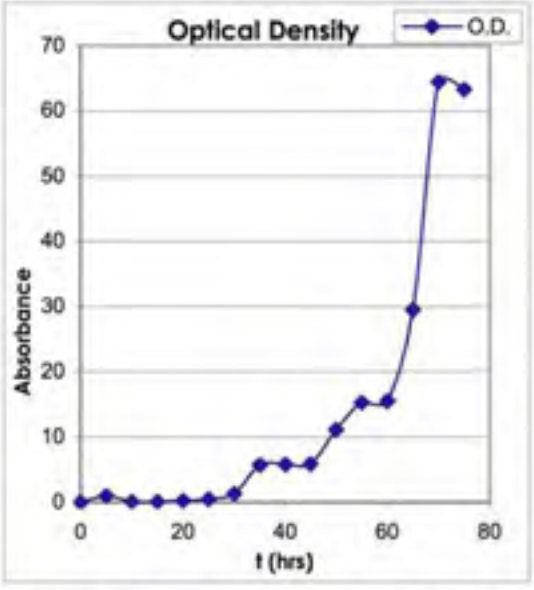

Figure 2. Growth Curve for Bio-plastic Producing Microbe showing Optical Density (growth) as a function of time (hours).

Phytovolatilization Measurements at Hill Air Force Base, Utah Operable Unit 2, August–September 2005

Principal Investigator(s):

William J. Doucette
Mike Petersen
Bruce Bugbee
Clint Rogers

Project Description:

Understanding the potential impact that plants have on shallow soil/groundwater systems contaminated with chlorinated solvents, such as trichloroethylene (TCE), is critical in evaluating the potential effectiveness of phytoremediation and quantifying the relative impact of plants on the overall natural attenuation processes involved with these hazardous chemicals. Information regarding the fate of TCE taken up into plants is also necessary to assess the potential risk associated with the consumption of these plants by humans and animals. Tree sampling for chlorinated solvents such as TCE could also be used to supplement the groundwater monitoring efforts used for plume delineation.

Accomplishments:

TCE was found in tree core samples collected from 10 of the 13 trees sampled within OU 2 with concentrations ranging from the method detection limit (<0.1 μg/kg dry weight) to 200 μg/kg fresh weight. TCE was also found in the corresponding stem and leaf samples collected at the same time at levels that were generally 10 (stems) to 100 (leaves) times lower than the cores. A number of tree cores also contained measurable concentrations of cis-DCE ranging from less than the minimum detection limit (MDL) to 180 μg/kg dry weight. Groundwater samples obtained from several wells near the tree locations range from 70 (seep) to 200 μg/L. Stable isotope samples were inconclusive regarding the source of water utilized by the trees but the presence of TCE in the tree core sample strongly suggests the trees at OU 2 were using primarily groundwater.

Five of the 13 OU 2 trees were also sampled for phytovolatilization. Measurable TCE was detected in the transpiration gas of all five of these trees with TSC values ranging from 1 to 50 μg TCE per L of transpired water collected. This compares with levels of 100 to 400 μg TCE/L of water during a previous phytovolatilization sampling conducted in fall 1999 on trees within the same general location. Given the variability observed between different trees in the same general location, the apparent difference in phytovolatilization observed between the two sampling events may not be significant; however, it may also be attributed to the general decrease in the TCE groundwater concentrations observed between 1999 and 2005. Overall, the results of the August-September 2005 sampling show that the indigenous poplar and willow trees are removing measurable amounts of TCE from the subsurface through uptake and phytovolatilization.

Using the range of TSC values (1 to 50 μg/L) measured along with estimates of daily transpiration by individual trees (10 to 200 L/day), the TCE phytovolatilized per tree can be estimated to range from 1.8 to 1800 mg/yr assuming a 180 day growing season. Estimates of the potential impact of phytovolatilization at the site could be improved if similar sampling was conducted at additional times throughout the year to determine if there is any significant seasonal variability associated with the measured TSC values and with refined transpiration estimates. Surface emissions ranged from less than 5.6 μg-TCE per day per square meter (μg-TCE/d-m^2) to 256 μg-TCE/d-m^2 indicating that impact of volatilization directly from the soil surface should be evaluated as a potentially significant attenuation mechanism for TCE at OU 2. The surface emission data are comparable to similar data obtained in 1999, where fluxes ranging from 28 to 750 μg-TCE/d-m^2 were observed at the OU 2 seep location.

Work Plan FY 07/FY 08:

Plant tissue samples (tree cores, stems, and leaves) were collected from 13 trees located within OU 2 and analyzed for TCE using a headspace gas chromatography mass spectrometry (GC/MS) method. Water and xylem samples were analyzed for stable isotopes using mass spectrometry at the University of Utah Stable Isotope Ratio Facility for Environmental Research (SIRFER) Laboratory. Phytovolatilization samples were obtained from 5 of the 13 trees by sealing a glass chamber over a representative section of branch, purging the chamber with compressed breathing air, and collecting the transpired water and TCE on sorbent traps. The mass of water collected in the silica gel traps was determined gravimetrically and the amount of TCE collected on the Tenax© sorbent tubes was determined using thermal desorption gas chromatography mass spectrometry (GC/MS). The amount of phytovolatilized TCE was expressed in terms of a transpiration stream concentration (TSC), μg TCE per liter of water transpired. Soil surface TCE emission measurements were made at three OU 2 locations near the trees sampled for phytovolatilization. A flow through sampling system was used to collect and concentrate TCE emitted from the soil surface independent of micrometeorological conditions within the lower atmosphere. Thermal desorption gas chromatography mass spectrometry (GC/MS) was used to quantify the amount of TCE collected.

Benefits to the State:

The results of this research will directly benefit the Environmental Management at Hill Air Force Base (HAFB) and the citizen advisory groups that monitor the groundwater pollution around HAFB and other contaminated groundwater sites in the state.

Soil Bioremediation and Beneficial Reuse

Principal Investigator(s):

Ronald C. Sims
Frank Olson

Project Description:

Beneficial reuse of contaminated soil is difficult to achieve because it requires restoration of agronomic uses of soil after it has been contaminated with toxic and/or carcinogenic chemicals. Soil bioremediation for beneficial reuse restores the ability of the soil to sustain agronomic production and uses, and this treatment was evaluated in this project.

Accomplishments:

Land application systems are appropriate for organic chemical industry waste, food industry waste, agricultural, and municipal solid wastes. The photograph (Figure 1) shows USU students evaluating solid waste from an agricultural industry in Ogden, Utah. Results demonstrate that when soil is adversely impacted by chemical wastes it is possible to utilize agricultural methods of tilling and aeration and nutrient addition to restore (bioremediate) soil for beneficial reuse. We have developed theoretical and practical applications of land farming principles to develop inexpensive and effective methods to restore damaged land to a positive economic impact on the industry, community, and state. Bioremediation of waste-impacted soil can be accomplished using natural microbes and traditional agricultural methods including tilling and fertilizing

Work Plan FY 07/FY 08:

Project completed.

Benefits to the State:

This project provided information concerning restoration of agricultural uses and other uses of soil systems (e.g., forestry, housing, etc.), and sustainability of soil through agricultural practices for the treatment of organic wastes in land treatment systems. In the State of Utah many rural municipalities and industries use land treatment for waste management, and other soils located at U.S. Forest Service sites, at Hill Air Force Base operable units, along railroad tracks, and at petroleum-based chemical industries have been contaminated with cancer-causing polycyclic aromatic hydrocarbon (PAH) compounds that can contaminate ground water sediments and ground water resources.

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Figure 1. Utah State University students evaluate solid waste produced by industry in Ogden, Utah.

Uptake of Chlorinated Solvents, Fuels, and Related Compounds into Fruits and Vegetables

Principal Investigator(s):

William J. Doucette
Mike Petersen
Bruce Bugbee
Erik Dettenmaier

Project Description:

Chlorinated solvents, fuel related compounds and explosives have contaminated shallow groundwater at many locations in the State of Utah including many communities surrounding Hill Air Force Base (HAFB). Previous research has documented the uptake of organic compounds into plants but little experimental information is available regarding the potential transfer of these compounds into fruits and vegetables. The Environmental Directorate at Hill Air Force Base (Hill AFB), the Department of Environmental Quality, and community citizen groups are interested in the potential contamination of fruits and vegetable growing in areas of contaminated groundwater.

Accomplishments:

Initial Pressure Chamber Results

TSCF values were calculated when the chemical concentration reached a steady state value. TSCF values were typically measured in triplicate.

Pressure chamber TSCFs verses log K_{ow} relationships was linear unlike those previously reported (Briggs et al., 1982).

Neutral, polar compounds, i.e., low log K_{ow}, showed the highest TSCFs.

Initial Hydroponic Results

TSCF values generated by intact hydroponic plants were lower than those measured using the pressure chamber.

The lower values are thought to represent losses within the plant shoots (i.e., volatilization, metabolism, and growth dilution) that are not accounted for using the pressure chamber technique.

Shoot/fruit concentrations tended to be greater for compounds having low log K_{ow} and low volatility (P_wH).

Initial Soil Column Results

Out of the six volatile compounds (operationally defined using a headspace analytical method) initially evaluated, only the compound with the lowest Henry's Law constant, 1,4-dioxane, was found in all above ground tissues; relationships among concentrations in different plant parts were found to be: 1,4-dioxane fruit BCF > stem BCF > leaf BCF. Lower volatilization losses maybe associated with smaller area/volume ratios.

Subsurface irrigation will be used in future column study to minimize volatilization of compounds during watering.

BCF measurements for a series of non-volatile compounds are currently being performed.

Conclusions

Pressure chamber methods provide a relatively rapid, reproducible approach to evaluate root-to-shoot translocation. However, potential compound losses from the above-ground tissues, such as volatilization, metabolism, or growth dilution, are not accounted for.

Hydroponic and soil studies using intact plants can be used to provide contaminant uptake and distribution information. Exposure concentrations are easier to control and measure in hydroponics but soil studies allow direct measurement of BCFs used in risk assessment.

Contrary to widely used plant uptake predictive schemes, highly polar, neutral compounds show the highest tendency for root uptake, translocation and transfer into fruit.

Work Plan FY 07/FY 08:

The uptake of chlorinated solvents and fuel related compounds and the subsequent transfer into fruits and vegetables will be determined by exposing triplicate tomato and zucchini plants to constant concentrations of the representative compounds during fruit production. Hydroponic and soil based exposure systems will be used depending on the physical chemical properties of the contaminants. A pressure chamber system will also be used to determine transpiration stream concentration factors (TSCF) for input into plant uptake models. The potential compounds to be studied include: trichloroethylene (TCE), perchloroethylene (PERC), carbon tetrachloride (CCl_4), cis-dichloroethylene (cis-DCE), trichloroethanol (TCEt), dichloroacetic acid (DCAA), benzene, toluene, m-xylene, and methyl tert-butyl ether (MTBE). All compounds have been identified as groundwater contaminants within the State of Utah. This small series of compounds includes volatile and non-volatile, polar and non-polar, neutral and acidic compounds. The diversity of physical/chemical properties within this small group of compounds should provide sufficient variation to evaluate and refine existing plant uptake models that are based primarily on the hydrophobicity of the compound.

Benefits to the State:

The results of this research will directly benefit the Environmental Management at Hill Air Force Base (HAFB) and the citizen advisory groups that monitor the groundwater pollution around HAFB and other contaminated groundwater sites.

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Water Quality Engineering

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Water Quality Engineering

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
Alternative Decentralized Wastewater Treatment Systems for Utah Conditions	$47,010.99	$0.00	$0.00
Chromium-6 Removal Treatment Technologies—Phase III Bridge Project	$22,334.69	$23,451.43	$24,154.97
Development of Sediment Management Protocols for Small Diversion Reservoirs in Utah	$7,815.03	$10,000.00	$0.00
Identification of Potential Risks to Utah Drinking Water from Chlorinated Solvents and the Potential for their Remediation	$11,300.87	$11,865.92	$12,221.90
Investigation of the Changes in Water Quality In the Little Bear River Watershed in Response to the Implementation of Best Management Practices	$10,025.93	$10,527.22	$10,843.04
"Lab-on-a-Chip" – Miniaturized Salinity Sensor Arrays for Water Quality Monitoring (Phase II)	$72,536.31	$31,000.00	$0.00
Potential Impacts of Septic Systems on Ground Water in Castle Valley, Utah	$19,527.82	$20,504.21	$21,119.34
Quantification and Management of Uncertainty in Salt Loading from the San Rafael Irrigation System	$28,462.08	$60,000.00	$0.00
Real Time Monitoring Internet Portal for the Utah Water Research Laboratory (UWRL)	$2,417.92	$22,000.00	$22,660.00
Real Time Streamflow and Water Quality Monitoring Station in the Logan River at the Utah Water Research Laboratory (UWRL)	$10,025.93	$10,527.22	$10,843.04
Temperature Modeling Support	$10,025.93	$10,025.93	$10,326.71
The Bear River Basin in Idaho, Utah, and Wyoming	$7,013.22	$7,363.88	$7,584.80
Treated Wastewater Use in Agricultural Irrigation: Technical Feasibility and Limitations	$11,115.68	$26,250.00	$26,250.00
Weather Station Network for the Little Bear River Basin	$10,025.93	$10,527.22	$10,843.04
Weber/Ogden Basin Water Quality Study – DSS Completion Support	$10,025.93	$10,000.00	$10,300.00
Designated Projects		$726,901.00	$810,460.32
Undesignated Projects		$25,000.00	$94,000.00
Total	**$279,664.26**	**$1,065,944.03**	**$1,071,607.16**

Alternative Decentralized Wastewater Treatment Systems for Utah Conditions

Principal Investigator(s):

Judith L. Sims
Darwin L. Sorensen
Jenny Hurst

Project Description:

Increasing development of rural areas in Utah is resulting in demands for more options for treatment and disposal of wastewater, especially in areas not suitable for the use of the conventional septic tank–drain field system. Many of these alternative options are more complex treatment and disposal systems that require increased expertise in site evaluation, design, installation, management, operation, and maintenance. Also small communities that are facing growth pressures that impact water supply resources may be interested in decentralized wastewater treatment technologies that provide for beneficial reuse of the wastewater.

Accomplishments:

Based on the information collected, we identified technologies (packed bed systems: intermittent and recirculating sand filters, peat and textile filters, constructed wetlands, and subsurface wastewater drip irrigation) that appeared to be the most desirable options for use in Utah. We prepared guidance materials that summarized the effectiveness, appropriateness, and operation and maintenance requirements of these various decentralized technologies. These guidance materials are being used in on-site workshops that are presented in support of the Utah mandatory certification program for on-site wastewater system professionals. We have also prepared a presentation on operation and maintenance (O&M) of packed bed media systems.

Work Plan FY 07/FY 08:

To achieve the project objective, initially we surveyed literature sources concerning alternative decentralized systems. We obtained information on various technologies from the refereed literature, from conference presentations, and from environmental and health state agencies, with a focus on those states with climatic and geological conditions similar to those in Utah. Equipment vendors of wastewater technologies were also surveyed. To determine if technologies were appropriate for use in Utah, we defined the climatic and geological conditions that might affect the use of various technologies in Utah. We also developed a standardized format/matrix for evaluation of information.

Benefits to the State:

Utah, as a result of administrative rule changes that became effective in May of 2006, is beginning to utilize a wider range of on-site technologies. The information developed in this project will be invaluable as a tool to ensure that appropriate siting, design, construction, installation, and operating and maintenance guidelines for these new systems are implemented. By providing thorough and complete information on the new technologies through the information developed in this project, state and local decision-makers will be able to make wise decisions in the selection of the appropriate technologies for specific problem sites. The use of these more complex treatment systems will allow continued development in Utah's more rural areas.

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Chromium-6 Removal Treatment Technologies—Phase III Bridge Project

Principal Investigator(s):

Laurie McNeill

Project Description:

Chromium is a contaminant of increasing interest in drinking water, especially after the success of the "Erin Brockovich" movie. This project will examine the demonstration-scale performance of various treatment technologies for removing chromium present in drinking water. Results will be utilized to recommend full-scale treatment technologies that can be installed by drinking water treatment utilities.

Accomplishments:

Approximately 500 samples analyzed for Total chromium and Chromium-6.

Work Plan FY 07/FY 08:

On-site pilot studies coupled with laboratory analysis.

Benefits to the State:

Utah will ultimately be affected by any new drinking water regulations implemented by EPA. This research provides information on the treatment options for chromium in drinking water.

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Development of Sediment Management Protocols for Small Diversion Reservoirs in Utah

Principal Investigator(s):

Mac McKee
Lizzette Oman
Andres Ticlavilca
Blake Tullis
Ronald C. Sims

Project Description:

Uncontrolled sediment releases from small reservoirs have been shown to produce deleterious impacts on downstream fish populations and their habitat. This is a significant non-point source water quality problem in Utah and around the west. The purpose of this project is to develop and disseminate management guidelines for the flushing of sediments from small reservoirs to minimize environmental impacts on water quality and aquatic resources, with emphasis on reservoirs located in regions with arid climates, such as Utah. These guidelines will be based on hydrology and geology of the watershed within which the reservoir is located, and on the hydraulic characteristics of the reservoir itself. The project will use First Dam, a small dam owned by Utah State University on the Logan River at the mouth of Logan Canyon, as a case study.

Accomplishments:

The project began in late FY 2003. It has developed an extensive literature review of reservoir flushing and sluicing approaches and available models for evaluating sediment mobilization needs and methods in reservoirs. A plan for controlled flushing of sediments from First Dam has been developed, including monitoring procedures to ensure protection of downstream fisheries resources during flushing events. A stream gauging station has been installed downstream of First Dam so that real-time flows can be measured during flushing events as well as throughout the rest of the year. In addition, instrumentation for real-time monitoring of turbidity upstream and downstream of First Dam has been installed. A sampling program has been implemented to collect data on total suspended sediment concentrations of water flowing into and out of the reservoir at First Dam. Work in FY 2005 and FY 2006 focused on using the data available from the real-time monitoring and grab samples to estimate a sediment budget for the reservoir. This monitoring program demonstrated a net accumulation of approximately one-half acre-foot of sediment in the reservoir during the high runoff period in spring of 2006. Results to date have been presented at the annual Utah Water Users Conference and other venues.

Work Plan FY 07/FY 08:

Work in FY 2005 and FY 2006 focused on the implementation of a water quality and stream flow monitoring program, and in refining the design of the reservoir flushing plan to better accommodate the requirements to irrigators and downstream fish spawning activities. The flushing plan will be tested in 2007 through controlled releases of sediment during spring runoff, and the effectiveness of these controls will be evaluated from monitoring data. The experience gained from sediment management experiments on First Dam will be used to develop guidelines for management of sediment in small diversion reservoirs in Utah.

Benefits to the State:

The knowledge gained from experimentation at First Dam will be used to prepare general guidelines appropriate for sediment management on the approximately 200 small reservoirs in Utah. These guidelines will address such factors as:

- Implications of watershed geology for water chemistry and sediment toxicity.
- Implications of watershed hydrology for sediment loading rates.
- Recommendations for most effective and/or least costly sediment control methodologies, based upon reservoir size, geomorphology, and bathymetry.
- Recommendations for flushing procedures, based on active reservoir volume, current morphologic characteristics of sediment deposits, inflow rates and discharge capacities, hydraulic limitations on control of outlet works, potential toxicity of bottom sediments, and downstream water quality regulations that must be met.

The general guidelines will be disseminated in electronic and hard copy form to Utah water resources agencies, river commissioners, water conservation districts, and dam owners and operators.

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Identification of Potential Risks to Utah Drinking Water from Chlorinated Solvents and the Potential for their Remediation

Principal Investigator(s):

R. Ryan Dupont
Shounak Krishnanand

Project Description:

Objectives

1. Create a user-friendly, spatially-based, GIS tool using the MapWindow application, developed at the Environmental Management Research Center at Utah State University, to integrate the spatially-distributed solvent source information with susceptible groundwater well receptor data for impacted communities throughout the state.

2. Develop a fate and transport model plug-in for this GIS tool that will incorporate local aquifer physical and geochemical properties into predictions of chlorinated solvent reaction and transport, and subsequent potential risk to groundwater extraction wells.

3. Validate the GIS tool/fate and transport plug-in using data from three test sites where solvent contamination has resulted in closure of drinking water wells, and develop a site evaluation protocol that can be implemented by the DEQ/DERR in their on-going management of these contaminated sites.

Accomplishments:

Development of the MapWindow utility for site groundwater management, data representation and transport/fate and risk modeling has been completed. The following data layers are included in the groundwater management tool: municipal plat maps for municipalities for which existing chlorinated solvent-impacted sites are known; existing users of chlorinated solvents; historical users of chlorinated solvents; municipal well locations; private well locations; monitoring well locations; and soil boring locations. The spatially distributed data have associated with them relevant attribute information such as name, address, date of operation, chemicals used, known releases, etc., for the chlorinated solvent users, or temporal depth to water and water chemistry data for monitoring wells.

The Fate and Transport component from MicroFEM has been successfully incorporated into the MapWidow tool, providing 3-D modeling of groundwater flow, identification of groundwater protection zones, estimates of groundwater movement to extraction wells, and contaminant flow path estimates. Several groundwater modeling capabilities have been included for implementation within this groundwater risk analysis and management tool. These include: 1) groundwater table gradient, groundwater direction, and estimated pore water velocity determinations based on measured monitoring well elevations and associated aquifer soil properties; and 2) contaminant travel time estimates using MicroFEM with options for no degradation, and field estimated degradation rates for starting compounds and degradation products, using associated soil properties and water chemistry data to aid in estimating sorption and transport. An "area of susceptibility" overlay graphically representing the expected downgradient area that is susceptible to contamination from release sites based on expected flow time, impacts from degradation, variability expected in groundwater gradient and direction, etc., will be included in the final groundwater modeling/risk analysis package.

Work Plan FY 07/FY 08:

The MapWindow development environment is being used to deploy a basic GIS data viewer with associated pre-built plug-ins for shape file editing, importing and converting grid data, viewing and editing shapefile attribute table data, carrying out comprehensive environmental summary and temporal data analysis and plotting, and for identifying features and adding labels.

The next step in the project is the integration of a Fate and Transport component into the MapWidow database structure. The original plan for the integration of an EPA groundwater capture zone model, WhAEM, was abandoned due to the limitation of the WhAEM model in describing the fate and transport of contaminants within a groundwater plume. Fate and transport modeling is being finalized via MicroFEM that provides 3-dimensional modeling of groundwater movement, and the capability to model contaminant retardation via sorption to aquifer organic material.

Validation of the groundwater management tool and associated plug-in tools developed in this project is currently underway using field site data available from a contaminated site labeled the Sugarhouse Well site that have resulted in water supply well abandonment. Estimates of "area of susceptibility" generated from the tool have been calibrated to the Source Water Protection zone originally published for the site, and a time series of contaminant migration to the impacted well is being generated for a series of release scenarios for comparison with recorded well contaminant concentration results as a way of validating, in a semi-quantitative sense, this screening-level risk management tool.

The final product of this effort will be the preparation of a Protocol Document for the use of the developed tool for the evaluation of the potential risk, remediation options, and prioritization of chlorinated-solvent impacted sites. This document will include an operator's guide for using the tool, a recommended procedure for data compilation and input to the GIS database, a recommended procedure to follow for the analysis of available site data in developing transport and fate results and "area of susceptibility" regions, guidance on site prioritization based on the transport and fate results, and guidelines for when and how to collect and analyze additional site data to improve this susceptibility analysis.

Benefits to the State:

A GIS based computer data management and modeling system has been completed to help the Utah Department of Environmental Quality prioritize actions needed at sites to protect groundwater supplies from contamination by chlorinated solvents. This project will have a direct and positive impact on citizens throughout the state as chlorinated solvent impacted groundwater sites have been identified throughout the Salt Lake Valley as well as in Bountiful, Delta, Logan, Ogden, Price, Tooele, Tremonton, Vernal, and Woods Cross. All citizens will benefit from an improved understanding by the Utah DEQ of potential groundwater resource contamination represented by current and historic chlorinated solvent users, by their more efficient expenditure of public dollars based on risk management prioritization that will be made possible by this tool, and by the preservation of groundwater resources in the state through proactive control of high risk sites.

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Investigation of the Changes in Water Quality in the Little Bear River Watershed in Response to the Implementation of Best Management Practices

Principal Investigator(s):

David K. Stevens
Jeffery S. Horsburgh
Darwin L. Sorensen
Nancy Mesner
Douglas Jackson-Smith
Ron Ryel
Joon Hee Lee

Project Description:

The Clean Water Act (CWA) of 1972 and its subsequent amendments have resulted in significant improvements in the quality of the nation's waters (USEPA and USDA, 1998). Waters have been restored to ecological health across the nation, primarily through the targeting and treatment of industrial and municipal point sources. The CWA requires that point sources be permitted through the regulatory NPDES system, which establishes allowable discharges and requires end-of-pipe monitoring and reporting.

Even with these major advances, however, it is estimated that 40% of the assessed waters of the U.S. still fail to meet their designated beneficial uses (USEPA and USDA, 1998). The principal culprit in these waters is nonpoint source (NPS) pollution. These various pollutants are generated by a wide range of land uses and activities, sources are distributed across the landscape, and transport to streams and lakes occurs primarily by surface and subsurface runoff and return flows. Agricultural activities are the most significant source of NPS pollution in the United states, and are considered a contributing factor for 70% of impaired streams and rivers and almost 50% of the impaired lakes and reservoirs in the nation (USEPA and USDA, 1998).

The CWA does not provide for regulatory control of NPS pollution. Rather, incentive programs that provide cost share have been coupled with educational efforts to promote voluntary implementation of best management practices (BMPs). BMPs are land use practices designed to reduce the generation of pollutants and runoff, trap sediments, or otherwise mitigate the water quality impacts of human activities. Over the last 2 decades, USDA and EPA have invested billions of dollars for cost share for agricultural producers through the Environmental Quality Incentive Program (EQIP), Conservation Reserve Program (CRP), Wetland Habitat Incentive Program (WHIP), 319 Nonpoint Source Pollution grants and other programs that promote the implementation of BMPs. Increasingly, the management unit for water quality improvement is the watershed, and watershed plans, such as Total Maximum Daily Load Implementation (TMDL) plans and Coordinated Resource Management Plans (CRMPs), have been used to help identify those areas in greatest need of remediation and to prioritize the distribution of funds. Because BMP implementation is strictly on a voluntary basis, however, the largest generators of NPS pollution may not choose to change their practices. In addition, cost share funds have not always been distributed according to the greatest potential improvement to water quality, but rather in response to other drivers, such as the political need to distribute funds equally across counties within a state.

An extensive literature exists on the effectiveness of BMPs (USEPA, 1993; USDA, 1995; Lant et al., 1995; Robinson et al., 1996; McGee et al., 1997; USDA, 2001) and at a field scale, when installed and maintained according to design criteria, the implementations clearly have the desired effect. However, studies that demonstrate the effectiveness of BMPs under real-world conditions at a watershed scale are

rare (DeBano and Schmidt, 1989; Edwards et al., 1996; Carline and Spotts, 1998; Wang et al., 2002). Of the few published studies on the impact of BMPs at a watershed level, watershed effects have been identified in only a few (Wang et al, 2002) and more typically studies have been unable to measure a statistically significant response in water quality (Rinne, J. 1999; Fields, 2004).

The unanswered questions surrounding the water quality impact of BMP implementation at the watershed scale include: Were appropriate types, distribution and numbers of BMPs implemented in a watershed? Were the BMPs properly installed and maintained over time? Is there a threshold level of implementation that must be met before a watershed scale response is seen, and are there lag times between implementation and response of a system? How does the spatial position of BMP implementation within the watershed influence impacts on water quality? Are monitoring efforts within a watershed, as they are currently designed, capable of identifying a response? Much of the social science research on agricultural conservation behavior has focused on the characteristics of adopters (and nonadopters), and the social and institutional networks thought to facilitate the adoption of recommended practices (Fuglie and Kascak, 2001; Guerin, 1999; Korsching and Hoban, 1990; Lovejoy and Napier, 1986; Rogers, 1995). This research has generally revealed that younger and better educated farm operators, persons with off-farm employment, and larger operations with greater labor and capital resources are the most likely to implement voluntary agricultural BMPs (Poe et al. 2001; Napier, Tucker and McCarter, 2000; Hooks, Napier, and Carter, 1983). However, most adoption/diffusion studies usually explain only a small percentage of the variance in adoption of environmental practices using socioeconomic and social-psychological variables (Fuglie and Kascak, 2001; Napier, 2000). By the same token, the lack of widespread adoption of many environmental best management practices (BMPs) has been linked to the fact that they may be inappropriate for many agricultural operations (Shepard, 2000; Nowak, 1993; Jackson-Smith and Barham, 2000). This has led to suggestions that renewed emphasis be placed on developing a more diverse portfolio of technological and management solutions to environmental problems that will be suitable for diverse types of agricultural producers.

Accomplishments:

In FY 06, the project team has completed its inventory of farms and farm fields adjacent to the Little Bear River and the entry of those data into a comprehensive BMP database, surveyed opinions of farmers about the implementation and benefits of best management, completed historical data analysis, installed and began collecting data from distributed water quality sensor networks along the Little Bear River mainstream, and prepared an annual CRIS report on project progress, among other, lesser, accomplishments.

Work Plan FY 07/FY 08:

Completion of water quality models and study of efficacy of nonpoint source pollution management programs. Presentations and the Water Environmental Association of Utah, Spring Conference, St. George, UT, and USDA conference in Savannah, GA.

Benefits to the State:

This study is designed to evaluate whether adoption of several agricultural BMPs in a Northern Utah watershed have had a measurable impact on phosphorus loadings into the Little Bear River. The use of fine-grained data from throughout this watershed will enable us to identify specific impacts of various BMPs across time and space. While the proposed research is designed primarily to assess the impacts of BMPs on water quality, we also seek to gain insights into the value of alternative water quality monitoring techniques. The results of our work will help future agricultural conservation programs focus on the most effective practices, and can be used to develop new protocols to increase the efficiency of water quality monitoring efforts.

This project is being carried out in conjunction with the State of Utah and the Colleges of Natural Resources and Humanities, Arts, and Social Sciences. The results of this work are reports, presentations, and software that will assess the effectiveness of best management practices in phosphorus reduction in the Litter Bear River water.

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"Lab-on-a-Chip" – Miniaturized Salinity Sensor Arrays for Water Quality Monitoring (Phase II)

Principal Investigator(s):

Anhong Zhou
Dr. Huifang Dou
Robert Gardner
Yan Shi
Nikita Zaveri
Rongtao Sun

Project Description:

The current techniques for measuring the concentration of individual salt ions in water (especially Cl^-, Na^+, SO_4^{2-}, Mg^{2+}, Ca^{2+}, and HCO_3^-) include either conductivity detection or ion-exchange chromatography (IEC). The major disadvantages of these methods are: 1) they cannot distinguish the individual ions concentration (conductivity); 2) measurement requires expensive instrumentation and time (IEC); 3) the detection limit is low (either conductivity or IEC). Development of a cost-effective portable device that can quantitatively and selectively measure these ions will greatly assist the assessment of effect of salinity in water quality.

The objective of this project is to design and fabricate a prototype detection device in the form of a miniaturized electrochemical (EC) chip with the integration of microfabricated ion-selective microelectrode arrays (μISMEAs), termed as "EC-μISMEAs". The simultaneous measurement of multiple salinity ions could be realized by this "lab-on-a-chip" device.

Accomplishments:

A prototype miniaturized EC chip was designed and fabricated and initially evaluated, and sensitive microelectrode array was fabricated and tested in standard heavy metal ion solutions. Satisfactory results were obtained.

Work Plan FY 07/FY 08:

In Phase I of the project (FY '05), we designed and fabricated a prototype EC circuit board and microelectrode arrays. The initial performance tests have been compared with expensive, commercially available EC instrumentation, and satisfactory results were obtained. The special aims in this phase of the project will include: 1) optimization of design and evaluation of a printed circuit board; 2) optimization of the fabrication of MEAs; 3) microfabrication and integration of μISEAs on the EC chip; 4) synthesis of ion selective polymer membrane (e.g., bis-pyrylium derivatives) which could be specific to the individual salinity ions, in our current stage, we will target SO_4^{2-} as our model salinity ion; and 5) integration of EC PCB with selective membrane coated MEA and initial performance evaluation. Performance factors such as sensitivity, selectivity, linear range, detection limit, life time and so on will be evaluated for SO_4^{2-} at the concentration range of 340 ~ 2850 mg/L, which is typical range of SO_4^{2-} ion in water samples from San Rafael River Basin in Emery County. Other salinity ions that have been identified by UWRL as the high priority ions that need quantification would be not difficult to detect by synthesis of different polymeric structures on the MEA surface.

Benefits to the State:

Seven western states in the United States (Arizona, New Mexico, California, Utah, Colorado, Wyoming, and Nevada) formed Colorado River Basin Salinity Control Forum to manage the salinity problem of the Colorado River. Each governor of these states has to provide support to improve salinity control treatment of the river, but there is substantial uncertainty 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 to develop a portable biosensor device for real-time measurement of the concentrations of individual salt ions in the field.

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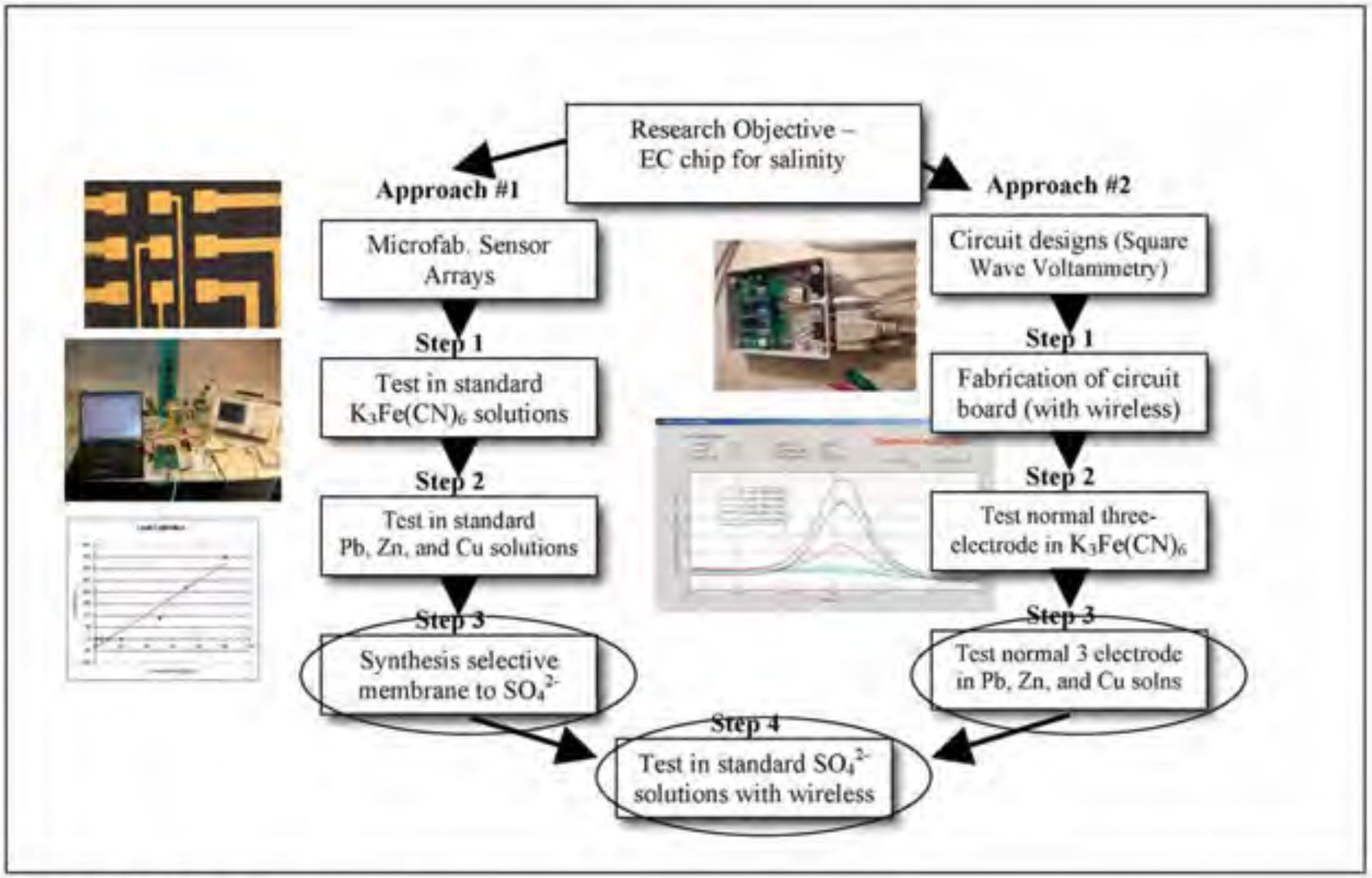

Figure 1. A flow chart for the project progress.

Potential Impacts of Septic Systems on Ground Water in Castle Valley, Utah

Principal Investigator(s):

Judith L. Sims
Joan E. McLean
Darwin L. Sorensen
Amanda Davis

Project Description:

This project addresses the protection of the groundwater quality in Castle Valley, Utah through the evaluation of potential impact from and management of on-site wastewater treatment systems in the Valley. Castle Valley is located in southeastern Utah approximately 17 miles east of Moab in Grand County, Utah. The Town of Castle Valley has 440 5-acre plots, each with their own well and septic system. Currently, the Town has approximately 270 approved water wells and 235 septic systems. Most of these wells and septic systems are situated on the unconsolidated deposits of the valley-fill, sole-source aquifer. The State of Utah Governor's Office of Planning and Budget estimates there will be almost 800 inhabitants in the Town by the year 2020, as Castle Valley is becoming increasingly popular as a site for vacation and retirement homes. The increase in development and its potential impact on the quality of groundwater resources is a cause of concern to the town. All of the studies to date have stated that the single greatest potential source of contamination to the aquifer is septic systems.

Accomplishments:

During FY 2006 we developed the Project Implementation Plan (PIP) and the Quality Assurance Project Plan (QAPP), which will be used to guide the performance of the project.

A practice site was set up in Smithfield, Utah, to test our sampling techniques and analytical procedures in an operating drain field.

In August of 2005 we visited Castle Valley and preliminarily selected 8 sites for installation of the lysimeters. We obtained septic system permit information on the sites from the Southeastern Utah Health Department and well logs from the Utah Division of Water Rights.

We conducted a preliminary septic system education program at a town council workshop on April 19, 2006, at which time we began to assess educational needs. We are also developing a septic system questionnaire for the town citizens that will guide them in their use of their septic systems. The final educational program will be presented at a town council workshop after the drain field study has been completed.

Work Plan FY 07/FY 08:

To achieve the project goal, we will investigate the volume and chemistry of leachate generated by a subset of septic systems in the Town of Castle Valley. Instruments (called lysimeters) capable of obtaining samples of the descending leachate plumes below drain fields will be placed beneath new and existing systems. Once the instruments are in place, they will be sampled for a period of one year or more. In this project we will focus on the analysis of nitrogen in the unsaturated zone, but will also selectively sample for phosphorus and pathogens in soil core samples.

We are recruiting volunteer residents to participate in the study, depending on their geographic location in the valley, as well as the household occupancy (seasonal, permanent, large family, etc.) Once the sampling instruments are in place, they will be sampled for a period of 18 months.

The information collected from the drain field study will be presented in a clear, scientifically defensible, and concise format that is understandable not only to the scientific community, but also to the lay public, so that the residents of Castle Valley can understand the results and make informed decisions through community planning processes on possible management options for the septic systems in the Valley. The project will also include training in local geology, local water quality issues, and septic tanks and drain fields (how they work and why they need to be maintained) for the citizens of Castle Valley. We propose to research existing educational materials and select/modify the material most appropriate for Castle Valley and other rural communities in the desert West. We will also investigate various means (workshops, flyers, brochures, etc.) of providing information in an effective manner to the residents of Castle Valley and select those that meet the needs of the community.

Benefits to the State:

Management of on-site wastewater disposal systems was identified as one of the nine priority non-point source pollution programs in the 2000 Utah Nonpoint Source Pollution Management Plan. This project addresses the protection of groundwater quality in Castle Valley, Utah through the evaluation of potential impact from and management of on-site wastewater treatment systems in the Valley. Results of this study will be used in the development of a community outreach and communication program for on-site wastewater systems, including education in local geology, local water quality issues, and septic tanks and drain fields for the citizens of Castle Valley.

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Quantification and Management of Uncertainty in Salt Loading from the San Rafael Irrigation System

Principal Investigator(s):

Mac McKee
Lizzette Oman

Project Description:

Irrigation in the valleys of the San Rafael River Basin in Emery County contributes substantial amounts of salt each year to the waters of the Green River. However, there is considerable uncertainty in how much salt flows out of these valleys, how much of the salt load is due to anthropogenic sources, including irrigation, and how salt management projects will affect total salt loads from the basin. This project has employed modern methods of data analysis to provide better estimates of salt loading from the basin and describe the amount of uncertainty contained in these estimates. The project has also sought to identify data collection methods to reduce the uncertainty in estimates of salt loading.

Accomplishments:

Work in prior years has focused on statistical analysis of data available from historic stream flow and salt concentration measurements, including the real-time data provided in the on-line database operated by the Emery Water Conservancy District (EWCD) (see http://www.ewcd.org/). In addition, statistical relationships between stage and discharge, and between electrical conductivity and salt concentration have been developed for key locations on Ferron, Rock Canyon, Cottonwood, and Huntington Creeks and on the mainstream of the San Rafael River. This has been done so as to provide the basis for a Bayesian belief network (BBN) model that has been used to quantify the uncertainty in the estimate of salt loading from the basin. Additional probabilistic relationships between conductivity and salt concentration have been developed from the fundamental principals of saline chemistry.

In FY 2006, a BBN model was developed and used to estimate daily, weekly, monthly, and annual salt loading from the EWCD into the San Rafael River, and to calculate the probability distribution of the salt loading estimate. The model shows annual salt loading to the San Rafael from the four EWCD streams to be on the order of 100,000 tons per year, with the uncertainty in this estimate reflected by a standard deviation of approximately 30,000 tons/year.

Work Plan FY 07/FY 08:

Work began in FY 2006 on programming the BBN salt loading model to run on the EWCD computers so that salt loading estimates can be displayed on the EWCD web site. This work will be completed in FY 2007. The Utah Water Research Laboratory (UWRL) will also work with the EWCD to provide information on how they can improve their data collection system in order to improve salt loading calculations. Other research at the UWRL is designed to produce a new design for a salinity probe, and if this is successful, this new probe will be tested in the field in the EWCD in FY 2007 or FY 2008.

Benefits to the State:

Control and management of salt in the tributaries of the Colorado River is a difficult problem that is fraught with uncertainty. Application of methods that are specifically tailored to quantify and manage uncertainty and that can exploit the wealth of data that is becoming available from basin-wide real-time monitoring systems, such as the one operated by the EWCD, can potentially provide efficient and cost-effective ways of quantifying these salt loads and evaluating alternatives for reducing them. This is what will be demonstrated by the use of BBNs in this project.

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Real Time Monitoring Internet Portal for the Utah Water Research Laboratory (UWRL)

Principal Investigator(s):

Jeffery S. Horsburgh

Project Description:

Integrate all real time and continuous data collection ongoing at the UWRL into a real time data website.

Create web applications for integrating, presenting, and disseminating data collected by investigators at the UWRL.

Accomplishments:

A web server has been purchased, set up, and configured to serve as the host for the portal.

Work Plan FY 07/FY 08:

Program the internet application in Visual Studio .Net and implement the Internet based website on a UWRL server.

Benefits to the State:

A variety of projects are ongoing at the UWRL where real-time or continuous data are being collected. These data can be useful for individuals, classes, researchers, and managers for research, management, or study of the systems that they represent. This project benefits Utah by making these data available and easily accessible for others to use.

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Real Time Streamflow and Water Quality Monitoring Station in the Logan River at the Utah Water Research Laboratory (UWRL)

Principal Investigator(s):

David K. Stevens
Jeff Horsburgh

Project Description:

The real-time monitoring station, located in the Logan River near the USGS gaging station at the exit from Logan Canyon, Logan, UT (UGSG 10109000), will provide continuous monitoring of water quality and will be coupled with the data stream from the existing real time USGS streamflow gage to provide a high frequency, continuous record of streamflow and water quality, with real-time climate data from the Utah Water Research Laboratory (UWRL) weather station funded separately. These data will support integrated water-related research and educational activities at Utah State University (USU) and the UWRL. The proposed monitoring station will also serve as a model in terms of logistics, equipment, and partnerships for potential future real time monitoring stations located throughout the Bear River Watershed in support of the Water Initiative's Laboratory Watershed effort.

Accomplishments:

Continued operation and maintenance of the monitoring station at the Logan River gauging station and provision of the data to the public via the internet using the Bear River Watershed Information System.

Work Plan FY 07/FY 08:

Continue to operate and maintain water quality and flow monitoring equipment. Database and data analysis report.

Benefits to the State:

The results of this work are to be a working real-time water quality monitoring station on the Logan River, supporting software and internet interface, and a data report. This will be beneficial to the Utah Department of Environmental Quality (UDEQ) in assessing water quality conditions and changes therein on the watersheds of Cache Valley.

Temperature Modeling Support

Principal Investigator(s):

David K. Stevens
Bethany Neilson

Project Description:

Temperature is an important physical characteristic of an aquatic system because of its integral relationship with chemical and biological reaction rates, and a mechanistic model of temperature in the Virgin River is under development. The Virgin River basin has an area of approximately 5,100 square miles in Utah, Arizona, and Nevada. Numerous small reservoirs exist in the study area that were constructed to provide irrigation water. Diversion dams often dry the stream leaving only water from seepage and return flows in the channel below the dams. Large portions of the flow in the Virgin River are diverted multiple times (e.g., Quail Creek diversion and Washington Fields diversion) providing the opportunity to test the model at extremely low flows. Hot springs enter the river and contribute to the elevated temperatures that will test the model's ability to deal with hot point flows. Additionally, sections of the basin that are completely exposed in extremely hot summer conditions that will test the model's ability to capture the effects of large amounts of evaporation, extremely hot air temperatures, and direct solar radiation. These features make the Virgin River an excellent test bed for modeling rivers in dynamic desert watersheds.

The focus of this work is to provide high-level technical support for conversion of the existing low-performance Visual Basic for Applications version of the temperature model to a high-level modern FORTRAN 95 that should improve computational performance by an order of magnitude, and provide links to an existing Metropolis-Hastings uncertainty analysis code. In addition we will be developing an automated calibration procedure and implementing that procedure for the Virgin River temperature model. Once completed, the entire modeling structure will be integrated within the Utah Water Research Laboratory's (UWRL) MapWindow-based decision support framework.

Accomplishments:

All of the technical tasks related to conversion of the temperature modeling code to FORTRAN 95 and linking the model to the Metropolis-Hastings uncertainty analysis code listed above have been accomplished. In addition, draft papers related to temperature and tracer data collection have been completed and are being revised for journal submission. Conference presentations were done for four national conferences.

Work Plan FY 07/FY 08:

In FY 07/08, we will be completing for submission the papers described above and two additional papers related to temperature modeling in the Virgin River using the above data collection protocols. We will implement the temperature model via a web page for use in forecasting water temperatures so that appropriate management actions can be carried out to protect sensitive fish species.

Benefits to the State:

Specific benefits to the State of Utah of the temperature modeling work ongoing at the UWRL include:

- Improved understanding of the temperature dynamics in the Virgin River basin.
- Ability to predict temperature impacts on habitat for endangered fish species in the Virgin River.
- Improved understanding of energy fluxes in desert rivers that will improve prediction of water column temperatures and the formation of and temperatures in thermal refugia for endangered species.
- Beginning of a framework for understanding surface and groundwater temperature interactions and their impact on groundwater management.
- Detailed uncertainty analysis for the temperature model using the Metropolis-Hastings algorithm.

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The Bear River Basin in Idaho, Utah, and Wyoming

Principal Investigator(s):

David K. Stevens
Nancy Mesner
Terry F. Glover
Arthur Kaplan
Jeffery S. Horsburgh
Joon Hee Lee

Project Description:

The 7,500 mi^2 Bear River Watershed exemplifies many of the complexities faced in water quality management and is an excellent candidate for study and demonstration of how trading based on integrated watershed information and management can improve water quality. Currently, 52 streams and 9 lakes in the basin are listed on 303(d) lists of impaired waters in three states, Idaho, Utah, and Wyoming. Pollutants include sediment, nutrients, fecal coliform bacteria, low dissolved oxygen, and high water temperature. Pollutant sources include animal feeding operations, grazing, agriculture, wastewater treatment, degraded stream banks, urban development, roads, phosphate mining, oil and gas exploration, and logging (Bear Lake Regional Commission and ERI, 1991; ERI, 1995; ERI, 1998). Eleven TMDLs have been completed, with an additional 42 presently in development. Funds from EPA 319, USDA EQIP and other programs, as well as considerable landowner match, have been used to implement past and ongoing water quality projects throughout the watershed.

Water quality management in the Bear River Basin is complicated by the transboundary nature of the river, which meanders through three states with multiple jurisdictions and planning authorities. This has resulted in fragmentation in water quality improvement efforts, and there is a pressing need for fully integrated watershed management using innovative and cost-effective water quality solutions.

The Bear River Water Quality Task Force (Task Force) was formed in 1993 to facilitate management of this multi-state watershed. The Task Force also provides water quality advice to the Bear River Commission, which oversees the allocation of water throughout the basin. The Task Force has identified the following needs for better watershed management: merged and common datasets; a coordinated, interstate approach for planning and implementation on a watershed scale; and a means to identify impacts and predict responses of program implementation on a watershed-wide basis.

This proposal for EPA Watershed Initiative designation will implement studies to develop and demonstrate: 1) an integrated watershed information system to facilitate data collection, data analysis, information transfer, and public outreach; 2) a water quality trading program to allow point and nonpoint pollutant sources to trade water quality credits; and 3) dynamic water quality modeling to support water quality trading and analysis of potential water quality management scenarios.

The set of problems and needs in the Bear River Basin are common to most if not all rural watersheds in the United States. Add to this the challenges associated with multiple jurisdictions and the benefit of having an organized interstate task force and commission, and the Bear River Basin is a microcosm for many western water issues and presents an excellent opportunity for studying innovative water quality improvement approaches.

Accomplishments:

Under the auspices of this project, we have established the Bear River Watershed Information System (WIS) for the purpose of collection and dissemination of information concerning flow, water quality, watershed improvement projects, historical scientific, engineering, and other studies, watershed community activities, and meetings of regulatory, volunteer, and other organizations concerned with the condition of the watershed. We have also developed a conceptual approach for implementation of phosphorus pollution credit trading for farmers and other dischargers in the lower portion of the watershed. Water quality models are nearly complete for instream conditions, and are underway for estimating loading of phosphorus into the Bear River subject to best management practices under a pollutant credit trading system.

Work Plan FY 07/FY 08:

Work in the next two years will involve completion of water quality models and economic analysis of pollutant trading potential, presentations at EPA Region 8 and the Water Environmental Association of Utah, Spring Conference, St. George, Utah, and preparation of project final report.

Benefits to the State:

Water quality on the Bear River will be improved through an integrative, holistic perspective on the watershed facilitated by the integrated watershed information system. Trading will promote the most economically beneficial solutions to water quality problems within the geographic constraints and physical connectivity of the river basin and stream network.

This project is being carried out in conjunction with the State of Utah and the Colleges of Natural Resources and Humanities, Arts, and Social Sciences. The results of this work are reports, presentations, and software that will assess the effectiveness of best management practices in phosphorus reduction in the Little Bear River water. This project has a strong interdisciplinary research focus.

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Treated Wastewater Use in Agricultural Irrigation: Technical Feasibility and Limitations

Principal Investigator(s):

Gary P. Merkley
David K. Stevens
Judith L. Sims
Mac McKee
Andrew Keller
Leila Ahmadi

Project Description:

As in many places in the United States and around the world, Utah is in the midst of a continuing trend to incrementally transfer water from agricultural applications to municipal and industrial (M&I) uses. As this occurs, two principal problems are emerging:

1. The water supply for agricultural irrigation is diminishing, threatening sustainable agricultural productivity.

2. What is to be done with the increasing quantities of treated wastewater from M&I sources?

The problem can be expressed along various lines of inquiry, such as water quality, water supply hydrographs versus crop water requirements, soil effects (e.g. infiltration rate, erodability, microbial activity), crop effects, health issues, appropriateness of different irrigation methods, ground and surface water effects, conveyance and storage issues, relative impact of different water treatment levels, and others.

But the premise is that the solution to the first principal problem can, to a significant extent, entail the solution to the second problem. That is, a transfer of water from agricultural to M&I users involves a significant return flow component which must be disposed of, and which could very well compensate for the "loss" of water to agricultural users. But the feasibility of such a complementary solution must be precluded by studies which determine the implications of using treated wastewater for agricultural irrigation.

Accomplishments:

Leila Ahmadi, has worked with her graduate committee to develop a complete research proposal to address the objectives stated above. She has interviewed several persons in Cache Valley, Weber Basin, and in California about the issues involved with treated wastewater reuse for irrigated agriculture. She attended a conference in Santa Rosa, California, in October 2006, to learn more about the issues and to make her proposal more complete.

Work Plan FY 07/FY 08:

The main objective is the development of a new mathematical model for simulating several important technical factors related to planning and management for the reuse of treated municipal and industrial (M&I) wastewater in irrigated agriculture. It is expected that the proposed model will be helpful as a computational tool to deal with some of the technical aspects of the current trend of water transfers from agriculture to M&I users in the western USA and many other areas of the world, and the retransfer of some water back to agriculture. The specific objectives are enumerated in the following list:

1. Develop a GIS-based model for the planning and management of treated wastewater reuse in agricultural irrigation.

2. Match treated wastewater supply versus agricultural irrigation water demand in a growing urban area according to time, economics and pumping costs, potential energy, irrigation method, crop type, and topography.

3. Apply the model in a case study in the State of Utah.

4. Propose best planning practices in order to match the water supply and irrigation water requirements.

Benefits to the State:

Understanding of the technical issues regarding the use of treated M&I wastewater for agricultural irrigation, potentially leading to a lessening of the impacts of water transfers on sustainable agricultural production, and to provide an economically and environmentally beneficial destination for augmented wastewater volumes from treatment plants. This work is expected to lead to a win-win situation for two groups which have increasingly competed for available water resources.

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Weather Station Network for the Little Bear River Basin

Principal Investigator(s):

David K. Stevens
Jeffery S. Horsburgh
Amber Spackman

Project Description:

The understanding of nonpoint loadings in watersheds is closely intertwined with the understanding of watershed hydrology and the estimation of runoff and stream flow. The Bear River Basin, in which the Utah Water Research Laboratory (UWRL) is actively involved in three water quality projects and which is the subject at least one proposal being prepared, and which is an integral part of the proposed Great Salt Lake Basin hydrologic observatory, is critically lacking in hydrologic information systems, including stream flow, water quality, and basic climate data collection facilities. Without these data collection facilities, our ability to assess basic water and pollutant mass balances is curtailed.

The primary driver of water-based transport in watersheds is hydrology. We measure hydrology in terms of stream flow and assess the contributions of particular drainages to the flow at a monitoring station by the contributing area. The tacit assumption is that every square km in a drainage receives and delivers the same amount of precipitation to the watercourse. Our observations in the Cache Valley, and in other Utah watersheds, is that the precipitation is highly location specific particularly for single storms in which one subdrainage in a watershed receives heavy rainfall and an adjacent subdrainage receives next-to-none. In addition, the orographic effects of the mountainous terrain exacerbate this variability.

Contaminant loading into water courses is even more site specific because the impact that a particular storm event will have depends on whether the precipitation falls directly on or immediately upstream of a contaminant source. So a parcel of land on which there is an animal management operation may receive heavy precipitation or overland flow may be adjacent to another, pristine, parcel that receives light precipitation and contaminant loading will be underestimated.

Accomplishments:

The weather stations have been purchased and await installation.

Work Plan FY 07/FY 08:

In FY 07/08, we will be completing installation of the weather stations in the Little Bear River watershed and providing connections of these stations to the Bear River Watershed Information System.

Benefits to the State:

The equipment purchased using these funds will benefit several efforts ongoing in the Bear River Basin: The Utah State University (USU) Water Initiative's drive to establish a Laboratory Watershed in the Bear River Basin.

One of the goals of the USU Water Initiative is to establish a Laboratory Watershed in the Bear River Basin. The attainment of this goal will require a commitment to establish the infrastructure in terms of equipment and data to make a Laboratory Watershed possible. The USU Water Initiative has already invested in real time monitoring equipment for the Logan River, and this existing equipment will serve as the beginning of the Bear River Monitoring Network. Equipment purchased under funding from this proposal will be used to extend the capabilities of the Bear River Monitoring Network.

Weber/Ogden Basin Water Quality Study – DSS Completion Support

Principal Investigator(s):

David K. Stevens
Thomas B. Hardy
Jeff Horsburgh
Yasser K. Nazzal

Project Description:

One of the pressing issues in the Weber Basin in Utah is lake eutrophication from increased phosphorus and nitrogen from point and nonpoint sources. Population density and resultant sewage disposal is also causing increase in biological contamination in the surface and ground water associated with numerous reservoirs.

The purpose of this study is to assist the State of Utah, local governments, and water districts in monitoring and understanding water quality in the Weber Basin. Specific water quality problems and their causes will be identified, and specific measures which should be implemented to preserve or enhance water quality will be determined. The study will result in a report documenting specific water quality problems and their causes and the procedures for implementing nonstructural or minimally structural solutions for preserving or improving water quality. Utah State University's role, in conjunction with the U.S. Bureau of Reclamation, Weber Basin Water Conservancy District, and the State of Utah Department of Environmental Quality, is to provide expertise in development of computer-based decision-support tools and models for water quality prediction and improvement in the Weber Basin.

Accomplishments:

This project has enhanced Utah State University's national reputation through research visibility based on several journal publications, papers presented at regional and national conferences. This project has built the foundation upon which an additional $10 million in externally funded research is based. During FY 06 we have worked on completion of the final report for the project and final debugging of the Decision Support System and Data Viewer code for the Weber System. In addition, we have worked with the Weber Basin Water Conservancy District to debug the water quality data in the project database and to update the water balance model to reflect recently completed plans to enhance the water supply to the Park City portion of the basin in response to population growth.

Work Plan FY 07/FY 08:

Source water protection, watershed protection strategy development will continue to be the focus of this project. Work will be carried out by project PIs to complete model modifications and final reporting. In addition, we will be creating the evaluating new flow scenarios related to changes in water supply options for the Park City area along with other reservoir operation options. Final project report, completed software, user's manuals, and other software documentation will be completed.

Benefits to the State:

This project is being carried out in conjunction with the State of Utah, Division of Water Quality, Division of Fish and Wildlife, Weber Basin Water Conservancy District, in addition to the U.S. Bureau of Reclamation. The results of this work will be a set of computer-based decision support tools and models to aid the state and the entities in the Weber Basin in managing basin stream flows to help maintain water quality, primarily for improving the operations and efficiency of water treatment plants using Weber Basin water.

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Water Education and Technology Transfer

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

Project Name	FY 2008 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
Graduate Assistanoe in Areas of National Need (GAANN)	$5,000.00	$5,250.00	$1,500.00
Statewide Nonpoint Source Pollution Eduoation Related to On-Site Wastewater Treatment Systems	$27,950.17	$0.00	$0.00
Utah On-Site Wastewater Treatment Training Program	$36,314.98	$38,130.73	$40,037.26
Designated Projeots		$43,380.72	$48,904.85
Undesignated Projeots		$5,000.00	$15,000.00
Total	**$69,265.15**	**$91,761.45**	**$105,442.11**

Graduate Assistance in Areas of National Need (GAANN)

Principal Investigator(s):

Randal S. Martin
Laurie McNeill
Sonia Manuel-Dupont
Christina Bandaragoda
Erik Dettenmaier
Jared Ervin
Heather Mickelson
Bethany Neilson
Mark Schmelter

Project Description:

The objective of the project is to increase the number of qualified PhD students in Environmental Engineering by providing money for stipends, research supplies, and travel funds.

Accomplishments:

All six graduate student positions were filled in FY2006. The students receiving GAANN fellowships produced the following products this year:

Bandaragoda C. and B. Neilson (2005). Data collection methodology for dynamic temperature modeling, testing, and corroboration. *Outstanding Student Paper Award at the 2005 Fall AGU (American Geophysical Union) Meeting.*

Doucette, W., E.M. Dettenmaier (2006). Investigating the relationship between chemical structure, plant uptake, translocation and transfer to fruit and vegetables. *12th International Workshop on Quantitative Structure-Activity Relationships Environmental Toxicology,* Lyon, France, May 8- 12, 2006 (Oral Presentation).

Dettenmaier, E.M., W.J. Doucette, O.N. Ogurechnikova, A. Hall (2006). The uptake of polar, non-ionizable organic compounds by tomato plants and transfer to fruit. *SETAC North America 27th Annual,* Montréal, Québec, Canada, November 5-9, 2006 (Poster Presentation).

Doucette, W.J., S. Trapp, E.M. Dettenmaier (2006). Accumulation of polar compounds in leaves and fruits – questioning the suitability of widely used TSCF – log Kow regressions. *SETAC North America 27th Annual,* Montréal, Québec, Canada, November 5-9, 2006 (Oral Presentation).

Neilson, B.T., D.K. Stevens, S.C. Chapra, C.M. Bandaragoda (2006). Model development for mass and energy transfer between main channel flows, dead zones, and the hyporheic zone in high gradient systems. *Joint Assembly 2006,* Baltimore, MD, May 2006 (Oral presentation).

Neilson, B.T., C.M. Bandaragoda, and D.K. Stevens (2006). Virgin River temperature and endangered species. *Water Environment Association of Utah 2006 Annual Conference,* St. George, UT, March 2006 (Oral presentation).

Neilson, B.T., C.M. Bandaragoda, and D.K. Stevens (2006). Data collection methodology for dynamic temperature model testing and corroboration. *USU Spring Runoff Conference 2006*, Logan, UT. March 2006 (Oral Presentation).

Neilson, B.T., C.M. Bandaragoda, and D.K. Stevens (2005). Data collection methodology for dynamic temperature model testing and corroboration. *AGU Fall Conference 2005*, San Francisco, CA, December 2005, (Poster).

Work Plan FY 07/FY 08:

Provide stipends and research/travel funds for PhD students, mentoring, and a 3-semester seminar series to prepare students for careers in academia.

Benefits to the State:

The project provided funding for six PhD students in FY2006. Current students are all doing research projects in the State of Utah (TMDL/management of in-stream resources, water resources management, hazardous waste remediation at Hill Air Force Base, plant uptake of organic chemicals).

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Statewide Nonpoint Source Pollution Education Related to On-Site Wastewater Treatment Systems

Principal Investigator(s):

Darwin L. Sorensen
Judith L. Sims
Patrick Andrew

Project Description:

This project developed and implemented an information and education program that provided elected officials, students, and the general public with on-site wastewater management information related to the prevention of nonpoint source pollution.

Accomplishments:

In the past, this project has provided support for educational materials presented at the annual meetings of the Utah On-Site Wastewater Association and at meetings of the Weber-Morgan Health Department Wastewater Advisory Committee. A guidance document: "Onsite Wastewater Treatment: A Guide for Elected Government Officials and Participants in City and County Government" has been prepared and will be distributed through the Utah League of Cities and Towns to local government officials.

Work Plan FY 07/FY 08:

Guidance for planning and implementing on-site wastewater treatment so that nonpoint source pollution can be prevented are being developed. This guidance is being developed principally for local government officials.

Benefits to the State:

The project has supported the development of curriculum materials for the Utah On-site Wastewater Treatment Training Program. This program continues to deliver training resulting in certification of on-site wastewater treatment professionals as required by Utah Department of Environmental Quality regulations. Support was also provided for the development of educational presentations to the Utah On-Site Wastewater Association in their professional conferences. Training was provided to senior Environmental Engineering students at Utah State University as they worked to develop an improved approach to evaluating appropriate septic system densities in rural, western Weber County, Utah, that would protect ground water quality. The project culminated in the preparation of a brochure entitled "Onsite Wastewater Treatment: A Guide for Elected Government Officials and City and County Government Employees in Utah." This brochure will be distributed to city and county governments by the Utah League of Cities and Towns.

High-priority issues addressed by this project include ground water quality protection and reduction of the potential for human exposure to pathogens from on-site wastewater disposal. Ground water is the source of municipal water supply for most rural communities in Utah and across the nation. Nearly every household outside of municipalities draws its water supply from ground water. It is imperative that the quality of ground water be protected for domestic supply and other municipal and industrial uses.

The conjunctive interaction of ground water and surface water resources provides a potential pathway by which nitrate, biochemical oxygen demanding substances, and pathogens may enter surface water. The quality of ground water should not degrade surface water quality.

When septic systems are improperly designed, installed and/or maintained, it is possible for sewage to back up into household plumbing fixtures. Sewage can also rise to the land surface where people can be exposed to pathogens. Objectionable odors from failing treatment systems may annoy neighbors.

Conventional septic systems and other on-site wastewater treatment systems can be effective in protecting ground water quality when site soil and ground water elevation properties are considered in land development planning, when the treatment system installation is done properly, and when the system is appropriately monitored and maintained. This project helped assure that this critical combination of planning, installation, and maintenance can occur across the State of Utah. Planning guidance for local government officials and employees, training of professionals in the design, construction, and enforcement communities, and information for homeowners as provided by local health department employees who were trained by project personnel were all products of the project. Informed decision makers acting at every juncture of the on-site wastewater treatment network are likely to make decisions that will result in lower levels of pollutants entering ground water and surface water thus helping to meet the goals of the Utah nonpoint source management program.

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Utah On-Site Wastewater Treatment Training Program

Principal Investigator(s):

Judith L. Sims
Darwin L. Sorensen
Ronald C. Sims
Margaret M. Cashell
Richard Jex
Brian Cowan
Jenny Hurst
Patrick Andrew
Amanda Davis

Project Description:

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 twelve Utah local health departments to provide 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 depends on having 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.

Although properly selected, designed, installed, and operated on-site wastewater treatment systems provide high levels of protection of human health and environmental quality, some systems do fail, with most of the documented failures of these systems occurring by discharge of effluent into saturated soils, backup into the house, or wastewater ponding on the soil surface. Systems are also considered to be failing if wastewater effluents high in nitrogen, phosphates, or pathogenic microorganisms reach surface or groundwater resources. Training of all those involved in wastewater treatment and disposal, i.e., those who evaluate a site to see if it is suitable for an on-site system, those who design and install the system, regulators who oversee the system, and homeowners who operate the system, will aid in the prevention of such failures.

Utah will continue to grow, and housing developments will continue to expand into current open space. Such development may include areas of groundwater recharge, shallow soils, or shallow groundwater. Current Utah rules allow the use of conventional septic tank systems as well as three alternative treatment systems that may be installed in areas with soils unsuitable for conventional systems. Training of those involved in the use of alternative systems will ensure that these types of systems, which require more management, will operate effectively.

Accomplishments:

We continue to provide workshops in support of the mandatory State-of-Utah certification program for on-site wastewater professionals.

On September 27-28, 2005 Ms. Judith Sims and Ms. Margaret Cashell provided a training program on on-site systems for approximately 40 persons associated with Region 8 U.S. Environmental Protection Agency in Denver, Colorado. In June of 2006 in Casper, Wyoming, Ms. Judith Sims, Ms. Margaret Cashell, and Mr. Brian Cowan taught a workshop on on-site programs and alternative systems to about 50 people associated with the Wyoming Department of Environmental Quality. Ms. Judith Sims also presented a training program for users of on-site systems in Crook County, Wyoming in June of 2006.

During FY 2005, the following workshops in support of the certification program were held:

Level I: Heber City, September 2005; Ogden, October 2005; Cedar City, April 2006; Vernal May 2006.

Level II: Heber City, September 2005; Ogden, October 2005; Logan, May 2006.

Level III: Logan, November 2005 and May 2006.

Level I Recertification: Cedar City, April 2006; Vernal, May 2006.

Level II Recertification: Cedar City, April 2006; St. George, April 2006; Vernal, May 2006.

Level III Recertification: Logan, November 2005 and March 2006.

In addition, Dr. Ronald Sims provided assistance to the State of Utah with regard to on-site wastewater treatment issues as a member of the Utah Water Quality Board. Ms. Judith Sims served as acted as chairman of the annual Utah On-Site Wastewater Association (UOWA) conference planning committee. The sixth annual conference of the UOWA was held in March of 2006 at the Davis Conference Center, with 100 people in attendance. Dr. Darwin Sorensen serves as a member of the Weber-Morgan Health Department On-Site Wastewater Treatment Advisory Board.

Work Plan FY 07/FY 08:

A state legislative initiative was introduced and passed as House Bill 14s during the 2001 Legislative Session to develop 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 Department of Environmental Quality, involves mandatory training provided by the Utah On-Site Wastewater Treatment Training Program.

The certification program includes three levels, each of which requires workshops provided through the Utah On-Site Wastewater Treatment Training Program:

Level I: Soil Evaluation and Percolation Testing.

Level II: Design, Inspection, and Maintenance of Conventional Systems.

Level III: Design, Operation, and Maintenance of Alternative Systems.

Level III certification expires after two years, so we are also conducting Level III recertification workshops. In 2006 we began providing Level I and Level II recertification workshops, as that certification expires after 5 years.

In addition, we are providing leadership in the development of an on-site wastewater treatment professional program (Utah On-Site Wastewater Association (UOWA)) to promote, facilitate, and elevate the professional development of individuals in the on-site industry and also to increase public awareness and education concerning on-site wastewater treatment issues.

Benefits to the Stste:

As population growth and associated housing developments continue to threaten the preservation of agricultural lands in Utah, there is an increased need for accurate and thorough information on on-site wastewater treatment technologies. The Utah On-Site Wastewater Treatment Training Program addresses these challenges through such means as workshops, newsletters, and educational brochures.

Many of the soils in Utah are marginal or unacceptable for use of conventional soil absorption systems due to high or fluctuating water tables, slowly permeable or highly permeable soil horizons, and extreme slopes. Experience with and knowledge of alternative systems that can be utilized on such sites with unsuitable conditions is generally low in Utah. The On-Site Training Program also provides the necessary education to utilize alternative systems in an effective manner that will protect both public health and the environment.

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Fluid Mechanics and Hydraulics

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Fluid Mechanics and Hydraulics

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
Calibration and Evaluation of Piute Dam Weir	$127.15	$36,000.00	$0.00
Culvert Hydraulic Analysis and Design for Rural Roads	$12,491.42	$12,866.17	$0.00
Experimental Determination of Shear Stress in the Laboratory	$16,643.51	$17,475.69	$0.00
Hydraulic Design Data for Environmentally Sensitive Culvert Installations	$16,643.51	$17,475.69	$17,999.96
Hydraulic Structures for Flood Control and Flood Bypass	$3,111.72	$3,267.30	$3,365.32
Numerical Modeling of the Great Salt Lake	$13,135.02	$43,000.00	$0.00
Sediment Transport and Flood Control	$3,039.35	$3,191.32	$3,287.06
Sizing Air Vents for Small to Medium Size Dams	$16,842.50	$25,000.00	$0.00
Submerged Head-Discharge Relationships for Cgee Crest Weirs	$16,643.51	$17,475.69	$0.00
The Effects of Pipe Aging on Head Loss	$2,223.60	$22,000.00	$22,660.00
Designated Projects		$233,232.99	$370,020.34
Undesignated Projects		$23,000.00	$60,000.00
Total	**$100,901.29**	**$458,984.85**	**$477,332.68**

Calibration and Evaluation of Piute Dam Weir

Principal Investigator(s):

Steven L. Barfuss

Project Description:

Discrepancies were observed between calculated low level outlet tunnel flow rates and flow rates over the USGS weir downstream of Piute Dam on the Sevier River. The purpose of the study is to ensure that the large amounts of sediment that accumulated on the upstream side of the weir during the rehabilitation of Piute dam has not affected the accuracy of the weir calibration.

Accomplishments:

The project will determine the appropriate rating curve that should be used at the USGS weir at Piute Dam and will also evaluate other possible problems that could affect flow rate measurements of releases from Piute Dam.

It took longer than expected to gather recent field calibration data (from Ray Owen, Upper Sevier River Commissioner) and historical USGS calibration data for the weir. Once these were gathered, the data were plotted with a theoretical curve and also with the data collected from a physical model of the weir. The physical model data was generated from a 10 scale model constructed and tested at the UWRL. Figure 1 illustrates the data.

Work Plan FY 07/FY 08:

1. Complete a preliminary literature review on 2-stage weirs. This is the type of weir that exists at Piute dam.
2. Obtain information from the USGS regarding past methodology for calibrating this weir.
3. Obtain past USGS calibration data for the weir.
4. Obtain recent calibrations from the Upper Sevier River Commissioner.
5. Obtain "as-built" drawings from the USGS.
6. Develop a spreadsheet program that predicts a rating curve for generic 2-stage weirs.
7. Plot theoretical rating curves along side actual USGS and other recent weir calibration data.
8. Build a full width scale model of the USGS weir structure at the Utah Water Research Laboratory (UWRL), and develop a rating curve with and without sediment loadings upstream.
9. Determine other problems with flow measurement techniques at the dam.

Benefits to the State:

The results of this project will confirm the accuracy of the existing calibration for the USGS weir downstream of Piute Dam. This will help dam owners more accurately manage Piute reservoir water, and the improved flow measurements will benefit all downstream water users.

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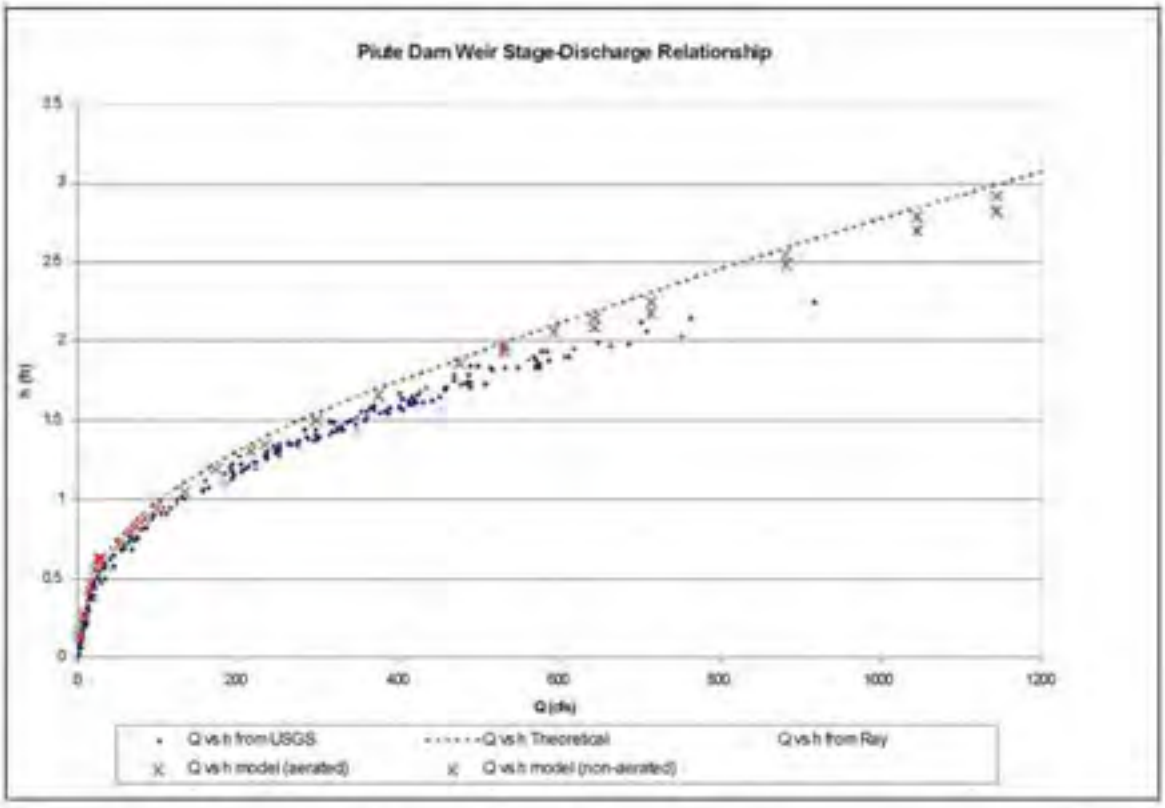

Figure 1. Rating curve for Piute weir from USGS data, theoretical calculations, physical measurements from the dam operator and the physical model

Culvert Hydraulic Analysis and Design for Rural Roads

Principal Investigator(s):

William J. Grenney

Project Description:

The objective of this research is to develop a computer program that can be effectively applied by local community design engineers for the analysis of the hydraulic characteristics of irregular shaped culverts. In particular, the program will address the hydraulic complexities of partially buried culverts as they relate to environmental impacts such as barriers to fish passage.

Accomplishments:

The prototype interface was further refined in response to comments from student evaluators. The interface was updated and a new architectural construct was introduced for the numerical algorithms. The interface for the analysis of hydraulic jumps in culverts is shown in Figure 1.

Work Plan FY 07/FY 08:

The plan of approach is to develop stand-alone, stable numerical algorithms for the purpose of generating the geometric parameters describing irregular culvert shapes. The parameters are used in hydraulic models for the analysis of hydraulic design properties.

Benefits to the State:

Over 80% of Utah roads and highways are low volume rural roads. Because of the great distances between communities and the dispersed population, budgets for construction and maintenance are severely stressed. Often drainage and environmental considerations are important transportation issues having direct impact on communities. This research will result in a methodology and a computer tool for small and medium sized rural communities to more effectively plan, design, and maintain culverts for unique situations as well as for most standard installations.

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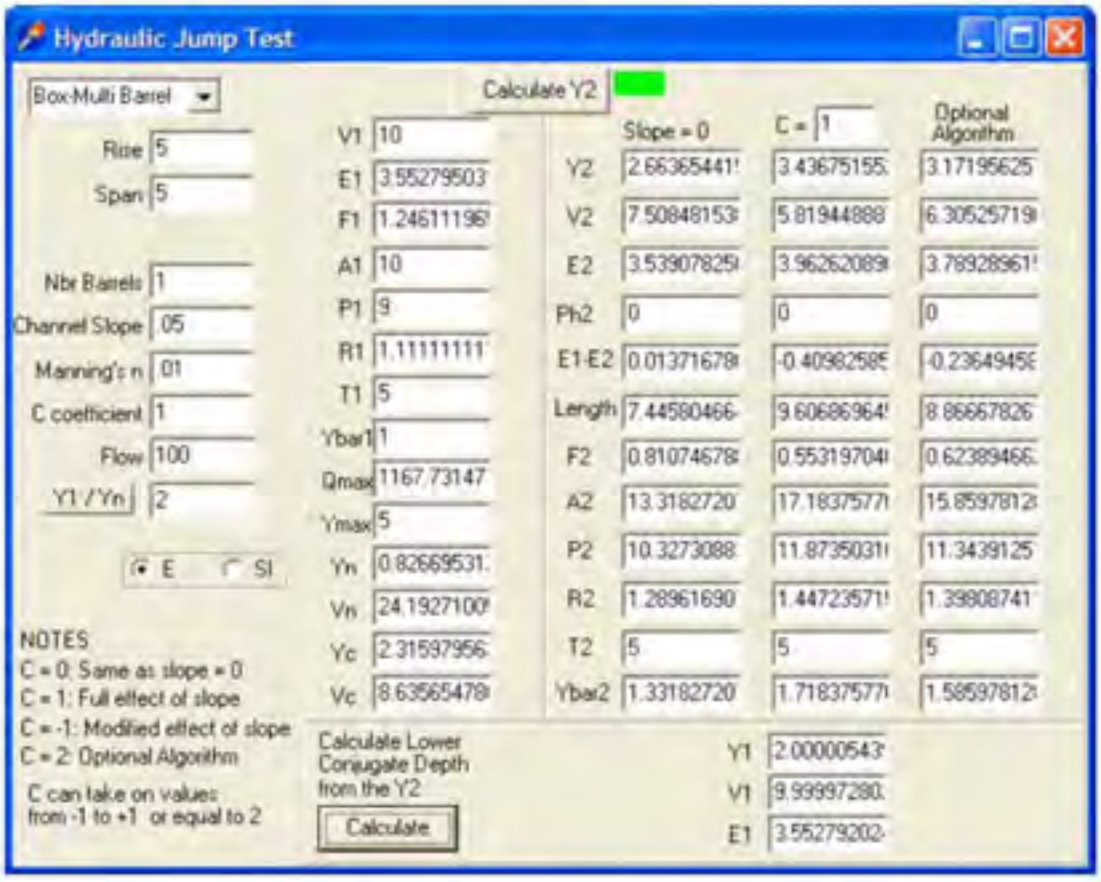
Hydraulic Jump Test
Box-Multi Barrel
Rise 5
Span 5
Nbr Barrels 1
Channel Slope .05
Manning's n .01
C coefficient 1
Flow 100
Y1 / Yn 2
E
SI
NOTES
C = 0: Same as slope = 0
C = 1: Full effect of slope
C = -1: Modified effect of slope
C = 2: Optional Algorithm
C can take on values from -1 to +1 or equal to 2
Calculate Y2
V1 10
E1 3.55279503
F1 1.24611198
A1 10
P1 9
R1 1.11111111
T1 5
Ybar1 1
Qmax 1167.73147
Ymax 5
Yn 0.82669531
Vn 24.1927100
Yc 2.31597956
Vc 8.63565478
Slope = 0
C = 1
Optional Algorithm
Y2 2.66365441 3.43675155 3.17195625
V2 7.50848153 5.81944888 6.30525719
E2 3.53907825 3.96262089 3.78928961
Ph2 0 0 0
E1-E2 0.01371678 -0.40982585 -0.2364945
Length 7.44580466 9.60686964 8.86667826
F2 0.81074678 0.55319704 0.62389466
A2 13.3182720 17.1837577 15.8597812
P2 10.3273088 11.8735031 11.3439125
R2 1.28961690 1.44723571 1.39808741
T2 5 5 5
Ybar2 1.33182720 1.71837577 1.58597812
Calculate Lower Conjugate Depth from the Y2
Calculate
Y1 2.00000543
V1 9.99997280
E1 3.55279202

Figure 1.

Experimental Determination of Shear Stress in the Laboratory

Principal Investigator(s):

Blake Tullis

Project Description:

Shear stress, created by flow passing near a boundary, is discussed in most fluid mechanics textbooks. Erosion control products for channel stabilization applications are sold based on the maximum allowable shear stress the product can withstand before failure occurs. If these products have a performance limit based on shear stress, then it would stand to reason that reasonable estimates of shear stress can be made in both the field and laboratory settings. This study will evaluate different methods of estimating shear stress values in the laboratory based on experimental data collection. The various predictive hydraulic methods will be compared with the shear force measured directly using a load cell.

Accomplishments:

The PIC system was purchased near the end of the fiscal year. Work to improve the shear flume facility began in June 2006.

Work Plan FY 07/FY 08:

Upgrade the shear flume testing facility by improving the instrumentation (load cell readout display and a PIV system). Conduct a comprehensive study comparing a variety of boundary layer shear stress predictive techniques to laboratory data. The input data required for the predictive methods will be supplied from the experimental data.

Benefits to the State:

UDOT, along with perhaps other state agencies, specifies types of erosion control products to be used in channel stabilization projects with ties to transportation. A better understanding of the accuracy of shear stress predictive methods, both in the laboratory and field will allow the agency specifications to be more accurately established and met. It may be that erosion control products should not be marketed and evaluated based on shear stress limitations if shear stress values cannot be accurately determined, particularly in the field.

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Hydraulic Design Data for Environmentally Sensitive Culvert Installations

Principal Investigator(s):

Blake Tullis

Project Description:

Currently, very little design information is available for culvert designs for environmentally sensitive areas. It is becoming more common to design culverts, not based on the smallest diameter required to pass a design flow rate, but rather limit the maximum design velocity to facilitate fish and debris passage. The missing design information includes inlet and outlet loss coefficients for outlet-controlled flow and design flow curves for inlet-control. Commonly, these culverts have buried inverts or are bottomless. With this type of configuration, the determination of a representative Manning's n value (hydraulic roughness) becomes much more complicated as the channel walls and floor are made of different materials.

Accomplishments:

Work on the inlet loss coefficients and inlet control flow capacity for circular and elliptical buried invert culverts (fish passage culverts) with varying degrees of invert burial was completed. For each culvert shape and invert burial scenario, a variety of inlet culvert end treatments were evaluated including square headwall, projecting, mitered to slope, and beveled. Each end treatment was evaluated for both ponded and channelized approach flow conditions.

The hydraulic characteristics of slip-lined culverts (i.e., culverts that are rehabilitated by sliding a smooth-walled pipe inside the old culvert and grouting the annular space between) portion of the study was also completed. This evaluated inlet loss coefficients and inlet control head-discharge relationships for various end treatment geometries that might be expected with slip-lined culverts. As culverts in Utah and elsewhere reach the end of their useful life, slip-lining is a practical and economical solution to extending the life of the culvert.

Multi-barrel culverts testing is part of our current research effort. A significant amount of data have been collected for evaluating their hydraulic characteristics based on the number of culverts, the spacing between culverts, and various approach flow conditions. That part of the study should be finished in 2007.

One aspect of quantifying composite hydraulic roughness in open channel flow is the ability to accurately quantify the hydraulic roughness of a uniformly roughened channel. Significant progress has been made in characterizing the hydraulic roughness parameters in open channel flow. Lab data for uniformly roughened channels, developed as part of this study, showed that a common hydraulic roughness coefficient (Manning's n) used in open channel flow calculations, has a dependency on the channel slope. Through the use of dimensional analysis and lab data, a new method has been developed for accounting for that slop effect. We are currently working on a publication on the topic.

In addition to the uniformly roughened channel work, the data collection phase of the composite roughness has continued as well. All work to date has been conducted in 4-ft wide by 4-ft deep by 48-ft long rectangular channel for both uniform and composite roughness scenarios. The boundary roughness material represented smooth, skin-friction, and form-loss boundary conditions. The experimental results are compared with the predictive results of 15 different published equations for predicting composite hydraulic roughness coefficients.

Work Plan FY 07/FY 08:

We will focus on the following objectives:

- Finish the performance of multi-barrel culverts to determine the appropriateness of superposition design methods.
- Publish results on the slope dependency of hydraulic roughness coefficients in open channel flow in a peer-reviewed journal.
- Continue work in the area of evaluating predictive methods for composite roughness in rectangular channels and in circular culverts with buried inverts, with the goal of identifying a method that can be applied to fish passage culverts. The rectangular channel tests will include additional form-loss boundary conditions, as form-loss boundary conditions are more consistent with buried-invert culvert flow boundaries. These results should also have applicability to culverts with composite roughness boundaries caused by sedimentation.

Benefits to the State:

Although Utah does not have a significant migratory fish population, fish habitat can be significantly reduced by a culvert, which inhibits fish passage. The need to facilitate natural debris passage may also become more important in the State of Utah as the need to maintain natural systems grows. In general, a design manual, which will function as supplement to the Federal Highways Administration's Hydraulic Design Study #5 (HDS-5), will be the final product of this study. It should prove a valuable resource for Utah Department of Transportation projects. Several Masters students are participating in this project.

More specifically, however, the results of the composite roughness and the buried-invert culvert studies should have direct application to culverts in Utah, which have been partially filled with sediment. As culvert with appreciable sediment deposition, will have a buried-invert geometry. The hydraulic roughness will fall under the composite category, and the results from this study should aid in the determination of head-discharge relationships, which are necessary for evaluating upstream flooding and roadway overtopping potential.

Hydraulic Structures for Flood Control and Flood Bypass

Principal Investigator(s):

William J. Rahmeyer
Steven L. Barfuss
Michael C. Johnson
John Newton
Mike Stover
Wade Goodridge

Project Description:

Participate with the Utah Floodplain and Storm Water Management Association and the Utah Office of Homeland Security in developing a series of joint workshops on flooding and floodplain problems. Represent the Utah Water Research Laboratory (UWRL) on the board of directors of the Utah Floodplain and Storm Water Management Association. Flood routing, management, and planning. Retro-fit of dams for drought control and storage. Rehabilitation and retro-fit of spillway control structures.

Accomplishments:

Detailed data and laboratory measurements were made of the side channel lateral weirs used for bypass control. The weirs were analyzed for both flood control and for the effect of sediment diversion. A very unique design was created that allowed flood diversion and negated the effects of sediment deposition at the bypass structure. A student thesis was published based on this concept.

Another study was the effect of bridge or highway columns on flooding in floodplains and flood ways. The study included column geometry, the effect of debris trapped by the columns, and the effect of the columns on sediment transport and deposition. The results of this study have importance to Utah because of the need to add additional bridge columns or piers to existing stream crossings to accommodate the widening of Utah roads and highways.

A curved ogee crest was studied for the Success Dam near Porterville California. Several different designs and crest shapes were evaluated. An important concept that was investigated was the effect of reducing the peak outflow hydrograph of the reservoir by improving the efficiency of the crest at lower flow rates and reservoir levels. Several new studies are now planned for the continuation of the remediation and storage raise phases for the Success Dam study. These studies are necessary due to a recent problem with unconsolidated soils located directly beneath the existing dam. The State of Utah also has a number of structures that share this problem.

The Physical Model of Gilboa Dam Spillway, Gannet Fleming/Hazen Sawyer, A Joint Venture and the New York City Department of Environmental Protection, was funded and will be completed by January 2007.

The Folsom Dam Auxiliary Spillway Physical Hydraulic Model, Cespk-Ed-D Contract W91238-05-D -0009, Task Order 0007 has just been funded.

Work Plan FY 07/FY 08:

Several papers will be written and published. Participation will continue in the Utah Floodplain and Storm Water Management Association, including service on the Board of Directors for the Utah Floodplain and Storm Water Management Association. Physical and numerical modeling of several reservoirs and dams will continue for the U.S. Army Corps of Engineers and the City of New York.

Benefits to the State:

There are several reasons why flood control has become even more of a critical issue for the State of Utah. One reason is the development along and within our floodplains. Urban growth not only contributes to larger floods, but also reduces the size and ability of our flood ways and channels to convey major flows. Research was conducted on two new and innovative concepts in hydraulic structures that will have a direct impact and benefit for Utah communities.

One concept that was researched this year was the concept that utilizes bypass conduits to route excess flows around a section of channel or river. The bypass conduits utilize large control weirs that control the flood hydrographs and manage the sediment transport. There are a number of issues related to the bypass concept that have prohibited the use of bypass structures in Utah. A current study is focusing on the effects of bridge pier columns on flow diversion in flood channels. The construction of the bypass culverts for the Guadalupe River in downtown San Jose, CA are partially finished and should be complete in early 2004.

The retrofit of dams and reservoirs for increased storage is an important issue. Such projects involve a unique design of a spillway and control structure that can both raise the pool elevation of the reservoir and also increase the outflow capacity of the spillway. Many of the dams and spillway structures in the Western United States are located in the diversion channels that were used to construct the reservoirs and dams. It is too expensive to widen and excavate the channels to increase flow capacity so new ideas and designs for the spillway crest control sections are being researched. A unique design concept of a curved ogee crest utilizing an under-designed crest was modeled. It was found that the design increased pool elevation and increased flow capacity without the need to widen the diversion channels.

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Numerical Modeling of the Great Salt Lake

Principal Investigator(s):

Robert E. Spall

Project Description:

The Great Salt Lake (GSL) is a terminal lake located in the northern portion of the State of Utah and is the remnant of prehistoric Lake Bonneville. The lake is roughly 75 miles long and 30 miles wide. However, in 1959, the Southern Pacific Transportation Co. completed construction of a railroad causeway across the lake (running in an east/west direction) which separated the lake into north (Gunnison Bay) and south (Gilbert Bay) arms. Three major fresh water tributaries flow into the south arm, consequently its salinity (approximately 120 parts per thousand (*ppt*)) is much lower than that of the north arm (approximately 280 *ppt*).

These high levels of salinity play a strong role in the lake's ecosystem. In particular, brine shrimp are one of the few species that lives within the lake, and play an important role in keeping the lake's water clean through algae consumption. The brine shrimp also support an industry in which brine shrimp eggs are harvested and sold worldwide as fish food. Other important industries involve the extraction of minerals such as common salt, magnesium metal, sodium and potassium sulfate, and magnesium chloride. Recreational uses of the lake have been hampered due to long-term fluctuations in water levels, leading to large changes in the surface area. Given the importance of the lake to the region, long-term efforts have been underway by the United States Geological Survey and the Utah Department of Natural Resources to define physical characteristics of the GSL, and to understand how man is affecting the lake.

Currently, there is no consensus as to the general circulation patterns that exist within the GSL, nor does consensus exist regarding the dominant (forcing) mechanisms that cause the circulation. This is likely, in part, due to the extremely complex interactions that occur between the lake and relevant forcing functions such as wind, solar radiation, temperature, humidity, river inflows, rain, and Coriolis forces. The objective of this work is to determine the influence of important external forcing functions on the circulation patterns within the south arm of the lake, and to predict these patterns under both summer and winter environmental conditions.

Accomplishments:

Results to date indicate that forcing the lake through surface heat flux, with minimal wind stresses, results in the formation of multiple, unsteady gyres, similar to those which have been observed to exist on the lake, at least during the summer. The sense of rotation of these computed gyres is generally counter-clockwise during spring and summer months, and clockwise during winter months, although the flows are quite unsteady. Representative results for forcing through surface heat transfer are shown in Figure 1, indicating dominant anti-cyclonic motions during late spring. These cyclonic gyres were not observed when forcing due to both with and surface heat fluxes was enforced simultaneously, even with the inclusion of atmospheric instability effects.

Work Plan FY 07/FY 08:

The hydrodynamics model ELCOM (Hodges and Dallimore, 2006) will be utilized to determine lake flow patterns, and to evaluate the influence of important forcing functions on these patterns. ELCOM solves the unsteady, three-dimensional, Reynolds-averaged Navier-Stokes (RANS) and scalar transport equations, and employs the hydrostatic assumption for pressure and the Boussinesq approximation for density. Coriolis effects, surface wind stresses and thermal forcing, inflows, and transport of salt are all capabilities of the code that were utilized in this work.

Benefits to the State:

A hydrodynamics model has been applied to the south arm of the Great Salt Lake. Model inputs allow users to examine the influences of a wide range of forcing functions on the hydrodynamic behavior of the lake. Consequently, the transport of pollutants and influxes of fresh water into the lake may be predicted, aiding in management of this water resource.

Reference

Hodges, B. and C. Dallimore (2006). *Estuary, Lake and Coastal Ocean Model: ELCOM.* v2.2 Science Manual, Center for Water Research, University of Western Australia.

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Sediment Transport and Flood Control

Principal Investigator(s):

William J. Rahmeyer
John Newton
Mike Stover
Wade Goodridge
Jan Miller

Project Description:

1. Fundamental hydraulics of sedimentation and erosion.

2. Equations and methodologies to predict the sediment transport in steep mountain streams and closed conduits.

3. Develop sediment transport equations and methods for UDOT.

4. An understanding of the effect of vegetation on the sediment transport in floodplains.

5. Study the effect of willows and salt cedars on flow resistance and flood plain management with W.E.S. and Salt Lake County (Brent Birdal), possibility expand to include Sevier River basin and Bear Lake districts.

6. Continue research and publishing journal articles on flood plain resistance and the effect of vegetation on flow resistance.

7. The effect of the sedimentation process on erosion and deposition at culverts and road crossings.

8. Present papers and discussion on sediment transport at the next symposiums sponsored by the IECA and USCOLD and EWRI.

9. Publish a journal paper of Floodplain Resistance Due to Vegetation with the International Hydraulic Research Association.

Accomplishments:

Conference presentations in St. George Utah and Moab, Utah.

Work Plan FY 07/FY 08:

Research projects with the Waterways Experiment Station of the U.S. Army Corps of Engineers. Publish papers on sediment transport and the effect of vegetation. Several conference presentations.

Benefits to the State:

Since Utah streams and rivers formed under unique geologic and climatic conditions, understanding sedimentation and erosion processes is important. How is sediment produced in our watersheds? How is it transported in the streams and rivers? What is the balance between erosion and deposition in our floodplains? The sedimentation process affects most man-made activities including agriculture,

urbanization, reclamation, and mining. Short-term and long-term changes in climate and precipitation interact with the sedimentation process to cause flooding and debris flow problems in Utah. A major interest to the State of Utah and other Western States is the effect of the sedimentation process on the flooding and flood routing in floodplains.

Present knowledge and methodologies were developed for climates and geology different from those in Utah. Our research objectives are: 1) continue developing prediction methods and models of sedimentation and scour, 2) conduct basic and applied research to solve specific sediment problems that affect Utah, and 3) work with local and state agencies to provide education and support in the area of sedimentation.

Direct benefits to the State of Utah will be from the knowledge and methodology gained from this research in sedimentation and erosion. Almost all areas of agriculture, mining, forestry, reclamation, and transportation should benefit directly from this research. The Division of Oil, Gas, and Mining; Division of Water Quality; Division of Water Resources; Utah Department of Transportation; and water conservancy districts will be informed of our results. A better understanding of this research and how it applies to Utah may positively impact federal guidelines and requirements of sedimentation and erosion control for Utah.

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Sizing Air Vents for Small to Medium Size Dams

Principal Investigator(s):

Blake Tullis

Project Description:

Venting air to the downstream side of control gates in low level outlet works is necessary to prevent or minimize the adverse effects of sub-atmospheric pressures in the pipe. Such effects include excessive structural loading and damage to pipe wall caused by cavitation. Air vents are required by the State of Utah for most dams, but no reliable method for determining the size of the vent pipe has been developed, particularly for small to medium sized dams, which are common throughout Utah.

Accomplishments:

The first phase of this study, which has been completed, included a literature review on sizing outlet works air vents for small and medium sized dams. Using data and a design method presented by the US Army Corps of Engineers (USACE), Chad Brown (MS Student) developed a spreadsheet program for predicting air demands and sizing air vents. A beta version release of the air vent sizing program was sent to dam safety official throughout the US in 2005 for evaluation.

Work Plan FY 07/FY 08:

The current phase has three primary tasks, collect air demand field data at small to medium sized dams in Utah, modeling the air entrainment process at specific dam sites at which field data were collected using computational fluid dynamics (CFD), and comparing the actual air demand (field data) with the empirical and computational predictive methods. Dr. Bruce Savage (Idaho State University), an alumnus of USU and the UWRL will be conducting CFD simulations of the air vent and outlet works to determine if CFD can be used as an effective tool for sizing air vents.

Benefits to the State:

The results of this study should prove beneficial to the State of Utah, specifically the Office of Water Rights, which also deals with dam safety in the state. At present, there are no specific guidelines in Utah for sizing air vents for outlet works. This is the case for most states.

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Submerged Head-Discharge Relationships for Ogee Crest Weirs

Principal Investigator(s):

Blake Tullis

Project Description:

When ogee crest weirs are used, particularly in irrigation applications for flow measurement or diversion structures, they may at times operate under a submerged condition, meaning that the tailwater exceeds the weir crest elevation. In such cases, the standard free-discharge relationships no longer apply. This study includes quantifying the effects of submergence on ogee crest weirs for use as a flow measurement device or to predict upstream flow depths (flooding) during the design phases, when flow data is typically an independent variable, provided by hydrologic modeling software.

Accomplishments:

Experimental data was collected by Jesse Neilson in FY 2006, as part of his MS program.

Work Plan FY 07/FY 08:

Additional data will be collected in FY 2007 to further refine the relationships proposed by Jesse Neilson's work. A peer-reviewed publication on the subject is being composed.

Benefits to the State:

The results of this study should be beneficial to the State of Utah, specifically the Office of Water Rights, as well as irrigation companies throughout the state, which also deals with water custody transfer issues. A better understanding of submerged ogee crest weirs will allow for more accurate flow discharge calculation when such a condition exits.

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The Effects of Pipe Aging on Head Loss

Principal Investigator(s):

Steven L. Barfuss
William J. Rahmeyer
Ryan Christensen

Project Description:

Managers of city water systems have a keen interest in the effects of pipe aging on head loss. The hydraulic roughness often increases in older pipes that have become corroded or in which deposits have formed on the interior wall of the pipe (see Figure 1). This project will perform laboratory tests on aged pipe to determine hydraulic roughness characteristics. The data that will be collected will be examined for trends that can be used to predict hydraulic roughness.

Accomplishments:

This research has determined that there is a smooth trend in the data when relating the ratio of the effective diameter of the pipe (d) to the diameter of the pipe in its new condition (D) with the friction factor f of the pipe (see Figure 2). Small d is found by measuring water volumes in the pipe and back-calculating the diameter. Seven different aged pipes, representing four new pipes have been tested.

Additionally, as indicated in Figure 3, the head loss was found to be between 2.5 and 25 times larger in the aged pipes that were tested, than in their companion new pipes. This differs considerably from the predicted values presented in several published references, which indicate that 15 to 70% increases in pipe head loss can be expected when a pipe ages. As illustrated in Figure 3, this study indicates head loss increases exceeding 2000 percent.

Work Plan FY 07/FY 08:

City managers in Utah have been contacted to request that old pipe that is pulled out of the ground be set aside for possible laboratory tests. In the laboratory, the "pulled" pipes are friction-tested to determine their roughness coefficients. An attempt is also made to quantify the roughness density and roughness height and relate these measurements to the experimental roughness value determined in the laboratory. The data are then analyzed to develop trends for predictive purposes.

Benefits to the State:

As water supply pipes age after installation, they can develop corrosion or deposits that increase friction loss, degrade system performance, and increase operation costs. Until now, the magnitude of pipe head loss due to pipe aging has been unknown due to lack of experimental data. When pipe roughness increases, pumping costs go up, available pressures go down, and the ability of the city to add connections is limited. Understanding the effect of pipe aging on pipe roughness will greatly help State of Utah municipal water systems do a better job of planning and management for water system design and operations.

Figure 1: Photograph of the 4-in cast iron pipe tested during this study

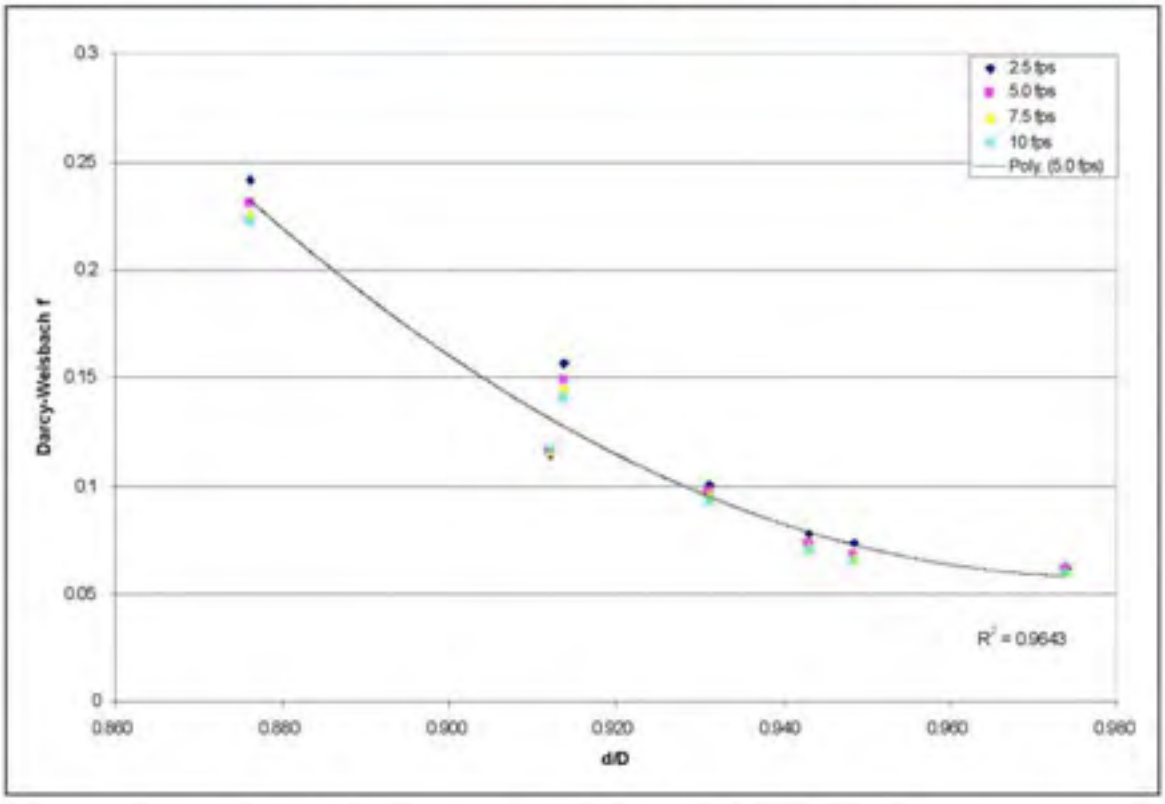

Figure 2: Relationship of d/D with hydraulic pipe roughness

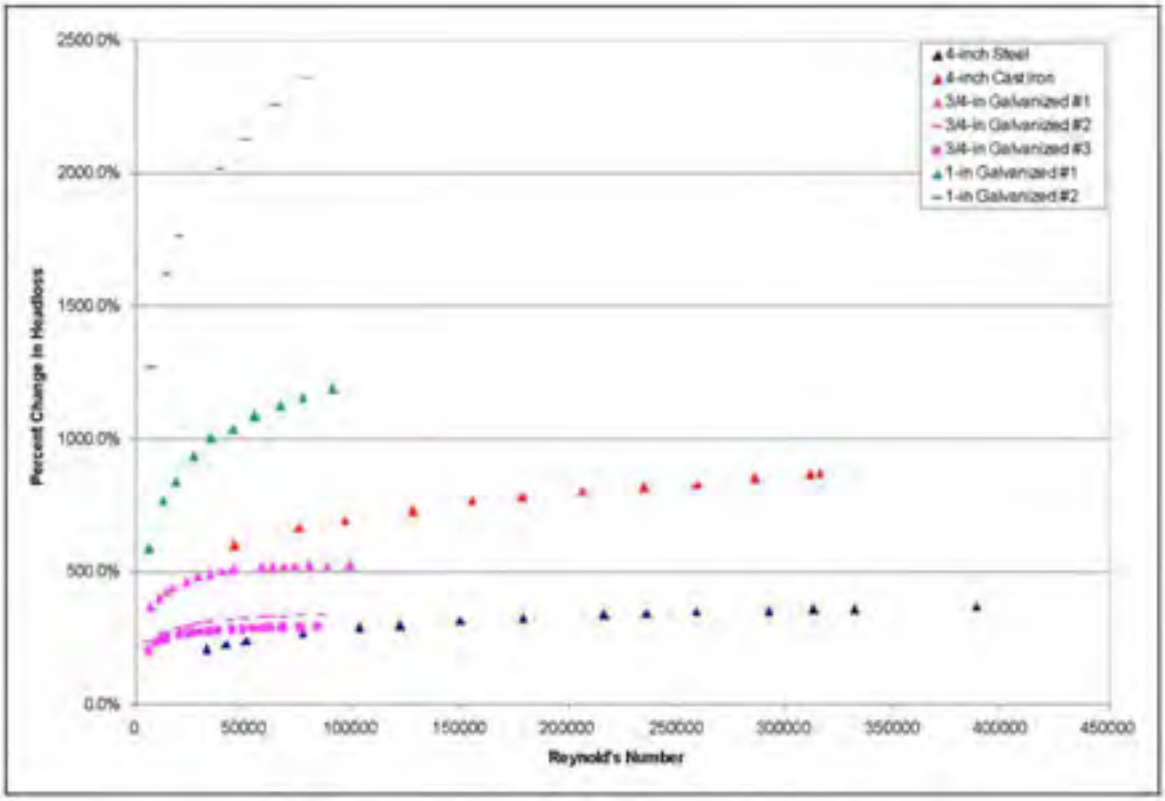

Figure 3: New and aged pipe roughness coefficient test data

Ground Water

Aotual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Ground Water

Project Name	FY 2005 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
Microbial Reduction of Structural Iron in Aquifer Sclids: Role of Iron Reducing Microbial Community, Production of Electron Shuttles and Iron Mineralogy	$32,818.82	$34,247.45	$35,274.87
Release of Arsenic from Aquifer Solids in Northern Utah Under Anaerobic Conditions: Exploring Relationships with Iron Mineral Reduction	$22,191.73	$71,000.00	$73,130.00
Remediation of TCE-Contaminated Soil and Groundwater at Hill Air Force Base (HAFB), Utah	$14,238.19	$14,950.10	$0.00
Designated Projects		$12,019.75	$12,380.35
Undesignated Projects		$7,000.00	$10,000.00
Total	**$69,046.54**	**$139,217.30**	**$130,785.22**

Microbial Reduction of Structural Iron in Aquifer Solids: Role of Iron Reducing Microbial Community, Production of Electron Shuttles and Iron Mineralogy

Principal Investigator(s):

Joan E. McLean
Darwin L. Sorensen
R. Ryan Dupont
Jeanette M. Norton
Heather Mickelson
Y. Q. Xu

Project Description:

This project identified and quantified Fe(III) reducing bacteria present in carbon-enriched microcosms of sediments and groundwater from Hill Air Force Base (HAFB). We hypothesized that the addition of acetate or glucose as the carbon donor will provide a biochemically active system that promotes a community of bacteria that function to support Fe reducing bacteria, including the production of electron shuttle compounds. Differences in enriched microbial communities will result in differential utilization of Fe(III) mineral phases and thus the rate and extent of biogenic Fe(II) produced. The overall goal of this project was to better understand the bacterial and geochemical interactions that influence the flow of energy within a carbon amended system; information needed to predict whether Fe reduction will dominate the system blocking reductive dechlorination of chlorinated solvents.

Accomplishments:

In the OA sediment, glucose addition led to the production of 1500 mg Fe(II)/kg, or 24% of the total Fe being reduced to Fe(II). With fermentation of glucose, some of the metabolites appear to be electron shuttling chemicals and chelating agents that facilitate the reductive dissolution of even crystalline Fe(III) oxides. The high biogenic Fe(II) production, aided by electron shuttle utilization, corresponded with a 23 times increase in the population of *Rhodoferax* spp. with the addition of glucose compared with the no carbon control. *Rhodoferax* has been shown to directly use glucose and acetate as the electron donor, whereas *Geobacter* only utilizes acetate. This selective utilization of carbon source was evident with the addition of glucose and acetate to the microcosms, which resulted in a four-times increase in *Geobacter* population with acetate addition and no response with glucose addition. *Rhodoferax* populations only showed the response to glucose addition.

Biogenic Fe(II) production was only 300 mg Fe(II)/kg when Fe(III) reduction was limited to *Geobacter* and mechanisms of direct contact, since acetate utilization would not facilitate electron shuttle production. With the addition of the electron shuttle, AQDS, to the microcosms, there was a 58% and 128% increase in biogenic Fe(II) production compared with glucose or acetate addition only, illustrating the importance of electron shuttles for accessing Fe(III) minerals. The addition of AQDS to acetate microcosms stimulated a 25 times increase in the *Geobacter* population compared with acetate only. The addition of AQDS to the glucose microcosms had no effect on the *Rhodoferax* population but did increase *Geobacter* by 10 times over microcosms with no AQDS.

The RA sediment showed a similar pattern of biogenic Fe(II) production dependence on carbon donor and the development of specific DIRB populations as observed for the OA sediment. The RA sediment is naturally reduced, so most of the iron in this sediment was as Fe(II). The addition of glucose, however, led to the production of 500 mg/kg Fe(II). Glucose with and without AQDS biostimulated *Rhodoferax* but not *Geobacter*. This reduced sediment had a large population of *Rhodoferax* in the original sediment (3x105 copies/μL, or 50% of the eubacteria present in the sediment) compared with no

detectable *Geobacter*. The addition of AQDS to the acetate treatment led to a doubling in biogenic iron and a 78 times increase in *Geobacter* population and a 32 times increase in *Rhodoferax* compared to treatments without AQDS. This again illustrates the role of electron shuttles in increasing biogenic Fe(II) production.

Our findings indicate that selection of carbon donor for biostimulation for remediation of chlorinated solvent impacted aquifers may greatly influence the extent of the reductive dissolution of iron minerals in direct competition with dechlorination processes, and may result in the significant release of Fe(II) to the solution phase, contributing to further contamination of the aquifer.

Work Plan FY 07/FY 08:

Microcosms containing sediments and groundwater from HAFB were constructed and analyzed over time to evaluate the utilization of iron minerals by native soil organisms. Sediments with different iron mineralogy were collected from sites at HAFB contaminated with TCE. One of the sediments collected was from an oxidized aquifer (OA) and the other from a reducing aquifer (RA). Glucose and acetate were used as carbon donors to stimulate microbial activity. No carbon addition was used as a control. These microcosms have been sacrificed for analysis of biogenic Fe(II) production, changes in Fe mineralogy, and general water chemistry parameters. The sediments were also extracted for DNA, and the DNA was analyzed using primers for *Geobacter* and *Rhodoferax* with standard polymerase chain reaction (PCR) and quantitative PCR (q-PCR). *Geobacter* have been the most commonly recovered dissimilatory iron reducing bacteria (DIRB) from sediments and subsurface environments. Sediments from HAFB, however, are dominated by *Rhodoferax*, a potentially important DIRB, but its role in the environment has not been described in the literature. An increase in microbial population was determined by a significant increase, over a four times changes with treatment compared with the no carbon control or microcosms without AQDS, in gene copy concentration as determined by q-PCR.

The objectives of the project are:

Objective 1: Identify and quantify the Fe(III) reducing bacteria, *Geobacter* and *Rhodoferax*, in microcosms of sediments and groundwater from Hill Air Force Base (HABF) with glucose and acetate as the carbon donors with and without the addition of a known electron shuttling compound, anthraquinone-2,6-disulfonate (AQDS).

Objective 2: Investigate interactions between the geochemistry of the sediments and the enrichment of Fe(III) reducing bacteria under biostimulation with glucose and acetate.

Benefits to the State:

Many military and industrial sites have groundwater contaminated with trichloroethylene (TCE) and other chlorinated solvents due to past disposal practices. On-site remediation methods are needed for clean up of such sites as Hill Air Force Base (HAFB), Tooele Army Depot, and Dugway Proving Grounds. Chlorinated solvents are also associated with dry cleaning, so there are contaminated sites throughout Utah.

Biostimulation has been used at various contaminated sites to promote the reductive dechlorination of TCE; but the addition of carbon donor also stimulates bacteria that use Fe(III) as the terminal electron acceptor (TEA) in potential competition with dechlorination processes. Our findings indicate that selection of a carbon donor for biostimulation for remediation of chlorinated solvent impacted aquifers may greatly influence the extent of the reductive dissolution of iron minerals in direct competition with dechlorination processes, and may result in the significant release of Fe(II) to the solution phase, contributing to further contamination of the aquifer. Our improved understanding of the interactions among carbon donor addition, microbial population stimulation, Fe(III) mineralogy and the biogeochemistry that influences the dechlorination of solvents will aid in the development of methods for evaluating sites and selection of bioremediation options for the successful reclamation of contaminated groundwaters.

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Release of Arsenic from Aquifer Solids in Northern Utah Under Anaerobic Conditions: Exploring Relationships with Iron Mineral Reduction

Principal Investigator(s):

Joan E. McLean
Darwin L. Sorensen
R. Ryan Dupont
Jeanette M. Norton
Yanna Liang

Project Description:

The project has the following objectives:

Objective 1: Determine the association of arsenic with Fe(III) minerals in aquifer solids collected from Hill AFB and other locations in Northern Utah and determine how this association affects the relationship between Fe and As biogeochemistry under biostimulation.

Objective 2: Investigate the roles of iron reducing bacteria and arsenic reducing bacteria as influenced by geochemical processes.

Accomplishments:

Anaerobic microcosms containing sediments and groundwater from Hill Air Force Base (HAFB) were constructed and analyzed over time to evaluate the utilization of iron minerals and the release of arsenic by native soil organisms. Preliminary studies showed that the addition of various carbon donors led to the release of arsenic in concentrations that exceeded the drinking water limit. The release of As to solution was independent of the reductive dissolution of Fe(III) minerals, contrary to the majority of other studies reported in the literature, which have shown As is solubilized as Fe(III) oxides dissolve under reducing conditions. The As dissolution observed during this study appears to have been the result of the direct use of As as an electron acceptor by dissimilatory arsenic reducing bacteria. Our findings indicate that selection of carbon donor for biostimulation for remediation of chlorinated solvent impacted aquifers may greatly influence the extent of the reductive dissolution of iron minerals in direct competition with dechlorination processes, but as importantly results in the significant release of Fe(II) and arsenic to the solution phase, contributing to further contamination of the aquifer.

Work Plan FY 07/FY 08:

Aquifer sediments have been collected from various sites at Hill Air Force Base. The arsenic and iron mineralogy was characterized using chemical extraction methods and geochemical modeling. Small columns will be packed with the aquifer solids and groundwater from the sites will be pumped through the columns at rates similar to groundwater flow. Batch microcosms will also be used. Glucose and acetate will be used as the carbon donors. Effluent samples will be collected over time and will be analyzed for water quality parameters, Fe(II), Fe(III), As(III), and As(V). Replicate microcosms/columns will be sacrificed at various time intervals, and the solid phase will be extracted to identify changes in Fe and As mineralogy. We will also identify the presence of select iron reducing bacteria and arsenic reducing bacteria using real-time PCR.

Benefits to the State:

Under aerobic conditions, iron oxides are the major sink for retention of toxic trace elements, such as arsenic. As subsurface environments are depleted of oxygen, iron oxides are solubilized, releasing arsenic and other toxic trace elements to solution. Subsurface environments may naturally undergo reducing conditions as oxygen is depleted. The major impact, however, is forced reducing conditions in engineered systems. One example is when biostimulation is used at contaminated sites, such as Hill Air Force Base (HAFB), Utah, to promote the degradation of toxic, chlorinated solvents including trichloroethylene (TCE); but the addition of carbon and an energy donor also stimulates bacteria that use Fe(III) as the terminal electron acceptor, dissolving the iron solid phase and releasing the associated arsenic. On-site remediation methods are needed for clean up of such sites as Hill Air Force Base, the Tooele Army Depot, and Dugway Proving Grounds. Chlorinated solvents are also associated with dry cleaning, so there are contaminated sites throughout Utah. Biological methods for remediation of such sites may, however, lead to further groundwater contamination from arsenic.

Another example is in municipal landfills, where biodegradation of organic material in the waste causes oxygen depletion leading to release of arsenic from the native geologic material. The presence of trace toxic elements, such as arsenic, is common in the geology of Utah. This is of concern at landfills across Utah, including the landfill for the City of Logan, but the process has not been investigated extensively.

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Remediation of TCE-Contaminated Soil and Groundwater at Hill Air Force Base (HAFB), Utah

Principal Investigator(s):

R. Ryan Dupont
Joan E. McLean
Darwin L. Sorensen
Jing Zhu

Project Description:

The objective of this study is to move from the laboratory microcosm scale to large-scale flow through column scale in evaluating the effectiveness of biostimulation versus bioaugmentation under simulated field conditions. Developing molecular biology monitoring techniques for identifying principal microbial community members in the dechlorinating inocula and refining these methods for quantifying the viability and mobility of organisms in the simulated field environment will also be accomplished in this phase of the project. Finally, the effectiveness of these molecular tools is being evaluated with DNA samples collected from active remediation sites from throughout the state, at DoD facilities and other sites of state regulatory interest.

Accomplishments:

These pilot-scale columns had been loaded and maintained for a cumulative time of 1180+ days by the end of the reporting period, during which time carbon donor addition had been carried out for more than 2 years. Significant differences in TCE transformation continue to be observed in these columns as indicated in the figures below, with complete TCE transformation being provided in the columns amended with whey as the carbon source (Figure 1), only intermediate transformation in emulsified oil amended systems (Figures 2 and 3), and no transformation in no carbon control columns (Figure 4). These data also indicate that with a single dose of emulsified oil equivalent to 1,000 mg/L column pore volume, TCE transformation persists for approximately 200 days. Significant methane and dissolved iron production continue to be observed in the whey amended reactors indicating that highly reducing conditions are present in these columns and that iron metabolism was important in these systems, serving as a competitive process to complete TCE degradation. Little methane is generated in the emulsified oil treatments, but iron metabolism is evident in them indicating that these systems were only partially reduced in response to this carbon amendment. The depletion of the emulsified carbon amendment evident by approximately 200 days after its application was not observed under batch reactor conditions in previous studies, indicating a significantly different TCE metabolism in flow-through columns than in small static microcosms. Complete TCE transformation through vinyl chloride and ethene has not been observed in any of the columns, however, despite adequate carbon donor and conditions thought to be supportive of complete TCE degradation for more than 200 days of continuous treatment. Complete microbial and geochemical analysis of the columns, with particular emphasis on the spatial distribution of microbial community members and iron related mineral species as a function of donor type, are underway to develop a more complete understanding of the role carbon source plays in stimulating the very different TCE transformation patterns (Figures 1 through 4) observed in these columns. These analyses will also serve as background samples for comparison with perturbated systems to which dechlorinating cultures are added during FY06.

Studies will be initiated in FY06 that will first reapply emulsified oil to the columns to evaluate the repeatability of microbial metabolism observed at this large column scale. Once TCE transformation has reestablished, an aliquot of a known TCE dechlorinating culture will be added to one of the duplicate columns for each treatment, and the change in TCE transformation rate and extent will be tracked over

time. Affects of carbon donor type on the rate and extent of TCE transformation by this culture in these flow through columns will be quantitatively assessed, and the use of molecular biology tools for the analysis of the viability and mobility of the added organisms will be tested at this pilot scale. This latter work is the subject of additional Mineral Lease Fund projects sponsored at the Utah Water Research Laboratory.

Work Plan FY 07/FY 08:

In this phase of the project, large-scale, flow-through soil columns (6 in diameter, 7 ft high) have been packed with aquifer material from OU5 in an area of existing TCE groundwater contamination. These columns have been loaded with OU5 groundwater to which a TCE solution has been added to generate groundwater TCE concentrations comparable to those found under field conditions. The influent and effluent of the columns has been periodically sampled and analyzed for TCE and its degradation products, as well as general water quality parameters to establish initial, background conditions from which comparisons of biostimulation and bioaugmentation remediation processes can be made. Optimal carbon donors identified in the small-scale microcosm studies have been added to subsets of the columns to document enhancements to TCE dechlorination that they provide, and to establish pretreatment conditions for the next phase of the study which is the pilot-scale application of the dechlorinating culture to the flow-through columns. In conjunction with the column studies is the development and application of molecular biology tools (molecular probes for key organism DNA detection and monitoring) to evaluate the viability and mobility of added culture organisms within the simulated field flow-through system. TCE degradation kinetics, intermediate product formation, microbial inocula survival and migration from the injection point, and the overall impact of carbon and inocula addition to the simulated aquifer system are being evaluated in these columns to aid in the design and planning of bioaugmentation at a field scale at Hill. Studies evaluating the production of intermediates from the degradation of surfactants used for source area treatment at OU2 following both microbial inocula addition and subsequent oxygenation of treated groundwater, and the testing of these molecular tools at a biostimulation site at Dugway to correlate DNA results with observed field performance are also integral parts of this Utah Water Research Lab effort.

Benefits to the State:

Soil and groundwater samples from Hill AFB, Operable Units (OUs) 5 and 2 have been used in laboratory microcosm studies to evaluate the effectiveness of carbon donor and microbial inocula addition in stimulating TCE remediation and removal from contaminated soil and groundwater. Soil from OU5 is being used in large-scale flow-through columns to evaluate TCE degradation rates in preparation for full-scale demonstration at the Hill site. Results have indicated the need for bioaugmenation at OU5, and have demonstrated the need for additional controls at OU2 to prevent undesirable degradation products from being produced and released from the site. These findings have provided site specific remediation design information that has been used to finalize remediation approaches at OU5 and has prevented Hill from making large scale expenditures in field studies that have been shown at the lab-scale to be ineffective.

Continuation of these soil and groundwater studies into the column flow-through scale provides specific design information for implementation of bioaugmentation at the source area at OU5 so that TCE contamination exposure and risk to adjacent property owners can be reduced over time in a cost effective manner. Verification of molecular biology tools in the monitoring of added microorganisms that effectively degrade TCE is being completed in this study, providing Hill AFB, and the Utah Department of Environmental Quality (DEQ) with cost effective techniques to monitor the movement and viability of added microbes to ensure that adequate control of this culture is provided during site remediation. In addition, treatment and design data for the control and production of degradation products at OU2 are being generated so that complete site remediation can be ensured. Information generated in this study will lead to the eventual cost effective recovery of the impacted water resource at these two Hill sites.

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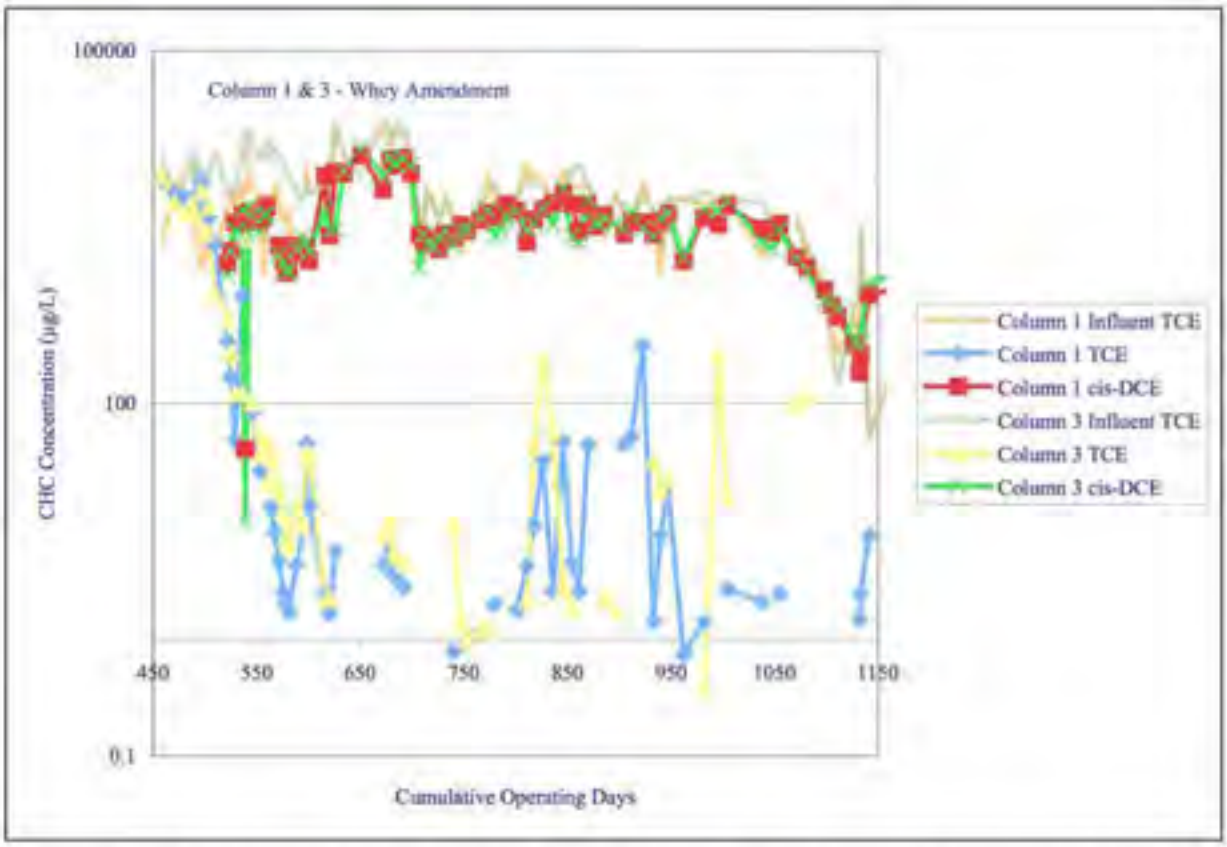

Figure 1. TCE and degradation product (cis-DCE) concentrations following Whey addition to pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. Whey concentration = 1,000 mg/L continuous supply beginning Day 450.

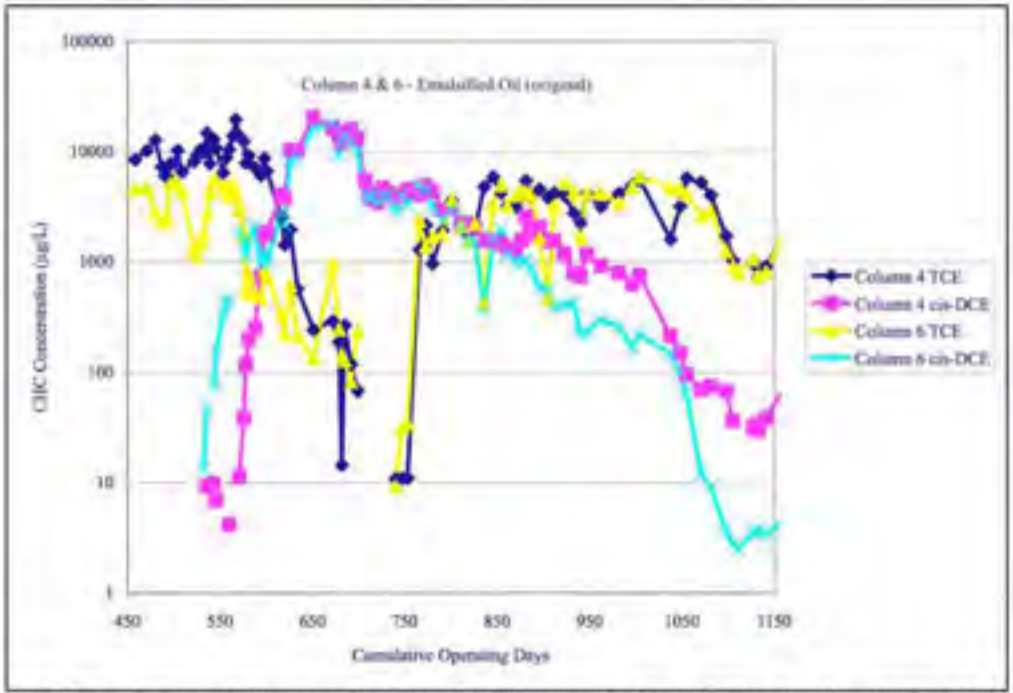

Figure 2. TCE and degradation product (cis-DCE) concentrations following Emulsified Oil, Type I addition to pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. Oil concentration = 1,000 mg/kg soil in a single dose on Day 450.

Figure 3. TCE and degradation product (cis-DCE) concentrations following Emulsified Oil, Type II addition to pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. Oil concentration = 1,000 mg/kg soil in a single dose on Day 450.

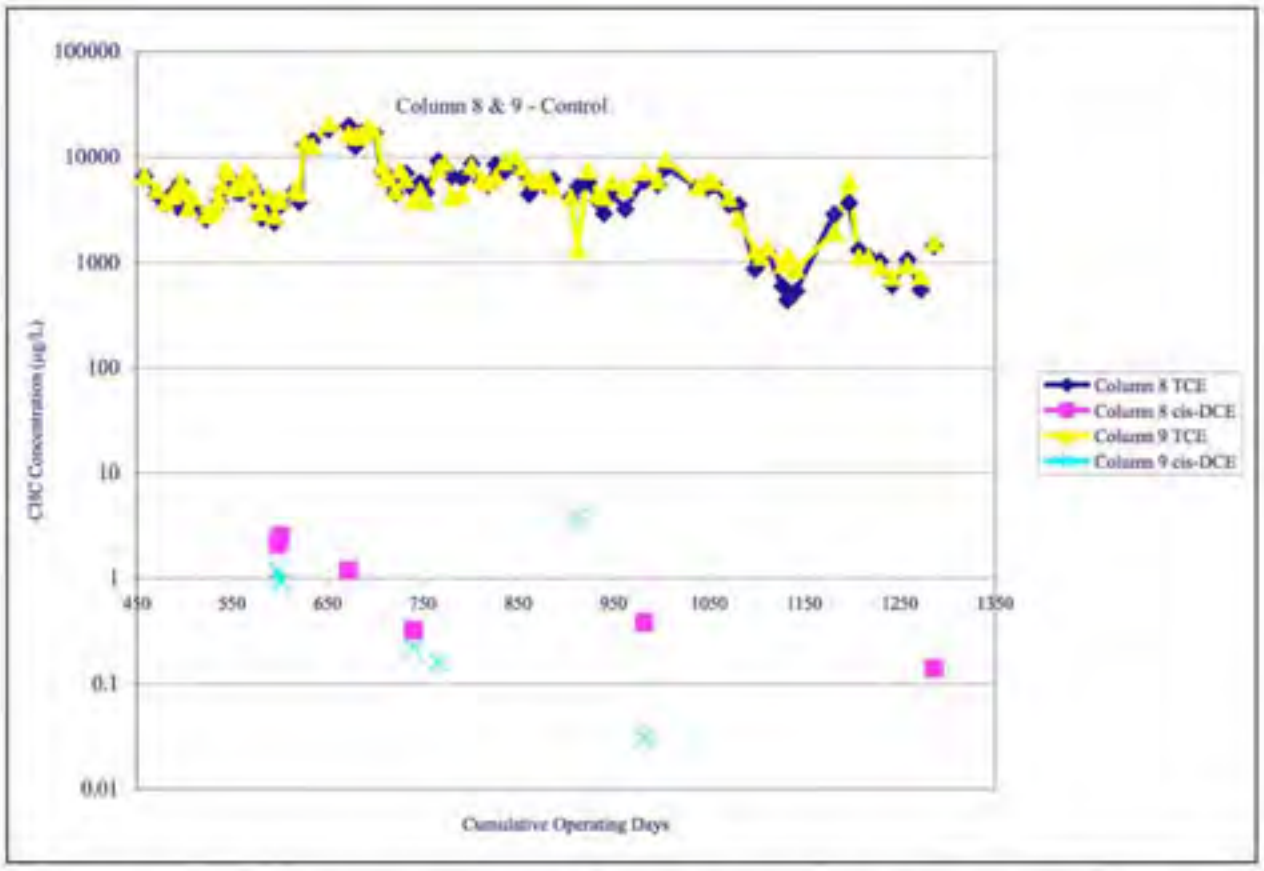

Figure 4. TCE and degradation product (cis-DCE) concentrations in no carbon addition, pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. These columns represent unfed Control Reactors.

Hydrology

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

Project Name	FY 2006 Actual Expenditures	FY 2007 Budgetod Expenditures	FY 2003 Planned Expenditures
Adapting Conventional Computer Tools To Analyze Crographio Effeot	$18,737.14	$19,299.25	$0.00
Forecasts to Improve Water Demand Prediotion in Irrigation Systems	$35,374.43	$25,000.00	$39,000.31
Intercomparison of Land Surfaoe Models in Semi-Arid Areas	$9,467.82	$9,941.21	$10,239.45
Investigation on the Application of Noo-Uniferm Cnds for Land Surface Modeling Cver Semi-Arid Areas and Evaluation Using Similarity Measures	$12,768.67	$0.00	$0.00
Model Diagnoois and Unoertainty Using Similarity Conoepts and Statistical Learning Theory	$9,467.82	$9,941.21	$10,239.45
Modeling of Creat Salt Lake Levels – Cnline Monitoring and Statistioal Analysis	$20,481.95	$21,506.05	$22,151.23
Modeling the Great Salt Lake	$24,675.40	$50,000.00	$51,500.00
Designated Projects		$58,943.10	$53,773.96
Undesignated Projeots		$12,000.00	$15,000.00
Total	**$130,971.23**	**$206,630.82**	**$201,904.40**

Adapting Conventional Computer Tools To Analyze Orographic Effect

Principal Investigator(s):

William J. Grenney
Sanup Bhulawala

Project Description:

Information gained during the state-wide roadway culvert survey indicated that there may be significant differences in the data used for estimating design flows for drainage structures based on orographic effects.

Because of the great land area in Utah and the scarcity of data monitoring sites, there is seldom sufficient river flow data or precipitation data available to directly estimate peak flows for the design of drainage structures. It is almost always necessary for a design agency to extrapolate data from one watershed to another using conventional engineering techniques. The techniques being used do not account for the effects of predominate wind direction over mountain ridges. However, as a result of doing site specific analyses, engineers have noticed what they believe to be significant effects.

The purpose of this research is to identify precipitation stations in four strategic geographical regions in Utah, to gather data from the most current sources, to statistically analyze for orographic effects, and to develop a computer program to provide users with a handy tool to calculate adjustment factors.

Accomplishments:

Raw data were collected and analyzed during the previous phase of the project, and a stand-alone computer program was developed to implement the findings. During this study it was found that additional complex statistical functions could be used to further refine the results. It was judged more efficient to adapt existing conventional computer tools for the analysis than to further modify the stand-alone computer program.

The "Visual Basic For Applications" computer programming language was used in conjunction with Excel workbook built-in functions to extend the analysis.

Work Plan FY 07/FY 08:

The results contained a great deal of randomness. However, significant differences that were previously found at the 90% and 95% confidence level for certain classes of precipitation using the stand-alone model, were estimated to be slightly more significant using the enhanced VBA/Excel version. The greatest differences occurred in North Eastern Utah. A graphical representation is shown in Figure 1.

This implementation approach is preliminary and further refinement is proposed for the next phase.

Benefits to the State:

There are major economic and liability reasons for applying the best available technology to estimate peak flows so that drainage structures can be properly designed. This research provides improved methods for estimating peak flows which are essential for the safe and economical design of drainage structures.

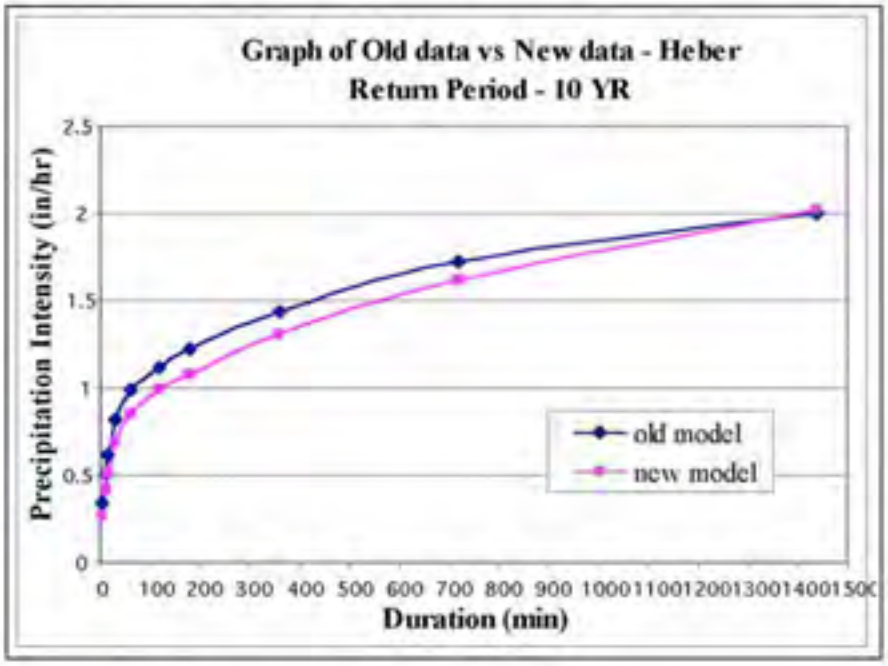
Graph of Old data vs New data - Heber
Return Period - 10 YR
Precipitation Intensity (in/hr)
2.5
2
1.5
1
0.5
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
Duration (min)
old model
new model

Figure 1.

Forecasts to Improve Water Demand Prediction in Irrigation Systems

Principal Investigator(s):

Luis A. Bastidas
Enrique Rosero
Yasir Kaheil

Project Description:

The project attempts to make use of the NOAA-issued precipitation forecast to estimate actual requirements of irrigation water from crops via incorporating this and other sources of information, such as farmers' demands and tracking of soil moisture, into an artificial intelligence-based system. The system will incorporate data assimilation techniques in order to improve the short-term forecasts. The lead time of the system will be in the order of up to five or six days.

The work includes the compilation of quantitative precipitation forecasts from NOAA for the growing season of the years 2004 and 2005 (the year 2006 is also considered) as well as compilation of data from the NASA Land Information System to keep track of the soil moisture content. Data from the Sevier River Basin irrigation system will also be compiled, with particular attention to the user water requests.

The prediction system will be based on the use of relevance and support vector machines and will be run in a hindcast simulation mode to allow for testing and evaluation. The lead time will be consistent with the NOAA issued forecasts, i.e., up to 12 days in advance.

A system for downscaling of the information will also be required. For that purpose the NOAA forecast and observational fields of 12-km will be downscaled to scales of 250-m using the LIS information of 1-km resolution together with local stations that will provide point information. The same artificial intelligence and statistical learning techniques mentioned above will be used for this and will be part of the overall system.

Accomplishments:

The project is ongoing. Forecast series for the growing seasons of the years 2004, 2005, and 2006 have been compiled and stored in the Utah Water Research Laboratory servers. A preliminary procedure for soil moisture downscaling has been developed and is currently being tested with information from the NASA Land Information System at 1-km resolution over the Bonville Ameriflux site in Illinois using soil moisture and latent heat information.

Work Plan FY 07/FY 08:

We plan to transfer the downscaling procedures to evapotranspiration fields. The evaluation procedures will be done applying the similarity techniques developed in other projects.

Benefits to the State:

Utah, being a semiarid/arid land, has extremely high interest in the careful management of its water resources. It is well known that even a small improvement in the capabilities for demand prediction of as little as 10-20% will have significant effects on the overall management of the scarce water resource. Furthermore, a system that can improve the demand forecast with a lead time of 3-5 days is definitely important for the management of reservoirs and canals, and will help water managers make more informed decisions about the releases from those system components.

Intercomparison of Land Surface Models in Semi-Arid Areas

Principal Investigator(s):

Luis A. Bastidas
Bart Nijssen, University of Arizona
Enrique Rosero

Project Description:

The Project for Intercomparison of Land Surface Parameterization Schemes (PILPS) experiment for semi-arid areas is an initiative within the GEWEX/GLASS (Global Energy Water Experiment/Global Land Atmosphere System Studies) panel. The objective of this study is the comparison of models that simulate water, energy, and CO_2 cycles with continuous observations at five different sites.

The availability of 4+ years of data at two sites and data from locations with similar vegetation coverage but hundreds of kilometers apart provide an exciting opportunity for cross-validation of the model results and for comparison of different models. The three different vegetation types existing at the data sites also provide a quick look at the diversity of environments in arid lands and will allow establishment of whether further distinction is required to better represent the water, energy, and CO_2 exchanges taking place over such areas.

In previous PILPS studies [Lettenmaier et al., 1996; Nijssen et al., 2003], it was shown that the manual calibration of model parameters yielded improvement in model performance. For this reason, we proposed to use a multi-criteria framework and a set of optimization codes for calibration of hydro-meteorological models that has been developed and successfully applied to a variety of land surface models [Gupta et al., 1998, 1999; Bastidas et al., 1999, 2001, 2002; Vrugt et al., 2003]. This framework is very appropriate for constraining the parameter estimation of land surface models to be consistent with observations and will allow for a comparison of "optimal" performances of the models.

Some of the science questions addressed by the PILPS San Pedro experiment are:

- What is the ability of the models to reproduce the water, energy, and carbon exchanges in semi-arid environments?
- Are the current (usually single) representations of semi-arid lands in the models enough to reproduce the different environments that exist in those areas?
- Does model calibration reduce the among-model range in the model simulations?
- How much influence does the model parameterization have on the parameter estimations of "physically meaningful" parameters?
- Do current carbon representations, developed for forests, properly reproduce carbon exchanges over vegetated arid lands?

The proposed experiment has unique characteristics. PILPS-San Pedro not only focuses on a different environment than previous PILPS experiments, but it also will employ appropriate system methods for parameter estimation, that will help the modeling groups to identify parameter sets that make the models consistent with the data.

Accomplishments:

The modeling groups located at various universities and research centers around the world have submitted results for the first two planned steps. A presentation regarding the results obtained so far was made at the Pan-GEWEX Meeting in October 2006 at the European Space Agency Research Institute in Rome. Results submissions have been received from 11 modeling groups from different countries around the world. A conference paper with preliminary analysis was submitted and was presented at the AMS Meeting in January 2006. A new conference paper was submitted and will be presented at the AMS Meeting in January 2007. A paper addressing energy balance and another addressing the water balance are being finished for submission to the Journal of Hydrometeorology.

Work Plan FY 07/FY 08:

The international multi-model study will be finished with the submission of the papers. We plan to carry out additional multi-model studies but only with three widely used community models both at research and operational centers in the United States (CLM, Noah, and JULES), specifically addressing issues of model parameter transferability across different semi-arid environments.

Benefits to the State:

Semi-arid environments are a significant part of the western United States, and in particular of the State of Utah. The performance evaluation and intercomparison of most of the state-of-the-art land surface models in semi-arid environments is of interest to determine the deficiencies that the models have in the representation of such areas and will be helpful in overcoming those problems. The current studies of model parameter transferability among semi-arid environments are of importance for improved simulations and forecasts of the turbulent heat and water fluxes. In the long term, this information can be made useful for water management at the scale of watersheds and river basins in Utah.

References

Bastidas, L.A., E. Rosero, and B. Nijssen (2006). The PILPS Semi-Arid Experiment - Preliminary Results. *AMS Hydrology Conference*, Atlanta, Georgia, January 29-February 3.

Bastidas, L.A., E. Rosero, B. Nijssen (2006). The PILPS Semi-Arid Experiment. *Pan-GEWEX Meeting*, Frascati, Italy, October 9-14.

Rosero, E., L.A. Bastidas, and B. Nijssen (2007). Evaluation of LSM Parameter Transferability Across Semi-arid Environments. *AMS Hydrology Conference*, San Antonio, TX, January 14-18.

Bastidas, L.A., E. Rosero, B. Nijssen, A. Pitman, H. Gupta, W. Emmerich, E. Small (2006). The PILPS Semi-arid Experiment: Energy and Water Balances. To be submitted to *Journal of Hydrometeorology.*

Bastidas, L.A., E. Rosero, B. Nijssen, A. Pitman, H. Gupta, W. Emmerich, E. Small (2006). The PILPS Semi-arid Experiment: High Frequency Analysis. To be submitted to *Journal of Hydrometeorology.*

Investigation on the Application of Non-Uniform Grids for Land Surface Modeling Over Semi-Arid Areas and Evaluation Using Similarity Measures

Principal Investigator(s):

Luis A. Bastidas
Shujun Li
Enrique Rosero

Project Description:

The purpose of the present project is to carry out an investigation to establish how much can be gained by using non-uniform grids for land surface modeling over the semi-arid Southwest U.S. The specific topographic characteristics of the terrain (basin and range), the vegetation distribution (riparian areas and desert floor), and the hydrologic processes (mountain recharge fronts, no recharge over desert floors) suggest that an approach with different resolutions will be more appropriate for that type of environments than the traditional mosaic approach currently used.

Land surface processes coupled to atmospheric models (AM) have been described as simple leaky bucket parameterizations in the late 1960s, to more complex surface vegetation atmosphere transfer schemes in the mid 1980s, to detailed land surface ecosystem-hydrology models. The evolution of coupled Atmospheric Model-Land Surface Model (AM-LSM) have taken into account more detailed physical processes (e.g., biogeochemistry, streamflow), but so far has always been oriented towards a single column (over a grid cell) conceptual representation of the processes. Data availability has become a limiting factor, especially as the model resolution increased to account for detailed fine-scale watershed processes (50-200 m). These models, which are computationally intensive, may lack sufficient input forcing for realistic solutions. Medium-scale (1-12 km) models, on the other hand, may avoid this limitation, but at a loss of information. Based on work carried out by Miller (1993, 1995) and as a bridge between these two approaches, we propose a non-uniform grid system that provides fine-scale structure at regions of high land surface sensitivity and medium-scale for regions of low sensitivity or problem-defined homogeneity. Such an approach will reduce computational demand and provide a framework for evaluating medium- and fine-scale models, as well as testing process sensitivities at a range of spatial scales.

Vegetation, topographic, and hydrologic characteristics of the semi-arid Southwest U.S. suggest that, for those environments, it will be more meaningful to link the inherent heterogeneity and scale of the terrain properties and hydrological processes with the grid cell size of the numerical representation in land surface models, rather than pursue the traditional mosaic-type or effective aggregation approach currently used by the state-of-the-art models.

To be able to evaluate and calibrate the spatially distributed models, we proposed the use of similarity measures. This is a novel approach in hydrology and has generated much interest from different agencies, the Weather Service in particular.

Specific objectives are:

- Design and apply non-uniform LSM grids over the San Pedro Basin and test the sensitivity of the hydrologic response as forced by dynamical (nested atmospheric mesoscale modeling) and statistical-dynamical (self-organized feature maps and/or support vector machines) downscaling procedures.

- Compare the 1-4 km spatially aggregated non-uniform grid and fine-scale grid simulations to the medium-scale 1-4 km simulations. Compare fine-scale and non-uniform solutions and determine the non-uniform scales that result in solutions of similar accuracy as the fine-scale.

Accomplishments:

The project has finished and has been the basis for the doctoral dissertation of Shujun Li, who graduated in August 2006. A manual procedure for multiple grid representation has been developed over the San Pedro catchment and an automation of this procedure has been completed. A new modified similarity measure was developed that reduces the computational overburden by two orders of magnitude. An invited seminar was given at the National Weather Service Office of Hydrology in Washington DC, January 2006; a presentation will be given at the AGU Fall Meeting 2006. A paper regarding the use of similarity measures for calibration and sensitivity analysis was submitted in September to *Water Resources Research* and a paper about the non-uniform procedure is in preparation.

As stated in last year's report, the similarity approach has generated interest from the NWS and a joint proposal with the Office of Hydrology, the NWS Salt Lake City Office, and the Colorado Basin River Forecast Center was submitted July 2006 to the NOAA CPPA program for additional funding. It also constitutes the core of a NSF proposal submitted in July 2006.

Work Plan FY 07/FY 08:

We plan to continue work to publish the results of the investigation and to continue to improve the computational overburden of the procedures and to apply them to different distributed models. The presentations at meetings have generated considerable interest and possible collaborations with NWS Office of Hydrology, Lancaster University, University of California-Irvine, and University of Colorado are envisioned.

Benefits to the State:

Semi-arid environments are a significant part of the western United States, and in particular of the State of Utah. The development of a parameterization specifically tailored for semi-arid regions is of obvious importance for the State of Utah. The procedures developed provide a way to evaluate the performance of models in a spatially distributed fashion and will be applied in a new forecast system for the state.

References

Bastidas, L.A. and S. Li(2006). Parameter Sensitivity and Calibration of a Distributed Model Using Similarity Concepts. Submitted to *Water Resources Research.*

Bastidas, L.A. (2006). The Use of Similarity Concepts for Calibration, Evaluation and Sensitivity Analysis of Hydrological Models. *Invited Seminar, National Weather Service Headquarters,* Silver Spring, MD, January 13.

Model Diagnosis and Uncertainty Using Similarity Concepts and Statistical Learning Theory

Principal Investigator(s):

Luis A. Bastidas
Enrique Rosero

Project Description:

The purpose of this project is to carry out an investigation to establish the impact of data, parameter, and model structure errors in the overall model output uncertainty with specific focus on distributed rainfall-runoff and land surface models.

Current implementations of multi-criteria methods for parameter estimation do not consider explicitly the role of errors in the model structure and frequently assume error-free calibration and meteorological forcing data. The error diagnosis step is overlooked because isolating different sources of error is complicated. In this project we will use a combination of multi-criteria optimization and statistical learning machines that, in the presence of multiple model realizations, will enable identification, and probabilistic quantification of the different sources of uncertainty. We will focus on a case study that uses tower flux data and the Noah land-surface model and the NWS SAC-SMA model to address two questions: (a) what is the relative contribution of model structural deficiency and data error to the prediction uncertainty, and (b) what is the uncertainty that should be recognized in surface exchanges when using 'optimal' sets of model parameters? The area of study will originally be in the Eastern US, Leaf River in Missouri, and the Ameriflux sites in Illinois. The rationale behind that is the previous extensive use of data for model development in those areas. When the methodology will be soundly established, we will apply it to the Bear River in Utah.

We will make use of support vector machines (SVMs) to extract the underlying relationship between forcing and observations and because of the theoretical capability of these kernel-based machines to perfectly fit observed values. By running ensemble simulations of perturbed input series through trained SVMs and evaluating the residuals with respect to perturbed observed outputs, the data error is quantified for the a series of realizations. To explicitly account for uncertainty coming from both input and output, we will generate hundreds of realizations of perturbed observational data with different levels of an additive uncorrelated heteroscedastic error. Mean, variance, and other statistical properties of the observed series will be maintained. The levels of noise will be related to typical values of measurement errors expected at the respective time scale in the most important forcing variables, (e.g., 10% precipitation, 5% net radiation, 10% discharge, etc.).

By running the input realizations through the SVMs to obtain synthetic realizations of perturbed outputs we could run multi-objective optimizations to obtain a set of parameters that minimize parameter uncertainty. We will assume that the multi-objective optimization identifies the Pareto optimum, i.e., removes the parameter error; thus, the resulting errors could only be ascribed to model structural error.

With an ensemble of 'zero' data error points and their associated Pareto fronts, we can infer distributions for all the model components. Then it is possible to make probabilistic inferences regarding the outputs (i.e., confidence bounds). While in the objective space, it is possible to quantify the relative contributions of different sources of errors by taking distances between the distributions.

Accomplishments:

- Devise an ensemble approach that will provide a means of estimating the uncertainty contributions from the different modeling components, i.e., data, parameters, initialization, and model structure.
- Test the performance of the procedure both in humid and semi-arid environments using data from the Western US and the Bear River in Utah.
- Further develop the similarity concepts and applications to two types of hydrologic models, soil moisture accounting rainfall-runoff models and land surface parameterizations.
- Determine the model complexity required – in the sense of the distribution required to make the models consistent with the observations, while maintaining a level of parsimony that will preclude the "curse of dimensionality".

Work Plan FY 07/FY 08:

This project builds on previous projects. We plan to continue work originated mainly in the projects "Investigation on the Application of Non-uniform Grids for Land Surface Modeling over Semi-Arid Areas and Evaluation Using Similarity Measures" and "Forecasts to Improve Water Demand Prediction in Irrigation Systems". During the present year we will focus on the development of the uncertainty estimation procedures and in particular in identifying optimal ways of generating the ensemble realizations and the appropriate type of kernel learning machines to have an efficient system.

Benefits to the State:

The procedures to be developed will allow creation of a probabilistic framework for estimating the reliability of model forecasts. The methodology will be model independent and could be extended to decision support systems (DSSs), such as the one existing in the Utah Water Research Laboratory which is currently applied in different basins of the State of Utah (e.g., the Weber and Virgin River Basins). The use of the Bear River as one of the testbeds is important and will serve as a way to extend the theoretical framework to other Utah basins. The procedures to be developed will provide a way to evaluate the performance of models in a spatially distributed fashion and will be applied in a new forecast system for the state.

▲

Modeling of Great Salt Lake Levels – Online Monitoring and Statistical Analysis

Principal Investigator(s):

Gilberto E. Urroz
Mohammed Abdel-Hafez

Project Description:

Fluctuations of the Great Salt Lake's (GSL) level are of direct concern to mineral industries along the shore, the Salt Lake City Airport, railways, and I-80 in the vicinity of the lake. They are also well correlated with regional water supply conditions. While several studies have been conducted aimed at predicting GSL's water levels, the information is not readily available to water managers or state agencies. This project aims at developing a web site where the existing models can be used to predict GSL's water levels, as well as to monitor the actual levels to evaluate the efficiency of the model predictions

The objectives are:

1. Review existing GSL water level models.
2. Produce a web site where existing GSL water level models can be implemented for prediction.
3. Incorporate GSL water level monitoring (e.g., from USGS data) to compare with predictions.
4. Produce statistical analysis to verify existing models.

Accomplishments:

We have collected and implemented existing models (e.g., neural networks, support vector machines, and other statistical techniques), and developed a model web site for implementing prediction and monitoring.

Work Plan FY 07/FY 08:

This project is the M.S. thesis of a graduate student at the Utah Water Research Laboratory (UWRL). In collaboration with the student, we plan to develop a web site were GSL level data can be predicted and monitored, following the objectives listed above.

Benefits to the State:

As a result of this project, a web site will be developed that will allow direct access to predicted and measured water levels in the Great Salt Lake. This resource will be useful to water managers in the Great Salt Lake basin, as well as to state agencies interested in the monitoring of Great Salt Lake levels.

Modeling the Great Salt Lake

Principal Investigator(s):

David G. Tarboton
Ibrahim Mohammed

Project Description:

The problem addressed in this work is modeling of changes in Great Salt Lake (GSL) volume and fluctuations in GSL level as they are related to the inputs, such as streamflow, precipitation, temperature, and other measures of climate that act on the lake-basin system.

The objectives are: Quantify the relationships between the GSL level/volume and streamflow, precipitation, temperature, and other measures of climate that act on the lake, through exploratory data analysis and statistical modeling.

Explore the possibility of relationships between modes in the lake volume distribution and attributes of the topographic area-volume relationship.

Accomplishments:

The dominant drivers affecting the GSL volume are streamflow, precipitation, and lake area that controls evaporation. From the data available we developed a regression model for the GSL volume changes. Explanatory variables were streamflow, precipitation and lake area. This model serves to quantify some of the functioning of the GSL system that when combined with forecasts for streamflow and precipitation could be used for prediction.

Modes in the GSL volume and area distributions were examined as part of our effort to understand lake dynamics and the different roles played by bathymetry and inputs from the hydrologic and climate system. The topographic area-volume relationship in the GSL plays a role in the system dynamics because area is a control on the evaporation outflux, the only outflow from the system. We re-examined the multimodality that had been previously interpreted as suggestive of preferred states in the lake dynamics (Lall, et al. 1996). We found that data acquired over the 14 years since the Lall, Sangoyomi and Abarbanel (1996) work was done has changed the estimate of the shape of the GSL volume probability density function. We found that multimodality in the distribution of lake area is more pronounced than multimodality in lake volume with the relationship between these two distributions being related to the bathymetry that describes the rate of change of area with lake level. This relationship had not been previously described.

Evaporation depends upon salinity. To account for this in our GSL modeling we developed a modification to the Penman equation for lake evaporation that adjusts evaporation rates for the reduction in saturated vapor pressure with increasing salinity. The modified Penman equation evaporation was compared to the mass balance estimates of the volume of GSL evaporation over the years of record, with the result that modified Penman estimates are reduced up to 40% from the unmodified Penman estimates and are closer to the mass balance estimates (See Figure 1). This improved approach for calculation of lake evaporation allows us to better quantify the overall water balance of the lake that leads to rises and drops in lake level.

Work Plan FY 07/FY 08:

The intent is for this work to contribute to better understanding of long-term, large-scale climatic fluctuations and their interaction with surface hydrology. We would like to understand the climate conditions that could lead to changes in lake levels/volumes. Better understanding of lake processes can help towards better physical model forecasts of lake levels and volumes. Such forecasts are important to assess the risks of low or high lake levels that have consequences for lake resources and management of infrastructure such as the pumps for protection against flooding.

Benefits to the State:

The Great Salt Lake is important for the economy and ecology of the State of Utah. High lake levels threaten infrastructure and the Salt Lake City metropolitan area. The brine shrimp and mineral industries depend upon the lake and its salinity which is related to level. It is, therefore, important to understand and be able to better predict the fluctuations in the level of the Great Salt Lake.

Reference

Lall, U., T. Sangoyomi and H. D. I. Abarbanel (1996). Nonlinear Dynamics of the Great Salt Lake: Nonparametric Short-Term Forecasting. *Water Resources Research*, 32(4): 975-985.

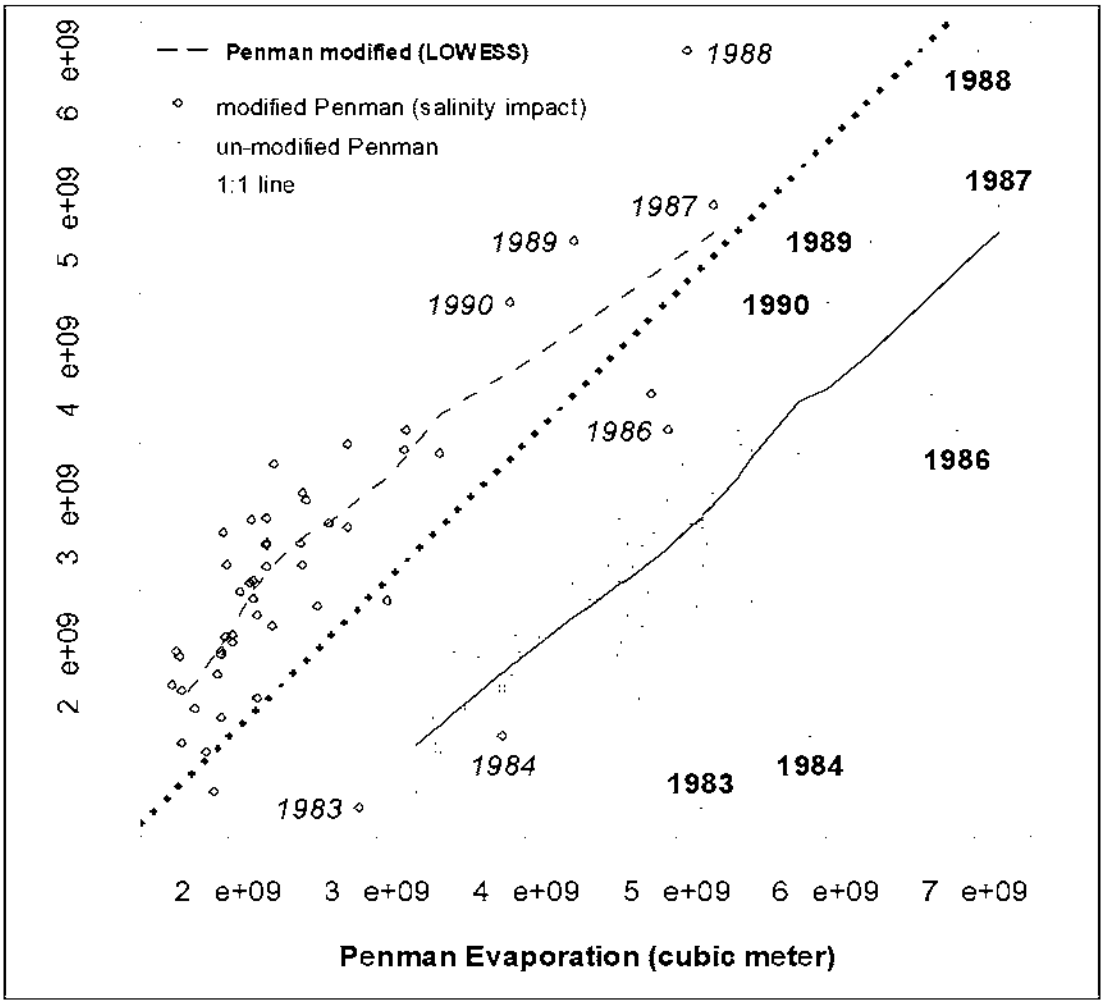

Figure 1. Comparison of GSL evaporation estimated from the modified and original Penman equations to mass balance evaporation estimates. The modified Penman estimate accounts for salinity and is closer to the mass balance estimate.

Water Resources Planning and Management

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

Prejeet Name	FY 2006 Actual Expenditures	FY 2007 Budgeted Expenditures	FY 2008 Planned Expenditures
A Decision-Support System for Optimal Agrioultural Water Management Under Wafer Deficit Oonditions	$12,386.16	$18,000.00	$18,540.00
A Tool to Analyze Environmental Impaots of Roads on Forest Watersheds	$20,584.18	$21,613.39	$22,261.79
Analysis of Watar Demand for Utah's Urban Water Supply Systems	$5,425.18	$15,000.00	$0.00
Box Elder County Flood Control Support	$8,856.50	$37,000.00	$38,110.00
Dam Breaoh Modeling and Extreme Flood Estimation	$13,628.55	$14,307.88	$14,737.11
Dam Failure Life Loss Estimation	$11,936.34	$12,533.16	$12,909.15
Dam Safety Risk Management	$11,936.34	$12,533.16	$12,909.15
Economio Worth of Data In Water Resouroes and Water Ouality Analyses	$10,374.22	$10,892.93	$11,219.72
Forecasting Irrigation Water Demand in the Sevier River Basin	$6,681.70	$17,000.00	$0.00
Green River Canal Sedimentation and Flow Distribution Project	$9,797.97	$15,000.00	$0.00
Implementation of a Olosed-Loop Real-Time Irrigation System for Soipio, Utah	$3,326.53	$50,000.00	$51,500.00
Improved Dam-Breaoh Flood Plain Inundation Mapping	$11,705.82	$57,000.00	$58,710.00
Internet-Based Viewer for Utah's Native Fish Speoies	$5,743.85	$10,000.00	$0.00
Real-Time Management of Irrigation Systems in the Sevier River Basin	$27,223.18	$79,000.00	$81,370.00
Stormwater Management in Irrigation Canals	$38,521.58	$18,000.00	$0.00
The Lower Provo River Bifuroation and Channel Restoration Projeot	$12,062.72	$34,000.00	$35,020.00
Virgin River Deoision Support System	$14,378.53	$40,000.00	$15,450.00
Virgin River Watershed Planning Support	$8,493.38	$8,918.05	$9,185.60
Water Resouroes Analysis and Optimal Allooation Strategies for Salt Lake Valley, Utah	$20,005.01	$5,000.00	$0.00
Designated Projeots		$855,041.34	$763,382.92
Undesignated Projeots		$25,000.00	$180,000.00
Total	**$253,063.74**	**$1,355,839.91**	**$1,325,305.44**

A Decision-Support System for Optimal Agricultural Water Management Under Water Deficit Conditions

Principal Investigator(s):

Jagath J. Kaluarachchi
Ahmed Al-Juaidy

Project Description:

The objectives of the project are to:

1. Develop a conceptual model describing different processes linking crop cultivation in a farming community, considering water allocation, irrigation practices, production costs, and market conditions.

2. Develop an optimization model to determine the maximum profit in an agricultural operation subject to limited available water and existing market conditions.

3. Demonstrate the applicability of the proposed methodology for a given agricultural community in Utah.

Accomplishments:

Work on Task 1 and a part of Task 2 are complete. The remaining tasks are currently ongoing.

Work Plan FY 07/FY 08:

The following tasks will be necessary to complete the above research objectives:

1. Literature review to identify existing work similar to the proposed objectives in agricultural water management.

2. Identity a suitable region of Utah where the model can be applied.

3. Develop the conceptual and mathematical models for water allocation.

4. Develop the mathematical model of economic analysis.

5. Develop the optimization module.

6. Simulate the agricultural water management in the region selected in Step 2.

Benefits to the State:

The rural parts of the State of Utah are still actively involved in agricultural activities, from crop cultivation to dairy farming and ranching. However, most parts of these agriculture-dominated regions of the state have moderate to severe water deficits that often hinder the full implementation of their desired agricultural goals. In these uncertain times of water deficit conditions, farmers cannot plan for the optimal

land area/crop combinations to cultivate in a given season to maximize their annual profits. Most Midwestern states have sophisticated analytical tools available to the farming community to address these concerns so that they can rotate their land use patterns every season based on the water deficit and local market conditions. In this work, we propose to develop a web-oriented agricultural water management system for the State of Utah such that the farming communities can use the system to determine the optimal land area/crop combination to cultivate in any given season knowing the water deficit and local market conditions such that agricultural profits can be maximized. We have teamed with the Utah Division of Water Resources and the USDA office in Salt Lake City to develop this decision support system (DSS) as a part of a PhD dissertation.

A Tool to Analyze Environmental Impacts of Roads on Forest Watersheds

Principal Investigator(s):

David G. Tarboton

Project Description:

The construction and use of forest roads can have impacts on geomorphic processes, erosion patterns and the ecosystem in forested basins. Analyzing these impacts will help forest managers to effectively manage road and road drainage system and hence minimize the negative impacts of forest roads.

Develop a set of GIS tools that takes input from the forest road inventory and quantifies sediment production from forest roads and resulting stream sediment inputs, predicts the effect of road drainage on terrain stability and erosion sensitivity, and analyzes fish habitat segmentation due to road stream crossing blockage or failures. To implement these tools as a toolbar for the Environmental Systems Research Institute (ESRI®) ArcGISTM GIS software.

Accomplishments:

The GRAIP model is complete and has been compared to previous approaches with favorable results.

Work Plan FY 07/FY 08:

USDA Forest Service road inventory data provides the starting point for analysis of the impact of roads on forest watersheds. The approach was to develop a set of GIS based analysis tools which were called the Geomorphologic Road Analysis and Inventory Package (GRAIP). The GRAIP model consists of:

1. The GRAIP database schema.
2. The GRAIP database preprocessor to ingest and validate USFS road inventory data while loading it into the database.
3. A set of GIS procedures to delineate the stream network segmented at points where roads cross streams.
4. A set of GIS procedures to develop a slope stability index map.
5. The GRAIP road surface erosion module to quantify the sediment production from each road segment and sediment delivery to the stream system.
6. The GRAIP mass wasting potential module to quantify the potential for mass wasting due to the impacts of road drainage on both landslide and erosion risk.
7. The GRAIP stream blocking analysis module to quantify the plugging risk of road drains.
8. The GRAIP habitat contiguity module to identify road stream crossings that block fish passage and fragment habitat.

Benefits to the State:

This work has resulted in the development of a GIS tool named Geomorphologic Road Analysis and Inventory Package (GRAIP) that uses information from USFS Global Positioning System (GPS) road surveys to analyze the impacts that the construction and use of forest roads can have on geomorphic processes and erosion patterns in forested basins. This tool will help forest managers to effectively manage road and road drainage system and hence minimize the negative impacts of forest roads. This tool has the following functionality:

- Calculation of road sediment production.
- Calculation of stream sediment inputs.
- Calculation of terrain stability and the impact of road drainage on terrain stability.
- Identification of road stream crossing for fish passage impassability and analysis of the contiguity and fragmentation of stream network fish habitat.

This information is beneficial for the management of forested lands in Utah.

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Analysis of Water Demand for Utah's Urban Water Supply Systems

Principal Investigator(s):

Bruce Bishop
Veerender Garg

Project Description:

A rapidly growing population and economy in the State of Utah is placing ever increasing demand on the state's water resources. The Wasatch Front Water Demand and Supply Model, which was originally developed in the early 1990's, helped state water management agencies forecast water demand and evaluate supply sources to meet future growth. Now, with the changes over the past decade, the data inputs and demand functions are in critical need of reevaluation, analysis and updating.

Accomplishments:

The project aims at improving the efficacy of the demand function that was proposed to estimate the future water demand in the Wasatch region. Cluster analysis was used as a tool to group the water connections in Salt Lake City into groups or clusters. A water demand function was estimated for each of these clusters using regression analysis. Statistical tests were then performed to verify the efficacy of the demand function. It was found that by clustering the connections based on the persons per household, the predictability of the demand function increased from an r^2 value of 0.29 with no clustering to 0.59 for clustered data sets. The higher correlations for demand functions for connections grouped with cluster analysis should help predict water demand with greater precision.

One paper has been accepted for presentation at the First Western Forum on Energy and Water Sustainability at UC Santa Barbara in March 2007. This paper treats the total number of connections in Salt Lake City using cluster analysis and then develops a demand function for each of the cluster. The results show an improved predictability of the water demand when compared with the demand function derived from all the connections. The analysis also demonstrates that the key dependent variable is persons per household (PPH). Using PPH to cluster the connections into smaller groups helps to increase the correlation of the water demand regression equations, and improve the prediction of future water demand, and plan for sustainable future water use.

In a second paper near completion, clusters were formed based upon characteristics of the connections and then plotted a spatial map using geographic information system (GIS) analysis. The groupings of connections formed using cluster analysis also show a corresponding spatial grouping when plotted on a GIS map of the service area. The clustered connections were also found to be in the same spatial areas, rather than randomly scattered all across the city. Thus, water demand estimation can be improved in both space and time using a combination of cluster analysis and GIS mapping.

Work Plan FY 07/FY 08:

1. Review recent literature on water demand analysis and the data and functions used in the Wasatch Front Model.
2. Evaluate the types, coverage and time series of the data sets assembled by the Utah Water Research Laboratory (UWRL) relative to specifications and requirements for water use/demand analysis.
3. Choose appropriate statistical tools and models to analyze the data and generate statistically significant demand functions.
4. Test the efficacy of the model with input data from the set not previously used in estimating the demand functions.

5. Compare the results with other current studies and the last version of the Wasatch Front model.
6. Prepare papers and follow on proposals appropriate to the results.

Benefits to the State:

The products of the project will provide water managers from the state to local level with new information and tools for analyzing future water use, coping with drought and other current water crises, and implementing new policies (e.g. pricing, landscaping requirements) to modify water use.

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Box Elder County Flood Control Support

Principal Investigator(s):

Mac McKee
Lizzette Oman
Andres Ticlavilca

Project Description:

Heavy rains in 2005, coupled with high groundwater levels and other unfavorable hydrologic and drainage conditions, caused severe flooding conditions and substantial property damage in numerous locations in northeast Box Elder County. This flooding problem is in part to the rate of urbanization of the area and the limited ability of local institutions and the tax base of unincorporated areas to provide flood protection services, especially in periods of exceedingly heavy rainfall.

The project was developed in response to requests for help from Box Elder County officials. The purpose of the project is to assist the county in developing a database for flood control planning and to help them acquire state and federal funding to conduct such planning.

Accomplishments:

In FY 2006, preliminary data were gathered (e.g., land use, stream and canal locations, topographic information, roads and highways, etc.) and placed in a GIS format. Numerous meetings were attended involving representatives of Box Elder County and the Utah Water Research Laboratory (UWRL). Most significantly, staff from the UWRL wrote a proposal to obtain funding for a planning grant from the state. This money is now available to the county to support more detailed flood planning and flood plane mapping.

Work Plan FY 07/FY 08:

Staff from the UWRL will continue to support the planning effort that rests in the hands of Box Elder County officials. Specific tasks that the UWRL will likely complete include the generation of rainfall intensity-duration-frequency curves for the county and continued further assistance in the planning process.

Benefits to the State:

Urbanization is occurring in many of Utah's formerly rural, agricultural areas. Typically, the available tax base and the institutional capacity to deal with the problems of urbanization lag behind the rate of urbanization. As a result, changes occur in the watershed that cause potential problems for drainage (e.g., the elevation and base-width of roads are increased without due attention given to the installation of larger drains; houses are built on lots that were previously agricultural fields, thereby interrupting drainage ditches and other facilities and, as a result, increasing the likelihood of ponding in areas where new, expensive houses now stand). Work in support of the planning activities of Box Elder County and research in the nature and extent of these flooding problems (that are in part a function of rapid urbanization) will help prepare Utah with experience and guidelines in other areas of the state where urbanization is occurring in formerly rural areas.

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Dam Breach Modeling and Extreme Flood Estimation

Principal Investigator(s):

David S. Bowles
Loren R. Anderson
Sanjay S. Chauhan
Wang Zhengang

Project Description:

1. To develop a three-dimensional simulation approach to accurately predict breach hydrographs resulting from the unique characteristics of a specific dam and reservoir if it were to fail under a particular combination of loading conditions and failure mechanism.

2. To develop approaches to developing inputs, displaying results and adapting results for dam failure flood consequences estimation using GIS with the HEC RAS model.

3. To develop a state of the practice presentation on probable maximum flood estimation and approaches to estimating annual exceedance probabilities for a wide range of floods.

Accomplishments:

1. Dam Breach Modeling.

   An erosion and force/moments equilibrium-based numerical method has been proposed to simulate one-dimensional head-cut migration in cohesive embankment overtopping breaches, and to simulate the one-dimensional breach process of zoned embankment dams before they fully breach through (Wang and Bowles, 2006e). At each time step of the simulation, the depths and velocities of the breach outflow are calculated by solving the one-dimensional shallow water equations, three-dimensional slope stability is checked, and the eroded soil and instable soil block are removed. The method was tested using data from a USDA-ARS cohesive embankment and the Yahekou zoned fuse plug. Test results showed that the proposed method predicts well the one-dimensional head-cut shape in the cohesive dam and the breach shape in the zoned embankment dam provided that the inputs are appropriately assigned. Sensitivity studies showed that the breach processes for a weakly cohesive dam under a small overtopping depth and a highly-cohesive dam are controlled by erosion only. They also showed that the breach processes for a weakly cohesive dam under a relatively large overtopping depth, a non-cohesive dam, and a zoned embankment dam are all controlled by erosion and force/moments equilibrium.

2. Applying GIS to Dam Breach Flooding Characterization.

   Our work on Flood Plain Delineation Using GIS and HEC-RAS for Emergency Action Planning and Risk Assessment Studies has been detailed in a Master's Report by Nanadoum (2005). Although our work has focused on using the HEC GeoRAS model, it should be readily generalizable to other one- and two-dimensional flood routing models.

3. PMF Determination and Extreme Flood Probability Estimation.

For the NATO Advanced Research Workshop (ARW) "Extreme Hydrological Events: New Concepts for Security" held in Novosibirsk, Russia Bowles (2005a) summarized the history and development of current practice in determining probable maximum precipitation (PMP), probable maximum storms (PMS), PMF and inflow design floods (IDF). He addressed the important relationship between PMF and extreme floods over a wide range of exceedance probabilities that are needed for characterizing flood loading as an input to dam safety risk assessment. He concluded that there is a lack of consistency in PMF estimates and that use of the PMF leads to a nonuniform dam safety standard. As risk assessment approaches assume a more prominent role in determining adequate dam safety levels, it is expected that the PMF concept will be "retired" and replaced by the relationship between annual exceedance probability and flood magnitude. The need to estimate extreme flood annual exceedance probability (AEP) relationships for dam safety risk assessment has lead to a trend towards abandoning the upper limit concept for the operational PMP, and the need to maximize the use of information from site-specific and regionalized observations and paleohydrology in conjunction with dynamical-stochastic models. The value of prescriptive procedures based on our broadest understanding of the physical limits of hydrometeorological processes for estimating AEPs for extreme floods and the shift in the dam safety decision point from the analyst who prepares the PMF to the owner and regulator as a result of using risk assessment were also recognized. The following important research needs were identified to improve the estimate of extreme floods:

- Improved understanding of the physics for developing extreme rainfall events.
- Improved quantification of storm dynamics and precipitable water.
- Improved physically-based hydrological models for use beyond range of observed events.
- Improved ways to treat uncertainties in dynamical-stochastic models.
- Approximate methods for preliminary and screening studies.

For the US Army Corps of Engineers Workshop on Proposed Methods of Generating the Annual Exceedance Probability of the Probable Maximum Flood held at the Hydrologic Engineering Center, Davis, California in July 2005 Bowles (2005b) described the following approaches that have been used historically as a basis for the design floods:

1. Factored Historical flood at a site or in region.

2. Probabilistic flood based on a prescribed a 1 in T year flood, AEP or Return Period (E.g. 1 in 10,000 AEP).

3. PMF as a reasonable maximum flood.

4. Base Safety Flood as the smallest magnitude of flood for which insignificant incremental consequences of failure occur relative to no failure.

5. Risk Assessment based on Tolerable (Life Safety) Individual and Societal Risk Guidelines.

6. Individual including the concepts of reducing risks "As Low As Reasonably Practicable" (ALARP) and Optioneering.

Work Plan FY 07/FY 08:

1. Dam Breach Modeling.

Non-cohesive embankment dams, cohesive embankments dams, and zoned embankment dams with an impermeable central core have distinct differences in their overtopping breach processes, which can be explained by differences in embankment soil properties. We have developed and tested an erosion and force/moments equilibrium-based three-dimensional (3D) numerical method for the non-cohesive embankment overtopping dam breach (Wang and

Bowles 2006a and b). An application of the model to represent the development of multiple overtopping breaches for a long non-cohesive dam under the actions of wind-generated waves and wave overtopping has also been developed and demonstrated (Wang and Bowles 2006c and d). This year we have developed and tested extensions of our model to simulate the 1D head-cut migration observed in the cohesive embankment dam overtopping breach process and the zoned embankment dam breach process before they are fully breached through (Wang and Bowles 2006e).

2. Applying GIS to Dam Breach Flooding Characterization.

We have developed and tested procedures for obtaining inputs to dam breach flood routing from GIS sources including digital elevation models and soils information. Procedures for displaying results in forms suitable for flood plain delineation and emergency action planning have also been developed and tested. An additional aspect of this project was to adapt results for dam failure flood life-loss and economic consequences estimation using GIS.

3. PMF determination and Extreme Flood Probability Estimation.

The probable maximum flood (PMF) is the design flood for reservoir safety under traditional approaches in some parts of the world including the USA, Australia and the UK. Other parts of the world use a rare flood such as the 1 in 10,000 annual exceedance probability (AEP) flood. Dr. Bowles has considerable experience in advancing the state of the art in PMF estimation as well as applied experience in estimating PMFs for reservoirs throughout the US and overseas, including the entire Snowy Mountains Scheme in Australia. Work focused on the preparation of invited state of the practice presentations on PMF determination and its relationship to the emerging use of dam safety risk assessment at the NATO Advanced Research Workshop (ARW) "Extreme Hydrological Events: New Concepts for Security" and at the US Army Corps of Engineers Workshop on Proposed Methods of Generating the Annual Exceedance Probability of the Probable Maximum Flood.

Benefits to the State:

The approaches to dam breach modeling, flood routing, and extreme flood estimation, which are being improved under this project, will be applicable to dams in Utah. Their application to dam safety in Utah will increase as a direct result of National Dam Safety Program initiatives in both risk ranking and potential failure modes analysis. Our research results are available for use by the Utah State Engineer's Office and practicing engineers in Utah and are being applied by federal dam safety agencies such as the US Army Corps of Engineers, the US Bureau of Reclamation and the Federal Emergency Regulatory Agency. Potential benefits include improved dam break flood delineation, improved estimation of dam failure consequences for dam safety risk assessment, and improved flood estimation for traditional and risk-based approaches to dam safety.

Publications:

1. Dam Breach Modeling.

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Zhu, Y. (2004). *Comparison of One- and Two-Dimensional Hydrodynamic Flood Severity Modeling for Life Loss Estimation*. Master of Science Thesis, Utah State University, Logan, UT.

Zhu, Y. and D.S. Bowles (2003). *Experiment Comparison of MIKE21 and DAMBRK*. Presented at the Second North American Danish Hydraulics Institute (DHI) Software Conference. San Francisco, CA, November.

2. Applying GIS to dam breach flooding characterization.

Nanadoum, K., Supervised by D.S. Bowles and S.C. Chauhan (2005). Flood Plain Delineation Using GIS and HEC-RAS for Emergency Action Planning and Risk Assessment Studies. MS Plan C Report, Utah State University, Logan, UT.

3. PMF determination and Extreme Flood Probability Estimation.

Bowles, D.S. (2005a). Probable Maximum Flood Approach to the Estimation of Design Flood. Invited Key Lecture at the *NATO Advanced Research Workshop Extreme Hydrological Events: New Concepts for Security*, Novosibirsk, Russia. July.

Bowles, D.S. (2005b). Role of Extreme Flood Frequency in Dam Safety Risk Assessment with USACE Examples. Invited presentations at the Workshop on *Proposed Methods of Generating the Annual Exceedance Probability of the Probable Maximum Flood at HEC*, Davis, CA. July.

Dam Failure Life Loss Estimation

Principal Investigator(s):

David S. Bowles
Loren R. Anderson
Terry F. Glover
Sanjay S. Chauhan
Anthony Chen

Project Description:

The overall objective of this project is to develop a practical approach to life-loss estimation and evacuation planning for natural and dam- and levee-failure floods, which overcome the limitations of the purely empirical approaches, while depending on only readily available data sources and requiring only a reasonable level of effort to implement.

Accomplishments:

We have developed LIFESim, a spatially-distributed dynamic simulation approach for estimating potential life loss for dam safety risk assessment. LIFESim has been formulated to overcome the limitations of spatially-lumped empirical life-loss estimation methods, such as the USBR Graham Method (Graham 1999).

The LIFESim development philosophy emphasized the important processes that have been found to affect the magnitude of life loss resulting from major floods, while depending on only readily-available data sources, as described above, and requiring only a reasonable level of effort for implementation. LIFESim comprises the following internal modules: 1) Loss of Shelter, including prediction of building performance; 2) Warning and Evacuation, including a dynamic transportation model component; and 3) Loss of Life, in which empirical fatality-rate probability distributions, developed by McClelland and Bowles (1999) in the first phase of this project, are applied to the number of people estimated by LIFESim to remain in one of three homogeneous flood-lethality zones at the time of arrival of the flood wave. Estimated flood dynamics are obtained from a dam break-flood inundation model such as DAMBRK or HEC RAS and input to the LIFESim model in GIS form.

LIFESim can be run in Deterministic or Uncertainty Modes for user-defined Failure-Event - Population-Exposure settings. The Uncertainty Mode propagates input, model and parameter uncertainties through the model to provide life-loss estimates as probability distributions. These probabilistic estimates are very important because uncertainties will always exist in making dam-failure life-loss estimates. They can be used in uncertainty analyses for dam safety risk assessment as shown by Chauhan and Bowles (2001, 2004) and as commonly used by the USBR.

The Deterministic or Uncertainty Modes of LIFESim have been demonstrated for two USACE dams under a wide range of warning times and conditions and for small and large downstream communities (Aboelata et al, 2004 and 2005). Recently LIFESim was applied for the Interagency Performance Evaluation Team (IPET) to estimate pre- and post-Katrina potential life loss for area protected by the New Orleans Hurricane Protection System for Headquarters, US Army Corps of Engineers, Washington, D.C.

Comparisons between Graham (1999) and LIFESim life-loss estimates have illustrated the difficulties associated with selection of representative Warning Time and Flood Severity categories in the Graham Method, and the lack of explicit consideration of evacuation in the Graham Method (Aboelata et al, 2004 and 2005). These comparisons have also illustrated the benefits of the LIFESim simulation approach in overcoming these and other limitations of spatially-lumped empirical approaches in general.

Input requirements for LIFESim can be classified into several categories. The first three categories characterize the affected area and the evacuation and warning systems in that area, as follows:

1. Area characterization – area-specific GIS data for initial population distribution, building types and occupancy class, road network and characteristics, and topography from databases maintained by the Census Bureau, FEMA and the USGS.

2. Evacuation system – system-specific features including GIS data on emergency shelter locations/evacuation destinations, transportation modal split, and final vertical distribution of people.

3. Warning system – warning system type.

The fourth category is the model relationships that are used in the various LIFESim simulation processes, as follows:

4. Model relationships – user-selected or default relationships from the literature for building performance, time-of-day population activities, warning and mobilization rates, human and vehicle stability criteria, and loss-of-life probability distributions.

The remaining three categories represent the particular flooding event and population exposure event that is run in LIFESim, as follows:

5. Run control parameters - simulation time period and computational time step.

6. Flooding event – event-specific GIS data from dam breach and flood routing model.

7. Exposure event – event-specific time of day and warning issuance time

A final project report (Aboelata and Bowles 2005) and Ph.D. dissertation (Aboelata 2005) were completed and contain a description of the entire modeling system, example applications and guidance on parameterization.

A Simplified Mode of LIFESim was explored using synthetic samples from the Uncertainty Mode for a range of Failure Event - Population Exposure settings. These synthetic samples were to be used to develop an "empirical" technique for life-loss estimation with the goal that for settings that are adequately represented, the Simplified Mode would provide life-loss estimates for preliminary risk assessments at a lower level of effort and avoiding the use of GIS, although with greater uncertainties than the Full Version. The preliminary Simplified Version of LIFESim was developed and initial trials provided some encouraging comparisons with the Full Version. However, the effort needed to prepare manually the Simplified Version inputs was found to be more than that required for obtaining inputs for the Full Version from the readily available GIS sources. In addition, the Full Version would be expected to provide more accurate results than the Simplified Version. Therefore our recommendation is that the Full Version of LIFESim, for which the input effort is quite reasonable, should be used.

The present version of LIFESim is a prototype version. To make it readily available for wider application, a user-friendly version of the software needs to be developed. This Phase 4 work has not yet been funded although the US Army Corps of Engineers has expressed interest in doing so. In the meantime, LIFESim can be applied by its developers to obtain life estimates or to evaluate the effectiveness of evacuation plans.

Work Plan FY 07/FY 08:

The project comprises the following phases:

1. Case history characterizations and analyses (McClelland and Bowles 1999).

2. Development, testing, and demonstration of a Deterministic Mode of the Full modeling system.

3. Development, testing, and demonstration of an Uncertainty Mode of the Full modeling system and a Simplified Mode.

4. Development, testing, and demonstration of user-friendly software for the Full modeling system.

Work on Phases 1 – 3 is now completed.

Benefits to the State:

The approach to dam failure life loss estimation, which is being improved under this project, will be applicable to dams in Utah. The use of dam safety risk assessment for dams in Utah will increase as a direct result of National Dam Safety Program initiatives in both risk ranking and potential failure modes analysis. Our research results are available for use by the Utah State Engineer's Office and practicing engineers in Utah and are being applied by federal dam safety agencies such as the US Army Corps of Engineers, the US Bureau of Reclamation and the Federal Emergency Regulatory Agency. Life loss estimates are needed as inputs for understanding, prioritizing, and justifying dam safety risk reduction measures. The effectiveness of major flood and dam failure evacuation planning can also be improved by using the LIFESim modeling system being developed under this project.

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Dam Safety Risk Management

Principal Investigator(s):

David S. Bowles
Loren R. Anderson
Terry F. Glover
Sanjay S. Chauhan
Mohammad Almasri
Anurag Srivatava

Project Description:

The overall objective of this ongoing research is:

To improve the availability and capability of practical risk-enhanced approaches to dam safety risk management.

Accomplishments:

1. Portfolio Risk Assessment

   Continued advances in portfolio risk assessment, including development of procedures for large portfolios in which screening is needed and for owners that have limited resources, such as those regulated by the states, the use of risk indexes, and for prioritizing investigations. Improved approaches for updating and integration of individual and portfolio risk assessment outcomes into all aspects of dam safety programs (e.g., monitoring and surveillance programs and emergency management) and various business and stakeholder processes. In addition, risk management practices from other industries such as the nuclear, chemical, aviation, space and offshore industries, are being reviewed and adapted to dam safety where appropriate.

2. Tolerable Risk Evaluation

   Further development of practical approaches to using information from tolerable risk evaluation for making dam safety decisions on individual dams and portfolio of dams. This work includes investigation of F-N curves for evaluating societal tolerable risk, the ALARP (as low as reasonably practicable) and disproportionality principles including comparisons with other areas of governmental or business expenditure, setting guidelines for medium-term risk as a progressive risk reduction strategy, establishing a basis for short-term risk reduction measures, and dam safety regulatory impact analysis.

3. Uncertainty Analysis

   Dams exist in an environment of risk and uncertainty. As with traditional approaches to dam safety evaluation, the risk-enhanced approach should address the existence of uncertainties. This work is addressing the following areas:

   a) Characterization of uncertainties associated with the extreme flood frequencies, earthquake hazard relationships, system response relationships and consequences relationships, various functional relationships that affect dam safety, and common cause failure model considerations.

   b) Improved approaches for the propagation of random (aleatory) and knowledge (epistemic) uncertainties in dam safety risk analysis.

c) Evaluation of the significance of uncertainties in risk analysis and risk evaluation results including the use of multiple regression analysis and correlation procedures, and assessing their implications for dam safety decision-making.

d) Guidance for decision makers for the interpretation of the uncertainties in risk assessment outcomes.

4. Dam Safety Risk Analysis Engine

Proprietary software developed for business risk analysis applications is ill-suited for use in dam safety risk assessment. Major weaknesses include a lack of capability for handling continuous initiating events such as floods and earthquakes and associated system response probability and consequences assignments to event tree branches. Other areas of weakness are the requirements that branching is only binary and limited capability for tracking event tree results and presenting them in suitable graphical and tabular forms, including F-N charts. In practice these limitations have been addressed through the use of spreadsheets, sometimes including Visual Basic macros. However, this approach lacks generality and can require significant effort to apply to a specific dam or to modify the event tree structure.

In response to these limitations, we are developing a generalized dam safety risk analysis model using VB.net and MS Access Data Base with the following major capabilities:

a) Event tree construction is conducted graphically and includes flexible options to update the event tree by, for example, inserting or deleting branches. The event tree and other inputs are stored in a database. The event tree can comprise discrete and continuous branches, where the continuous ones would be for example the flood (e.g. peak reservoir pool elevation) or earthquake (e.g. peak ground acceleration or magnitude) loading variables, which can be represented by a range of intervals that can be varied in number and size to achieve numerical precision. The event tree also includes state functions for relationships between variables in the event tree, such as stage-discharge, stage-duration and estimates of vertical and horizontal deformations in response to earthquake loading.

b) Probability, consequences and state variable relationships can be input as assigned numerical values, equations or tables for interpolation; in the latter two cases, values can be calculated or interpolated as a function of state variables that are located to the left of the variable to be calculated in the event tree.

c) Structuring event tree calculations based on the event tree graphic, which is built on the screen. This involves creating a "pedigree", which is a unique address for each end node in the event tree that indicates every level of branching that is passed through to reach an end node. In addition to making the probability calculation possible with all the different conditional probability relationships that can exist, the pedigree is stored in the database to obtain information about the contributions of different factors to the overall risk. The pedigree concept is the key to implementing this flexible approach to event tree modeling for dam safety risk analysis and represents a significant contribution from this work.

d) Basic risk calculations commence with the assignment of state variable values, probabilities and consequences to branches in the event tree and continue with the calculation of branch probabilities, annualized life loss and annualized economic loss (risk cost), although "probability-consequences pairs" are also stored in the data base for post-processing. Probability calculations are structured in a general form that includes the common cause adjustment for non mutually-exclusive events.

e) Post processing of the basic risk calculations results will include tabular and graphical outputs with flexibility in formatting based on the event tree structure and user needs, including risk evaluation using a range of tolerable risk guidelines.

A demonstration version of the risk analysis software is being developed for proof of concept. It is being tested using the Success Dam Earthquake and Flood event trees (Bowles et al 2005), which include a wide range of requirements including a common cause adjustment.

Additional developmental work will be needed to add capability to efficiently handle risk reduction measures, sensitivity analyses, and uncertainty analyses; although the prototype version has been built with these in mind.

5. Guidance on Dam Safety Risk Management

Technical notes are being prepared and updated on a series of topics and made available through the Institute for Dam Safety Risk Management at USU. Dr. Bowles is serving as a reviewer, advisor or author for guidelines for dam safety risk analysis and risk assessment that are under development by various organizations including the American Society of Civil Engineers, Federal Energy Regulatory Commission, International Commission on Large Dams Canadian Dam Association and New South Wales Dam Safety Committee (State Dam Safety Regulator), Australia.

6. Seminars and Workshops

Further development and presentation of briefings, seminars, and workshops to professional groups in the United States and overseas.

Work Plan FY 07/FY 08:

For more than two decades, Utah State University (USU) researchers have developed procedures that explicitly consider the risks associated with the performance of dams. They have also applied these procedures to about 500 dams in Utah, in other parts of the United States (including dams owned by the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers, and regulated by the Federal Energy Regulatory Commission) and in Australia and England. Information obtained from these applications has provided valuable bases for many decisions to improve the safety of existing dams. Applications have provided an opportunity to field-test procedures and have lead to the identification of additional research needs. Training programs have been given on six continents and to major federal agencies with dam safety responsibilities. International guidelines have been contributed to and national, regulatory and federal agency guidelines have been reviewed.

This research project is advancing the state of the art and the state of the practice in dam safety risk management in several areas, in the following areas:

1. Portfolio Risk Assessment.
2. Tolerable Risk Evaluation.
3. Uncertainty Analysis.
4. Prototype Dam Safety Risk Analysis Engine.
5. Guidance on Dam Safety Risk Management.
6. Seminars and Workshops.

Benefits to the State:

The approaches to dam safety risk management being developed under this project are applicable to dams in Utah. It is expected their use for dams in Utah will increase as a direct result of National Dam Safety Program initiatives in both risk ranking and potential failure modes analysis. Our research results

are available for use by the Utah State Engineer's Office and practicing engineers in Utah and are being applied by federal dam safety agencies such as the US Army Corps of Engineers, the US Bureau of Reclamation and the Federal Emergency Regulatory Commission. Benefits are expected to include improved understanding, prioritization, and justification of dam safety risk reduction measures.

Publications:

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Economic Worth of Data in Water Resources and Water Quality Analyses

Principal Investigator(s):

Jagath J. Kaluarachchi
Ashraf Shaqadan

Project Description:

The objectives of the project are to:

1. Develop a common methodology to quantify the economic worth of data in water resources planning and management and water quality analysis.
2. Collect data from selected field sites representing water resources problems, water quality concerns, and water policy issues.
3. Demonstrate the applicability of the proposed methodology in each of these scenarios.

Accomplishments:

The work on Tasks 1 and 2 are complete. The remaining tasks are currently undergoing.

Work Plan FY 07/FY 08:

The following tasks will be completed to address the objectives of the research:

1. Literature review to identify existing work similar to the proposed objectives in water sciences or other areas.
2. Identify candidate field site with different problems and gather available data from each site.
3. Develop the methodologies to predict the worth of data.
4. Apply the methodology to the individual case studies and demonstrate the applicability.

Benefits to the State:

Collection of data for water resources planning and management and water quality assessment is a crucial step. Typically, such data gathering efforts are expensive and time consuming. Therefore, a sound scientific understanding of the value of data is important in resource allocation, especially in decision-making to collect additional data and information. In summary, this is a common global issue in water resources and environmental management and applicable to watershed planner and managers in Utah.

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Forecasting Irrigation Water Demand in the Sevier River Basin

Principal Investigator(s):

Todd K. Moon
John Flake

Project Description:

The project consists in taking data which have been collected from the automated Sevier River Basin control system and from other sensors in the vicinity of the canal, and developing a model for it. The basin control system consists of automated gates, as well as a system of level and flow sensors. Sensor data is logged online. In addition, weather data, such as precipitation and temperature data, is also used. Several years of data are available, for several different canals.

The predictive model is being built using relevance vector machines. Various input values are used, including previous period's water, evapotranspiration data, etc., then trained to match the recorded demand data.

The overall problem is to develop a machine-learning model which takes the data and "mines" it by developing a model which predicts the flow.

The initial objective is to train a model which predicts the flow in a single canal (the Richfield Canal) over the period of one season. Various prediction periods are used. We first start with a short prediction, then move up to predicting delays roughly comparable with the transit time in the canal (which could be as long as five to six days).

Having gained some experience on a single canal, the next objective is to train a similar machine on a different canal (the Brooklyn Canal), to see how much of the same technique generalizes to different canals.

Accomplishments:

The work began in January of this year. To date, we have developed several different models, but are still refining the results.

The following plot (Figure 1) shows an instance of our predictor. The blue line shows actual flow for the Richfield canal. The red line shows the result of the RVM predictor. Results are shown from late April until late May (the first hay crop period). Input data include an annual date, evapotranspiration data, and previous flows.

As is clear from this result, the model is not perfect. In fact, it starts off with a significant error, but it fairly quickly seems to catch on to the problem and does a good job of "learning" the operation of the canal by the end of the period.

Work Plan FY 07/FY 08:

The plan is partly described in the approach. More specially, we are using support vector machine (SVM) and relevance vector machine (RVM) toolboxes that run in Matlab. We are applying various sorts of input/output data to see which matches best in terms of flow, measuring mean-square and mean flows. A very large number of experiments have been performed to see which variable best work for the predictor.

Benefits to the State:

In this project, we are attempting to construct a predictive model for water demand in the Sevier River Basin. Such a model will allow better use of the water resources in the basin. First, by having a good predictive model, releases from the dam can be controlled to minimize fluctuation, which will result in reduced seepage losses. Second, the predictive model can be used to assist water managers so that water needed is actually supplied. Third, the model is trained based on current practice. This will provide a mechanism by which the knowledge of the water manager is captured for use in the future.

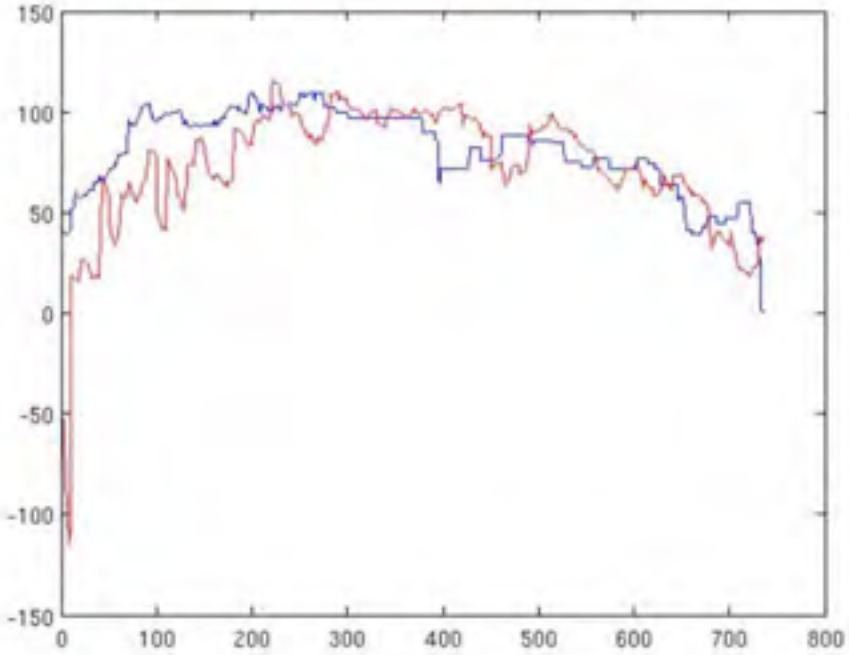

Figure 1.

Green River Canal Sedimentation and Flow Distribution Project

Principal Investigator(s):

William J. Rahmeyer
Mac McKee
Mike Stoeber
John Newton
Stewart Edwards
Jan Miller

Project Description:

The Green River Canal is experiencing serious sediment deposition at several locations along the canal. The physical removal of the sediment is too costly for the Green River Canal Company and farmers to remain in business. The Utah Water Research Laboratory (UWRL) is investigating possible management practices that could reduce or prevent the buildup of sediment in the canal.

The principal objective of this project is to provide information to the Green River Canal Company regarding the sediment material found in the Green River Canal as a result of the sedimentation process. This includes grain size distribution and a classification of the types of soils present, and the minimum velocity required to maintain suspension of the silt particles entering the irrigation canal. A second objective is to create an accurate map of the Green River irrigation canal including the location of all turnouts, returns, and check gates to aid the Green River Canal Company (GRCC) in locating, governing, and maintaining the irrigation structures in their system. The third objective is to create a spreadsheet accounting model which describes the operating conditions of the canal and allows canal operators to minimize sedimentation by identifying potential problem areas. The fourth objective is to provide the GRCC with a set of operational guidelines for the Green River irrigation canal, and which also describes how the Green River Canal model functions. The final objective is to provide the GRCC with recommendations for canal operation in order to limit sedimentation.

Accomplishments:

Several site visits have been conducted where data was collected on sediment, flow distribution, and flow velocities. A map of the canal has been created using ArcGIS software. A flume study at the UWRL was conducted with sediment from the canal to determine the minimum velocities necessary to prevent sediment deposition. A numerical model has been created to aid in the operation of the canal.

Work Plan FY 07/FY 08:

Research on the canal will continue until the objectives are met. Findings will be presented to the Green River Canal Company.

Benefits to the State:

Since irrigation of farmland using canals is so prevalent throughout Utah, understanding of the sedimentation problems involved with this type of irrigation through the research conducted for this project will not only benefit the Green River Canal Company and the City of Green River, Utah, but many other canal systems in Utah.

Implementation of a Closed-Loop Real-Time Irrigation System for Scipio, Utah

Principal Investigator(s):

YangQuan Chen
Mac McKee
Roger Hansen, US Bureau of Reclamation
Christophe Tricaud
Varsha Bhambhani

Project Description:

If sufficient soil moisture data were available, it would be ideal for purposes of achieving more efficient management of irrigation water supplies to consider the irrigation control problem, involving the entire irrigation system from reservoir storage to on-farm application, as a closed-loop system. Lacking this detailed database, however, the current practice is to use estimates of evapotranspiration (ET) based on calculations from weather-station information. However, the ET-based representation is an open-loop system because soil moisture is not directly controlled. The irrigation system in Scipio, Utah, is an ideal site to implement a truly closed-loop real-time irrigation system. We consider first the ET-based closed-loop irrigation system using the matured data collection and retrieval technology as represented in the Sevier River Basin. Eventually, we will consider how to integrate soil moisture sensors to make a true closed-loop real-time irrigation system.

The fundamental objective of the study is to find ways to utilize the readily available system information about the Scipio irrigation system on flows and pond and reservoir pool elevations to improve overall irrigation system efficiency by incorporating real-time closed loop thinking.

Accomplishments:

- Better understanding the research problem.
- Literature review.
- On-line gage data exploration and analysis for prediction purposes.
- Modeling of the whole system and simulation of some control algorithms.

Work Plan FY 07/FY 08:

The Scipio irrigation system is not fully instrumented and web-enabled. As a result, the starting point will be installation of the automation equipment, to be accomplished by Dr. Roger Hansen's team at the U.S. Bureau of Reclamation. Initially, control of the pond level will be investigated to make it robust and reliable under uncertain demands. When the entire irrigation system is web-enabled, closed-loop real-time control algorithms will be evaluated for the purpose of optimizing the operation. In addition, use of soil moisture sensors will be evaluated from the perspective of achieving a true closed-loop control system. Some theoretical and simulation studies will be performed to address the optimal sensor location problem and the irrigator location problem. These research efforts could fit nicely into a multiyear program.

Benefits to the State:

Irrigated agriculture accounts for more than 85 percent of Utah's total water use, yet most irrigation systems experience very large water inefficiencies. Greater water use efficiencies can be obtained through more intensive management. This project will benefit the irrigators in Scipio and, through their experience and the lessons learned in this research, other irrigators in the Sevier River Basin and Utah more generally, through the development and application of advanced control techniques to improve management of the irrigation water delivery system.

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Improved Dam-Breach Flood Plain Inundation Mapping

Principal Investigator(s):

Sanjay S. Chauhan
David S. Bowles
Brian Stevens

Project Description:

Inundation maps are a useful decision-making tool for emergency management, flood warning, and evacuation. Unsteady flow models such as DAMBRK, FLDWAV, and HEC-RAS are available for dam breach analysis. Advanced GIS tools are also available for processing the terrain data and displaying the results of breach analysis to develop inundation maps. Despite these technological advancements, their application seems to lag in practice due to laborious and time consuming steps involved in their use. Objectives are:

1) To review the state-of-the-practice in dam-breach flood modeling and inundation mapping using GIS tools.

2) To develop a list of possible improvements to capabilities that have already been implemented in an earlier project funded by the Corps of Engineers.

3) To develop an improved GIS-based inundation mapping system to automate the routine tasks for model development and to efficiently transfer and display the dam-breach modeling results in GIS to develop inundation maps.

Accomplishments:

Literature review and identification of potential improvements has been conducted.

Work Plan FY 07/FY 08:

Procedures for obtaining inputs to dam breach flood routing from GIS sources including digital elevation models and soils information, and displaying results in forms suitable for flood plain delineation and emergency action planning have been developed and tested (Nanadoum 2005) on an earlier project funded by the US Army Corps of Engineers. Dr. Chauhan has considerable experience in dam breach modeling using Dambrk and HEC-RAS computer applications. In this project we plan to recalibrate by reviewing the state-of-practice in breach modeling and inundation mapping using GIS tools and computer automation. A list of possible improvements to the time consuming steps involved in the process will be developed based on the review of previous experience on breach modeling and inundation mapping projects. An improved GIS-based inundation mapping system will be developed and tested on a case study of a dam in the State of Utah.

Benefits to the State:

The State of Utah will benefit from our work by having a tool to develop consistent and efficient GIS-based inundation maps for its dams. It will be of help to the state's overall emergency management preparedness.

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Internet-Based Viewer for Utah's Native Fish Species

Principal Investigator(s):

Jeffery S. Horsburgh

Project Description:

This project aims to address the needs of 4th and 9th grade students and teachers for tools and information to learn more about Utah's native fish species. The current software requires a software installation on each machine, and is limited to PCs running the Windows operating system.

The objectives of this work are to create a software application that can be used by 4th and 9th grade students and teachers in the State of Utah to learn more about Utah's native fish species and to eliminate the need for a software installation to use the tool.

Accomplishments:

A Utah's Native Fishes viewer website has been developed and implemented at:

http://water.usu.edu/utahfish/

Work Plan FY 07/FY 08:

Program the software application in Visual Studio .Net and implement the Internet-based Utah's Native Fishes Viewer on a computer server based at the Utah Water Research Laboratory (UWRL).

Benefits to the State:

This project will provide an Internet-based software tool that 4th and 9th grade students throughout the State of Utah can use to learn more about Utah's native fish species, which is part of their regular curriculum. Teachers throughout the state can use this software in their lesson plans for teaching students about Utah's native fish species.

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

Principal Investigator(s):

Mac McKee
Kashif Gill
Yasir Kaheil
Andres Ticlavilca

Project Description:

As water demands increase in the western states and as concerns for endangered species and water quality begin to affect the allocation of water resources, greater emphasis will have to be placed on efficient water management if existing water rights are to continue to be met. Improvements in efficiency of water management require a low-cost mechanism for obtaining and distributing information about the state of the water supply system. The object of this project is to develop and add significant data analysis functionality to the existing Sevier River Water Users Association (SRWUA) web site to support real-time and long-term water management information needs.

Accomplishments:

In prior years, real-time operations models were developed using methods from statistical learning theory. These include artificial neural network (ANN) models, support vector machine (SVM) models, and "lazy learner" (LL) models. These models have been constructed to help provide real-time management information for determining releases from Piute Reservoir and diversions into the Sevier Valley/Piute Canal. The models have been made available to the SRWUA for implementation on their website and for use by reservoir and canal operators. Short-term predictive models were also built using artificial neural network approaches to forecast diurnal flows from Clear Creek into the Sevier River.

Long-term predictive models were also constructed in prior years to forecast stream flows at the Hatch gage in the Upper Sevier River Basin. These predictions come from an artificial neural network model that uses historical stream flow data, Snotel data, and sea surface temperature anomaly data from the Pacific and Atlantic Oceans.

Previous work focused on development and statistical verification of an hourly operational model for predicting required releases from Piute Reservoir. The modeling process utilizes a combination of support vector machines and relevance vector machines (RVMs) to screen incoming data to recognize outliers and/or "drift" in the underlying probability distribution of the input data, develop a revised predictor model if drift in the underlying distribution is detected, and then make a prediction for required reservoir releases for the next hour. Adoption of the RVM approach for developing the predictor model has provided the capability of estimating confidence intervals on the prediction made by the model. This capability, which has not been previously possible, gives the reservoir operator valuable information about the uncertainty in the prediction made by the model. The suite of models is designed to run in real time and to provide the reservoir operator with an hour-by-hour recommendation for releases needed from the reservoir in order to meet downstream demands for nine irrigation canals. It does this in order to meet water orders that arrive 24 to 48 hours in advance of deliveries, even though travel times from the reservoir to the end of the furthest canal is on the order of five or six days. The suite of models was developed using data from the 2001 and 2002 irrigation seasons, and then tested against the 2003 and 2004 irrigation season. This suite of models was reprogrammed in FY 2006 to run on the SRWUA computers. In cooperation with the SRWUA, Stonefly Inc. (who maintains the SRWUA website), and the Provo, Utah, office of these programs have been linked to the gate controllers of Piute Reservoir, making it operationally possible for these programs to run the reservoir in real-time without intervention by a human.

Work began in FY 2006 to install approximately 50 soil moisture probes in the Delta, Utah, area of the Sevier River Basin and to link them into the automated data collection network that is run by the SRWUA. Further, two downscaling algorithms were developed in FY 2006 to interpolate coarse-scale satellite or aerial photographs to a finer resolution. These algorithms will be used to combine data from the real-time soil moisture probes and available satellite imagery to prepare fine-scale estimates of soil moisture on irrigated areas in the Sevier River Basin. In addition, a model for predicting short-term changes in soil moisture (say, for one to seven days in advance) was also developed and tested.

Several publications were produced by this project in FY 2005 and FY 2006 and published in the highest quality peer-reviewed journals.

Work Plan FY 07/FY 08:

Work will continue on development of short-term forecasting of irrigation demand. This will include the completion of the installation of the soil moisture probes in the Delta area, and linking them into the automated data collection network that is run by the SRWUA. Work was begun on this task in 2006 and will be completed prior to the beginning of the 2007 irrigation season. The data from these probes will be analyzed using the upscaling/downscaling algorithms that were developed this year to estimate changes in soil moisture in fields served by specific canals. This information will be used to estimate a continuous soil moisture water balance for irrigated lands and, when this balance falls low enough in given areas, to estimate the irrigation requirement that farmers will be requesting over a five-day period. These predictions will be used to anticipate future water demand and provide better information to canal and reservoir operators.

Benefits to the State:

Application of this and related technologies in the Sevier River Basin in the past several years have already shown a dramatic increase in 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. These forecasting techniques could potentially provide valuable information for better long-term decisions by farmers and ranchers for investments in crops and livestock, especially in years where drought might be likely. Similarly, the short-term forecasting methods could supply system managers with information necessary to more precisely control the operation of large irrigation systems, thereby saving water and increasing the overall productivity of the system.

Publications:

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Stormwater Management in Irrigation Canals

Principal Investigator(s):

Gary P. Merkley
Alfonso Torres

Project Description:

The problem description is twofold:

1. Stormwater runoff enters several Cache Valley irrigation canals during rainstorms, often causing over-topping of the canals and damage to adjacent properties. These canals were never designed to handle stormwater runoff, but have been obligated to serve in this function due to increasing urbanization in formerly agricultural areas.

2. The stormwater runoff issues, which have been exacerbated in recent years, have brought to light various areas of improvement in canal operation and maintenance by the canal companies. Thus, walkthrough operation and maintenance surveys were needed to document the existing practices and the areas in which improved practices might have the greatest beneficial impact.

Accomplishments:

Seven digital shaft encoders were purchased for placement at existing flow measurement structures in irrigation canals in Cache Valley, Utah. Five radio transmitters with antennas and three data loggers were also purchased for the transmission and recording of water level data. A summary of the installation work completed as of November 16, 2006 is given in Table 1. Five of the seven encoders have been installed and calibrated. A repeater tower was placed on the roof of the Engineering Building at Utah State University (USU), and all radio transmission systems including power supplies have been installed and are functioning. The data loggers are currently being programmed to interface with the digital shaft encoders.

The installation of a data acquisition and radio telemetry system is currently underway on irrigation canals of Cache Valley, Utah as a collaborative water management project involving USU and the Utah Division of Water Rights (UDWR). Installation and programming of the digital shaft encoders and data loggers is being done by Evan Thompson, undergraduate student in Biological and Irrigation Engineering (BIE), under the direction of Dr. Gary Merkley, professor in the Biological and Irrigation Engineering Department at USU. They are assisted by Alfonso Torres, graduate student in BIE, and Omar Alminagorta, also a graduate student in BIE. The radio telemetry system was installed under the direction of Aaron Hunt, a UDWR employee in Cache Valley.

The project consists of installing a data acquisition and telemetry system, along with a power supply, at each proposed site. Where radio signal was unavailable due to vegetation, buildings, or other obstructions, a data logger was used in place of a telemetry system to record, rather than transmit, flow data. A summary of project components and their respective uses is given in Table 2. A small shelter houses the data acquisition system, protecting it from the weather and vandalism. The shelter rests over a stilling well, and the depth of water in the well corresponds to the depth of the water in the canal. The digital shaft encoder is connected to a pulley with a float and counter weight that is placed in the stilling well. A steel pole was cemented into the ground next to each shelter for mounting of the radio telemetry system and power supply.

Telemetry System

Repeater Antenna. In order to transmit flow data from various locations around Cache Valley to the UDWR base station, a system of repeat towers was necessary. One such repeater tower was placed on the roof of the Engineering Building at USU and is seen in Figure 1. The installation took place on June 19, 2006.

Radio Transmitter and Antenna. At each site with radio reception, a radio antenna and transmitter were installed to establish signal connection with the repeater antenna. They were mounted to the steel pole that was previously installed.

A 900 MHz, 9dBi Yagi Antenna manufactured by HyperLink Technologies was purchased and installed at each site. They were coupled with an XStream-PKG-R RS-232/485 RF Modem manufactured by MaxStream. The modem, or transmitter, has a range of up to 20 miles with a high gain antenna. The transmitter uses an RS-232 serial port to receive data from the encoder, thus it was used in conjunction with a signal converter.

Signal Converter. As the encoder outputs the signal in SDI-12 form and the radio transmitter only has an RS-232 input, a signal converter was necessary. This was accomplished with a RS-232 to SDI-12 Host Interface manufactured by Water Log Series.

Data Acquisition

Digital Shaft Encoders. At each site, a digital shaft encoder replaced the old Steven's Recorder. Installation procedures varied slightly at each sight, as the existing shelters were all found in different condition. A map of installation locations is given in Figure 2.

Logan Northern Canal. The first encoder was installed on September 11, 2006 in the shelter on the parshall flume near the beginning of the Logan Northern Canal. Bushes and shrubs were trimmed back to from the work area and access trail. A new board was measured and cut to fit into the house, as the existing board had many holes in it and was deteriorating. Holes were drilled in the new board for the cable to run through. The encoder was mounted on the board using three screws. A one-eighth inch cable pinch was purchased for attachment of the cable to the float and counter weight. The installed encoder is seen in Figure 3.

Crockett Canal. The second encoder was installed on September 13, 2006 in the shelter next to the parshall flume. In this case, the existing board over the stilling well was in good condition and the new encoder was simply mounted next to the old Steven's Recorder as seen in Figure 4. The same cable pinch as used in the installation of the first encoder was also used in this case.

Benson Canal. The third encoder was installed over the stilling well on the parshall flume at the Benson Canal, west of Logan, on September 19, 2006 and is displayed in Figure 5. In this case the stilling well was only big enough to fit one float, so the Steven's Recorder was removed. Although there were many holes in the existing board covering the well, it was in otherwise good condition and was found to be adequate for mounting the new encoder. One of the existing holes was used and a new hole drilled for the beaded cable to pass through. The recorder was mounted using only two screws, due to a seam in the board running down the middle of the encoder, exactly where the third screw was to be drilled.

Providence Canal. The fourth encoder was installed at the Providence Canal on September 29, 2006. Although the existing board had many holes already drilled in it, none of them matched up perfectly, so one new hole was drilled. The beaded cable was run through the holes and the encoder mounted to the existing board over the stilling well, as shown in Figure 6.

Northwest-Field Canal. The fifth encoder was installed on October 18, 2006 on the broad-crested weir at the beginning of the Northwest Field Canal, behind the old "Anderson Mill," which is currently "Design West." In addition, a radio antenna was installed on the roof of the Design West building to provide radio signal for the encoder to be connected to the telemetry network. All necessary wiring was run from the top of the building to the shelter below that houses the encoder. The encoder was placed on a new board and holes were drilled for the cable. The antenna and encoder are shown in Figures 7 and 8, respectively.

Power Supply

At each location a 20 watt solar panel was installed to provide continuous power to the battery. A sealed, lead-acid 12-volt, 24-amp-hour battery was used at each site. A 4.5-amp solar controller was also installed to prevent the solar panel from overcharging the battery. The batteries were placed in the shelters along with the encoders, while the solar panels and controllers were mounted on the steel pole that was previously installed, as seen in Figure 9.

Timeline for Completion

Solar panels, solar controllers, and one battery are still needed in order to maintain year-round power supply at sites using the data loggers. All other equipment has been obtained. A timeline and summary of remaining work is given in Table 3. Programming of the data loggers to interface with the encoders can be done throughout the winter. However, calibration will require water in the canal, and many of the canals throughout Cache Valley have little, if any, water at this time of year. As a result, calibration of encoders will be done as soon as the canals begin to fill again.

Since radio communication was established at the Logan Northfield Canal behind Design West, one extra data logger remains unused. A location for this data logger has yet to be determined.

Work Plan FY 07/FY 08:

- Document operation and maintenance issues in Cache Valley irrigation canals.
- Suggest improvements in operation and maintenance practices by canal companies.
- Install new water level recorders and connect them to a telemetry system for real-time monitoring of flow rates at key locations in Cache Valley irrigation canals.
- Design new flow measurement structures for improved water management in Cache Valley irrigation canals.

Benefits to the State:

This project has already resulted in significant water management improvements in Cache Valley by better quantifying flow rates (greater accuracy and more frequent measurements) at key locations in irrigation and drainage canals, and by improving operation and maintenance practices by the canal companies. These improvements are expected to result in the sustainable conservation of water for irrigated agriculture, municipalities, and industry, as well as ameliorate technical and legal problems associated with the excessive stormwater runoff into the canals during rainstorms.

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Table 1. Summary of Completed Digital Shaft Encoder Installations.

Location	Data Collection	Installation Date
1. Logan Northern Canal	Radio Transmitter	9/11/2006
2. Crockett Canal	Radio Transmitter	9/13/2006
3. Providence Canal	Radio Transmitter	9/29/2006
4. Logan Northfield Canal	Data Logger	-
5. Beginning of Logan Northwest Field Canal	Radio Transmitter	10/18/2006
6. Smithfield Hyde-Park Canal	Data Logger	-
7. Benson Canal	Radio Transmitter	9/19/2006

Table 2. Summary of Project Equipment.

Equipment	Use
Telemetry System	
Repeater Antenna	Relay radio signal to base station at UDWR
Radio Transmitter and Antenna	Send flow measurements to repeater antenna
Signal Converter	Convert SDI-12 signal from encoder to RS-232 for radio transmission
Data Acquisition	
Digital Shaft Encoder	Measure depth of flow in canal and transmits via SDI-12 signal
Data Logger*	Record depth measurements from encoder and convert to flow rate
Power Supply	
Solar Panel	Gather sunlight and convert to power
Solar Controller	Prevent solar panel from overcharging the battery
Battery	Provide power to the system

*only used on sites where radio reception is not available

Table 3. Timeline for Project Completion.

Details	Expected Date of Completion
Purchase Remaining Power Supplies	November, 2006
Installation of Remaining Encoders	November, 2006
Programming of Data loggers	February, 2007
Final Calibration of Encoders	March, 2007

Figure 1. Aaron Hunt and Alfonso Torres install the repeater antenna on the roof of the USU Engineering Building.

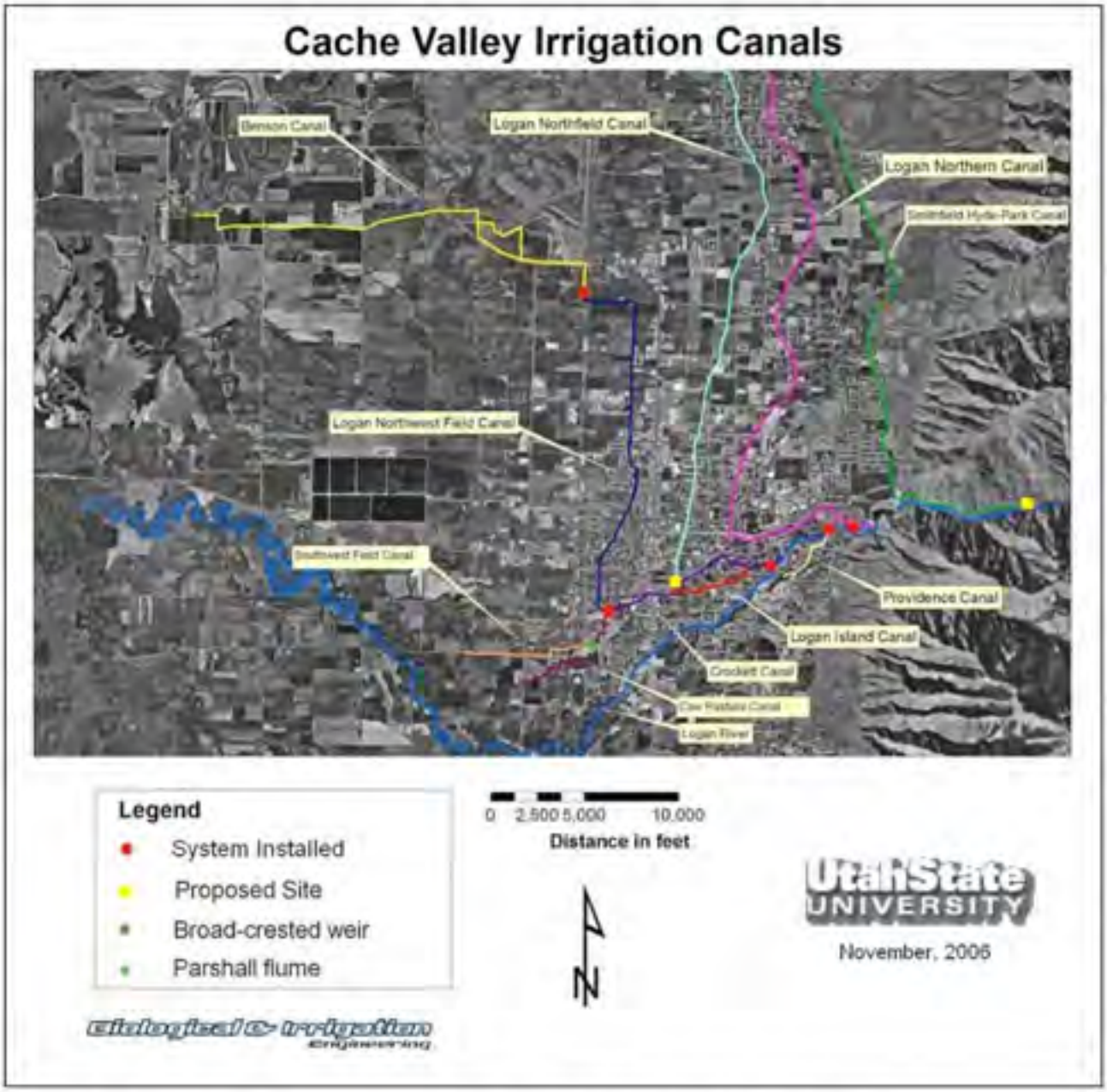

Figure 2. Map showing completed and proposed sites of installation of digital shaft encoders.

Figure 3. New digital shaft encoder over the stilling well on Logan Northern Canal

Figure 4. Digital shaft encoder next to an old Steven's Recorder at the Crockett Canal.

Figure 5. Evan Thompson checks the cable on the installed digital encoder at the Benson Canal.

Figure 6. Encoder ready to be installed after passing the cable through the drilled holes in the shelter at the Providence Canal.

Figure 7. Antenna and Solar Panel on roof of Design West, as seen from below at the Logan Northfield Canal

Figure 8. Digital shaft encoder in the shelter at Logan Northfield Canal.

Figure 9. Aaron Hunt works on the solar panel and controller at Logan Northern Canal.

The Lower Provo River Bifurcation and Channel Restoration Project

Principal Investigator(s):

Thomas B. Hardy
Andrew Hall
Johathan Bingham
Ren Bagley

Project Description:

June sucker fry on their out-migration from the Provo River to Utah Lake face intense competition and predation from introduced species. Increasing the survival of this limiting life stage is key to the long-term restoration and delisting of the species.

Provide preliminary design evaluations for an artificially constructed rearing channel and bypass structure for June suckers on the lower Provo River for use by the Utah Endangered Species Program in evaluating targeted restoration projects.

Accomplishments:

Field data collection and processing for the existing channel topography of the Provo River in the vicinity of the proposed artificial rearing channel as well as the channel topography along the alignment of the proposed channel have been completed. Preliminary hydraulic model calibrations are complete, and work continues on the remaining technical evaluation efforts.

Work Plan FY 07/FY 08:

A technical approach has been outlined that included field data collection, hydraulic modeling of the Provo River and theoretical design channel, and design of a bypass structure suitable for use with June suckers.

Benefits to the State:

This project will provide the preliminary feasibility design and proof of concept for a specific restoration project on the Provo River that will ultimately lead to improvement in endangered fish habitat and recruitment.

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Virgin River Decision Support System

Principal Investigator(s):

Thomas B. Hardy
Jeffery S. Horsburgh

Project Description:

A wealth of data, such a streamflow, water quality, and fish habitat, are available from many different agencies and organizations that can be used to inform watershed management decisions. Data visualization, manipulation, and management tools are needed to combine these data for better-informed decisions in managing the Virgin River basin.

Create software applications that provide watershed managers with better tools for data visualization, manipulation, and management.

Accomplishments:

The project is on-going. The software has been distributed to managers in the Virgin River Basin who have requested modifications based on changing data acquisition needs and capturing of historical sampling data.

Work Plan FY 07/FY 08:

The DSS software will be programmed in Visual Studio .Net and distributed to watershed managers and interested stakeholders. This includes conversion of the existing Virgin River Fishes Database and Basinwide Assessment applications.

Benefits to the State:

The Virgin River decision support system (DSS) provides watershed managers in the Virgin River basin with data manipulation and visualization tools that assist them in better managing the Virgin River where water supply and endangered fish species are of concern.

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Virgin River Watershed Planning Support

Principal Investigator(s):

Thomas B. Hardy
Ekaterina Saraeva

Project Description:

Existing efforts of the Virgin River Program are targeting selective watershed planning efforts that include evaluation of stream protection and enhancement that will benefit native fish species and related aquatic resources within the Virgin River Basin. The Utah Water Research Laboratory (UWRL) has completed a basin wide assessment of the main stem Virgin River and its principal tributaries that have identified specific river segments where protection and/or enhancement actions would benefit native fish species. These results can now be utilized to formulate specific management actions that require further technical evaluations.

The objectives of this work is to refine the field based and associated technical assessments to allow the Virgin River Program to conduct cost-benefit assessments of various proposed strategic watershed restoration actions.

Accomplishments:

Preliminary ground based assessment locations were identified and provided to Virgin River Program participants. However, emergency non-native fish eradication efforts, extensive flooding, and coordination delays resulted in this project being deferred into FY 2007.

Work Plan FY 07/FY 08:

These assessments will be conducted through a collaborative field and analysis effort with the state and federal resource agencies working through the Technical Committee of the Virgin Program. Due to other Program priorities and coordination timing this work was deferred into FY 2007.

Benefits to the State:

This effort will provide critical field data, analyses, and modeling results for use in strategic watershed planning in the Virgin River Basin under constraints imposed by endangered aquatic species.

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Water Resources Analysis and Optimal Allocation Strategies for Salt Lake Valley, Utah

Principal Investigator(s):

Jagath J. Kaluarachchi
Wafa Hassan

Project Description:

The objectives of the project are to:

- Assess the water resources in the Salt Lake Valley and forecast future water demands based on population growth and land use changes.
- Develop a methodology to optimize allocation of existing water resources in the future based on proposed land use changes while considering water quality impacts and economic productivity.
- Demonstrate the applicability of the methodology and provide guidelines and suggestions to improve existing water allocation policies.

Accomplishments:

The work related to Tasks 1-3 has been accomplished. The work related to other tasks is currently undergoing.

Work Plan FY 07/FY 08:

The project work consists of the following research tasks:

1. Gathering existing information related to water resources, economic growth, environmental concerns, and pollution in the Salt Lake Valley.
2. Analyze the data and information to assess the current situation of water in the Salt Lake Valley.
3. Develop models to predict the future water demands based on population growth and land use changes.
4. Develop models to forecast the economic productivity resulting from existing water allocation strategies.
5. Discuss potential alternative water allocation strategies considering tradeoffs between economic productivity and societal needs for water.

Benefits to the State:

The purpose of this work is to understand the current and future water deficit scenarios of the Salt Lake Valley and to determine the economic consequences, if any, of the current practices of water allocation in the valley. We propose to provide an insight into the economic issues and identify potential alternatives for optimal water allocation considering economic return on water and the available water supply in future years. The results of the study will provide greater insight into water allocation and deficit issues so that an economic perspective can be brought to future planning and management by the State Engineer.

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