MINERAL LEASE FUND REPORT

Utah Water Research Laboratory

Fiscal Year 2005

for

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

by

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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 2005
2) Budgeted expenditures for FY 2006
3) Planned expenditures for FY 2007

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 nine program areas. A table summarizing actual, budgeted, and planned expenditures for FY 2005, FY 2006, and FY 2007, 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 2005 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 2005, SAF and MLF accounted for 28% 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 2005 were $9.2 million.

The UWRL is organized into nine 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. Ninety-seven graduate students were supported in FY 2005. 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 58 undergraduate students in FY 2005 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 almost $9.2 million in FY 05, 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 42 support staff at the UWRL. During FY 2005, 67 master's students and 30 doctoral students received support from UWRL projects. An additional 58 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) salinity control on irrigated lands, using the area served by the Emery Water Conservancy District as the case study, and (3) design and management of on-site wastewater treatment systems. 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 2005, FY 2006, and FY 2007 by the nine 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 17% of total MLF, budgeted and planned expenditures in FY 2005.

Relevancy and Benefits of the Mineral Lease Fund

Research Identification

In FY 2005, 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 faculty 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 Utah relevancy of our research programs. We are doing 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 Division of Hazardous Wastes, 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 which benefited from five UWRL luncheon speakers at various training workshops conducted in FY 05 in Salt Lake City.

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 San Diego. 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 2003-2005 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 Argentina, Peru, Pakistan, Iraq, and the Philippines.

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

- UWRL faculty are assisting Utah Department of Environmental Quality (UDEQ) personnel in the evaluation of state needs regarding Total Maximum Daily Loads (TMDLs) for many of Utah's lakes, rivers, and streams. This has resulted in the development and transfer of analytic techniques and models to UDEQ and the private sector that can be used to more efficiently analyze and document TMDL issues.

- Results of our laboratory investigations continue to provide cost-saving methods for improving the performance of dam spillways in Utah and can be expected to play an important role in future dam safety rehabilitation in the state.

- UWRL faculty and staff taught on-site wastewater treatment workshops throughout the State of Utah over the past 24 months to local health department personnel and contractors that included: Level 1: Soil Evaluation and Percolation Testing; Level 2: Design, Inspection, and Maintenance of Conventional Systems; and Level 3: Design, Inspection, and Maintenance of Alternative Systems.

- The Utah On-Site Wastewater Association (UOWA) provides a major technology transfer service regarding site selection, installation, maintenance, and monitoring for Utah local health departments, UDEQ, and other on-site professionals.

- Real-time management of irrigation systems in the Sevier River Basin is being implemented in collaboration with the U.S. Bureau of Reclamation and the Sevier River Water Users Association using computer models developed at the UWRL to increase the efficiency of basin-wide water management. This is especially useful when the total quantity of water decreases as in the recent drought conditions in Utah.

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 current, past, and expected future benefits of MLF funding are listed below:

- Nonylphenol ethoxylates (NPEs) are widely used surfactants that are commonly disposed of in wastewater collection systems in Utah. NPEs are subject to biological treatment within wastewater treatment facilities, but measurable amounts of untreated NPE and biodegradation intermediates such as nonylphenol (NP) have been identified in digested sewage biosolids. These biosolids are often applied to agricultural soils for their nutrient value. Quantitative information regarding potential plant uptake and transfer of NP and other surfactant-related compounds into plant foliar tissue is needed by the State of Utah to determine appropriate loading rates for the land application of municipal sewage sludge (biosolids). The Utah Water Research Laboratory is collaborating with the Utah Department of Environmental Quality (UDEQ), Division of Water Quality, to identify land application sites for sampling and analysis. The information developed in this project will be provided to the UDEQ for purposes of achieving better management of the disposal of these materials.

- Potential uptake and transfer of trichloroethylene TCE and other chlorinated solvents into fruits and vegetables is a critical concern for residents living near Hill Air Force Base. TCE contaminated groundwater originating from Hill Air Force Base (HAFB) in northern Utah has migrated into surrounding communities. A preliminary survey of edible fruit and vegetables

growing above contaminated groundwater plumes in the communities of Clinton, Layton, Riverdale, Roy, South Weber, and Sunset was conducted in the fall of 2001. Low levels of TCE were found in several samples ranging from non-detectable to 18-μg/kg fresh weight using a headspace gas chromatography electron capture detection method. To further investigate the transfer of TCE into fruits, a smaller, more focused field sampling effort was conducted in 2004 and 2005 at five locations around HAFB. The main focus was to evaluate the potential for seasonal variability associated with the TCE concentrations in the tree cores or fruit samples. Results obtained from this study will benefit the State of Utah by providing baseline information that can be used in screening-level risk assessments.

- In a related project, a greenhouse study was conducted to quantify ^{14}C-trichloroethylene (TCE) uptake and transfer into the edible fruit of apple and peach trees. Trees were sub-surface irrigated with solutions of ^{14}C [TCE] that bracketed the range of groundwater concentrations (5 and 500 mg/L) found in residential areas surrounding Hill Air Force Base, Utah, where trace amounts of TCE had been found in several fruits during a preliminary field survey. At the end of the study, TCE was detected only in roots implying that the ^{14}C in the leaves, stems, and fruit is associated with non-volatile TCE transformation products and/or is non-extractable. However, trichloroacetic acid (TCAA) and dichloroacetic acid (DCAA) were positively identified only in leaves collected during the first year from an apple tree exposed to the high dose treatment. Results obtained from this study will benefit the State of Utah by providing baseline information that can be used in screening-level risk assessments.

- Evaluating the potential removal of pharmaceuticals during drinking water treatment processes is an important issue for regulatory agencies involved in setting drinking water standards. The potential impact of drinking water treatment processes (coagulation, flocculation, sedimentation, filtration, and ozonation) on the removal of low levels of pharmaceuticals was evaluated in a project conducted by the UWRL for four compounds (caffeine, estradiol, salicylic acid and trovafloxacin mesylate) using pilot (23-26 L/min) and bench (0.03 L/min) scale systems. The compounds were selected to be representative of a variety of pharmaceuticals in terms of charge (neutral, cationic, anionic and zwitterionic) and expected fate within drinking water treatment facilities. Pilot and bench systems were compared to determine the influence of scale on contaminant fate. The pilot scale system, owned and operated by the Metropolitan Water District of Salt Lake City and Sandy, Utah was used to optimize treatment in a conventional plant and evaluate ozonation processes. The bench scale system was designed and constructed to mimic the operation of a full-scale system. Results obtained from this study will benefit the State of Utah by providing baseline information that can be used in screening-level risk assessments.

- A GIS based computer data management and modeling system is being developed at the Utah Water Research Laboratory 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.

- Soil and groundwater samples from Hill Air Force Base, Operable Units (OUs) 5 and 2, have been used in laboratory microcosm studies at the Utah Water Research Laboratory to evaluate the effectiveness of carbon donor and microbial inocula addition in stimulating trichloroethylene (TCE) remediation and removal from contaminated soil and groundwater. Soil from OU5 has been 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 bioaugmentation 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. The primary benefit of this study is to residents that live adjacent to Hill AFB, but findings and methods for monitoring and process analysis are relevant at TCE contaminated sites throughout Utah. Samples have also been obtained from a Dugway site where biostimulation is being attempted, making results applicable directly to problems in Toole County as well.

- 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. The Utah Water Research Laboratory is conducting research will result in a methodology and a computer tool to be used by small and medium sized rural communities to more effectively plan, design, and maintain culverts for unique situations as well as for most standard installations.

- 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. These techniques 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 Utah Water Research Laboratory is conducting a project 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 so that peak flows can be better estimated for any watershed in the state. This will be useful for designing drainage structures for roads and other facilities.

- The existing Virgin River Decision Support System (VRDSS) currently being developed in MapWindows for the Virgin River Integrated Resource and Recovery Program (Program) within the Virgin River Basin was expanded this year at the Utah Water Research Laboratory to include data and analyses developed at the UWRL on a basin-wide assessment of aquatic and riparian resource habitats. This effort entails an expansion of the existing VRDSS to include the data collected by the UWRL on the main stem Virgin River and its principal tributaries within native fish distributions and include on-line analysis capabilities to rank habitats in terms of watershed planning and restoration activities. In partnership the Virgin River Fishes Recovery Team, the Utah Division of Wildlife Resources, the U.S. Fish and Wildlife Resources, the Bureau of Land Management, and the National Park Service, this UWRL effort has directly benefited the state in support of the Virgin River Integrated Resource and Recovery Program for planning and implementation of on-going resource recovery efforts for the endangered woundfin minnow and Virgin roundtail chub, conservation species spinedace, and other native fish within the basin.

- The Utah Water Research Laboratory has developed a software application based on the MapWindows programming platform (which was also developed at the UWRL) directed at providing the Utah Museum of Natural History support for the State of Utah grade school curriculum targeting 4th and 9th grades. This application is designed to engender knowledge and understanding of native fishes within the State and provide a flexible tool for use by both students and teachers. The specific curriculum objective for the State is to increase an understanding of the native fish and water resource issues within Utah. The tool will provide a flexible working environment with existing lesson plans that directly meet the stated curriculum objectives while allowing the teacher to create or modify new lesson plans and share these via the internet with other teachers throughout the state. The Utah Native Fishes Viewer has been made available on-line to all Utah 4th and 9th grade schools for use in meeting mandated core curriculum objectives to learn about native fish in Utah and the factors that affect them. This module is the first on-line learning module that directly meets core curriculum objectives for 4th and 9th grades.

- The Utah Water Research Laboratory is conducting a study 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 pattern of water allocation in the valley. This study will provide an insight into the economic issues and provide potential alternatives for optimal water allocation considering economic return on water and the available water supply in the future. The results of the study will provide greater insight to the water allocation and deficit issue beyond considering questions of just supply and demand so that some economic perspective can be brought to future planning and management by the State Water Engineer and water purveyors in the valley.

- The levels of particulate matter less than 2.5 microns ($PM_{2.5}$) in Cache Valley's ambient air has exceed the 24-hour National Ambient Air Quality Standard (65 $\mu g/m^3$) in most of the last few winters. Logan consistently records the highest wintertime concentrations in the state, with the Utah record value being recorded February of 2002 (138 $\mu g/m^3$). Federal declaration of non-attainment status has not yet been achieved; however, the three-year averaging protocol of the standard is likely to cause official exceedance in 2006. The Utah Water Research Laboratory has provided leadership in the collection and analysis of air quality data to support local decision-making efforts for air quality management. Data generated from these studies were instrumental in the passage of recent resolutions in the Cache Valley for the future implementation of a vehicle I &M Program. A more complete understanding of the sources and behaviors of Cache Valley ambient particles will directly benefit the State of Utah by providing detailed information to the relevant authorities in order for them to make the best possible decisions regarding future remediation schemes. Additionally, three separate symposiums held through the spring and summer of 2005 relayed much of the information to the local population, as well as state and local regulators.

- With 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 and 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. Though appearing unrelated, the solutions to these two important environmental issues, i.e., biosolids management and disturbed rangeland restoration, are potentially interconnected. Biosolids land application represents a potentially cost-effective and scientifically defensible approach for (1) improving the ecological health and vegetative productivity of disturbed rangelands and (2) managing Utah-generated biosolids. The Utah Water Research Laboratory is working on a project to generate information critical for the State of Utah in identifying scientifically defensible long-term opportunities for beneficially using biosolids. Moreover, if successful, land application of biosolids to restore disturbed rangelands will have the added benefit of providing more effective use of public and private rangelands for animal grazing. It is anticipated that the results of this research will lead to management practices that will result in minimizing the indirect discharges of nitrogen and phosphorus as well as other pollutants from biosolids land application sites in the State of Utah.

- The Utah Water Research Laboratory has been measuring selenium concentrations in the Mallard Springs Wildlife Management Area to support the Utah Division of Wildlife Resources in decision-making about management of the area. Selenium in water can adversely impact the health of waterfowl species in the water. This project will measure selenium concentrations in samples from the Mallard Springs Wildlife Management Area (WMA) in order to help determine if modifications to the WMA (such as dredging) will cause selenium levels to exceed safe levels for wildlife.

- In the State of Utah many rural municipalities and industries use land treatment for waste management, and 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 resources. The Utah Water Research Laboratory is conducting research to provide: (1) information concerning beneficial reuse and sustainability of soil for treatment of organic wastes in land treatment systems, and (2) a practical tool (a genetic probe) for low-cost bioremediation to restore contaminated soils to economic benefit and to prevent the spread of contamination to ground water.

- 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 Utah Water Research Laboratory is engaged in interdisciplinary research in conjunction with the State of Utah and the Colleges of Natural Resources and HASS to assess the effectiveness of best management practices (BMPs) in phosphorus reduction in the Litter Bear River water. 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, it will also provide insights into the value of alternative water quality monitoring techniques. The results of this 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 work is supported in part through investments by the UWRL in support of a stream flow and water quality monitoring network in the Bear River Basin.

- The Utah Water Research Laboratory is working to develop analytic tools to support planning and management efforts in the Weber Basin. 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. 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 Great Salt Lake is important for the economy and ecology of Utah. The brine shrimp and minerals industries are dependent upon the lake and its salinity which is related to the level of the lake. High lake levels threaten infrastructure and the Salt Lake City metropolitan area. It is therefore important to understand and be able to better predict the fluctuations in the level of the Great Salt Lake. Analysis of historic lake level, stream flow, and other hydrologic data has allowed researchers at the Utah Water Research Laboratory to quantify the expected relationships between lake volume changes and precipitation, streamflow, and temperature and the relationship between evaporation and lake area. UWRL researchers have also found in this analysis connections between evaporation and salinity that can be quantified by a simple model based on the total salt load in the lake. The results of this study improve understanding of the sensitivity of the Great Salt Lake level to the interplay between topography and fluctuations in precipitation and climate.

- The faculty at the Utah Water Research Laboratory are currently assisting the Utah Department of Environmental Quality personnel in the evaluation of state needs regarding Total Maximum Daily Loads (TMDLs) for Utah's lakes, rivers, and streams, and the impacts of proposed land use changes on water quality. Personnel from the UWRL have provided direct technical assistance in 2005 for the preparation of TMDLs in several Utah locations.

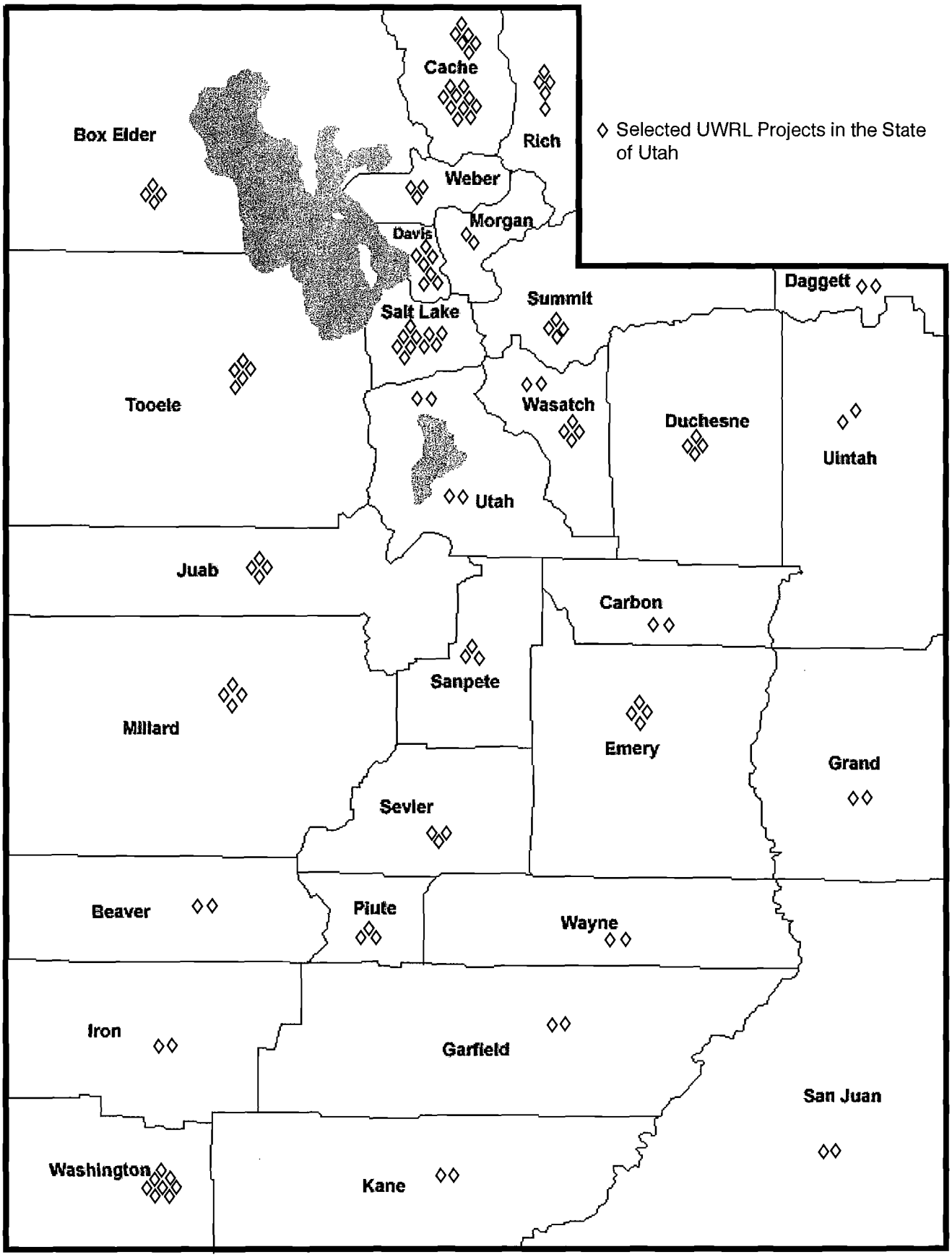

Figure 1. Projects conducted by the UWRL in the State of Utah

Actual, Budgeted, and Planned Expenditures of Mineral Lease Funds
Total Program Areas

Projeot Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Administration	$176,077.52	$216,359.84	$227,177.34
Bioprooess Engineering	$43,541.56	$125,200.00	$123,460.00
Hazardous and Texio Waste Management	$168,834.11	$718,158.54	$788,492.46
Water Quality Engineering	$244,484.17	$630,254.43	$563,730.37
Water Eduoation and Teohnolgy Transfer	$52,151.76	$131,076.79	$96,163.03
Fluid Mechanics and Hydraulios	$119,757.79	$343,386.97	$337,200.95
Ground Water	$11,307.13	$39,307.13	$6,150.00
Hydrology	$56,711.29	$196,412.63	$213,193.16
Water Resources Planning and Management	$213,261.49	$893,231.75	$927,819.77
Totals	**$1,086,126.82**	**$3,293,388.08**	**$3,293,388.08**

Summaries of Major UWRL 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 UWRL on air quality problems in the state.

Natural Systems Engineering

Impacts of engineered systems on habitat in aquatic ecosystems are evaluated through the development and application of assessment methods using computer simulation data analysis, and remote sensing. This program addresses threatened and endangered species, habitat enhancement, instream flow assessments, remote sensing of fish habitat, and videography-based prediction of stream sediment and meso-scale hydraulic features.

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 Utah Water Research Laboratory, 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 groundwater 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.

Bioprocess Engineering

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

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Land Application of Biosolids and Animal Manure to Reclaim Disturbed Utah Rangelands	$43,541.56	$85,200.00	$93,460.00
Designated Amount for FY06/FY07 Research Projects		$40,000.00	$35,000.00
Undesignated research projects in program area		$0.00	$0.00
Total	**$43,541.56**	**$125,200.00**	**$128,460.00**

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

Principal Investigator(s):
Michael J. McFarland
Dharmin Desai
Heath Hall

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. Though appearing unrelated, the solution to these two important environmental issues, i.e., biosolids management and disturbed rangeland restoration, is potentially interconnected. More precisely, biosolids land application represents a potentially cost effective and scientifically defensible approach for: 1) improving the ecological health and vegetative productivity of disturbed rangelands and 2) managing Utah-generated biosolids.

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, Utah (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, Utah 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, 2005, all of 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.

Table 1. **Summary** of Biomass Growth - Six Months after Land Application

Type of Biosolids Application	Ave. Biomass Yield (lbs/acre) Wet Weight
Control Plot (no biosolids application)	366.6 ± 204.4
Lime Stabilized (10X agronomic rate)	1546.4 ± 293.6
Lime Stabilized (5X agronomic rate)	2043.7 ± 537.6
Lime Stabilized (1X agronomic rate)	591.69 ± 198.1
Aerobically Digested (20X agronomic rate)	1688.0 ± 490.9
Aerobically Digested (10X agronomic rate)	1346.7 ± 213.8
Aerobically Digested (5X agronomic rate)	798.6 ± 832.7
Aerobically Digested (1X agronomic rate)	733.3 ± 311.1

Land application of beef cattle manure occurred in February, 2005. In August, 2005, the beef cattle manure 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 2.

Table 2. **Summary** of Biomass Growth - Six Months after Land Application

Type of Biosolids Application	Ave. Biomass Yield (lbs/acre) Wet Weight
Control Plot (no manure application)	751.4 ± 300.81
Manure (1X)	1060.0 ± 194.9
Manure (5X)	508.2 ± 444.5
Manure (10X)	228.7 ± 86.4
Manure (20X)	522.7 ± 107.3

Biosolids application was observed to increase vegetative biomass production above that which was recorded for the control plots in all cases except for the lime stabilized plots that received just 1X the agronomic rate. Although there was considerable variability found in the biomass data, initial inspections suggested that test plots that received lime stabilized biosolids, in general, had a greater vegetative response that those sites that had received aerobically digested biosolids (except at 1X the agronomic rate). Visual observations of the land treatment site indicated that some of the plots that received large amounts of biosolids (e.g., 10X the agronomic rate or larger) contained areas in which vegetative growth was spotty. It is suspected that this was due primarily to the obscurence of sun light caused by the large amount of biosolids required to achieve the desired application rate.

Finally, 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).

Soil Nitrate Results

The pH of all soil samples was found to range from 7.7 to 9.2 indicating that the soils at the tests plots were alkaline. Of primary importance to the federal and state regulatory biosolids field study participants was the impact of biosolids application on soil nitrate concentrations. For all plots, the nitrate concentrations were found to increase with soil depth. For example, in the control plots, soil nitrate concentrations were found to range from 7.5 mg/kg at 0.75 ft (bgs) to a maximum of 88.0 mg/kg at 5.0 ft (bgs). The reason for the large nitration concentrations found in these background soil samples was presumably due to the historical animal management practices conducted at the site. The site was not only used for animal grazing but was also employed as a temporary holding area where large concentrations of animals were kept (and fed) prior to being transferred to other grazing areas.

For the lime-stabilized biosolids, nitrate concentrations ranged from 17.5 mg/kg at a depth of 0.75 feet (bgs) for plots receiving biosolids application at 1X the agronomic rate to a maximum of 143.3 mg/kg at a depth of 5.0 feet for plots receiving biosolids application at 10X the agronomic rate. Similarly, for the plots receiving aerobically digested biosolids, the nitrate concentration ranged from 12.3 mg/kg at a depth of 0.75 ft (bgs) for plots receiving biosolids application at 1X the agronomic rate to a maximum of 183.6 mg/kg at a depth of 5 feet (bgs) (for plots receiving biosolids application at 10X the agronomic rate).

As expected, at those sites that received biosolids at application rates significantly above the agronomic rate, the nitrate concentrations were above those levels detected in the control plots. Although high nitrate concentrations were found, field results only reflect the subsurface conditions that existed after six months following biosolids application. Presumably the nitrate that was not utilized by rangeland vegetation leached below the root zone. Since the depth to groundwater is over 80 feet (bgs) at the biosolids land application site and the quality of groundwater is characterized by a high mineral content, the leaching of nitrate from the biosolids land application site is expected to have a minimal adverse environmental or public health impact. Moreover, in future sampling, the nitrate concentrations associated with those field plots receiving biosolids are expected to be comparable to the control plots. The rationale for this assumption is that future nitrate levels will depend entirely on the nitrogen that is released through the slow mineralization of organic nitrogen.

Figure 1 provides illustrative photographs of the benefits of biosolids and manure land application to improving the disturbed rangeland in Skull Valley, Utah.

Work Plan FY06/FY07:

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, Utah. 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 has been critical for the State of Utah in identifying scientifically defensible long-term opportunities for beneficially using biosolids. Moreover, if successful, land application of biosolids to restore disturbed rangelands will have the added benefit of providing more effective use of public and private rangelands for animal grazing. It is anticipated that the results of the research will lead to management practices that will result in minimizing the indirect discharges of nitrogen and phosphorus as well as other pollutants from biosolids land application sites in the State of Utah.

Presentations:

McFarland, M.J. (2005). Biosolids Application on Utah Rangelands. Technical Presentation at the *Water Environment Association of Utah (WEAU) Biosolids Management Conference,* Utah Dept. of Natural Resources, Salt Lake City, Utah, September 30.

McFarland, M.J., M. Schmitz, R.B. Brobst, D. Desai, and H.R. Hall (2006) Land Application of Aerobically Digested and Lime Stabilized Biosolids to Restore Disturbed Western Rangelands. Presentation to the *Water Environment Federation (WEF) Residuals & Biosolids Conference 2006,* Cincinnati, OH, March.

Control

Snyderville Basin Biosolids 5X Agronomic Rate

Tooele City Biosolids 5X Agronomic Rate

Figure 1. Photographs of the Skull Valley, UT, Biosolids/Manure Land Application Site

Beef Cattle Manure 5X Agronomic Rate

Figure 1. (Continued)

Hazardous and Toxic Waste Management

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

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
A Modeling and Risk Analysis Tool to Evaluate the Impact of TCE on Utah Groundwater Sources	$7,609.41	$12,987.70	$13,377.33
Ambient Particulate ($PM_{2.5}$ and PM_{10}), Gaseous Ammonia, and Other Particulate Precursors in Cache Valley, Utah	$31,394.33	$57,323.53	$60,180.81
Analysis of Environmental Organic Contaminants	$4,528.58	$14,528.58	$26,000.00
Analysis of Microbial Diversity and Dechlorinating Potential at Solvent Contaminated Sites Throughout Utah	$6,043.36	$12,086.72	$18,130.08
Applications of Gene Probes to Utah Sites for Remediation	$8,385.21	$38,540.84	$50,311.26
Components of the Alternative Electron Acceptor-Using Bacterial Community in TCE Contaminated Aquifers in Northern Utah	$8,980.52	$25,000.00	$40,000.00
Defining the Bioavailability of Toxic Trace Elements Using Microbial Biosensors	$18,390.10	$18,941.80	$19,888.89
Evaluating the Uptake of Nonylphenol and Nonylphenol Ethoxylates by Crested Wheatgrass	$9,672.18	$51,201.13	$56,000.00
Health Risk-Based Economic Framework to Assess Pesticide Management	$11,307.13	$11,646.84	$11,995.73
Identification of Potential Risks to Utah Drinking Water from Chlorinated Solvents and the Potential for their Remediation	$8,497.20	$8,602.12	$0.00
Remediation of TCE-Contaminated Groundwater at Hill Air Force Base (HAFB)	$7,609.42	$24,000.00	$40,000.00
Soil Bioremediation and Beneficial Reuse	$5,399.84	$10,799.68	$21,599.36
Uptake of ^{14}C-TCE by Apple and Peach Trees: Greenhouse Study	$9,057.16	$12,000.00	$20,000.00
Uptake of TCE by Apple and Peach Trees and their Fruit Near Hill Air Force Base (HAFB)	$41,959.67	$24,000.00	$40,000.00
Designated Amount for FY06/FY07 Research Projects		$391,500.00	$368,000.00
Undesignated research projects in program area		$15,000.00	$10,000.00
Total	**$168,834.11**	**$718,158.64**	**$788,492.46**

A Modeling and Risk Analysis Tool to Evaluate the Impact of TCE on Utah Groundwater Sources

Principal Investigator(s):
R. Ryan Dupont

Project Description:

Spatially and temporally varying groundwater supply data were integrated with known and potential chlorinated solvent release information into a GIS-based risk analysis package to help identify high risk water supplies, to prioritize expenditure of limited assessment and remediation funds, and to improve the management and protection of sensitive water supplies.

Accomplishments:

Salt Lake County has been used as a study area for this project. The known and potential solvent contaminated sites in this county have been identified and databases of these spatially referenced sites have been created so that they can be mapped according to their geographical location. Public and private groundwater extraction wells have been identified and databases of the location, physical construction, and operating characteristics of these spatially referenced drinking water wells have been created. Databases of temporal water quality data and geologic soil profiles associated with these wells have also been compiled. MapWindow, a mapping GIS data management/data analysis/data visualization system developed by the Environmental Management Research Center (EMRC) at Utah State University is used for data compilation and mapping purposes. Source Water Protection Zones provided by DEQ have been mapped onto these data layers. A Water Quality Analyst plug-in has been integrated into this groundwater risk analysis and management tool to provide statistical analysis and graphical output (i.e., Time-Series plots, histograms, probability plots, etc.) of temporal water quality data associated with these wells. A Well Log Viewer plug-in graphically displays a soil log of the wells to describe the geologic setting in which contaminant migration is taking place. Two- and three-dimensional groundwater capture zones for these wells are delineated using MicroFEM to explore the real or potential impact of chlorinated solvent release sites on drinking water quality. Risk determinations of existing contamination sources, and management of risk through new source siting are included in the tool's risk management options.

Work Plan FY06/FY07:

Plans for the next year include the seamless integration of MicroFEM results into MapWindow. Currently, the graphical results of MicroFEM are in DXF format which is not fully compatible with MapWindow. The integration of the results of the three-dimensional groundwater and contaminant modeling from MicroFEM fully into MapWindow for graphical display and GIS spatially referenced analysis, necessitates the creation of a plug-in to provide MicroFEM/MapWindow compatibility. In addition, the three-dimensional modeling of MicroFEM that generates groundwater time of travel contours for water from a particular location into a well, does so now for contaminants, only accounting for their retardation within the aquifer due to sorption onto aquifer solids (worst case scenario, and applicable to chlorinated solvents that are essentially non-reactive under aerobic aquifer conditions).

Another plug-in is under development which will model contaminant transport including the impact of dilution and biological transformation as contaminants move through the groundwater system from their point of release under the influence of water supply wells. A user's manual for State DEQ staff for the development of a water quality and water supply well database within the MapWindow environment is being completed, along with instructions in the use and examples of the data visualization and statistical analysis capabilities of the MapWindow tool, and procedures and instructions on the construction of a finite element grid for groundwater flow and transport modeling within MicroFEM. Finally, documentation of case studies in the application of MapWindow/FEM is being compiled to provide local regulators and system managers with specific and relevant examples of the use of tool for site risk assessment and water supply management.

Benefits to the State:

A growing number of contaminated groundwater sites have been brought to the attention of the DEQ, and any of these sites pose a current or potential risk to the groundwater supplies across the state. There is currently, however, no tool DEQ has available to integrate water supply and groundwater contamination data geographically or temporally. This modeling package facilitates the compilation of information on known and potential sources of contamination, known solvent plumes, current and historic solvent users, and existing groundwater extraction wells and protection zones so that proactive protection and management of Utah's groundwater resources can now be more feasible.

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Ambient Particulate (PM2.5 and PM10), Gaseous Ammonia, and Other Particulate Precursors in Cache Valley, Utah

Principal Investigator(s):
Randal S. Martin
Philip Silva
Kori Moore
Vishal Doshi

Project Description:

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 (65 $\mu g/m^3$) in most of the last few winters. The Logan site consistently records the highest wintertime concentrations in the State of Utah (see Figure 1 at the end of this document), with the Utah record value being recorded February, 2002 (138 $\mu g/m^3$). Federal declaration of non-attainment status has not yet been achieved; however, the three-year averaging protocol of the standard is likely to cause official exceedance in 2006.

The determination of the sources/causes of these elevated levels is, therefore, of great interest to local and regional regulators and scientists. The overall goal of this project, therefore, is to determine the composition and valley-wide behavior of the $PM_{2.5}$ particulate matter and, thereby, estimate the various source strengths. Translating this information to local and state officials would, in turn, allow elected officials and regulators to identify and implement the most efficient and effective remediation strategies.

Work conducted previously by Dr. Randal Martin and colleagues within Utah's Division of Air Quality (DAQ) has found that the chemical composition of the $PM_{2.5}$ can be broken down into five broad classes: light absorbing carbon (3-6%), organic carbon (16-19%), soils/metals (1-2%), sulfates (9-21%), and nitrates (43-59%). The sulfates and nitrates are typically associated with combustion, the latter especially associated with vehicular emissions. Chemically, sulfates and nitrates actually exist in the particulate phase as their ammonium salts. As such, it is equally important to understand the atmospheric ammonia budget of Cache Valley to determine whether the basic component (NH_3) or the acidic components (NO_3 and SO_4) are the formation limiting species. Studies from fiscal year 2004 have pointed to Cache Valley being ammonia-rich. Given the agricultural nature of Cache Valley and the documented release of ammonia from such operations, an abundance of atmospheric ammonia can be expected. The derivation of the sources of the organic carbon component must also be solidified.

Furthermore, it has been locally suggested that while prevention is the ultimate goal, protection is also important, and the recommendation that the population may be "safer" by remaining indoors needed to be verified.

Accomplishments:

As with the earlier studies, the Smithfield particulate concentrations, generally reflect the Logan (and now other established locations) $PM_{2.5}$ and PM_{10} levels. Having nearly four years of data, it was decided in the early summer of 2005 to suspend the Smithfield sampling. However, it should be noted

that a gravel pit is planned for operation nearby the Smithfield site and the sampling station maybe reestablished in 2006.

The ambient ammonia study has shown that the rural area (Amalga) has NH_3 concentrations on the order of three to five times higher than the urban area (Logan). Figure 2 shows the average monthly NH_3 concentrations at both sampling locations. This has large potential implications on control strategies since previous Logan studies suggested the Valley was ammonia-rich by a factor of approximately two. If the relationship between urban and rural NH_3 holds true, than the region may even be more NH_3-rich than initially believed, meaning any NH_3 control strategy would have to be even more carefully evaluated to ensure what potential benefits may be obtained via NH_3 reduction scenarios. Furthermore, it was found that the elevated rural NH_3 concentrations are essentially independent of wind direction (refer to Figure 3). This would indicate that the NH_3 in Cache Valley is ubiquitous, emitted from a numerous of sources, and likely homogeneous throughout the Valley.

The indoor/outdoor study found that at all experienced ambient $PM_{2.5}$ levels, the indoor air stayed well below the National Ambient Air Quality Standard (NAAQS). On average, the indoor $PM_{2.5}$ levels for 40% of the outdoor levels. It should be mentioned that one school, Summit Elementary, which was an older school, fitted with radiator-type heating consistently showed the highest indoor levels, although they were still well below the NAAQS. Figure 4 shows the measured relationships between indoor and outdoor $PM_{2.5}$ concentrations. Overall, a linear regression found the following relationship: $[PM_{2.5}]Indoor = 0.104*[PM_{2.5}]Outdoor + 8.4$, which more realistically indicates an average, base indoor concentration of approximately 8.4 mg/m^3, modified by approximately 10% of the outdoor $PM_{2.5}$ concentration.

The main projects initiated under the Utah Water Research Laboratory (UWRL) MLF monies were the continued measurement of $PM_{2.5}$ and PM_{10} at the Smithfield, UT location; measurement ambient ammonia (NH_3) at rural and urban locations within Cache Valley; measurements of indoor versus outdoor $PM_{2.5}$ at several location within Cache Valley; and preparations for and presentations at three local air quality symposiums (although these did extend into fiscal year 2006).

The Smithfield measurements are a continuation of exeriments of previous years and were accomplished using Federal Reference Method (FRM) techniques specific to $PM_{2.5}$ and PM_{10}. These measurements have shown the general homogeneity of the particulate pollution in Cache Valley and, along with previous valley-wide saturation studies, have been the impetus for the establishment of additional state-monitored air quality stations at Hyrum and Amalga, UT, as well as Franklin and Preston, ID.

The rural and urban NH_3 measurements were set up as a cooperative study with the Utah Division of Air Quality and the Idaho Department of Environmental Quality. Real-time NH_3 monitors were set up in Logan (at the current DAQ site) and near Amalga, UT. These systems were operated from November 2004 through April 2005. The data were then compiled and analyzed by USU/UWRL and UDAQ personnel.

The indoor/outdoor $PM_{2.5}$ studies were conducted during January through March of 2005, followed by subsequent particle mass and chemical analysis at the UWRL facility. In brief, portable $PM_{2.5}$ samplers were placed inside and outside of several local schools and operated for one week periods, during school hours only to reflect typical exposure levels.

Work Plan FY06/FY07:

A final, compiled report concerning all of Cache Valley's air pollution studies is currently in preparation for delivery to the Utah DAQ. Although not presented until fiscal year 2006, several presentations and documents were also prepared for three local air quality symposiums during this reporting year.

Benefits to the State:

A more complete understanding of the sources and behaviors of Cache Valley ambient particles will directly benefit the State of Utah by providing detailed information to the relevant authorities in order for them to make the best possible decisions regarding future remediation schemes. Data generated from these studies were instrumental in the passage of recent resolutions in Cache Valley for the future implementation of a vehicle I & M Program. Additionally, three separate symposiums held through the spring and summer of 2005, have relayed much of the information to the local population, as well as state and local regulators.

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 and the Idaho Department of Environmental Quality in the form of donated research and teaching equipment, contacts for future employment of students, and presentations of graduate seminars by state personnel. Furthermore, Kori Moore, formally an undergraduate student, and now a graduate student, presented results at a student competition at the International Air & Waste Management Association convention in June of 2005, where he was awarded 1st place in the undergraduate division. Additionally, Vishal Doshi, a graduate student, presented separate work at the same conference and was awarded 2nd place in the M.S. division.

Figure 1. Cache Valley inversion from Dry Canyon Ridge (ele. 6300', [$PM_{2.5}$] = 101.6 mg/m³)

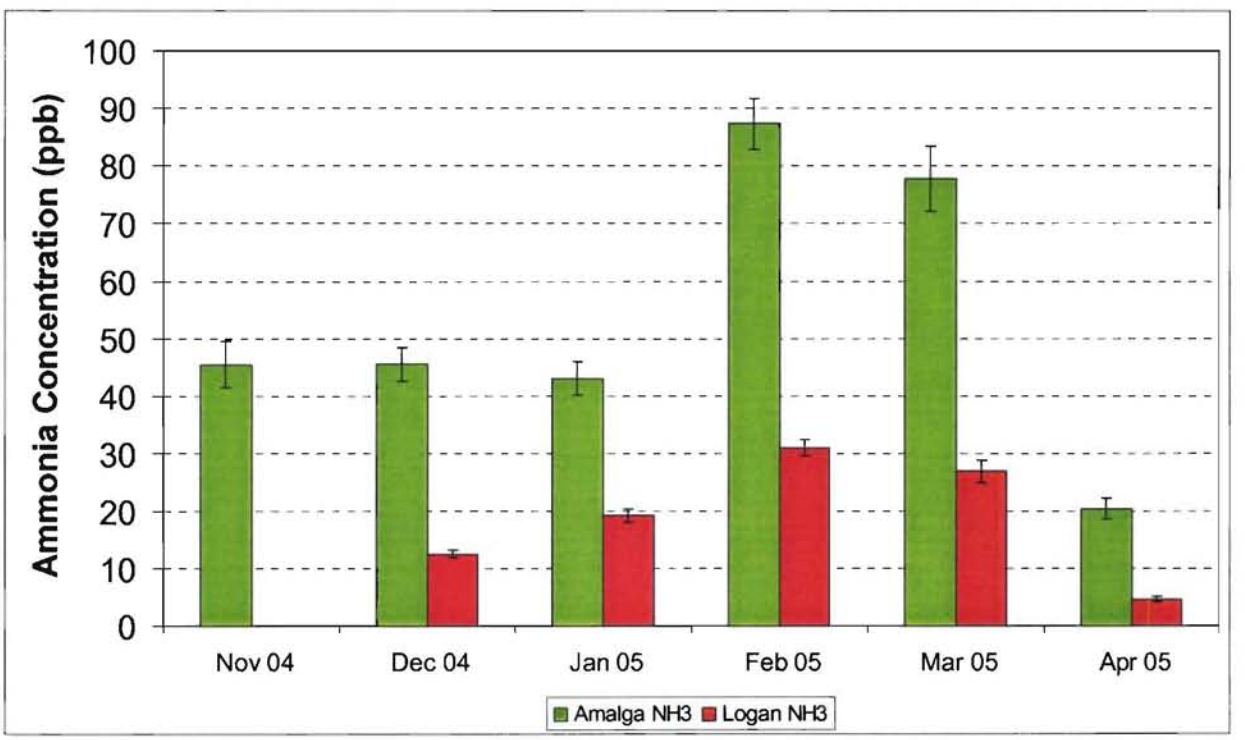

Figure 2. Monthly averaged NH_3 at Cache Valley urban (Logan) and rural (Amalga) locations (error bars represent 95% confidence intervals)

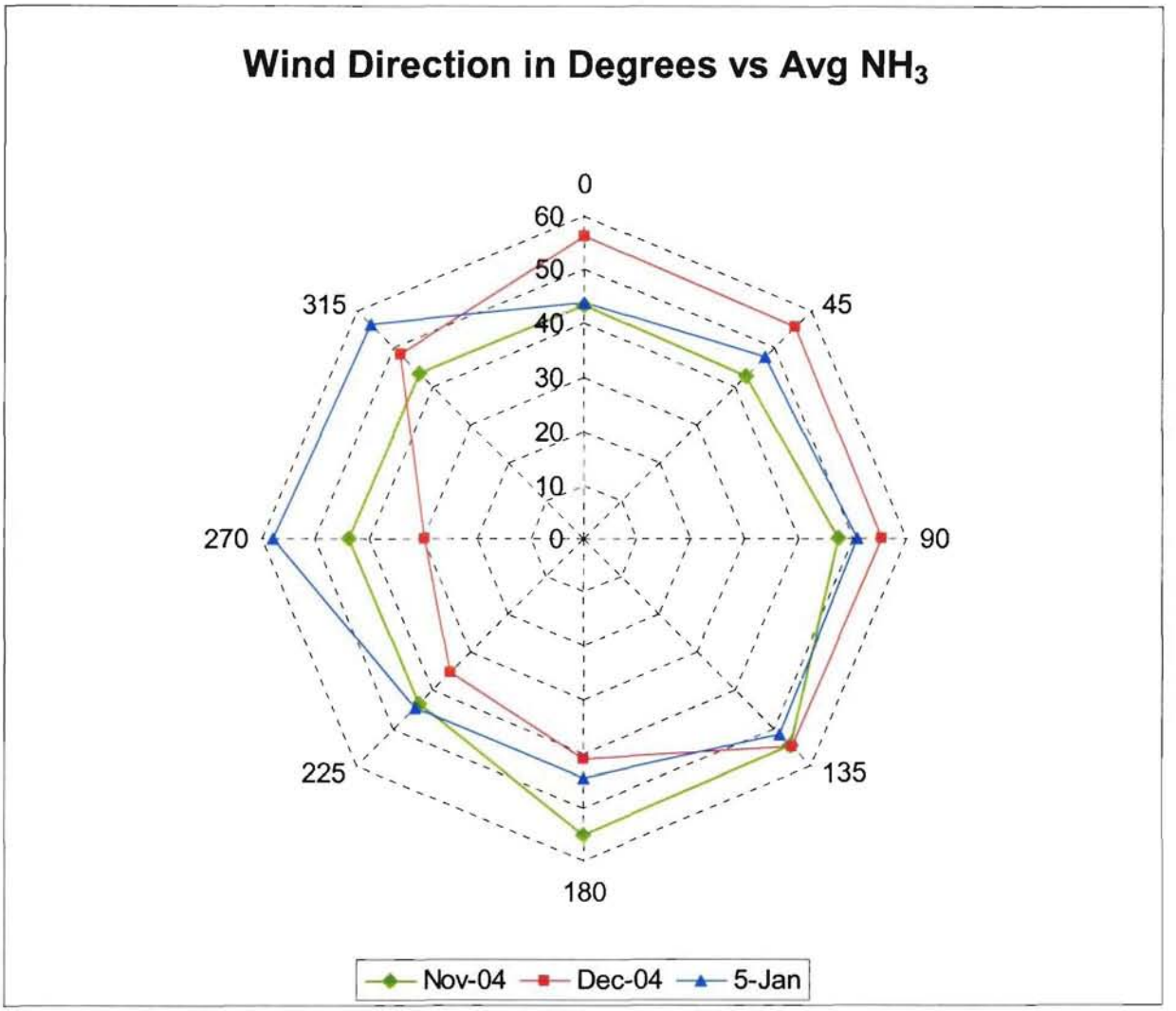

Figure 3. Cache Valley rural NH_3 as a function of wind direction

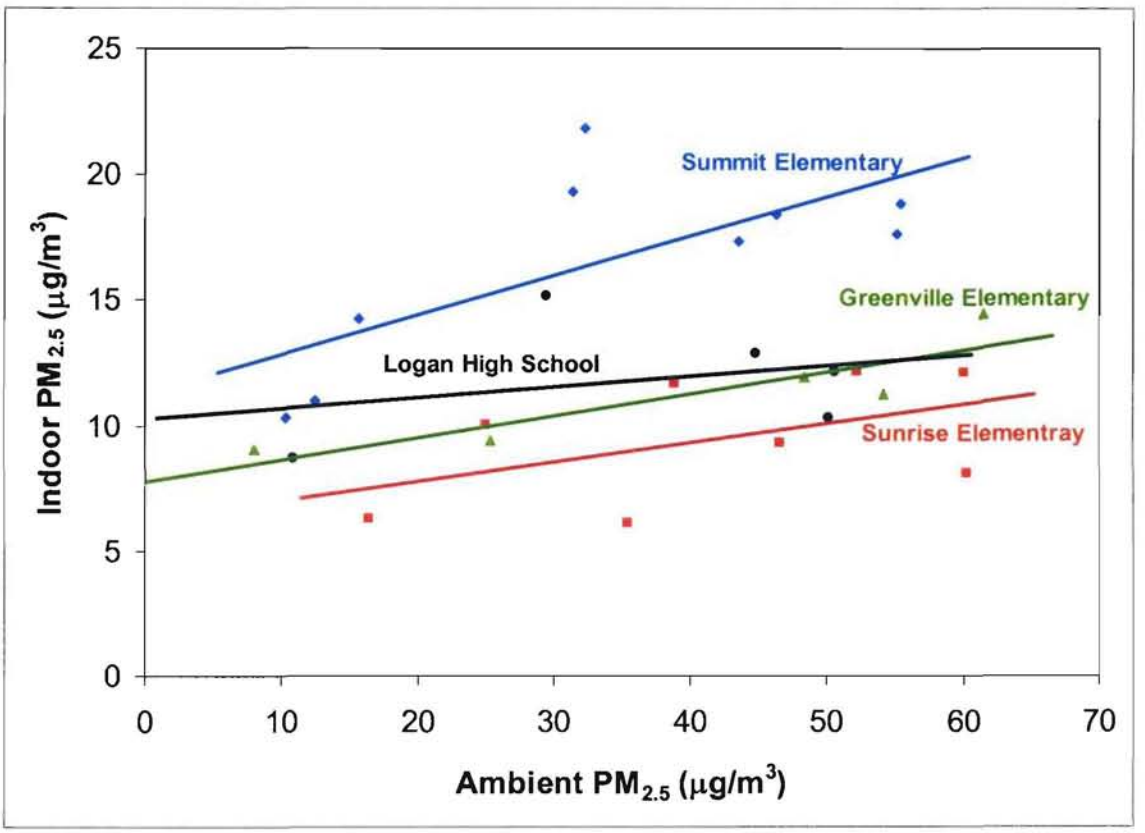

Figure 4. Ambient (outdoor) vs. indoor $PM_{2.5}$ concentrations at several Cache Valley schools

Analysis of Environmental Organic Contaminants

Principal Investigator(s):
William J. Doucette
Mike Petersen
Coreen Crouch

Project Description:

The Organic Analysis Section of the Environmental Quality Laboratory of the Utah Water Research Laboratory (UWRL) is involved with the identification and quantification of organic compounds in Utah environmental field samples, or in samples derived from laboratory experiments. Methods for the analysis of environmental organic contaminants in a variety of environmental matrices including soil, water, air and biota are developed using techniques such as: supercritical fluid extraction, purge and trap extraction/concentration, headspace extraction, solid phase extraction, high performance liquid chromatography (HPLC), gas chromatography (GC), and gas chromatography/mass spectrometry (GC/MS).

Accomplishments:

Analytical methods utilizing HPLC, GC, and GC/MS have been developed for a wide variety of organic compounds and samples in support of laboratory and field scale studies including trichloroethylene (TCE), methyl tertiary butyl ether (MTBE), and pharmaceutical chemicals such as estradiol that affect water quality in Utah.

Work Plan FY06/FY07:

Method development will continue with a focus on headspace/GC/MS methods for the determination of metabolites of TCE, PAH, and MTBE in soil and plant tissue samples and solid phase extraction/HPLC methods for pharmaceutical chemicals in drinking water.

Benefits to the State:

The analytical methods developed by the Organic Analysis Section are used for the analysis of samples collected from various sites in Utah, such as Hill Air Force Base, in support of projects involved with soil and ground water monitoring and remediation.

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

Principal Investigator(s):
R. Ryan Dupont
Jing Zhou

Project Description:

This study is designed to identify 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 developed and 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 two other groups of organisms that were originally to also be targeted in this study, i.e., the nitrate reducers and the methanogens. Work is continuing to develop and verify the effectiveness of molecular probes for these two groups, and future work will include quantitative data for these organisms as well as the dechlorinators and iron reducers.

Results. Results from these standard PCR techniques 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, 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 r^2 values and reduced p values for the regression relationships. In addition, analysis of soil samples are seen in Table 3 to also increase the predictability of the developed relationships based on the negative slope of the regression equation, the increased r^2 values, and the equivalent p values for far fewer number of samples included in the regression analysis.

While the 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 sites throughout TCE contaminated sites in northern Utah. This functional relationship

suggested by these qualitative standard PCR results lead to the need for more quantitative analysis of community composition through the use of Real Time PCR (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. A follow-on UWRL funded effort to generate RT-PCR data from these field site soil and groundwater samples is currently underway.

Work Plan FY06/FY07:

The original project research plan was as follows: Groundwater (and soil samples when available) were to be collected from known chlorinated solvent impacted sites from throughout northern Utah that have historical water chemistry data available for them. DNA from these samples was to be extracted and analyzed for specific organisms and a range of functional metabolic capability using 16s rDNA and functional gene molecular probes. DNA was to be amplified via standard PCR techniques using the 16s and functional gene probes of interest, and amplified DNA would then be separated and size fractionated using gel electrophoresis. Specific organisms of interest included: 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; three species of sulfate reducing organisms; and three species of methanogenic bacteria. Functional gene probes were to include: four probes designed to detect cprA, pceA/pceB, tceA, and vcrA in dechlorinating organisms; three probes designed to detect iron reductase genes in iron reducers; three functional gene probes for nitrate reducers; and two functional probes for genes coding for methane production in methanogenic bacteria.

Using these molecular probe results for the detection of specific microorganisms, relationships were then to be explored between the abundance of specific microorganisms and their functional capability, and the observation of the nature and extent of dechlorination activity in samples throughout these field sites.

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 AFB. 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 Hill AFB by the 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.

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

Target	Probe Name	Species/Strain	Product Size (bp)
Dehalococcoides	2	*ethanogenes*/195, BAV1; *sp.* CBDB1, FL2	104
Dehalococcoides	3	*ethanogenes*/BAVI; *sp.* CBDB1, FL2	137
Dehalococcoides	9	*ethanogenes*/195, BAVI; *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	*Rhodoferraxferrireducens*	207

Table 2. 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 3. 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

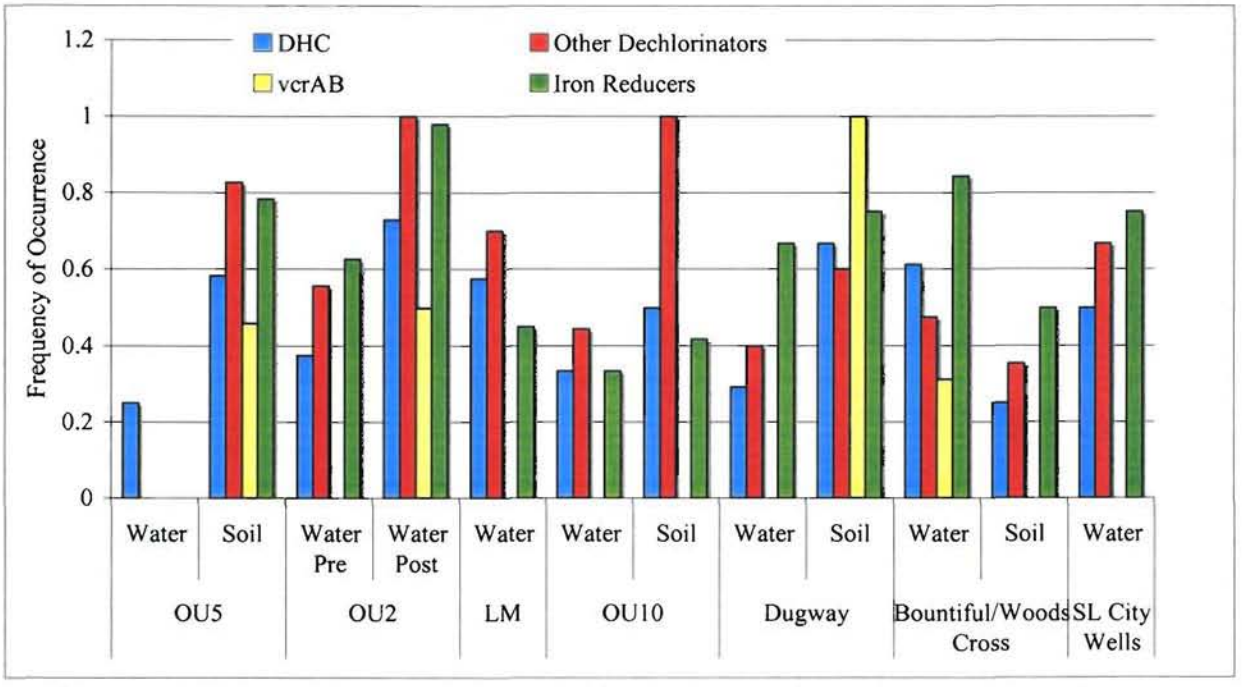

Figure 1. Frequency of Occurrence of positive PCR detections of *Dehalococcoides sp.*, Other Dechlorinators, Iron Reducing bacteria, and the functional gene vcrAB in field samples collected from throughout northern Utah in 2005.

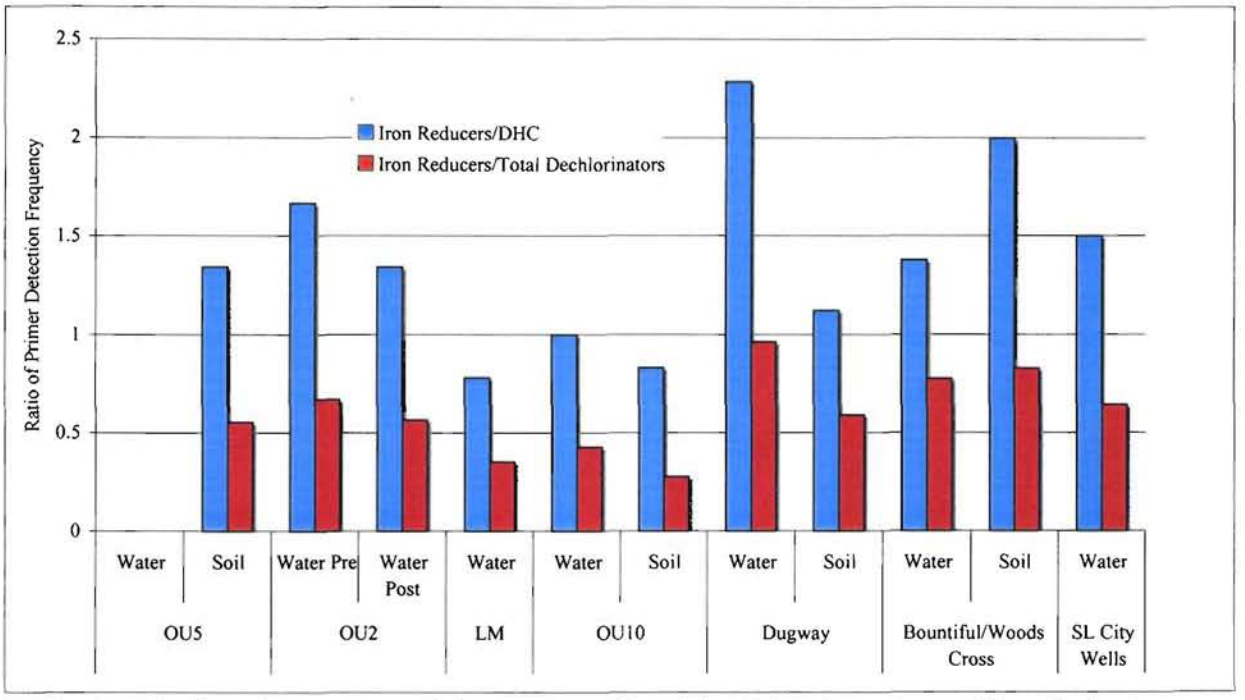

Figure 2. Ratio of Frequency of Occurrence of positive PCR detections of Iron Reducing Organisms to *Dehalococcoides sp.* and Iron Reducing Organisms to Total Dechlorinators in field samples collected from throughout northern Utah in 2005.

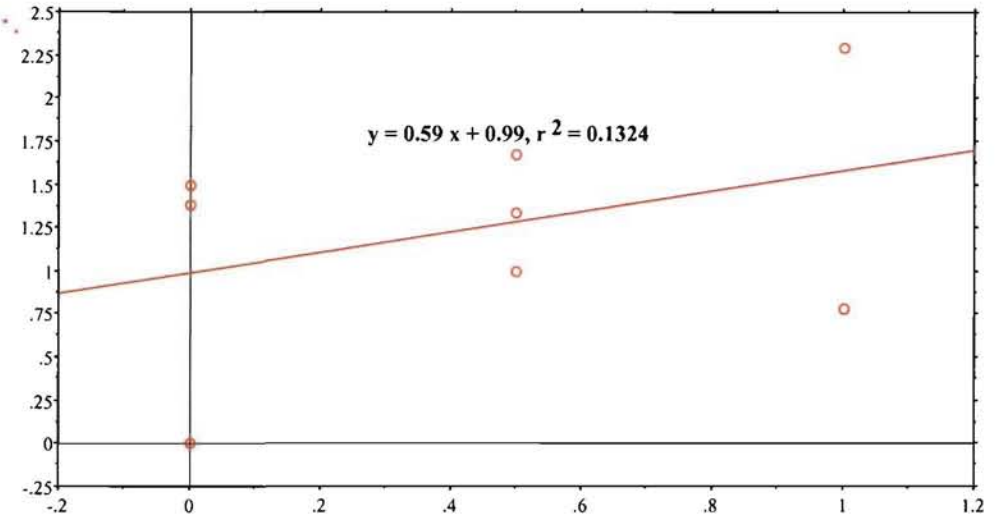

Figure 3. Linear regression analysis of the ratio of the frequency of detection of iron reducing to *Dehalococcoides* bacteria in water samples collected from field sites throughout northern Utah in 2005.

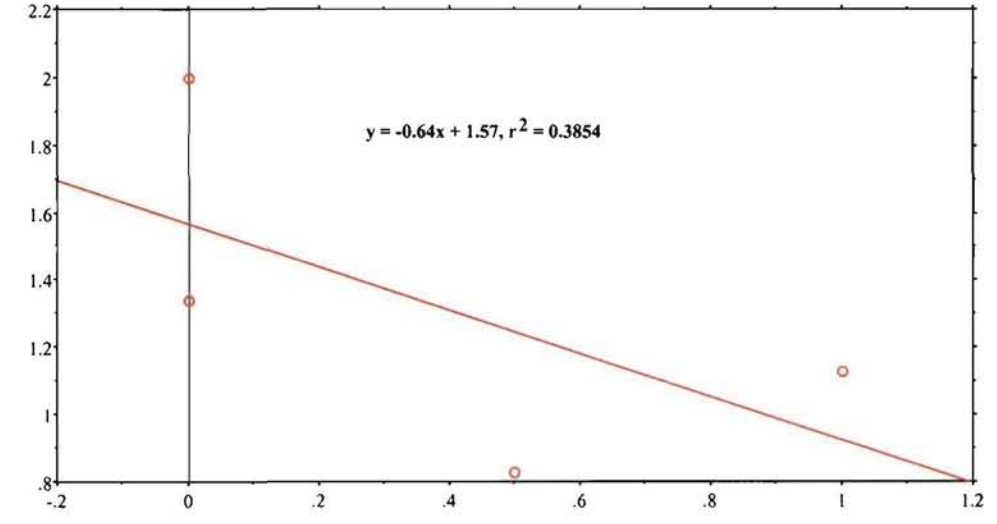

Figure 4. Linear regression analysis of the ratio of the frequency of detection of iron reducing to *Dehalococcoides* bacteria in soil samples collected from field sites throughout northern Utah in 2005.

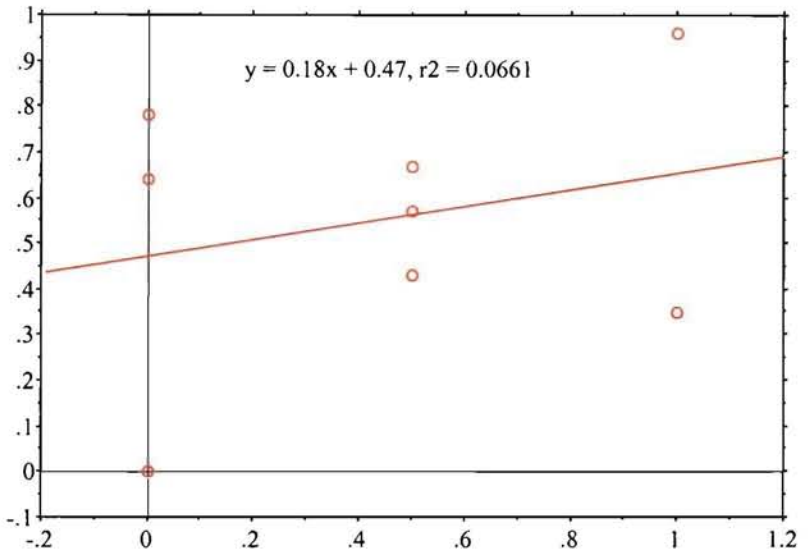

Figure 5. Linear regression analysis of the ratio of the frequency of detection of iron reducing to total dechlorinating bacteria in water samples collected from field sites throughout northern Utah in 2005.

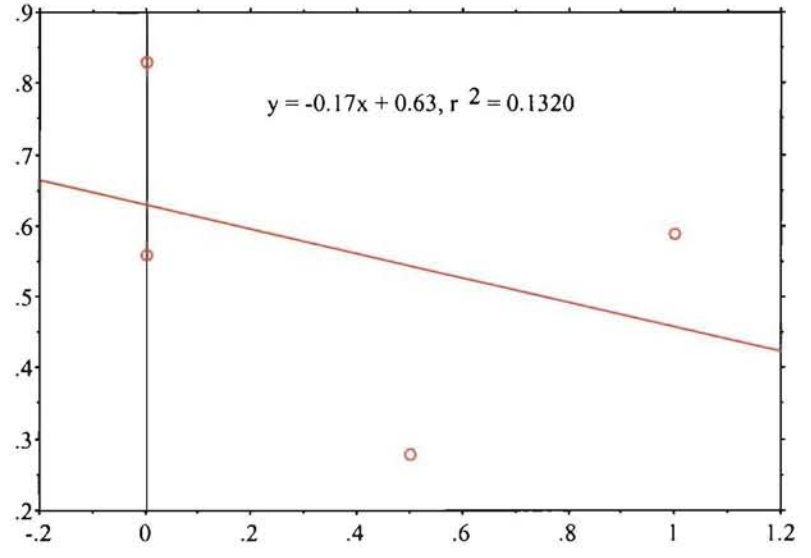

Figure 6. Linear regression analysis of the ratio of the frequency of detection of iron reducing to total dechlorinating bacteria in soil samples collected from field sites throughout northern Utah in 2005.

Applications of Gene Probes to Utah Sites for Remediation

Principal Investigator(s):

Ronald C. Sims
Anne Anderson
Charles Miller
Judith L. Sims
Joan E. McLean
Darwin L. Sorensen
Frank Olson
Aaron Swank
Mark Greenwood

Project Description:

1. Provide a review and recommendations for soil/land treatment of organic wastes to address beneficial reuse of soil and protection of public health.

2. Develop a procedure to use a genetic probe to test for the presence of PAH-degraders in Utah soils.

Accomplishments:

1. Summary and recommendations for land treatment of organic wastes were published.

2. Description of the genetic probe tool for bioremediation of soil was published.

3. A procedure was developed for testing Utah soils for the presence of PAH-degraders.

4. Soils were identified throughout the State of Utah for testing for PAH-microbes.

Work Plan FY06/FY07:

1. Review and evaluate historic information and regulations to develop a summary and a set of guidelines to achieve beneficial reuse of soils receiving organic wastes.

2. Develop a method to evaluate the presence of naturally occurring PAH-degrading microbes.

3. Identify Utah soils for testing for PAH-degrading microbes.

Benefits to the State:

This project has provided: (1) a practical tool (gene probe) for determining if microorganisms are naturally present in soil at Utah sites 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, and (2) information concerning 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.

Publications:

Hall, K., C.D. Miller, D.L. Sorensen, A.J. Anderson, and R.C. Sims (2005). The genetic probe tool for soil bioremediation was published in the refereed publication: "Development of a Catabolically Significant Genetic Probe for Polycyclic Aromatic Hydrocarbon-degrading Mycobacteria in Soil." *Biodegradation Journal,* 16:475-484.

Miller, C., A. Anderson, and R.C. Sims (2006). A "Provisional Application for Patent" was submitted through USU/TCO to the Commissioner for Patents, Alexandria, VA, for a patent title "Probes and Methods for Identifying PAH-Degrading Mycobacteria," by Drs. Registration No. 40,831, Docket No. 14185.7.3, June 2.

Nieman, J.K.C., R.C. Sims, D.L. Sorensen, and J.E. McLean (2005). Humic Acid Toxicity in Biologically Treated Soil Contaminated with Polycyclic Aromatic Hydrocarbons and Pentachlorophenol. *Arch. Env. Contam. Tox.,* 48:1-8.

Overcash, M.R., R.C. Sims, J.L. Sims, and J.K.C. Nieman (2005). Summary and recommendations for soil/land treatment of organic wastes were published in the refereed publication: "Beneficial Reuse and Sustainability: The Fate of Organic Compounds in Land-Applied Waste." *Jour. of Environmental Quality,* 34:29-41.

Components of the Alternative Electron Acceptor-Using Bacterial Community in TCE Contaminated Aquifers in Northern Utah

Principal Investigator(s):

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

Project Description:

The project is directed at describing the microbial ecology of TCE contaminated aquifers at Hill Air Force Base (Hill AFB) in terms that can be used in treatment system design. The objective is to describe populations of bacteria within selected aquifers' microbial communities, and their biostimulated counterparts, which participate in or compete with dechlororespiration. Other anaerobic respiratory processes especially iron reduction, sulfate reduction, and methanogenesis, have the potential of shunting energy (electron flow) away from dechlororespiration. There is evidence from microcosm studies that iron reduction may be a major sink of electrons in anaerobic respiration in some Hill AFB aquifer materials.

Accomplishments:

Funding for this project was initiated in April, 2005. Arrangements are being finalized for collecting soil cores in a TCE-contaminated plume at OU5 on and near Hill AFB. These cores will be 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. An enrichment culture for poorly-crystalline-iron reducing bacteria has been initiated.

Work Plan FY06/FY07:

Culture-independent methods of identifying and quantifying bacteria, including polymerase chain reaction (PCR) probing and real-time, quantitative PCR (RTPCR), from aquifer material are being used. Enrichment culture methods are also being used. The presence and approximate concentration of iron reducing bacteria including members of the *Geobacteriaceae*, and the genus *Shewanella* will be determined in unamended samples of aquifer material from OU5 and OU9 at Hill AFB. These samples will also be assayed for sulfate reducing bacteria using real time or quantitative PCR (qPCR) using the *dsrAB* functional gene for dissimilatory sulfite reduction. The density of selected functional methanogenesis genes will also be determined using qPCR. Similar assays will be conducted on aquifer material that has been treated in biostimulation microcosms to determine changes in the populations of these anaerobically respiring bacteria. A research proposal to the National Science Foundation will be submitted.

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. Improving cleanup technology represents an opportunity for improvement of the Utah environment and protection to the health of the citizens of the state. The project has been focused on Hill AFB but will have application to trichloroethene (TCE), and other chlorinated ethene, contamination at several locations within Utah.

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., Cd2+, is bioavailable, although metal complexes are also available. Current methods does not allow for a direct measurement of the bioavailable fraction. 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 is being tested. Also we are using these bacteria to better understand the relationship among solution chemistry, metals adsorption to the cell wall, metal uptake, and the corresponding bioresponse.

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

Accomplishments:

The three developed mutants of *Pseudomonas putida* Corvallis, Bfr, CatA, and FeSOD, have been tested for sensitivity and selectivity to copper and cadmium. The mutants respond to oxidative stress and are, therefore, not selective to specific metals. 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. We are continuing work to improve the sensitivity of the response of the mutants to be useful for drinking water and aquatic standards. Adsorption/absorption studies are underway. Preliminary studies have shown that the bacteria does respond to free metal ion activity and is not responsive to metal complexes, with the exception of copper hydroxide complexes that are bioavailable. This finding illustrates the need for direct measurements of bioresponse, since all chemical and modeling efforts make assumptions regarding the bioavailable.

Work Plan FY06/FY07:

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

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 soil 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.

Presentations:

Miller, C.D., M.L. Wouden, J. McLean, A.J. Anderson (2005). The development of metal biosensors using mutants of *Pseudomonas putida*. *Annual meeting of the Institute of Biological Engineers.* Atlanta GA.

Anderson. A.J., C.D. Miller, B. Pettee, M. Wouden, and J.E. McLean (2005). Biosensing materials used in nanotechnology. *Annual meeting of the American Chemical Society.* San Diego, CA.

Evaluating the Uptake of Nonylphenol and Nonylphenol Ethoxylates by Crested Wheatgrass

Principal Investigator(s):
William J. Doucette
Bruce Bugbee
Julie Chard
Mike Petersen
Coreen Crouch
Erik Dettenmaier

Project Description:

Nonylphenol ethoxylates (NPEs) are widely used surfactants that are commonly disposed of in wastewater collection systems in Utah. NPEs are subject to biological treatment within wastewater treatment facilities, but measurable amounts of untreated NPE and biodegradation intermediates such as nonylphenol (NP) have been identified in digested sewage biosolids. These biosolids are often applied to agricultural soils for their nutrient value. Further biodegradation of NPE and NP within the soil/biosolids system has been observed, but little is known about the potential of plants to take up these compounds or their metabolites.

Accomplishments:

Microcosm experiments, 150 days in duration, were conducted to evaluate the mineralization and plant uptake of ^{14}C-labeled nonylphenol (NP), nonylphenol tetraethoxylate (NPE_4), and nonylphenol nonylethoxylate (NPE_9) in a soil/biosolids (99.5:0.5% w/w) environment planted with crested wheatgrass (*Agropyron cristatum*). Three concentrations 6, 24, and 47 mg/kg dry wt of NP, NPE_4 and NPE_9 were examined along with planted and unplanted poisoned controls. A single concentration of phenol 22 mg/kg was also evaluated as a more degradable reference compound. The biosolids, containing approximately 1000 mg/kg of non-labeled NP, were obtained from a municipal wastewater treatment plant receiving industrial, commercial and domestic wastewater and the loamy sand soil was collected from a local agricultural field. Mineralization was quantified by collecting the $^{14}CO_2$ produced during the course of the study. Roots and foliar tissue were analyzed for ^{14}C and NP. The extent of mineralization based on cumulative $^{14}CO_2$ measurements over the course of the study ranged from 7% for NP to 53% for phenol. No enhancement of mineralization was observed in the planted systems. For NP, NPE_4 and NPE_9, ^{14}C concentrations in the foliar tissues were proportional to the exposure concentration but were 10 times lower than concentration in the roots and 2-3 times lower than the soil. NP was found in both soil and plant tissues at the end of the study with bioconcentration factors (BCFs) ranging from 0.31 to 0.48 g NP/kg dry soil.

Work Plan FY06/FY07:

Project ended December 2005.

Benefits to the State:

Quantitative information regarding potential plant uptake and transfer of NP and other surfactant-related compounds into plant foliar tissue is needed by the State of Utah to determine appropriate loading rates for the land application of municipal sewage sludge (biosolids). The Utah Water Research Laboratory is collaborating with the Utah Department of Environmental Quality (UDEQ), Division of Water Quality, to identify land application sites for sampling and analysis. The information developed in this project will be provided to the UDEQ.

Health Risk-Based Economic Framework to Assess Pesticide Management

Principal Investigator(s):
Jagath J. Kaluarachchi
Aklilu Tesfamichael

Project Description:

1. Develop a framework to assess the uncertainty of risk estimation due to atrazine in drinking water in the presence of data limitations.

2. Perform risk benefit analysis of atrazine at different application rates and provide a framework for determining best management options.

3. Develop appropriate statistical methods to predict the concentration of substitute pesticide(s) of atrazine in surface water and assess the impact of banning atrazine.

Accomplishments:

The work related to this work is almost complete.

Work Plan FY06/FY07:

1. Collect necessary data and information from public databases across the United States.

2. Develop statistical models to describe longitudinal and cross-sectional uncertainty of predicted risk due to limited data such that the results can be used in developing monitoring strategies.

3. Develop regression models to predict the substitute pesticide residue in drinking water using watershed characteristics, pesticide chemical data, and usage data.

4. Develop economic models to predict the costs and economic benefits of using atrazine and/or substitute pesticides.

5. Demonstrate the applicability of the overall framework in scenarios involving atrazine ban; assess the changes in public health and economic costs and benefits to the consumers and farmers.

Benefits to the State:

Pesticide usage is common in Utah where there are many agricultural watersheds in rural parts of the state. Although the work developed in this research is addressing pesticide management as a national issue and provides information on policy-making and decisions, the final outcome of these decisions and policy are applicable to stakeholders in Utah. The results of this work serves both nationwide policy implementation and provides better information and insight to land managers of Utah.

Publications:

Tesfamichael, A.A., A. Caplan, and J.J. Kaluarachchi (2005). Risk-cost-benefit analysis of atrazine in drinking water from agricultural activities and policy implications. *Water Resources Research, 41, W05010.*

Tesfamichael, A. and J.J. Kaluarachchi (2005). A methodology to assess the risk of an existing pesticide and potential future pesticides in regulatory decision-making. *Environmental Science and Policy,* September.

Tesfamichael, A.A. and J.J. Kaluarachchi (2005). A regression method to estimate the distribution of atrazine in surface water. P*roceedings of the Annual Meetings of the American Water Resources Association,* San Diego, CA.

Tesfamichael, A.A. and J.J. Kaluarachchi (2004). Uncertainty analysis in pesticide residue risk assessment in drinking water. *Human Ecology and Risk Assessment,* 10(6), 1129-1135.

Tesfamichael, A.A. and J.J. Kaluarachchi (2004). Uncertainty propagation in drinking water risk assessment. *Subsurface Science Symposium,* Inland Northwest Research Alliance, Spokane, WA.

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:

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.

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.

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 ongoing 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, know 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 FY06/FY07:

The MapWindow development environment is being used to deploy a basic GIS data viewer with associated prebuilt 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 carried out 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 will be carried out using field site data available from up to three sites that have resulted in groundwater well abandonment. Estimates of "area of susceptibility" generated from the tool will be compared to the observed extent of contaminant migration at sites with existing groundwater contamination for comparison of the screening-level information the tool can provide. In addition, ranges of specific contaminant concentration results predicted from the fate and transport calculations will be compared against measured values as a more quantitative evaluation of the 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 is being developed to help the Utah Department of Environmental Quality (DEQ) 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.

Remediation of TCE-Contaminated Groundwater at Hill Air Force Base (HAFB)

Principal Investigator(s):

R. Ryan Dupont
Joan E. McLean
Darwin L. Sorensen
Jing Zhou
Han Lai

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 will be evaluated with DNA samples collected from active remediation sites throughout the state at Department of Defence facilities and other sites of state regulatory interest.

Accomplishments:

These pilot-scale columns had been loaded and maintained for a cumulative time of 780+ days by the end of the reporting periods, during which time carbon donor addition had been carried out for one year. Significant differences in TCE transformation have been 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. Significant methane and dissolved iron production was observed in the whey-amended reactors indicating that highly reducing conditions were present in the columns and that iron metabolism was important in these systems, serving as a competitive process to complete TCE degradation. Little methane was generated in the emulsified oil treatments, but iron metabolism was evident in them indicating that these systems were only partially reduced in response to this carbon amendment. Depletion of the emulsified carbon amendment was evident approximately 200 days after its application at a concentration of 1,000 mg/kg soil, resulting in only partial transformation to cis-DCE after that time. This partial TCE degradation 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. 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, is being carried out 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. This latter work is the subject of ongoing external and MLF projects.

Work Plan FY06/FY07:

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 may provide if any, 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 Water Lab effort.

Benefits to the State:

Soil and groundwater samples from Hill AFB, Operable Units 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 has been used in large-scale flow-through columns to evaluate TCE degradation rates in preparation for full-scale demonstration at the Hill AFB 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 AFB 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 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 AFB sites.

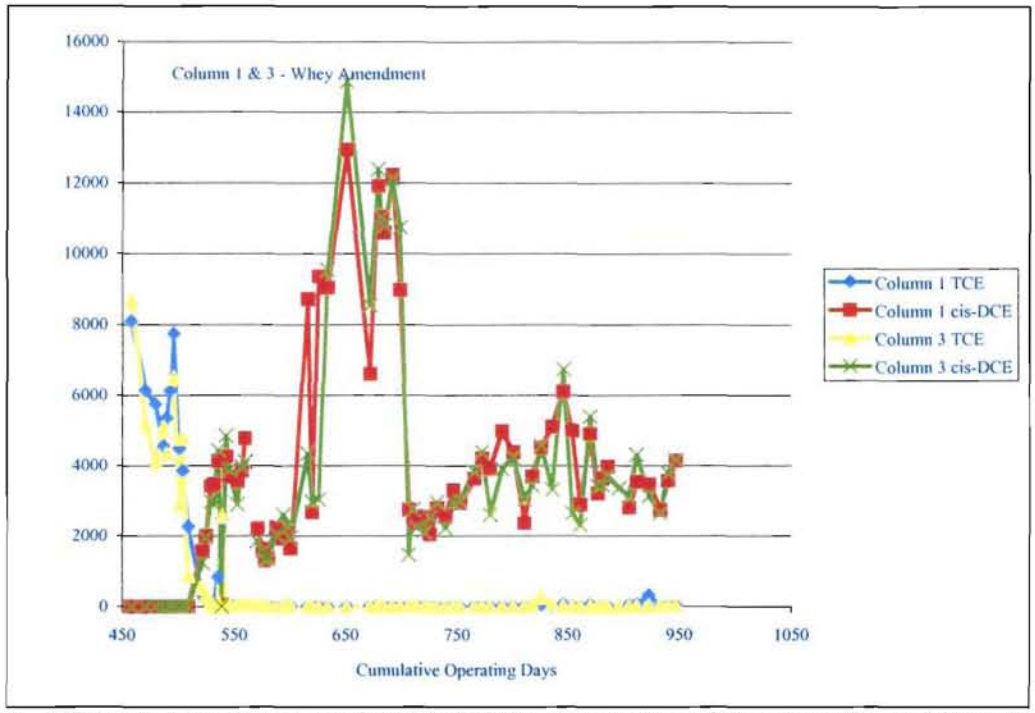

Figure 1. TCE and degradation product (cis-DCE) concentrations following Whey addition to pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. Whey concentration = 1,000 mg/L continuous supply beginning Day 450.

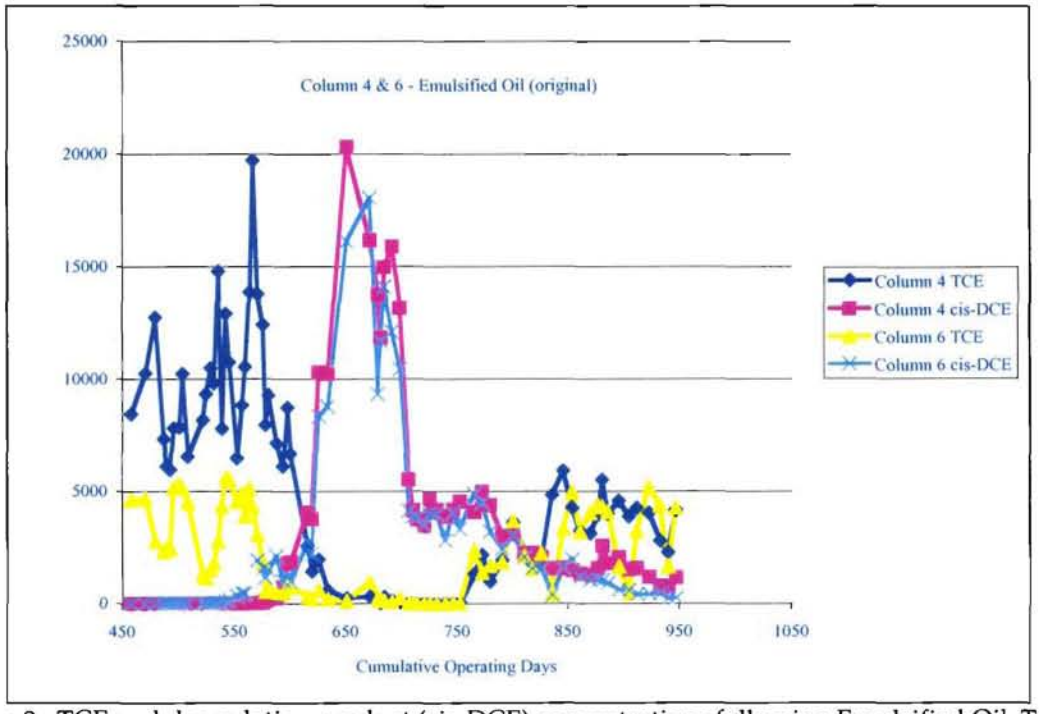

Figure 2. TCE and degradation product (cis-DCE) concentrations following Emulsified Oil, Type I addition to pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. Oil concentration = 1,000 mg/kg soil in a single dose on Day 450.

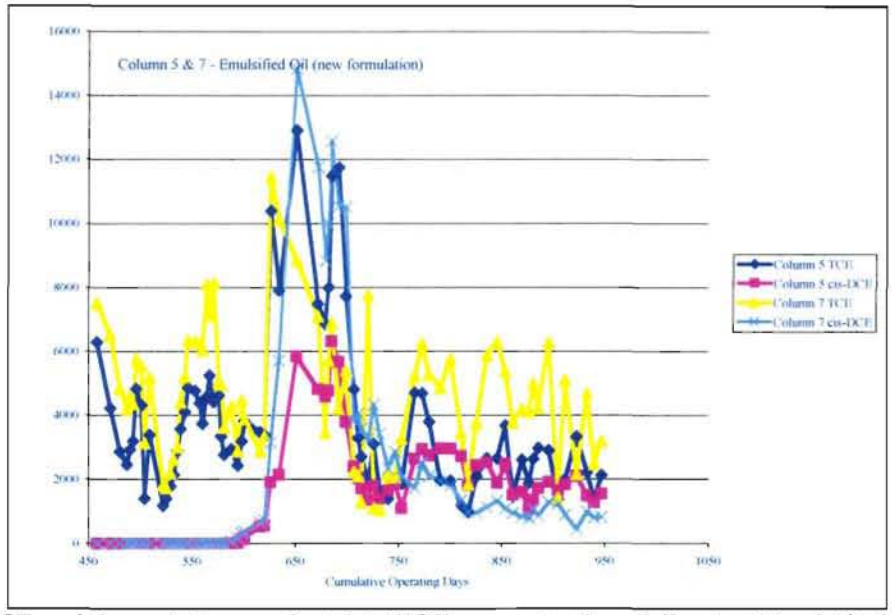

Figure 3. TCE and degradation product (cis-DCE) concentrations following Emulsified Oil, Type II addition to pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. Oil concentration = 1,000 mg/kg soil in a single dose on Day 450.

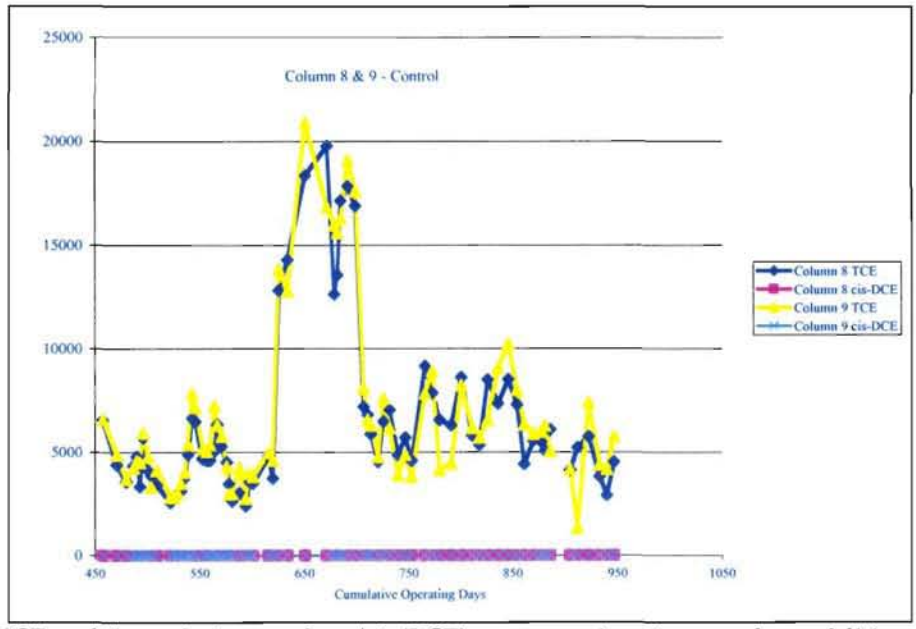

Figure 4. TCE and degradation product (cis-DCE) concentrations in no carbon addition, pilot-scale flow-through columns containing OU5 soil and fed TCE saturated OU5 groundwater. These columns represent unfed Control Reactors.

Soil Bioremediation and Beneficial Reuse

Principal Investigator(s):
Ronald C. Sims
Anne Anderson
Charles Miller
Judith L. Sims
Darwin L. Sorensen
Frank Olson
Aaron Swank

Project Description:

1. Provide a review and recommendations for soil/land treatment of organic wastes to address beneficial reuse of soil and protection of public health.

2. Develop a procedure to use a genetic probe to test for the presence of PAH-degraders in Utah soils.

Accomplishments:

1. Summary and recommendations for land treatment of organic wastes were published.

2. Description of the genetic probe tool for bioremediation of soil was published.

3. A procedure was developed for testing Utah soils for the presence of PAH-degraders.

4. Soils were identified throughout the State of Utah for testing for PAH-microbes.

Work Plan FY06/FY07:

1. Review and evaluate historic information and regulations to develop a summary and a set of guidelines to achieve beneficial reuse of soils receiving organic wastes.

2. Develop a method to evaluate the presence of naturally occurring PAH-degrading microbes.

3. Identify Utah soils for testing for PAH-degrading microbes.

Benefits to the State:

This project provided: (1) information concerning beneficial reuse and sustainability of soil for treatment of organic wastes in land treatment systems, and (2) a practical tool (genetic probe) for low-cost bioremediation to restore contaminated soils to economic benefit and to prevent the spread of contamination to ground water. 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 resources.

Uptake of ^{14}C-TCE by Apple and Peach Trees: Greenhouse Study

Principal Investigator(s):
William J. Doucette
Bruce Bugbee
Coreen Crouch
Mike Petersen
Julie Chard
Brandon Chard
Demetrio Cabanillas

Project Description:

A greenhouse study was conducted to quantify the uptake of ^{14}C-trichloroethylene (TCE) by apple and peach trees and determine if TCE or ^{14}C was transferred into edible fruit. Triplicate dwarf apple and peach trees were subsurface irrigated with solutions of TCE (^{14}C-labeled and unlabeled) at total concentrations of approximately 5 and 500 mg/L. These concentrations bracketed groundwater levels observed during a field survey conducted in the fall of 2001 where trace levels of TCE were detected in several fruit samples collected from residential areas surrounding Hill Air Force Base (HAFB), Utah. Control trees were grown within the canopy of the dosed trees and in a separate greenhouse. Tissue samples (leaves, stems, fruit, trunk, and roots) were analyzed for TCE and ^{14}C using headspace gas chromatography mass spectrometry (HS/GC/MS) and combustion/liquid scintillation counting (LSC).

Accomplishments:

A greenhouse study was conducted to quantify ^{14}C-trichloroethylene (TCE) uptake and transfer into the edible fruit of apple and peach trees. Trees were subsurface irrigated with solutions of ^{14}C [TCE] that bracketed groundwater concentrations (5 and 500 mg/L) found in residential areas surrounding Hill Air Force Base, Utah, where trace amounts of TCE had been found in several fruits during a preliminary field survey. Control trees were grown within the canopy of the dosed trees and in a separate greenhouse. Tissue samples were analyzed for ^{14}C and TCE using combustion/liquid scintillation counting (LSC) and headspace/gas chromatography/mass spectrometry (HS/GC/MS). Tissue was also extracted and analyzed by GC/MS for dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), and trichloroethanol (TCEt), three specific TCE metabolites that have been previously identified in laboratory and field studies. All non-control plant tissue contained levels of ^{14}C that were proportional to the exposure concentration. ^{14}C concentrations were greatest in leaves followed by stems and fruits. At the end of the study, TCE was detected only in roots implying that the ^{14}C in the leaves, stems, and fruit is associated with nonvolatile TCE transformation products and/or is non-extractable. However, TCAA and DCAA were positively identified only in leaves collected during the first year from an apple tree exposed to the high dose treatment.

Work Plan FY06/FY07:

Sampling and analysis of fruit and fruit trees for ^{14}C and TCE will continue through the 2004 growing season. The greenhouse project is anticipated to end after the fall 2004 sampling.

Benefits to the State:

The potential uptake and transfer of TCE and other chlorinated solvents into fruits and vegetables is a critical concern for residents living near Hill Air Force Base. Results obtained from this study will benefit the State of Utah by providing baseline information that can be used in screening level-risk assessments.

Uptake of TCE by Apple and Peach Trees and their Fruit Near Hill Air Force Base (HAFB)

Principal Investigator(s):

William J. Doucette
Bruce Bugbee
Coreen Crouch
Mike Petersen
Julie Chard
Brandon Chard
Demetrio Cabanillas
Tiffany Leo
Blake Wilde

Project Description:

Trichloroethylene (TCE) contaminated groundwater originating from Hill Air Force Base (HAFB) in northern Utah has migrated into surrounding communities. In the fall of 2001, a preliminary survey of edible fruit and vegetables growing above contaminated groundwater plumes in the communities of Clinton, Layton, Riverdale, Roy, South Weber, and Sunset was conducted. Low levels of TCE were found in several samples ranging from non-detect to 18-μg/kg fresh weight using a headspace gas chromatography electron capture detection method. A follow-up survey conducted in Fall 2002, found no TCE in any edible fruit or vegetables above the method detection limit. However, TCE was identified by GC/MS in several fruit samples below the reporting limit and was consistently found in cores collected from some of the fruit trees. The apparent difference between the Fall 2001 and 2002 results was thought to be the result of more conservative reporting limits, improved data quality (no false positives) and/or changes in the environmental conditions associated with transfer of TCE into fruit.

Accomplishments:

To further investigate the transfer of TCE into fruits, a smaller, more focused field sampling effort was conducted in 2004 and 2005 at five locations around HAFB. The main focus was to evaluate the potential for seasonal variability associated with the TCE concentrations in the tree cores or fruit samples. Previous sampling was conducted only during the fall, as the fruits were ready for harvest. Evaluating seasonal variability was intended to give some insight into the mechanism of TCE transfer into fruit. Higher levels in fruit collected during the spring would suggest that TCE enters primarily via the xylem. Higher levels in the fall would suggest that TCE moves into the fruit via the phloem or is concentrated in the fruit over the growing season. In addition, shallow groundwater samples were collected from stainless steel sampling probes placed within each of the five fruit tree sampling locations in order to evaluate the relationship between TCE groundwater and fruit tree concentrations.

Results from the 2004 and 2005 sampling showed that TCE was consistently found in several trees but only sporadically in the fruit collected from the same trees.

Work Plan FY06/FY07:

Sampling and analysis of fruit and fruit trees for TCE at the five sites sampled in 2004 will continue. The field project is anticipated to end after the fall 2005 sampling.

Benefits to the State:

The potential uptake and transfer of TCE and other chlorinated solvents into fruits and vegetables is a critical concern for residents living near Hill Air Force Base. Results obtained from this study will benefit the State of Utah by providing baseline information that can be used in screening-level risk assessments.

Water Quality Engineering

Aetual, Budgeted, and Plannee Expenditures ef Mineral Lease Funds
Water Quality Engineerine

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Alternative Deoentralized Wastewater Treatment Systems far Utah Conditions	$50,329.92	$45,820.17	$13,952.35
Demonstration of Pllot-Scale Hexavalent Ohromium Treatment Technologies	$2,920.01	$5,840.02	$11,680.04
Development of Envirenmentally Friendly Selection Methods for Surface Coatings	$3,217.43	$3,313.95	$0.00
Development of Sediment Management Pretocols for Small Diversion Reservoirs in Utah	$37,590.44	$71,805.82	$75,396.10
Echo Reservoir TMDL Study	$4,215.38	$0.00	$0.00
Fate of Pharmaoeuticals in Drinking Water Treatment Plants: Benoh and Pilot Soale Evaluations	$5,615.41	$5,783.87	$0.00
Investigation of the Changes in Water Quality In the Little Bear River Watershed in Response to the Implementation of Best Management Practices	$5,631.42	$16,894.26	$33,788.52
Lab-on-a-Chip – Miniaturized Salinity Sensor Arreys for Water Ouality Monitoring	$1,077.42	$55,000.00	$63,250.00
Miorobial Reduction of Structural Iron in Aquifer Solids: Role of Iron Reducing Miorebial Community, Produotion of Electron Shuttles and Inon Minerelogy	$14,252.33	$14,679.90	$15,120.30
Coourrenoe Survey for Boron and Hexavalent Chromium	$4,709.66	$4,350.97	$0.00
Potential Impacts of Septio Systems on Ground Water in Castle Valley, Utah	$6,133.45	$6,317.46	$6,633.33
Cuantification and Management of Unoertainty in Salt Loading from the San Rafael Irrigation System	$50,952.40	$25,476.20	$26,240.49
Real Time Streamflow and Water Ouality Monitoring Station in the Logan River at the Utah Water Researoh Laboratory (UWRL)	$3,154.33	$9,462.99	$13,925.93
Researoh Project for Hexavalent Ohromium Removal	$2,354.84	$2,425.49	$0.00
Selenium Sampling	$4,709.68	$4,850.97	$0.00
Source Water Proteotion Tools Development	$26,844.66	$3,948.22	$0.00
Statewide Nonpolnt Souroe Pollution Eduoation Related to On-Site Wastewater Treatment Systems	$13,572.17	$13,979.34	$14,393.72
Weber/Cgden Basin Water Cuality Study	$7,203.20	$10,604.30	$11,345.04
Designated Amount for FY06/FY07 Research Projeots		$306,000.00	$253,000.00
Undesignated researoh projeots in program area		$16,000.00	$15,000.00
Total	**$244,484.17**	**$630,254.43**	**$566,730.87**

Alternative Decentralized Wastewater Treatment Systems for Utah Conditions

Principal Investigator(s):
Judith L. Sims
Darwin L. Sorensen
Jenny Paget Hurst

Project Description:

In this project we are surveying, reviewing, and critically evaluating existing information on various wastewater technologies that would be protective of public health and the environment under Utah climatic, geological, and regulatory conditions, while at the same time addressing the pressures of population growth. Based on the information collected, we are developing guidance materials for state and local decision-makers on decentralized treatment technologies and appropriate management strategies.

Accomplishments:

Based on the information collected, we are preparing guidance materials that summarize effectiveness, appropriateness, and operation and maintenance requirements of various decentralized technologies for use in Utah. These guidance materials will be presented to local health department staff and other interested on-site wastewater professionals at a series of workshops throughout Utah during the spring and fall of 2006. We are in the process of completing operation and maintenance (O&M) manuals for packed bed media systems.

Work Plan FY06/FY07:

Specific tasks that are being accomplished include: 1) Survey and collect existing information on alternative decentralized on-site and wastewater reuse technologies; 2) Evaluate information with regards to applicability of technologies to Utah's climatic, geological, and regulatory conditions - also we are considering life cycle costs, treatment efficiencies, management requirements, reliability and failure rates, and potential for beneficial reuse of wastewater; and 3) Develop guidance materials for state and local decision-makers concerning wastewater treatment technologies and management programs that will be protective of public health and the environment.

Benefits to the State:

By early 2006, Utah, as a result of administrative rule changes, will begin 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 and small community wastewater treatment systems will allow continued development in Utah's more rural areas.

Demonstration of Pilot-Scale Hexavalent Chromium Treatment Technologies

Principal Investigator(s):
Laurie McNeill
Han Lai
Crystal Viator

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 pilot-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 1,450 samples have been analyzed for Total Chromium and Chromium-6. Report has been submitted to funding agency, and papers have been submitted for publication.

Work Plan FY06/FY07:

On-site pilot studies coupled with laboratory analysis will continue.

Benefits to the State:

The State of Utah will ultimately be affected by any new drinking water regulations implemented by the U.S. Environmental Protection Agency (EPA). This research provides information on the treatment options for chromium in drinking water and will be useful to Utah in formulating state standards relative to chromium treatment.

Development of Environmentally Friendly Selection Methods for Surface Coatings

Principal Investigator(s):
R. Ryan Dupont
John Gershenson, Michigan Tech
Richard Ratliff
Revathi Pepalla

Project Description:

In this research project, a method is being developed for quickly comparing different industrial coating choices based on their environmental and societal impacts and their performance in a given application. The method will expedite the selection of industrial coatings during conceptual design by developing a set of expressions that relate coating key performance criteria (abrasion resistance, hardness, corrosion resistance, chemical resistance, *ete.*) to environmental and societal impacts (human health effects, resource depletion, energy utilization, *etc.*). These performance-based relationships provide a common ground for choosing among similarly functioning alternatives and provide insight for minimizing the environmental burdens these coating alternatives represent. Final coating selections can then be made based upon their cost and their ability to minimize the magnitude of their environmental and societal impacts. These impact characteristics are chosen, not only for their importance in determining the environmental burden of the coating selection, but also for their auditability. The impact characteristic must be reliably quantifiable to insure the development of stable and meaningful relationships.

Design and manufacturing engineers need tools to allow them to weigh the environmental and societal impacts along with the cost of their component and process selection decisions early in the design process when information is scarce. While the proposed method is applicable to a wide range of manufacturing processes and products, industrial coatings were selected as the initial application for the development of the methodology due to the size of the coatings industry, the wide range of industries utilizing product and special purpose coatings, the wide range and large quantity of raw materials used in the production of commercial coatings, and the large variety of alternative coating methods that are available for analysis and alternative coating selection.

The selection process provides a rapid, quantitative methodology for identifying the most environmentally benign candidate for a given coating application, which minimizes energy and resource utilization, without conducting exhaustive analyses of the systems. The method is used during conceptual design and it is understood that traditional optimization of specifications should be used during embodiment design.

Accomplishments:

A subset of coating performance variables was used for development and demonstration of the coating selection tool. These include abrasion resistance, impact resistance, dry heat resistance, and moisture vapor transmission. A coating selection taxonomy was developed that generates a list of feasible coating alternatives based on requirements of a given performance variable. For example, for a given coating performance variable (abrasion resistance), based on the environmental conditions under which the coating is to function (dry/moist, acid/alkaline, saline/fresh water, etc.), the substrate on which it is to be placed (wood, plastic, metal, composite), and what layer of coating it is

to be used for (primer, intermediate coat, top coat), a list of various coatings within a range of available coating types (acrylic, epoxy, alkyd, etc.) is generated.

Environmental impact indices were estimated for each feasible coating based on the components of each coating, and the surface preparation (primer, cleaning, etc.), application (chemical reducer requirements and application equipment efficiency), and removal processes utilized for each coating type. The impact taxonomy generates impact estimates over the life cycle of the coating at the global (global warming potential, ozone depletion potential, fossil fuel depletion), regional (acid rain production, ozone production, water use), and local (toxicity, land use) scales. The impact of each coating is expressed as an impact index that allows the selection of an optimal coating generated from the performance taxonomy based on the minimal life-cycle environmental footprint.

Work Plan FY06/FY07:

A subset of coating performance variables were selected for development and demonstration of this tool. Based on these performance criteria establishing a list of feasible coatings, an environmental impact taxonomy was then applied to components of each feasible coating to generate environmental impact estimates over the life cycle of the coating. The impact of each coating is then expressed as an impact index that allows the selection of an optimal coating generated from the performance taxonomy based on the minimal life-cycle environmental footprint.

Benefits to the State:

This project is focused on improving the selection of industrial coatings by design and manufacturing engineers by reducing the overall environmental, energy, and resource-use impact, their decision ultimately have. The product of this research will benefit the numerous users of industrial coatings in the public and private sector in the state, it can benefit manufacturers of coatings (e.g., Huntsman Chemical) by facilitating their evaluation of a coating's environmental impact during coating initial conceptual and final process design, and will benefit citizens within the entire state through improving environmental quality by facilitating the selection and use of coatings that minimize local and regional environmental impacts.

Development of Sediment Management Protocols for Small Diversion Reservoirs in Utah

Principal Investigator(s):
Mac McKee
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 was added this year. A sampling program was added this year to collect data on total suspended sediment concentrations of water flowing into and out of the reservoir at First Dam. Work in FY 2005 focused on using the data available from the real-time monitoring and grab samples to estimate a sediment budget for the reservoir. Results to date were presented at the annual Utah Water Users Conference in March, 2005.

Work Plan FY06/FY07:

Work in FY 2005 focused on the implementation of a water quality and stream flow monitoring program. A reservoir flushing plan will be tested in 2006 and 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.

Echo Reservoir TMDL Study

Principal Investigator(s):
David K. Stevens

Project Description:

Echo Reservoir, in Summit County, UT, is the subject of a total maximum daily load (TMDL) project to protect its long-term use as a mixed-use reservoir for irrigation, recreation, and culinary water support. It is protected for primary contact recreation (swimming) and as a cold-water fishery. Excessive phosphorus loadings into the reservoir have resulted in the deterioration of the fish-habitat resource and have resulted in excessive algal growth leading to deterioration of the resource as a culinary water supply. The objectives of this project are to establish existing phosphorus loading conditions to the reservoir, to develop acceptable loadings for restoring the reservoir for these purposes, and to develop an implementation plan for load reduction.

Accomplishments:

This project has enhanced Utah State University's national reputation through hands-on involvement with water quality improvement, part of the critical mission of the Clean Water Act. These project reports are published by the State of Utah and the U.S. Environmental Protection Agency (EPA), and successful projects are touted by the U.S. EPA regional offices (Denver, Region 8 for Utah).

Work Plan FY06/FY07:

Project completed.

Benefits to the State:

This project is being carried out in conjunction with the State of Utah and Cirrus Environmental. The results of this work are a data report, and loading report, and a set of computer-based data visualization and analysis tools to aid the state establishing and implementing load reductions to return Echo Reservoir to its designated use.

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Fate of Pharmaceuticals in Drinking Water Treatment Plants: Bench and Pilot Scale Evaluations

Principal Investigator(s):
William J. Doucette
Laurie McNeill
Coreen Crouch
Mike Petersen
Clayton TenEyck
Clint Rogers
Demetrio Cabanillas
Tiffany Leo

Project Description:

The potential impact of drinking water treatment processes (coagulation/flocculation, sedimentation, filtration, and ozonation) on the removal of low levels of pharmaceuticals was evaluated for four compounds (caffeine, estradiol, salicylic acid and trovafloxacin mesylate) using pilot (23-26 L/min) and bench (0.03 L/min) scale systems. The compounds were selected to be representative of a variety of pharmaceuticals in terms of charge (neutral, cationic, anionic and zwitterionic) and expected fate within drinking water treatment facilities. Pilot and bench systems were compared to determine the influence of scale on contaminant fate. The pilot scale system, owned and operated by the Metropolitan Water District of Salt Lake City and Sandy, UT was used to optimize treatment in a conventional plant and evaluate ozonation processes. The bench scale system was designed and constructed to mimic the operation of a full-scale system.

Accomplishments:

The impact of drinking water treatment on pharmaceutical removal was evaluated for caffeine, estradiol, salicylic acid and trovafloxacin mesylate using pilot (23-26 L/min) and bench (0.03 L/min) scale systems. The compounds were selected based on charge and expected removals. Pilot and bench systems were compared to determine the influence of scale. Influent concentrations ranged from 100 to 500 μg/L based on detection limits. Influent and effluent samples were analyzed to determine removals. Conventional treatment (coagulation, flocculation, sedimentation, and filtration) removed 100% of the estradiol and trovafloxacin mesylate, 17% of the caffeine, and none of the salicylic acid in the pilot plant. Ozonation, as an isolated treatment, removed 63%, 12%, 99%, and 7% of the same compounds. Similar results were observed at the bench scale with removals of 100%, 100%, 18%, 10% using conventional treatment and 100%, 33%, 31%, and 11% using ozonation for estradiol, trovafloxacin mesylate, caffeine, and salicylic acid, respectively.

Work Plan FY06/FY07:

Project completed July 2005.

Benefits to the State:

Evaluating the potential removal of pharmaceuticals during drinking water treatment processes is an important issue for regulatory involved in setting drinking water standards. Results obtained from this study will benefit the State of Utah by providing baseline information that can be used in screening-level risk assessments.

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
Darwin L. Sorensen
Nancy Mesner
Ron Ryer
Douglas Jackson-Smith
Joon Hee Lee

Project Description:

The Clean Water Act 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:

This project has enhanced Utah State University's national reputation through winning the national competition for these awards from U.S. EPA.

Work Plan FY06/FY07:

Water quality models and data analysis, 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 San Antonio, TX.

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.

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

Principal Investigator(s):
Arlhong Zhou

Project Description:

The project will 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-μSMEAs". The simultaneous measurement of multiple salinity ions will be realized by this "lab-on-a-chip" device. Field tests of the device will be conducted in the San Rafael River Basin in Emery County in coordination with the Emery Water Conservancy District. Patents will be sought for the various components of the device.

Accomplishments:

In Phase I, a prototype EC circuit board has been made and a microelectrode array has been fabricated. Sulfate, SO_4^{2-}, was selected as the initial target salt ion for this preliminary stage. SO_4^{2-} is a good ion for this because it will provide a full test of the entire concept, it represents the largest share of the salt loading from many Utah watersheds (including the San Rafael), and it is a very ecologically significant ion. The initial performance tests have been compared with the commercial EC instrument and extremely satisfactory results were obtained.

Work Plan FY06/FY07:

In Phase I (this reporting period), a prototype EC board and microelectrode arrays will be fabricated. Initial performance tests will be conducted to compare the performance of the device against that of much larger, more expensive commercial-grade EC laboratory equipment. In Phase II (next fiscal year), the design of the device will be optimized and its performance in the form a printed circuit board will be evaluated; fabrication of the MEAs and microfabrication and integration of the μISEAs on the EC chip will be optimized; the ion selective polymer membrane (e.g., bis-pyrylium derivatives) which must be specific to individual salt ions will be synthesized; finally, the EC PCB will be integrated with the selective membrane-coated MEA and initial performance evaluations will be conducted. In the final phase, the device will be linked to standard data logging equipment and field-tested.

Benefits to the State:

Salinity is a major problem in the Colorado River Basin, causing millions of dollars annually, mostly in the lower basin. Most of the anthropogenic salt in the Colorado River results from activities in support of irrigated agriculture in the Upper Colorado River, especially in drainages such as the Price and San Rafael Rivers in Utah. Management of salts requires availability of accurate and cost-effective methods for measuring salt concentrations in natural streams and rivers. Available real-time measurement technologies (e.g., electrical conductivity probes) are subject to error of up to ±15 percent, making it very difficult in some cases to actually measure the effects of expensive salt

management measures. Development of a "lab-on-a-chip" will benefit Utah in three ways. First, it will produce a technology that is capable of achieving an order-of-magnitude improvement in the measurement of salt loading in critical Utah rivers. This will enable better management of Utah's irrigated areas that are major producers of salt loading in the Colorado River Basin. Second, the technology being developed will yield several patents (one per ion measurable by the chip) that will have significant commercial value. The potential market for the device is worldwide. Finally, the technology under development in this project has applications in many other areas that are socially important and economically attractive, such as the medical industry.

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.

Objective 1: Identify and quantify the Fe(III) reducing bacteria, *Geobacter* and *Rhodoferax*, in microcosms of sediments and groundwater from 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.

Accomplishments:

In the OA sediment, glucose addition led to the production of 1,500 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 113 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. When compared to carbon donor addition without AQDS, the addition of AQDS to glucose microcosms stimulated a doubling in the population of *Rhodoferax* and a 14 times increase in the *Geobacter* population when added to acetate microcosms.

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 did not show biostimulation of either *Geobacter* or R*hodoferax*. The population of R*hodoferax* was stimulated with glucose addition to the OA sediment, however, enrichment was not observed with the RA sediment because of the large population of *Rhodoferax* in the original sediment (3x105 copies/μL, or 50% of the eubacter present in the sediment) preventing observation of increases over this high background level. The addition of AQDS to the acetate treatment led to a 121% increase in biogenic iron (4 mg/kg Fe(II)) and a 36 times increase in *Geobacter* population and a nine times increase in R*hodoferax* 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 FY06/FY07:

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 Hill Air Force Base (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 R*hodoferax* 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 R*hodoferax*, 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 change with treatment compared with the no carbon control or microcosms without AQDS, in gene copy concentration as determined by q-PCR.

Kyle Gorder is the contact person at HAFB. Dr. R. Ryan Dupont et al. also have contact with Curtis Payton of the Army Corp of Engineers and Scott Reed of US Army Dugway Proving Grounds for continued application of results from this study at Dugway. The State of Utah's contact is David Larsen with the DEQ.

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, 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 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.

Publications:

McLean, J.E., R.R. Dupont, and D.L. Sorensen (Submitted). Iron and arsenic release from aquifer solids during enhanced trichloroethylene degradation. *J. Environ. Qual.*

Mickelson, H.L., J.E. McLean, R.R. Dupont, and D.L. Sorensen (2005). Transformation of iron phases and electron shuttle production during anaerobic biostimulation for TCE degradation. *Annual Battelle International In situ and On-Site Bioremediation Symposium,* Baltimore, MD.

Mickelson, H.L., J.E. McLean, J.M. Norton, R.R. Dupont, and D.L. Sorensen (2005). Electron shuttle activity affects iron availability in non-dehalogenating TCE contaminated sediments. *Annual meeting of the American Society of Microbiology,* Atlanta, GA.

Mickelson, H.L., J. Zhou, J.E. McLean, D.L. Sorensen, J.M. Norton, Y.Q. Xu, and R.R. Dupont (2005). Transformation of iron phases and identification of known iron-reducing bacteria during anaerobic biostimulation for trichloroethylene degradation. *Joint International Symposia for Subsurface Microbiology and Environmental Biogeochemistry,* Jackson. WY.

Zhou, J., R.R. Dupont, D.L. Sorensen, J.M. Norton, and J.E. McLean (2005). Phylogenetic analysis of dechlorinating culture and a TCE-contaminated aquifer. *Annual Battelle International In situ and On-Site Bioremediation Symposium,* Baltimore, MD.

Occurrence Survey for Boron and Hexavalent Chromium

Principal Investigator(s):
Laurie McNeill
Han Lai
Crystal Viator

Project Description:

Hexavalent chromium and boron are under consideration for new drinking water regulations. In order for the U.S. Environmental Protection Agency (EPA) to develop new drinking water standards, we must determine the extent to which the contaminants to be regulated occur in water. This study will conduct a national survey of boron and hexavalent chromium, as well as other major and trace elemental constituents, in U.S. drinking waters. This will allow an analysis of occurrence patterns in water sources, to determine the potential number of water utilities that will be impacted by new regulations as well as an estimate of the national cost of implementing new regulations. Analysis of co-occurring elements will help determine potential limitations or enhancements of treatment techniques to remove Cr and B.

Accomplishments:

Over 260 water samples were analyzed for 30 different elements in their raw water, and treatment profiles were conducted at additional utilities. One publication of peer-reviewed journal article in Water Research, was presented at the AWWA Water Quality Technology Conference.

Work Plan FY06/FY07:

Collection and analysis of samples from ~800 water utilities.

Benefits to the State:

The State of Utah will ultimately be affected by any new drinking water regulations implemented by the U.S. EPA. This research provides national occurrence data to help EPA develop rational new standards that will be appropriate for Utah.

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

Principal Investigator(s):
Judith L. Sims
Amy Davis

Project Description:

The overall goal of this project was to initiate the development and implementation of a plan to protect the ground water in Castle Valley from contamination from septic systems. In order to accomplish this goal, we first need to understand the potential for contamination of the ground water from septic systems within the Valley. To accomplish this, we will conduct a drain field lysimeter study at selected locations within the Valley.

Accomplishments:

In this project we tested the feasibility of our sampling and analysis techniques and selected potential study sites in Castle Valley, Utah.

Eight potential sites were selected - we then obtained information about each potential site from the Southeast Health Department and from the Division of Water Rights. We also set up a practice site in Smithfield, Utah, to test out our techniques and analytical procedures in an operating drain field.

A challenge we face in this study is the long distance from Utah State University (USU) to Castle Valley - the travel time makes it impossible to use standard laboratory analytical techniques because of the possibility of exceeding sample holding times. Therefore we purchased a Colilert System for the Utah Water Research Laboratory's (UWRL) Environmental Quality Laboratory. This system is highly recommended (required) by the Utah Department of Environmental Quality (UDEQ) for detection of E. coli bacteria in water samples. We also obtained field portable analytical testing kits in order to be able to complete sample analysis in the field within the required holding times.

The study will require long-term (18 months) of sampling activities - the results will be used for a master's thesis and for a refereed journal publication. In addition, we will develop and present workshops for the citizens of Castle Valley. Based on our results, we will be able to provide them with an assessment of the potential for their ground water to be impacted by septic systems as well as steps they can take to prevent adverse impacts.

Work Plan FY06/FY07:

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. 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

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.

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 on possible management options for the septic systems in the Valley.

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 addressed 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.

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

Principal Investigator(s):
Mac McKee
Lizette Oman
Abedalrazq Khalil
Saket Pande

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 will employ modern methods of data analysis to provide better estimates of salt loading from the basin and describe the amount of uncertainty those estimates contain. The project will also seek to identify data collection methods to reduce the uncertainty in estimates of salt loading.

Accomplishments:

Work in FY 2004 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/). Work has focused thus far on analysis of salt loading from the San Rafael into the Green River. This will be extended further upstream as data and resources allow. In particular, statistical relationships between stage and discharge, and between conductivity and salt concentration have been developed. This has been done so as to provide the basis for a Bayesian belief network (BBN) model that will be 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 2005, a BBN model was developed 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.

Work Plan FY06/FY07:

In FY 2006, the BBN salt loading model will be programmed to run on the EWCD computers so that salt loading estimates can be displayed on the EWCD web site. The Utah Water Research Laboratory (UWRL) will 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.

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 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:

This proposal is to request funds from the Utah State University (USU) Water Initiative Research Initiation Program for the creation of a real time water quality monitoring station in the Logan River. This real time monitoring station, to be 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 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:

Purchase, install, and commission water quality and flow monitoring equipment.

Work Plan FY06/FY07:

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.

Research Project for Hexavalent Chromium Removal

Principal Investigater(s):
Laurie McNeill
Joan E. McLean
Han Lai
Crystal Viator

Project Description:

Chromium is a contaminant of increasing interest in drinking water, especially after the success of the "Erin Brockovich" movie. This project will be the first to examine the oxidation and reduction chemistry of low levels of chromium present in drinking water, as well as to evaluate the behavior and stability of chromium treatment process residuals.

Accomplishments:

Laboratory studies established rates of reaction of various oxidants and reductants with chromium in drinking water. Paper submitted for publication in Journal of Environmental Engineering was accepted November 2005.

Work Plan FY06/FY07:

Laboratory studies will continue.

Benefits to the State:

The State of Utah will ultimately be affected by any new drinking water regulations implemented by the U.S. Environmental Protection Agency (EPA). This research provides information on the treatment options for chromium in drinking water appropriate for conditions in Utah.

Selenium Sampling

Principal Investigator(s):
Laurie McNeill
Tiffany Leo
Clint Rogers

Project Description:

Selenium in water can adversely impact the health of waterfowl species in the water. This project will measure Selenium concentrations in samples from the Mallard Springs Wildlife Management Area (WMA) in order to help determine if modifications to the WMA (such as dredging) will cause selenium levels to exceed safe levels for wildlife.

Accomplishments:

Samples were collected and analyzed from four locations in the wetlands at four different times of the year.

Work Plan FY06/FY07:

Will collect samples and measure Selenium by ICP-MS.

Benefits to the State:

Selenium will be measured in the Mallard Springs Wildlife Management Area to support the Utah Division of Wildlife Resources in decision-making about management of the area.

Source Water Protection Tools Development

Principal Investigator(s):
Darwin L. Sorensen
David G. Tarboton
Mariush W. Kemblowski
David K. Stevens
Nickhil Monga

Project Description:

Integrate the principles of watershed management and drinking water quality management into the development of a simplified exploratory hydrologic and pollutant transport model that retains indispensable mechanisms to provide managers with an assessment system with low data requirements. The objectives of the work done this year were (1) integrate a reservoir pollutant fate and transport model into the modeling system and (2) demonstrate the adaptability and performance of the modeling system in a Utah water supply watershed other than the development watershed.

Accomplishments:

The reservoir model modification work is nearing completion. The Ogden River watershed is being used as the case study for development purposes (Figure 1).

Nikhil Monga, graduate research assistant, has prepared a proposal for his Master's of Science plan B report. It describes the conceptual "box model" (Figure 2) approach that will be used in the modeling system to simulate the fate and transport of pollutants in reservoirs.

Work Plan FY06/FY07:

The computer code for an existing reservoir model is being modified to incorporate the necessary components for pollutant fate and transport modeling.

Benefits to the State:

Utah drinking water purveyors are engaged in planning and conducting source water protection programs. The drinking water industry uses a multi-barrier approach to protecting the safety of drinking water that is distributed to the public. Assuring a safe source of untreated water is the first barrier. Protective measures may be expensive and land use restrictions to protect water quality can decrease the potential for development. It is very important that source water assessments correctly identify potential risks and present a scientifically credible evaluation of the magnitude of the risk so that public health can be protected while the monetary and social costs of protective management are minimized. It is vital that sound scientific principles are used to direct the assessment approach and that arbitrariness is avoided.

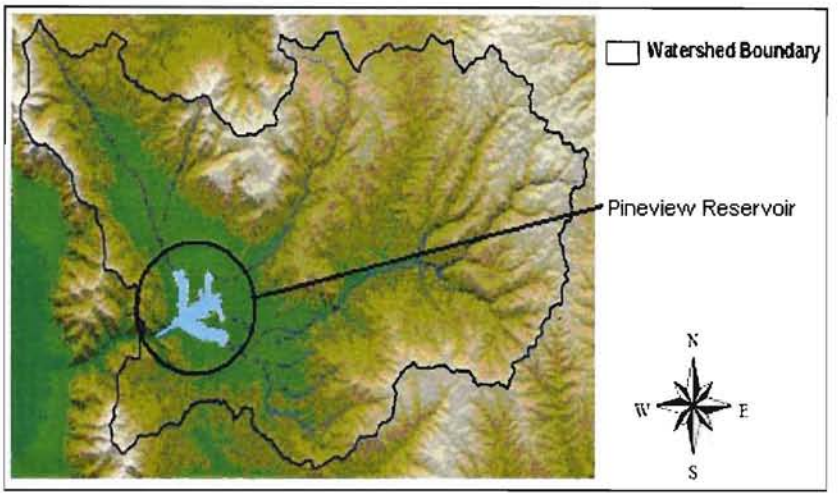

Figure 1. Ogden River watershed and Pineview reservoir

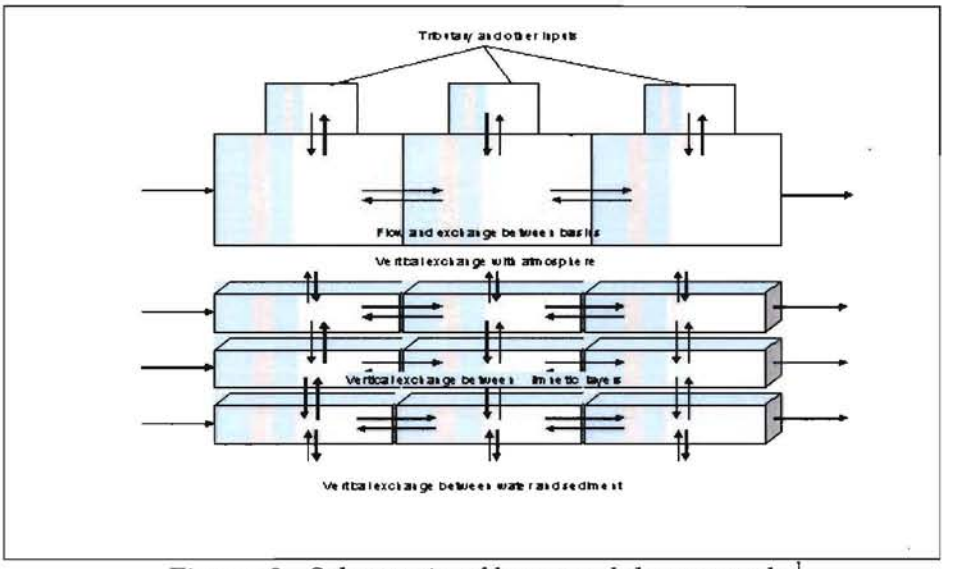

Figure 2. Schematic of box model approach.[1]

[1] Stevens, D.K., B.T. Neilson, and J. Horsburgh. 2003. EDN 8- Information needs for Lake Whatcom Model and its incorporation into the WRIA1 WMA Decision Support System. Technical Memo. Utah Water Research Lab., Logan, UT.

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 is developing and implementing an information and education program that will provide elected officials, students, and the general public with on-site wastewater management information related to the prevention of non-point 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 (UOWA) and at meetings of the Weber-Morgan Health Department Wastewater Advisory Committee. A draft guidance document: "Onsite Wastewater Treatment: A Guide for Elected Government Officials and Participants in City and County Government" has been prepared and, when finalized, will be distributed through the Utah League of Cities and Towns to local government officials. This document will be introduced through a presentation at the Utah League of Cities and Towns annual Water Conference in October, 2005.

Work Plan FY06/FY07:

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:

Local government officials, health department officials, and homeowners living in rural areas must respond to many technical and economic issues related to ground water quality protection while providing for domestic wastewater treatment and disposal. It is very important that people in each of these groups are aware of the need to properly locate, install, and operate on-site wastewater treatment systems.

Weber/Ogden Basin Water Quality Study

Principal Investigator(s):
David K. Stevens
Thomas B. Hardy
Jeff Horsburgh

Project Description:

One of the pressing issues in the Weber Basin in Utah is lake eutrophication from increased phosphorus and nitrogen from point and non-point 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.

Work Plan FY06/FY07:

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. Final project report, completed software, user's manuals, and other software documentation.

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.

Water Education and Technology Transfer

Aotual, Budgeted, and Planned Expenditures of Minoral Loase Funds
Water Education and Teohnology Transfer

Projoot Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Graduate Assistance in Areas of National Need (GAANN)	$12,819.62	$13,204.21	$2,310.74
Utah Native Fishes Viewer	$24,036.83	$12,018.42	$12,018.42
Utah On-Site Wastewater Treatment Training Pregram	$15,295.31	$15,754.16	$16,541.87
Designated Amount for FY06/FY07 Research Prejects	$0.00	$85,100.00	$60,000.00
Undesignated research projects in program area	$0.00	$5,000.00	$5,292.00
Total	**$52,151.76**	**$131,076.79**	**$96,163.03**

Graduate Assistance in Areas of National Need (GAANN)

Principal Investigator(s):
Randal S. Martin
Laurie McNeill
Sonia Manuel-Dupont
Bethany Neilson
Heather Mickelson
Christina Bandaragoda

Project Description:

This project will increase the number of qualified PhD students in Environmental Engineering by providing money for stipends, research supplies, and travel funds. These costs are met with outside funding. Mineral Lease money is used to support some faculty time in directing research done by the GAANN students on projects in Utah.

Accomplishments:

Four of six graduate student positions were filled in FY 2005.

Heather Mickelson's work was presented at the American Society for Microbiology, June 5-9, 2005 and the In Situ and On-Site Bioremediaton Symposium on June 5-9, 2005.

Work Plan FY06/FY07:

Outside funding will provide stipends and research/travel funds for PhD students, mentoring, and a 3-semester seminar series to prepare students for career in academia. Mineal Lease funds will support continued faculty mentoring time for GAANN students to work on projects in the Virgin, Bear, and Provo River Basins and near Hill Air Force Base (Hill AFB).

Benefits to the State:

The project provided funding for four PhD students in FY 2005. 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 AFB).

Utah Native Fishes Viewer

Principal Investigator(s):
Thomas B. Hardy
Levi Barton
Greg Heuer
Michelle Hospodarsky
Chris Michaelis

Project Description:

We have developed a MapWindows-based application directed at meeting the Utah Museum of Natural History support of the State of Utah curriculum that targets 4th and 9th grades involving knowledge and understanding of native fishes within the state and provide a flexible tool for use by both the students and teachers.

The specific curriculum objective for the state is to increase an understanding of the native fish and water resource issues within Utah. The tool will provide a flexible working environment with existing lesson plans that directly meets the stated curriculum objectives while allow the teacher to create or modify new lesson plans and share these via the world wide web to other teachers throughout the state.

Accomplishments:

This effort entailed the development of a MapWindows GIS application that shows the historical and current distribution of native fishes throughout the State of Utah and includes on-line information on the life history requirements of each native fish. In addition, the system supports the customization of lesson plans for use in the classroom in both the 4th and 9th grade levels.

Work Plan FY06/FY07:

The Utah Native Fishes Viewer was demonstrated to over forty 4th grade children in the St. George area in the fall of 2005 that included both a field visit to the Virgin River as well as use of the tool to demonstrate its utility using existing lesson plans. The tool is now on-line for downloading to all teachers within the State of Utah and additional work with other schools throughout the state have been planned for 2006.

Benefits to the State:

The Utah Native Fishes Viewer has been made available on-line to all Utah 4th and 9th grade schools for use in meeting mandated core curriculum objectives to learn about native fish in Utah and the factors that affect them. This module is the first on-line based learning module that directly meets core curriculum objectives for 4th and 9th grades. It provides a valuable resource for teachers and students with all the known distribution and life history requirements of native fishes within the state and provides access to a number of predefined lesson plans to facilitate the teachers need to meet core curriculum objectives.

Utah On-Site Wastewater Treatment Training Program

Principal Investigator(s):
Judith L. Sims
Darwin L. Sorensen
Margaret M. Cashell
Richard Jex
Brian Cowan
Jenny Paget Hurst
Patrick Andrew
Amy 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 designers, and installers, and the general public with an interest in on-site wastewater treatment.

Accomplishments:

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

On March 24, 2004, Professor Sims provided an overview of the Utah On-Site Wastewater Treatment Program at the Annual Conference of the Idaho Environmental Health Association Conference in Boise, Idaho.

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

Level I: Ogden, October 2004; Logan, May, 2005

Level II: Ogden, October, 2004; Logan, May, 2005

Level III: Logan, November, 2004

In addition, Dr. Ronald C. 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. Sims served and acted as chairman of the annual conference planning committee. The fifth annual conference of the UOWA was held February at the Ogden Conference Center, with 90 people in attendance.

Work Plan FY06/FY07:

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 will begin providing Level 1 and Level II re-certification 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 State:

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.

Fluid Mechanics and Hydraulics

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

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Culvert Hydraulio Analysis and Design for Rural Roads	$32,113.52	$42,113.52	$44,224.45
Hydraulio Design Data for Environmentally Sensitive Culvert Installations	$36,337.57	$37,942.70	$39,030.93
Hydraulio Structures for Flood Control and Flood Bypass	$21,626.94	$22,275.75	$22,944.02
Sediment Transport and Flood Control	$19,362.58	$19,943.45	$30,951.50
The Effects of Pipe Aging on Head Loss	$9,812.13	$10,106.55	$0.00
Designated Amount for FY06/FY07 Research Projeots		$204,000.00	$192,000.00
Undesignated researoh projects in program area		$7,000.00	$3,000.00
Total	**$119,757.79**	**$343,386.97**	**$337,200.95**

Culvert Hydraulic Analysis and Design for Rural Roads

Principal Investigator(s):
William J. Grenney
Anisha Arora

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:

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.

Work Plan FY06/FY07:

The continuing requirements to examine the effects of existing culverts on aquatic habitat has generated a need to analyze the hydraulics of culverts that are partially buried in the streambed. This condition produces a nonstandard irregular cross section, and current design tools for this condition are complex and awkward to use. This research will provide a simpler tool for the analysis of such conditions.

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 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:

Evaluated inlet loss coefficients and inlet control flow capacity for circular and elliptical buried invert culverts (fish passage culverts) with varying degrees of invert burial. 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.

Experiments were conducted to identify the appropriateness of various culvert exit loss expressions in an effort to identify the most accurate method. Tests were conducted using prototype-scale culverts (12-, 24-, 48-, and 60-inch diameter) with circular cross sections. Tests were conducted featuring free-surface and pressurized culvert flow for both submerged and unsubmerged pipe exit conditions. The study concluded that the Borda-Carnot sudden expansion minor loss expression, commonly used to quantify the energy loss in sudden expansions in pressurized pipe flow, predicted the experimentally determined culvert exit loss with a significantly higher level of accuracy than other more traditional methods. A literature review produced no evidence of the Borda-Carnot expression having been recommended for predicting culvert exit loss.

Preliminary work investigating the effectiveness of currently published for predicting composite roughness in rectangular channels has been completed. Three different boundary roughness conditions were evaluated for hydraulic roughness in a 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 were compared with the predictive results of 15 different published equations for predicting composite hydraulic roughness coefficients.

Work Plan FY06/FY07:

We will focus on the following objectives:

- Evaluate the performance of multi-barrel culverts to determine the appropriateness of superposition design methods.
- Evaluate the performance of slip-lined (rehabilitated) culverts to identify design parameters specific to the resulting end treatment.
- Evaluate 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 included additional form-loss boundary conditions, as form-loss boundary conditions are more consistent with buried-invert culvert flow boundaries.

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 Master's students are participating in this project.

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Hydraulic Structures for Flood Control and Flood Bypass

Principal Investigator(s):
William J. Rahmeyer
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:

Detail 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.

Proposal for the Hydraulic Model Study of the Spillway Stilling Basin at the Main Cooling Reservoir, South Texas Project Electric Generating Station, for MWH Americas, Inc, Denver Colorado, January 2005 (not funded).

Proposal for the Physical Model of Gilboa Dam Spillway, Gannet Fleming/Hazen Sawyer, A Joint Venture and the New York City Department of Environmental Protection, January 2005 (Funded).

Work Plan FY06/FY07:

Several papers will be written and published. Continued participation in the Utah Floodplain and Storm Water Management Association. Co-chair the next annual Floodplain and Storm Water Management meeting in St. George, Utah. Physical modeling and numerical modeling of several reservoirs and dams 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 retrofit of dams and reservoirs for increased storage is an important issue in Utah. 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.

Sediment Transport and Flood Control

Principal Investigator(s):
William J. Rahmeyer
John Newton
Mike Stover
Wade Goodridge

Project Description:

Fundamental hydraulics of sedimentation and erosion; equations and methodologies to predict the sediment transport in steep mountain streams and closed conduits; develop sediment transport equations and methods for Utah Department of Transportation (UDOT); an understanding of the effect of vegetation on the sediment transport in floodplains; 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 Sever River basin and Bear Lake districts.

Continue research and publishing journal articles on flood plain resistance and the effect of vegetation on flow resistance; the effect of the sedimentation process on erosion and deposition at culverts and road crossings.

Present papers and discussion on sediment transport at the next symposiums sponsored by the IECA and USCOLD and EWRI; publish a journal paper of Floodplain Resistance Due to Vegetation with the International Hydraulic Research Association.

Accomplishments:

Conference presentation in St. George, Utah and in Logan, Utah.

Work Plan FY06/FY07:

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.

Presentations:

Rahmeyer, W. (2004). The Effects and Problems Associated with Sediment Blockage of Road Crossings and Culverts During Flood Events. *Utah State University, Utah Floodplain and Storm Water Management Conference*, St. George, Utah October 17.

The Effects of Pipe Aging on Head Loss

Principal Investigator(s):
Steven L. Barfuss
William J. Rahmeyer
Ryan Christensen

Project Description:

Perform laboratory tests on aged pipe to determine hydraulic roughness. The initial objective of this project is to determine the magnitude of change in hydraulic roughness from a new pipe to aged condition. The following are the focus of the project:

- Source water protection in Utah
- Ground water management
- TMDLs--setting them and managing in-stream resources
- Water conservation
- Water resources planning/management for agriculture, recreation, etc.
- Drinking water treatment (e.g., arsenic contamination)
- Air quality issues along the Wasatch Front and especially in Cache Valley
- Remediation of ground water and soil in Utah
- Management of small dams to mitigate aquatic resource impacts
- Watershed protection strategy development
- On-site/decentralized wastewater treatment issues in Utah
- Dam safety and emergency preparedness
- Great Salt Lake Management
- Municipal water system planning and management

Accomplishments:

Preliminary results indicate that pipe head losses can increase considerably due to barnacle growth on the inside of water pipes. The laboratory test shown in figure 1 illustrates that if the new pipe diameter is used for calculation purposes, the Darcy f increased from approximately 0.02 for the new pipe condition to approximately 0.07 for the condition shown in the photograph (Figure 2). This equates to a 3.5 times increase in the head loss of the pipe.

Work Plan FY06/FY07:

Call city managers to request that old pipe that is pulled out of the ground be set aside for possible laboratory tests. Attempt to quantify the roughness density and roughness height and relate these measurements to the experimental roughness value determined in the laboratory.

Benefits to the State:

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 have formed barnacles on the interior wall of the pipe. 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 that the city has to add connection is limited. Understanding the effect of pipe aging on pipe roughness will greatly help State of Utah municipal water system planning and management.

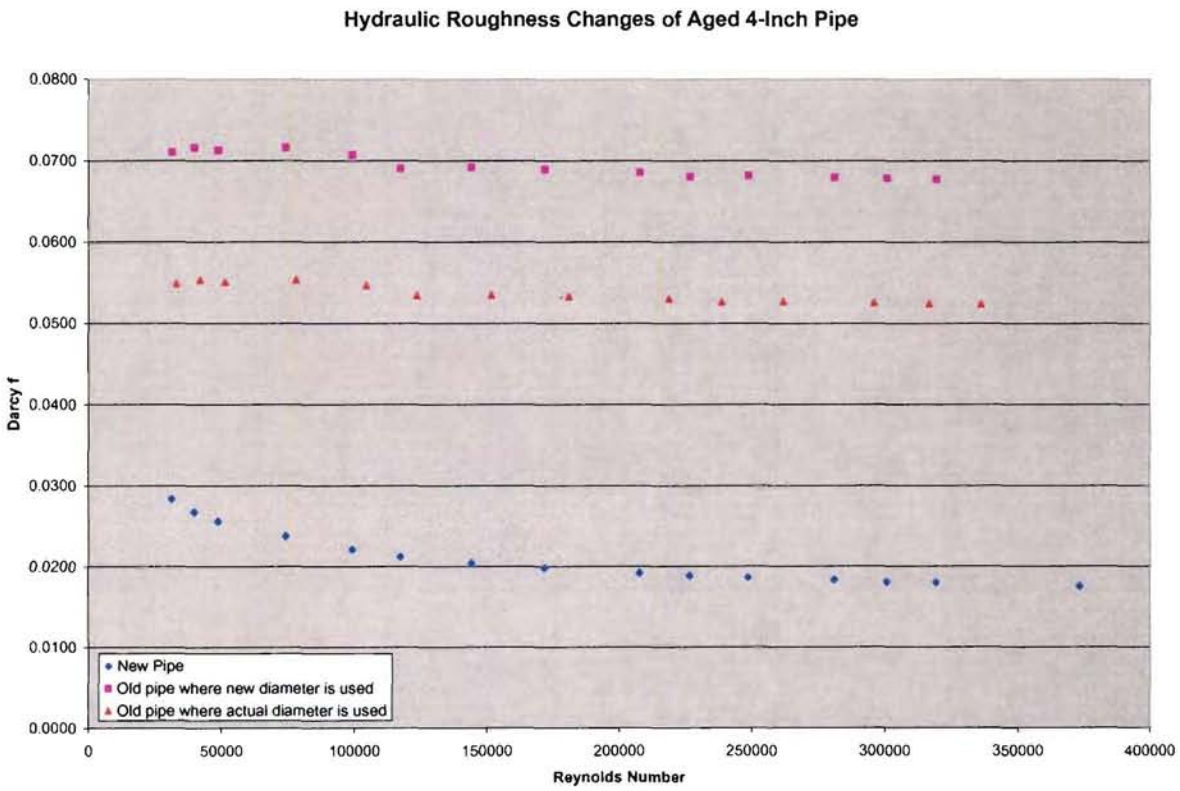

Figure 1. Hydraulic roughness changes of aged 4-inch pipe.

Figure 2. Four-Inch pipe picture provided by Weber Basin Water in Ogden, Utah.

Ground Water

Aetual, Budgeted, and Planned Expenditures of Minoral Lease Funds
Ground Water

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Aquifer Vulnerability Assessment Under Competing Land Use Scenarios	$11,307.13	$36,307.13	$3,150.00
Designated Amount for FY06/FY07 Research Projects		$0.00	$0.00
Undesignated researoh projects in program area		$3,000.00	$3,000.00
Total	**$11,307.13**	**$39,307.13**	**$6,150.00**

Aquifer Vulnerability Assessment Under Competing Land Use Scenarios

Principal Investigator(s):
Jagath J. Kaluarachchi
Navin Twarakavi

Project Description:

1. Develop a methodology for assessing aquifer vulnerability to heavy metals and demonstrate the applicability of the methodology at a regional-scale.

2. Demonstrate the model applicability on a national-scale for assessing arsenic contamination of ground water in the conterminous United States

3. Application of the aquifer vulnerability techniques to answer the question of future ground water quality sustainability.

Accomplishments:

The work related to this work is almost complete.

Work Plan FY06/FY07:

1. Develop a model based on logistic regression to predict aquifer vulnerability in different concentration thresholds such as MCL and the background value.

2. Develop a simple economic analysis to predict the cost effectiveness of various MCL values of arsenic.

3. Demonstrate the overall vulnerability framework to arsenic contamination of shallow ground waters of the US.

Benefits to the State:

Use of chemicals in agricultural activities and other land use related practices is common in Utah especially in rural watersheds. The results of this work can be easily used in assessing the vulnerability of shallow ground water to chemicals used in various land use activities ranging from non-carcinogens such as nitrates to carcinogens present in heavy metals and pesticides. Once the vulnerability is known, then the results can be used to better design land use practices and make necessary changes in land management to minimize future pollution of valuable ground water resources. The results of this work can be readily used by the Utah Department of Natural Resources.

Publications:

Twarakavi, N. and J. Kaluarachchi (2004). *Aquifer vulnerability to arsenic contamination in the conterminous United States: Health risks and economic implications*. Fall Meetings, American Geophysical Union, San Francisco, CA, December 13-18.

Twarakavi, N. and J.J. Kaluarachchi (2005). Ground water quality vulnerability and uncertainty assessment under changing land use scenarios. *Proceedings of the Fifth International Conference on Calibration and Reliability of Groundwater Modeling from Uncertainty to Decision-Making*. Amsterdam, Netherlands, June 6-9.

Twarakavi, N.K.C. and J.J. Kaluarachchi (2005). Arsenic in ground waters of conterminous United States: assessment, health risk, and cost. *Journal American Water Resources Association, accepted.*

Twarakavi, N.K.C. and J.J. Kaluarachchi (2005). Assessment of aquifer vulnerability due to heavy metals using ordinal logistic regression analysis, *Ground Water*, 43(2), 200-214, 2005.Twarakavi, N.K.C. and J.J. Kaluarachchi (2005). Sustainability of ground water quality considering land use changes and public health risks. *Journal of Environmental Management, accepted.*

Hydrology

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

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Intercomparison of Land surface Models in Semi-Arid Areas	$16,872.95	$17,379.15	$34,758.30
Investigation on the Application of Nonuniform Grids for Land Surface Modeling Over Semi-Arid Areas and Evaluation Using Similarity Measures	$14,554.87	$34,991.52	$44,611.64
Modeling the Great Salt Lake	$25,283.46	$26,041.96	$26,823.22
Designated Amount for FY06/FY07 Research Projects		$109,000.00	$99,000.00
Undesignated research projects in program area		$9,000.00	$8,000.00
Total	**$56,711.29**	**$196,412.63**	**$213,193.16**

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 Land Atmosphere System Studies) panel. The objective of this study is the comparison of models that simulate water, energy, and CO2 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 of the diversity of environments in arid lands and will allow to establish whether or not further distinction is required to better represent the water, energy, and CO2 exchanges taking place over such areas.

In previous PILPS studies *[Lettenmaier et al., 1996; Nijssen et al., 2003]*, it was shown that the calibration of model parameters yielded improvement in the models performance. For this reason, we propose to use the 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. However, the use of this multi-criteria framework is not compulsory and the participants may carry out parameter estimation in the way they see fit.

Some of the science questions to be 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 have been slow in submitting the results. Only two of the planned seven steps have been accomplished. A presentation regarding the preliminary results so far was made at the GLASS Science Panel Meeting was made September 2005 at the Dutch Royal Meteorological Institute. Results submissions for the first two steps have been received from 11 modeling groups from different countries around the world, and a conference paper with preliminary analysis was submitted and will be presented at the AMS Meeting in January 2006.

Work Plan FY06/FY07:

We plan to complete the experiment for the summer of 2006 at which point we expect to produce three papers about the results of the experiment.

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. That has been the result of previous PILPS experiments at different locations over the world with the consequence of having better forecasting skills regarding climate and weather predictions.

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.

Investigation on the Application of Nonuniform 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 nonuniform 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 (50-200m). 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 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 nonuniform 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 a lot of interest from different agencies, the Weather Service in particular.

Specific objectives are:

- Design and apply nonuniform 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 nonuniform grid and fine-scale grid simulations to the medium-scale 1-4 km simulations. Compare fine-scale and nonuniform solutions and determine the nonuniform scales that result in solutions of similar accuracy as the fine-scale.

Accomplishments:

The project is ongoing and has been partially supported also by a grant from Utah State University new faculty and the NSF-STC SAHRA. A manual procedure for multiple grid representation has been developed over the San Pedro catchment and an automation of such procedure has been completed. We have made presentations at the AGU Fall meeting and at the NSF STC SAHRA Annual Meeting. A paper regarding the use of similarity measures for calibration and sensitivity analysis is almost ready and will be submitted early in January 2006.

Work Plan FY06/FY07:

We plan 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 a lot of interest and possible collaborations with NWS Office of Hydrology, Lancaster University, University of California-Irvine, and University of Colorado are envisioned. Shujun Li is expected to defend his dissertation January 23, 2006.

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 spatially distributed fashion and will be applied in a new forecast system for the state.

References

Bastidas, L.A. and S. Li (Submitted). On the use of similarity measures for distributed model performance evaluation. In preparation for submission to *Water Resources Research.*

Bastidas, L.A. and S. Li (2005). Multi-objective calibration and sensitivity analysis of a distributed model using similarity measures. *2005 AGU Fall Meeting*, San Francisco, California, December 5-9.

Bastidas, L.A., E. Rosero, and W.J. Shuttleworth (2005). Influence of data uncertainty on Sib2 parameter estimation for the Amazon Basin. *LBA Conference*, Sao Paulo, Brazil, November 10-12.

Bastidas, L.A., S. Li, and I. Tcherednichenko (2005). National weather service hydrology meeting. *Evaluation, Calibration and Sensitivity Analysis of Distributed Models Using Similarity Concepts*, Park City, UT, October 4-6.

Li, S. and L.A. Bastidas (2004). A Quantitative and objective procedure for evaluation of distributed hydrologic and hydrometeorological models. *AGU Fall Meeting*, San Francisco, California, USA, December 13-17.

Li, S. and L.A. Bastidas (2004). Distributed land surface modeling over the San Pedro Basin using a multiple resolution grid. *SAHRA Annual Meeting*, Albuquerque, NM, October 13-15.

Miller, N.L. (1993). The hierarchical systems flux scheme: The homogeneity test. *Conference in Hydroclimatology*, pp. 36-40, American Meteorological, Society, Boston, MA.

Miller, N.L. (1995) Sensitivity of surface heat and moisture fluxes due to topographic slope and azimuth. *Journal of Geophysical Research*, 100(D9):18,669-18,685.

Modeling the Great Salt Lake

Principal Investigator(s):
David G. Tarboton
Ibrahim Mohammed

Project Description:

The goal of this project is to develop and improve the capability for modeling the changes in volume and level of the Great Salt Lake as they are related to climate, land use, hydrology and water management in the contributing basins.

Accomplishments:

We have examined the role played by the topographic elevation-area-volume relationship on lake dynamics, and the correspondence between modes in volume and area distributions and peaks in the area-volume derivatives was examined. We derived, using a steady state approximation, the relationship between distributions of lake volume and lake area and the area-volume derivative from the topography/bathymetry. This analysis showed that both the topography/bathymetry and multimodality in the area distribution are required to explain the observed multimodality in the volume distribution. We also separated lake volume changes into increases in the spring (due to spring runoff) and declines in the fall (due to evaporation) and then related these volume changes to streamflow, precipitation, and basinwide climate inputs. Analysis of this data has allowed us to quantify the expected relationships between lake volume changes and precipitation, streamflow and temperature, and the relationship between evaporation and lake area. We have also in this analysis found connections between evaporation and salinity that can be quantified by a simple model based on the total salt load in the lake. The results of this study improve understanding of the sensitivity of the GSL level to the interplay between topography and fluctuations in precipitation and climate.

Results have been reported in presentations at the Geological Society of America Annual Meeting in Salt Lake City and American Geophysical Union Meeting in San Francisco as follows:

Mohammed, I.N. and D.G. Tarboton (2005). Connecting the Dynamics of the Great Salt Lake Volumes to the Volume - Area Relationship. *Geological Society of America Annual Meeting*, Salt Lake City, Paper No. 174-5, http://gsa.confex.com/gsa/2005AM/finalprogram/abstract_94336.htm.

Mohammed, I.N. and D.G. Tarboton (2005). Modeling the Dynamics of the Great Salt Lake as an Integrator of Regional Hydrologic and Climate Processes. *Eos Trans. AGU*, 86(52): Fall Meet. Suppl., Abstract H41C-0422.

Tarboton, D.G., I.N. Mohammed and U. Lall (2005). What Makes the Great Salt Lake Level Go up and Down. *Geological Society of America Annual Meeting*, Salt Lake City, Paper No. 64-7, http://gsa.confex.com/gsa/2005AM/finalprogram/abstract_95867.htm.

A MS Thesis and papers on this work are under preparation.

Work Plan FY06/FY07:

The Great Salt Lake is a terminal lake whose level is reflective of the balance between inflows and outflows. Inflows are from three major rivers, the Bear, Jordan and Weber rivers as well as groundwater seepage. The only outflow is evaporation. The evaporation depends upon climate, and the lake surface area which fluctuates with level. This research uses four data sources: (1) Climate data, (2) Streamflow data, (3) Great Salt Lake Bathymetry data, and (4) Great Salt Lake level and salinity data. These datasets have been assembled and relationships between precipitation, temperature, streamflow, salinity and changes in lake volume and level have been analyzed.

Benefits to the State:

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

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Water Resources Planning and Management

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

Project Name	FY2005 Actual Expenditures	FY2006 Budgeted Expenditures	FY2007 Planned Expenditures
Analysis of Water Demand for Utah's Urban Water Supply Systems	$6,409.58	$6,601.87	$6,799.92
Comparative Analysis of Orographic Effects for Estimating Peak Flows	$32,118.51	$37,113.51	$33,974.44
Economic Worth of Data in Water Resources and Water Quality Analyses	$11,307.13	$16,307.13	$17,122.48
Flow Measurement in Cache Valley Irrigation Canals	$5,409.33	$25,000.00	$35,000.00
Forecasts to Improve Water Demand Prediction in Irrigation Systems	$7,277.44	$7,495.76	$0.00
Real-Time Management of Irrigation Systems in the Sevier River Basin	$59,680.83	$33,507.78	$37,326.98
Sustainable Watershed Management Considering Hydrology, Water Quality, and Economics	$8,324.00	$16,643.00	$17,313.36
The Bear River Basin in Idaho, Utah, and Wyoming	$4,216.34	$8,430.63	$8,683.60
Virgin River Decision Support System (VRDSS)	$67,203.20	$78,432.33	$95,800.13
Water Resources Analysis and Optimal Allocation Strategies for Salt Lake Valley, Utah	$11,307.13	$16,307.13	$17,122.43
Designated Amount for FY06/FY07 Research Projects		$606,000.00	$633,176.33
Undesignated research projects in program area		$41,332.01	$20,000.00
Total	**$213,261.49**	**$893,231.75**	**$927,819.77**

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 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.

The primary objective of this project is to update and refine the models for analyzing, predicting and forecasting urban water demand.

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 the 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 r2 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.

Two publications are in preparation. The first 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.

In the second paper, clusters were formed based upon characteristics of the connections and then plotted a spatial map using a Geographic Information System. 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 FY06/FY07:

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.

Comparative Analysis of Orographic Effects for Estimating Peak Flows

Principal Investigator(s):
William J. Grenney
Ramya Cuduvalli Nataraj

Project Description:

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 objectives of this research are 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:

The plan of approach involved the following steps: 1) meet with agency representatives who have a concern regarding orographic effects on peak flow estimations, 2) collect Intensity-Duration-Frequency data from the most current sources, 3) statistically analyze the data for orographic effects, 4) develop a computer program to calculate the results, and 5) prepare a final report containing all of the data and analyses.

Work Plan FY06/FY07:

Focus will be concentrated on the regions and classes of precipitation where the greatest statistical differences occur. Analytical techniques will be developed to help an engineer take orographic effects into account when estimating peak flows.

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. This will be of particular use to the Utah Department of Transportation.

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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:

1. Develop 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 resource problems, water quality concerns, and water policy issues.

3. Demonstrate the applicability of the proposed methodology in each of these sites.

Accomplishments:

The work on Objective 1 is complete. The remaining tasks are currently undergoing.

Work Plan FY06/FY07:

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 value of data is important in resource allocation. This is a common global issue in water resources work and applicable to watershed planner and managers in Utah.

Flow Measurement in Cache Valley Irrigation Canals

Principal Investigator(s):
Gary Merkeley
Andres Ticlavilca
Balraj Tammali

Project Description:

The major objective of the study was to calibrate, site, and design flow measurement structures in irrigation canals to help water management in Cache Valley. The specific sub-objectives were to:

1. Examine and inventory the current locations and conditions of existing flow measurement structures in irrigation canals that draw water from the Logan River.

2. Check the calibration of existing flow measurement structures.

3. Design flow measurement structures in appropriate locations in order to improve the overall flow measurement capability of the entire system.

Accomplishments:

All of the objectives of the project were accomplished. Practical problems were seen during the walk-through surveys such as sediment deposition, side walls damage, unauthorized water diversion, seepage loss and other maintenance problems that can hinder the operation of the canal if not taken care at appropriate time. Communication among the people involved in the entire canal system also helps resolve most of the technical problems aw well as social problems of the canal system. Interviews with Canal Company personnel conducted during this project helped to understand the current condition of the canals and problems that are pertinent according to the canal company personnel. All the problems witnessed during the walk-through surveys and the problems discussed with canal company personnel were documented and utilized in developing a maintenance plan for these canals. A maintenance and operations plan addresses the problems of these canals in detail.

Operations and Maintenance

A better knowledge of the demand and the supply of irrigation water will result in well designed system. This well-designed system should be operated accordingly to meet the requirements of the farm system. To achieve this, the water flow in the canal should be regulated, monitored and possibly measured quantitatively including water flows through tertiary turnout structures. In this process, flow measurement structures, head gates, diversion gates, outlet gates play an important role.

Some problems were witnessed during this project those hinder the smooth operation of these canals; thus, there would be no control on the flow in the canals. This results in minor disputes among the people and also destroys the purpose of the canal. During the interviews it was told that storm water runoff into the canal became one of the major operational problems. It is evident that these canals were built to serve as delivery (distribution) system but does not have enough ability to serve as both delivery and collection system. It can be said that these canals do not have sufficient capacity to accept all of the stormwater runoff without overtopping the banks. When the stormwater runoff is diverted to these canals it causes flooding problems to the residents living in the vicinity of the canal and also canal banks get eroded, channel section would be destroyed.

Lack of a Maintenance Plan

None of these canals have a maintenance plan to take up maintenance works. A maintenance plan is a set of works that are to be taken periodically for the smooth operation of the canal. When asked about any maintenance plan that was adopted by the canal companies they said that they have none. But, they do take up maintenance works when the need arises.

Unsanctioned Water Withdrawals

During the walk-through surveys, at some locations unauthorized water delivery to the property was noticed. Due to this, the designed canal system might face some problems in the operation of the canal as per the design. Since the water is withdrawn without any mention in the design process, it may lead to an inaccurate estimation of demand and supply.

Lack of Adequate Flow Measurement Structures

Lack of adequate flow measurement structures causes problems in the operation of the canals. Logan Northern Canal is a fifteen-mile-long canal. It has only one flow measurement device near the upstream end, along Canyon Road in Logan. There is no other direct means of knowing the flow in the entire canal. It becomes hard to manage water and have control on the flow for such a long distance. The knowledge of flow rate in the canal would help in achieving the control over the flow in the canals and thus leaves scope for improvements in the operation of the canal.

Lack of Specialized Labor

A lack of specialized labor is also noticed as a major operational problem. The field staff is the one who monitor the flow in the canal. During this project it was noticed that field staff were not qualified in the water resources field. Because of this they don't have an idea of what they were doing and how improvements can be achieved in delivering the water efficiently. The field staff does not even know the working methods of the flow measurement devices installed in the canal. It was seen on one of these canals, the flow measurement device (Parshall flume) was designed and installed to work under critical flow conditions but the flume was completely submerged and nobody knows about the procedure to estimate the flow rate under such conditions. They were reading the flow as they did for critical condition by doing so they were over estimating the flow in that section.

Maintenance works are classified as:

- Regular maintenance
- Emergency maintenance
- Deferred maintenance

Regular maintenance works are the works that should be done periodically to maintain the canal good. Most of the maintenance works that are noticed during the walk through surveys are discussed. Everybody knows these regular works but pay little attention to it. Regular maintenance comprises works such as cleaning debris from trash racks, removal of vegetation from the canal, greasing or oiling the gate structures, removal of sediment deposition and routine checkup of flow measurement device. Emergency works are the ones that hinder the operation of the canals and hence it needs immediate attention. Works such as damage of flow measurement structures, over topping of the canals, and damaged sidewalls of the canal because of big trees around the side walls are considered as emergency works. Deferred maintenance works are the works that can be deferred to a later stage based on the availability of funds and material. Seepage loss is such a case that based on the availability of funds, the nature of work can be decided. For example, if there are no abundant funds available then cheaper

material a plastic cover can used to prevent seepage loss otherwise concrete lining can be done for long time purpose to minimize the seepage loss if the abundant funds are available. Similarly, based on the availability of material, some works like embankment protection, can be undertaken.

Seepage Loss Study Results

Seepage loss is a significant concern in most of the Cache Valley irrigation canals because they are mostly unlined and are primarily built in areas with soils which are subject to percolation of water. Some of the canal reaches are build on sloping hillsides and have a high hydraulic gradient to the downhill side, encouraging seepage. These losses are problematic in terms of both operation and maintenance. Operationally, the losses limit the flow that can be delivered at downstream locations, and in terms of maintenance, the losses require frequent inspections and corrective measures. Finally, at some locations, the seepage losses contribute to significant underground bank erosion, threatening a sudden washout.

A report detailing the procedures and findings of the study has been prepared:

Ticlavilca, A. and G. Merkley (2006). *Water Management Surveys in Logan River Irrigation Canals.* Utah State University, Logan, Utah.

Various presentations before irrigation groups have been conducted to disseminate the project results.

Work Plan FY06/FY07:

The same objectives will be continued.

Benefits to the State:

Irrigated agriculture is responsible for the bulk of water use in Utah and in many other western states. Proper understanding of overall irrigation system operation is critical for achieving water use efficiency in the management of the system. In addition, maintenance of water rights and assurance of delivery of proper amounts of water to irrigation users is always a critical issue. Accurate data on diversion quantities and canal flows are required in order to adequately address all of these issues. The purpose of this project was to develop maintenance and operations plans for several irrigation canals in Cache Valley in order to achieve water management improvements for these irrigation systems.

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 the 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 to six days.

The work includes the compilation of quantitative precipitation forecast from the 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 evaluation. The lead time will be consistent with the NOAA issued forecasts, i.e. up to 12 days in advance will be considered.

It is foreseen that 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 AI techniques mentioned above will be used for this and will be part of the overall system.

Accomplishments:

The project is ongoing. The forecast series for the years 2004 and 2005 have been compiled and stored in the UWRL servers. The data for 2006 is being compiled also. A preliminary procedure for soil moisture downscaling has been developed but remains to be properly tested.

Work Plan FY06/FY07:

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 the specific reservoirs and will help the water managers make more informed decisions about the releases from those reservoirs.

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

Principal Investigator(s):
Mac McKee
Abedalrazq Khalil
Saket Pande
Kashif Gill
Yasir Kaheil

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 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 FY 2002 and FY 2003, 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. Comparisons of model predictions versus actual canal operations are given in Figure 1.

Short-term predictive models were also built using artificial neural network approaches to forecast diurnal flows from Clear Creek into the Sevier River. An example of these forecasts, made hourly for a period 24 hours in advance, is given in Figure 2.

Long-term predictive models were constructed in FY 2003 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. A comparison of the forecasts obtained from the ANN model versus historically measured flows is shown in Figure 3.

In FY 2004, 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. Figure 4 provides an example comparison of actual reservoir releases and model-generated recommendations for release quantities, as well as confidence intervals, for the 2003 season.

Work in FY 2005 focused on the following:

- *Programming of the Piute Reservoir operating model to run on the SRWUA website servers*: Development of the real-time operations model for Piute Reservoir was done using the *Matlab* modeling software. The selection of *Matlab* as the development platform was a good choice because of the wide range of statistical and simulation capabilities that are built into the language. However, SRWUA has adopted a policy requiring that only open-source software be used to run their website. As a result, the Piute Reservoir operating model has to be re-coded into a different language. Work this year has focused in part in providing a version of the software in the *R* computer language. This represents a substantial commitment in programming time.

- *Development of irrigation demand forecasting capabilities for short-term prediction of canal operations*: Work began this year to take advantage of short-term meteorological forecasts that are available from the National Oceanic and Atmospheric Administration and the National Weather Service to forecast daily water demands for individual canals for up to five days into the future. When available, these forecasts will be used to improve reservoir operations for portions of the Sevier system that are subject to large travel times between the point of water release, the point of canal diversion, and the point of distribution to the farmer's headgate. Once developed, this forecasting ability will represent a significant step forward in canal and reservoir operations capabilities. It will require development of complex upscaling-downscaling algorithms to synchronize on-ground and NOAA satellite data that are of different geographic resolutions, and it will require the identification and implementation of economic information on farmer behavior with regard to irrigation decisions. In FY 2005, the upscaling-downscaling algorithm was developed and tested on soil moisture data. Initial modeling began on forecasting of irrigation demands.

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

Work Plan FY06/FY07:

Re-programming of the hourly operational model for Piute Reservoir will be completed and assistance will be provided to the SRWUA in its implementation. Work will continue on development of short-term forecasting of irrigation demand. This will include installation of approximately 50 soil moisture probes in the Sevier River Basin and linking them into the automated data collection network that is run by the SRWUA. The data from these probes will be analyzed using the up-scaling/down-scaling 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.

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:

Asefa, T., M. Kemblowski, M. McKee, and A. Khalil (2006). Multi-time scale stream flow predictions: The support vector machines approach. *Journal of Hydrology*, 318:7-16.

Khalil, A., M. McKee, M. Kemblowski, and T. Asefa (2005). Basin-scale water management and forecasting using artificial neural networks. *J. American Water Resources Association*, 41(1):195-208.

Khalil, A., M. McKee, M. Kemblowski, and T. Asefa (2005). Sparse Bayesian learning machine for real-time management of reservoir release. *Water Resources Research*, 41(W11401).

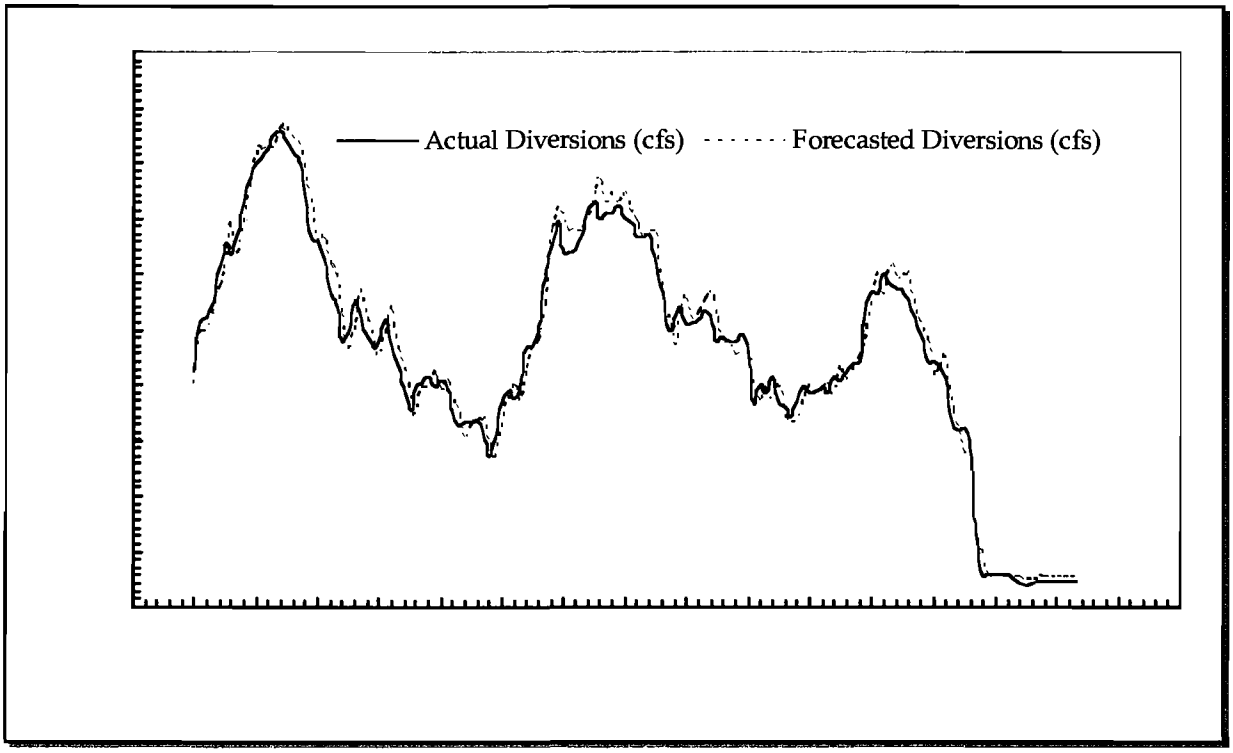

Figure 1. Comparison of Actual Sevier Valley/Piute Canal Diversions in 2002 with ANN Model Forecasted Diversions

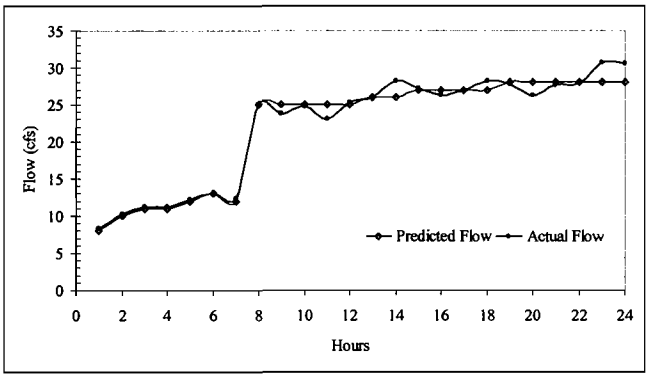

Figure 2. Predicted Versus Actual Diurnal Fluctuation of Flows in Clear Creek on 4/4/2001

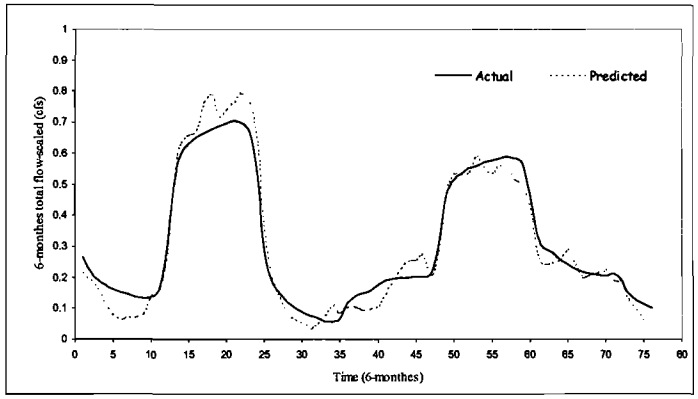

Figure 3. Time-Series Performance of the ANN Model in Predicting Seasonal Flows at Hatch

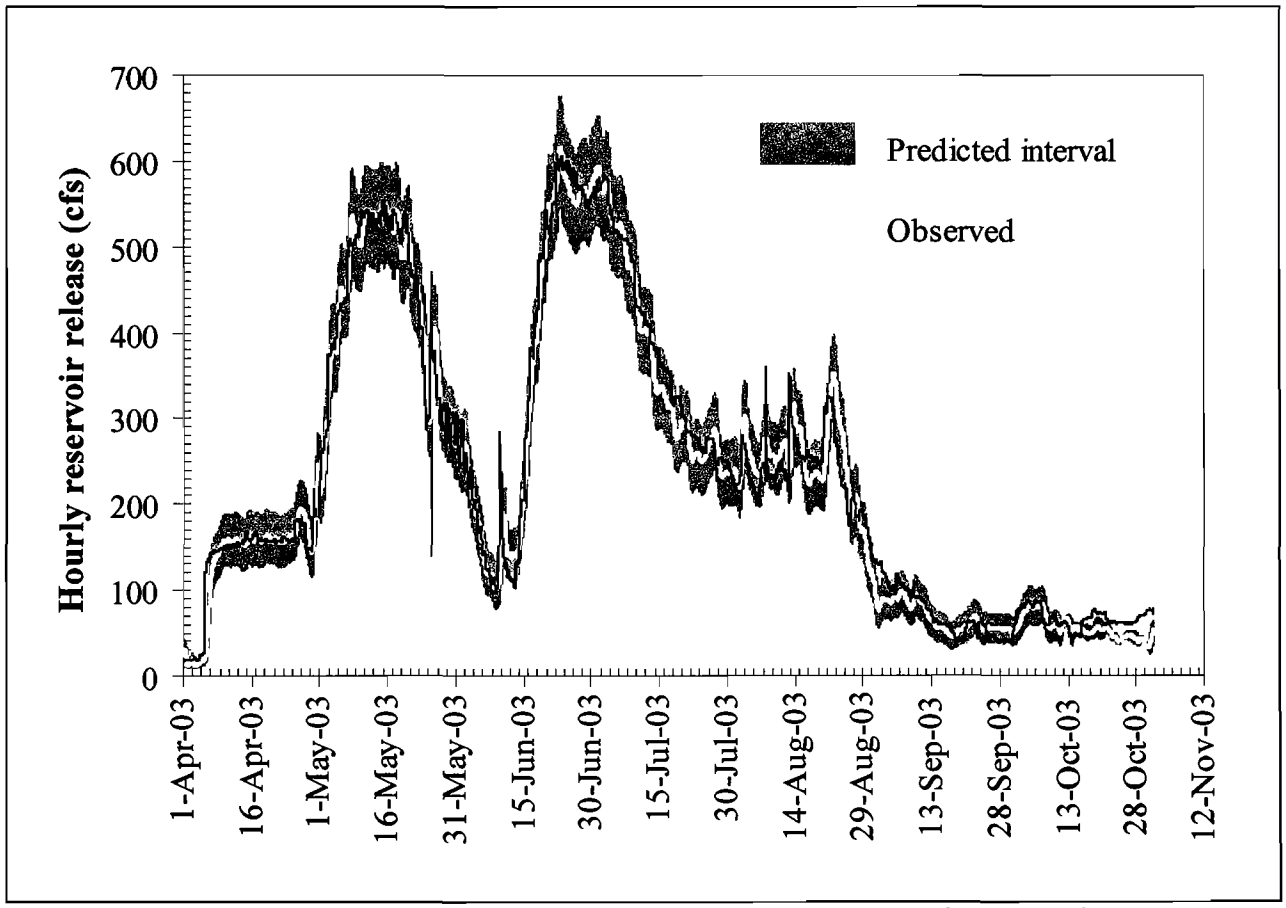

Figure 4. Comparison of Actual Piute Reservoir Releases in 2003 with the SVM/RVM Model Forecast Releases

Sustainable Watershed Management Considering Hydrology, Water Quality, and Economics

Principal Investigator(s):
Jagath J. Kaluarachchi
Ibrahim Khadam

Project Description:

1. Develop a methodology that would allow the use of soft information to describe relative uncertainty of calibration data in hydrologic models.

2. Develop a methodology to predict the P-loading from a watershed accounting for hydrologic variability and parameter uncertainty using export coefficients.

3. Develop a framework for objective assessment of the tradeoff between economic efficiency and equity in allocation of pollution control responsibilities.

4. Demonstrate the overall framework developed for hydrologic modeling, water quality analysis, and economic analysis of pollutant load trading in the previous objectives to the Fishtrap Creek catchment in Washington State.

Accomplishments:

The work related to this work is almost complete.

Work Plan FY06/FY07:

1. Develop available describing water quality, stream flow, watershed characteristics, economic productivity of the Fishtrap Creek Watershed, WA.

2. Develop rainfall-runoff model of the watershed and assess the model uncertainty.

3. Develop a model for P transport using the export coefficient method and develop methods to include hydrologic variability.

4. Develop a model to predict pollution control responsibilities considering economic equity among stakeholders.

5. Demonstrate the overall framework using various management scenarios for the Fishtrap Creek Watershed.

Benefits to the State:

The work performed here is related to watershed management by considering water quantity and quality issues. The work focuses on water quality impacts in multiple watersheds and the allocation of water restoration responsibility among polluters by considering economic equity while maintaining cost minimization. Since the State of Utah has many watersheds providing valuable water resources to users as well as providing economic productivity to the stakeholders. In the process of harvesting its values, water quality impairments are produced and the restoration of water quality to acceptable levels should be the responsibility of the polluters as well as the regulators.

In addition, the innovative results obtained from the work have been published through three manuscripts in reputed research journals. In addition a number of scientific presentations has been made over the past 18 months. One student has received a PhD through this work.

Publications:

Khadam, I. and J.J. Kaluarachchi (2005). Analysis of trade-offs between cost minimization and equity in water quality management in agricultural watersheds. *Submitted, Water Resources Research*, July.

Khadam, I. and J. Kaluarachchi (2004). Use of soft data to describe the relative uncertainty of calibration data in hydrologic models. *Water Resources Research*, 40(11), W11505.

Khadam, I. and J. Kaluarachchi (2004). Water quality modeling under hydrologic variability and parameter uncertainty using export coefficients, *submitted, J. of Hydrology*, November.

Khadam, I. and J.J. Kaluarachchi (2003). Model calibration using data with varying levels of uncertainty. *Proceedings of the XIIV International Conference on Computational Methods in Water Resources*, Raleigh, NC. June.

Khadam, I. and J.J. Kaluarachchi (2003) Probabilistic risk assessment and multi-criteria decision analysis for the management of contaminated subsurface. *Proceedings of the XIIV International Conference on Computational Methods in Water Resources*, Raleigh, NC, June.

The Bear River Basin in Idaho, Utah, and Wyoming

Principal Investigator(s):
David K. Stevens
Nancy Mesner
Terry F. Glover
Arthur Kaplan
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:

This project has enhanced Utah State University's national reputation through winning the national competition for these awards from U.S. EPA.

Work Plan FY06/FY07:

Water quality models and economic analysis of pollutant trading potential. Presentations and the Water Environmental Association of Utah, Spring Conference, St. George, UT.

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.

Virgin River Decision Support System (VRDSS)

Principal Investigator(s):
Thomas B. Hardy
Leon Basdekas
Lisa Kent

Project Description:

The existing Virgin River Decision Support System (VRDSS) currently being developed in MapWindows for the Virgin River Integrated Resource and Recovery Program (Program) within the Virgin River Basin was expanded to include data and analyses developed at the Utah Water Research Laboratory (UWRL) on a basin-wide assessment of aquatic and riparian resource habitats. This effort entails an expansion of the existing VRDSS to include the data collected by the UWRL on the main stem Virgin River and its principal tributaries within native fish distributions and include on-line analysis capabilities to rank habitats in terms of watershed planning and restoration activities.

The objectives of this effort are to provide expanded access by local, state, and federal resource agencies to available data within the Virgin River Basin critical to formulating strategic water resource allocation decisions in which impacts to native fish species can be minimized or eliminated as well as provided the necessary resources for strategic planning in watershed restoration and recovery of the federally listed fish within the basin.

Accomplishments:

The VRDSS was upgraded with a module to allow meso-habitat and reach level rankings that incorporate measured and derived metrics that can be used in support of watershed planning and restoration efforts for native fish species.

Work Plan FY06/FY07:

The work entailed updating the database structures necessary to contain all the collected data, development of data visualization modules in VRDSS for aquatic meso-habitat attributes, adjacent riparian system composition and status, and adjacent land use classifications.

Benefits to the State:

This effort has directly benefited the state in support of Virgin River Integrated Resource and Recovery Program, the Virgin River Fishes Recovery Team, Utah Division of Wildlife Resources, U.S. Fish and Wildlife Resources, Bureau of Land Management, and the National Park Service for planning and implementation of on-going resource recovery efforts for the endangered woundfin minnow and Virgin roundtail chub, conservation species spinedace, and other native fish within the basin. This on-going effort will increase the visibility of the UWRL state-wide in its pro-active solution to on-going water resource issues.

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

Principal Investigator(s):
Jagath J. Kaluarachchi
Wafa Hassan

Project Description:

- Assess the water resources in the Salt Lake Valley and forecast the future demands based on population growth and land use changes.
- Develop a methodology to optimal 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 the existing water allocation policy.

Accomplishments:

The work related to Objectives 1-2 has been accomplished. The work related to other objectives is current undergoing.

Work Plan FY06/FY07:

1. Gathering existing information related to water resources, economic growth, environmental concerns, and population 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 understand the current and future water deficit scenarios of Salt Lake Valley and to find out the economic consequences, if any, of the current practices of water allocation in the valley. We propose to provide an insight to the economic issues and provide potential alternatives for optimal allocation considering economic return on water and the available water supply in the future

years. The results of the study will provide more insight to the water allocation and deficit issue beyond considering the supply and demand issue so that some economic perspective can be brought to future planning and management by the State Engineer.

Publications:

Hassan, W. and J.J. Kaluarachchi (2005). *Sustainable water resource management considering population growth and land use changes*. Fall Meetings, American Geophysical Union, San Francisco, CA, December 5-9.

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