Center for Water Resources Research
Annual Technical Report
FY 2004

Introduction

The Utah Center for Water Resources Research (UCWRR) is located at Utah State University (USU), the Land Grant University in Utah, as part of the Utah Water Research Laboratory (UWRL). It is one of 54 state water institutes that were authorized by the Water Resources Research Act of 1964. Our mission is related to stewardship of water quantity and quality through collaboration with government and the private sector. The UCWRR facilitates water research, outreach, design, and testing elements within a university environment that supports student education and citizen training. The UCWRR actively assists the Utah Department of Environmental Quality (UDEQ), the Utah Department of Natural Resources (UDNR), the State Engineer's Office, all 12 local health departments, and several large water management agencies and purveyors in the state with specific water resources problems.

In FY 04, the UWRL expended a total of almost $9 million in water research support. USGS Section 104 funds administered through the UCWRR accounted for about one percent of this total. These funds were used for research addressing water and wastewater management problems, outreach, information dissemination, strategic planning, water resources, and environmental quality issues in the State of Utah.

The "Data Fusion for Improved Management of Large Western Water Systems" project described under the Research Project section of this report is an integrated research and information transfer project that was planned, developed, and implemented with the collaboration of the Utah Center for Water Resources Research (UCWRR) and the relevant state and local water agencies in Utah. Please refer to the Research Project section of this report for specific information transfer activities related to this research effort supported by the USGS Section 104 funds.

An Information Transfer project entitled "Alternative Decentralized Wastewater Treatment Systems for Utah Conditions" was supported by Section 104 resources to help address the information needs of public health and environmental quality managers in Utah with respect to the protection of freshwater supplies from contamination by untreated or poorly treated wastewater discharges from on-site wastewater systems. Refer to the Information Transfer Program section of this report for a summary of this effort.

Research Program

USGS Section 104 funds were used to address water management issues for large irrigation systems in Utah at the request for assistance from the Sevier River Water Users Association (SRWUA) and the Emery Water Conservancy District (EWCD). Water management issues in the SRWUA focus principally on real-time system operation over a large geographical area. Section 104 resources were used to support the development and installation of a suite of models that provide both long-term forecasts of water availability and real-time management information for key decisions on reservoir releases and canal diversions. The results of these modeling activities are being reported in the technical literature, and the models that have been developed are under implementation on the SRWUA's web site. In the EWCD, the principal management problem is salt loading into the San Rafael River, a tributary of the Green River. While the EWCD has a real-time monitoring program in the basin, the quality of data collected is limited by both technical monitoring capabilities and constraints on the types of equipment that can be installed in the field. As a result, estimates of total salt loading on the San Rafael have very wide confidence intervals. The project supported by Section 104 funds has developed a Bayesian belief network (BBN) model that, together with the available data, provides an improved estimate of salt loading, a quantification of the uncertainty in this estimate, and identification of measures that can be followed to improve the monitoring system. The BBN model will be implemented on the EWCD web site, and the results of the research project will be reported in the technical literature.

Data Fusion for Improved Management of Large Western Water Systems

Basic Information

Title:	Data Fusion for Improved Management of Large Western Water Systems
Project Number:	2004UT46B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	UT1
Research Category:	Water Quality
Focus Category:	Management and Planning, Models, Irrigation
Descriptors:	Water System Operation, Short-Term Management, Long-Term Forecasting, Uncertainty
Principal Investigators:	Mac McKee, Mariush Kemblowski

Publication

1. Khalil, A., M. McKee, M. Kemblowski, and T. Asefa. 2005. Basin-scale water management and forecasting using multi-sensor data and artificial neural networks. J. American Water Resources Association.
2. Khalil, A., M. McKee, M. Kemblowski, and T. Asefa. 2005. Sparse Bayesian learning machine for real-time management of reservoir release. Water Resources Research.
3. Asefa, T., M. Kemblowski, M. McKee, and A. Khalil. 2005. Multi-time scale stream flow prediction: The support vector machines approach. J. Hydrology.
4. Khalil, A., and M. McKee. 2004. Hierarchical Bayesian analysis and statistical learning theory, I: Theoretical concepts. In: Proceedings of the 2004 Water Management Conference, Water Rights and Related Water Supply Issues, U.S. Committee on Irrigation and Drainage. Salt Lake City, October, 2004. pp. 433-444.
5. Khalil, A., and M. McKee. 2004. Hierarchical Bayesian analysis and statistical learning theory, II: Water management application. In: Proceedings of the 2004 Water Management Conference, Water Rights and Related Water Supply Issues, U.S. Committee on Irrigation and Drainage. Salt Lake City, October, 2004. pp. 445-455.
6. Khalil A. and M. McKee, 2004. An adaptive model paradigm for water resources management. In: AWRA Annual Conference, Orlando, Florida. November, 2004.

Data Fusion for Improved Management of Large Western Water Systems

Problem

The relative scarcity of water in the western US is growing due to population and economic growth, pollution, and diversification of the types of demands that are being placed on water use (e.g., traditional consumptive uses such as irrigation and municipal supply, as well as emerging uses for such concerns as water quality maintenance and endangered species protection). This increasing relative scarcity brings: (1) a greater need to more intensively manage the resource, and, as a result, (2) a requirement for better information about the current and potential future states of our water resources systems so that management decisions can be better informed.

In spite of these increasing needs for better water resources management information, investments in traditional water resources data collection programs (e.g., point stream flows, snow pack, soil moisture, etc.) are declining at the federal and state levels. For example, USGS support for maintenance of several stream gages in Utah has been withdrawn in recent years due to a lack of state cost-sharing commitments. In contrast, investments on the part of other Federal agencies (that have not traditionally played a significant role in support of water resources management) in new data collection methods are increasing (e.g., satellite imagery of land cover, snow cover, ocean surface temperatures, etc.; radar estimation of precipitation; aircraft and satellite imagery for estimation of evapotranspiration). These new data streams will have to be used to back-fill the decline in availability of traditional data. Moreover, analytic methods will need to be developed to apply to these data in order to improve the quality of the information base available to managers of large water systems.

Today's managers have not been schooled in new ways of collecting data or in the analytic approaches required to understand the data. Before new methods of gaining information and making decisions can be practical, investments must be made to place the resulting capabilities into the hands of the water managers who need them. These must be practical and effective, and the water managers must themselves see the value of the information that results.

These are information problems facing managers of large water systems toady, especially large irrigation systems, in several places in Utah as well as in many other arid river basins in the western US.

Research Objectives

Research is needed to develop the data now becoming available from emerging telemetric and remote sensing sources into useful information for all temporal and geographical scales of water resources management. This must be done in such a way as to maximize the total value of the information coming from both these new, emerging data sources and from the traditional water resources monitoring approaches. Further, the products of such research must be of practical use to the water resources managers who (1) are now losing access to traditional data sources and (2) have not been trained in how to access and use the information flowing from new remote sensing capabilities. In addition, the research products must also be of use to a growing range of stakeholders who have heterogeneous technical backgrounds and skill levels.

The purpose of this project is to develop a significantly enhanced capability within the state of Utah--that will also be appropriate for application in the arid West--to more efficiently manage the state's scarce water resources by exploiting emerging technologies in data collection and analysis.

The objectives of the research are to:

1. Develop and test methodologies from statistical learning theory for combining meteorological and hydrological data from traditional and new remote sensing sources to produce information valuable to managers of large water resources systems. These methodologies will be directed at supplying information for improving water management decisions on problems having a wide range of time and spatial scales (e.g., from daily reservoir releases and canal diversions to long-term commitments for reservoir operations and water exchanges).

2. Develop and implement inexpensive and effective web-based methodologies to disseminate the resulting decision-relevant information to all potential stakeholders.

3. Evaluate and report on the results of the application of the methodologies.

Methodology

The Sevier River Basin, managed by the Sevier River Water Users Association (SRWUA) and the area served by the Emery Water Conservancy District (EWCD) were used as case study areas for the project. Project research personnel have excellent working relationships with the SRWUA and EWCD, as well as with the Provo, Utah, office of the US Bureau of Reclamation, who assists both the SRWUA and EWCD in the maintenance, operation, and extension of the monitoring programs that collect, archive, and display real-time data on the state of both of these large water systems.

Research Tasks

Development of Models from Statistical Learning Theory

The major objective of this research effort is to develop and implement a set of tools that can be used to reconcile data and measurements that come from various sources and are characterized by different temporal and spatial scales of resolution, such as NASA remote sensing information and local, on-ground measurements such as stream flow data collected by the USGS. The tools will be used to fuse various pieces of information into one coherent and seamless representation of river basin states, both current and predicted. The resulting information will be provided to stakeholders, decision-makers, and water managers using modern information technologies.

This effort takes advantage of recent research experience to formulate a general framework for hydrologic data assimilation and forecasting, utilizing the following components:

- Bayesian Belief Networks (BBNs). This is a graph-based methodology that was developed by the AI community over the last decade. It is recognized as the most consistent and powerful tool for building statistical expert systems, and is used, for example, by the army to fuse intelligence information coming from multiple sources. Project researchers have published the results of research using this tool for various water and environmental problems (for example, see Ghabayen and McKee, 2003; and Ghabayen et al., 2003, 2004), and a graduate student on the project will examine the use of BBNs in assessing uncertainties in salt loading estimates in the EWCD.

- Statistical Learning Theory (SLT). This approach constitutes a general framework for machine learning, and is currently a subject of intensive research in academia and industrial research laboratories. It provides a sound and very efficient environment for building statistical models that include physical insights into the modeled phenomena. Researchers on this project have used this approach to build models for subsurface quality monitoring network design, evaluating information value for groundwater measurements, and spring runoff predictions. Examples of development of models from STL applications that show excellent promise for application to the problems posed for this research include Hassan and McKee (2003), Pande and McKee (2003), and Khalil and McKee (2003).

Specific models to be developed by the project consist of:

- a model for providing long-term forecasts of spring runoff in the Upper Sevier River Basin
- a models for providing short-term operations guidance for reservoir operations for Piute Reservoir in the Upper Sevier Basin
- a model for providing short-term operations guidance for canal diversions on the Piute-Sevier Valley Canal in the Upper Sevier Basin
- a model for estimating monthly and annual salt loading from the San Rafael River into the Colorado River, and quantification of uncertainty in those estimates

Implementation of Models

The models are to be integrated with the SRWUA or EWCD databases and implemented on the websites of those organizations. Implementation will be accomplished through collaborative work among USU project staff, representatives of the managing water districts, and contractors who work for the districts to maintain the water resources monitoring systems, databases, and websites.

Evaluation and Dissemination of Results

In addition to the use of standard statistical methods for assessing the quality of model predictions, the project will conduct an analysis of the real-time performance of the operation of the short-term forecasting models as they are being applied during the 2004 irrigation season. As necessary, project personnel will work directly with end-users in the SRWUA and EWCD to identify and correct problems with the models, and to educate the users in proper model operation and interpretation. The lessons learned from these interactions will be documented and recommendations for implementation and management of such models within the institutional framework of these types of water resources organizations will be documented. In addition to the use of web-based dissemination of research products, the results of the project will be published in the normal academic venues.

Principal Findings

Water Management in the Sevier River Basin

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 operational on the SRWU web site 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 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. The work shown in Figures 1-3 has been recently published (Khalil et al., 2005).

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 seasons. Figure 4 provides a comparison of actual reservoir releases and model-generated recommendations for release quantities, as well as confidence intervals, for the 2003 season. At the time of preparation of this report, the SRWUA was in the process of operationalizing the software that will connect the output of this model to the gate controllers that manage releases from Piute Reservoir. In the coming irrigation season, the model will be running the reservoir and its performance will be monitored by the reservoir operators and project researchers.

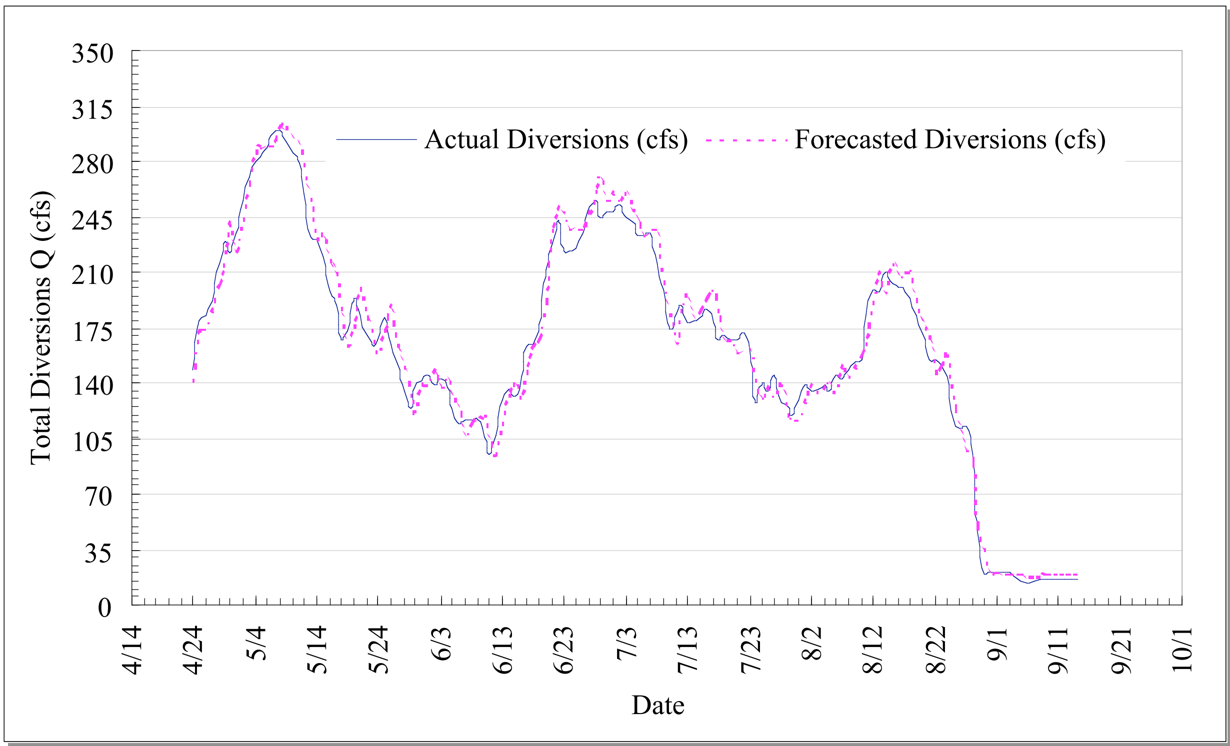

Figure 1. Comparison of Actual Sevier Valley/Piute Canal Diversions in 2002 with ANN Model Forecasted Diversions

Salt Loading in the San Rafael River Basin

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. In particular, statistical relationships between stage and discharge, and between conductivity and salt concentration have been developed for the major tributaries of the San Rafael. 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 salt chemistry. A preliminary BBN model has been constructed that estimates total daily, weekly, monthly, and annual salt loading from the San Rafael drainage into the Green River. The model is being verified and prepared for implementation on the EWCD web site.

Significance

The Sevier River Basin, managed by the Sevier River Water Users Association (SRWUA), and the Emery Water Conservancy District (EWCD) in Utah have been used as case studies and experimental sites. They were chosen because of their significant size, their importance in the agricultural sector of the state, their highly developed on-line databases, and the willingness of local water resources managers to cooperate with the research and make use of the outputs of the project. The project has focused on development of data sensor fusion approaches to reduce the uncertainty that accompanies significant water management decisions through the implementation of real-time management and long-term forecasting models. In the case of the Sevier River Basin, these models are being useful for real-time reservoir release and canal diversion decisions and for long-term forecasting of water availability. For the EWCD, the modeling is resulting in improved estimates of salt loading into the Colorado River from the region, as well as improved quantification of the uncertainty in these salt loading estimates. The output of these models is being utilized for development and deployment of decision-support systems that are being made available to water managers from these organizations. Project staff are continuing to work with these water districts to help integrate these models with their local database systems so that the resulting information will be available to water managers and stakeholders via the internet.

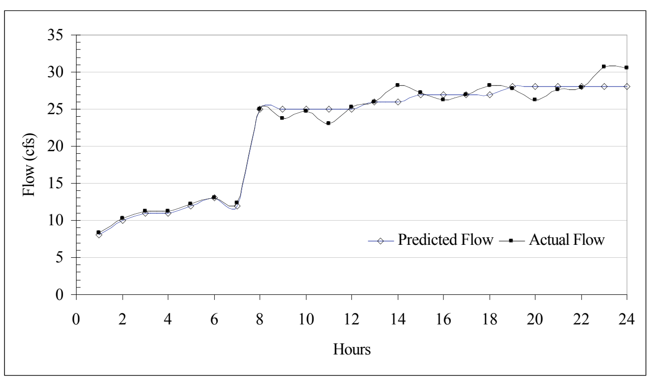

Figure 2. Predicted Versus Actual Diurnal Fluctuation of Flows in Clear Creek on 4/4/2001

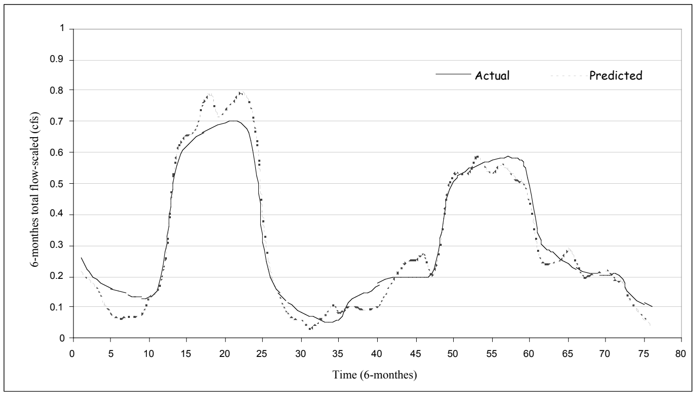

Figure 3. Time-Series Performance of the ANN Model in Predicting Seasonal Flows at Hatch

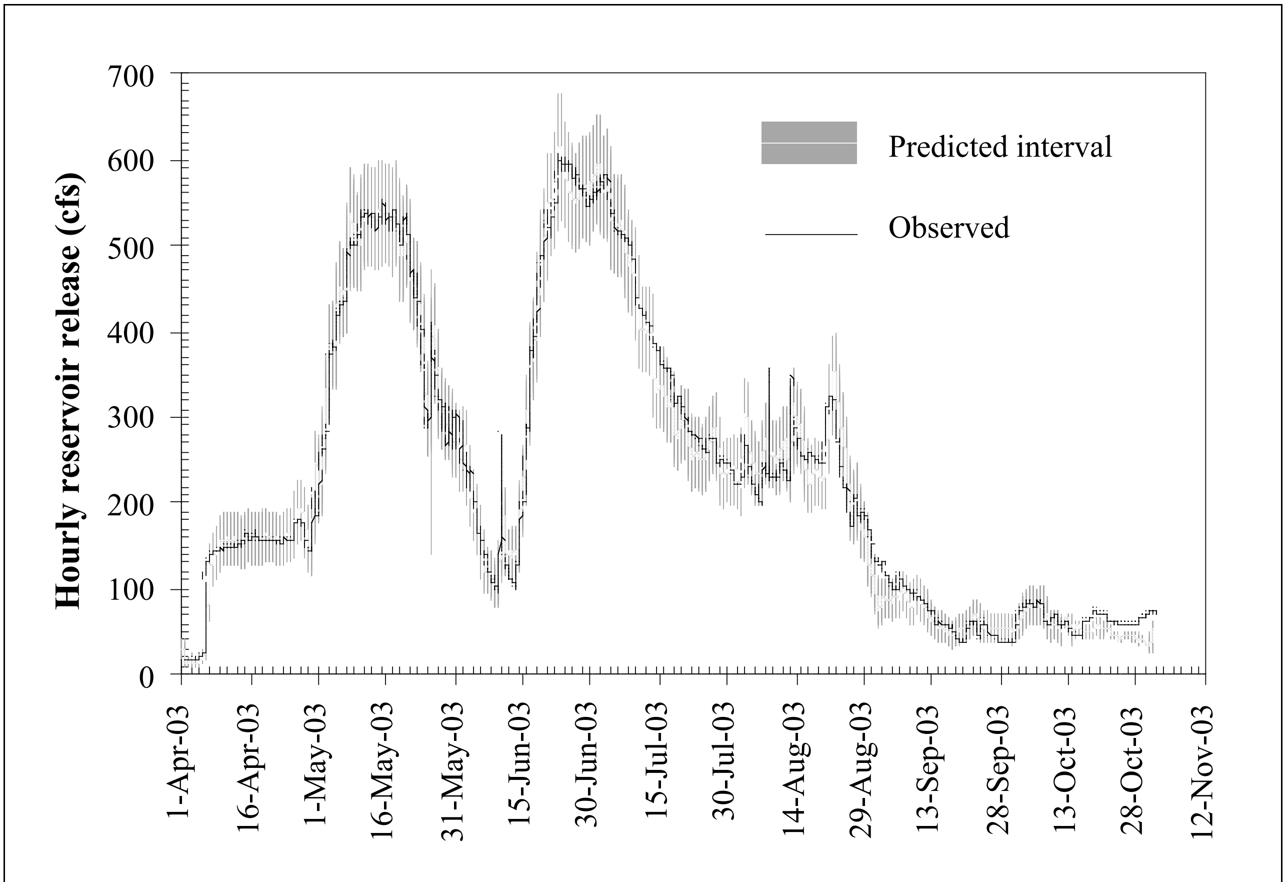

Figure 4. Comparison of Actual Piute Reservoir Releases in 2004 with the SVM/RVM Model Forecast Releases

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Information Transfer Program

The individual research project documented in the Research Project section of this report has integrated within it information and outreach components. These include publication of research findings in the technical literature and provision of findings and water management models and tools on the web pages of the Utah Center for Water Resources Research (UCWRR) and individual water agencies.

Beyond the information transfer project entitled "Alternative Decentralized Wastewater Treatment Systems for Utah Conditions" discussed in the following section, Information Transfer and Outreach within the UCWRR are forms of scholarship that were stimulated, supported, and rewarded in FY 04-05. Outreach activities through the UCWRR, the Utah Water Research Laboratory (UWRL), and Utah State University (USU) have had an impact on the technical and economic development of the State of Utah. As part of the UCWRR outreach activities supported by USGS 104 funds, there continues to be a vigorous dialogue and experimentation with regard to efficiency and effectiveness of outreach activities of the UCWRR. Faculty are engaged in regular meetings with State of Utah water resources agencies, including the Department of Environmental Quality (DEQ), the Department of Natural Resources (DNR), and the State Engineers Office to provide assistance in source water protection, on-site training, non-point source pollution management, technology transfer, and development of source water protection plans (SWPPs) within the context of water-related issues in Utah.

UCWRR staff, through the facilities at the UWRL, provides short courses both on- and off-site within the State of Utah, regionally, and globally. Generally offered from one- to five-days duration, short courses are tailored to meet the needs of the requestor. The following is a partial list of short courses, field training, and involvement of UCWRR staff in information transfer and outreach activities:

- "Soil Evaluation and Percolation Testing." Utah On-Site Wastewater Treatment Training Program, St. George, UT, March 23-24, 2004. Judith L. Sims, Peg Cashell, and Richard Jex.

- "Design, Inspection, and Maintenance of Conventional Systems." Utah On-Site Wastewater Treatment Training Program, St. George, UT, March 25-26, 2004. Judith L. Sims, Peg Cashell, and Richard Jex.

- "Design, Inspection, and Maintenance of Alternative Systems." Utah On-Site Wastewater Treatment Training Program, Utah State University, Logan, UT, April 16, 2004. Judith L. Sims and Peg Cashell.

- "Instream Flow Habitat Modeling Physical Habitat Modeling (PHABSIM)." Institute for Natural Systems Engineering, Utah State University, Logan, UT, May 10-14, 2004. Thom Hardy.

- "Soil Evaluation and Percolation Testing." Utah On-Site Wastewater Treatment Training Program, Heber City, UT, May 18-19, 2004. Judith L. Sims, Peg Cashell, and Richard Jex.

- "Design, Inspection, and Maintenance of Conventional Systems." Utah On-Site Wastewater Treatment Training Program, Heber City, UT, May 20-21, 2004. Judith L. Sims, Peg Cashell, and Richard Jex.

- "Design, Inspection, and Maintenance of Alternative Systems." Utah On-Site Wastewater Treatment Training Program, Utah State University, Logan, UT, July 14-16, 2004. Judith L. Sims, Peg Cashell, and Richard Jex.

- "Design, Inspection, and Maintenance of Alternative Systems." Utah On-Site Wastewater Treatment Training Program, Utah State University, Logan, UT, August 6, 2004. Judith L. Sims and Peg Cashell.

- "Designing Hydrologic Observatories as a Community Resource: A CUAHSI National Workshop." The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) held a workshop centered on the formation of a pilot network of five Hydrologic Observatories. (http://www.usu.edu/water/cuahsi/). College of Engineering, Utah State University, Logan, UT. August 24-25, 2004. David G. Tarboton.

- "Dam Safety Portfolio Risk Assessment Workshop." Invited Two-day Workshop for U.S. Army Corps of Engineers, Cincinnati, Ohio. September 2004. D.S. Bowles and L.R. Anderson.

- "Soil Evaluation and Percolation Testing." Utah On-Site Wastewater Treatment Training Program, Ogden, UT, October 5-6, 2004. Judith L. Sims.

- "Design, Inspection, and Maintenance of Conventional Systems." Utah On-Site Wastewater Treatment Training Program, Ogden, UT, October 7-8, 2004. Judith L. Sims.

- "AWWA Training Seminar." American Water Works Association's Water Utility Management Institute, Salt Lake City, UT, October 20, 2004. Mac McKee and Laurie McNeill.

- "Design, Inspection, and Maintenance of Alternative Systems." Utah On-Site Wastewater Treatment Training Program, Utah State University, Logan, UT, November 3-5, 2004. Judith L. Sims.

- "AWWA Training Seminar." American Water Works Association's Water Utility Management Institute, Salt Lake City, UT, November 10, 2004. Mac McKee.

- "Design, Inspection, and Maintenance of Alternative Systems." Utah On-Site Wastewater Treatment Training Program, Utah State University, Logan, UT, November 19, 2004. Judith L. Sims.

- "Dam Safety Risk Assessment." Pre-Conference Invited Short Course, 15th Southeast Asian Geotechnical Conference (SEAGS), Asian Institute of Technology, Bangkok, Thailand. November 2004. D.S. Bowles and L.R. Anderson.

- "Dam Safety Risk Assessment." Invited one-week workshop Provided for Division of Dam Safety and Inspections, Federal Energy Regulatory Commission, Washington DC by IDSRM, Utah State University, Logan, Utah. January 2005. D.S. Bowles, M.W. McCann, Jr., L.R. Anderson and S.S. Chauhan.

- "AWWA Training Seminar." American Water Works Association's Water Utility Management Institute, Salt Lake City, UT, January 27, 2005. William J. Rahmeyer and Gilberto E. Urroz.

- "On-Site Wastewater Treatment in Utah: Changes and Challenges." Fifth Annual Conference of the Utah On-Site Wastewater Treatment Training Program, Ogden, UT, February 2-3, 2005. Judith L. Sims.

- "Risk Analysis Applied to Dam Safety in Spain." Invited one-day Workshop on Universidad Politecnica de Valencia, Valencia, Spain. March 2005. D.S. Bowles.

- "Risk Analysis Applied to Dam Safety." Invited two-day course as part of the Doctoral course, "Dam and Reservoir Safety Evaluation," funded by a Quality Award from the Spanish Ministry of Education, Universidad Politecnica de Valencia, Valencia, Spain. D.S. Bowles.

- "Dam Safety Portfolio Risk Assessment National Workshop." Invited Three-day Workshop for U.S. Army Corps of Engineers, Sacramento, CA. April 2005. D.S. Bowles, L.R. Anderson, and S.S. Chauhan.

Principal Outreach Publications

Principal outreach items include the Comprehensive Water Education Grades K-6 manual (several thousand copies of the manual have been distributed throughout the country, and distribution is now being planned in the United Kingdom and Australia), newsletters addressing the on-site wastewater issues (Utah WaTCH), and a Mineral Lease Report to the Utah Office of the Legislative Fiscal Analyst. The UWRL prepared and distributed two water education manuals for 4th grade elementary school teachers and students. The UCWRR, through the UWRL, provides outreach materials related to public service, information dissemination, technology transfer, and short courses. These are provided for the benefit of Utah state agencies, elected officials, Utah citizens, and the nation. Additional outreach is available through the UWRL web site at: http://www.engineering.usu.edu/uwrl/. An on-line journal, the "Utah Water Journal," is a collaboration between USU and state, local, and private organizations involved in stewardship issues that include managing and protecting Utah's water quality and quantity. The Utah Water Journal is available on-line at: http://www.engineering.usu.edu/uwrl/uwj.

Additional technical publications in FY 04-05 that were partially supported by the cooperative program described in this (beyond those listed in the "Research Program" section) report are listed below. Other publications from the Utah Water Research Laboratory appear regularly as technically-reviewed project reports, professional journal articles, other publications and presentations, theses and dissertation papers presented at conferences and meetings, and project completion reports to other funding agencies.

Luce, C., D.G. Tarboton, E. Istanbulluoglu and R. Pack, (2005) "Reply to Comment by Jonathan J. Rhodes on Modeling of the Interactions between Forest Vegetation, Disturbances, and Sediment Yields," Journal of Geophysical Research - Earth Surface, 110:F01013, doi:10.1029/2004JF000279.

Bandaragoda, C., D.G. Tarboton and R. Woods, (2004) "Application of Topnet in the Distributed Model Intercomparison Project," Journal of Hydrology, 298:178-201, doi:10.1016/j.jhydrol.2004.03.038.

Luce, C.H. and D.G. Tarboton, (2004) "The Application of Depletion Curves for Parameterization of Subgrid Variability of Snow," Hydrological Processes, 18:1409-1422, DOI: 10.1002/hyp.1420.

Istanbulluoglu, E., D.G. Tarboton, R.T. Pack and C.H. Luce, (2004) "Modeling of the Interactions Between Forest Vegetation, Disturbances and Sediment Yields," JGR - Earth Surface, 109(F1): F01009, doi: 10.1029/2003JF000041.

Alternative Decentralized Wastewater Treatment Systems for Utah Conditions

Basic Information

Title:	Alternative Decentralized Wastewater Treatment Systems for Utah Conditions
Project Number:	2004UT44B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	UT1
Research Category:	Water Quality
Focus Category:	Water Quality, Treatment, Non Point Pollution
Descriptors:	On-site Wastewater Treatment, Alternative Systems, Decentralized Wastewater Tretment
Principal Investigators:	Judith L. Sims

Publication

Alternative Decentralized Wastewater Treatment Systems for Utah Conditions

Executive Summary

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

In this project, we are surveying, reviewing, and 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 will develop guidance materials for state and local decision-makers on decentralized treatment technologies and appropriate management strategies for those technologies.

Specific tasks include:

1) Survey and collect existing information on alternative decentralized on-site and wastewater reuse treatment technologies.

2) Evaluate information with regards to applicability of technologies to Utah's climatic, geological, and regulatory conditions – consider life cycle costs, treatment efficiencies, management requirements, reliability and failure rates, and potential for beneficial reuse of wastewater.

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.

Statement of Critical State Water Problem

Populations are increasing in many rural and small municipalities in Utah, with housing developments expanding into areas that can only be served by on-site wastewater systems. Freshwater supplies in Utah are limited and must be kept free from contamination from untreated or poorly treated wastewater discharges. The need for effective wastewater treatment in these areas is a major concern for public health and environmental quality managers.

In many of these areas, site conditions such as steep slopes, shallow ground water or bedrock and local soil characteristics such as clayey or sandy soils may preclude the use of the conventional septic tank/drain field system. To accommodate growth in these areas, the use of more complex systems that will provide equal or better treatment than that provided by the conventional system may be an option that will allow continued development. However, for these systems to be effective, they must be appropriate for Utah climatic and geological conditions, design, management and operating requirements must be known, and construction guidelines must be thorough.

Also as the drought in the western United States continues, the use of wastewater treatment technologies for individual homes or businesses or small communities that result in groundwater recharge or provide for beneficial reuse of treated wastewater is another goal of wastewater treatment.

In Utah at the present time, the opportunities to use more complex on-site wastewater treatment systems for individual homes and businesses and for small groups of homes and businesses is limited by prescriptive regulations. However, as population and growth demands increase, the options available need to also increase, but with adequate regulatory oversight and management programs. To ensure that Utah will make wise decisions in the use of complex on-site wastewater systems and systems in the future, in this project we are developing a rational scientific framework to evaluate potential technology options that will provide effective treatment and beneficial reuse while being protective of Utah's public health and environmental resources. The use of wastewater treatment technologies for small communities and individual households that provide adequate treatment are essential to maintain the quality of Utah's surface and groundwater supplies while adding to the sustainability of the water supply resources.

Statement of Benefits

The use of more complex on-site and small community wastewater treatment systems will allow continued development in Utah's more rural areas. By providing thorough and complete information on the range of technologies available, state and local decision-makers will be able to make wise decisions in the selection of technologies and will be able to ensure that appropriate siting, design, construction, installation, and operating and maintenance guidelines are implemented.

Nature, Scope, and Objectives

In this project, we are surveying, reviewing and 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.

Specific tasks include:

1) Survey and collect existing information on alternative decentralized on-site and wastewater reuse treatment technologies.

2) Evaluate information with regards to applicability of technologies to Utah's climatic, geological, and regulatory conditions – consider life cycle costs, treatment efficiencies, management requirements, reliability and failure rates, and potential for beneficial reuse of wastewater.

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.

Methods, Procedures, and Facilities

To accomplish the project tasks, during the first year of the project we surveyed literature sources concerning alternative decentralized systems. We extensively utilized the resources associated with the National Small Flows Clearinghouse at West Virginia University (NSFC, 2004). We also obtained information on various technologies from environmental and health state agencies, with a focus on those states with climatic and geological conditions similar to those in Utah. Equipment vendors of wastewater technologies were also surveyed.

To determine if technologies were appropriate for use in Utah, we defined those climatic and geological conditions that might affect the use of various technologies. We also developed a standardized format/matrix for evaluation of information, including:

- Treatment efficiencies anticipated in Utah's varying climatic and terrain conditions
    - Requirements to achieve predicted treatment efficiency (for example, residence time, loading rates, dose frequency, biomat effects, soil characteristics)
    - Dependence of technology on soil treatment
    - Dependence of technology on mechanical treatment

- Treatment efficiency expected through time

- Reliability of technology

- On-going monitoring, maintenance, and management requirements

- Projected life spans and failure rates of technologies

- Potential for:
    - Containment or removal of pathogens (disease-causing microorganisms)

    - Removal of nutrients (nitrogen and phosphorus)

- Life cycle costs
    - Site evaluation
    - Design
    - Installation and construction
    - Operation, monitoring and maintenance
    - Repair and replacement

- Beneficial reuse and groundwater recharge potential

Summaries of information on two technologies are presented in Tables 1 and 2. Additional information on these technologies, references for the information presented in Tables 1 and 2, and information on additional technologies can be found on the project web site: [http://www.engineering.usu.edu/uwrl/training/onsitesystems/].

Based on the information collected, evaluated, and assessed, during year 2 of the project we are preparing guidance materials that summarize the effectiveness and appropriateness of various decentralized technologies for use in Utah. This information will be used by state and local decision-makers as they develop programs to utilize alternative decentralized systems. A workshop on the use of packed bed filter technologies (sand, gravel, peat, and textile filters) in Utah will be given in the fall of 2005 to local health department and Utah Department of Environmental Quality staff.

Table 1. Peat Filters	
	Peat Filters
Residence time	36-48 hours (Bord Na Mona Products, 1999)
Loading rates	300 L/day/bedroom (Patterson, 2004); 1 gal/sq. ft./day (Gustafson et al., 2002); 360-480 gpd (Lindbo, 2001); Loading rates are designed for a four bedroom home with loading to 450 gpd per unit. You can twin two units together for more. (Festa, 2004); No more than 4 bedrooms served by 1 peat filter (Ecoflo, 2004)
Dose Frequency	60 L pumped at a time (Patterson, 2004); 30-40 L per dosing (Premier Tech, 2003)
Biomat effects	
Soil Characteristics	Works well in highly permeable soils over light sandy clays and in soils with low cation exchange capacity (Patterson, 2004); Areas with:Compacted, cut, or filled soil, Shoreline areas, Shallow bedrock areas, Aquifer recharge areas, Wellhead protection areas (Gustafson et al., 2002); Works with all soil types (Bord Na Mona Unlimited, 2004); If Group I or II soil, a level base percolation area is recommended (Bord Na Mona Products, 1999); If Group III or IV soil, piping the effluent to remote trenches is recommended (Bord Na Mona Products, 1999);The system will work in any soil that has a percolation rate and with drip irrigation it can work in moderate clay with proper sizing (Festa, 2004); Soil has to pass the perc test for a sand mound (Ecoflo, 2004)
Climate	Until 1993, confined to cool temperate climates with relatively long winters and mild summers (O'Driscoll, 1998); The effectiveness is not subject to significant seasonal variation with ambient air temperature fluctuations (Born Na Mona Products, 1999); All climates are acceptable. The system was tested from Maine to Florida with the same results (Festa, 2004); Approved for use in Alabama, Arizona, Georgia, Iowa, Massachusetts, Michigan, North Carolina, Ohio, Pennsylvania, South Carolina (Ecoflo, 2004)
Credit	30% reduction in adsorption area (Festa, 2004); 40% smaller adsorption area than for a sand mound (Ecoflo, 2004)
Dependence of technology on soil treatment	Soil can act as tertiary treatment or as a polishing, but is not required (Patterson, 2004); Since the peat filter is not 100% effective, soil is still needed as the final step (Lindbo, 2001)

Dependence of technology on mechanical treatment	Gravity flow: water may pond on top of the peat and compress it (Gustafson et al., 2002); Pressurized distributions system (Patterson, 2004): applied evenly over the peat surface (Gustafson et al., 2002)
Treatment efficiency expected through time	Performance after 10 years: Percent removal of BOD (96+), TSS (95+), NH_3-N (90+), Total Coliforms (99.9+) (Born Na Mona Products, 1999)
Reliability of technology	
On-going monitoring, maintenance, and management requirements	Add lime yearly to maintain P-sorbtion (Patterson, 2004); Low maintenance compared to other technologies (Patterson, 2004; O'Driscoll, 1998); Yearly to quarterly maintenance: Inspection of component, flow meter, and effluent (Gustafson et al., 2002), De-sludge when needed (Bord Na Mona Unlimited, 2004), Make sure the systems are water tight to avoid infiltration (Lindbo, 2001); Experience has shown that after five years it is good to add two extra bags of loose peat and after ten years replace all the peat in the unit (Festa, 2004)
Projected life spans and failure rates of technolgy	10 year life span (saturates with phosphorus in about 7 years) (Patterson, 2004); 10-15 years (Gustafson et al., 2002; Bord Na Mona Unlimited, 2004); Life span depends on homeowner use (Festa, 2004); 8 years (Ecoflo, 2004; Premier tech, 2003)
Removal of pathogens and nutrients	Containment or removal of pathogens (disease-causing microorganisms): 99.7% removal (Patterson, 2004), 93% removal (O'Driscoll, 1998), 99% removal (Bord Na Mona Unlimited, 2004; Lindbo, 2001; Premier Tech, 2003); Removal of Nitrogen: Ammmonia-N is oxidized to Nitrate-N in the aerobic zones of the peat: 275% increase in nitrate-N (Patterson, 2004), Ammonia nitrogen removal 96% (O'Driscoll, 1998), Nitrate-N is reduced in the anaerobic zones: 53.9% loss of nitrate-N (Patterson, 2004), Measured to be 4.5 mg/L (which is below the MCL of 10 mg/L) (Lindbo, 2001), 70-90% reduction of NH_3 levels (Bord Na Mona Product, 1999); Removal of Phosphorus: 74.6 % removal (Patterson, 2004), 58-96% reduction (Lindbo, 2001); Removal of BOD, 90% reduction (Lindbo, 2001), 95% reduction (Bord Na Mona Product, 1999; Premier Tech, 2003)

Life cycle costs	Site evaluation: Depends on contractor (Festa, 2004); Design: Depends on contractor (Festa, 2004); Installation and construction: Easier to install in small lots (Gustafson et al., 2002), Cost is higher where peat is not commonly found (USEPA, 2001), Standard ST-650 Biofilter: $3,895.00 (USEPA, Sept. 2004),Total materials and installation $11,808 (USEPA, Oct. 2004); Operation, monitoring and maintenance: Low energy inputs (Patterson, 2004); Yearly costs: $200-$500/year (included pumping, repairs, maintenance, and electricity) (Gustavson et al., 2002), A maintenance contract is recommended at of fee of $150 to $175 yearly (Festa, 2004), Costs to maintain or operate have not been standardized (USEPA, 2001), Present Value total O&M $12,604 (USEPA, Oct. 2004), Total over life of system $24,412 (USEPA, Oct. 2004), Monthly averaged over the life of the system $150 (USEPA, Oct. 2004); Repair and replacement: If the peat itself is replaced and added, the system as a whole should not ever need to be placed (Festa, 2004)
Beneficial reuse and groundwater recharge potential	
Disadvantages	Not consistent from batch to batch or from different suppliers (USEPA, 2001)

Table 2. Drip irrigation	
	Drip Irrigation
Residence time	Longer residence time enhances denitrification in the soil (Beggs et al., 2004)
Loading rates	Water application rate should not exceed the water absorption capacity of the soil (Geoflow, 2003): rate should be less than 10 percent of the saturated hydraulic conductivity (Geoflow, 2003), design for saturated events (rainfall) by including a safety factor of 10 or 12 (Geoflow, 2003); Design based on nitrogen loading rates: Lower for sandy soils, Higher for fine soils (Beggs et al., 2004)
Dose Frequency	Once-daily pulse application is better for nitrification/denitrification than smaller daily pulses (Beggs et al., 2004); Frequent, small doses are better than large doses once or twice a day (USEPA, 2002); Rule of Thumb: dose volume equals five times the network volume (USEPA, 2002)
Biomat effects	
Soil Characteristics	Should not be built in flood plain or bottom of a slope where excessive water may collect after rain (Geoflow, 2003); Must be classified as either well drained or moderately well drained (BF Environmental, 2005); Percolation test should be between 3 and 90 minutes per inch (BF Environmental, 2005); Slope 0-25% (BF Environmental, 2005)
Climate	1. No operational problems were found in cold temperatures (soil temperatures of -12°C) when properly designed aind installed (Bohrer and Converse, 2001); Less problems in cold weather if drip lines are buried 6" or more below the surface or a winter grass can be planted to provide insulation (Lesikar and Converse, 2005); In colder climates, the dripline should be buried deaper. Mulching the area the winter after construction (and the winter afterward) can help insulate the dripline (USEPA, 2002)
Credit	Must be 20 inches from the surface of the ground to a high water table or slower permeable soil conditions (BF Engineering, 2005); Must be 26-32 inches from a high permeable material or fractured rock (BF Engineering, 2005)
Dependence of technology on soil treatment	It is used as a polishing treatment and to get rid of the water
Dependence of technology on mechanical treatment	

Treatment efficiency expected through time	
Reliability of technology	
On-going monitoring, maintenance, and management requirements	Clean filter cartridges (Geoflow, 2003); Flush the field (Geoflow, 2003); Check the pressure in the drip field (Geoflow, 2003)
Projected life spans and failure rates of technolgy	10 year warranty for root intrusion, workmanship and materials (Geoflow, 2003); Durable with a long expected life (Geoflow, 2003)
Removal of pathogens and nutrients	Nitrogen removal by plant roots (Austin, 2001)
Life cycle costs	Installation and construction: Drip line $0.51-1.16 per foot (Geoflow, 2004), Controler $807.00-2,420.00 (Geoflow, 2004), Headworks $550.00-4,396.00 (Geoflow, 2004), Accessories $10.00-500.00 (Geoflow, 2004), System, installation (includes controls and alarm) $15,000 (Austin, 2001); Operation, monitoring and maintenance: Energy costs $0.47/month (Austin, 2001), O&M maintenance contract $45/month (Austin, 2001); Repair and replacement: 4.17/month (Austin, 2001)
Beneficial reuse and groundwater recharge potential	Irrigation of crops and Irrigation of landscapes
Disadvantages	Not consistent from batch to batch or from different suppliers (USEPA, 2001)

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	2	0	0	0	2
Ph.D.	3	0	1	0	4
Post-Doc.	0	0	0	0	0
Total	6	0	1	0	7

Notable Awards and Achievements

David G. Tarboton was awarded the Department and College of Engineering, Utah State University, "Outstanding Researcher" award, 2005.

Jenny Paget Hurst was the recipient of the Water Environment Association of Utah (WEAU), "Dr. Robert W. Okey Scholarship" for her achievements in the environmental engineering MS program at Utah State University. For her scholarship application essay she wrote about water reuse in Utah, examining the disappearance of freshwater resources and the possibilities of reusing treated water from wastewater treatment plants for agriculture, wetlands, landscaping, and toilet water as a ways to preserve fresh water.

Kori Moore, a senior in the environmental engineering program, recently won first place in the Undergraduate Division of the Air and Waste Management Association's 2004 Student Poster/Paper Competition at the Association's national conference in Indiana. Kori has been working with Dr. Randal Martin in his research. Kori's research found that there is a strong correlation between a strong, wintertime temperature inversion and high pollution episodes, such as those experienced in Cache Valley, Utah in January and February 2004. He also found that the bottom of the temperature inversion occurs about 500 feet above the valley floor. This means that the pollutants released can only mix with the air contained below that level, which produces high concentrations of pollutants.

Dr. Thom Hardy received a Certificate of Appreciation for Outstanding Service by the Water Science and Technology Board of the National Research Council of the National Academies. This is in recognition of his service as a member of the Committee on Review of Methods for Establishing Instream Flows for Texas Rivers.

The Utah On-Site Wastewater Treatment Training Program has recently received the Lynn Thatcher Award from the Utah Environmental Health Association (UEHA) at the UEHA Educational Conference in Layton, Utah. The award was established to honor an entity outside the UEHA that has made a significant contribution to the field of environmental health.

A collaborative team of Utah State University researchers, including Dr. David Stevens, Mr. Jeffery Horsburgh, and Dr. Darwin Sorensen, was awarded a grant from the USDA Cooperative State, Research, Education, and Extension Service: Evaluating the Effects of Conservation Practices on Water Quality within the Biophysical Setting of a Watershed. The team will study the effects of conservation practices on water quality in the Little Bear River Watershed in Northern Utah. The study is designed to evaluate whether adoption of several agricultural best-management practices have had a measurable impact on phosphorus loadings into the Little Bear River.

The USEPA’s Targeted Watersheds Grants Program has awarded a grant to another collaborative team at Utah State University, this one including Dr. David Stevens and Mr. Jeffery Horsburgh, to implement studies in the tri-state Bear River basin 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.

Dr. William J. Rahmeyer was invited to a dedication luncheon and ribbon cutting on June 7, 2004 for the Lake Kaweah Enlargement Project Dedication. This is a special luncheon that included the Governor of California. Dr. Rahmeyer worked on the design for the fusegate spillways for the Terminus Dam on Lake Kaweah, CA.

Monday, April 26, 2004 was officially declared "Said Ghabayen Day" in Logan, UT. Mayor Doug Thompson honored Said Ghabayen with this distinction at a farewell party. This is the first time the mayor has dedicated a day to an individual. During his four years in Logan, Said was heavily involved with the Cache Community Connections (CCC) and the Logan Islamic community. In the wake of the September 11, 2001 events, Said became the voice and image of Cache Valley’s Islamic community. He was also involved in many other community events, including a "Tribute to Freedom", a candlelight vigil and many interfaith services. Said has graduated and he and his family moved back to their native Palestine on May 30, 2004 where he works for the Islamic University in Gaza.

Dr. William J. Rahmeyer received the "2003 Crosby Field Award" and "2003 Technical/Symposium Paper Award" from ASHRAE. Dr. Rahmeyer received these awards at the Society’s 2004 Annual Meeting in Nashville, Tennessee on June 26th, 2004.

Abedalrazq Khalil, received word from the Journal of the American Water Resources Association (AWRA), that his paper had been featured on the AWRA website. The name of the paper is: "Basin Scale Water Management and Forecasting Using Artificial Neural Networks." Authors: Abedalrazq F. Khalil, Mac McKee, Mariush Kemblowski, and Tirusew Asefa.

Dr. Wynn Walker, Associate Dean in the College of Engineering, received the 2004 Governor’s Medal in Science and Technology. As a professor of Biological and Irrigation Engineering, Dr. Walker is an international figure in the field of irrigation engineering and water management. Throughout his years of service to Utah State University, he has taught at both the undergraduate and graduate level and has mentored more than 30 masters students and more than 20 doctoral students. His former students now hold significant positions in governments around the world, many making water resources and policy management decisions that effect millions of people on five continents.

Publications from Prior Projects

1. 2003UT29B ("Source Water Protection Assessment Tools Development") - Conference Proceedings - Gogate, S., D.G. Tarboton, M. Kemblowski, Q. Shu, W. Wahlstrom, D.L. Sorensen, and D.K. Stevens (2004). "Terrain analysis for water quality modeling." In: American Water Resources Association 2004 Spring Specialty Conference. Geographic Information Systems (GIS) and Water Resources III. Nashville, TN, May 17-19.
2. 2003UT29B ("Source Water Protection Assessment Tools Development") - Conference Proceedings - Sorensen, D.L., K.D. Moncur, D.G. Tarboton, M. Kemblowski, S. Quiang, and S. Gogate (2003). "A Surface water protection assessment tool that uses digital elevation models." In: American Water Works Association, Source Water Protection Symposium, Albuquerque, NM, January, 19-22.