Center for Water Resources Research
Annual Technical Report
FY 2005

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 Engineers Office, all 12 local health departments, and several large water management agencies and purveyors in the state with specific water resources problems.

In FY 05, the UWRL expended a total of approximately $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 state and local decision-makers on decentralized treatment technologies and appropriate management strategies for those technologies. 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 SRWUAs 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 physical 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 are subject to very high uncertainty. 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 is being 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
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Congressional District:	UT1
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Focus Category:	Management and Planning, Models, Irrigation
Descriptors:	Water System Operation, Short-Term Management, Long-Term Forecasting, Uncertainty
Principal Investigators:	Mac McKee, Luis A Bastidas

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 (W11401).*
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.

7. Pande, S., L. Bastidas, E. Rosero, M. McKee, W. Shuttleworth, H. da Rocha, and S. Miller. 2005. Effects of Data Uncertainty on Parameter Uncertainty within a Multi-Objective Parameter Estimation Framework. Presented at the *Annual Meeting of the American Geophysical Union*, San Francisco, December, 2005.
8. McKee, M. 2005. Real-time Management of Irrigation Facilities in the Sevier River Basin. Presented at the *Utah Water Users Workshop*, St. George, Utah, March, 2005.
9. Kaheil, Y., M. Gill, M. McKee, and L. Bastidas. 2006. A New Bayesian Recursive Technique for Parameter Estimation. *Water Resources Research* (in press).
10. Gill, M., M. Kemblowski, and M. McKee. 2006. Soil Moisture Data Assimilation using Support Vector Machines and Ensemble Kalman Filter. *Water Resources Research* (in press).
11. Oman, Lizzette. 2006. *Use of Bayesian Belief Network to Quantify the Uncertainty in Estimates of Salt Loading from an Irrigated Watershed.* Unpublished MS Thesis, Department of Civil and Environmental Engineering, Utah State University, Logan, Utah.

Data Fusion for Improved Management of Large Western Water Systems

Problem

The relative scarcity of water in the western U.S. is increasing 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 (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 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 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 project will extend and exploit advanced information technologies to design and test better tools for the management of scarce water resources at the geographic scale of a river basin. 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 will take 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; Ghabayen et al., 2003, 2004, 2006), and a graduate student on the project will examine the use of BBNs in assessing uncertainties in salt loading estimates in the EWCD. The effort this year will focus on full web-based implementation of the BBN that was constructed last year for 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). Work this year will involve the web-based implementation of the models constructed last year for improved operation of Piute Reservoir (see Khalil and McKee, 2004a, 2004b) and short- and long-term forecasting of stream flow in the upper Sevier River Basin (Khalil and McKee, 2005). The planned implementation of the Piute Reservoir operations model includes the computer systems programming to connect the model to the reservoir gate controllers in such a way that, with human supervision, the model will be directly operating the reservoir during the irrigation season.

- Sensor and Data Fusion for Irrigation Demand Forecasting. One PhD student to be partially supported by this project will focus on the application of SLT techniques to develop better models for short-term forecasting of irrigation diversion requirements.

The system operations models built to date have been directed at improving the efficiency of water supply. There has been little work, however, to exploit the vast wealth of real-time canal diversion data, real-time meteorological data, GIS data on cropping patterns and command areas served by specific canal reaches, and, very importantly, the short-term forecasts of precipitation and evapotranspiration available from NOAA. This task will involve the development and application of SLT methodologies to re-scale the large footprint of the NOAA forecasts down to a scale useful for predicting evapotranspiration requirements of the land area served by specific reaches of canals. From this, required canal diversions will be forecasted for one to seven days in advance. If such forecasts can be made reliable, they will provide information of significant utility to canal and reservoir operators. The models will be developed and tested from data available in the Sevier River Basin.

Specific models to be developed and/or implemented this year will likely consist of:

- A model for providing long-term forecasts of spring runoff in the Upper Sevier River Basin (to be implemented on the SRWUA web site)
- A model for managing short-term operations for Piute Reservoir in the Upper Sevier Basin (to be implemented on the SRWUA web site, and then tested for reliability)
- A BBN model for estimating monthly and annual salt loading from the San Rafael River into the Colorado River, and quantification of uncertainty in those estimates (to be implemented on the EWCD web site)
- A model to provide short-term (one to seven days) forecasts of irrigation demands on a canal reach basis

Implementation of Models

The models all 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 2005 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 website for use by reservoir and canal operators. Comparisons of model predictions versus actual canal operations are given in Figure 1.

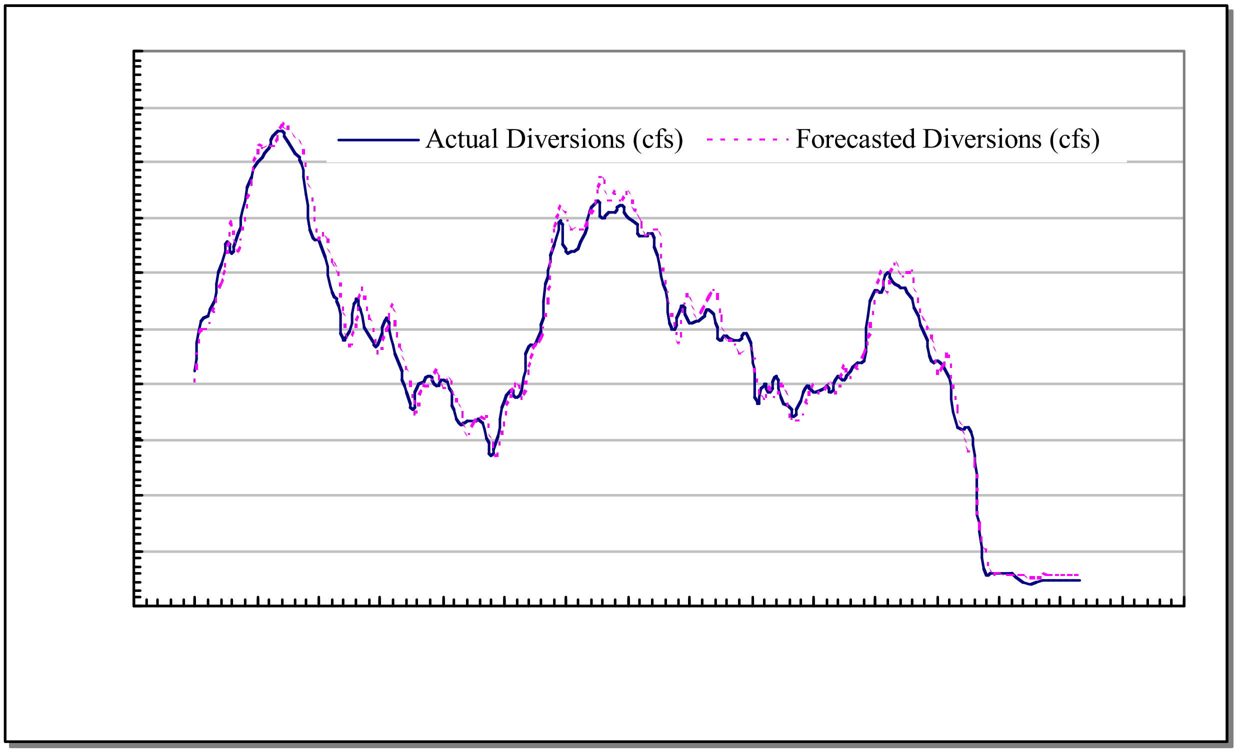


Figure 1. Comparison of Actual Sevier Valley/Piute Canal Diversions in 2002 with ANN Model Forecasted Diversions

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).

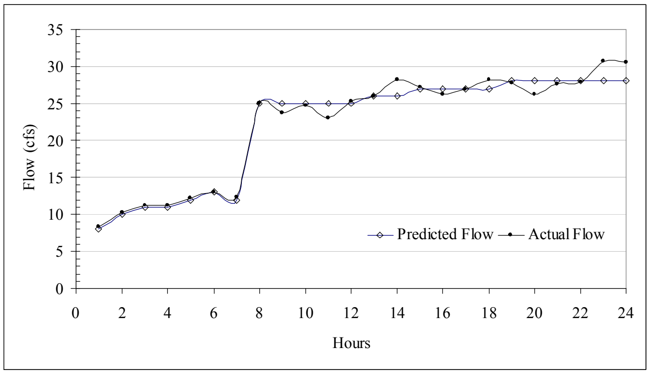


Figure 2. Predicted Versus Actual Diurnal Fluctuation of Flows in Clear Creek on 4/4/2001

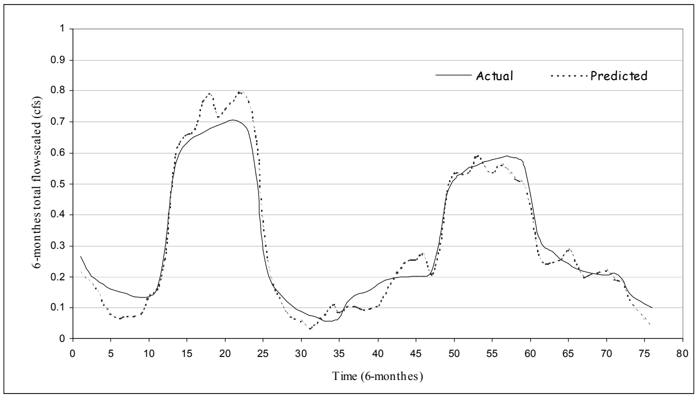


Figure 3. Time-Series Performance of the ANN Model in Predicting Seasonal Flows at Hatch

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. The suite of models developed for real-time operation of Piute Reservoir was programmed re-programmed according to specifications required by the SRWUA. This has been implemented on SRWUA computers and its output made available to reservoir operators. At the time of preparation of this report, the SRWUA is evaluating the performance of the model and plans to turn give direct control of Piute Reservoir to it.

The modeling approach and findings relative to model performance were published in Khalil et al. (2005).

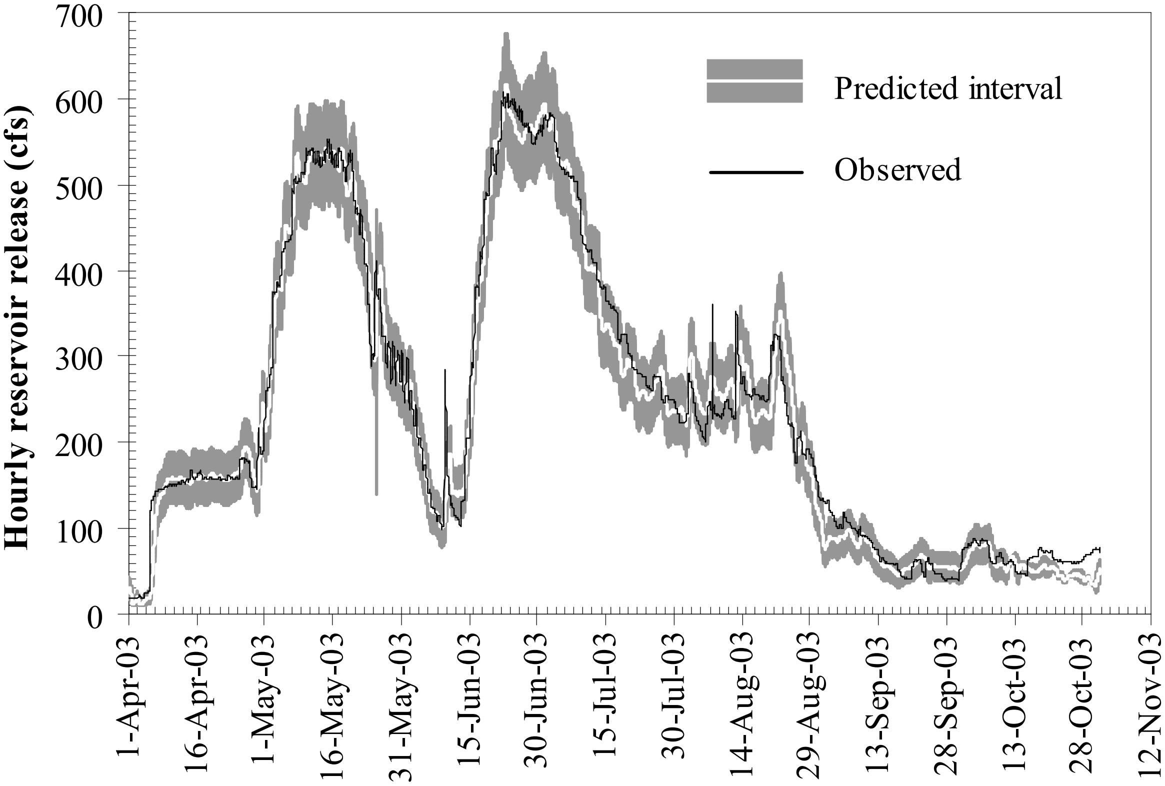


Figure 4. Comparison of Actual Piute Reservoir Releases in 2003 with the SVM/RVM Model Forecast Releases

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/). This dealt mainly with analysis of statistical relationships between stage and discharge, and between conductivity and salt concentration for the major tributaries (Huntington, Cottonwood, Rock, and Ferron Creeks) of the San Rafael River (see Figure 5). This was done to provide the basis for a Bayesian belief network (BBN) model that can be used to quantify the uncertainty in the estimate of salt loading from the basin.

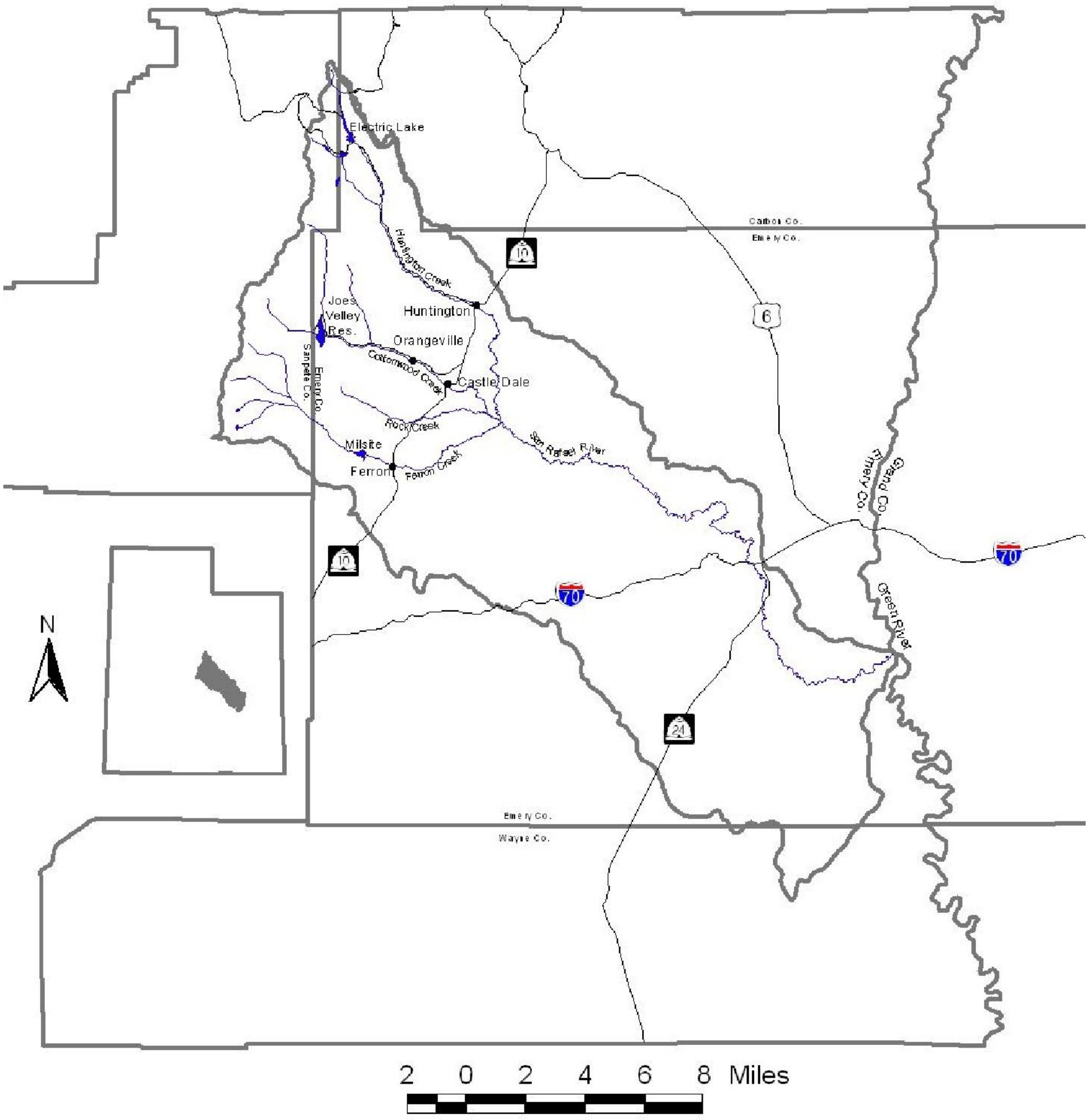


Figure 5: San Rafael River Basin

Two alternative BBN models have been constructed that estimate total daily, weekly, monthly, and annual salt loading from the San Rafael drainage into the Green River. These models have the general form shown in Figure 6. Flows in the San Rafael are modeled as the sum of estimated flows in the four tributary creeks that converge to form the San Rafael. Salt loading in the San Rafael is modeled as the sum of the estimated salt load from the four tributaries. Uncertainty in these estimates is due to instrumentation/measurement uncertainty and uncertainty in the relationships between stage (which is measured) and flow (which is estimated from stage), and between electrical conductivity (which is measured) and salt concentration (which is estimated).

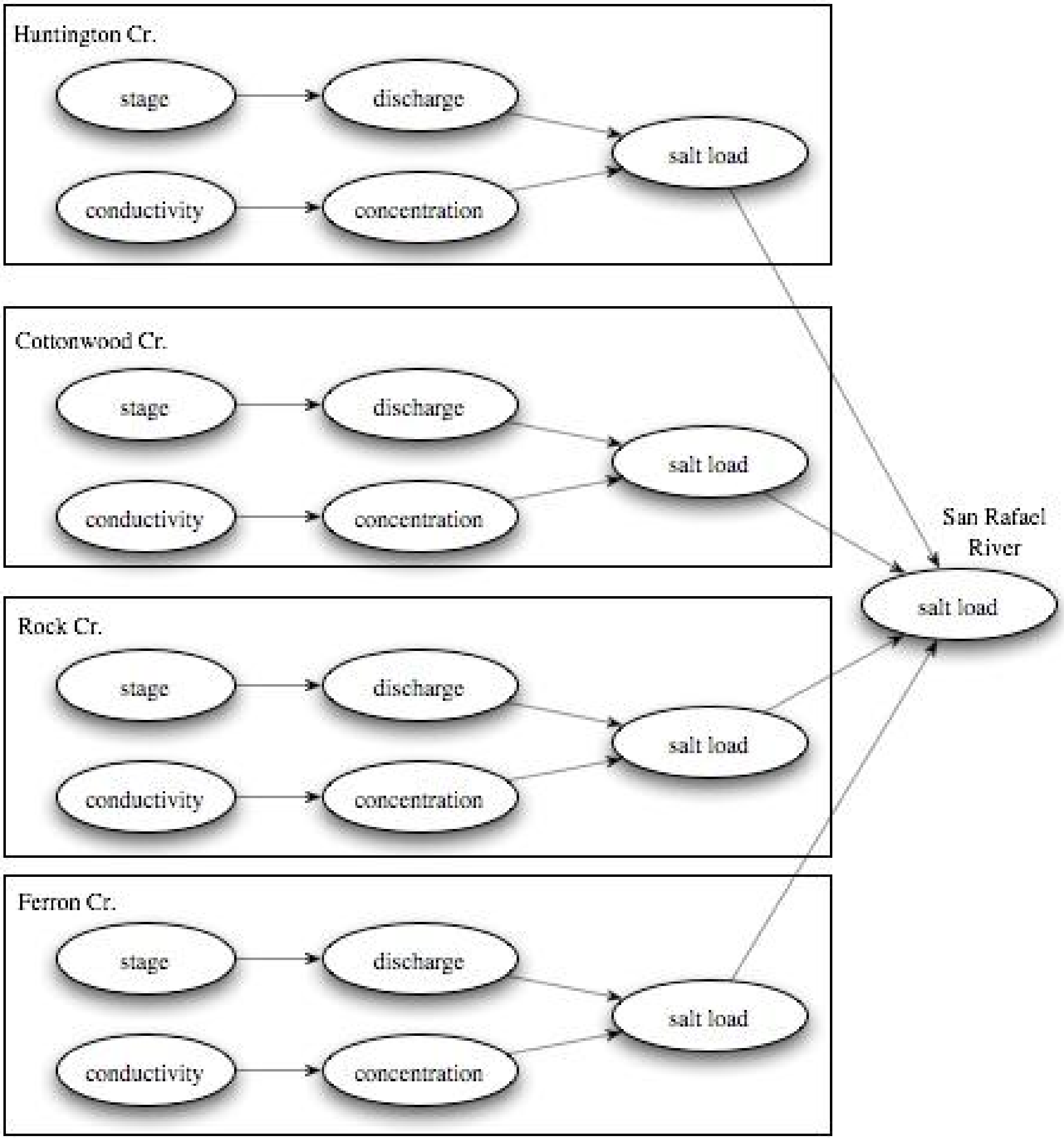


Figure 6: General BBN Design for Estimating Salt Loading to the San Rafael River from the EWCD

These models use hourly data available from the EWCD real-time data collection system to populate the marginal probability distributions for the stage and electrical conductivity nodes. The uncertainty in the relationship between stage and discharge and between conductivity and salt concentration is encoded in the BBN for each tributary. The BBN can then estimate salt concentration and flow rate, as well as quantify the uncertainty in those estimates. Salt loading for each tributary is simply the product of the estimated flow and salt concentration. The total loading to the San Rafael is simply the sum of the loading estimates of the individual tributaries. The BBN can calculate this estimate on a daily basis, and it can obtain weekly, monthly, and annual estimates of salt loading by simply summing the daily estimates.

Data available from the EWCD monitoring network are sufficient to estimate annual salt loading for two years. The BBN models show an annual loading of approximately 100,000 to 150,000 tons/year, which is consistent with estimates made in other studies. However, the BBN models also show 95 percent confidence intervals that are as much as ±50,000 tons/year, indicating that salt loading estimates are subject to considerable uncertainty. Application of backpropagation analysis indicated that the major sources of uncertainty in the loading estimates lie in the estimates of stream discharge. These analyses showed that investments in better flow measurement devices would be the most effective way to decrese the uncertainty in the final salt loading estimate.

The research conducted on the EWCD salt loading issue is reported in Oman (2006). At the time of preparation of this report, work is underway to prepare and submit a manuscript that describes this research for publication in a professional journal.

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 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 continue 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.

References

Almasri, M.N., and J.J. Kaluarachchi. 2002. Application of artificial neural networks in predicting stream-aquifer interaction. *ACTA Universitatis Carolina-Geologica*, 46(2/3):54-57.

Bowman, C.L., and A.N. Steinberg. 2001. A systems engineering approach for implementing data fusion systems. In: D. L. Hall and J. Llinas (eds.). *Handbood of Multisensor Data Fusion*, Chapter 16. CRC Press, London.

Carroll, T.R. 1990. Operational airborne and satellite snow cover products of the National Operational Hydrologic Remote Sensing Center. *Proceedings of the 47th Eastern Snow Conference*, Bangor, Maine, CRREL Special Report 90-44, June 7-8.

Grody, N.C., and A.N. Basist. 1996. Global identification of snow cover using SSM/I measurements. *IEEE Transactions on Geoscience and Remote Sensing*, 34(1):237-249.

Gautam, M.R., K. Watanabe, and H. Saegusa. 2000. Runoff analysis in humid Forest catchment with artificial neural network. *Journal of Hydrology*, 235:117-136.

Ghabayen, S., and M. McKee. 2003. A Bayesian belief network model for multi-objective optimization of the Gaza Water Resources System. Presented at the *Annual Conference of the American Water Resources Association*, San Diego, CA, November 3-6.

Ghabayen, S., M. McKee, and M. Kemblowski. 2003. Using Bayesian belief networks, ionic molar ratios, and isotopes for identification of salinity origin and monitoring requirements in the Gaza Coastal Aquifer. Presented at the *Annual Conference of the American Water Resources Association*, San Diego, CA, November 3-6.

Ghabayen, S., M. McKee, and M. Kemblowski. 2004. Characterization of uncertainties in the operation and economics of the proposed seawater desalination plant in the Gaza Strip. Accepted for publication in *Desalination*, January.

Ghabayen, S., M. McKee, and M. Kemblowski. 2006. Ionic and Isotopic Ratios for Identification of Salinity Sources and Missing Data in the Gaza Aquifer. *Journal of Hydrology*, 318:360-373.

Govindaraju, R.S. (2000). Artificial neural networks in hydrology. II: Hydrologic Applications. *Journal of Hydrologic Engineering*, 5(2):124-137.

Hall, D.K., A.B. Tait, J.L. Foster, A.T.C. Chang, and M. Allen. 2000. Intercomparison of satellite-derived snow-cover maps. *Annals of Glaciology*, 31:369-376.

Hassan, R., and M. McKee. 2003. Canal flow regulation using support vector machines. Presented at the *Annual Conference of the American Water Resources Association*, San Diego,CA, November 3-6.

Hiramatsu, K., S. Shikasho, and K. Mori. 1999. Nonlinear prediction of river water-stages by Feedback Artificial Neural Network. *J. Fac. Agr., Kyushu Univ.*, 44(1.2):137-147.

Kaplan, A., Y. Kushnir, M. Cane, and M. Blumenthal. 1997. Reduced space optimal analysis for historical datasets: 136 years of Atlantic sea surface temperatures. *Journal of Geophysical Research*, 102:27,835-27,860.

Kaplan, A., M. Cane, Y. Kushnir, A. Clement, M. Blumenthal, and B. Rajagopalan. 1998. Analyses of global sea surface temperature 1856-1991. *Journal of Geophysical Research*, 103-18)567-18,589.

Khalil, A., and M. McKee. 2003. Basin-scale water management and forecasting using multisensor data and neural networks. Presented at the *Annual Conference of the American Water Resources Association*, San Diego, CA, November.

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* (W11401).

Kim, G., and A. P. Barros. 2001. Quantitative flood forecasting using multisensor data and neural networks. *Journal of Hydrology*, 246:45-62.

Liong, S. Y., and C. Sivapragasam. 2002. Flood stage forecasting with support vector machines. *Journal of the American Water Resources Association*, 38(1):173-186.

Nghiem, S. V., and W. Tsai. 2001. Global Snow Cover Monitoring with Spaceborne Ku-band Scatterometer. *IEEE Transactions of Geoscience and Remote Sensing*, 39:2118-2134.

Oman, Lizzette. 2006. *Use of Bayesian Belief Network to Quantify the Uncertainty in Estimates of Salt Loading from an Irrigated Watershed*. Unpublished MS Thesis, Department of Civil and Environmental Engineering, Utah State University, Logan, Utah.

Pande, S., and M. McKee. 2003. Probably approximately optimal (PAO) feature subset selection for incremental local learning algorithms. Presented at the *Annual Conference of the American Water Resources Association*, San Diego, CA, November 3-6.

Pulliainen, J., and M. Hallikainen. 2001. Retrieval of regional snow water equivalent from space-borne passive microwave observations. *Remote Sensing of Environment*, 75:76-85.

Sivapragasam, C., S.Y. Liong, and M.F.K. Pasha. 2001. Rainfall and runoff forecasting with SSA-SVM approach. *Journal of Hydroinformatics*, 3:141-152.

Vapnik, V. N. 1995. *The nature of statistical leering theory*. Springer-Verlag.

Wilson, L. L., L. Tsang, J. N. Hwang, and C. Chen. 1999. Mapping snow water equivalent by combining a spatially distributed snow hydrology model with passive microwave remote-sensing data. *IEEE Transactions on Geoscience and Remote Sensing*, 37:690-704.

Yu, X., S. Liong, and V. Babovic. 2002. An approach combining chaos-theoretic approach and support vector machines: Case study in hydrologic forecasting. Volume 2: 690-695. In: Johan Junke Guo (Ed.). *Advance in Hydraulics Water Engineering*, Proceedings of the 13th IAHR-APD Congress. Singapore, 6-8 August.

Award No. 04HQAG0212 The Integration of Multispectral Imaging and LIDAR to Evaluate the Geomorphic Changes Associated with a Levee Setback along the Puyallup River, WA

Basic Information

Title:	Award No. 04HQAG0212 The Integration of Multispectral Imaging and LIDAR to Evaluate the Geomorphic Changes Associated with a Levee Setback along the Puyallup River, WA
Project Number:	2005UT79S
Start Date:	8/20/2004
End Date:	4/30/2005
Funding Source:	104B
Congressional District:	UT1
Research Category:	Engineering
Focus Category:	Methods, Conservation, Education
Descriptors:	Riverine Habitats, Airborne Multispectral Imagery, Remote Sensing
Principal Investigators:	Christopher M.U. Neale, Robert W. Black, Christopher P. Konrad

Publication

1. Konrad, C.P., R.W. Black, F. Voss, and C.M.U. Neale (2006). Integrating remote sensing and field methods to assess effects of levee setbacks on riparian and aquatic habitats in glacial-melt water rivers. In final internal review, to be submitted to Rivers Research, and Application.

The Integration of Multispectral Imaging and LIDAR to Evaluate the Geomorphic Changes Associated with a Levee Setback Along the Puyallup River, WA

Problem

The Puyallup River originates from the Puyallup glacier of Mount Rainier, in the Cascade Range, and empties into Puget Sound at Commencement Bay. The Puyallup River has two major tributaries, the White and Carbon Rivers. The White River enters the Puyallup River near the city of Puyallup and the Carbon River enters about 18 river miles from the mouth of the Puyallup, between Puyallup and Orting. Mud Mountain Dam, at about river mile 28 on the White River, affects flow in the Puyallup River, and water was removed from the White River at about river mile 24 and stored in Lake Tapps for power generation, then returned to the White River at about river mile 4.

The lower Puyallup River Basin has a temperate marine climate, with warm, dry summers and cool, wet winters. The mean annual temperature is about 52 F (degrees Fahrenheit). The warmest month is July, with an average temperature of about 64 F; the coolest month is January, with an average temperature of about 39 F (Western Regional Climate Center, 2003). The long-term (1931-95) average annual precipitation at the Washington State University Experimental Station in Puyallup is 39.9 in., about 70 percent falling during the months of October through March (Western Regional Climate Center, 2003). Snow occasionally falls in the area, but quickly melts.

Local flooding along the Puyallup River has traditionally been addressed by constructing levees along the river banks to prevent floodwater from flowing into areas where they could damage roads, buildings, agricultural fields, or other developed areas of the floodplain. Levees, however, can worsen flooding upstream because of backwater effects or downstream because of a reduction in floodplain storage. Levees constrain streamflow during floods, which can produce deeper flows with higher velocities. These hydraulic changes result in increased shear stress applied by streamflow on riverbed material and, potentially, increased entrainment of riverbed material, sediment transport, and disturbance of benthic habitat used by salmonids for incubation as well as by periphyton and macroinvertebrates. At the same time, the wetted channel and floodplain area is reduced by levees, which may limit habitat available to aquatic organisms during floods and ecologically-important processes such as fluvial recharge of shallow ground water, recruitment of large woody debris, deposition of sediment and debris, and creation/opening of aquatic and riparian habitat.

Pierce County has begun a series of levee setback projects. These projects involve the removal of existing levees and the construction of new ones located further away from the active river channels. These setbacks are intended to alleviate local flooding and improve habitat conditions along some of its rivers.

To evaluate the geomorphic changes and hydrologic and habitat benefits of these setbacks as well as to refine the use of aerial multispectral imaging in conjunction with thermal imaging in the interpretation of hydrologic modifications, high-resolution shortwave and thermal imagery was acquired with the Utah State University airborne system.

Research Objectives

1) Document and verify current geomorphic conditions in three study reaches: the proposed levee setback reach on the Puyallup River, a historic levee setback reach on the Puyallup River, and a control reach on the Carbon River using high resolution multispectral images.

2) Verify existing LIDAR data for the study reaches.

3) Compare current geomorphic conditions within the proposed levee setback reach with those of a previously restored reach on the Puyallup and a control reach on the Carbon River.

4) Refine the use of an aerial based multispectral and thermal imaging system to evaluate geomorphic dynamics in large glacial fed Pacific Northwest rivers.

Methods

The investigation assessed aquatic and riparian habitats in three reaches of the Puyallup River and one reach of the Carbon River using high-resolution airborne, multispectral imaging acquired on 27 July 2004, in conjunction with field surveys on 26-28 July 2004, and an analysis of hydraulic conditions on selected days during 2005 in two of the Puyallup River reaches. The habitat features identified in field surveys were used to classify the multispectral imagery and evaluate the classification. The resulting classification was used to compare the amount and distribution of aquatic and riparian habitats in the different reaches. The hydraulic analysis provided information about effects of levee setbacks on streamflow velocity, stream depth, and bed stability.

Mean streamflow in the Puyallup River near Orting was 20.3 m^3/s for 26-28 July 2004, with a diurnal cycle of $\pm$ 4 m^3/s produced by mid-day snowmelt. Because of travel time from snowfields and glaciers on Mount Rainier, the daily streamflow peak during summer is around 2 AM with streamflow ranging from 16 to 19 m^3/s during imaging and field surveys.

Multispectral Image Acquisition and Processing

High-resolution multispectral imagery was acquired with the USU airborne multispectral digital system (Neale and Crowther, 1994; Cai and Neale, 1999) at a nominal spatial resolution of 0.5 m (1,070 m above ground level), over the Puyallup and Carbon Rivers. The image acquisition flight was between 11:36 A.M. and 12:06 P.M. Pacific Daylight Time under clear sky conditions. The USU system consists of three Kodak™ Megaplus 4.2i digital cameras with interference filters forming spectral bands in the green (0.545-0.555 µm), red (0.665-0.675 µm), and near infrared (NIR) (0.790-0.810 µm) wavelengths. (Note: use of trade names does not constitute an endorsement of the product by USGS or USU). Cameras were mounted through a porthole in a Piper Seneca II aircraft, dedicated for remote sensing missions. The cameras were controlled through software using Epix boards in a Pentium III computer, mounted in an equipment rack.

System digital cameras were calibrated against a radiance standard, though no calibration was applied to this set of images. The system also uses an Inframetrics 760 thermal infrared camera mounted through a separate porthole that acquires images in the 8-12 μm range, though these images were not used in the habitat classification. Shortwave images were acquired at a nominal overlap of 60 percent along the flight lines in a 1-km swath centered over the river. For the most part, a single swath was wide enough to cover the river and riparian zone on both sides of the river. Individual spectral band images were geometrically corrected for radial distortions and also radiometrically adjusted for lens vignetting effects and registered into three band images. The 3-band images were rectified through a rubber-sheeting technique to color digital orthophoto quads, using common control points visible in both imagery sets. The rectified images were combined into image mosaics along the flight lines, representing river reaches. Finally, all strips were stitched together forming a mosaic.

Aquatic and Riparian Habitat Field Survey

A field survey of selected aquatic and riparian habitats was conducted along about 3 km of the Puyallup River and 1 km of the Carbon River. Field-mapped habitat features were located in the multispectral images to identify and verify the spectral ranges of different habitat types, but were not used to create a complete habitat map of the floodplain and river. A habitat feature represented a discrete area of the river or floodplain surface at least 5-m long and with a consistent surface that could be distinguished from surrounding areas. Some features had heterogeneous surfaces as in the case of rough water surfaces, patches of mixed vegetation patches, and cobbles embedded in sand, but heterogeneity was consistent across the feature.

Three types of aquatic habitat features were mapped in the field: pools, riffles, and runs. Pools were identified as lower-velocity regions of the river with greater than average depths and relatively tranquil, lower gradient water surfaces where a downstream obstruction (e.g., a gravel bar or log jam) creates a backwater. Riffles were identified as higher-velocity regions with less than average depths and turbulent, higher-gradient water surfaces formed where the river flows over gravel bars. Runs were identified as average- or higher-velocity regions with relatively uniform depths and only slightly turbulent water surfaces.

Three broad categories of riparian habitat features were identified and mapped in the field: exposed sediment, vegetated surfaces, and large woody debris (LWD). Dominant and subdominant substrate size of exposed sediment were estimated visually and recorded in one of eight feature types. The feature types were aggregated into three categories (sand, gravel, and cobble) for image classification. Vegetation features were evaluated as herbaceous, deciduous shrub and forest, or coniferous forest. Qualitative observations about vegetation density and substrate uniformity also were noted.

Latitude and longitude of upstream and downstream ends of most features were located with a hand-held global positioning system (GPS) receiver, though in some cases only the coordinates of the center point of the feature was determined. Three measurements of length and width for each feature were made with a tape measure.

Hydraulic conditions were assessed in the Puyallup River to evaluate the comparative effects of levees and setback levees on velocity distribution and riverbed stability. Stage and water-surface slopes in the upper and lower reaches of the Puyallup River were documented at staff gages for three different flows, including a flood event near Orting on 18 January 2005, when daily mean discharge was 224 m^3/s. Relative elevations of staff gages in each reach were determined by topographic surveys using a total station. This information was combined with cross sections derived from a LiDAR coverage (Puget Sound LiDAR Consortium, 2005) to calculate the hydraulic radius and velocity at the cross-section for the flood event using Manning's equation. Intermediate diameters of 200 particles randomly selected from an exposed gravel bar were measured at each cross-section. Cross-sectional topography was verified with a tape measure and hand level. The hydraulic radius, R, water surface slope, S, and median particle size, D_{50}, at the cross section were used to calculate reach-average dimensionless shear stress, τ^*, for the January 2005 flood event:

$$\tau^* = \frac{\gamma_s D_{50}}{\gamma_w RS} \tag{1}$$

where γ_s and γ_w are the specific weights of sediment and water respectively. Dimensionless shear stress provides an approximate index of the spatial extent of gravel entrainment from the bar surface with limited gravel entrainment beginning around 0.02 to 0.04 and extensive entrainment (more than about 50 percent of the bar area) at values greater than 0.08 (Konrad *et al*., 2002).

Habitat Classification

Habitat classification was based on the spectral signatures of pixels corresponding to habitat features mapped in the field. A point coverage of the habitat feature coordinates mapped in the field was created in a GIS. Feature locations were verified visually by overlaying the point coverage on the airborne images of rivers and floodplains. The three spectral bands were used to perform a supervised classification based on the spectral signature of each habitat type (ERDAS, 2003; Lillesand *et al*., 2004). The spectral signature of a habitat type is the range of raw digital numbers (0 to 255) representing the relative reflectance in each of three spectral bands for all pixels of that feature type. Due to a limited number of features in some habitat types, exposed sediments were grouped into five categories (silt, sand, gravel, cobble, and boulder) and vegetated surfaces were grouped into two categories (herbaceous and deciduous shrubs and trees) for the development of spectral signatures. About one-half of the field-mapped features were selected at random and used to develop the spectral signature for classifying each habitat type. Edge detection also was used to locate pieces of LWD (ERDAS, 2003). In this case, lines that divide groups of pixels with distinct spectral signatures were identified automatically by the computer program.

After the images were classified in terms of the habitat type of each pixel, the pixels corresponding to features mapped in the field were aggregated for each feature. Because the spectral properties of a habitat feature (i.e., a stand of trees, a riffle, or sand bar) are not homogeneous over the feature's surface, pixels classified with different habitat types may represent a single feature. For example, a cobble bar could have 40 percent of its pixels classified as cobble, 25 percent as gravel, 25 percent as sand, and 10 percent as riffle. Consequently, each feature was assigned the same habitat type as the mode classification of its pixels.

Results

Supervised classification of the multispectral images was evaluated by comparing habitat types of pixels representing each field-mapped feature to the habitat type assigned to the feature in the field. Two types of errors were possible: errors of omission representing features identified in the field as a given type but incorrectly classified, and errors of commission representing the fraction of features classified incorrectly with a given habitat type.

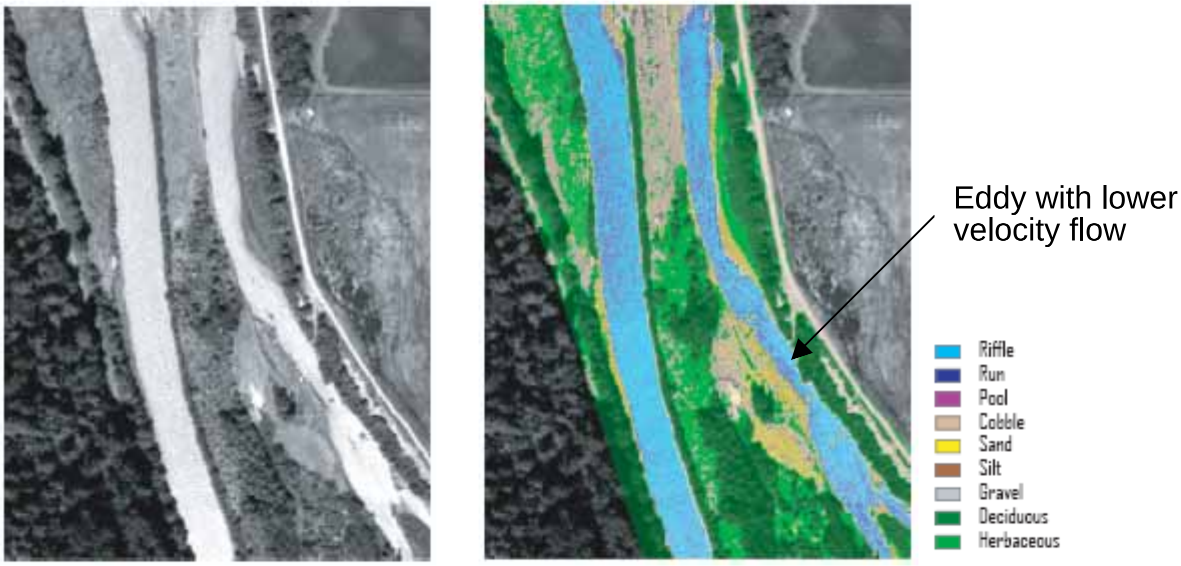
Supervised classification of the multispectral images consistently distinguished between aquatic and riparian habitats with a high degree of accuracy: only 1 aquatic feature out of 13 was classified with riparian habitat types (a riffle classified as 33 percent sand, 33 percent deciduous, and 33 percent herbaceous) and only 1 out of 18 total riparian features was classified with any aquatic habitat types (a sand bar classified as 70 percent sand, 10 percent cobble, 10 percent boulder, 5 percent riffle, 5 percent run). When aquatic and riparian habitats were classified into more specific habitat types (e.g., riffle, sand, herbaceous vegetation), image accuracy classification decreased. Accuracy of the specific habitat feature classification was evaluated based on the modal habitat type (i.e., habitat type represented by the greatest number of pixels in a feature) and the fraction of pixels in a feature with the same habitat type assigned to the feature in the field survey. The modal habitat type for 5 of 13 aquatic habitat features was the same as the habitat type assigned in the field survey. The modal habitat type for 11 of 14 exposed sediment features was the same as the habitat type assigned to those features in the field survey. The modal habitat type for each of the four vegetated surfaces was the same as the habitat type assigned in the field survey.

Supervised classification of specific habitat types also was evaluated based on the fraction of pixels in a habitat feature with the same classification as assigned in the field survey. These results indicated the same basic accuracy pattern. Classification was most accurate for vegetated surfaces: the median fraction of pixels in a vegetated feature with the same classification assigned in the field was 95 percent. Classification was least accurate for aquatic features: the median fraction of pixels in an aquatic feature with the same classification assigned in the field survey was 20 percent.

Multispectral images were particularly useful for distinguishing between rough and smooth water surfaces, which were associated with faster and slower currents, respectively. For example, slow, shallow-water habitat is evident along the river margins and at an eddy on the downstream side of a point bar (fig. 1).

Exposed sediments were well classified into three groups (silt, sand, and cobble), though 2 cobble features were classified as sand (22 percent error of omission) and 3 features classified as sand were other habitat types (43 percent error of commission). Two types of vegetated surfaces (herbaceous and deciduous shrubs and trees) were well resolved in the images without error.

Automatic classification of LWD from multispectral images was not successful because no distinct spectral signature could be developed. Most LWD was gray due to weathering and a coating of fine sediment. Image resolution also may be a factor limiting the identification of individual logs, though larger LWD jams were identified in the field that were 10s of meters long and wide. Edge detection identified LWD in some cases, but it also identified many non-log edges that obscured the results.


Eddy with lower velocity flow

a. Visible image

b. Habitat types

Figure 1. A segment of Puyallup River near Orting, Washington, shown as visible image and habitat types classified from multispectral image

Effects of the setback levee on the area and distribution of aquatic and riparian habitats are evident along the floodplain corridor of the Puyallup River upper reach. The upper reach is largely (66 percent of the total corridor area) covered by vegetation with an intermediate proportion of exposed sediments (22 percent) and a low proportion of aquatic habitat (12 percent) (Table 1). The lower reach of the Puyallup River and the Carbon River, both with traditional levees, have higher proportions of exposed sediments (35 percent and 48 percent, respectively). The lower reach of the Puyallup River, which is constrained by levees to a narrow corridor, had the largest proportion of aquatic habitat (24 percent) under summer baseflow. Nonetheless, this reach provided less aquatic habitat per unit length of reach than either the Carbon River or upper reach of the Puyallup River (Table 2).

The comparative effects of levees and setback levees were also evident in differences in hydraulic conditions during the January 2005 flood event for the upper a and lower reaches of the Puyallup River. Mean velocity in the two reaches was similar, but velocity distributions across the channel were distinctly different: 73 meters (41 percent) of the cross section in the upper reach had velocities less than 1.0 m/s, while only 3 meters (4 percent) of the cross section in the lower reach had velocities less than 1.0 m/s.

The stability of gravel bars also varied between the reaches based on an evaluation of the peak dimensionless shear stress (τ^*) during the flood. In the upper reach, the value of $\tau^* = 0.036$ indicated limited bar material entrainment, except for sand lying over large gravel and cobble. In contrast, bar material entrainment likely was extensive, approaching one-half of the bar surface, in the lower reach given the value of $\tau^* = 0.060$, despite a somewhat coarser bed (D_{50} = 69 mm) than the upper reach (D_{50} = 59 mm).

Table 1. Area of aquatic and riparian habitats determined from classified images for the Puyallup and Carbon Rivers near Orting, Washington. [m^2, square meter]

Habitat Feature	Puyallup River						Carbon River	
	Upper reach		Middle reach		Lower reach			
	(m^2)	(percent)	(m^2)	(percent)	(m^2)	(percent)	(m^2)	(percent)
Run	23,995	35.6[1]	24,490	42.5[1]	14,995	36.5[1]	29,651	38.6[1]
Riffle	43,127	64.0[1]	33,105	57.4[1]	26,109	63.5[1]	17,587	22.9[1]
Pool	294	0.4[1]	44	0.1[1]	3	0.0[1]	29,593	38.5[1]
Aquatic habitats total	**67,416**	**12.0**[2]	**57,639**	**20.2**[2]	**41,107**	**23.7**	**76,831**	**7.4**[2]
Cobble	51,349	41.7[1]	42,480	50.6[1]	30,298	49.4[1]	376,929	74.9[1]
Sand	46,919	38.1[1]	27,521	32.8[1]	19,807	32.3[1]	1	0.0[1]
Silt	8,770	7.1[1]	4,946	5.9[1]	2,957	4.8[1]	NA	NA
Gravel	3,204	2.6[1]	2,044	2.4[1]	979	1.6[1]	126,060	25.1[1]
Boulder	12,949	10.5[1]	7,036	8.4[1]	7,303	11.9[1]	NA	NA
Exposed sediments total	**123,191**	**22.0**[2]	**84,027**	**29.5**[2]	**61,344**	**35.3**	**502,990**	**48.2**[2]
Deciduous	303,189	82.0[1]	104,231	72.9[1]	57,977	81.6[1]	365,180	100.0[1]
Herbaceous	66,640	18.0[1]	38,738	27.1[1]	13,102	18.4[1]	--	--
Vegetated surfaces total	**369,829**	**66.0**[2]	**142,969**	**50.2**[2]	**71,079**	**40.9**	**365,180**	**35.0**[2]
No data	**197**	**0.04**	**13**	**0.005**	**88**	**0.05**	**98,262**	**9.4**
Total aquatic and riparian features	**560,633**	**100**	**284,648**	**100**	**173,618**	**100**	**1,043,263**	**100**

[1] Percentage of each habitat (aquatic, exposed sediment, vegetated surface) represented by habitat type.

[2] Percentage of total area represented by aquatic habitat, exposed sediment, or vegetated surfaces.

Differences in velocity distribution and bed stability between upper and lower reaches of the Puyallup River are a direct result of differences in how water-surface gradients and mean water depths change with streamflow in the reaches. In the upper reach, the water surface gradient was about 0.010 during low flows on 10 March 2005, which was lower than the gradient of 0.008 during high flows on 18 January 2005. The lower gradient dampens the shear stress applied to the riverbed at higher streamflows in the upper reach with the setback levee. In contrast, the gradient of the lower reach was about the same (0.008) for the high flow event in January and low-flow conditions in March. Likewise, the difference in mean depth between high flow in

January and low flow in March was 0.3 m in the upper reach where flows spread out over the floodplain, but was 1.4 m in the lower reach where flows are confined by levees. As a result, velocities in the lower reach are much faster and can move larger sediment particles during high flow conditions.

Table 2. Area of aquatic and riparian habitats per reach length classified in multispectral images, Puyallup and Carbon Rivers near Orting, Washington. Puyallup River upper reach is 1,950-m long, middle reach is 1,830 m, lower reach is 2,020 m, and Carbon River reach is 3,360 m [m^2/m, square meters per meter.]

Feature	Puyallup River			Carbon River
	Upper reach [m^2/m]	Middle reach [m^2/m]	Lower reach [m^2/m]	[m^2/m]
Run	12	13	7	9
Riffle	22	18	13	5
Pool	0	0	0	9
Total aquatic habitat area	**35**	**31**	**20**	**23**
Cobble	26	23	15	112
Sand	24	15	10	0
Silt	4	3	1	NA
Gravel	2	1	0	38
Bolder	7	4	4	NA
Total exposed sediment	**63**	**46**	**30**	**150**
Deciduous	155	57	29	109
Herbaceous	34	21	6	NA
Total vegetated surfaces	**190**	**78**	**35**	**109**
No data	**0**	**0**	**0**	**29**
Total aquatic and riparian habitats	**288**	**156**	**86**	**310**

Differences between sums of feature areas, subtotals, and totals are due to rounding.

The accuracy of the supervised classification for riparian and aquatic habitat types likely could have been improved by identifying additional habitat features in the field surveys. Spectral signatures of a given habitat type varied from image to image in the mosaic that covered the study area with the desired resolution (~ 0.5 m for the visible bands). Having representatives of each feature class in each image would have better defined the variation in spectral signatures across the images. Differences in the spectral signatures of different habitat types among the images used to cover the study area indicates that it may be difficult to define spectral signatures of habitat types independent of specific time and place of imaging. If incoming radiation is measured on the day of the flight and images are calibrated based on surface reflectance values, then some portability of the spectral signature set to other locations, as well as to imagery acquired at a different time of day, might have been possible.

We attribute the relatively poor performance of the specific classification of aquatic features to suspended sediment in the water column and the general lack of large contiguous regions of slow water habitat (e.g., pools) in the study reaches. The water column of the Puyallup River is characteristically opaque even in quiescent flow areas because of a high silt and clay sediment load from its glacial headwaters. During the field survey in July 2004, suspended-sediment concentrations were high enough to obscure the riverbed at depths greater than about 0.2 m. Sediment suspended in the water column reduces the spectral distinction between aquatic habitat and exposed sediments, particularly wet sand or silt, and between rough and smooth water surfaces in the visible wavelength bands.

High suspended-sediment concentrations are especially problematic for refined aquatic habitat classification: rough and smooth water surfaces had similar spectral properties than if the water were clear, in which case smooth regions would absorb more light than rough regions. Although the lack of large well-developed pools in either the Puyallup or Carbon River limits a detailed evaluation of the spectral properties of pools in the multispectral images, we anticipate that large, quiescent pools in sediment-laden rivers would have a less distinct spectral signature than in rivers with lower suspended-sediment concentrations.

The morphology of these rivers, braided with only weakly developed pools and riffles, challenges the conceptual basis of aquatic habitat as a mosaic of meso-scale “units” associated with channel forms that can be feasibly delineated by field surveys. The reaches are relatively steep (0.8 percent) with swift currents and few bends, debris jams, or other constrictions sufficiently large to create extensive backwater regions. Only three pools were identified in the field survey, two of which were used to develop a spectral signature for slow-water habitats and one to verify the accuracy of the classification. Nonetheless, the classification identified small regions of slow-water habitat that are not feasible to survey comprehensively in the field. In this case, multispectral imaging provides the spatial resolution and comprehensive coverage needed for a quantitative assessment of habitat conditions.

Final Observations

Data analysis is continuing with the incorporation of the thermal infrared imagery and the variability of the water surface temperature according to vegetation cover and in-stream hydraulic features. Future studies of this type should be included additional ground truth information in order to better characterize the errors in the classification methodology vis-à-vis the different habitat types.

References

Cai B, Neale CMU. 1999. A Method for Constructing 3-Dimensional Models from Airborne Imagery, *in* Color Photography and Videography for Resource Assessment Proceedings of the 17th Biennial Workshop. *American Society for Photogrammetry and Remote Sensing*: Bethesda, Maryland

ERDAS, 2003. ERDAS Imagine v. 8.7, Leica Geosystems

Konrad, CP, Booth, DB, Burges, SJ, Montgomery, DR. 2002. Partial entrainment of gravel bars during floods. *Water Resources Research* **38**, 10.1029/2001WR000828.

Lillesand TM, Kiefer RW, Chipman JW. 2004. *Remote sensing and image interpretation*. John Wiley & Sons: New York

Neale CMU, Crowther BG. 1994. An airborne multispectral video/radiometer remote sensing system: development and calibration. *Remote Sensing of Environment* **48**: 1-25.

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 05-06. 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 Engineer's 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 internationally. 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:

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.

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

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. 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.

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

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

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

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

Design, Inspection, and Maintenance of Conventional Systems. Utah On-Site Wastewater Treatment Training Program, Logan, Utah, May 26-27, 2005. Judith L. Sims and Brian Cowan.

Design, Inspection, and Maintenance of Alternative Systems. Utah On-Site Wastewater Treatment Training Program, Logan, Utah, April 14, 2005. Judith L. Sims, Peg Cashell, and Brian Cowan.

Development and Analysis of Piping Systems. ASHRAE, January 2006, William J. Rahmeyer.

Integrated Approach to Well Development and Associated Environmental and Public Health Protection (for Armenian Water Professionals). US. Department of Agriculture, August, 2005. Darwin L. Sorensen.

Introduction to Dam Safety Risk Assessment. Invited presentation at the National Dam Safety Program Technical Seminar # 12 Potential Failure Mode Analysis and Monitoring, Emmitsburg, Maryland, February 2005. D.S. Bowles.

Linking Dam Safety and Security at a Corporate Level. Invited presentation at FERC Workshop on Responding to Natural Hazards and Human Threats at Dams: Unifying Dam Safety and Security, Forth Worth, Texas, February 2005. D.S. Bowles.

Physical Habitat Simulation and Habitat Time Series Short Course. Utah State University, Logan, Utah, May 9-13, 2005. Thomas B. Hardy.

Risk Analysis Applied to Dam Safety. Two-day invited course as part of the Doctoral course, Dam and Reservoir Safety Evaluation funded by a Quality Award from the Spanish Ministry of Education, Universidad Politécnica de Valencia, Valencia, Spain, March 2005. D.S. Bowles.

Risk Analysis Applied to Dam Safety in Spain. Universidad Politécnica de Valencia, Valencia, Spain. March 2005. D.S. Bowles.

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

Soil Evaluation and Percolation Testing. Utah On-Site Wastewater Treatment Training Program, Logan, Utah, May 24-25, 2005. Judith L. Sims and Brian Cowan.

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/.

Additional technical publications in FY 05-06 that were partially supported by the cooperative program described in this 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.

Asefa, T., M. Kemblowski, M. McKee, and A. Khalil. 2005. Multi-time scale stream flow prediction: The support vector machines approach. *J. Hydrology.*

Gill, M., M. Kemblowski, and M. McKee. 2006. Soil Moisture Data Assimilation using Support Vector Machines and Ensemble Kalman Filter. *Water Resources Research* (in press).

Kaheil, Y., M. Gill, M. McKee, and L. Bastidas. 2006. A New Bayesian Recursive Technique for Parameter Estimation. *Water Resources Research (in press).*

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.

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.

Khalil A. and M. McKee, 2004. An adaptive model paradigm for water resources management. In: *AWRA Annual Conference*, Orlando, Florida. November, 2004.

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.*

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

McKee, M. 2005. Real-time Management of Irrigation Facilities in the Sevier River Basin. Presented at the *Utah Water Users Workshop,* St. George, Utah, March, 2005.

Oman, Lizzette. 2006. *Use of Bayesian Belief Network to Quantify the Uncertainty in Estimates of Salt Loading from an Irrigated Watershed.* Unpublished MS Thesis, Department of Civil and Environmental Engineering, Utah State University, Logan, Utah.

Pande, S., L. Bastidas, E. Rosero, M. McKee, W. Shuttleworth, H. da Rocha, and S. Miller. 2005. Effects of Data Uncertainty on Parameter Uncertainty within a Multi-Objective Parameter Estimation Framework. Presented at the *Annual Meeting of the American Geophysical Union,* San Francisco, December, 2005.

Alternative Decentralized Wastewater Treatment Systems for Utah Conditions

Basic Information

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Principal Investigators:	Judith L. Sims

Publication

1. Hurst, Jenny. 2006. *The use and management of alternative systems in Utah.* M.S. Thesis, Department of Civil and Environmental Engineering, Utah State University, Logan, Utah.

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 surveyed, reviewed, and evaluated 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 developed 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 surveyed, reviewed and evaluated 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 developed guidance materials for state and local decision-makers on decentralized treatment technologies and appropriate management strategies.

Specific tasks included:

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
    - 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

Principal Findings

The alternative treatment systems that were selected for investigation as being promising for use in Utah included intermittent sand filters, peat filters, recirculating sand filters, textile filters, constructed wetlands, and aerobic treatment units. Drip irrigation was investigated as an alternative disposal technology.

Summaries of information on the technologies are presented in Tables 1 - 7. Additional information on these technologies and references for the information presented in the tables can be found on the project web site: [http://www.engineering.usu.edu/uwrl/training/onsitesystems/].

Table 1. Intermittent sand filters

	Intermittent Sand Filter
Residence time	Need finer media than in recirculating sand filters for longer residence time and greater contact with surfaces (USEPA, 2002)
Loading rates	The higher the loading rate, the more quickly the bed will clog (Venhuizen, 1998). 40.7 L/m2/d (Sievers, 1998) 0.8-5 gpd/ft^2 depending on if you want a high or a low rate (Gustafson et al., 2002d; Loudon et al., 2005; USEPA, 2002; Washington, 2000) 1.2 gpd/ft2 is in the rule, but it has been found to be too high for long term service (Washington, 2000). 0.05-0.1 gal/orifice (Loudon et al., 2005)
Organic loading rates	5 lb BOD$_5$/1000 ft^2-d (USEPA, 2002)
Dose Frequency	On-demand dosing or time dosed (which is more common) (USEPA, 2002) 4-24 doses/day (Ball, 1998; Hoover and Hampton, 1997; Loudon et al., 2005; USEPA, 2002; Washington, 2000).
Biomat effects	Effluent water quality improves as the biological maturity is increased with age (Vanlandigham and Gross, 1998)
Soil Characteristics	Can be built where the following are prevalent: Shallow soils, Very loose or very tight soils, and Fractured soils (Weaver et al., 1998)
Climate	High-rate sand filters are more common in warmer climates because they can be left open or one can easily remove the lid (Gustafson et al., 2002d) Cold weather not a problem. Cold weather design includes insulated tank lids and piping systems that drain between cycles (Norlin, 2005)

Table 1. (continued)

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	
Dependence of technology on mechanical treatment	Gravity fed system: Free access (Flows by gravity over the surface until it infiltrates, Pumps large quantity doses,Often produces odors, Biomat must be broken up periodically) Buried Gravity flow (Gravity flow from septic tank, Not dosed, Rests only between water use episodes, Lacks control and uniformity,More prone to clog up than pressure dosed systems) Pressure Dosed: Pressure distribution system (Uniform application, Longer time before clogging, Orifice spacing can help optimized the uniformity, Covered with pea stone or coarse stone layer instead of sod (for improved aeration), Pumps are not operated at times when there is no flow) (Loudon et al., 2005; Norlin, 2005)
Treatment efficiency expected through time	
Reliability of technology	
On-going monitoring, maintenance, and management requirements	Filters with high loading rates need regular cleaning (2-3 months) (Gustafson et al., 2002d) Inspect all components and effluent, clean, and repair when needed (Gustafson et al., 2002d) Lab analysis of the effluent may be necessary (Gustafson et al., 2002d)Flow meters and timers can be installed to be able to ensure the correct amount of the effluent is being pumped (Gustafson et al., 2002d)Monitoring ports can be installed to easily check for ponding (Washington, 2000) Maintenance visit per year (Loomis et al., 2004) Annual flushing, pump screen cleaning, and monitoring scum and sludge to optimize the pumping intervals (Norlin, 2005)
Projected life spans and failure rates of technolgy	Need to replace the sand in high-rate systems every 2-5 years (Gustafson et al., 2002d) Lower rate systems will operate longer than high-rate systems (Gustafson et al., 2002d) No operational complications reported in 4 years of operation (Loomis et al., 2004) 30 years or more when properly designed, operated, and constructed (Norlin, 2005)

Table 1. (continued)

Removal of pathogens and nutrients	Containment or removal of pathogens (disease-causing microorganisms) (Unsaturated flow enhances the inactivation of viruses (Vanlandigham and Gross, 1998) Virus Removal efficiencies 88.953% to 99.956% (Vanlandigham and Gross, 1998) 4 log reduction (Converse and Converse, 1998; Sievers, 1998) 3-4 log removal of Cryptosporidium oocysts (Logan et al., 2001) Better removal of fecal coliforms than recirculating filters due to finer media and lower hydraulic loading (USEPA, 2002)) Removal of nitrogen:TKN - 99.4% (Weaver et al., 1998), 34% (Converse and Converse, 1998), 15% (Loomis et al., 2004) NH3-N - 99.1% (Weaver et al., 1998), 98.7% (Sievers, 1998) Removal of Phosphorus: 40% (Loomis et al., 2004) Removal of BOD: 98.4% (Weaver et al., 1998), 98% (Converse and Converse, 1998), 99% (Sievers, 1998; Loomis et al., 2004)
Life cycle costs	Installation and construction:\$11,000-\$14,000 (which includes design, permitting, construction of ISF and drain field)\$6,000-\$8,000 (for just the materials)(Norlin, 2005); Operation, monitoring and maintenance: \$150-\$200/year, includes electricity and management visits (USEPA, 2002), \$200-\$500/ year, includes cleaning tanks, repairs, maintenance, and electricity (Gustafson et al., 2002d); \$200/year for Inspection and Maintenance,\$1.50/month for power (Norlin, 2005).
Beneficial reuse and groundwater recharge potential	

Table 2. Recirculating sand filters

	Recirculating Sand Filter
Residence time	
Loading rates	2-5 gpd/ft2 (USEPA, 2002), 3-5 gpd/ft2 (Loudon et al., 2005; USEPA, 2002), 1-20 gpd/ft2 (most widely used 4-5 gpd/ft2) (Christopherson et al., 2002)
Organic loading rates	≤ 5 lb BOD5/1000 ft2-d (USEPA, 2002)
Dose Frequency	2-3 times per hour (USEPA, 2002), 48-96 doses/day (Loudon et al., 2005), 24-48 doses/day (Hoover and Hampton, 1997), 48 times/day or more (USEPA, 2002)

Table 2. (continued)

Dose Volume	Dose volume = Design flow (gpd) x (Recirculation Ratio +1)/ Number of Doses per day (USEPA, 2002), 0.1-0.5 gal/orifice (Loudon et al., 2005), 1-2 gal/orifice (USEPA, 2002)
Recirculation Rate	3:1 or 5:1 (USEPA, 2002), Ratio determined by dividing the recirculated flow by the influent flow (Loudon et al., 2005), 3:1 to 7:1 (Loudon et al., 2005), 3:1 to 5:1 – 4:1 most common (Ball and Denn, 1997), 2:1 to 10:1 – 4:1 min rate for acceptable treatment (Christopherson et al., 2002), 3:1 to 5:1 (Austin, 2001; Norlin, 2005), 2:1 to 5:1 acceptable (Hoover and Hampton, 1997; Loudon et al., 2004)
Biomat effects	
Soil Characteristics	
Climate	High level of nitrogen removal was maintained during the colder months (Jan-April) in Wisconsin. (Venhuizen et al., 1998), Used a modified at-grade, low-pressure-dosed trench for the drain field to accommodate for the the cold weather in Wisconsin (Venhuizen et al., 1998), Coarser media causes less heat loss (Roy and Dube, 1994), Extreme cold temperature caused only minimal disruption to the treatment efficiencies. Only nitrification rates seemed to be affected. (Martinson et al., 2001), cold weather not a problem, cold weather design includes insulated tank lids and piping systems that drain between cycles (Norlin, 2005)
Credit	
Dependence of technology on soil treatment	No dependence on soil for treatment (Christopherson et al., 2002)
Dependence of technology on mechanical treatment	Pressure Distribution to provide uniformity (Loudon et al., 2005), Pumps are run continuously regardless of inflow, odor problems occur when the pump is not continuously running (Norlin, 2005)
Treatment efficiency expected through time	
Reliability of technology	

Table 2. (continued)

On-going monitoring, maintenance, and management requirements	Inspect flow meters, pump, recirculation tank, recirculation pump, distribution systems, media and effluent quality(Christopherson et al., 2002), Clean and repair when needed (Christopherson et al., 2002), Lab analysis may be necessary (Christopherson et al., 2002), Periodically rake and/or remove and replace the top few inches of sand (Austin, 2001), Annual flushing, pump screen cleaning, and monitoring scum and sludge to optimize the pumping intervals (Norlin, 2005), Screen cleaning will be needed more often than an ISF due to recirculation (Norlin, 2005)
Projected life spans and failure rates of technolgy	
Removal of pathogens and nutrients	Containment or removal of pathogens (disease-causing microorganisms): Fecal Coliform Removal - 90% (Christopherson et al., 2001), less than in an intermittent sand filter because the coarser media is not as effective at removing the pathogens (Christopherson et al., 2002), 2-3 log reduction (Austin, 2001), more than 99% (Venhuizen et al., 1998) Nitrogen: Total Nitrogen - 40% (Christopherson et al., 2001), 70-80% - if an anoxic reactor is used ahead of the recirculation tank (USEPA, 2002), 30-70% (Christopherson et al., 2002), 30-80% (Austin, 2001), 60-90% (Venhuizen et al., 1998), 20% when the influent total nitrogen concentrations are high such as at schools and restaurants (Richardson et al., 2004), 25-84% (residential, club/casino, and commercial) (Loudon et al., 2004). NH_3-N - 70-90% (Nitrification) (Austin, 2001) Phosphorus: 25% (Christopherson et al., 2001), 10-30% (Christopherson et al., 2002) BOD – Effluent concentration: < 10 mg/L (Richardson et al., 2004)
Life cycle costs	Installation and construction: \$6,000-\$10,000 (Christopherson et al., 2001), \$8,000-\$11,000 (USEPA, 2002), \$7,000 (Austin, 2001), \$6,000-\$8,000 (for just the materials) (Norlin, 2005) Operation, monitoring and maintenance:\$200-\$500 per year (Christopherson et al., 2001; Christopherson et al., 2002) Power for pumping - \$90-\$120 per year (USEPA, 2002),\$5-\$10/month (Norlin, 2005). Management - \$150-\$200 per year (USEPA, 2002), \$20/month Repair and replacement:\$5/month (Austin, 2001), 20-year NPW - \$10,502.22 (Austin, 2001)
Beneficial reuse and groundwater recharge potential	Lower effluent nitrate concentrations allow the water, after disinfection, to be land applied, used in drip irrigation or directly to a surface water body (Louden et al., 2004)

Table 3. 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., 2002b); 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., 2002b); 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., 2002b); Pressurized distributions system (Patterson, 2004): applied evenly over the peat surface (Gustafson et al., 2002b)
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)

Table 3. (continued)

Reliability of technology	
On-going monitoring, maintenance, and management requirements	Add lime yearly to maintain P-sorption (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., 2002b), 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 technology	10 year life span (saturates with phosphorus in about 7 years) (Patterson, 2004); 10-15 years (Gustafson et al., 2002b; 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., 2002b), 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, 2004a), Total over life of system \$24,412 (USEPA, 2004a), Monthly averaged over the life of the system \$150 (USEPA, 2004a); 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)

Table 3. (continued)

Beneficial reuse and groundwater recharge potential	

Table 4. Textile filters

	Textile Filter
Residence time	
Loading rates	15-30 gpd/ft2 (Bounds, 2002), single pass = 10 gpd/ft2 (design), 30 gpd/ft2 (peak) (Crites et al., 1998), recirclating = 30 gpd/ft2 (design), 45 gpd/ft2 (peak) (Crites et al., 1998)
Organic loading rates	
Dose Frequency	
Dose Volume	
Recirculation Rate	(Leverenz et al., 2004), can be single-pass application (Bounds, 2002)
Biomat effects	
Soil Characteristics	
Climate	
Footprint	20-40 square feet (OWDP, 2005)
Credit	
Dependence of technology on soil treatment	
Dependence of technology on mechanical treatment	Utilizes mechanical filtration to physically remove matter (Bounds, 2002)
Treatment efficiency expected through time	
Reliability of technology	Variations in performance of different textile filter units (Wren et al., 2004), Only filtrate is discharged, no matter if there are problems earlier in the treatment process. Therefore only high quality effluent will be discharged (Bounds, 2002)

Table 4. (continued)

On-going monitoring, maintenance, and management requirements	2 scheduled maintenance visits per year (Loomis et al, 2004), Easy access makes means cleaning and servicing can be done in less than an hour (Bounds, 2002), Low maintenance – Annual maintenance visit: Inspect - effluent clarity (turbidity, grease and oil films, foam, color, etc.), odor; Clean - pump filters, distribution piping (Bounds, 2002)
Projected life spans and failure rates of technolgy	No operational complications in four years (Loomis et al, 2004), Indefinite life (durable and biodegradation resistant polymers (Orenco, 2003)
Removal of pathogens and nutrients	Containment or removal of pathogens (disease-causing microorganisms): 3.1-3.4 log removal of fecal coliform (Loomis et al, 2004) Nitrogen: 44-47% (Loomis et al, 2004) Phosphorus: 0-2% (Loomis et al, 2004) BOD: 99% (Loomis et al, 2004), 80% (cBOD) within the first day of operation (Bounds, 2002), Treats to secondary standards (Orenco, 2004) TSS: 95-98% (Loomis et al, 2004), Treats to secondary standards (Orenco, 2004)
Life cycle costs	Installation and construction: Lightweight medium and smaller filter size reduce the cost to install (Bounds, 2002; OWDP, 2005), $4,500 (AX20 with telemetry, but without tank, installation and drainfield) (Orenco, 2004) Operation, monitoring and maintenance: Annual operating cost - $40/year (Loomis et al, 2004), Annual inspection and maintenance costs - $250/year (Loomis et al, 2004), Low energy consumption - 32-96 cents/month for energy (Bounds, 2002), $1-2/month (Orenco, 2004)
Beneficial reuse and groundwater recharge potential	Effluent quality is superior and may be ideal for water-reuse applications (Bounds, 2002), Effluent can be used for irrigation (Orenco, 2004)

Table 5. Constructed wetlands

	Constructed Wetlands
Residence time	2-3 days (Lenning et al., 2005; Lesikar, 2005), 10-13 days (Gustafson et al., 2002c), >2 days (White and Shirk, 1998)
Loading rates	
Organic loading rates	BOD: 1.6 g/m2-d (for 20 mg/L effluent) – 6 g/m2-d (for 30 mg/L effluent) (USEPA, 2006a), TSS: 20 g/m2-d (for 30 mg/L effluent)
Dose Frequency	
Dose Volume	
Recirculation Rate	
Biomat effects	
Soil Characteristics	Good for sites where soil conditions are limiting (White and Shirk, 1998)
Climate	In colder climates: liquid depth may be lowered (Lenning et al., 2005) (Lesikar, 2005), vegetation may appear to be dead in the winter (Lenning et al., 2005), can insulate with mulch, but may reduce oxygen transfer (Gustafson et al., 2002c), snow cover positive factor in avoiding freezing the system (Henneck et al., 2001), reed-sedge peat can be used as insulation (Henneck et al., 2001)
Footprint	
Credit	
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	Passive O&M (Lenning et al., 2005), Manage as a rock garden (Lenning et al., 2005) (Lesikar, 2005), May need to remove and/or replant vegetation (Lenning et al., 2005) (Gustafson et al., 2002c), Must keep pores open (Lenning et al., 2005), 3-4 times a year to inspect the systems and make any adjustments (USEPA, 2006a), Control the water level so that it remains below the media surface (Lesikar, 2005), 1-4 times a year (Gustafson et al., 2002c)

Table 5. (continued)

Projected life spans and failure rates of technolgy	
Removal of pathogens and nutrients	Containment or removal of pathogens (disease-causing microorganisms): Fecal coliform - 99-99.9% reduction (Lenning et al., 2005), less than 10,000cfu/100 mL (Gustafson et al., 2002c) Nitrogen: Insignificant removal (Lenning et al., 2005), small percentage due to anaerobic conditions (USEPA, 2006a) Phosphorus: small percentage due to anaerobic conditions (USEPA, 2006a) BOD: <30 mg/L (Lenning et al., 2005) (Gustafson et al., 2002c), 20-30 mg/L depending on the organic loading rate (USEPA, 2006a) TSS: <30 mg/L (Lenning et al., 2005; USEPA, 2006a), <25 mg/L (Gustafson et al., 2002c)
Life cycle costs	Installation and construction: \$20/ft2 (USEPA, 2006a), \$6650/400ft2 (excluding final disposal) (Henneck et al., 2001), \$8325 (excluding labor and final disposal) (Henneck et al., 2001), For 53 m2 wetland: Materials = \$3200, Installation = \$2500 (White and Shirk, 1998) Operation, monitoring and maintenance: \$100/year (USEPA, 2006a), \$200-\$500/year (includes pumping, repairs, maintenance, and electricity) (Gustafson et al., 2002c)
Beneficial reuse and groundwater recharge potential	

Table 6. Aerobic treatment units

	Aerobic Treatment Units
Residence time	
Loading rates	Rate that will pass through the device (Seabloom and Buchanan, 2005), must provide sufficient retention time (Seabloom and Buchanan, 2005), washouts can occur on laundry day (Seabloom and Buchanan, 2005), 250 gal/day (McCarthy et al., 2001), Based on home square footage and/or number of bedrooms (Lesikar, 2005), Can treat 500 gal/day (Lesikar, 2005)
Organic loading rates	More bugs than food (Seabloom and Buchanan, 2005)
Dose Frequency	Intermittent flow (Seabloom and Buchanan, 2005)
Dose Volume	
Recirculation Rate	
Biomat effects	
Soil Characteristics	Have been approved in areas with low soil permeability and shallow seasonal soil saturation (Wallace and Louden,, 2004), Compacted, cut or filled soil (Gustafson et al., 2002a), Poor soil (PATH, 2005)
Climate	Works better the warmer the temperature (USEPA, 2000b; McCarthy et al., 2001)
Footprint	
Credit	Soil depth and sizing reductions are permitted depending on the quality of effluent (Lenning et al., 2005), May allow for a reduction in drainfield size (USEPA, 2000b) (PATH, 2005), May be allowed in environmentally sensitive areas such as near lakes, in shallow bedrock areas, aquifer recharge areas, and well head protection areas (Gustafson et al., 2002a) (PATH, 2005), May allow reduction in 3-foot separation between system and limiting soil layer (Gustafson et al., 2002), High groundwater/bedrock (PATH, 2005)
Dependence of technology on soil treatment	Works well in shallow soils that will not provide enough depth for sufficient treatment (Seabloom and Buchanan, 2005)
Dependence of technology on mechanical treatment	Mechanical aeration (Seabloom and Buchanan, 2005), Sensors and controls that can detect failure (Seabloom and Buchanan, 2005)
Treatment efficiency expected through time	

Table 6. (continued)

Reliability of technology	Need backup for power source (Seabloom and Buchanan, 2005)
On-going monitoring, maintenance, and management requirements	Easy access for easy maintenance (Seabloom and Buchanan, 2005), Sludge in the ATU must be removed every 6-9 months (Seabloom and Buchanan, 2005), Operators should inspect 2 times a year (Seabloom and Buchanan, 2005), Inspections every 2 months (USEPA, 2000b), 12-48 man-hours/year (USEPA, 2000b), Maintenance checklist: Inspect alarm system, Check effluent for odor and color, Inspect clarifier, Inspect test port cover, Check and clean aerator filters, Inspect water level in clarifier, Check disposal field area (Wallace and Louden, 2004)
Projected life spans and failure rates of technolgy	Should last longer than a conventional system because it produces cleaner wastewater (Gustafson et al., 2002a)
Removal of pathogens and nutrients	Containment or removal of pathogens (disease-causing microorganisms): Properly operating ATU – 10,000 cfu/mL fecal coliform (Gustafson et al., 2002a), <104/100 ml (Lenning et al., 2005) Nitrogen: Not good at nitrogen removal (Seabloom and Buchanan, 2005), Reduces ammonia discharged (USEPA, 2000b), May release more nitrates (USEPA, 2000b), ammonia removal 0-31 % (Christopherson et al., 2004), TKN removal 0-23 % (Christopherson et al., 2004), Better nitrification in the summer (McCarthy et al., 2001) Phosphorus: Not good at phosphorus removal (Seabloom and Buchanan, 2005), 1-53 % removal (Christopherson et al., 2004) BOD: Properly operating ATU – 30 mg/L (Gustafson et al., 2002a), Works well in wastewater with high BOD loads due to too much organic load and/or wastewater from bakeries or dairies(Seabloom and Buchanan, 2005), 5-60 mg/l (Lenning et al., 2005), 70-90% removal (USEPA, 2000b), 20 mg/L (USEPA, 2000b) 42-92% removal (Christopherson et al., 2004) TSS: Properly operating ATU – 25 mg/L (Gustafson et al., 2002a), 5-60 mg/l (Lenning et al., 2005), 20 mg/L (USEPA, 2000b), 41-62 % removal (Christopherson et al., 2004)

Table 6. (continued)

Life cycle costs	Installation and construction: Packaging easy for easy installation (Seabloom and Buchanan, 2005), \$2,500 - \$7,000 + for the unit (Lenning et al., 2005), \$2,500 - \$9,000 installed (USEPA, 2000b), \$5,700-\$14,000 (Christopherson et al., 2004), \$3,200-\$5,000 (PATH, 2005) Operation, monitoring and maintenance: Maintenance contract - \$350/year (USEPA, 2000b), \$200-\$500/year (Gustafson et al., 2002a), \$50-75/year (PATH, 2005); Electrical cost - \$4/month (PATH, 2005)
Beneficial reuse and groundwater recharge potential	Treat water well enough to be used with spray systems if it contains a disinfection component (Lesikar, 2005)

Table 7. 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	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)

Table 7. (continued)

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

Based on the information collected, evaluated, and assessed, during Year 2 of the project we prepared guidance materials that summarized the effectiveness and appropriateness of various decentralized technologies for use in Utah. By considering population growth, climate, and system monitoring issues specific for Utah, suggestions were made as to which alternative systems are suitable for Utah.

Utah is recognized nationally as a desirable place to live, which is resulting in rapid population growth. The population is expected to increase about fifty percent during the next two decades, going from 2.2 million people in 2002 to a projected 3.2 million by 2020 (Utah Governor's Office, 2000). Many places that could be built upon are limited by the lack of a central sewer system but may also not be suitable for conventional onsite systems due to slopes, high water table or inadequate separation from bedrock, and unsuitable soils, as well as housing density issues. Many alternative decentralized systems are not as dependent on soil for treatment as are conventional systems. This reduced dependence makes it possible to build in areas with high water tables or bedrock and in soils where the wastewater moves through either too slowly or too quickly.

Housing density is also an important issue with a growing population. To avoid contaminating groundwater, the density of decentralized on-site systems must be considered. Many alternative decentralized systems remove contaminants to a greater degree than conventional septic tank/drain field systems and their use may not have as great an impact on the groundwater as conventional systems.

The climate in Utah is overall dry and cold. Utah receives an average of 13 inches of precipitation per year, which is the second lowest annual precipitation in the US, behind Nevada (State of Utah Natural Resources, 2001). Although the precipitation has been above normal the last two years, the southeastern parts of Utah are still abnormally dry or have moderate drought conditions (Drought Monitor, 2006).

Arid conditions can actually be helpful with alternative decentralized systems that are open to the environment, such as intermittent and recirculating sand filters. As precipitation decreases, so does the volume of added rainwater that needs to be treated in the system. Also, disposal of final effluent from the alternative decentralized systems can result in groundwater recharge or provide for beneficial reuse as irrigation water due to the higher quality of effluent, especially taking into account nutrient and pathogen removal.

The coldest temperatures in Utah usually occur in the month of January. The average low temperatures in Logan, Salt Lake, and St. George are 10° F, 18° F, and 27° F, respectively. Many of the alternative systems investigated were found to function in Minnesota where the average low temperature in January is 5° F (Country Studies, 2003; University of Minnesota, 2005). At these colder temperatures, overall performance will decrease because the microorganisms that are an active part of the treatment do not thrive at lower temperatures as they do at more moderate temperatures. All the technologies may require insulation of components, especially if there is no or very little snow cover in the winter (USEPA, 2002). Drip irrigation and the two types of sand filters can have their pipes buried deeper and/or be designed to include insulation for cold weather so as to avoid freezing (Bohrer and Converse, 2001; Lesikar and Converse, 2005; Norlin, 2005; USEPA, 2002). However, it has been found that nitrogen removal in alternative systems is reduced in colder temperatures (Martinson et al., 2001; Venhuizen et al., 1998)

Alternative decentralized systems require more monitoring and maintenance than conventional systems, which in turn requires the use of a comprehensive management plan. A private sector business could act as a management entity providing required inspection and maintenance activities. A business built on entrepreneurship means creating a company of long-term value that has a durable cash flow (Timmons, 2001).

In this project we developed a business plan for a company targeting the management of on-site systems in Utah under current regulatory conditions. When starting a new business, writing a business plan can be an important part of starting the venture. A business plan is used to determine what topics need to be researched and how to organize ideas for starting a business. It is also commonly used to present to a potential investor to try to persuade him/her that this would be a profitable venture to contribute to. A business plan includes subjects such as a description of the industry, a market analysis, the economics of the business, a marketing plan, the design and development, an operations plan, possible risks, a financial plan, and a proposed offering (Timmons, 2001). The example business plan developed in the project can be found on the project web site: [http://www.engineering.usu.edu/uwrl/training/onsitesystems/]

Based on the results of the project, packed bed systems (intermittent and recirculating sand filters, peath and textile filters) appear to be the most desirable options for Utah. They can be used in areas where the soils or slope are restrictive for conventional systems. These systems would continue to work well during Utah's cold winters, especially the recirculating sand filters. They do require monitoring and maintenance. Subsurface flow constructed wetlands would also be a viable option for Utah. The design, including the vegetation, would have to be site specific and should take into account the cold weather during the winter months.

Drip irrigation has been found to be a useful way to distribute the treated wastewater for beneficial reuse. The quality of the water that will be distributed will need to be maintained at a higher level than for a conventional drain field so as to protect public health and the environment. Once again, the design would have to take into account cold weather. At this time, it appears that aerobic treatment units should not be considered an option for use in Utah due to their many mechanical parts that need to be managed and maintained at a more rigorous level than what the State of Utah is prepared to require at the present time.

Management entities need to include three main components in order to be successful. These components are to: (1) educate the public, (2) secure enforcement mechanisms, and (3) tailor the details of the entity to the specific needs of the community. When educating the public, it is important to stress the need to protect a resource of value, whether that is public health, the environment, or a rural way of life. Also, the public should be educated on how valuable it is in the long run to be part of a management program. Legal enforcement gives the program an option for those who choose not to comply. Although the enforcement action, whatever it may be, may only be used for a few people, it will send a message to the rest of the public that may not have been convinced by education. Lastly, the program needs to be structured so as to meet the needs of the community, taking into consideration public health, the environment, the onsite technologies used, and the people themselves. The U.S Environmental Protection Agency management models are helpful to use as a guide, but creativity and adjustments should be used as needed.

Population growth in Utah has resulted in increased development. This growth and development has been restricted in some locations by the lack of a centralized sewer system or the soil and landscape are restrictive for conventional onsite wastewater treatment systems. Alternative onsite technologies offer more options to develop in such areas. Management of these systems is an important tool to ensuring that the treatment is sufficient.

The information developed in this project will be used by state and local decision-makers as they develop programs to utilize alternative decentralized systems. Information from this project will also be used to develop a workshop on the use of packed bed filter technologies (sand, gravel, peat, and textile filters) and drip irrigation in Utah will be given in the fall of 2006 to local health department and Utah Department of Environmental Quality staff and to private service providers responsible for system operation and maintenance.

Works Cited

Bohrer, R.M. and J.C. Converse. 2001. Soil Treatment Performance and Cold Weather Operations of Drip Distribution Systems. *Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems.* Fort Worth, Texas. March 11-14, 2001.

Country Studies. 2003. US Weather. http://countrystudies.us/united-states/weather/. Accessed May 2006.

Drought Monitor. 2006. U.S. Drought Monitor. http://drought.unl.edu/dm/drmon.gif. Accessed May 2006.

Lesikar, B.J. and J.C. Converse. 2005. Subsurface Drip Dispersal Text. In*:* M.A. Gross and N.E. Deal, (Eds.). University Curriculum Development for Decentralized Wastewater Management. National Decentralized Water Resources Capacity Development Project. University of Arkansas, Fayetteville, AR.

Martinson, M.J., J.M. Anderson, and C.A. Snell. 2001. Cold Climate Recirculating Sand Filter Design and Experiences: Case Examples of Two Community Systems on Wisconsin Indian Reservations. In: *Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems.* American Society of Agricultural Engineers, St. Joseph, MI.

State of Utah Natural Resources Division of Water Resources. 2001. Utah's Water Resources: Planning for the Future. http://www.water.utah.gov/waterplan/. Accessed May 2006.

Timmons, J.A. 2001. NewVenture Creation Entrepreneurship for the 21st Century. 5th Edition. Irwin/McGraw-Hill.

University of Minnesota. 2005. Onsite Wastewater Treatment Program. http://www.extension.umn.edu/OnsiteSewage/. Accessed May 2006.

US Environmental Protection Agency (USEPA). 2002. Onsite Wastewater Treatment Systems Manual. EPA/625/R-00/008. Office of Water. Office of Research and Development.

Utah Department of Environmental Quality (UDEQ). 2006b. Administrative Rules for Onsite Wastewater Systems. R317-4, Utah Administrative Code. Effective date of last revision – May 19, 2006.

Utah Governor's Office of Planning and Budget. 2000. Strategy Analysis: QGET Quality Growth Efficiency Tools. Salt Lake City, UT.

Venhuizen, D. 1998. Sand Filter/Drip Irrigation Systems Solve Water Resources Problems. In: *Proceedings of the Eighth National Symposium on Individual and Small Community Sewage Systems.* American Society of Agricultural Engineers, St. Joseph, MI.

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	2	0	0	0	2
Ph.D.	4	0	1	0	5
Post-Doc.	0	0	0	0	0
Total	6	0	1	0	7

Notable Awards and Achievements

David S. Bowles has been elected to serve a second three-year term on the Board of Directors of the U.S. Society on Dams (USSD).

Thomas B. Hardy received formal recognition in 2005 from the U.S. Forest Service for over 10 years work to achieve the settlement agreement in the Snake River Adjudication.

Michael C. Johnson was nominated for Engineering Educator of the Year for the American Council of Engineering Companies Utah Chapter, Fall 2005.

Jagath J. Kaluarachchi became a Fellow in the American Society of Civil Engineers, December 2005.

Jagath J. Kaluarachchi received a citation in Whos Who in Science and Engineering, Marquis Whos Who, 8th Edition, 2005-2006.

Jagath J. Kaluarachchi received the Researcher of the Year Award for the Department of Civil and Environmental Engineering, Utah State University, 2006.

Mac McKee has been elected as a board member on the Universities Council on Water Resources (UCOWR).

Laurie McNeill received the Teacher of the Year Award for the Department of Civil and Environmental Engineering and the College of Engineering, Utah State University, 2006.

David G. Tarboton was elected Member of Consortium of Universities for Advancement of Hydrologic Science, Inc., Board of Directors, 2005-2007.

David G. Tarboton is a Member of the Steering Committee for the National Center for Airborne Laser Mapping, 2003-present.

Kori Moore, Undergraduate Student in Environmental Engineering, received 1st Place in the undergraduate category for his paper at the International Air and Waste Management Association meeting, 2005.

Vishal Doshi, MS Student in Environmental Engineering, received 2nd place in the MS category for his paper at the International Air and Waste Management Association meeting, 2005.

Bethany Neilson, Environmental Engineering graduate student and Christina Bandaragoda, Water Engineering graduate student, have been selected to receive an "Outstanding Student Paper Award" for their presentation at the 2005 Fall Meeting of the American Geophysical Union (AGU).

Publications from Prior Projects