Colorado Water Resources Research Institute
Annual Technical Report
FY 2006

Introduction

Water research is more pertinent than ever in Colorado. Whether the project explores the effects of decentralized wastewater treatment systems on water quality, optimal irrigation scheduling, household conservation patterns, the effects of wastewater reuse on turfgrass, the economics of water transfers, or historical and optimal streamflows, water is a critical issue. In a headwaters state where downstream states have a claim on every drop of water not consumed in the state, the quality and quantity of water becomes essential to every discussion of any human activity.

Our charges this year included requests from the legislature and state and federal agencies. Water allocations and agreements and the potential treatment and reuse of industrial water are two examples. Colorado State Legislature and Department of Natural Resources requested our assistance in engaging researchers and Cooperative Extension in the public discussions of water quantity issues around the state. A series of public meetings in designated water basins elicited input from stakeholders with the goal in mind of creating an interbasin water compact in the state.

The Bureau of Reclamation asked us to help stage a workshop on produced waters those waters resulting from the extraction of coal bed methane and other energy materials. A national workshop was held April 4-6, 2006 in Fort Collins.

The Colorado Water Resources Research Institute serves to connect the water expertise in Colorados institutions of higher education to the information needs of water managers and users by fostering water research, training students, publishing reports and newsletters and providing outreach to all water organizations and interested citizens in Colorado.

Research Program

Colorado Water Resources Research Institute funded ten research projects this fiscal year; two of these projects were designated to receive federal funding due to their relation to water supply issues. The Advisory Committee on Water Research Policy selected these projects based on the relevancy of their proposed research to current issues in Colorado.

CWRRI was fortunate to receive $500,000 in one time funds from the State of Colorado in FY07 to expand the research portfolio in FY07. Under Section 104(b) of the Water Resources Research Act, CWRRI is to plan, conduct, or otherwise arrange for competent research that fosters the entry of new scientists into water resources fields, the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and disseminates research results to water managers and the public. The research program is open to faculty in any institution of higher education in Colorado that has demonstrated capabilities for research, information dissemination, and graduate training to resolve State and regional water and related land problems. We received twenty proposals for consideration this year from four institutions of higher education in Colorado. The general criteria used for proposal evaluation included: (1) scientific merit; (2) responsiveness to RFP; (3) qualifications of investigators; (4) originality of approach; (5) budget; and (6) extent to which Colorado water managers and users are collaborating. A call for proposals went out last July and was responded to by over 20 high quality requests totaling over $1 million in requested support. A peer review process and ranking by the CWRRI Advisory Committee resulted in funding 10 projects for FY07. Project titles and investigators and listed below. For more information on any of these projects, contact the PI or Reagan Waskom at CWRRI. Special appreciation is extended to the many individuals who provided peer reviews of the project proposals.

- **Effects of Pine Beetle Infestations on Water Yield and Water Quality at the Watershed Scale in Northern Colorado.** John D. Stednick, Dept of Forest, Range and Watershed Stewardship, Colorado State University. $49,658 ($15,000 in federal funding)
- **Occurrence and Fate of Steroid Hormones in Sewage Treatment Plant Effluents, Animal Feedlot Wastewater, and the Cache la Poudre River of Colorado.** Thomas Borch, Dept. of Soil & Crop Sciences, Colorado State University. $49,944
- **Detecting Trends in Evapotranspiration in Colorado.** Nolan Doesken, Colorado Climate Center. $47,802
- **Evaluation of Engineered Treatment Units for the Removal of Endocrine Disrupting Compounds and Other Organic Wastewater Contaminants During Onsite Wastewater Treatment.** Robert L. Siegrist, Environmental Science and Engineering, Colorado School of Mines. $49,746
- **Direct Determination of Crop Evapotranspiration in the Arkansas Valley with a Weighing Lysimeter.** Abdel Berrada, Arkansas Valley Research Center, Colorado State University. $49,995
- **Refining Water Accounting Procedures Using the South Platte Mapping and Analysis Program.** Luis Garcia, Dept of Civil and Environmental Engineering, Colorado State University. $22,985
- **Development of Oilseed Crops for Biodiesel Production Under Colorado Limited Irrigation Conditions.** Jerry J. Johnson, Dept. of Soil & Crop Sciences, Colorado State University. $47,933
- **Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater Under Uncultivated Land in an Irrigated River Valley.** Jeffrey D. Niemann, Luis Garcia, Dept of Civil

and Environmental Engineering, Colorado State University. $49,942 ($15,000 in federal funding)

- **Predictability of the Upper Colorado River Streamflows.** Jose D. Salas, Colorado State University and Balaji Rajagopalan, University of Colorado. $44,859
- **Simultaneous Water Quality Monitoring and Fecal Pollution Source Tracking in the Big Thompson Watershed.** Lawrence Goodridge, Dept. of Animal Sciences, Colorado State University. $49,995

Federally Funded Projects

Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater Under Uncultivated Land in an Irrigated River Valley. Jeffrey D. Niemann, Dept. of Civil and Environmental Engineering, Colorado State University.

The Lower Arkansas River is an important water resource for Southeastern Colorado, supplying water to more than 100,000 ha (250,000 acres) of irrigated agriculture. Over the last century, intensive irrigation has produced shallow water tables with high concentrations of salt and other minerals in the river valley. These conditions have led to waterlogging and high soil salinity that have decreased crop productivity by 11-19% according to recent research, and they have caused large loading of salts and selenium to the river. These problems can be addressed by reducing excess recharge and lowering the elevation of the shallow water table, but any alteration to water management practices in the valley must also consider Colorado's legal obligation to maintain historical flows in the Arkansas River at the Kansas border. If the water table is reduced, crop productivity is expected to improve, which would increase the consumptive use of water from the irrigated lands, potentially reducing return flows to the river. However, the lower water table might also reduce the non-beneficial consumptive use of water from adjacent fallow fields and other uncultivated lands in the valley. The savings of water from these areas may be significant, more than offsetting the increase in consumptive use from cropped fields. Non-irrigated lands represent roughly 50% of the alluvial valley, and preliminary estimates suggest that the loss of water from these lands may currently amount to tens of thousands of acre-feet per year. Moreover, similar savings might be possible by lowering saline water tables in other intensively irrigated river valleys in Colorado and throughout the western United States. However, much more work needs to be done to understand how non-beneficial consumptive use depends on the water table depth and other factors such as the vegetation cover and soil salinity. The objective of this proposal is to observe and quantify the relationship between evapotranspiration (ET) losses water table depth for uncultivated areas in the Lower Arkansas River Valley. Two ~10 ha (25 acres) fieldsone fallow field and one naturally-vegetated fieldwill be monitored. ET will be estimated using remote sensing, and water table depth will be measured using ~20 new observation wells in each field. Other variables such as soil moisture, biomass, rooting depth, and soil salinity also will be measured. Together, these observations will allow us to directly identify the role that the water table plays in determining ET losses from uncultivated lands under known soil and vegetation conditions. Ultimately, this research is expected to improve our understanding of the water balance in the Lower Arkansas River Valley and to improve the numerical models that are being used to evaluate potential solutions to waterlogging and salinization problems.

Effects of pine beetle infestations on water yield and water quality at the watershed scale in Northern Colorado. John D. Stednick, Dept. of Forest, Rangeland, and Watershed Stewardship, Colorado State Univeristy.

A beetle epidemic in Colorado is killing trees in the subalpine and montane settings. The decrease in forest canopy due to defoliation will result in decreased precipitation interception and decreased summer evapotranspiration. Changes in these hydrologic process rates will result in increased soil moisture and increased annual water yield (streamflow). A series of watersheds that have been aerially mapped for beetle kill by the USDA Forest Service in Northern Colorado will be selected. A progression of watershed areas that have been beetle killed will be used to assess if water yield increases are measurable using nearby relatively undisturbed' watershed as a paired watershed study (control vs. treatment watershed comparisons using analysis of covariance). Streamflow records from gauging stations operated by the US Geological Survey will be used. Streamflow metrics including annual water yield, peak flows, and low flows will be investigated using analysis of covariance and flow duration curve analysis. The literature suggests that the disruption of nutrient cycles will result in increased nitrate nitrogen concentrations in surface waters. Water quality samples will be collected from the selected watersheds and analyzed. The progression of watershed areas affected by beetle kill should enable us to determine a threshold of response, both for water quantity and water quality. The ability to more accurately predict water yield from watersheds with beetle killed areas is significant for downstream users and water mangers.

CWRRI Fellows

Colorado Water Resources Research Institute completed three graduate Fellowships this fiscal year. The Advisory Committee on Water Research Policy previously awarded these fellowships based on the relevancy of their proposed graduate research to current issues in Colorado.

Kathleen Conn, CWRRI Fellow at Colorado School of Mines, works with Robert Siegrist. They are exploring the treatment options for onsite wastewater treatment systems in the management of organic wastewater contaminants (OWCs) which result from pharmaceuticals and personal care products. Conn's fellowship work augments an ongoing USGS project on this topic. The study encompasses a variety of sources such as single and multi-family residential systems, commercial systems for restaurants, convenience stores, and retail centers, and institutional systems such as veterinary hospitals, schools, and churches. Some of the management options explored include septic tank options, pre-treatment units such as filters and wetlands, and methods of mitigating percolation through the soil absorption field prior to groundwater discharge.

Julia Keedy, graduate student in Civil Engineering at Colorado State University received a graduate Fellowship to pursue research on the sensitivity of a model of the Colorado River system. Utilizing data from previous studies and naturalized data sets based on tree ring records, Keedys work is an effort to apply various analytical methods and determine critical reservoir levels, reservoir releases, and shortage and surplus occurrences for the length of the stream. This study is co-sponsored by the Colorado River Water Conservation District.

Jennifer Thorvaldson's graduate project is to analyze the economic impacts on various Colorado communities of a potential reduction in irrigated agriculture. With her advisor, James Pritchett, she will develop a model representing the economy and economic interactions within four water basins in Colorado: Arkansas, Republican, Rio Grande, and South Platte. Significant reductions in irrigated agriculture by 2030 are predicted by a variety of experts and state agencies. The model will attempt to quantify the impacts of reduced agricultural production across the entire community, including reduced sales of agriculture related products, retail sales to households, and reduced job opportunities. This project is co-sponsored by the Colorado Agricultural Experiment Station.

Colorado's Evolving Irrigated Agriculture: Economic Accounting Impact Analysis

Basic Information

Title:	Colorado's Evolving Irrigated Agriculture: Economic Accounting Impact Analysis
Project Number:	2005CO115B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	4th
Research Category:	Social Sciences
Focus Category:	Economics, Agriculture, None
Descriptors:	None
Principal Investigators:	Reagan M. Waskom

Publication

1. Thorvaldson, Jennifer and Pritchett, James, 2006, Economic Impact Analysis of Reduced Irrigated Acreage in Four River Basins in Colorado, Completion Report 207, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 48 pp.
2. Thorvaldson, Jennifer and Pritchett, James, 2006, Economic Impact Analysis of Reduced Irrigated Acreage in Four River Basins in Colorado, Colorado Water Newsletter of the Water Center of Colorado State University, April/May 2007, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 20-22 pp.

Economic Impacts of Reduced Irrigated Agriculture in Eastern Colorado: A Summary of Three Studies

by Jenny Thorvaldson, PhD Student
and James Pritchett, Assistant Professor, Department of Agricultural and Resource Economics

Irrigated agriculture is a primary water user in the West, but rapid population growth is driving a reallocation of water use. As Colorado's population grows, water will shift from agriculture to municipal and industrial (M&I) uses. Indeed, it is expected that 428,000 acres of irrigated farmland will dry up to meet future needs (Colorado Water Conservation Board, 2004), and these estimates may be quite conservative (Smith, 2005). In addition, evolving legal institutions and groundwater depletions have significantly decreased available irrigation water and have reduced irrigated cropland.

Initial Research: *Colorado's Evolving Irrigated Agriculture: Economic Accounting and Impact Analysis*

The primary goal of this research project was to estimate the short-term regional economic impacts associated with a reduction in irrigated agriculture as a result of increasing population and urbanization in Colorado. The study involved four river basins in eastern Colorado (the Arkansas, Republican, Rio Grande, and South Platte basins). Each basin was analyzed separately because of the unique economic base and idiosyncratic water demand/supply conditions in each basin. Specific outcomes included:

- Establishment of economic demographics for each basin, including a description of irrigated agriculture's contribution to the local economy.
- Development of an Input-Output (I-O) model for each basin, representing the financial interactions between all of the sectors in that basin's economy.
- "Shocking" each I-O model to approximate the short-term economic effects of a reduction in irrigated agriculture. Acreage reductions were based on projected population growth and were provided by the SWSI report publicly released in December 2004. All formerly-irrigated acres were assumed to be fallowed, with the original crop-mix being maintained (i.e., acres were assumed to be taken out of irrigation proportionately). A summary of the output impacts can be seen in Table 1.
- Multiple outreach presentations to stakeholders, a presentation in the CSU Department of Agricultural and Resource Economics seminar series, and a presentation to the annual Western Agricultural Economics Association meetings in Anchorage, Alaska.
- Four fact sheets published on the Colorado State University website and a Completion Report (# 207) published on the CWRRI website and in print.
- A Master's thesis.

Table 1: Output Impacts by Basin

Basin	Estimated Acres Lost	Total Economic Impact	Impact as % of Total Output	Impact as % of Agriculture	Impact as % of Irrigated Crop Sales	Economic Activity per Acre
East South Platte	159,500	-$110,065,962	1.02%	3.20%	13.87%	$428
East Arkansas	47,500	-$20,333,467	0.12%	5.64%	52.28%	$690
Republican	20,000	-$13,550,801	0.43%	0.82%	2.08%	$678
Rio Grande	80,000	-$98,783,450	3.95%	8.16%	8.72%	$1,235

Current Research: *Some Economic Effects of Changing Augmentation Rules in Colorado's Lower South Platte Basin: Producer Survey and Regional Economic Impact Analysis*

The previous research project focused on building the capacity to examine the economic contribution of irrigated agriculture, and then quantifying the economic impacts of reduced irrigated acres due to the growth and urbanization of Colorado's population, based on the forecasts from SWSI. It focused on four basins in eastern Colorado, where the majority of the state's agricultural production takes place and where the majority of water transfers are expected to originate. Economic demographics have been established in each basin for building the appropriate model, resulting in a baseline value for the impacts in each basin.

The current project focuses on agricultural producers in the Lower South Platte (LSP) basin[1] that had GASP wells. To fine-tune the model and estimates from the initial study, the current project began by administering a survey of these producers to better gauge producers' responses to the increasingly limited water supply in Colorado. Thus, rather than assuming that all formerly-irrigated land is fallowed and that cropping patterns remain unchanged, the survey provides more-precise estimates of changing acreages and cropping patterns. As irrigated acres are reduced, different cropping patterns may result, suggesting alternative impacts to the regional economy. For instance, the impact will likely be greater if the lost irrigated acres are all converted to grassland (i.e., taken out of production) than if they are converted to dryland crops (those reliant on rainfall). Furthermore, if the acres are all converted to dryland crops, the magnitude of the impact will depend on which dryland crops are chosen (e.g., winter wheat vs. sunflowers), as each of these crops will bring in varying amounts of revenue and will require different inputs from local agribusiness. Specific objectives include:

- Development of an Input-Output (I-O) model for the LSP basin, representing the financial interactions between all of the sectors in the regional economy.
- "Shocking" the I-O model to approximate the regional economic effects of changes in irrigated agriculture based on two scenarios:
    1. The high-end scenario assumes acreages change exactly as estimated by the survey.

[1] For the purposes of this study, the Lower South Platte Basin is defined as Logan, Morgan, and Sedgwick counties.

2. The low-end scenario makes the assumption that the high-valued crops taken out of production by GASP farmers are replaced elsewhere in the LSP basin by farmers that have irrigation sources other than GASP wells. These non-GASP producers are assumed to replace some of their lower-valued crops with the higher-valued crops, such that the *net* loss of acreage in the LSP is the same as estimated by the survey but the lost acres are composed of lower-valued crops.

- Multiple outreach presentations to stakeholders and a presentation in the CSU Department of Agricultural and Resource Economics seminar series.
- A fact sheet published on the Colorado State University website and a Completion Report published on the CWRRI website and in print.

Preliminary results (as of yet unpublished) are shown in Table 2.

Table 2: Output Impacts by Scenario

Scenario	Acreage Change	Total Impact	Impact as % of Total Output	Impact as % of Agriculture	Impact as % of Irrigated Crop Sales	Economic Activity Generated by Lost Acres
High-End	-29,190	-$28,209,654	0.8%	3.4%	18.7%	$966.42 / ac.
Low-End	-29,190	-$10,752,816	0.3%	1.3%	7.1%	$368.37 / ac.

Forthcoming Research: *Preparing for Drought: A Survey of Producer Adoption of Limited Irrigation Practices and Dynamic Optimization of Limited Irrigation Cropping Patterns*

In the West, the economic sustainability of agricultural producers is tightly woven with water availability. Irrigation is an important risk-reducing input that shelters farm income from drought and boosts crop yields. In addition, irrigation permits farmers to produce crops that otherwise could not be grown competitively in our semi-arid environment. As irrigation was developed, farms generated important economic activity for rural communities and regional economies.

Irrigated agriculture is a primary water user in the West, but rapid population growth is driving a reallocation of water use. As Colorado's population grows, water will shift from agriculture to municipal and industrial (M&I) uses. Indeed, it is expected that 428,000 acres of irrigated farmland will dry up to meet future needs (Colorado Water Conservation Board, 2004), and these estimates may be quite conservative (Smith). In addition, evolving legal institutions and groundwater depletions have significantly decreased available irrigation water and have reduced irrigated cropland.

Specific objectives of this research project include:

- Analyzing the feasibility and profitability of potential irrigation systems. In particular, comparing cropping systems according to the ability to meet a financial need is central to farmers' ability to make strategic cropping decisions.

- Estimating current and future adoption rates of such systems and the resulting changes in cropping patterns and irrigated acreages.
- Using the adoption rate estimates, provide initial examination of the impact of changing cropping patterns on regional economies.

The procedure begins by calculating whole farm net returns based on different cropping patterns and irrigation systems. These financial data will be presented to agricultural producers in eastern Colorado, after which a survey of these same producers will be administered to gauge the adoption rates of limited irrigation practices and any corresponding changes in cropping patterns. The IMPLAN software will then use the most recently available data to create an Input-Output (I-O) model for each of the major water conservation districts in eastern Colorado. The baseline I-O model will be used to gauge irrigated agriculture's relative importance to rural communities in the study area and the spillover effects that irrigated agriculture's sales create for local economies. The changes in cropping patterns and irrigated acreage estimated by the survey will then be used to "shock" the I-O model in order to estimate the economic impacts of these changes on regional economies. Significant economic effects will result as cropping patterns evolve from full irrigation to innovative cropping systems and dryland agriculture.

Occurrence and Fate of Organic Wastewater Contaminants in Onsite Wastewater Systems and Implications for Water Quality Management

Basic Information

Title:	Occurrence and Fate of Organic Wastewater Contaminants in Onsite Wastewater Systems and Implications for Water Quality Management
Project Number:	2005CO117B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	4th
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Water Quality, Treatment
Descriptors:	
Principal Investigators:	Dr. Robert L. Siegrist, Reagan M. Waskom

Publication

1. Conn, Kathleen, Robert Siegrist, and Larry Barber, 2007, Colorado School of Mines (CSM) research regarding occurrence and fate of organic wastewater contaminants during onsite wastewater treatment, Colorado Water Newsletter of the Water Center of Colorado State University, August/September 2007, 12-14 pp.

Colorado School of Mines (CSM) research regarding occurrence and fate of organic wastewater contaminants during onsite wastewater treatment

Kathleen Conn, Ph.D. Candidate, Environmental Science & Engineering, CSM, Golden, CO
Dr. Robert L. Siegrist, Professor and Director, Environmental Science & Engineering, CSM, Golden, CO
Dr. Larry B. Barber, Research Scientist, U.S. Geological Survey, Boulder, CO

Organic wastewater contaminants (OWCs) such as pharmaceuticals and personal care products have received increasing attention in the last decade due to their possible adverse effects on ecosystems and human health. Several studies have identified wastewater as a primary contributing source of OWCs to the environment, but few have quantified their occurrence and fate in onsite wastewater treatment systems and associated receiving environments. A substantial portion of the wastewater generated in the U.S. is processed by onsite wastewater treatment systems before discharge to the environment. For example, in Colorado there are over 600,000 onsite systems in operation serving approximately 25% of the State's population and 7,000 to 10,000 new systems are being installed each year. As a result, over 100 billion liters of wastewater are being processed by onsite systems and then discharged to the environment every year in Colorado alone. A research project was initiated by the Colorado School of Mines (CSM) in collaboration with the U.S. Geological Survey (USGS) to (1) determine the occurrence of OWCs in wastewaters produced from varying sources and by different types of onsite wastewater treatment units, (2) to assess the treatment of OWCs in confined treatment units such as septic tanks and packed bed biofilters, (3) to assess the fate and transport of OWCs in soil treatment units prior to groundwater and surface water recharge, and (4) to assess the potential for OWCs to impact receiving waters.

Between 2002 and 2005, the CSM/USGS research team quantified the occurrence of OWCs in 30 Colorado onsite wastewater treatment systems serving different homes, businesses, and institutions, and varied types of confined treatment units (Conn *et al.* 2006).Of the 24 OWCs studied 21 were identified in at least one onsite system effluent, and six compounds- caffeine, the sterols cholesterol and coprostanol, the metal-chelating agent EDTA, the disinfectant 4-methylphenol, and the surfactant metabolite group 4-nonylphenolethoxycarboxylates- were identified in every residential septic tank effluent. Wastewater concentrations of OWCs were highly variable, ranging from less than 1 g/L to greater than 500 g/L. Differences in wastewater compositions regarding OWCs may be due to differences in water- and chemical-using activities at the source. For example, residential systems receive wastewater from a number of indoor activities, including toilets, kitchen and bathroom faucets, dishwashers, clothes washers, and showers. Onsite system wastewaters from residential sources were composed of a diluted mix of biogenic and anthropogenic compounds. Wastewater treated by onsite systems

serving veterinary hospitals, on the other hand, originates mostly from cleaning activities such as disinfecting and washing practices. The OWC composition from veterinary hospitals was composed of high concentrations of surfactant metabolites and other cleaning product chemicals. In contrast, most of the wastewater entering an onsite system serving convenience stores originates from public restrooms. The highest concentrations of 14 pharmaceuticals and antibiotics were found in convenience store wastewater, reflecting the large and diverse population visiting the stores each day.

To understand the fate of OWCs during onsite wastewater treatment, wastewater samples from confined treatment units (e.g. septic tank, textile biofilter) were collected and analyzed for OWCs to identify potential removal during confined unit treatment. Concentrations of OWCs in effluents before and after septic tank treatment were usually similar, suggesting low to negligible removal of OWCs during septic tank treatment alone. Apparent removal efficiencies during textile biofilter treatment varied by compound. OWCs that have been shown to be aerobically biotransformed, such as caffeine, 4-methylphenol, and 1,4-dichlorobenzene, had apparent removal efficiencies of greater than 90% during textile biofilter treatment. Other compounds such as EDTA that are resistant to the removal mechanisms employed during aerobic biofilter treatment (e.g. biotransformation, sorption, and volatilization) showed similar concentrations in effluents before and after the biofilter unit. Concentrations of compounds that are the degradation products of biotransformed OWCs, such as the surfactant metabolites nonylphenolethoxycarboxylates, increased during textile biofilter treatment. Therefore, concentrations of some OWCs were higher in the effluent from a confined treatment unit and which might be applied to the soil treatment unit than in the wastewater entering the onsite system. Additional sampling of confined treatment unit influent and effluent is underway at the Mines Park Test Site on the CSM campus (Figures 1 and 2) to better quantify expected removal efficiencies by accounting for temporal variability and hydraulic detention time within the treatment units.

Results from the reconnaissance survey of 30 onsite wastewater treatment systems suggest that OWCs are being applied to onsite system soil treatment units at environmentally-relevant concentrations. To help understand the fate of OWCs in wastewater effluents during soil treatment, a tracer test was conducted at the CSM Mines Park Test Site using a conservative tracer (potassium bromide) and a pharmaceutical surrogate (rhodamine WT). Known concentrations of both tracers were added to tap water dosed to 14 soil test cells for 22 days at hydraulic loading rates ranging from 2 to 8 cm/d. Soil solution at 60, 120, and 240 cm below the infiltrative surface of each test cell was collected using *in situ* soil suction lysimeters and analyzed for both tracers for 20 months. Results indicate significant retardation of the pharmaceutical surrogate relative to water movement, as indicated by the conservative tracer (Figure 3). Water travel times from the infiltrative surface to 60 cm below the infiltrative surface ranged from 5 to 25 days. The time required for 10 % of the added pharmaceutical surrogate to reach 60 cm below the infiltrative surface ranged from 35 to over 200 days between test cells. After 20 months, mass recovery of the pharmaceutical surrogate at 60 cm below the infiltrative surface varied between test cells, ranging from less than 1 % to approximately 100 % (average = 40 %) recovery of the total mass of pharmaceutical surrogate added. The differences in mass recovery are likely due to differences in hydraulic loading rates and inherent variability in the native soil properties between test cells. The results suggest that OWCs with similar properties

as the pharmaceutical surrogate may be retarded and/or removed during onsite system soil treatment depending on the site-specific soil characteristics.

To further elucidate the fate and transport of OWCs during onsite system soil treatment, soil solution is being collected from 60, 120, and 240 cm below the infiltrative surface of the Mines Park soil treatment test cells for analysis of a suite of conventional wastewater parameters and OWCs. The absence of ammonia, presence of nitrate, and low levels of dissolved organic carbon and phosphorus in the soil solution suggests that treatment processes such as nitrification and sorption are occurring in the vadose zone. Target OWCs have been identified that are amenable to analysis by the sample collection methods, which exclude some volatile and sorptive compounds. Results of the occurrence of OWCs in the soil solution compared to levels measured in the effluent being applied will provide information regarding expected removal efficiencies of select OWCs during vadose zone soil treatment prior to recharge of underlying groundwater.

The occurrence of endocrine disruptors such as surfactant metabolites in wastewater raises concerns about their adverse impacts on the environment following recharge of groundwater and potential recharge of surface waters. The U.S. Environmental Protection Agency has established a toxicity-based water quality criteria for the surfactant metabolite 4-nonylphenol with the 4-day average concentration in freshwater systems not to exceed 6.6 g/L. Twenty five of the 30 sites included in the study had detectable concentrations of 4-nonylphenol in their confined unit effluents and approximately half of those exceeded the water quality criteria, some by greater than ten times. The effect from multiple endocrine disruptors, such as the suite of alkylphenolic compounds studied here, is unknown but studies have indicated an additive effect. Understanding the additional treatment that occurs during soil infiltration and percolation through the vadose zone and within the groundwater and surface water receiving environments is critical to aid in defining potential adverse effects to ecosystem and human health due to OWCs being discharged from onsite wastewater treatment systems. Such information will also enable a comparison of onsite system performance relative to that associated with centralized systems. Laboratory and field research is ongoing at CSM along with modeling studies, the results of which will help guide wastewater facilities planning and design.

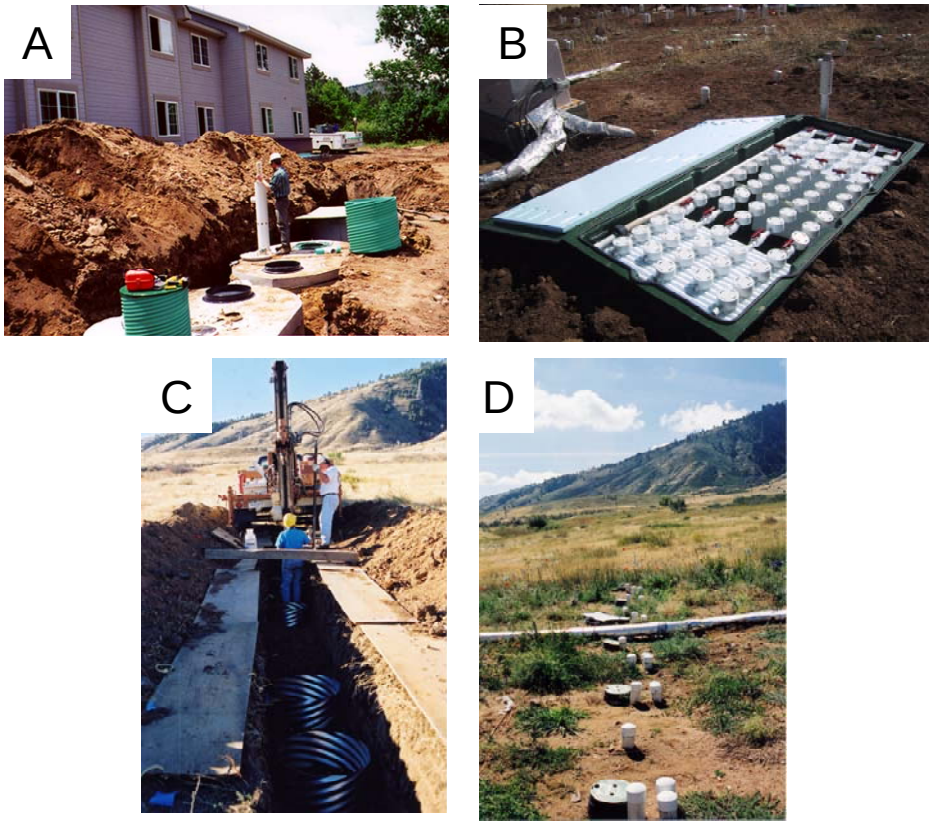

Figure 1. The fate of organic wastewater contaminants in onsite wastewater treatment systems is currently being investigated at the Mines Park Test Site where wastewater from a multifamily residence is intercepted (A) and managed using pilot-scale unit operations such as a textile biofilter (B) and in-ground soil test cells (C,D).

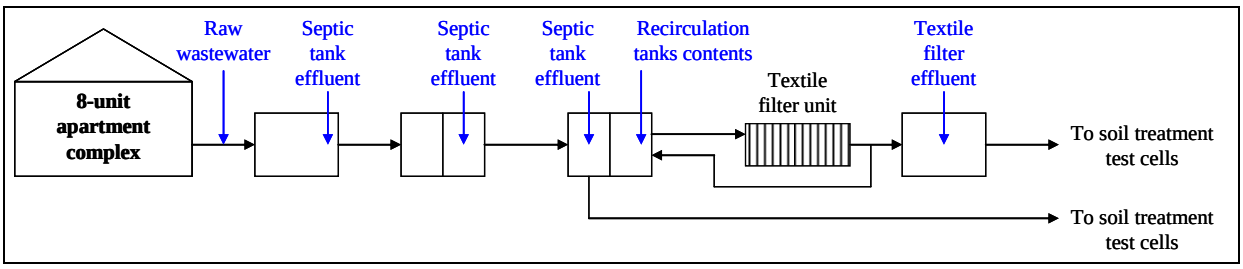

Figure 2. Schematic of the Mines Park Test Site confined treatment unit sampling locations.

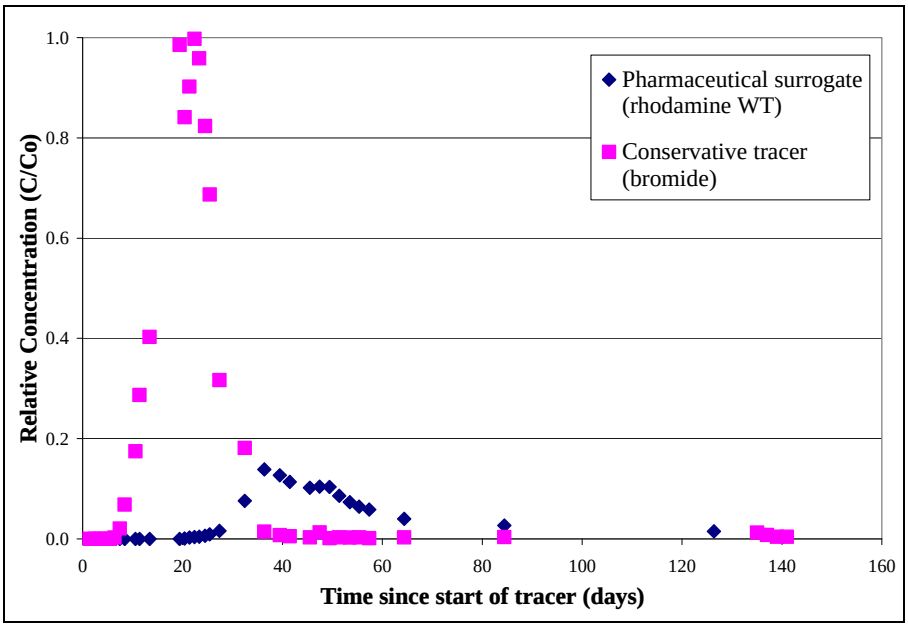

Figure 3. Comparison of the breakthrough curves at 60 cm below the infiltrative surface for a conservative tracer (bromide) and a pharmaceutical surrogate (rhodamine WT) added to an onsite system soil test cell.

Reference:

Conn, K.E.; Barber, L.B.; Brown, G.K.; and R.L. Siegrist. Occurrence and fate of organic contaminants during onsite wastewater treatment. Environmental Science & Technology, 2006, 40: 7358-7366.

Development of Characterization Approaches and a Management Tool for the Groundwater-Surface Water System in the Vicinity of Sutherland Reservoir and Gerald Gentlemen Station, Lincoln County, Nebraska

Basic Information

Title:	Development of Characterization Approaches and a Management Tool for the Groundwater-Surface Water System in the Vicinity of Sutherland Reservoir and Gerald Gentlemen Station, Lincoln County, Nebraska
Project Number:	2005CO118G
Start Date:	9/1/2005
End Date:	8/31/2007
Funding Source:	104G
Congressional District:	4th
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Quantity, Groundwater, Models
Descriptors:	
Principal Investigators:	Eileen Poeter

Publication

1. None to date

Development of Characterization Approaches and a Management Tool for the Groundwater-Surface Water System in the Vicinity of Sutherland Reservoir and Gerald Gentlemen Station, Lincoln County, Nebraska

Progress Report Submitted by Principal Investigator, Eileen P. Poeter, Professor of Ground Water Engineering, Department of Geology and Geological Engineering, International Ground Water Modeling Center, Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401-1887.

Problem and Research Objectives

Conflict between competing uses for water (e.g. water for a power plant to generate electricity to run an irrigation pump and water for irrigation) indicates a need for improved management approaches. Effective use of data is essential to resolving this problem. Generally, we, as a society, have not fully tapped the information in available data because of difficulties associated with its integration. The global problem addressed by the research is improving hydrologic system characterization to reduce predictive uncertainty associated with ground water management problems through an iterative process that couples development of alternative conceptual models and data needs assessment. The specific problem to be used as a platform for developing this approach is water management in the vicinity of Sutherland Reservoir and the Gerald Gentlemen Station power plant, which overlies the High Plains (formerly Ogallala) Aquifer in Lincoln County, Nebraska.

This project develops an effective approach to characterization that focuses on reduction of the associated predictive uncertainty. In an iterative process, available data (of varying type) are integrated through modeling that yields predictions (and associated uncertainty) for evaluated scenarios. Analysis of the models indicates the most valuable additional data (type, location, and time) that could be collected and this is incorporated into the field investigations. The resulting data are used to modify the initial set of alternative models. The evolving models facilitate evaluation of the impact of alternative management scenarios on water levels in wells and discharges to the South Platte River.

The Specific Problem that serves as a Platform for Improved Data Fusion

Sutherland Reservoir provides cooling water for the Gerald Gentleman Station (GGS), a 1.4 Gw coal-fired power plant, one of the primary sources of power for Nebraska and surrounding states. Sutherland Reservoir stage has been maintained at or above a critical level since the late 1970s to allow the power plant intakes to receive cooling water for GGS. Over the years, measured and simulated ground-water levels in the underlying High Plains Aquifer indicate that leakage from the reservoir has raised ground water levels in a large, although poorly-defined, region surrounding the reservoir (Nebraska Conservation and Survey Division, 2004). Nearby farms and ranches have come to depend on this ground water for domestic and irrigation use. As of December 2004, nearly every major reservoir in the North Platte River Basin contained less than 30 percent of capacity storage water (Ed Kouma, USBR, personal comm.). The water supply

forecast indicates that surface water supplies available to maintain Sutherland Reservoir elevations necessary for operations at GGS will be insufficient by the summer of 2006. To maintain water levels in times of drought, Nebraska Public Power District (NPPD) installed 38 high capacity wells in a 20-square mile area near the reservoir on the Gerald Gentleman Station property in the spring of 2004. These wells will extract water from the High Plains Aquifer and discharge to Sutherland Reservoir. Currently, NPPD project managers plan to utilize the well field starting in the summer of 2006, with a majority of the wells operating daily for up to four months. Pumping rates for these wells range from 1,600 to 2,700 gallons per minute. The same pumping schedule will likely occur during the summers of 2007 and 2008, and if dry climatic conditions persist, beyond 2008. If necessary, the well field may be used for more than the currently planned four months each year.

Data characterizing the system are sparse and estimates of hydraulic parameters differ in previous studies of the area, and interaction of groundwater within the High Plains Aquifer and water stored in Sutherland Reservoir is not understood. Consequently, the impact of the alternative management scenarios on water levels in wells and discharge to the South Platte River is unknown and a groundwater management model is needed for the study area. The Global Problem Sparse subsurface data cause us to be uncertain of the exact nature of ground water system structure and components. Consequently, it is best, although not always customary, practice to consider multiple representations of the structure of a ground water system before making predictions of system behavior. To the extent possible, items constituting differences in model structure should be automatically adjusted in the calibration process. However, this has been difficult to achieve, thus the need to consider a set of alternative models to some extent. The adjustable parameters of each alternative model must be calibrated (i.e. parameter values adjusted to obtain the best fit to the field data, e.g. using nonlinear regression) before models can be compared (Poeter and Hill 1997). Fortunately, the advent of high speed computing and robust inversion algorithms makes calibration of multiple models feasible. Often, prediction uncertainty is larger across the range of alternative model structures than arises from the misfit and insensitivity of any one optimized model, even to the extent that confidence intervals on predictions from some of the models may not include the values predicted by others. This issue is addressed by weighting the alternative models and calculating model-averaged predictions and intervals (Poeter and Anderson, 2005). If the model averaged predictions are so uncertain that a reasonable decision is untenable, then additional data should be collected to better constrain the range of reasonable models. Hence the iterative process of model development and data collection. The problem involving management of Sutherland Reservoir in Nebraska and predicting its impact on the High Plains aquifer is well suited to the development of a structured approach to iterative alternative model definition and data needs assessment.

Methodology

Task 1: Delineation of the Model Domain

Except for the South Platte River to the north, well defined natural hydraulic boundaries do not occur near the reservoir. Consequently, the model will extend from the Platte River on the north, southward on the order of fifteen miles, with an east-west extent of about 15 miles. The west, south and east boundary will be defined as constant head reflecting the approximate heads in the aquifer at those locations. Simulations of the regional COHYST model will facilitate delineation

of boundary conditions and average material properties. The influence of stress on boundary 8 fluxes will be evaluated through out the project and the model domain will be adjusted appropriately.

Task 2: Compilation of available data
Historic data from NPPD, the USGS, and the University of Nebraska Conservation and Survey Division on hydrostratigraphy, hydraulic properties, water levels and flow rates will be coupled with the new lithologic and geophysical borehole data from the well field installation. These data will be supplemented with pertinent COHYST data for this locale in project databases of various formats (primarily in GIS formats). This database will also be the repository for all USGS hydrochemical data and age dates once it becomes available.

Task 3: Delineation of the hydrostratigraphic framework and associated hydraulic properties
Historical interpretation of the hydrostratigraphinc framework (Harza, 1993; Gutentag et al., 1984) will be used as a starting point for further refinement given the hydrostratigraphic data from the newly drilled well field. The surficial geology of the area is dominated by multiple layers of Quaternary loess and fine dune sand deposits that can locally be 50 to 100 feet thick. The base of the reservoir is directly within sand and gravel deposits up to 25 feet thick which facilitate rapid seepage rates. Discontinuous zones of paleosol, a few to several feet thick, presumably the Sangamon, exist below the coarse channel deposits. This sequence of deposits (coarse over fine) creates conditions that enhance horizontal flow of seepage below the reservoir. Fine to medium texture deposits (silts to fine sands up to 40 feet thick) underlie the paleosol. These units lie directly above the Ogallala Group, the primary unit comprising the High Plains Aquifer (up to 350 feet thick). The water table occurs within the upper units. The Ogallala in this area is a mixed sequence of sands and gravels, silts, clays, sandstones, and siltstones, varying substantially over short distances due to the depositional environment. Well yields can be large in this area of the Ogallala with some irrigation wells pumping on the order of 2,000 gallons per minute. The base of the High Plains Aquifer as defined by the USGS High Plains RASA and the Nebraska Platte River Cooperative Hydrology Study (2004) in this area is the Brule Formation, a massive clay- and siltstone (with some coarse deposits locally) within the White River Group (Gutentag and others, 1984).

Task 4: Development of alternative conceptual models Given the hydrostratigrphy and associated uncertainties developed in Task 3, alternative conceptual models will be developed and starting values for hydraulic parameters defined. The simplest geometry consists of continuous horizontal layers from the surface downward of 1) fine loess and sand dunes (50-100 feet), 2) sand and gravel (up to 25 feet thick), 3) paleosol, 4) silts and fine sands (up to 40 feet thick), and 5) the Ogallala, a heterogeneous mix of mixed sequence of sands and gravels, silts, clays, sandstones, and siltstones (up to 350 feet thick). Clearly some of these layers are discontinuous and vary in thickness. Evaluation of the presence, distribution and thickness of these materials will be explored through alternative conceptual models.

Task 5: Construction of numerical models representing the conceptual models Based on the results of tasks 1 through 4, numerical models will be developed using GMS to build the hydrostratigraphy, generate the grid and assign properties. The resulting files will be used for simulation external to GMS (EMRL, 2004) to facilitate manipulation of material zones 9 and

inversion with UCODE_2005 and resulting heads and fluxes imported to GMS for visualization. Alternative schemes for finding an optimal zonation of the aquifer zones will be evaluated. Options include the alternatives discussed in a later section titled “Related Research”. The more appropriate methods will be selected once the general character of the units are identified by analysis of the detailed hydrostratigraphic data recently acquired from drilling the new well field.

Task 6: Calibration of the models using nonlinear regression
The models will be calibrated using nonlinear regression techniques as implemented in UCODE_2005 (Poeter et al., 2005; Poeter and Hill, 1998, Poeter and Hill, 1997), which performs inverse modeling, posed as a parameter-estimation problem, using nonlinear regression. UCODE_2005 is a JUPITER (Joint Parameter IdenTification and Evaluation of Reliability) application (Banta et al., 2005). The JUPITER API is a computer programming environment that includes conventions and software components designed to support the development of computer programs that perform model sensitivity analysis, data needs evaluation, calibration, uncertainty evaluation, and (or) optimization currently under development by the USGS, in coordination with EPA. Statistics generated by UCODE and its post-processor (RESAN_2005) will be used to evaluate the most important parameters in each model as well as the type and location of additional data that would be most useful in reducing parameter and associated predictive uncertainty (Task 7). Evaluation of the important parameters will guide further conceptual model development. In addition, the statistics will be used to compare alternative models and guide development of an improved conceptual model of the region (Tasks 8 and 9).

Task 7: Recommendation of types and locations of data that will improve the model and reduce uncertainty Sensitivities of a model to given types, locations and time of data, as computed by UCODE, are independent of the data value. Increased sensitivity and decreased parameter correlation reduce predictive uncertainty. Consequently various options for data will be considered (at minimal cost) using the calibrated models before the substantial expenditure of field sampling and laboratory analysis. This feedback will be most valuable to the USGS in selecting locations where samples will be collected in 2006 to analyze for the characteristic natural tracers of the reservoir water identified by their work in 2005. The results of their findings in 2006 will be used to further improve the models and reduce prediction uncertainty.

Task 8: Estimation of seepage volume and flow paths
Seepage volume and flow paths will be calculated using the calibrated models and YCINT_2005, a UCODE_2005 post-processor. The values will be model-averaged to generate the best estimate of the volume and paths and the associated uncertainty. This will be accomplished using MMRI (Poeter et al., 2005), a multi-model inference algorithm, and a member of the Jupiter family of codes. MMRI operates on data exchange files from any JUPITER-based inversion algorithm (e.g. UCODE_2005), using them to rank and weight alternative models, then model-averages 10 parameters and predictions (Poeter and Anderson, 2005), using flexible, user-specified algorithms which include the maximum likelihood Bayesian model average (MLBMA) algorithm recommended by Neuman and Weirenga (2003).

Task 9: Prediction of the response of the flow system to various management scenarios
Alternative management scenarios will be defined as the project proceeds. At a minimum they will include steady pumping of all wells in the well field at the distributed rate found necessary to maintain the reservoir at a minimum level given the model calibrations, and some combinations of a subset of wells maintaining minimum levels. Additional scenarios will involve various strategies to recharge the aquifer by raising water levels in the reservoir via canal inflow during wet periods. Further scenarios will be developed as problems are identified (e.g. excessive drawdowns in surrounding wells or low flows in the Platte River) by modeling results. The predictions for each scenario will be averaged for all models using MMRI as discussed in task 8. Their uncertainty will be considered and if the range of uncertainty in predicted conditions is unacceptable recommendations will be made for further data collection to reduce that uncertainty.

Task 10: Preparation of papers delineating the approach, implementation and findings
Two papers will be prepared. One paper will delineate the approach for hydrologic system characterization that reduces predictive uncertainty associated with ground water management problems through an iterative process that couples development of alternative conceptual models, model averaging of predictions, and data needs assessment. The second paper will discuss the implementation of the approach for management of the Sutherland Reservoir and the findings of the project.

Task 11: Preparation and posting of a web page presenting project information
A web site, targeting a multi-level audience, will be developed with graphical displays highlighting project findings, the project report, public domain data, project model input and output files, and directions for their use (see section titled: Information Transfer Plan). Facilities Colorado School of Mines and the International Ground Water Modeling Center have complete computing facilities and software (e.g. Arc/Info, Access, MODFLOW2000, MODPATH, MT3D, GMS, GWV, UCODE among other hydrologic and geologic software) for conducting this work. Students and faculty will write software as necessary to accomplish the tasks. Basic field equipment including pumps, water level sounders, and water quality sampling equipment are available through Colorado School of Mines, but will be supplied by NPPD or their contractors. The USGS will provide geochemical sampling equipment and analysis laboratories.

Principal Findings and Significance

The model domain for the Sutherland Reservoir/ Gerald Gentlemen Station (GGS) investigation was defined as an area of approximately 1,000 square miles with the reservoir located slightly north of the center of the model domain and grid area. This area includes several surface water features and land use types and is sparsely populated.

Several types of pre-project data were compiled for the study. Sources for nearly all of these data include: the Nebraska Department of Natural Resources (NDNR); US Geological Survey (USGS); the University of Nebraska Conservation and Survey Division (CSD); the Nebraska Public Power District (NPPD); and the Platte River Cooperative Hydrology Study (COHYST). The data include historic river flows at several gages on the South Platte River (NDNR, USGS, COHYST), geologic borehole data (CSD, COHYST, NPPD), evapotranspiration data

(COHYST), area well records (NDNR), historic canal diversion and reservoir stage data (NDNR, NPPD), and land use imagery in the last 10 years (COHYST). A considerable effort was expended preparing the data for use in the groundwater model and other software interfaces.

To enhance model calibration, 7 multi-well monitoring nests were installed around the GGS wellfield and Sutherland Reservoir to monitor groundwater levels and identify distinct geochemical signatures of the groundwater at varying locations both vertically and horizontally. Surface water features, including canals, drains, the South Platte River, and Sutherland Reservoir were sampled for water quality. The samples were analyzed by the US Geological Survey. Sampling will continue to evaluate changes after pumping the well field for summer operation of GGS. Flow was, and continues to be measured at six previously unmonitored locations along drains in the model area. It appears that flow at these locations will be important to groundwater model calibration.

A database of geology from boreholes at the GGS site that were installed since 2004 was developed. Pre-project geologic borehole data were incorporated in the data base, such that it now includes over 70 boreholes within an area of less than 60 square miles in the vicinity of GGS. These borehole data have been analyzed in a stratigraphic modeling software interface which allows for three-dimensional modeling of the complex geologic data found at the Sutherland Reservoir/GGS site. These data have been used to generate one of the conceptual models being created for this project. Automated procedures for generating alternative conceptual models are under development.

Currently, four conceptual models with varying hydrostratigraphy at the Sutherland Reservoir/GGS site are being evaluated. These conceptual models include a two-dimensional representation, a three-dimensional two-layer representation, a four-layer representation using previously constructed COHYST data, and a five-layer representation using the new hydrostratigraphy that combines the new geologic borehole data with the COHYST borehole data. Additional conceptual models include alternate hydrostratigraphic representations of the geologic data, and varying representations of boundary conditions based on land-use practices that influence groundwater recharge and evapotranspiration.

Each model has been constructed as a numerical model and calibration has begun. Details of the calibration schemes are under development at this time. Based on preliminary assessments, recommendations have been for additional streamflow data and water quality data that will provide flow paths and mixing ratios for use in model calibration.

Information Transfer Program

Requests from the Colorado legislature to facilitate and inform basin-level discussions of water resources and help develop an interbasin compact for water management purposes emphasized the role Colorado Water Resources Research Institute plays in providing a nexus of information. Some major technology transfer efforts this year include:

- Provide training for Extension staff in various water basins to help facilitate discussions of water resources
- Encourage interaction and discussion of issues between water managers, policy makers, legislators, and researchers at Colorado Water Future one-day conference
- Publication of the bi-monthly newsletter which emphasizes water research, current water issues
- Posting of all previously published CWRRI reports to the web for easier access
- Worked with Colorado Institute for Public Policy to develop a charter for the state Interbasin Compact Commission
- Working with land grant universities and water institutes in the intermountain West to connect university research with information needs of Western Water Council, Family Farm Alliance, and other stakeholder groups.
- Work closely with the Colorado Water Congress, Colorado Foundation for Water Education, USDA-CSREES funded National Water Program to provide educational programs to address identified needs.

Technology Transfer and Information Dissemination

Basic Information

Title:	Technology Transfer and Information Dissemination
Project Number:	2005CO116B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	Education, Law, Institutions, and Policy, Management and Planning
Descriptors:	
Principal Investigators:	Reagan M. Waskom

Publication

1. Brown, Jennifer, ed., 2006, From Gold Rush to Urban Crush: the Past, Present, and Future of the South Platte River Basin, Information Series Report 103, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 23 pp.
2. Keammerer, Warren K., ed., 2006, Proceedings: High Altitude Revegetation Workshop No. 17, Information Series Report 101, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 277 pp.
3. Wickramasinghe, Sumith Ranil and Reagan Waskom, ed., 2006, Produced Waters Workshop, Information Series 102, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 242 pp.

Technology Transfer and Information Dissemination Overview

Given the call for assistance with the Water Basin Roundtables, the travel budget for CWRRI will be increased this year. Participation in various regional conversations about water will be a primary activity for the director of CWRRI. The Colorado legislature has mandated specified roundtables to discuss water policy and water use within the state. These roundtables frequently make use of the expertise and research results from the CWRRI community of scholars. The director's presence, or the presence of an appropriate expert, will be requested at various meetings this year, and CWRRI assistance with travel expenses will be an important encouragement to accomplish this interaction.

Colorado Water, bi-monthly newsletter of CWRRI and Colorado State University Water Center, provided research updates, meeting briefs, and other water resources news on topics such as conjunctive use, water basin roundtable process initiated by the Colorado State Legislature, river restoration, and the water-energy nexus. Archived newsletters are available from our web page www.cwrri.colostate.edu .

The bimonthly, 28-40 page newsletter, with a paper distribution of 2100 copies, has not been revamped in several years. Our goal for this year is to dissect the features and functions of the newsletter, assess each individual component for relevancy and priority, and then reassemble the publication template to reflect current needs with an updated look. Our web pages are truly legacy web pages -- a wealth of information in a cluttered layout with an outdated appearance. This year we focused on posting research results to the web page so that the public has easy access to all information in the reports. Now, the formatting and appearance of the web pages need to be updated with new technology, new design trends. Because of our limited capacity (one administrative staff member and one support person) we will hire a consultant to complete the redesign of both the web pages and the newsletter.

CWRRI publishes several report series and these are posted to the web page. Completion reports are published at the end of each project, and at least four of these documents are scheduled for production in the next fiscal year. The information series provides information on special topics such as proceedings of conferences on water-related topics and four such documents are expected in the coming year. Special reports are publications of interest to the water community in the state of Colorado, sometimes best management practices for a specific segment of water users or histories of water in Colorado, and are published erratically as our clients or interest groups require or provide them. Our series of public education pieces called Water in the Balance are on topics of general interest and are written for non-technical audiences. The final category of reports is technical reports on research projects and no documents are scheduled in this topic for the coming year.

Web pages for the center were updated to include immediate access to the documents published by CWRRI. More than 300 reports were scanned, saved as .pdf files, and uploaded to the webpage this year. Reports are available from our web page at www.cwrri.colostate.edu.

Taking the Plunge: Colorado Water Basins Explored Research, Data Tools for Regional Water Decisions

The Colorado's Future 2006 conference on Oct. 6 brought together nearly 100 water stakeholders from around the state. Approximately half of the attendees were elected members of their local Colorado water basins; other participants included ranchers, engineers, municipal water providers, watershed representatives, researchers, and federal agencies.

Recognizing this need, in 2005 the Colorado Legislature passed legislation known as "The Colorado Water for the 21st Century Act" that created nine geographically defined state water basins, and mandated that specific interests, such as agriculture and recreation, be represented at each basin roundtable.

Additional funding gives these water basins the opportunity to conduct their own basin needs assessments. The results of these needs assessments will frame discussions about future water diversions and allocations within Colorado. The needs assessment must address both water needs and availability issues, including:

- Consumptive and nonconsumptive water needs
- Available and unappropriated waters in the basin
- Projects or non-structural methods for meeting water supply needs

The meeting was produced by the Colorado Institute of Public Policy at Colorado State University, the Colorado Department of Natural Resources, and the Center for Policy Studies at the University of Colorado, Colorado Springs. Additional conference sponsors included the Colorado Water Resources Research Institute, Parker Water & Sanitation, Aqua Engineering, Aurora Water, Colorado Water Conservancy District, The Nature Conservancy, Northern Colorado Water Conservancy District, Pueblo Board of Water Works, and the Rocky Mountain Farmers Union.

Conference speakers included Eric Kuhn, Colorado River Water Conservation District; Dr. Dan Smith, Colorado State University; Tom Iseman, The Nature Conservancy; and Jim Westkott, Colorado Demography Office.

The conference featured key basin assessment participants, including Eric Hecox, the manager of the Office of Interbasin Compact Negotiations, and Susan Morea, a vice president of CDM and the contractor selected by the Colorado Department of Natural Resources to conduct the basin needs assessments.

Water Tables Whets Appetites and Nearly Doubles Fundraising for Water Resources Archive in Second Year

For a second year in a row, the archival reading room of Morgan Library was alive with the sounds of laughter, debate, and wonderment as a crowd of 130 gathered for Water Tables 2007. A benefit for the Water Resources Archive, the evening offered guests a chance to explore primary source materials documenting landmark achievements in water resource development while engaging with the foremost water experts tackling some of the state's most pressing resource concerns. Sponsors and participants raised $20,000 to support the Archive and the evening, and proceeds will help the Archive to acquire, preserve, and promote additional and existing collections significant to Colorado's water history.

"Archival collections are what the National Archives terms 'history in the raw,' said Colorado State University Libraries Dean, Catherine Murray-Rust. "They are the collections that define a research library equipped to support a great research university like Colorado State and little else compares with watching someone discover this kind of living history for the first time." Guests donned white gloves and literally held history in their hands as they wandered around an array of materials from the Archive's holdings including Delph Carpenter's briefcase, Ival Gosling's hardhat, and lanternslides from the Ralph Parshall Collection. This year's display also featured "Dam Beautiful: Robert Glover and Arch Dams," an exhibit exploring the beauty and controversy of the arch dams that dramatically alter the western landscape - in both positive and negative ways.

While the archival collections mark the foundation from which many water policy decisions have been made, guests were escorted across the plaza to the Lory Student Center for topic conversations with the foremost water experts helping to make those decisions for the future. Hosts expertise ranged from natural resource management to environmental advocacy to extensive knowledge of water law to in-depth historical understanding. Conversations ranged from discussing wildlife, water issues, and conflicts to opportunities and challenges in urban water conservation to current problems in border water management.

Additional sponsors for the event included Aqua Engineering, Inc. Bishop-Brogden Associates, Inc., Black & Veatch, Bureau of Reclamation, Kennedy/Jenk Consultants, Meurer & Associates, Inc., Northern Colorado Water Conservancy District, Norlarco Credit Union, Tetra Tech, Inc., TST, Inc. Consulting Engineers (Bronze Level Sponsors donating $500 or more), Hilton Fort Collins, Odell Brewing Company, and Harrison Resource Corporation.

Stream Depletion Model Developed by IDS Group Adopted by State Engineer

The Integrated Decision System Alluvial Water Accounting System (IDS AWAS), developed by a CSU research team lead by Luis Garcia, has been adopted by the State Engineers office. On May 6, 2006, Hal D. Simpson, the State Engineer issued Procedures Memorandum 2006-1 to all Division of Water Resources Staff announcing "*In an effort to modernize the software used to model stream depletion caused by well pumping, the Division of Water Resources has selected the IDS AWAS software as the standard software to be used by all."* Furthermore, the memorandum stated, *"Evaluators and Engineering staff must use the IDS AWAS Stream Depletion Model, and the Records staff must direct customers to use this software in conjunction with our data"*

IDS AWAS is one component in a suite of tools called the South Platte Mapping and Analysis Program that was initiated with funding from the Colorado Water Resources Research Institute (CWRRI) in 1995. Since that time, the user-centered tools have garnered support and funding from numerous other sources including several water users organizations, the state engineers office, Colorado Cooperative Extension Service, and the Colorado Agricultural Experiment.

The South Platte Mapping and Analysis Program (SPMAP) tools are developed by the Integrated Decision Support (IDS) Group at Colorado State University (www.ids.colostate.edu) with the active participation of area water users and staff from the Division One State Engineer's Office. The primary function of these tools is to accurately determine the timing and amounts of tributary groundwater withdrawals used for irrigated agriculture and resulting river depletions in a region where ground and surface water are conjunctively used. The tools have confirmed their worth by easing disputes during Colorado's recent unprecedented drought.

IDS AWAS and the other SPMAP tools were developed in a collaborative manner which involved water user groups, the state engineer's office and university researchers. The SPMAP project is an excellent example of how a number of diverse stake holders can contribute to the development and use of common computer tools which can benefit all.

Educational Program Targets Arkansas & Colorado Basin Roundtables

Irrigation water is an important risk management tool in limiting drought impacts and boosting crop yields. Additionally, rural communities are directly dependent on the availability of water and the sustained tax revenue base of irrigated agriculture. It is expected that 428,000 acres of irrigated farmland will dry up to meet future municipal and industrial uses (Colorado Water Conservation Board, 2004).

Colorado State University will offer an educational program to the Arkansas and Colorado Basin Roundtables on the impacts of reduced water availability to Colorado Agriculture. The proposed three-hour educational program is designed to help roundtable members better understand the potential consequences associated with water movements from agriculture to nonagricultural uses.

Speakers include Rod Sharp, Jeff Tranel, and James Pritchett – Agricultural and Business Management Economists with Colorado State University. Sharp (located in Grand Junction) and Tranel (located in Pueblo) are currently serving as CSU's liaisons with the Colorado and Arkansas Basin Roundtables. They have joint appointments with Cooperative Extension and the Department of Agricultural and Resource Economics. Pritchett is an Assistant Professor in the Department of Agricultural and Resource Economics in Fort Collins.

GS 592 – Water Resources Seminar
Fall 2006 theme: Current Topics in Colorado Water Law

The appropriation and administration of Colorado's water resources rests upon 140 years of territorial and state law. This body of law prescribes how we put water to beneficial use in an arid land that never has enough water to satisfy all of the appropriated and environmental uses. The Doctrine of Prior Appropriation has guided the State for many years but the recent drought exposed a number of water management challenges that required new legislation and court rulings to allow water administration to continue evolving.

The purpose of the 2006 Water Resources Seminar was to examine the changing nature of Colorado water law and to ground students in basics of how our water legal system works.

- Describe the theories, history and background of Colorado water law;
- Examine the role and function of the water court system and legislature;
- Discuss strengths and weaknesses of the law in surface and ground water administration;
- Examine current topics in Colorado water law, including: ground water use and augmentation, environmental and recreational flows, municipal acquisition and transfer of agricultural water, endangered species needs, interstate compacts, water quality protection and other topics.

GS 592 – Water Resources Seminar Guest Speakers

- David Robbins, Attorney Interstate Compacts and Federal Water Law (Case Study: Arkansas River Settlement)
- Rep. Kathleen Curry, Colorado House Member The Legislative Process and the Evolution of Water Rights (Case study: Recreational Flows)
- Bill Brown, Attorney Water Right Transfers & Adjudication: How the Water Court System works
- Melinda Kassen, Attorney Defending Environmental Needs and Water Quality
- Andy Jones, Attorney & Tom Cech, Central Colorado Water Conservancy District Current Issues in Groundwater Law and Administration (Case Study: South Platte Basin)
- Mike Shimmin, Attorney Colorado Groundwater Law
- Ken Knox, Deputy State Engineer Implementing Colorado Water Law (Case Study: San Luis Valley)
- Mark Squillace, CU Natural Resources Law Center Other State Approaches to Water Administration and Adjudication

Produced Waters Workshop

Basic Information

Title:	Produced Waters Workshop
Project Number:	2005CO147S
Start Date:	9/26/2005
End Date:	8/31/2006
Funding Source:	Supplemental
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	Water Use, Methods, Treatment
Descriptors:	
Principal Investigators:	Robert C. Ward

Publication

1. Wickramasinghe, Sumith Ranil and Reagan Waskom, ed., 2006, Produced Waters Workshop, Information Series 102, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 242 pp.

Produced Waters Workshop
Energy and Water: How Can We Get Both for the Price of One?
April 4-6, 2006

Potential use of produced water was discussed at a workshop held at the Marriott Hotel in Fort Collins, Colorado on April 4 and 5. Produced water is water associated with oil and gas reservoirs that is extracted when the oil and gas are extracted. The workshop goal was to enhance understanding of opportunities and challenges involved in converting produced waters to beneficial use. Discussion of possible solutions began with the assembly of people representing academic disciplines and other entities that could provide information and perspectives to characterize produced water sources, issues, and opportunities. Looking for responsible identification and development of realistic beneficial uses, the workshop featured seminars concerning quantity, "how to", and the role of various government agencies. Participants included lawyers, geologists, oil and gas companies, private environmental agencies, extension agents, and state and federal agency representatives. The Powder River Basin in Wyoming was used as a primary example of how produced waters could be put to use, as many panel members were from Wyoming, and that basin deals with uses of large amounts of produced waters. Highlights of the workshop included a keynote address by Mark Limbaugh, Assistant Secretary for Water and Science for the U.S. Department of Interior, and a panel discussion between oil and gas lawyer, Jack Palma, Laurie Goodman with Trout Unlimited, and Kate Fox, Wyoming attorney. There were approximately 200 people who attended the conference. Along with various speakers, there were panels open for discussion throughout the two-day event. This gave all who attended the conference a chance to ask questions and offer opinions and solutions about produced waters.

ORGANIZING COMMITTEE MEMBERS
Pat O'Toole, President of Family Farm Alliance
Dave Stewart, President of Stewart Environmental Consultants
Chuck Hennig, Bureau of Reclamation
Steve Kasower, Bureau of Reclamation
Katie Benko, Bureau of Reclamation
Earl Cassidy, USGS
Jim Otten, USGS
David Burnett, Global Petroleum Research Institute at Texas A&M University
Harold Bergman, Director of the William D. Ruckelshaus Institute at the University of Wyoming
Gregg Kerr, Director of the Wyoming Water Resource Research Institute
Gretchen Rupp, Director of the Montana Water Center
Carl Wood, Director of the New Mexico Water Resources Research Institute
Ranil Wickramasinghe, Professor in Chemical and Biological Engineering at CSU, and
Reagan Waskom, Director of the Colorado Water Resources Research Institute

CO-SPONSORS
Colorado State University
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National Institutes for Water Resources
Ruckelshaus Institute of Environment and Natural Resources
U.S. Geological Survey

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	5	2	0	0	7
Masters	2	0	0	2	4
Ph.D.	1	1	0	0	2
Post-Doc.	0	0	0	0	0
Total	8	3	0	2	13

Notable Awards and Achievements

Robert Ward Recognized by Universities Council on Water Resources

The Universities Council on Water Resources (UCOWR) held its annual meeting in Santa Fe, New Mexico, July 18-20, 2006. The meeting focused on the theme of Increasing Fresh Water Supplies and featured water managers from Southwestern municipalities and members of the academic community discussing their findings on urban water use and conservation.

Robert Ward was honored with the 2006 Warren Hall Medal presented annually by UCOWR. Robert served as Director of the Colorado Water Resources Research Institute from 1991-2005, as well as Director of the Colorado State University Water Center from 1998-2005. Among the many accomplishments cited by UCOR was Robert's leadership in water resources education over his 35 year career at Colorado State University. Robert taught two generations of CSU students in operations research, engineering design and water quality monitoring. His research focused on the design of water quality monitoring systems and he authored two books on water quality monitoring and continues to consult on the subject.

The Hall Medal is the highest honor bestowed by UCOWR and is a memorial to recognize Dr. Warren A. Hall, known worldwide for his active involvement and distinctive scholarly accomplishments in water resources research and education. He was one of the founders of the Universities Council on Water Resources in 1962. Dr. Hall served on the CSU Civil Engineering faculty in the late 1970s and early 1980s. Gilbert White (1995) and Chuck Howe (2003), both with CU Boulder, and Neil Grigg (1998) and Bob Young (2004), both with CSU, have also received the Warren Hall Medal in the year noted by their name.

17th Annual South Platte Forum Honors Robert Ward's Contributions

Robert Ward was honored with the Friends of the South Platte Award at the annual South Platte forum in recognition of his contributions to the organization over many years. The award includes a framed copy of the photo South Platte Sunset, generously provided by John Fielder.

Publications from Prior Projects

1. 2005CO116B ("Technology Transfer and Information Dissemination") - Water Resources Research Institute Reports - Brown, Jennifer, ed., 2006, From Gold Rush to Urban Crush: the Past, Present, and Future of the South Platte River Basin, Information Series Report 103, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 23pp.
2. 2005CO116B ("Technology Transfer and Information Dissemination") - Water Resources Research Institute Reports - Keammerer, Warren K., 2006, Proceedings: High Altitude Revegetation Workshop No. 17, Information Series Report 101, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 277 pp.
3. 2005CO147S ("Produced Waters Workshop") - Water Resources Research Institute Reports - Wickramasinghe, Sumith Ranil and Reagan Waskom, ed., 2006, Produced Waters Workshop, Information Series 102, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 242 pp.
4. 2004CO99B ("Salt Chemistry Effects on Indirect Field Salinity Assessment in the Arkansas River Valley, Colorado") - Water Resources Research Institute Reports - Water Resources Research Institute Reports-Cooper, Curtis A., Cardon, Grant and Davis, Jessica, 2006, Salt Chemistry Effects on Salinity Assessment in the Arkansas River Basin, Completion Report 206, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 49 pp.
5. 2002CO6B ("Evaluating Strategies to Mitigate Waterlogging and Salinization in Colorado's Lower Arkansas River Valley") - Water Resources Research Institute Reports - Water Resources Research Institute Reports-Gates, Timothy K., Garcia, Luis A., and Labadie, John W., 2006, Toward Optimal Water Management in Colorados Lower Arkansas River Valley: Monitoring and Modeling to Enhance Agriculture and Environment, Completion Report 205, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 45 pp.
6. 2003CO71B ("Urban Landscape Irrigation with Reclaimed Wastewater: Water Quality Assessment and Community Experience") - Water Resources Research Institute Reports - Water Resources Research Institute Report-Qian, Yaling, 2006, Urban Landscape Irrigation with Recycled Water, Completion Report 204, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 35 pp.
7. 2005CO115B ("Colorado's Evolving Irrigated Agriculture: Economic Accounting Impact Analysis") - Water Resources Research Institute Reports - Water Resources Research Institute Reports-Thorvaldson, Jennifer and Pritchett, James, 2006, Economic Impact Analysis of Reduced Irrigated Acreage in Four River Basins in Colorado, Completion Report 207, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 48 pp.