Colorado Water Institute
Annual Technical Report
FY 2007

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 requested a briefing on water education activities of the Institute. The Colorado Department of Natural Resources requested our assistance in engaging researchers and Extension in the public discussions of water quantity issues around the state. Water Roundtables in designated water basins elicited input from stakeholders with the goal in mind of creating an environment for water sharing arrangements in the state.

The Colorado Water Resources Research Institute serves to connect the water expertise in Colorado's 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 fourteen 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 an additional $150,000 in one time funds from the State of Colorado in FY08 to expand the research portfolio in FY08. 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 ten new proposals for consideration this year from three 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 peer review process and ranking by the CWRRI Advisory Committee resulted in funding 4 new projects for FY08. Project titles and investigators are listed below. For more information on any of these projects, contact the Principle Investigator or Reagan Waskom at CWRRI. Special appreciation is extended to the many individuals who provided peer reviews of the project proposals.

- **Developing a GIS Database for Source-Tracking of Human Versus Agricultural Inputs of Antibiotic Resistance Genes (ARG) in the Watershed**. Amy Pruden and Mazdak Arabi, Department of Civil and Environmental Engineering, Colorado State University. $15,280
- **Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin**. Stephanie Kampf, Department of Forest Rangeland and Watershed Stewardship, Colorado State University. $35,000
- **Observing and Modeling Non-Beneficial Evaporative Upflux from Shallow Ground Water under Uncultivated Land in an Irrigated River Valley**. Jeffrey Niemann, Timothy Gates, Luis Garcia, Civil Engineering, Colorado State University. $40,000
- **Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation**. James Pritchett, Agriculture & Resource Economics, Colorado State University. $47,981
- **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
- **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
- **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

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.

<u>The Specific Problem that serves as a Platform for Improved Data Fusion</u>

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.

<u>The Global Problem</u>

Sparse subsurface data cause us to be uncertain of the exact nature of the 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 fluxes will be evaluated throughout 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 hydrostratigraphy 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 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. 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 Linear_Uncertainty, 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 MMA (Poeter et al., 2007), a multi-model inference algorithm, and a member of the Jupiter family of codes. MMA 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 conceptual models for this project.

Project efforts have focused on both continued data gathering (including pertinent documented data and field observations/samples) as well as testing key components of the flow system in various two- and three-dimensional numerical model renderings of the system. Beginning in 2005, the US Geological Survey collected seasonal water samples from multi-level well nests specifically installed for this project. Samples were also obtained from several surface water sites and from inactive pumping wells in the GGS wellfield. The first suite of water samples, obtained from the first three well-nests installed in July 2005, revealed the geochemical nature of the flow system and provided the basis for which types of chemical constituents would provide the best understanding of water age, mixing, and usefulness in terms of flowpath calibration with the numerical groundwater model. In May of 2006, four addition multi-level monitoring well nests (see figure) were installed along expected groundwater flowpaths surrounding the lake. The results of analyzing samples collected at all of the available sites during 2006, indicate that the relative amounts and distribution of dissolved chloride and sulfate provide the best representation of source water mixing in area monitoring wells (relatively younger reservoir seepage vs. older ambient aquifer water). In addition to these key geochemical constituents, tritium age dating provided estimated ages of water at various depths, which further characterizes the nature of the aquifer flow system. Although some age-dating information is still pending, preliminary findings of the geochemistry and age at the site indicate definite stratification in age and source water within the aquifer. At shallow depths in the aquifer down-gradient from Sutherland Reservoir, nearly all of the source water is young in age and shows a chemical signature very close to that of the reservoir. This younger water, originating as reservoir seepage, appears to flow from the lake in the upper alluvial deposits towards the South Platte River. Below this zone, the chemical signature and ages of the water indicate a distinct water type that is characterized as regional High Plains Aquifer water that is greater than 50 years in age. A monitoring well nest installed on the south side of the South Platte River indicates an upward gradient of groundwater flow, indicating that the river receives both local flow-system water derived from Sutherland Reservoir seepage, as well as the older, regional High Plains aquifer water. This information provides the basis for model calibration of flow-system parameters using simulated particle tracking.

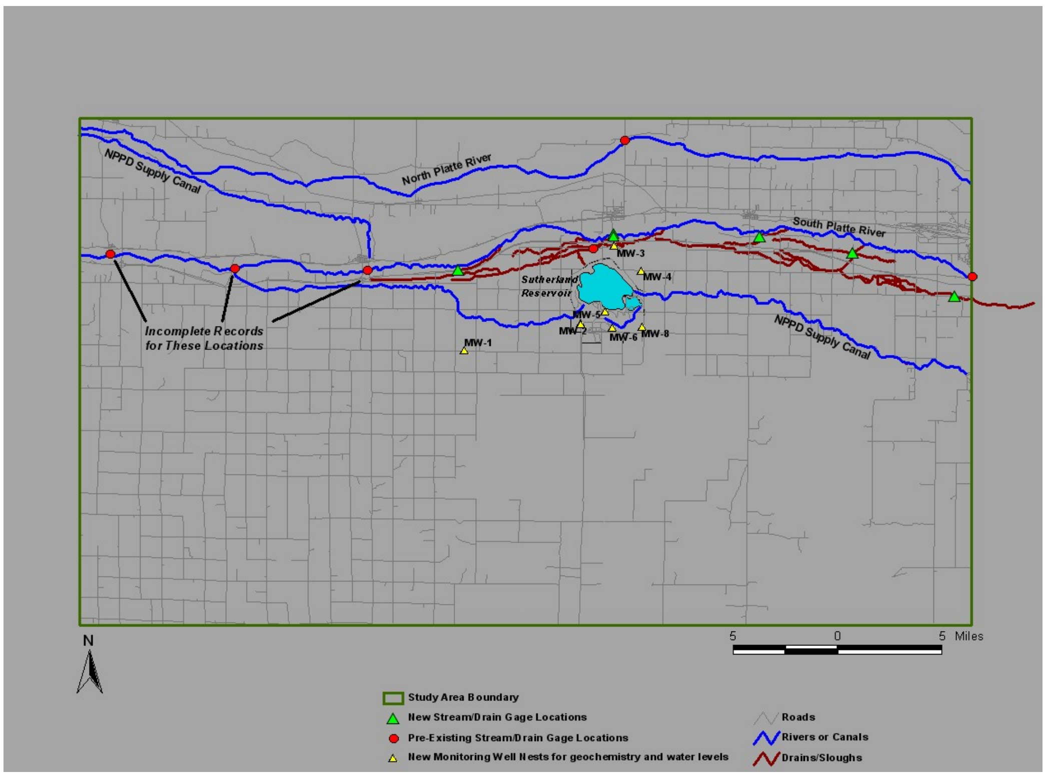
Field investigations made it clear that the area was lacking in applicable surface water flow observations for model calibration. Observations of ground water flow to/from streams/rivers/drains are crucial to parameter estimation because they improve the uniqueness of the estimated parameter values. To provide additional flow information for model calibration, six stream gages were installed in the model area (see figure). Two gages were installed to measure flow in the South Platte River (two channels of the South Platte River exist at the observation location), and four gages were installed in area drains. The flows are measured monthly by the Nebraska Department of Natural Resources (NDNR).

Data analysis has focused on assessment of historic stresses on the flow system in order to define an appropriate period for calibration and thus an appropriate set of data for calibration. System conditions over the last several decades were evaluated with regard to both surface and subsurface flow resulting from varying irrigation practices, cropping patterns, climate variations, and modifications to engineered surface water structures. The goal of the analysis was to determine a period when the system could be represented, approximately by steady-state flow (i.e. no significant changes in water levels). Based on hydrographs from regional observation wells, it was determined that within the study area, groundwater levels fluctuated over time, with both increases and decreases occurring at different locations within the model area. However, the period of 1997 to 2001 exhibited relatively stable conditions and is considered the “steady-state” period for the calibration process in this project. Crop patterns and irrigation were analyzed for the 1997-2001 time period. Using satellite imagery of cropping patterns from the University of Nebraska, and the registered well database from the NDNR, it was determined that only minor variations in the distribution of dryland and irrigated farming occurred during this period (although the specific crop type may have varied at individual locations). Following the initial steady-state stress period the model simulates transient flow from 2001 through 2006.

It is conceptualized that land use practices will have a significant impact on spatially-variable groundwater recharge in the study area. To account for this, various recharge models based on precipitation and land-use designation are evaluated. To provide a greater account of spatial variability in precipitation, data from the NDNR volunteer observation network (http://dnrdata.dnr.ne.gov/NeRAIN/?&) is being utilized in this study. Observations available from this database both provide data where National Weather Service observations are lacking, and indicate how precipitation events can vary substantially within the study area.

In addition to system inputs, a considerable amount of effort was conducted to test the representation of Sutherland Reservoir in various two- and three-dimensional model grid configurations. At the simplest level, the reservoir can be modeled using a constant-head boundary. This representation provides a stable solution within the model, but within a stress period the reservoir stage and area remain constant. From both water balance analysis of field data and model experiments, the flux of reservoir seepage is highly sensitive to reservoir stage and area. Therefore, the MODFLOW-2000 Lake Package was incorporated into the model and rigorously tested. Initially, use of the Lake Package was problematic in terms of obtaining a model solution. As expected, the simulation was sensitive to both Lake Package parameter inputs and the selected solver package and its settings. Although the Lake Package requires a significantly greater amount of input data, it is clear that it will provide an improved representation of the potential impacts to both the reservoir and underlying aquifer during the transient stress periods of the GGS models.

Numerous conceptual models with varying hydrostratigraphy at the Sutherland Reservoir/GGS site are being calibrated and evaluated. These 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. Preliminary assessments have led to recommendations for additional streamflow data and water quality data that will provide flow paths and mixing ratios for use in model calibration. A final report will be ready in the autumn of 2008.



Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater Under Uncultivated Land in an Irrigated River Valley

Basic Information

Title:	Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater Under Uncultivated Land in an Irrigated River Valley
Project Number:	2007CO152B
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End Date:	2/29/2008
Funding Source:	104B
Congressional District:	4th
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Focus Category:	Water Supply, Agriculture, Groundwater
Descriptors:	None
Principal Investigators:	Reagan M. Waskom, Jeffrey D Niemann

Publication

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Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater under Uncultivated Land in an Irrigated River Valley

by Jeffrey D. Niemann, Assistant Professor Dept. of Civil and Environment Engineering
Nik Hallberg, Graduate Student, Dept. of Civil and Environment Engineering
Timothy Gates, Professor, Dept. of Civil and Environmental Engineering
Colorado State University

Many agricultural water systems in the Western U.S. are facing extraordinary pressures that constrain water availability and use, and the Lower Arkansas River Valley (LARV) in southeastern Colorado is no exception to this situation. As early as the 1870's, the Arkansas River was harnessed to irrigate lands in the river's alluvial valley. Now, more than 1000 miles of major canals provide irrigation water to more than 100,000 ha (250,000 acres) of agricultural land stretching from Pueblo to the eastern border of Colorado. This agricultural system is the primary economic driver for southeastern Colorado. Since the 1970's, Front Range municipalities have been buying water rights in the valley. The resulting transfers of water from the Colorado Canal and Rocky Ford Ditch have dried up approximately 78,000 acres of irrigated land. Furthermore, recent litigation surrounding the Arkansas River Compact has produced increasingly strict requirements on farmers to maintain historical flows for downstream users.

Jeffrey Niemann

In the face of such pressures, various strategies have been proposed to conserve water in agricultural systems like the LARV. One conservation strategy is the removal of invasive phreatophytes such as tamarisk (salt cedar). Studies indicate that tamarisk stands may transpire significantly more water than native species, but their consumptive use is expected to depend on the water table depth, soil salinity, and many other factors (Shafroth et al., 2005). Another proposed strategy for conserving water is the application of polyacrylimides (PAM) to canals. PAM is a flocculant that promotes settling of clay particles out of canal water, which forms a lining on the canal bed that can reduce seepage losses. Improved irrigation practices, such as drip irrigation, have been suggested as another possible method for water conservation.

All of these conservation strategies aim—directly or indirectly—to reduce the amount of non-beneficial consumptive use in the system, which is the evapotranspiration (ET) from uncultivated areas. The ET from uncultivated lands within the Arkansas Valley is likely a major component of the overall water balance. Figure 1 shows a roughly 50 mile segment of the LARV above John Martin Reservoir. In this figure, colored areas indicate land that falls within the command of the irrigation systems. Green areas were planted during the growing season of 2003. Yellow and brown areas identify naturally-vegetated and fallow lands, respectively. Approximately 50% of the land area was uncultivated during the growing season of 2003. This percentage is expected to vary between years, depending on the amount of available water, and to vary seasonally with much larger areas of uncultivated land occurring in the winter. Preliminary estimates of ET from uncropped areas in a portion of the region shown in Figure 1 during 1999-2001 are on average about 52,600 acre-ft per year (Burkhalter and Gates, 2005).

Much uncertainty persists regarding the effectiveness of proposed water conservation strategies, and a key source of uncertainty is the actual reduction of the non-beneficial consumptive use that would occur if the water table is lowered by a particular amount. From studies in the literature, it is known that the ET depends on the proximity of the water table to the ground surface, and various functions have been proposed to represent this dependence including a power function (Gardner, 1958), an exponential function (Ripple et al., 1972), and a linear function (Banta, 2000). It is also known that the upflux from the ground water depends on the density and type of vegetation (Weeks and Sorey, 1973; Grismer and Gates, 1988; Jorenush and Sepaskhah, 2003). Furthermore, soil texture, salinity, salt crusting, surface cracking and transport of water vapor in the soil near the surface may play a role in determining this upflux (Grismer and Gates, 1988; Jorenush and Sepaskhah, 2003; Gowing et al., 2006). However, it is still not well-understood how all of these factors combine to control field-scale ET rates from uncultivated lands in a semi-arid environment. For example, Cooper et al. (2006) found that the reduction in ET due to a drawdown of the water table was over-predicted by 65-155% by two available models at one particular arid location. They hypothesized that the error in that case was due to long-term changes in vegetation cover as the water table dropped.

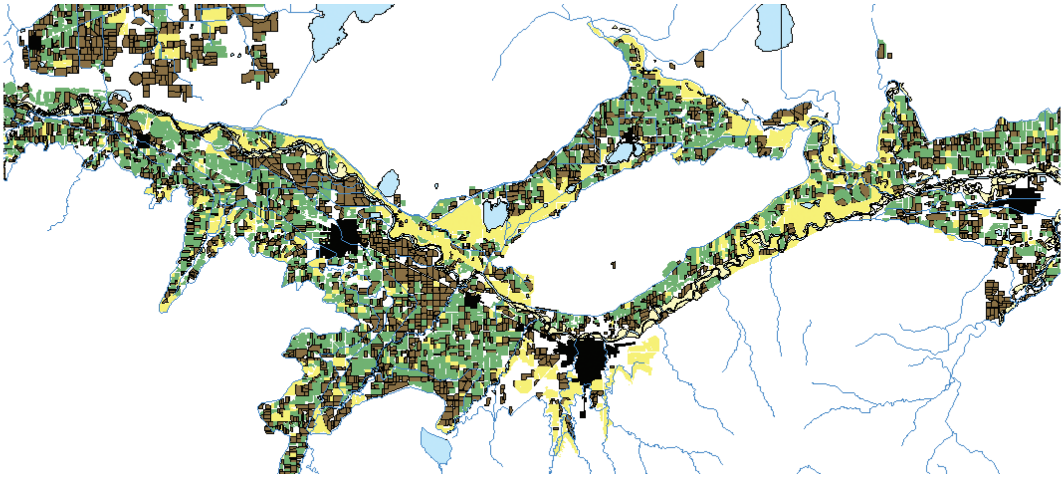

Fig 1: A portion of the agricultural lands in the LARV upstream from John Martin Reservoir. Green areas are cropped, yellow areas are naturally-vegetated, and brown areas are fallow. Data are derived from NDVI processing of five LandSat5 images taken in 2003. (Visit the CWRRI website for color version)

The overarching objective of this project is to quantify the controls on non-beneficial consumptive use of water from uncultivated lands in an intensively irrigated valley. In particular, we seek to determine: (1) the portion of total ET from uncultivated lands that comes from groundwater upflux and (2) the sensitivity of the non-beneficial ET to the water table depth. An improved understanding of the evaporative upflux from fallow fields and naturally-vegetated lands in the Arkansas Valley is expected to directly benefit the assessment of water conservation strategies in the valley. Such assessments necessarily rely on a calibrated regional model, such as MODFLOW-MT3DMS (Banta, 2000; Burkhalter and Gates, 2006), to forecast the changes in the hydrologic system that would result from proposed interventions. Such models typically calculate ground water upflux using an empirical function that depends on the water table depth DWT and reference crop evapotranspiration (ET0), which plays a central role in determining the sensitivity of ET losses to changes in DWT. An improved understanding of evaporative upflux is also expected to benefit soil salinity and water quality assessments. For example, Burkhalter and Gates (2006) used their model to estimate that a 30% reduction in ground water recharge from fields and a 50% reduction in seepage losses from canals would increase DWT by about 0.8 m in the upstream study region. The deeper water table is associated with an estimated 390 mg/l decrease in the soil salinity, which is expected to improve crop productivity. Moreover, reducing excess recharge and thereby lowering the water table may reduce the hydraulic gradient toward the river and diminish salt loads to the river by as much as 20 to 40% (Burkhalter and Gates, 2006). Such assessments are expected to be sensitive to the modeled relationship between ET losses and water table depth.

Approach

Our strategy focused on making detailed measurements at two uncultivated field sites in the LARV. ET was estimated using a remote sensing method, and potential explanatory variables, such as DWT, were measured in the field using a variety of techniques as described below. The two field sites were selected to represent different land-use conditions found in the valley (Figure 2). One of these sites is a retired field north of the town of Swink and close to the Arkansas

Fig 2: (left) Researcher downloading data from a raingage at the Swink field site and (right) Researcher downloading water table depth measurements at the Manzanola site.

River. The field is no longer cropped because it lies in a conservation easement that aims to reduce agricultural losses from floods. Because the site lies within the alluvial valley, it has very little topographic relief. The other site is located southeast of the town of Manzanola and adjacent to the Rocky Ford Highline Canal. It is naturally vegetated and has some topographic relief because it lies at the edge of the alluvial valley.

Both ET and vegetation greenness at the two field sites were estimated from remote-sensing. Elhaddad and Garcia (2006) used thermal infrared and visible band information from the Landsat5 satellite in an energy balance approach to estimate ET in the LARV. These estimates were calibrated using weather station observations and are expected to have an accuracy of 10-20% (Elhaddad and Garcia, 2006). This approach provides ET estimates on a 30 m grid once every 16 days if cloud cover is not present (Figure 3). The remote sensing algorithm also produces the normalized difference vegetation index (NDVI), which measures the greenness of the vegetation. NDVI is related to the photosynthesis and transpiration of plants (Sellers, 1985), so it is expected characterize the extent to which the vegetation is actively transpiring water.

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Both field sites were extensively instrumented to quantify potential influences on the space-time variation of ET. Multiple monitoring wells were drilled using a GiddingsTM truck-mounted drill rig that was available from the USDA Natural Resources Conservation Service. 33 wells were drilled on a 60 m grid at the Swink site, and 22 wells were drilled on an irregular, approximately 45 m grid at the Manzanola site. Hobo® Water Level Loggers were placed at the base of most wells to continuously measure the water level above the sensor (accuracy of +/- 2.1 cm). One water level logger was also placed at the ground surface at each field site to measure variations in atmospheric pressure, which improves the accuracy of the water table estimates. At each site, precipitation was measured using two tipping bucket gages, and reference crop ET was estimated using two atmometers. ET_o was also computed using data from a CoAgMet weather station at Rocky Ford, which is located about 5 mi from the Swink site and 15 miles from the Manzanola site.

On each date that the satellite passed and the sky was clear, measurements were made in each field of potential explanatory variables. Spot measurements of DWT were made at all wells using an electric tape. Gravimetric soil moisture was measured near all wells using soil samples

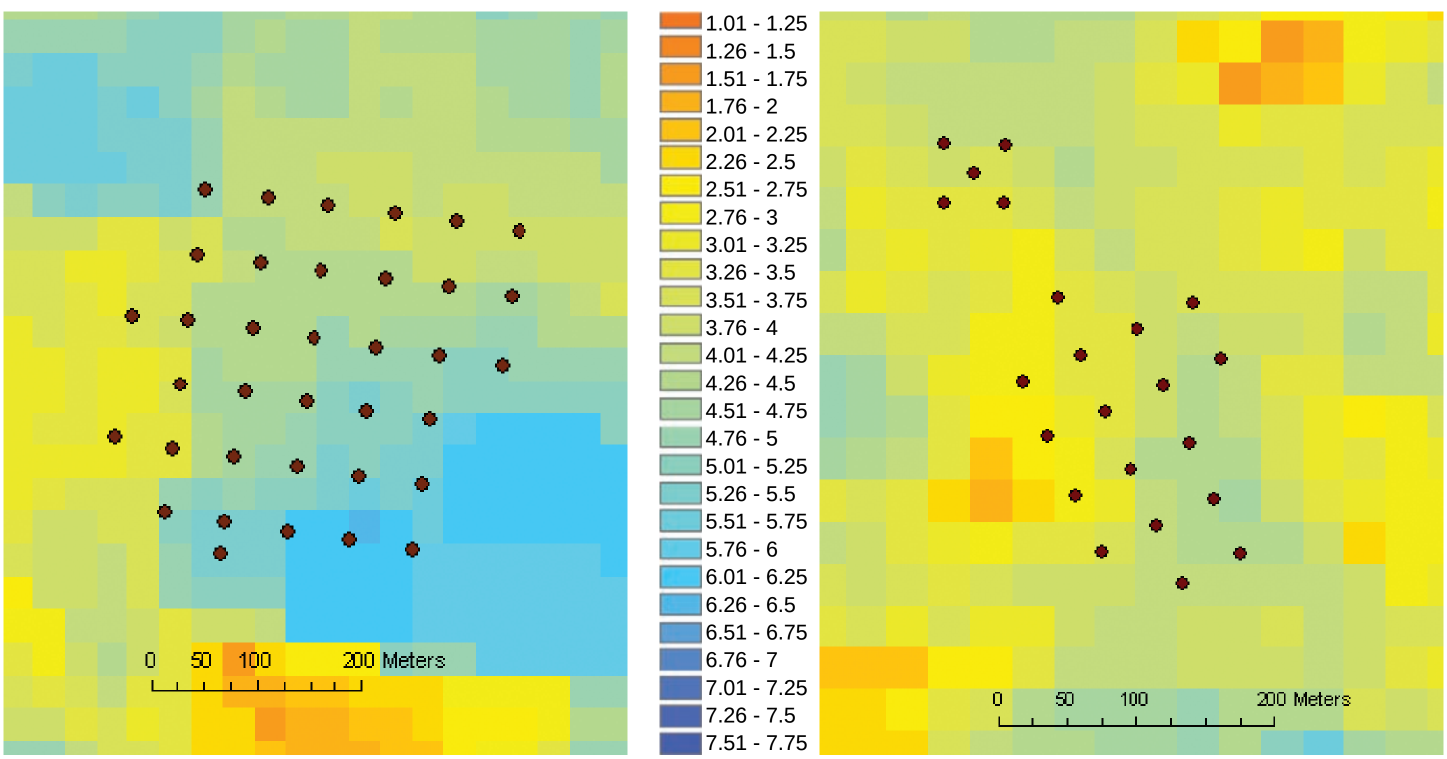

Fig 3: Spatial patterns of ET (mm/day) on 6/15/07 at the (left) Swink and (right) Manzanola field sites as estimated from the remote sensing algorithm. Dots indicate the locations of monitoring wells. (Visit the CWRRI website for color version)

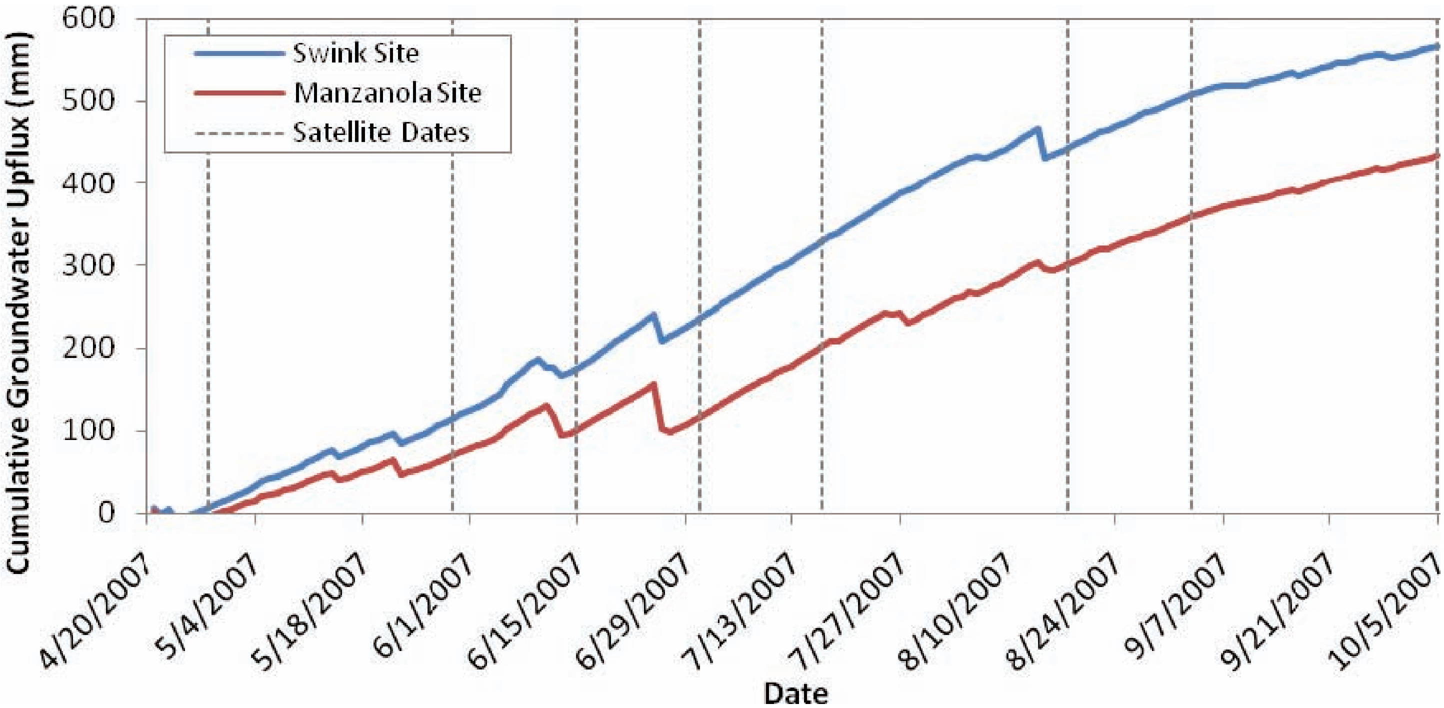

Fig 4: Estimated cumulative groundwater upflux in support of ET (mm) for the Swink and Manzanola field sites. Vertical lines indicate dates on which ET is estimated from remote sensing.

collected with an Oakfield probe at a 1 ft depth. Samples at 2 ft, 3 ft, and 4 ft depths were collected near 4 wells at each site using a soil auger. Soil salinity was estimated using a calibrated GeonicsTM EM-38 electromagnetic induction probe.

Analysis and Key Results

The contribution of groundwater upflux to the total ET was estimated using a water balance approach. First, the ET efficiency (ET / ET_o) for each field was estimated on each clear date that the satellite passed. The ET efficiency was then linearly interpolated between observation dates and multiplied by the continuous record of ET_o from the CoAgMet station to estimate the actual ET on each day during the growing season. Water for the actual ET can be supplied by changes in soil water storage, precipitation events, and groundwater upflux. No significant lateral flow or runoff is expected due to the dry condition of the soil during the study period. The maximum possible contribution by changes in soil water storage was estimated by assuming that the soil began saturated and then fully dried over the course of the study period. This maximum possible contribution was found to be insignificant in comparison to the total ET during the study period. It is assumed that all precipitation became ET (i.e. no groundwater recharge occurred). Thus, the cumulative groundwater upflux during the study period can be estimated as the cumulative ET minus the recorded precipitation depths. These results are shown in Figure 4. Reference crop ET is on average 5.2-7.7 mm/day during the growing season. Actual ET for the two sites is estimated to be about 4.9 mm/day at Swink and 4.0 mm/day at Manzanola based on the remote sensing measurements. Based on the results in Figure 3, the groundwater upflux to ET is on average 3.4 mm/day at Swink and 2.6 mm/day at Manzanola, which is 65-70% of the actual ET. These estimates suggest that the non-beneficial consumptive use of water at both sites is primarily supplied from upflux from the shallow water tables at both sites.

We have also examined how much of the variability in ET can be explained by variations in the groundwater depth and other site characteristics. This issue was primarily investigated through a series of linear and nonlinear stepwise correlation analyses. In particular, the correlation analysis attempts to explain variations in ET / ET_o as linear or specified nonlinear functions of the potential explanatory variables. The stepwise approach incrementally adds variables to the regression equation and by evaluating whether the variance explained by each additional variable is statistically significant. At the Swink site, DWT is relatively uniform, varying less than 1.5 m between all the wells and all times. As a result, the variations of ET / ET_o within this field are not significantly influenced by the variations in DWT. Instead, vegetation as described by NDVI is the most important variable in explaining the variations in ET / ET_o (Figure 5a). The Pearson correlation coefficient between ET / ET_o and NDVI is 0.60 when grouping the observations from all dates at the Swink site. In contrast, the Manzanola site exhibits a larger range of DWT, varying from nearly 0 m to more than 2.5 m. At this site, the most important variable in explaining the variation in ET / ET_o is DWT (Figure 5b).

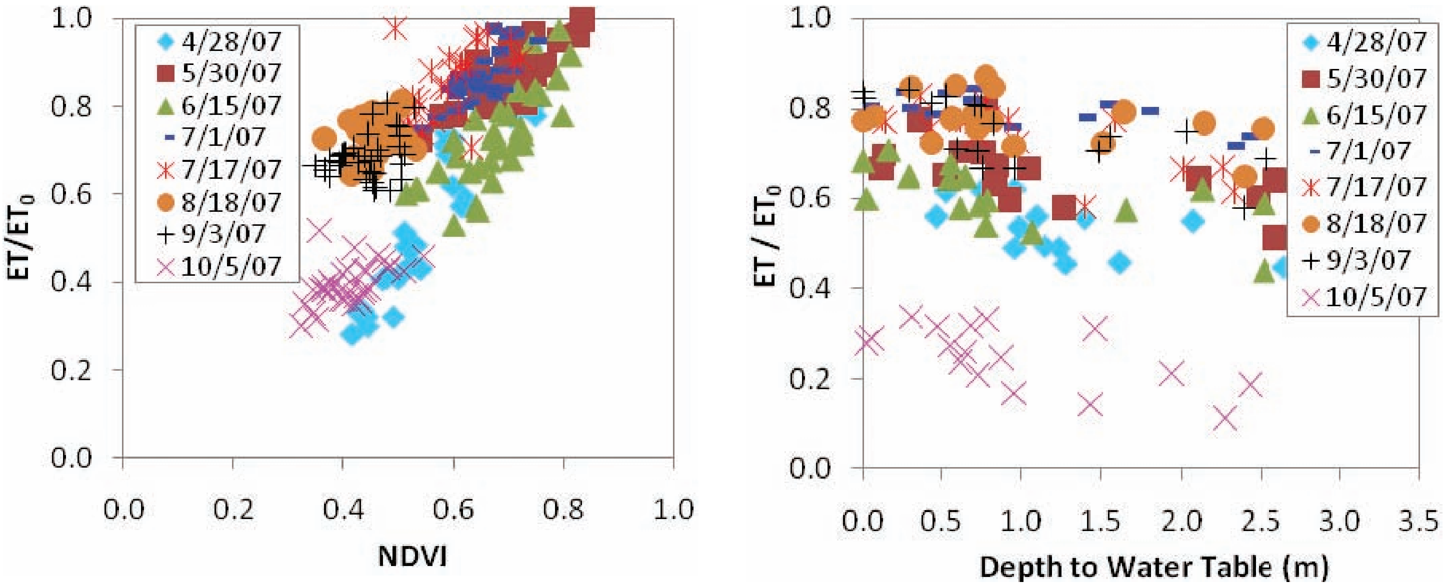

Fig 5: (left) The observed relationship between the evaporative efficiency (ET / ET0) and NDVI at the Swink field site, and (right) the observed relationship between evaporative efficiency and DWT at the Manzanola field site. (Visit the CWRRI website for color version)

When observations from all dates are included in the regression analysis, the correlation coefficient between ET / ET_o and DWT is -0.42, indicating that a larger water table depth tends to result in a smaller evapotranspiration efficiency.

Key Conclusions

Although monitoring and data analysis are ongoing, these preliminary results demonstrate that groundwater upflux was the dominant contributor to ET at both field sites during the growing season of 2007. This confirms that non-beneficial ET is closely linked to the presence of a shallow water table under the uncultivated lands in the LARV. Groundwater upflux is expected to be an important contributor to ET at uncultivated sites in the LARV where the water table is relatively close to the ground surface, but the quantitative contribution of groundwater upflux is expected to depend on the local soil and vegetation characteristics. Fluctuations in ET were shown to depend on fluctuations in the depth to the water at one of the two study sites. This site (the Manzanola site) exhibited a wider range in water table depths due to the topographic variability at the site. The relationship identified at this site still contains much unexplained scatter, but it hints that observable reductions in ET could be achieved if the water table is lowered by 1 to 2 m. Much more research is needed to clarify this relationship. In particular, the spatial variations of ET observed here may not be analogous to the temporal changes in ET that would result from lowering the water table. In particular, the vegetation patterns have likely adapted to the spatial variations in water table depth within these sites. If the water table was abruptly lowered, the vegetation would require a significant period of time to adapt to the new conditions, which would potentially alter the relationship between water table depth and non-beneficial ET.

Effects of Pine Beetle Infestations on Water Yield and Water Quality at the Watershed Scale in Northern Colorado

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Effects Of Pine Beetle Infestations On Water Yield And Water Quality At The Watershed Scale In Northern Colorado

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Past forest management practices have altered forest structure and diversity. Many forested landscapes in the Rocky Mountain area are composed of overstocked even-aged stands. As a result, larger, more contiguous landscapes in these areas have become susceptible to bark beetle outbreaks. Both biotic and abiotic factors affect bark beetle population development and spread (Samman et al., 2000). Biotic factors include bark beetle population biology, and type, age, and tree species. Abiotic factors include climate, geographic location, and weather related phenomena such as extended periods of drought.

The mountain pine beetle (MPB) is killing millions of lodgepole pine trees in Colorado. Though the beetles are part of forest succession, the natural cycles of the forest have been disrupted over the past century. As a result, the impact of the beetle epidemic is greater than ever seen before. As the forests succumb to the beetles and die, tree mortality has altered the hydrological processes, decreasing interception and evapotranspiration, thus potentially increasing soil moisture and streamflows. What are the effects of beetle killed forests on water quantity and quality?

Problem Statement

In 1939 a severe wind storm in the high plateaus of Colorado created ideal breeding conditions for the Engelmann spruce beetle (Love, 1955). By 1946, the beetle had killed trees covered hundreds of square miles. When the epidemic finally ran its course, it killed up to 80% of the forest trees in the affected area. Before the outbreak, the forest consisted of Engelmann spruce and sub-alpine fir in a 4:1 ratio, with a basal area of 34 m^2/ha and a volume of 343 m^3/ha. Twenty five years later, dead trees were still standing, and the spruce to fir ratio was 1:4 with a basal area and volume of 10 m^2/ha and 60 m^3/ha respectively.

Research focused on 4 watersheds, 2 treatment (White River and Yampa River) and 2 control (Elk River and Plateau Creek) watersheds. Average water yield increases for a 15 year (1946-60) post epidemic period were 22% for the White watershed and 14% for the Yampa watershed. The higher water yields in the treatment watersheds were attributed to their exposure. The Yampa River drains primarily to the north (lower solar energy) whereas the White River drains to the west (higher solar energy). Maximum annual instantaneous rate of flow for the White watershed increased 27% whereas no significant change occurred for the Yampa. The variable response was again attributed to watershed exposure. Interestingly, spring thaw was delayed for all watersheds, both for the treatment and control during the post epidemic period. The delay was attributed to "general climatic conditions." Overall, the increased discharge from the White and Yampa River watersheds was due to greater accumulations of snow that melted in the spring to produce more water (Love, 1955). Analysis of streamflow records revealed that a major increase in stream flow occurred after the epidemic. The smallest increases on both drainages occurred during the first 5-year period (when the beetle population was multiplying to epidemic proportions); the largest increases occurred 15 years later. Water yields 25 years after the outbreak were approximately 10% greater than expected yields (Bethlahmy, 1974). A constant White River annual flow increment indicated that some type of stabilization was occurring on the watershed that is replacing the beetle-killed spruce and pine (Mitchell and Love 1973).

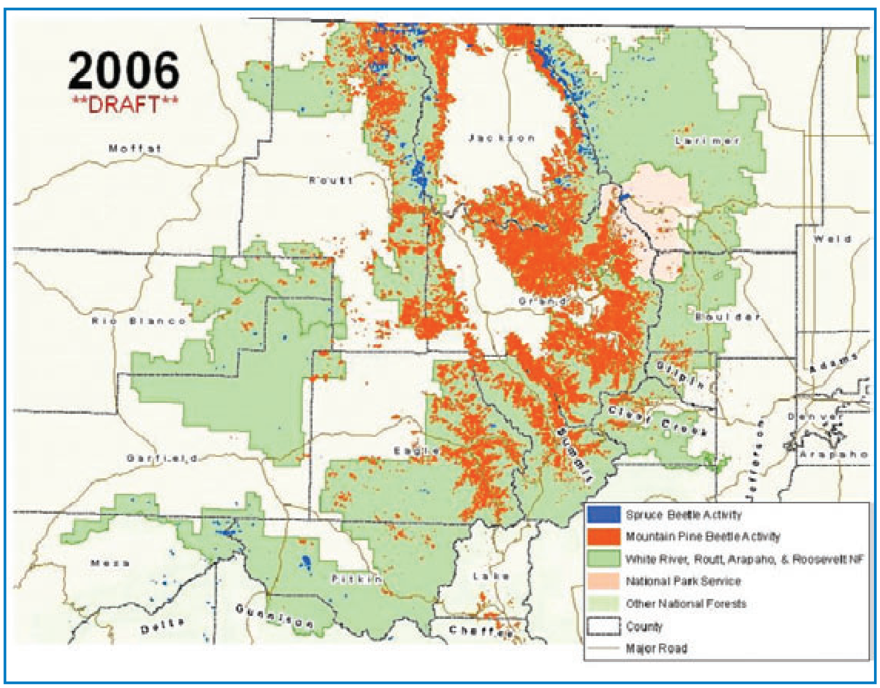


Figure 1. Extent of beetle-killed areas in North-central Colorado (Adapted from Colorado State Forest Service.

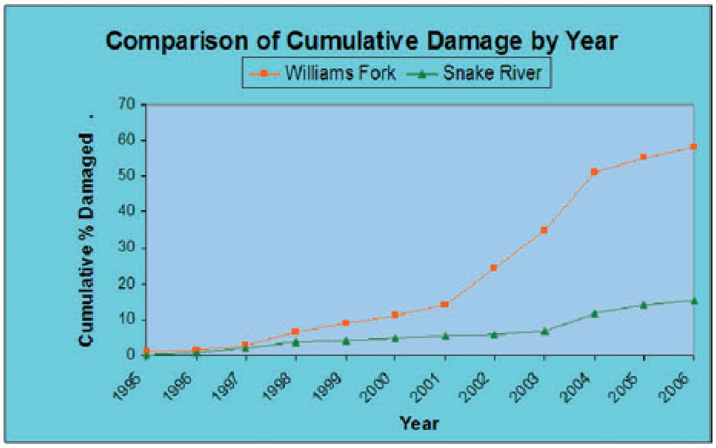


Figure 2. Beetle killed area over time for Williams Fork and Snake River watersheds.

A mountain pine beetle outbreak in 1975-1977 killed an estimated 35% of total timber in Jack Creek in Southwest Montana. Data analysis for 4 years prior to and 5 years after tree mortality indicated a 15% increase in water yield, a 2-3 week advance in the annual hydrograph snowmelt peak, and a 10% increase in low flows and little increase in peak flows. The streamflow is snowmelt dominated. The advance in snowmelt timing was due to reduced springtime soil moisture recharge requirements and changes in the forest canopy cover from the tree mortality. Because of the de-synchronization, the 15% increase in average annual water yields did not produce a large difference in peak flows. The data indicated that, in the absence of major site degradation by soil compaction, timber harvesting spread uniformly throughout drainage may not increase peak flows. However, the pre- and post epidemic discharge records indicate that the highest daily discharges occurred during the last 2 weeks of May and the first 2 weeks of June. Therefore caution must be used before drawing absolute conclusions about impacts on peak discharges (Potts 1984).

The paired watershed technique was used to assess the streamflow changes of Camp Creek in interior British Columbia after clear-cut logging occurred over 30% of it 8,400 acre watershed. Existing hydrometric data for Camp Creek (beetle infested) and those of an adjacent control, Greata Creek (not beetle infested), were analyzed for both the 1971-1976 pre-logging and 1978-1983 post-logging periods. Post-logging Camp Creek streamflow changes are characterized by increases in annual yield and annual peak flows, as well as earlier annual peak flow and half-flow volume occurrence dates. The direction and magnitude of these post-logging streamflow increases are clear and consistent. The results are in good agreement with the findings of most previous studies conducted on smaller watersheds.

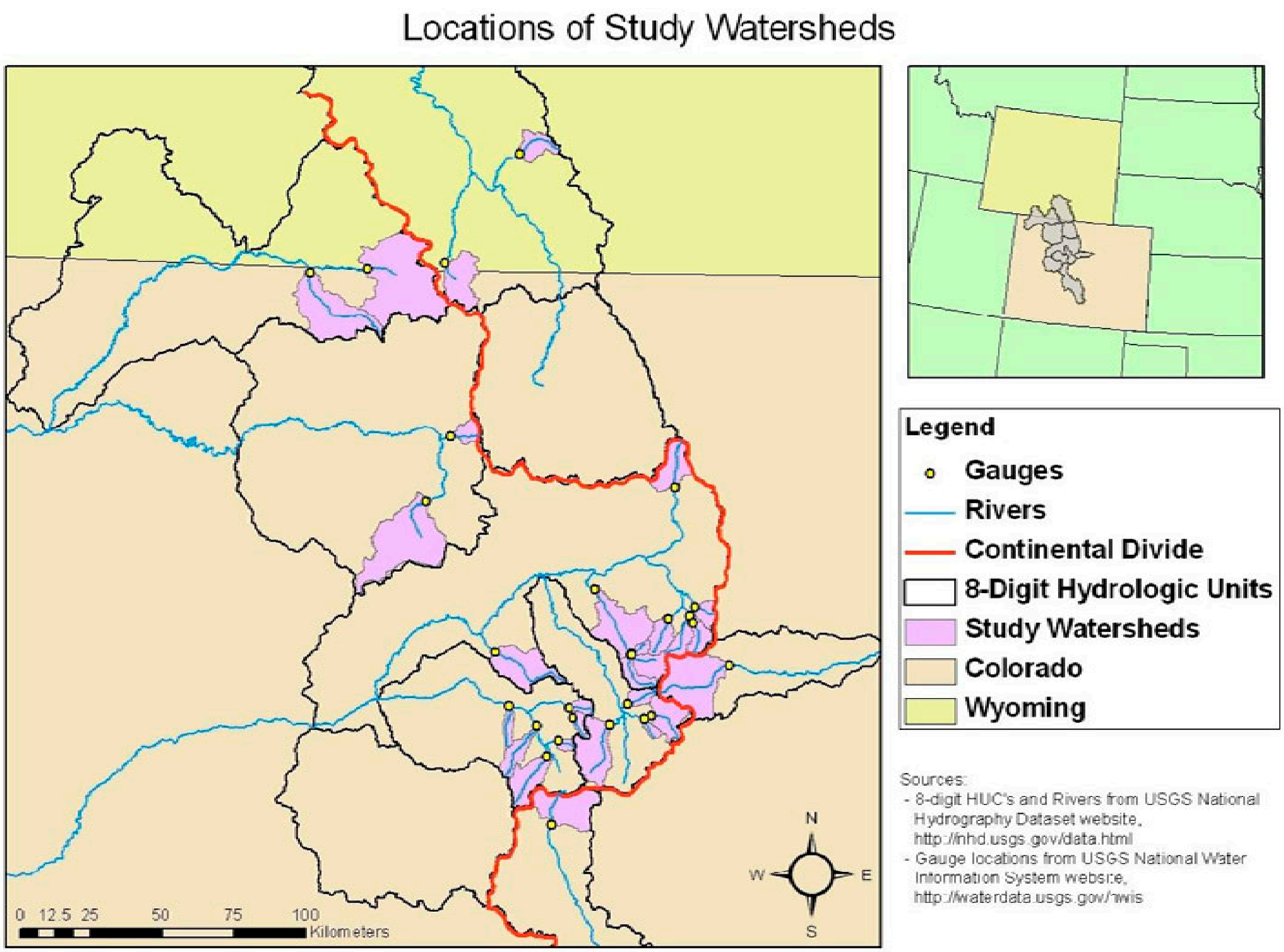


Figure 3. Location of selected watersheds used in this study.

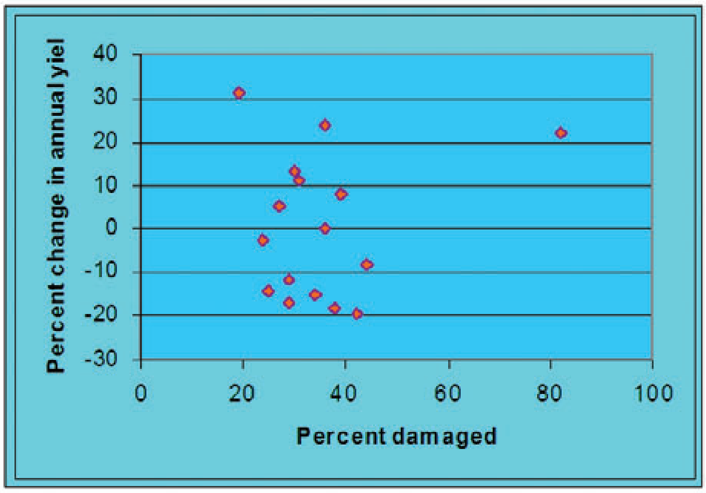


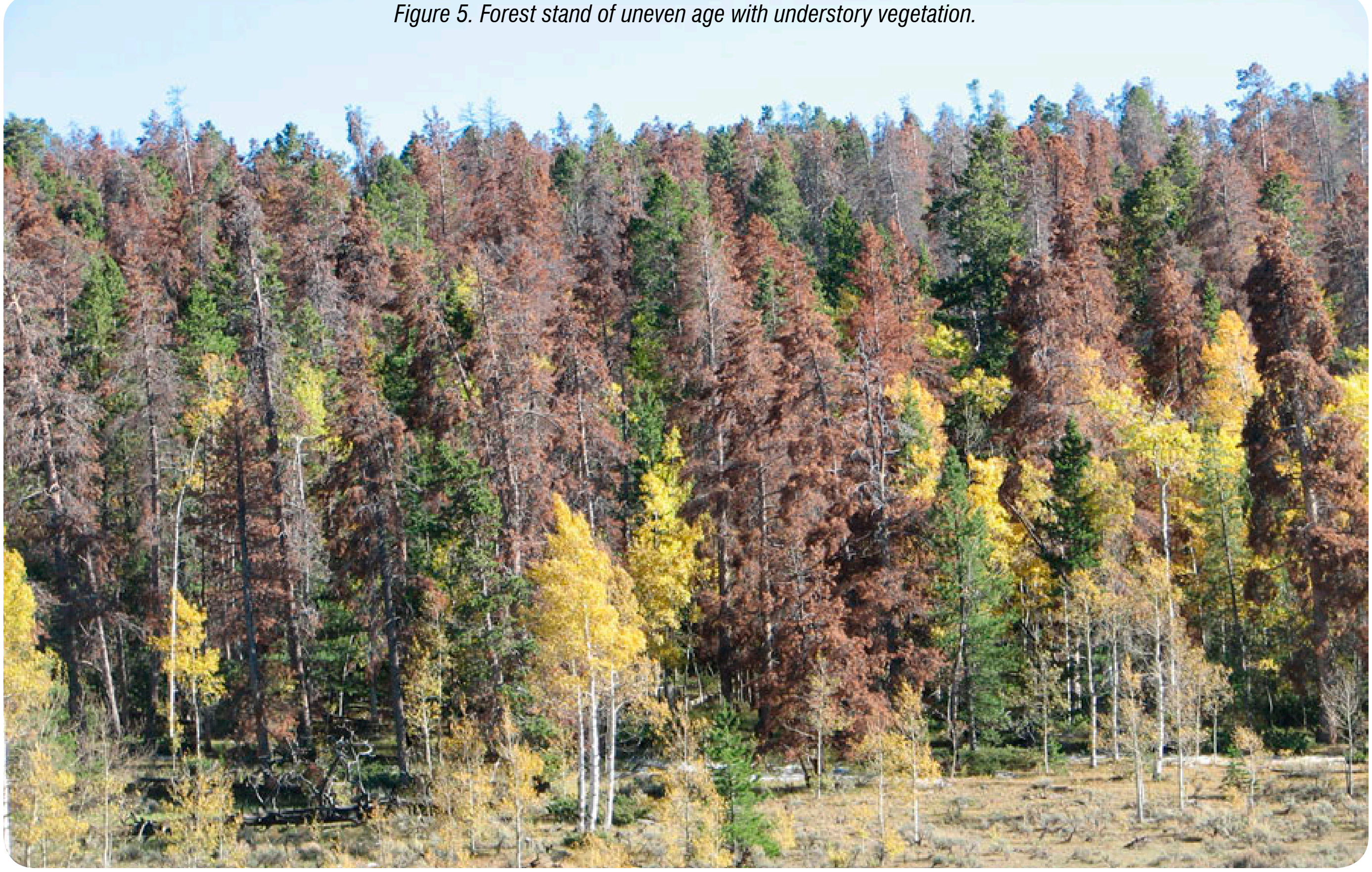
Figure 4. Changes in annual water yield as a function of beetle killed area in the watershed.

This study provided strong evidence that changes in streamflow from large forested watershed can be significant if a sizeable portion of its drainage is clear-cut (Cheng 1989).

A review of the literature on the effects of timber harvesting on water yield has been done (Stednick, 1996) and specifically for Colorado (MacDonald and Stednick, 2003). From these efforts it was determined that the annual water yield in the higher elevation forests is proportional to the amount of forest canopy as indexed by the basal area. Timber harvesting will remove the forest canopy removed and increase water yield due to the reduction of winter interception and losses and summer evapotranspiration. The increase in water yield decreases as the forest regrows. Beetle killed forest will have reduced interception and reduced evapotranspiration losses, and thus should respond similarly as timber harvesting.

Changes in hydrologic processes after an insect infestation will alter streamflow responses. Removing the forest cover (harvesting or beetle kill) from areas that receive less than about 20 inches of annual precipitation will have little effect on the amount and timing of runoff (MacDonald and Stednick, 2003). The reason is that the potential reductions in interception and transpiration are negated by the increase in soil evaporation. Once annual precipitation exceeds 20 inches, forest harvest or dieback can increase the amount of annual runoff, and this increase generally is proportional to the amount of annual precipitation. At least 20% of the forest canopy needs to be killed or removed before there was any measurable increase in annual runoff in the Rocky Mountains (Stednick, 1996; Stednick and Troendle, 2004). Removing a smaller proportion of the forest cover may still increase the amount of runoff, but this increase probably will not be detectable using standard stream gauging techniques. Nearly all of the increased water yield will come on the rising limb of the snowmelt hydrograph in May-June. Detection of water yield increase downstream or outside the treatment watershed, in the case of paired watershed studies has always been problematic (Stednick and Troendle, 2004).

Figure 5. Forest stand of uneven age with understory vegetation.



Study Objectives

A beetle epidemic in Colorado is killing trees in the sub-alpine 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 progression of watershed areas that have been beetle killed were 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 and cooperation by some drinking water providers were used. Streamflow metrics included annual water yield, peak flows, and low flows. The literature suggests that the disruption of nutrient cycles may result in water quality changes. 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.

By using a combination of beetle-killed forest areas and watershed boundaries with USDI Geological Survey stream gauging stations a threshold of response for water quantity and quality was hypothesized. Study objectives were to:

1. Select a set of watersheds in Northern Colorado with increasing areas of beetle killed areas with existing long-term streamflow records
2. Obtain streamflow records for undisturbed and beetle affected watersheds, analyze with analysis of covariance and flow duration curves
3. Determine a threshold of response for beetle killed watershed area and water yield response
4. Similarly quantify the threshold of response for water quality changes

Given the expanse of the beetle outbreak, how much water yield increase could be expected, and are these increases detectable with the current stream gauging network. The federal and state forest service have initiated silvicultural prescriptions to improve forest health and

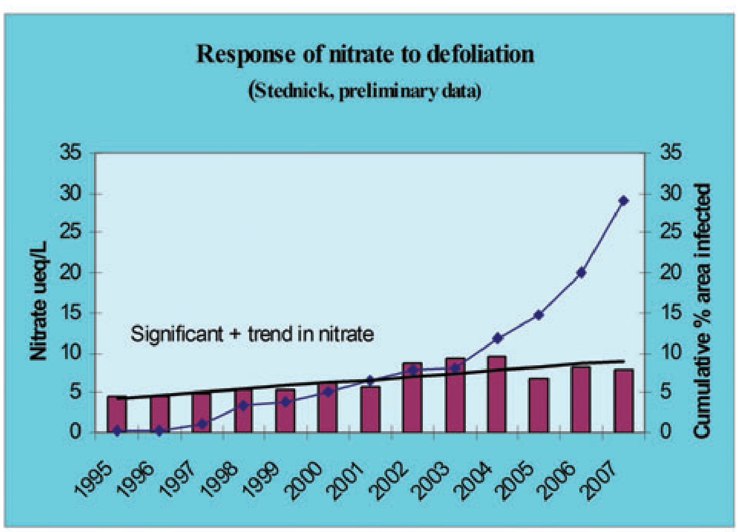


Figure 6. Increases in nitrate-nitrogen concentrations and beetle-killed area over time in Williams Fork.

reduce beetle population viability, but water yield increases can be expected already.

The USDA Forest Service conducts annual aerial surveys of forest health (Harris, 2005). The aerial coverage of beetle killed areas has dramatically increased over the past 6 years, especially in Northern Colorado (Figure 1). The USDI Geological Survey has the largest network of stream gauging stations, albeit the loss funding for stations over time is a critical loss. Stream gauging stations were evaluated for long term stability and homoscedastcity of data (e.g. Troendle and Stednick, 1998). The research effort was to identify a progression of watershed areas of beetle killed forests and relate the water yield from these systems to other watershed with minimal disturbance of beetle killed areas (Figure 2). The direct comparison of stream flows over a long period of time eliminates the need to include precipitation as a qualifier.

On-site visits were conducted on the selected watersheds to determine suitability of the watershed for study (Figure 3). Many watersheds in Colorado are subject to water transfers or other hydromodification. If hydromodification does occur, streamflow diversion data were obtained. Watersheds were evaluated for land use changes over the period of record of streamflow. Land use changes need to be separated from the effects of the beetle kill. Given that most of the watersheds are on national forest lands, land use changes should be minimal.

Annual Water Yield, Peak Flows and Low Flows

Changes in annual water yield following beetle kill were variable (Figure 4). We expected an increase in annual water yield with increased beetle killed area. Instead, we detected water yield decreases, that is less water yield than before the beetle kill. With further examination, we found that not all forest stands infected by beetles are equal. In watersheds with even-aged forests, water yield increases were detected. Even-aged forest often have little to no understory vegetation, thus interception and evapotranspiration saving increased annual water yields. Where watersheds were uneven-aged (Figure 5) a vegetation understory, often of other tree species was able to effectively use the increased soil moisture. The understory vegetation responded to the increased soil moisture by increasing their growth rates. Most watershed-scale investigations described assume that infested forests are dead or alive; however, a stand-scale investigation in the Rocky Mountains of Colorado found that infested forests are more complex and that the presence of a multi-story stand may mitigate the hydrologic effects of beetle-kill (Schmid et al., 1991).

The effects of MPB on forest hydrology may be similar to those experienced after forest harvesting. Within even-aged stands without significant understory, these effects include: increases in annual water yield, increases in late summer and fall low flows, variable responses (no change or increases) in peak flow size, and possibly earlier timing of peak flows. Furthermore, these effects may last up to 60–70 years. The presence of uneven-aged stands will likely reduce these effects (Schmid et al. 1991).

Peak flows are the maximum flow rate that occurs within a specified period of time, usually on an annual basis and occurs between May and June due to spring snow melt. Snow accumulation and melt control peak flows. Beetle killed forested watersheds may increase peak flows as they can allow for greater accumulation of snow, reduced sublimation and accelerated snow melt. The literature showed mixed responses to peak flow increases. Similarly, the watersheds used in this study showed mixed responses. Some watersheds had increased peak flow, albeit not statistically significant, while other watersheds did not show peak flow increases. Peak flow increases were not always associated with increased annual water yields.

A variety of watershed metrics were derived from the GIS coverages in an attempt to identify casual mechanisms for water yield and peak flow changes. Aspect, slope, elevation, watershed position, and climate metrics were not able to predict water yield changes. Additional work in watershed modeling is needed. Additional work using flow duration curves is ongoing in an attempt to better identify other stream flow changes, both magnitude and timing.

Water Quality

Water quality from forested environments has long been noted for its excellent water quality (Stednick, 2000). Water quality changes following timber harvesting are considered negligible at the watershed level (MacDonald and Stednick, 2003; Stednick and Troendle, 2004). The loss of forest vegetation through beetle infestations or epidemics will interrupt the nutrient cycle. Little research has been conducted on the effects of tree mortality on nutrient concentration in surface waters. Nitrate concentration increased after a beetle attack in surface waters for the Bavarian Forest National park in Germany (Huber et al., 2004; Huber, 2005). It is uncertain if the nitrate increase was due to lack of processing of atmospheric inputs or disruption of the nutrient cycle. The highest concentrations were measured five years after the dieback, but concentration increases were detectable up to 17 years later (Huber, 2005).

Water quality monitoring on the White River Plateau suggested increased nutrient concentrations in surface waters, particularly nitrate-nitrogen (Stednick, unpublished). Additional water quality monitoring showed increased nitrate concentrations in surface waters in several watersheds. Nitrate concentrations increased over time concurrently as the percent watershed area increased (Figure 6). Similar responses have been observed in forested watersheds infected with the defoliating gypsy moth. The nitrate concentration increases are probable related to increased soil nitrification, due to increased soil moisture, increased soil temperature, increased food source (litterfall), and decreased vegetation uptake. A water quality response was also measured in stream temperature, especially when the riparian forest was killed. Additional water quality parameters did not change.

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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 water policy information 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:	2007CO149B
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End Date:	2/28/2008
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Descriptors:	
Principal Investigators:	Reagan M. Waskom

Publication

1. Brown, Jennifer, ed., 2007, A River of Change, Information Series Report 104, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 24 pages.
2. Pritchett, James and Jennifer Thorvaldson, 2007, Some Economic Effects of Changing Augmentation Rules in Colorado's Lower South Platte Basin: Producer Survey and Regional Economic Impact Analysis, Completion Report 209, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 44 pages.
3. Fontane, Darrell and Julia Keedy and Jose Salas, 2007, Impact of Steamflow Variability on the Colorado River System Operation, Completion Report 208, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 86 pages.
4. Colorado Water Newsletter, Volume 24 - Issue 1 (February/March 2007), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 28 pages.
5. Colorado Water Newsletter, Volume 24 - Issue 2 (April/May 2007), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 38 pages.
6. Colorado Water Newsletter, Volume 24 - Issue 3 (June/July 2007), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 36 pages.
7. Colorado Water Newsletter, Volume 24 - Issue 4 (August/September 2007), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
8. Colorado Water Newsletter, Volume 24 - Issue 5 (October/November 2007), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
9. Colorado Water Newsletter, Volume 25 - Issue 1 (January/February 2008), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 36 pages.

Third Annual Water Tables Benefit: A Night of History and Heritage

by CSU Libraries Staff

CSU Vice President Joyce Berry views historic documents in the Archive with table host John Hill during the opening of Water Tables 2008.

Water Tables made another big splash this year. The annual benefit, hosted by Colorado State University Libraries, attracted nearly two hundred respected guests from across the state and raised more than $30,000 for the CSU Water Resources Archive, which preserves materials critical for documenting the state's water history.

"Water Tables allows the Archive to make connections with friends in Colorado's water community," said Patty Rettig, the institution's head archivist. "The collections here are important, and this event helps people learn more about them."

During the cocktail hour, hosted in the Morgan Library, guests were able to tour the archive and invited to inspect materials documenting the state's water heritage, including items related to interstate water compacts, reclamation projects, groundwater, and the environment. On display was an array of historic items, including an exhibit featuring Colorado water leaders and innovators Ival V. Goslin and Ralph L. Parshall.

Now in its third year, Water Tables surpassed previous records for attendance and donations. Guests were treated to good food, lively conversation and networking opportunities in what has become a showcase for distinguished personalities in the Colorado water community.

Among those in attendance was Dick MacRavey, a fixture at the Colorado Water Congress for nearly fifty years. MacRavey recently donated to the archive several personal items documenting his long and celebrated career in water policy and administration. Other guests included water engineers, lawyers, administrators, farmers and ranchers, and interested citizens.

A highlight of the evening came when Dick Farr remembered his late father WD, a respected figure in Colorado's water history who is best remembered for his leadership and his ability to unite the state's fractious water interests behind common causes. The Farr family recently announced its decision to donate the papers of WD to the Water Resources Archive.

"Dad would be thrilled to know the work you all are doing," said Farr.

In addition, more than a dozen CSU graduate students were able to attend the event thanks to the benefit's silver sponsors. Students Carol Hutton and Nick Kryloff offered remarks highlighting the importance of archival collections for historical research.

Dick MacRavey and Dick Farr converse after addressing the crowd during Water Tables 2008. Dick Farr represented the Farr family in announcing the donation of his father's papers to the Archive.

CSU graduate student Nick Kryloff emphasizes the importance of the Archive to primary research.

The 2008 Water Tables hosts--experts in all fields related to water who moderated discussions for guests.

"At the archive I found a wealth of untapped information here that made my graduate research possible," Kryloff said. Hutton, a first-year graduate student still deciding on a research topic, received encouragement and advice from some of the state's top water professionals.

Dave Stewart, head of the event's planning committee, similarly emphasized the importance of the Water Resources Archive for CSU students. "Tonight is really all about the students," Stewart said. "And tonight we are helping to develop a key resource for them to use."

Guests enjoyed a three-course dinner, as well as discussions at each table about important water issues—from reclamation and environmentalism to imminent personalities in western water history. Each table was hosted by water experts from a wide range of disciplines, including water history, policy, and administration.

Many attendees commented on the organization and classiness of the event, as well as the extensive knowledge of their table hosts.

"The evening was enjoyable, and it was a credit to CSU and its library system," noted Ken Wright of Wright Water Engineers, event sponsor and Archive donor whose materials are housed in the Archive. "The 19 or so tables all had good discussion moderators who had been thoughtfully selected. We are already looking forward to the 2009 Water Tables."

The benefit has grown significantly since its inception in 2006, thanks to the guidance of the Water Tables Planning Committee and the support of the event's sponsors. With its success this year, Water Tables promises to continue to raise awareness of the materials at the Water Resources Archive and to attract outstanding members of the state's water community.

Table Hosts

Dick Bratton, John Hill, Karl Dreher, Sara Duncan, Jo Evans, Alan Hamel, Mark Harvey, Diane Hoppe, Dave Little, Don Lopez, Dan Luecke, Dan Merriman, Del Nimmo, Don Pisani, Leroy Poff, Jack Ross, Steven Schulte, Dan Tyler, Brian Werner, Ellen Wohl

Water Tables Planning Committee

Mike Applegate, Mark Fiege, Webb Jones, Mary Lou Smith, Dave Stewart, Robert Ward

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Mr. and Mrs. Robert Ward
Wright Water Engineers, Inc.

Hydrology Days 2007

The 2007 Hydrology Days will be held at Colorado State University during March 19 - March 21, 2007.

Abstracts are due by February 9, 2007.

Hydrology Days has been held on the campus of Colorado State University each year since 1981. Hydrology Days is a unique celebration of multi-disciplinary hydrologic science and its closely related disciplines. The Hydrology Days vision is to provide an annual forum for outstanding scientists, professionals and students involved in basic and applied research on all aspects of water to share ideas, problems, analyses and solutions. The focus includes the water cycle and its interactions with land surface, atmospheric, ecosystem, economic and political processes, and all aspects of water resources engineering, management and policy.

The Hydrology Days Award is presented each year to an outstanding individual in recognition of his/her contributions to hydrology and related fields. In recognition of his outstanding contributions to hydrologic science in the areas of infiltration theory, soil water hydrology, and preferential flow and solute transport in soils, the 2007 Hydrology Days Award will be presented to Professor J-Y Parlange. The award will be presented during a special session in which Professor Parlange will present the Hydrology Days Award Lecture titled "Recent Advances in Hydrological Sciences"

In addition to the Annual Hydrology Days Award session, and the sessions associated with the Borland Lecturers in Hydrology and Hydraulics:

- Recent Advances in Hydrological Sciences - Hydrology Days Award Lecture: Prof. J-Y Parlange - Cornell University
- Behavioral Modeling: A New Theoretical Framework for Hydrologic Predictions - Borland Lecture in Hydrology: Prof. M. Sivapalan - U. of Illinois
- Sediment Transport and Storage in the Andes-Amazon Sediment Dispersal System - Borland Lecture in Hydraulics: Prof. T. Dunne - UCSB

Special sessions will address:

- Land Use Changes and Streams
- Nutrient Dynamics in Alluvial Streams
- Biocomplexity Issues Related to Interactions between Humans, Aquatic Ecosystems and Complex Landscapes
- Emerging Contaminants
- Measuring and Modeling the Mountain Snowpack;
- Monitoring and modeling pollution and water quality in irrigated stream-aquifer systems
- Estimating evaporation and evapotranspiration in the field
- Groundwater Remediation - focusing on advancements in groundwater remediation technologies
- Transport in Porous Media - focusing on fate and behavior of contaminants in subsurface environments
- Ground water-Surface water conjunctive management
- Semi-arid region vadose zone hydrology and contaminant transport
- Scaling issues: scale dependence and scale invariance in hydrology
- Morphodynamics
- Detecting and Modeling Climate Variability and Change Using Stochastic Approaches
- Stochastic Techniques in Water Resources Planning and Management

For detailed information about Hydrology Days 2007, including details about special sessions, please go to our web page at:
http://HydrologyDays.ColoState.edu/

The web page also provides information about on-line registration and on-line submission of abstracts and papers.

MEETING BRIEFS

2007 Lower South Platte Water Symposium

HIGHER DEMANDS FOR WATER AND PRIORITIZATION OF water use, along with concerns about climate variability prompted approximately 140 participants to attend the Lower South Platte Water Symposium held on March 7, 2007 at Northeastern Junior College in Sterling. This year's theme, Today's Actions for Tomorrow's Livelihood, included a variety of topics relevant to water management in the Lower South Platte.

Conference speaker Brad Udall, Western Water Assessment, answers a reporter.

Rick Brown (Colorado Water Conservancy Board) opened the conference by describing the Statewide Water Supply Initiative (SWSI) and the Roundtable process, noting the contention he has observed over quantifying of even very small amounts of water during these processes. Rick posed four questions to the predominately agricultural audience: Is preservation of Colorado Ag a goal? What is Ag willing to do to achieve the goal? Is new water development preferable to Ag transfers? Should Ag water use continue in all areas that are currently irrigated? Rick observed that the SWSI process is almost 10 years into the 2000-2030 planning horizon and only one new project has been built thus far. He stated that we must be able to make decisions in midst of uncertainty, as we cannot wait for complete certainty in water planning. To move forward in the face of uncertainty Colorado must resolve some key issues, specifically the Black Canyon and Aspinall Unit reauthorization, endangered species issue on the Gunnison, the Colorado River Compact, and growth in areas lacking renewable water supplies. Rick concluded his talk by stating the importance of resolving these issues in order to maintain water in Ag.

Jim Hall, Division 1 Engineer, told the audience that it looked like most Eastern Plains reservoirs will fill this spring before addressing what has happened on the South Platte recently. Jim observed that fear of drought is almost as serious as drought, as people become aggressive about protecting water supplies and acquiring new ones. To date, over 1000 wells have been shut down on the S. Platte and Jim has seen both more conflict and more cooperation. The biggest change is that historically, there was no call on river during winter. During the last 5 years, however, the S. Platte has been under administration for most of year, keeping both junior users and augmentation plans out of priority. The gentlemens' agreements on out of priority storage have broken down and now reservoirs cannot store out of priority unless they can send water back to the river promptly. An increased level of scrutiny over expansion of irrigated acres is also occurring.

Jim observed the following farmer responses to these changes:

- Increased use of surface water rights over wells
- Heavier use of reservoirs for irrigation
- Increased sprinkler installation, thereby reducing return flows
- Change in cropping patterns - more wheat, less corn/alfalfa
- Increased use of S. Platte alluvial aquifer

Frank Jaeger, Parker Water and Sanitation, describes the Parker / CSU project while conference organizer Joel Schneekloth looks on.

- More use of reusable effluent for replacement
- More active in water court

Municipal water suppliers have also responded to the recent changes:

- Purchase of Ag water rights
- Increased use of gravel pits for storage
- More reuse and plans for reuse
- More active in water court

Other conference speakers included Alan Berryman (Northern Colorado Water Conservancy District), who brought the audience up to date on the three-state water agreement between Colorado, Nebraska, and Wyoming. Brad Udall (Western Water Assessment at University of Colorado) provided the state of the knowledge on climate change and speculated on how this may impact water management in the basin.

Former State Representative Diane Hoppe provided the lunch time keynote address.

Diane Hoppe provided a keynote presentation during the lunch hour. She reminded the audience about the history of groundwater law and administration; she then went on to describe current water related bills in the state legislature. The most pressing future legislative need described by Representative Hoppe was more flexibility for the State Engineer to practice common sense water management based upon geography and gravity. Afternoon speakers included Frank Jaeger of Parker Water and Sanitation, Jay Winner of the Lower Arkansas Valley Water Conservancy District, and Dr James Pritchett of Colorado State University.

The 2007 Lower South Platte Water Symposium was sponsored by CSU Extension, USDA-NRCS and the Lower South Platte Water Conservancy District. The organizing committee included Joel Schneekloth, Alan Helm, Bruce Bosley, Joe Frank, Ron Neher and Louie Rinaldo.

Emerging Issues in Soil and Water

GARY A. PETERSON AND DWAYNE G. WESTFALL ANNUAL LECTURE

Colorado State University

"On the Sustainable Management of Soil and Water Resources: Historical and Contemporary Perspectives."

Please join us on April 19, 2007 in the Lory Student Center, North Ballroom from 2:00 - 3:30 p.m. for this year's lecture.

Presented by

Dr. Daniel Hillel

Daniel Hillel is an international authority on sustainable management of land and water resources. He is Senior Research Scientist at the Goddard Institute for Space Studies of the Columbia Earth Institute and Professor of Plant, Soil, and Environmental Sciences at the University of Massachusetts.

A world-renowned environmental scientist and hydrologist, Dr. Hillel is known especially for his work on soil-water relations in arid and semiarid ecosystems. He has worked in over 30 countries in Europe, Asia, Africa, the Americas, and Australia. A major focus has been on the Middle East, where he served as a consultant to the governments of Israel, Pakistan, the Sudan, Iran, Egypt, Jordan, Cyprus, and elsewhere; and as advisor to the World Bank and to the United Nations.

His twenty-plus books include definitive works on arid-zone ecology, low volume irrigation, and soil and water physics, which are widely adopted as standard texts in universities and research institutions around the world and which have been translated into at least thirteen languages.

Among the honors Dr. Hillel has received are a Guggenheim Award and several honorary doctorates. He has been elected Fellow of the American Geophysical Union, American Association for the Advancement of Science, the Soil Science Society of America, and the American Society of Agronomy.

Also attend the evening lecture:

The Natural History of the Bible: An Environmental Exploration of the Hebrew Scriptures.

7-8:30 P.M.

Integrated Decision Support Consumptive Use and Alluvial Water Accounting System

One Day Training Course

May 17, 2007

Colorado State University

The Integrated Decision Support Group at Colorado State University will conduct a one day hands-on training course on the use of the IDS Consumptive Use model (IDSCU) and the IDS Alluvial Water Accounting System model (IDS AWAS). These models were developed as a part of the South Platte Mapping and Analysis Program (SPMAP), a collaborative effort between IDS and water users in the South Platte Basin. The models are data driven and being used around Colorado. This training course will instruct users on how to create and use templates to develop data sets; use diversion records from HYDROBASE; and access weather data from HYDROBASE, COAGMET, and NCWCD. Features of the IDSCU model that will be discussed include: 1) computing a complete water budget, 2) using the model to compare CU values computed with different ET methods (this will be used to demonstrate how a user might develop calibrated Blaney-Criddle crop coefficients), and 3) evaluating the application efficiencies of wells by comparing depletions of groundwater computed using a water budget with pumping records multiplied by a presumptive depletion factor.

The training course will include an introduction on how to export depletion of groundwater information to the IDS AWAS model or generate input files for the IDS AWAS model. Participants will then be shown the major features of the IDS AWAS model. The participants will be introduced to a number of GIS tools that IDS has developed to calculate the input parameters for the IDS AWAS model such as distance to river, distance to boundary, and transmissivity. The training course will be conducted on Thursday May 17, 2005 at Colorado State University.

The cost of the registration is $250. Course registration will be limited due to the availability of computers for hands-on training.

Obtain more information and register at www.ids.colostate.edu.

USDA-CSREES Northern Plains and Mountains Regional Water Program

Addressing Shared Water Resource Issues Across the Region

by Matt Neibauer, Reagan Waskom, and Troy Bauder, Colorado State University

In order to address shared water resource concerns across Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming, Colorado State University serves as the host institution for a collaborative program striving to coordinate the education and research activities at these states' land-grant institutions. This program is funded by the United States Department of Agriculture – Cooperative State Research, Education, and Extension Service (USDA-CSREES) and works to research and provide education concerning water issues related to agriculture, energy development, mining, recreation, and tourism within the Northern Plains and Mountains Region (NPM). More specifically, the NPM Regional Water Program utilizes regional collaboration to investigate and share current practices and management techniques to address the availability and quality of water resources needed to meet competing demands from agricultural, municipal, recreational, and ecological uses throughout the region and nationally.

The NPM Regional Water Program facilitates interstate partnerships by building upon the existing state land-grant university network to include federal, regional, state, and local organizations with similar research and educational goals related to water resources. The program create a wide variety of water resources research and education opportunities throughout the region because of the financial and human resource support provided by this network of land-grant institutions, state university water resources centers, soil and water conservation districts, private industry, numerous private landowner partners, and other water/natural resource groups. The program also fosters the development and application of environmentally sustainable water resource management and policy practices. This facilitation is achieved by providing leadership for water resource research and education to help people, industry, and governments prevent and solve current as well as emerging water quality and quantity problems.

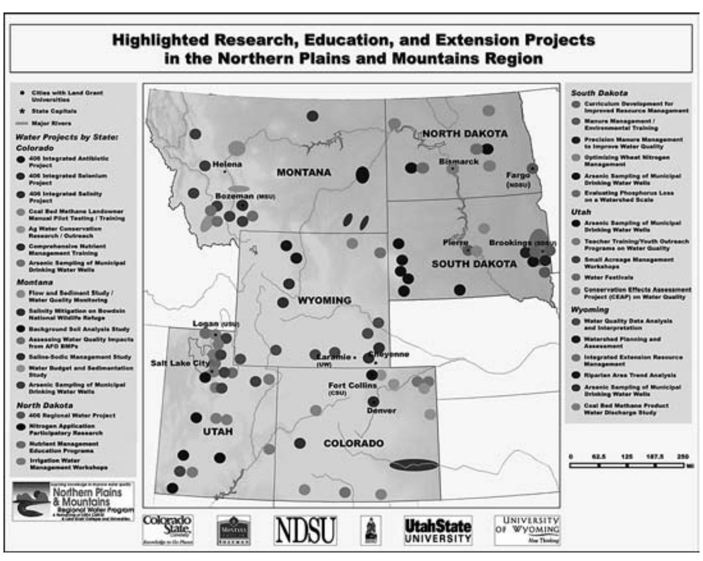


Figure 1. Highlighted regional water program impacts.

The NPM Water Program has developed four regional initiatives to implement regionally coordinated education, extension, and research programs addressing critical agricultural water quality issues in the region. These initiatives include Watershed Management; Water Conservation and Protection; Drinking Water – Human and Livestock Health; and Production Agriculture Water Quality. The program is actively involved in a variety of research and educational outreach activities and has achieved a number of accomplishments within the six-state region.

Watershed Management

Currently, the regional project is developing a program designed to monitor, analyze, and interpret water resource data for natural resources management and education. The region is in the process of developing educational program materials concerning watershed and riparian zone management, coal bed methane product water issues, and best management practices for rangelands. Regional team members also hold workshops on youth water education, manure management, GIS, and precision farming. Youth water quality education programming such as watershed festivals, 4-H camp presentations, and watershed monitoring is a priority for the program, as is providing K-12 education on watershed functions, links between land use and water quality, teacher training and support, Web site development, and macro invertebrate monitoring. The development of the Stream-Side Science Curriculum for Ninth Grade Earth Systems Science Program and its use in watershed education courses has reached over 14,000 youth and 1,200 teachers learning about water quality and watershed functions.

Figure 2. Stream monitoring in Montana.

Production Agriculture Water Quality

Another regional initiative, Production Agriculture Water Quality, is currently developing a precision farming manual, GIS decision support systems, remote sensing for crop assessment, and a septic tank video. The regional project is also conducting

Figure 3. Regional team talking with rancher in Wyoming.

Figure 4. Coal bed methane water discharge in Wyoming.

research on the fate and transport of agricultural chemicals, as well as implementing educational programs concerning pesticide and fertilizer BMPs.

Another priority of this initiative is the development and implementation of a model that provides flexible nitrogen management strategies that can be adopted without a loss of yield or quality. Furthermore, regional efforts are being made to develop mapping tools to assess aquifer sensitivity, land use and water quality, and impervious area development. The region is also conducting workshops on GPS/GIS, pesticide assessment maps, and pesticide application certification. By collaborating with the Colorado Agricultural Chemicals and Ground Water Protection Program, the regional program has assisted with the testing of wells for 120 private property owners in Colorado. Furthermore, the program has developed and implemented a Comprehensive Nutrient Management Plan (CNMP) workbook for training workshops, influencing 270,000 cattle producing 400,000 tons of manure per year, on the 240 livestock operations that have participated in these workshops.

Drinking Water – Human and Livestock Health

Drinking water quality and its effects on humans and livestock is a universal issue throughout the region, nation, and world. This is why the NPM Regional Water Program is actively addressing drinking water quality/quantity issues and mitigation of drought impacts. A key component of this initiative is the applied field research investigating the fate and transport mechanisms of P, N, and other emerging contaminants – such as pharmaceuticals and other bioactive substances – as is the development and implementation of water quality testing, interpretation, and treatment programs to improve regional water quality

Another issue being addressed by this initiative is the development of ways to better manage the water quality of small water bodies. Moreover, the regional program continues to conduct applied research on arsenic, as well as address tribal water quality concerns.

Water Conservation and Protection

Water conservation and protection is another issue of significant importance in the Northern Plains and Mountains Region and throughout the Western United States. Therefore, the regional water program is initiating education and research projects related to the urban/agriculture interface, as well as developing workshops to address irrigation water management, conservation, and protection. Ultimately, the NPM Regional Water Program is striving to address issues related to agricultural water policy and develop standards at the request of state legislatures and environmental agencies. Regional team members are also actively involved in addressing drought issues affecting rangeland, livestock management, and grazing on small acreages.

Regional Water Issues Survey

In order to assist in the development and achievement of its regional initiatives, the NPM Water Team designed and conducted a statistically valid survey for each state in the region. The main goals of the survey were to investigate peoples' attitudes and behaviors toward the environment, water issues, the need to protect and preserve water resources, and water resources education preferences. The survey will help identify future programming needs of the regional program and the state of Colorado.

During the fall of 2004, 309 (51%) of the 600 randomly sampled surveys were completed in Colorado – each identifying the age, gender, education level, occupation, time of residence, and size of community of the Colorado respondents.

The first set of survey questions queried residents' attitudes toward environmental and water issues. The majority (>95%) of Colorado respondents thought clean drinking water, ground water and rivers were extremely important issues, with water for recreation and landscaping rating the least important (see Figure 6). The survey also indicated residents (>75%) recognized better agricultural practices, preservation of agricultural land and open space, and watershed management were important actions to protecting water resources in Colorado.

Figure 5. Resource monitoring workshop in Colorado.

When asked about the quality of their drinking water, 92% of respondents thought their drinking water was safe to drink. Interestingly, only 68% of respondents were satisfied with their drinking water, while 18% were not satisfied. In terms of awareness about which pollutants predominantly affect water quality, Colorado residents identified fertilizers, minerals, and pesticides as the most suspicious or problematic. Surprisingly, many people (38-47%) did not know bacteria, fertilizers, heavy metals, minerals, pesticides, mining waste, salinity, and pharmaceuticals could affect water quality in Colorado. When asked about which societal sector or condition was most responsible for existing water quality problems, residents identified wastes from urban areas (44%), industry (38%), drought (36%), and mining (35%) as the most responsible.

In considering ways to protect and preserve water resources in Colorado, many respondents stated they have changed their landscaping practices (73%), their home water use (68%), their purchases and installation of water saving devices (68%), or how they wash their vehicles (50%).

On the subject of educational opportunities, Colorado residents preferred to read fact sheets, articles, and/or visit Web sites over all other types of venues (see Figure 7). Residents also indicated they were most interested in learning about protecting drinking water (55%), watershed management (34%), water policy (33%), community actions on water issues (33%), and water needs for fish and wildlife (33%).

Several key programming needs identified by the survey indicate educational opportunities exist concerning the conditions affecting water quality and drinking water in Colorado. Furthermore, the finding that residents were more likely to engage in passive types of educational opportunities (e.g., publications, Web sites), indicates barriers to more active educational settings (e.g., workshops, trainings) need to be addressed by organizations charged with educating Colorado residents about water resources.

Final Thoughts

The NPM Regional Water Program allows the existing land-grant university network to coordinate water quantity and quality issues on a regional scale. The program's ability to develop and implement effective research and educational activities is enhanced by its ability to form collaborative partnerships with a variety of external organizations. By continually evaluating its priorities and program effectiveness, the NPM Regional Water Program continues to provide citizens throughout the region valuable water resources research and education. For more information, please go to the Northern Plains and Mountains Regional Water Web site: www.region8water.org.

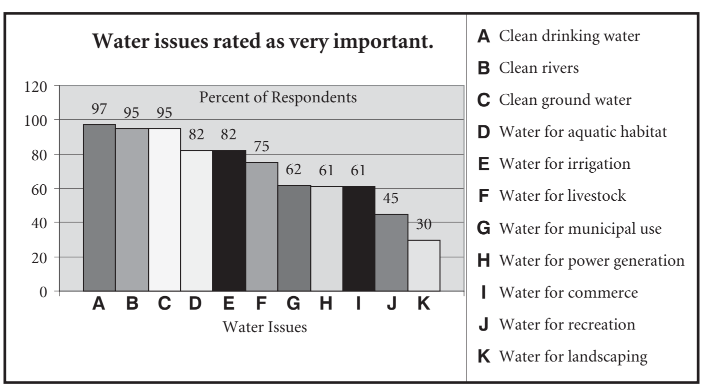


Figure 6. Water issues rated as very important in Colorado.

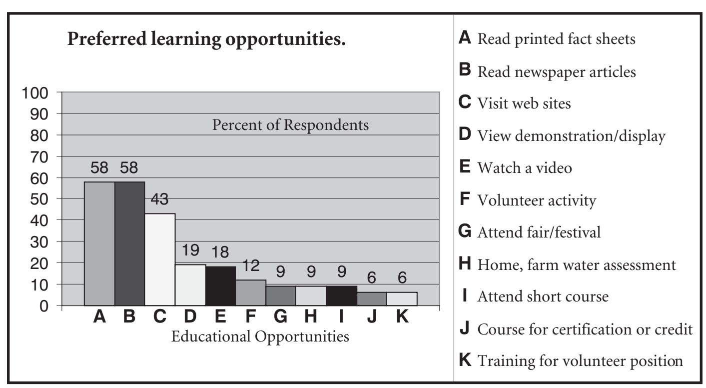


Figure 7. Preferred learning opportunities in Colorado.

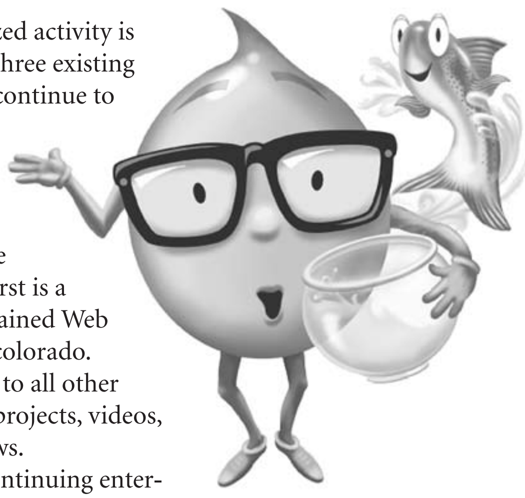
Moving Nonpoint Source Outreach to a New Level

by Loretta Lohman, Nonpoint Source Outreach Coordinator, Colorado State University Extension

Nonpoint source pollution (NPS), like politics, is primarily local.

Colorado's NPS Outreach program recognizes the importance of individual or local actions in remedying nonpoint source pollution. The project is evolving from statewide informational approaches like brochures and advertisements, to local and regional efforts to foster behavioral changes necessary to protect water quality.

This localized activity is building upon three existing assets that will continue to provide the information and awareness basis needed to create local activity. First is a regularly maintained Web page, www.npscolorado.com, with links to all other activities, NPS projects, videos, and current news.



Another continuing enterprise is the educational program of readers, activity books, CD-ROMs, and interactive Internet materials developed and maintained by the Colorado Foundation for Agriculture for young people. (See www.growingyourfuture.com.)

Finally, a common thread is increasingly being created as H2O Jo and Flo are being adopted as symbols for water quality in Colorado. Jo and Flo were developed and tested to become the Colorado water quality mascots under a NPS grant to the city of Boulder's watershed program. The grant also created a marketing campaign, "Keep It Clean, 'Cause We're All Downstream" strategy and materials.

While traditional in approach, using advertisements, posters, brochures, and other type of handouts, the Keep It Clean campaign tapped into some underlying attitudes as well as quickly becoming a favorite at conferences, water festivals, and other watershed activities.

There are now two H2O Jo inflatable mascots, one available on the Western Slope and one housed in Boulder and used around the Front Range and in several places across the country. The mascot is part of the EPA Nonpoint Source tool kit. A video, a coloring book, and other materials can be downloaded from www.npscolorado.com.

In keeping with the water quality concept that created the mascot, Boulder County has a Keep It Clean Partnership, and Jo has been a featured player in Boulder, Erie, Superior, Louisville, Longmont, Castle Pines, Loveland, Fort Collins, Grand Lake, Denver, Thornton, Westminster, Niwot, Commerce City, Brighton, Castle Rock, Chicago, and Ohio. On the Western Slope the Keep It Clean Campaign, with Jo and Flo's assistance, encompasses Roaring Fork Conservancy, Mount Sopris Conservation District, Aspen, Colorado River Water Conservation District, Eagle County, Pitkin County, Glenwood Springs, Aspen Center for Environmental Studies, Snowmass Village, Carbondale, and Basalt.

Originally intended to be a draw for children, the mascot equally attracts the attention of adults and helps lay the foundation for more serious information and activities. At a Colorado Water Congress conference, H2O Jo and Flo were instrumental in raising funds for Water for People, a charity founded by the U.S. water and wastewater industry. A number of stormwater entities are using H2O Jo and Flo in their outreach programs, and Denver is undertaking a major campaign using the mascot and some of the campaign strategies.

The success of school education and mascot programs serve to promote awareness and receptivity to the next big challenge in the NPS program. The program has, in the last half year, hosted workshops where Doug McKenzie-Mohr trained attendees in the concepts of community-based social marketing. This is one method that fosters measurable, sustainable behavior change, which is the only way many causes of nonpoint source pollution can be addressed.

Currently, most education campaigns are information-intensive and link attitudes or economic self-interest to behavior. Unfortunately, research does not find this approach very successful. Research and case studies show little or no relationship between knowledge or economic self-interest and sustained behavior change.

Doug McKenzie-Mohr at workshop.

In one well-studied example, California annually spends about $200 million in utility ads promoting energy conservation tips and methods. The program has had little discernable effect. The offer of free in-home energy audit had only a slight effect. Only 6% of the target population requested the audit, and less than half of those took any action to achieve a 2% to 3% energy savings. Doing the math on 2% to 3% of 6% of the population demonstrates that redirecting the education advertisement money could have retrofitted a many low-income homes with significant energy conservation measures.

There is not a lot of evidence that information-intensive or economic self-interest campaigns work, but we keep taking these two approaches because it seems as if we are doing something. As long as we continue to evaluate outputs (advertisements, presentations, etc.) rather than outcomes, these approaches will continue to be popular. Our failure to measure actual behavior change contributes to continuation of information and economic self-interest approaches that produce few results.

The difficulty of changing behavior is systematically underestimated, and the literature of environmental psychology is not easily accessible. This is one reason McKenzie-Mohr has created a Web site. Fostering Sustainable Behavior, http://www.cbsm.com/, requires registration so that the site can continuously add materials appropriate to each user. There is a wealth of materials and research available.

An abbreviated description of a social marketing campaign is:

- First, the behaviors in need of change must be selected.
- The barriers or benefits of changing those behaviors need to be identified.
- A program must be designed to overcome the barriers and amplify the benefits.
- The program must be piloted, tested, and piloted again.
- Finally, the program is implemented with thorough and ongoing evaluation.

Selecting behaviors is critical in this process as each suggested change has its own barriers and benefits – this is an incremental process. Only one or another closely related change can be approached in a given program.

Careful observation shows that determining proper tire inflation involves a series of steps. Each step is a behavior that has its own set of barriers. An activity is a series of behaviors. The entire process is a series of steps. A first, small request leads to greater participation and can lead to measurable success.

A critical step is to get a commitment to make a change that is public and visible in the community. A commitment checklist:

- Will not be coercive.
- Will obtain written or public commitment.
- Will actively involve the person.
- Will assist in changing self-perceptions.
- Will facilitate social diffusion and creates a social norm.

Changing behavior involves research, a willingness to prioritize targets, selection of incremental changes that will lead to incorporation of additional changes, and testing and re-testing the program and methods selected.

After 20 years of work in nonpoint source pollution, Colorado has determined that long-term significant changes in preventing increasing amounts of such polluted runoff required a different way of doing many ordinary things – like mowing grass, dealing with weeds, pursuing outdoor recreation, even raking leaves in the fall.

The Colorado NPS Outreach effort will be exploring the best ways to apply the research in fostering sustainable behavior to the problems identified by the NPS program. With the help of H2O Jo identifying the program, it should be an interesting ride.

Colorado State University

Extension

"Walking Through the Water Year" – First Steps

by Nolan Doesken, State Climatologist, Colorado State University

"Walking Through the Water Year" is a water education initiative introduced a few years ago by the Colorado Climate Center at Colorado State University in collaboration with several organizations involved in water monitoring, climate, and education. After getting off to a slow start, WTTWY is about to take its first steps. A pilot project currently being planned could begin this fall. This effort will be funded by the U.S. Bureau or Reclamation in partnership with the Poudre School District in northern Larimer County. Media broadcasts distributed to classrooms, local cable TV, and via Internet streaming video will creatively show how the progression of storms and weather patterns throughout the year delivers water to the region. Students from the school district and interns from CSU will produce these broadcasts with the help of local weather and water experts.

Colorado's water managers, planners, forecasters, and water users traditionally track water resources using the water year calendar that begins October 1 and ends September 30. The beginning of the Water Year coincides with the start of the snow accumulation season in the Colorado high country. It includes the dynamic spring snowmelt period, when the mountain snowpack relinquishes water to tumbling rivers and streams. The year ends with the completion of the summer growing season and irrigation season. Each year follows a common seasonal cycle, but the number, size, intensity, location, and timing of rain and snow storms dictates the amount of water available to Colorado each year. This is modulated by the sequences of warm and cold weather along with variations in wind, sunshine, and humidity that influence evaporation and transpiration.

Water experts, accustomed to tracking weather conditions through the water year, learn through years of experience the intimate connections between weather and water. There is tension and drama each year as weather patterns unfold and our water story is told. Walking Through the Water Year will strive to capture this excitement to bring a greater awareness and appreciation for our limited water resources.

Colorado State Climatologist Nolan Doesken

For more information about Walking Through the Water Year or to find out how you or your organization can get involved, please contact:

Nolan Doesken
Colorado Climate Center
Department of Atmospheric Science
Colorado State University
(970) 491-3690
nolan@atmos.colostate.edu

Colorado State University
AGRICULTURAL EXPERIMENT STATION

Colorado Water Resources Research Institute

FY 2008 Request for Proposals

CLOSING DATE: SEPTEMBER 20, 2007

Proposals are invited for the Colorado Water Resources Research Institute FY 2008 water research program.

The Colorado Water Resources Research Institute (CWRRI) is established under the federal Water Resources Research Act, as amended, and is authorized by the Colorado Legislature, most recently in 2006, under S.B. 06-183. At the federal level, CWRRI is one of 54 water institutes administered by the U.S. Geological Survey in the Department of Interior. 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."

Priority Research Topics

For the FY 2008 competition, the CWRRI Advisory Committee for Water Research Policy has identified needs for new water knowledge that will assist in answering the following questions:

What are the water quality concerns relative to oil shale development, what is the extent of these problems in western Colorado, and what is the potential for mitigation?

What new tools, methods, and demonstration projects are needed to analyze the changes and vulnerability of water systems in Colorado to climate variability, including new or improved hydrologic models that convert changes in temperature and precipitation into changes in streamflow?

What is the array of technically feasible agriculture water conservation strategies and options for Colorado, and what are the basin-level impacts of implementing these measures?

How can we refine current groundwater augmentation accounting procedures and methods for replacing depletions caused by ground water pumping?

What are the direct and indirect water-related impacts and needs surrounding bioenergy production in Colorado?

Funds Available

The FY08 CWRRI Request for Proposals is supported by the State of Colorado, with supplemental funding provided through the U.S. Geological Survey, pending federal budget allocations. It is anticipated that approximately $150,000 in funds will be available for the FY08 competition. CWRRI research funds are awarded through a competitive process guided by the CWRRI Advisory Committee on Water Research Policy. Proposals that contain matching funds from Colorado water and water-related organizations are strongly encouraged.

Proposal Review Process

All proposals are due in the CWRRI office by September 20, 2007, at 5:00 p.m. (MDT). Proposals will be peer-reviewed before final review and ranking by the CWRRI Advisory Committee for Water Research Policy. The general criteria used for proposal evaluation include: (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.

Eligibility

The competition is open to regular, full-time faculty at Colorado's research universities.

Applications Not Eligible for Funding

A. Applications for research on health effects involving human subjects.
B. Applications for research involving oceanography.
C. Applications submitted by an investigator that has not met reporting requirements on a previous award from the USGS or CWRRI.

Project Budget Amount and Duration

The total life of the project must not exceed 24 months in duration. The total budget request cannot exceed $50,000 during the 24-month period. Projects of shorter duration and/or budgets less than $50,000 will also be considered. Project start date will be January 1, 2008.

Proposal Submission

Proposals, in both hard and electronic copy, are to be submitted no later than 5:00 p.m. MDT, September 20, 2007.

Hard Copy Submission
Colorado Water Resources Research Institute
E102 Engineering Building
Colorado State University
1033 Campus Delivery
Fort Collins, CO 80523-1033

Electronic Submission
E-mail to: nancy.grice@research.colostate.edu

Questions: If there are questions about this solicitation, contact Reagan Waskom by phone at (970) 491-6308 or by e-mail at reagan.waskom@colostate.edu.

http://cwrri.colostate.edu

Internship in Water Resources Research

The Watershed Modeling project of the U.S. Geological Survey (USGS) National Research Program (NRP) is seeking a currently enrolled graduate student to work on development of simulation models and modeling tools across environmental and computer science disciplines. The intern would be employed by the Colorado Water Resources Research Institute.

PROJECT DESCRIPTION: Due to the increasing complexity of environmental and water resource problems and ad hoc development of effective simulation models and modeling tools, policy and management decisions regarding natural and engineered systems are often made without considering the interaction between atmospheric, surface, and subsurface processes. The common theme among these problems is the need for integration: integration of computer science and environmental science, integration of different types of GIS and water resources data, integration of processes across spatial and temporal scales, and integration of science and management objectives. The Integrated Watershed Modeling project builds upon a solid foundation of watershed modeling to investigate, formalize, and document integration methods.

STATEMENT OF WORK: Software development and research to integrate USGS watershed models and data preparation and analysis tools with the Object Modeling System (OMS) and other environmental models and modeling tools. The OMS, using a modular programming strategy, facilitates integration, evaluation, and deployment of simulation models and other natural resource technology from various disciplines, provides interfaces to geospatial tools, linkages to databases, and analysis and visualization tools for parameter estimation, delineations, and uncertainty. The OMS is being developed by the Agricultural Research Service (ARS) and Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture in cooperation with the USGS, the EPA, and Friedrich-Schiller-University Jena, Germany.

SKILLS: Interns at all degree levels are considered. Applicants should already have attained undergraduate core technical skills, with interest in multidisciplinary study. Object-oriented programming experience using Java and an integrated development environment (IDE), such as, the NetBeans IDE, is required. Experience in one or more of the following is desired: a Geographic Information System (GIS), simulation models, optimization and sensitivity tools, and database design and management.

LOCATION: U.S. Department of Agriculture Building, Fort Collins, Colorado, with oversight from the USGS Integrated Modeling project located at the Denver Federal Center in Lakewood, Colorado.

DURATION: Up to three years, beginning September 1, 2007.

COMPENSATION: $13.83 to $20.95/hour dependent upon amount of education completed.

APPLICATION: For more information or to apply, please contact R. Steve Regan:

rsregan@usgs.gov
(303) 236-5008 (office)
(303) 236-5034 (fax)
PO Box 25046, MS 412
Denver Federal Center
Lakewood, CO 80225-0046

Colorado School of Mines (CSM) Research Regarding Occurrence and Fate of Organic Wastewater Contaminants During Onsite Wastewater Treatment

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

CSM Graduate student Kathy Conn

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 United States 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) (1) to 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, 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 µg/L to greater than 500 µ/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,

Dr. Robert L. Siegrist

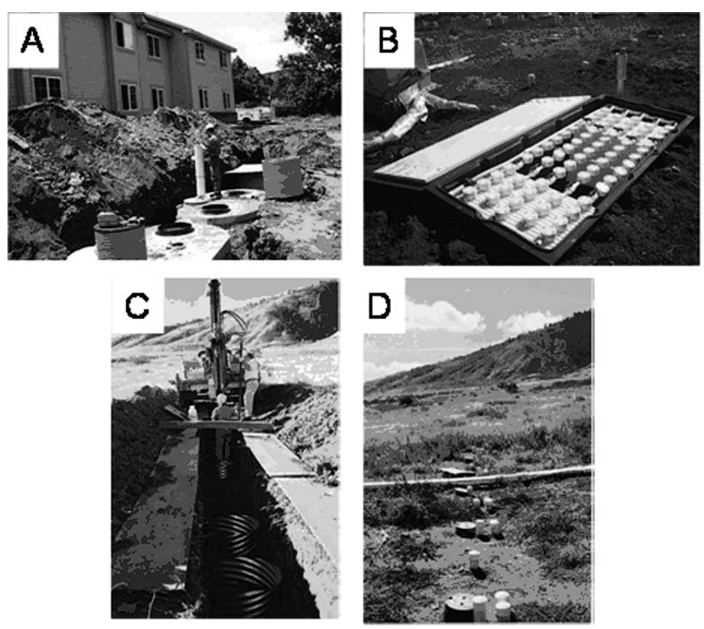


Figure 1. The fate of organic wastewater contaminants in onsite wastewater treatment systems is currently being investigated at the Mines Park Test Site, where wastewater from a multifamily residence is intercepted (A) and managed using pilot-scale unit operations such as a textile biofilter (B) and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

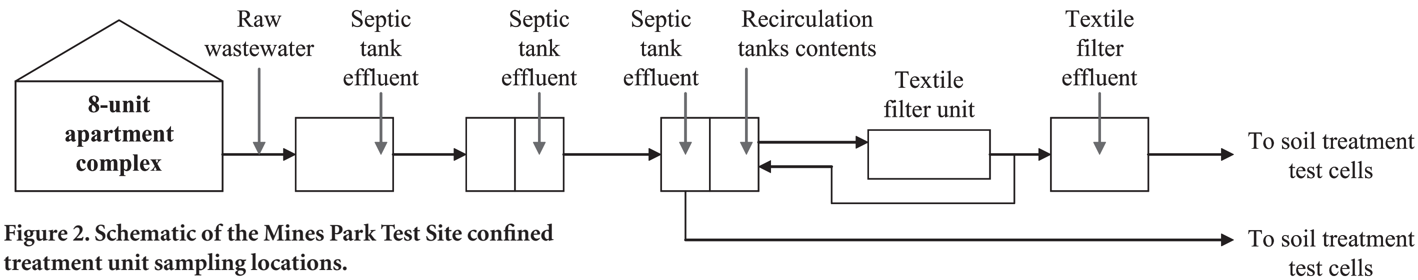


Figure 2. Schematic of the Mines Park Test Site confined treatment unit sampling locations.

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 cm/d to 8 cm/d. Soil solution at 60 cm, 120 cm, 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 (Fig-

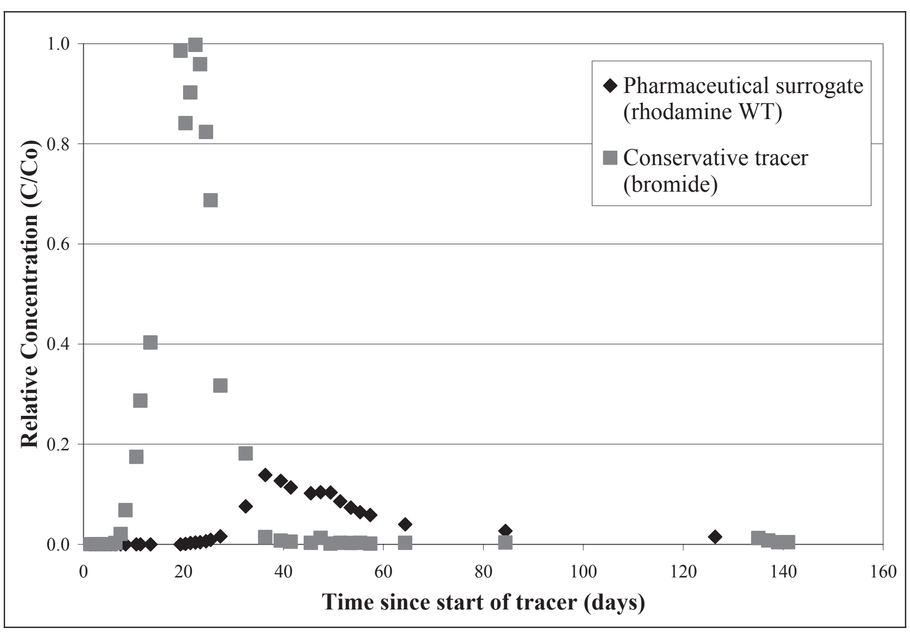


Figure 3. Comparison of the breakthrough curves at 60 cm below the infiltrative surface for a conservative tracer (bromide) and a pharmaceutical surrogate (rhodamine WT) added to an onsite system soil test cell.

ure 3). Water travel times from the infiltrative surface to 60 cm below the infiltrative surface ranged from 5 days to 25 days. The time required for 10% of the added pharmaceutical surrogate to reach 60 cm below the infiltrative surface ranged from 35 days 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 cm, 120 cm, 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 four-day average concentration in freshwater systems not to exceed 6.6 μg/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 10 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.

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.

Rapid Detection of FRNA Bacteriophages, and Their Use in Water Quality Assessment

by Lawrence D. Goodridge, Department of Animal Sciences, Colorado State University, 350 West Pitkin Street, Fort Collins, CO 80523-1171

Inadequate drinking water and sanitation are considered two of the world's major causes of preventable morbidity and mortality, and international bodies such as the World Health Organization (WHO) estimate that 50,000 deaths per day are due to water-related diseases. While the majority of waterborne illness occurs in the developing world, water quality problems also abound in the developed world. The detection, isolation, and identification of waterborne pathogens continues to be expensive, difficult, and labor intensive.

To alleviate the issues with waterborne pathogen testing, indicator microorganisms are commonly used to determine the relative risk from the possible presence of pathogenic microorganisms in a sample. The detection, isolation, and identification of waterborne pathogens continues to be expensive, difficult, and labor intensive (Scott *et al.* 2002). To alleviate the issues with waterborne pathogen testing, indicator microorganisms are commonly used to determine the relative risk from the possible presence of pathogenic microorganisms in a sample. Since most of the microbial pathogens present in water are of fecal origin, the detection of fecal contamination has been the main aim of the testing methodologies. Historically, the coliform, thermotolerant coliform group, enterococci, and *Clostridium perfringens* have been the bacterial indicators used to detect fecal contamination (Scott *et al.* 2002), based on the rationale that these indicator organisms are indigenous to feces, and their presence in the environment is therefore indicative of fecal pollution. However, there are major problems with the current use of indicator bacteria to detect fecal pollution. Many of these bacteria are routinely isolated from soil and water environments that have not been impacted by fecal pollution. In addition, these bacteria are able to grow in biofilms within drinking water distribution systems and are occasionally absent in water supplies during outbreaks of waterborne disease. Also, while the persistence of these bacteria in water distribution systems is comparable to that of some bacterial pathogens, the relationship between bacterial indicators and the presence of enteric viruses and protozoa is poor. Viruses and protozoa account for approximately 44% of waterborne outbreaks in the United States, where the etiologic agent has been identified (Blackburn *et al.* 2004). Finally, the methods used to detect the indicators are problematic. While there are established culture and molecular methods for the detection of most microbial pathogens, most of these methods have important limitations, including the length of time required for the test result (1-5 days) and the specificity and sensitivity of detection (Scott *et al.* 2002). Due to the limitations of the bacterial indicators, and the problems with their rapid detection, other biological indicators of water quality have been proposed.

Figure 1. Graduate student Travis Steiner completes a plaque assay for detection of FRNA phages in a water sample.

Several researchers have investigated the presence of coliphages (bacteriophages [phages] that grow on *Escherichia coli*) as indicators of the presence of fecal contamination in water. These studies have originated from the idea that certain phages isolated from water could serve as indicators of fecal contamination. In this scenario, the presence of these phages would indicate the presence of their bacterial hosts (i.e., *E. coli*, which may be present in low concentrations, making them difficult to detect), which grow in the intestines of warm-blooded animals and are therefore indicative of the presence of fecal contamination from these animals. FRNA phages have attracted interest as useful alternatives to bacterial indicators because their morphology and survival characteristics closely resemble the human enteric gastrointestinal viruses (Scott *et al.* 2002), meaning that, in addition to the usefulness of these phages as indicators of the presence of their host bacteria (*E. coli*), and therefore the presence of fecal pollution, they could also indicate the presence of enteric viruses (noroviruses, rotaviruses) in water. Several studies have confirmed that for monitoring purposes, FRNA phages are reliable indicators of the possible presence of human enteric viruses because they behave like water-borne viruses (Havelaar 1993). The most commonly used technique to detect phages is the plaque assay, in which dilutions of the water sample to be tested are incubated with a suitable host bacterial strain, and the mixture is added to a dilute concentration (0.5%) of molten agar and poured onto solidified agar in a petri plate. After incubation at 37°C overnight, the bacteria will form a homogeneous lawn in the top layer of agar, except in areas where phages have infected the cells. These areas will be clear (and are known as plaques), because phage infection has caused the death of bacterial cells. However, the plaque assay is tedious, requires standard laboratory equipment (Petri plates, incubators, etc), and takes at least 24 hours to complete (Figure 1). These attributes mean that the plaque assay method is not amenable for use in the field, where water quality testing would ideally be situated.

In this study, we have developed a rapid method to detect FRNA phages based on the use of a lateral flow device (LFD) that can identify the presence of these phages within 5 minutes. The LFD is a simplified version of the Enzyme Linked Immunosorbant Assay (ELISA), and these single step immunochromatographic assays utilize similar technology to that used in home pregnancy tests. Furthermore, the LFDs are portable, rapid, require no instrumentation, and can be used with little or no previous experience. This will allow for the rapid evaluation of the presence of FRNA phages in water, directly in field. To demonstrate the feasibility of using LFDs to detect FRNA phages in water, a LFD based upon the FRNA phage MS2 was developed. A series of 10 fold dilutions of MS2 were added to water obtained from a feedlot, and the LFDs were used to determine the concentration at which the MS2 could no longer be detected (Figure 2). The results indicated that less than 106 PFU/ml of MS2 was undetectable. This result demonstrates the usefulness of the LFD technique and also indicates that water samples will need to be concentrated to enable detection of FRNA phages in the water, since the concentration of FRNA phage observed in water can be as low as 100-1000 PFU/ml.

Current work is focused on developing a method to rapidly concentrate FRNA phages from water samples, based on the use of cationically charged paramagnetic beads. These 2.8 µm beads have the unique property of becoming magnetized in the presence of a magnetic field, but upon removal of the field, the beads lose their magnetism, allowing them to resuspend in a liquid sample. Cationically charged paramagnetic particles can selectively bind and capture viruses, including phages. For example, these beads have been utilized as an efficient way to capture enteric viruses including hepatitis A virus and the noroviruses (Plante *et al.* 2005a, 2005b). We have developed a method that allows for water samples to be incubated with the cationically charged beads. A portable hand-held magnet allows for the beads (and any bound phages) to be concentrated (Figure 3). Once the phages have been concentrated, they can be detected with the lateral flow device.

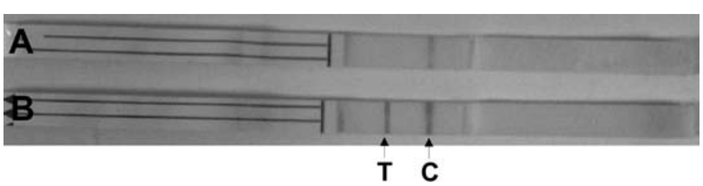


Figure 2. Lateral Flow Devices (LFDs) used to detect the presence or absence of phage MS2 in water obtained from a feedlot. The test line (T) and quality control Line (C) are denoted. (A) The LFD indicates that the level of phage in the water was not detectable (< 106 PFU/ml) (absence of the test line). (B) The LFD indicates that the level of phage in the water is detectable (> 106 PFU/ml) (presence of the test line). The presence of the quality control line indicates that the test is working properly.

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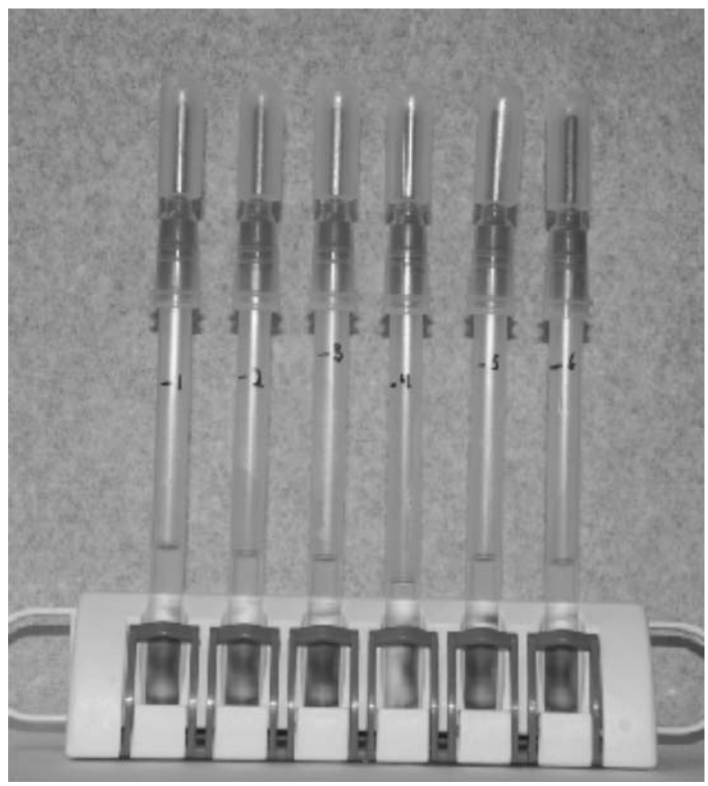


Figure 3. Concentration of FRNA phages from water samples using cationically charged paramagnetic beads. The water sample is placed into a disposable test device, and the beads are added. After a 10-minute incubation, the test devices are placed into a portable magnet, and the beads (and any bound phage) are attracted to the magnet, allowing the water to removed from the device. The phages are then eluted from the surface of the beads in a small volume of elution buffer, followed by detection with the lateral flow device.

GRAD 592
INTERDISCIPLINARY WATER RESOURCES SEMINAR

Mondays, 4:00 - 5:30 p.m.
A-206 Clark Building
Colorado State University, Fort Collins, Colorado

Fall 2007 Theme:
Colorado Water Development in the 21st Century

The purpose of the 2007 Interdisciplinary Water Resources Seminar (GRAD 592), through a series of invited speakers, is to examine how new water supplies are being developed in Colorado during the current era and to study an array of projects that are in various stages of development. These projects include Animas La Plata, Elkhead Reservoir, Reuter Hess Reservoir, NISP, Barr Lake pipeline, the Prairie Water project, and others. More specifically, the seminar will:

1. Examine the steps and processes involved in water supply development.
2. Understand the legal and environmental aspects of water development.
3. Discuss the intra- and interstate issues that increase the complexity of water supply planning in the 21st century.
4. Examine current Colorado water projects to understand the issues of public water supply, drought protection, environmental mitigation, transfer of agricultural water, endangered species needs, interstate compacts, water quality protection, and other topics.

All interested faculty, students, and off-campus water professionals are encouraged to attend and participate.

Aug. 20	Dave Little, Denver Water	Life after Two Forks – What happened and how the Two Forks veto changed our approach to water resources planning
Aug. 27	Rick Brown, Colorado Water Conservation Board	Colorado's water development needs for the 21^{st} Century
Sept. 10	Dave Merritt, Colorado River Water Conservation District	Intrabasin, interbasin, and transmountain water movement to meet growing water demands – Case studies: Wolford Mt. Reservoir, Union Park, and the Gunnison pumpback
Sept. 17	Mark Pifher, Aurora Water	The Prairie Waters Project – A sustainable approach to increasing water demands
Sept. 24	Dan Birch, Colorado River District	Elkhead Reservoir Enlargement – Partnerships and "multiple use" as a mechanism to build new projects
Oct. 1	Frank Jaeger, Parker Water	Permitting, water acquisition, and other legal aspects of developing water projects – Case study, Rueter Hess Reservoir
Oct. 8	Dave Kaunisto, East Cherry Creek Valley Water and Sanitation District	Urban partnership and competition for a limited water supply – Barr Lake pipeline project
Oct. 15	Carl Brouwer, Northern Colorado Water Conservancy District	Navigating the EIS process – Northern Integrated Supply Project
Oct. 22	Sean Cronin, Greeley Water	Integrated Water Resources Planning in Northern Colorado
Oct. 29	Wayne Vanderschuere, Colorado Springs Utility	Development of new water resources, Southern Delivery System, planning, process, and challenges
Nov. 5	Jay Winner, Lower Arkansas Water Conservancy District	The Super Ditch – Ag Transfer as a new source of M&I Water
Nov. 12	Kelly DiNatale, CDM	South Metro water needs and supply options
Nov. 26	John Hendrick, Centennial Water and Sanitation	Highlands Ranch: 0 to 100,000 in 30 years
Dec. 3	David Robbins, Council for the Southwest Colorado Water Conservation District	Animas La Plata Project – Last of the big federal projects in Colorado?

Upper Yampa Water Conservancy District Scholarship Awarded to CSU Student

The Upper Yampa Water Conservancy District (UYWCD) continues to fund a scholarship in support of CSU students preparing for careers in water-related fields. The scholarship program is administered by the CSU Water Center.

The scholarship provides financial assistance to committed and talented students who are pursuing water-related careers at CSU. The UYWCD $2,500 scholarship is open to any major at CSU. Criteria for the scholarships require the recipient to be a full-time student enrolled at CSU; financial need may be considered; preference is given to students from the Yampa Valley area; and a minimum GPA of 3.0 is required. The scholarships are for one year.

The Upper Yampa Water Conservancy District Scholarship Recipient for the 2007-08 academic year is Samantha Winter. A senior majoring in civil engineering at CSU, Samantha is from Steamboat Springs, Colorado. Her areas of interest in water include small-scale water system design and implementation, aquaculture, irrigation engineering, and water conservation. Samantha currently works as a GIS student technician at the USDA-APHIS, where she works in their information technology program. Past accomplishments include volunteer work as a tutor, participation in Engineers Without Borders, international work in Latin America, study abroad in England, and numerous scholarship awards and achievements. Samantha plans to pursue a career in sustainable development of water resources with Native American tribes and in the international arena.

We had a number of outstanding applicants for this year's Upper Yampa Water Conservancy District scholarship, and we congratulate Samantha and wish her success in her studies. The ongoing support of CSU students by the UYWCD is acknowledged and greatly appreciated.

Consensus Development For Augmentation Accounting

by Luis A. Garcia, Colorado State University, Department of Civil and Environmental Engineering

Luis A. Garcia

The severe drought of 2002 and rapidly growing urban populations have exacerbated conflicts between ground and surface water users. These conflicts have caused the amount of groundwater depletions from well pumping in alluvial aquifers to be scrutinized more closely. Water managers are attempting to reconcile the desire to make use of the large amount of storage in the alluvial aquifer with the need to protect Colorado's Doctrine of Prior Appropriation and more senior surface water rights. To accomplish this, the development and understanding of a common framework of information is essential. Such a framework is especially needed in areas like the Lower South Platte River where conjunctive use of surface and groundwater is fairly common. One way to develop this framework is with a common set of computer tools and data that can be used to accurately estimate augmentation requirements.

For the past twelve years, as director of the Integrated Decision Support (IDS) Group at Colorado State University and CSU Extension Water Resources Engineer, I have had the opportunity to study the data and modeling needs of water users in the Lower South Platte River in Colorado. With the active participation of water users, IDS has prioritized their data and modeling needs and collected or generated the data and modeling tools to meet their needs. Our work in the South Platte is one framework for the development and implementation of decision support tools to assist water managers in addressing the complex issues surrounding conjunctive management of Colorado's ground and surface waters. As the modeling tools are employed in the 'real world' of water management in Colorado, we have developed a framework that allows us to enhance the capabilities of the software to continue to provide upgrade the tools for the fair and equitable management of Colorado's limited water resources.

The tools that IDS has developed for the Lower South Platte Basin are collectively called the "South Platted Mapping and Analysis Program" (SPMAP). These tools and data are designed to help build consensus concerning water accounting when dealing with conjunctive use and augmentation requirements. This effort was initiated in 1995 with funding from the Colorado Water Resources Research Institute (CWRRI). As a result of this process, a number of data and modeling needs have been identified, and with funds from a number of organizations most recently: CWRRI, Colorado Agricultural Experiment Station, CSU Extension, and Northern Colorado Water Conservancy District we have developed a framework that is dynamic and is based on a "user centered approach" for data and model development. This process is as open and transparent as possible with all the products being distributed via the web (www.ids.colostate.edu/projects/splatte).

Quantification of Augmentation Requirements

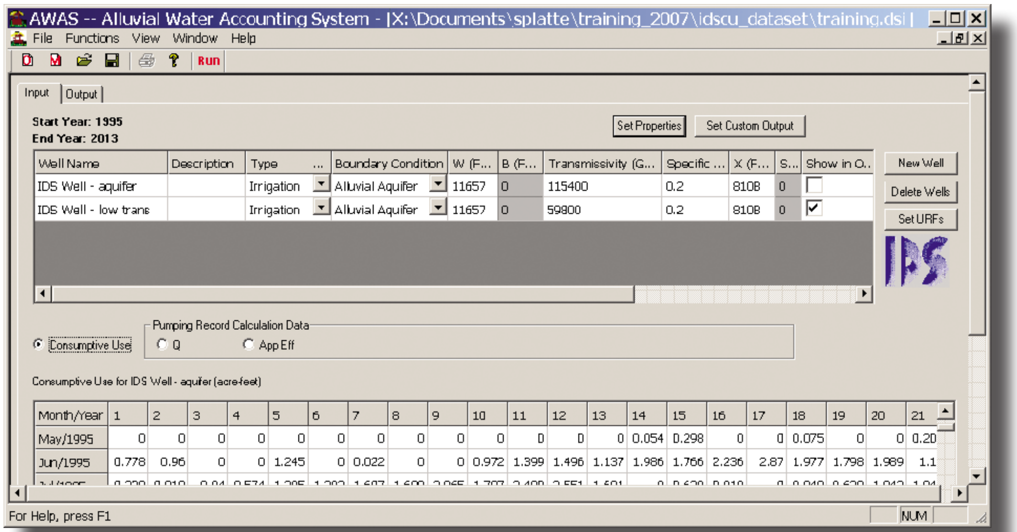
Colorado water managers need to determine the lag time from when a well is pumped or water is recharged to a recharge site and when a depletion or accretion happens in the river. Historically the Stream Depletion Factor (SDF) (Jenkins, 1968) methodology has been used in Colorado to determine the impact of the depletions of groundwater on a particular stream, and the IDS Group developed a model to calculate the monthly depletions or accretions (in the case of recharge sites) using the SDF methodology (SDF View). The SDF methodology is an analytical technique based on several boundary assumptions that are viewed by some as unrealistic. However, analytical techniques are convenient and, if properly calibrated, very valuable tools. Therefore the need for using other analytical techniques that support different boundary conditions (no flow boundaries, alluvial aquifers, etc.) was identified.

To meet the additional needs expressed by water users, a new model based on the State Engineer's Office system was implemented by IDS: the IDS Alluvial Water Accounting System (IDS AWAS). The model is based on The Analytical Stream Depletion method developed in 1987 by Dewayne R. Schroeder. This method uses analytical equations described by Glover (Glover 1977) and others. The model allows users to calculate depletions using daily or monthly time steps. The user may evaluate a number of different boundary conditions (alluvial, infinite, no flow, unit return flow and effective SDF). IDS AWAS can create model input in two ways:

1. Each well can have a list of pumping records consisting of a pumping rate and duration (original mode).
2. Input records consisting of net consumptive use or recharge in a daily or monthly time step can be used.

Year type can be set to calendar, irrigation, or USGS. Data can be projected into the future or past based on

Figure 1: IDS AWAS GUI Input Screen



historical data, and the effect of turning off the well by specifying an end date beyond the period of record can be simulated. Figure 1 shows the IDS AWAS input screen and Figures 2 shows an example of the IDS AWAS output plot of depletions. This software can be downloaded from: http://www.ids.colostate.edu/projects/idsawas.

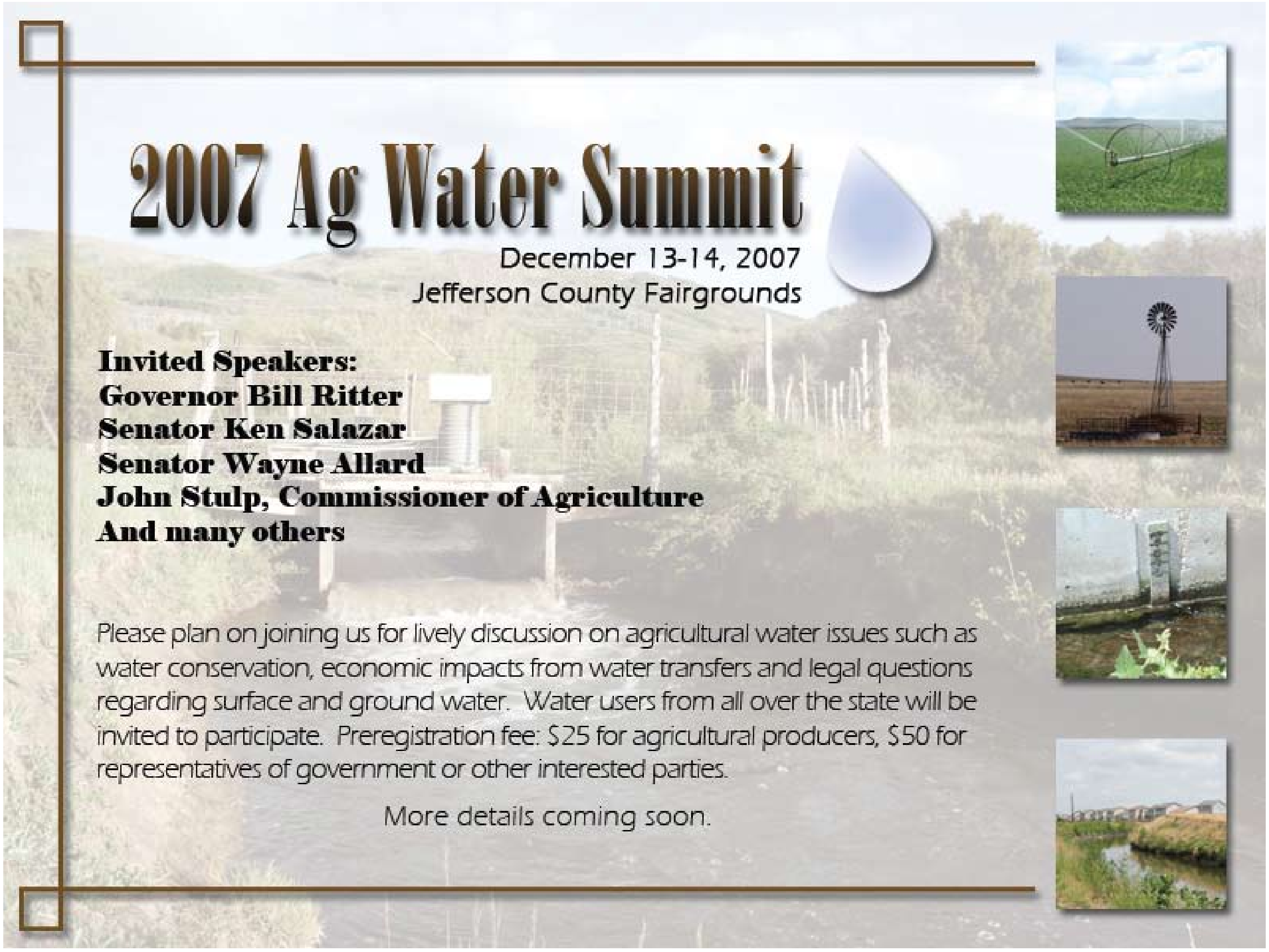
On May 6, 2006, Hal D. Simpson, the State Engineer at the time issued Procedures Memorandum 2006-1 to all Division of Water Resources Staff announcing "*In an effort to modernize the software used to model stream depletion caused by well pumping, the Division of Water Resources has selected the IDS AWAS 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*"

The combination of using existing models, building graphical interfaces, following a modular approach and developing good documentation makes this software flexible, generalized, and easy to use. These tools have been developed with the active participation of area water managers and staff from the Division One State Engineer's Office. The result is a transparent and inclusive development process that has been coupled with quick responses to users' needs and feedback and has resulted in a set of tools that are helping to build consensus on water accounting in the Lower South Platte.

The IDS Group's work in the South Platte is one framework for the development and implementation of decision support tools to assist water managers. The tools and process used to develop them have confirmed their worth by their wide use and helping work through water disputes during Colorado's recent unprecedented drought. I have been very fortunate to be part of this collaborative process and look forward to the continue to work closely with water managers to develop tools and data to meet their needs.

There continues to be opportunities for updating the current methodology used for calculating augmentation requirements. Fertile areas for ongoing research include developing, maintaining, updating, and deploying DSS.

Figure 2: IDS AWAS Output Sample Plots


2007 Ag Water Summit
December 13-14, 2007
Jefferson County Fairgrounds
Invited Speakers:
Governor Bill Ritter
Senator Ken Salazar
Senator Wayne Allard
John Stulp, Commissioner of Agriculture
And many others
Please plan on joining us for lively discussion on agricultural water issues such as water conservation, economic impacts from water transfers and legal questions regarding surface and ground water. Water users from all over the state will be invited to participate. Preregistration fee: $25 for agricultural producers, $50 for representatives of government or other interested parties.
More details coming soon.

The Lysimeter Project in Rocky Ford: Objectives and Accomplishments

by Abdel Berrada, Lane Simmons, Michael Bartolo, Dale Straw, and Thomas Ley, Colorado State University, Division of Water Resources

Rationale and Objectives

One of the recommendations that came out of the Kansas v. Colorado Arkansas River Compact litigation is for Colorado to use the ASCE (American Society of Civil Engineers) Standardized Penman-Monteith equation to estimate crop consumptive use in the Arkansas River Valley. The Penman-Monteith equation (PME) calculates the evapotranspiration (ET) of a reference crop, which in Colorado is alfalfa, using meteorological data such as maximum and minimum temperature, relative humidity, solar radiation, and wind speed (Allen et al., 1998). The ET of other crops (ETc) is derived from reference ET (ETr) with the equation:

ETc = ETr x Kc (for well-watered crops)

Kc or crop coefficient varies with crop type, growth stage, crop condition (plant density, health, etc.), and soil wetness, among other things. When the crop is water-stressed,

ETc = ETr x Kc x Ks

The coefficient Ks is derived from the water balance (water inputs minus water outputs) in the root zone.

ETr is defined as the evapotranspiration of a non-stressed, well watered alfalfa crop, 50 cm in height, covering the ground fully. In other states, the reference ET is that of a non-stressed grass or similar short crop that is 12 cm in height at full canopy and is usually denoted ETo.

Direct measurement of ET is best achieved with weighing lysimeters. Precision weighing lysimeters measure water loss from a control volume by the change in mass with an accuracy of a few hundredths of a millimeter. Non-weighing lysimeters are more common but they "are not considered suitable for reference ET equation verification and crop coefficient research. They may, however, be very suitable low cost alternatives for studying the effects of varying water salinity levels and high water table conditions on crop ET up and down the Arkansas River Valley." (Ley, 2003).

Fig 1: The inner tank being pushed into the ground to acquire the soil monolith. Photo taken by Dale Straw of DWR.

In the absence of locally generated algorithms for calculating ETr with PME and Kc, the Colorado Division of Water Resources (DWR) has been using estimates from Kimberly, ID and Bushland, TX. However, the crop growing conditions (soil, elevation, climate, etc.) in the Arkansas Valley vary greatly from the prevailing conditions in Kimberly or Bushland. In his findings relating to the Arkansas River Compact compliance litigation initiated by Kansas, Special Master Arthur Littleworth accepted that the method used for calculating crop consumptive use in the Arkansas Valley be changed from Blaney-Criddle to PME. Consequently, Colorado's Attorney General requested that the Colorado Water Conservation Board (CWCB) fund the "design, installation, and operation of weighing lysimeters at the Colorado State University Agricultural Experiment Station at Rocky Ford, Colorado". The requested funds also cover the enhancement of CoAgMet weather stations, the investigation of irrigation water management in the Arkansas Valley, and the review of the changes made to the Hydrological-Institutional (H-I) Model by experts. The H-I Model has been used by the State Engineer's Office (DWR) to determine depletions to usable water flows to Kansas.

Colorado State University (CSU) has a network of twelve automated weather stations along the Arkansas Valley. Temperature, solar radiation, humidity, and wind speed data from these stations will be used to validate ETr and Kc estimates for the whole Valley.

The lysimeter project at the Arkansas Valley Research Center (AVRC) consists of one large weighing lysimeter and one reference lysimeter. The large or test lysimeter was installed in 2006 and the reference lysimeter will be installed in 2008.

The project objectives, according to Thomas Ley of DWR (2003), are to:

1. Evaluate the performance and predictive accuracy of the ASCE Standardized PME for computing alfalfa reference crop ET for the growing conditions in southeastern Colorado,
2. Determine crop coefficients (for use with PME) for the various crops grown in the Arkansas River Valley under well-watered conditions, and,
3. Determine the effects of typical local growing conditions (which may include limited irrigation, high water table conditions and irrigation with water of high salinity contents) on crop water use.

Fig 2: The inner tank plus soil being lowered inside the containment tank. Photo taken by Michael Bartolo.

The latter objective may require additional lysimeters e.g., non-weighing ones to achieve. It is worth noting that the effects of limited irrigation, high water table, and salinity on crop growth and water use in the Arkansas Valley have been studied by CSU scientists for several years using traditional (water balance estimates) and non-traditional (remote sensing) methods. However, the impact of salinity for example on crop water use can be determined more accurately with a weighing lysimeter. Relatively high salt levels have been reported in the soils and waters of the Arkansas Valley (Gates et al., 2006).

The installation of the test lysimeter was completed in the fall of 2006, but some of the meteorological sensors were put in place in 2007. Consequently, it will be two to three years before achieving Objective 1 and several more years before having usable Kc values and formulas for the major crops grown in the Arkansas Valley.

In the remainder of article, we will describe the main characteristics of the test lysimeter and its location and briefly review land preparation, crop establishment, and future plans.

Site Characteristics

The lysimeter is located at the Arkansas Valley Research Center, approximately two miles east of Rocky Ford in Otero County, Colorado (NW1/4 Sec 21, T23S, R 56W). The elevation at the site is approximately 1,274 m, latitude: 38° 2´ 17.30´´, and longitude: 103° 41´ 17.60´´. The soil type is Rocky Ford; coarse-loamy, mixed, superactive, mesic Ardic Argiustoll. Selected soil properties are shown in Tables 1 and 2.

The long-term average annual precipitation at the site is 11.8 inches, with May through August having the highest rainfall. The total average annual snowfall is 23.2 inches. The average minimum temperature is 36.3 °F and the average maximum temperature 70.0 °F. The last spring frost (32.5 °F) occurs on or before May 1 and the first fall frost on or before October 5 in 50% of the years; thus the average length

Table 1. Soil characteristics of the test lysimeter site

Horizon	Depth	Textural Class	pH water(1:1)	CEC (meq/100g)	EGe (dS/m)	Total C g/kg	SAR
Ap	0-23	Clay loam	8.1	17.2	0.82	15.5	1.70
Bt	23-26	Clay	8.0	16.9	0.90	14.8	2.08
Btk	36-100	Loam	8.3	10.0	0.58	9.0	2.46
Bk1	100-170	Loam	8.3	10.9	0.72	9.5	2.40
Bk2	170-230	Clay Loam	8.3	13.5	0.88	10.8	2.18
2C	> 230	Course Sand	8.7	1.5	-	1.7	-

Table 2. Soil bulk density and hydraulic properties (calculated)

Horizon	Depth (cm)	Bulk Density (g/cm3)	Matric Suction in J/kg						Hydraulic Condutivity (cm/hr)
			1500	1000	500	100	33	10	
Ap	0-23	1.36	123	131	144	182	214	254	0.34
Bt	23-36	1.36	124	132	145	182	213	252	0.33
Btk	36-100	1.45	77	84	97	134	167	213	1.25
Bk1	100-170	1.43	82	89	103	141	176	224	1.06
Bk2	170-230	1.35	118	126	141	183	219	266	0.42
2C	> 230	1.86	19	22	26	40	53	73	16.9

of the growing season for warm-season crops like corn is 158 days.

Lysimeter Characteristics

The test lysimeter consists of an inner tank of 10 ft x 10 ft x 8 ft and an outer containment tank. The chamber between the two tanks houses the weighing mechanism, the drainage tanks, data loggers and has standing room for a half-dozen people (Fig. 3). The inner tank was filled with undisturbed soil (soil monolith) from the same field where the lysimeter is located (Fig. 1). Figure 2 shows the tank being lowered into its permanent location. The soil tank moves freely within the outer tank and the two are separated at the top by a fraction of an inch.

The weighing mechanism consists of a mechanical lever scale-load cell combination. The load cells are connected to Campbell Scientific CR-7 data logger which records the weight of the inner tank plus soil every 10 seconds. The readings are given in millivolts per volt (mV/V). A thorough calibration procedure was performed in 2006 to convert the load cell output in mV/V to the weight of water in kilograms.

The standard deviation of the weight measurements (accuracy) was less than 0.02%. The change in total weight of the soil tank represents the amount of consumptive water use (transpiration plus evaporation from the surface of the soil monolith) by the crop. An example of load cell reading is shown in Figure 4.

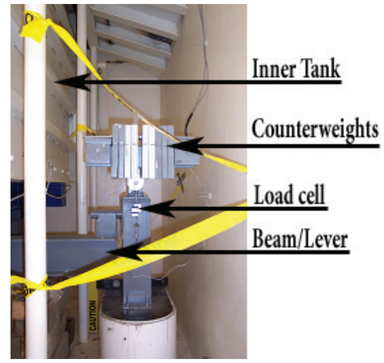
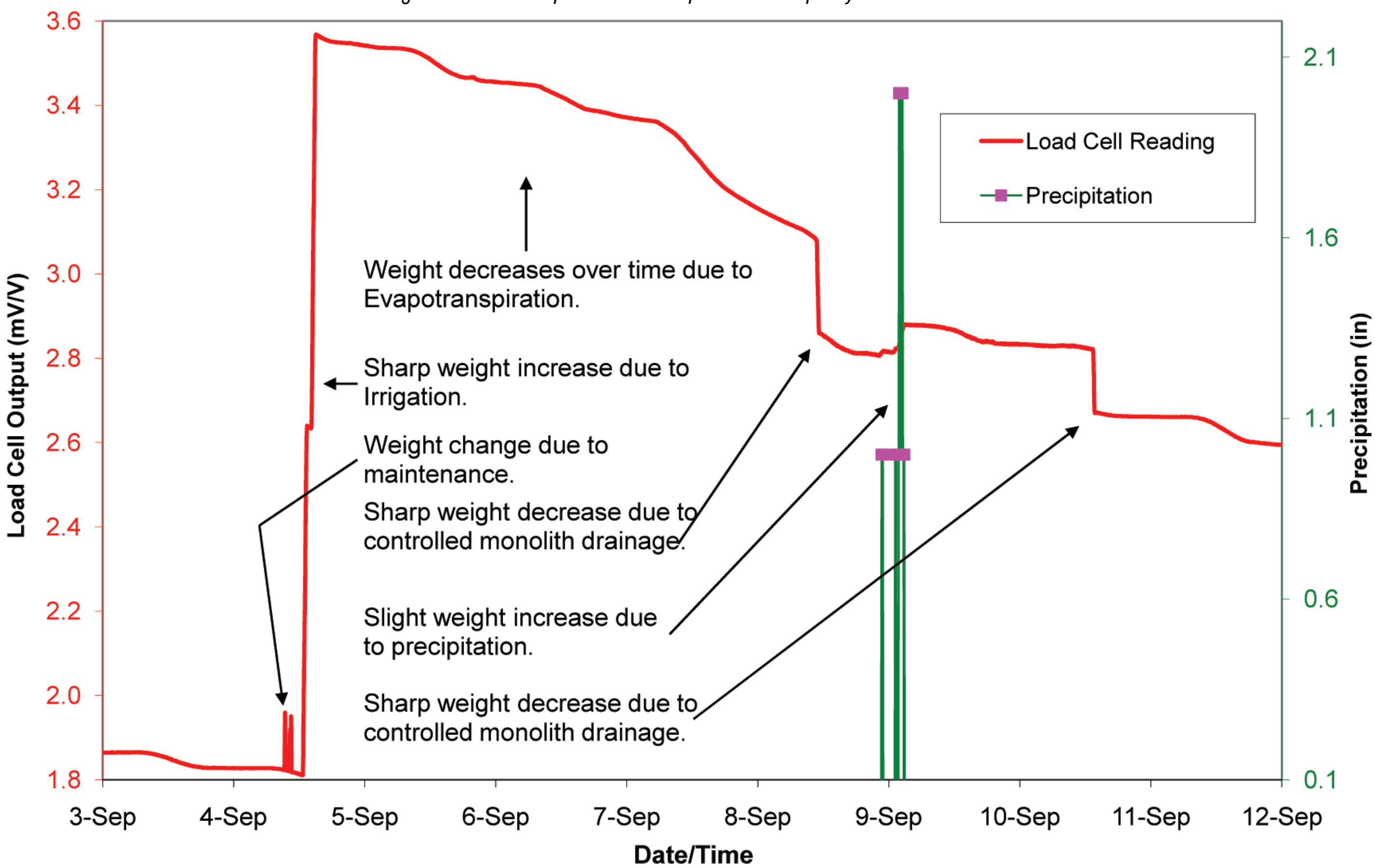


Fig 3: Inside the containment tank (west side). Photo taken by Dale Straw of DWR.

Water that percolates through the soil monolith is collected in two drainage tanks suspended from the scale frame that supports the soil tank, so that there is no overall weight change as water drains into the tanks. One tank collects water from the internal portion of the monolith and the other tank collects water from the perimeter of the monolith.

Fig 4: Load cell output for 3-12 Sept. 2006. Graph by Lane Simmons



Instrumentation

Several instruments are located in, above, or outside the monolith. They are used to measure:

- Precipitation, wind speed and direction, minimum and maximum air temperature, barometric pressure, dew point temperature, relative humidity, and net radiation.
- Incoming (from the sun) and reflected (from the ground or plants) radiation, and incoming and reflected photosynthetic active radiation (PAR)
- Crop canopy temperature
- Soil temperature at various depths and heat flux in or out of root zone
- Soil moisture at 0- to 2.0 m in 20-cm increments with the CPN 503DR neutron probe. A calibration was performed to convert the probe readings into volumetric water content. The calibration procedure and results will be published elsewhere. Comparison of the soil water content inside and outside the soil monolith will be used to adjust the amount of water applied to the monolith and the amount of drainage.

Soil Preparation

Shortly after the installation of the test lysimeter in 2006, the ground around it was flooded to settle the soil. Later, the ground was ripped with a Big Ox chisel plow to alleviate compaction, then plowed, disked, leveled, furrowed, and rolled. The distance between furrows is 30 inches, as is common in the Arkansas Valley. The top eight inches of the monolith were tilled with a rototiller and the beds and furrows were prepared with shovels and spades. There are three full beds in the middle and a half bed against the eastern and western edges of the monolith, and four furrows. They are aligned with the beds and furrows outside the monolith and run north-south.

Fig 5: View of the lysimeter & meteorological instrumentation in late June '07. Photo taken by Michael Bartolo.

Fig 6: Water being applied to the soil monolith. Photo taken by Michael Bartolo.

The total area designated for the test lysimeter to ensure a good fetch is 10 acres (520 ft x 840 ft), of which 6 acres were fallowed since 2005 and an adjacent 4 acres was in alfalfa since 2003. It was paramount to get all 10 acres managed uniformly, thus in early spring 2007, the area in alfalfa was sprayed with Roundup and the whole field was planted to oats on 5 April 2007 at 140 lb/acre. The oat crop inside and outside the monolith was irrigated four times and cut for hay on 25 June. Figure 5 shows the lysimeter after the oat was cut.

The hay was baled on 2 July and the bales removed shortly after that. Oat was chosen as the first crop to be planted after the installation of the test lysimeter because it is easy to grow and could be planted and harvested early, allowing enough time for soil preparation and the seeding and establishment of the next crop (alfalfa) before fall dormancy.

In the latter part of July, the soil in the lysimeter field was again ripped, disked, and leveled. Alfalfa variety 'Genoa' was seeded on 9 August at 19 lb/acre and the field was then furrowed and rolled. The soil inside the monolith was prepared and seeded by hand. The number and arrangement of beds and furrows was the same as with the oat crop. Two hundred pounds of 11-52-0 per acre were broadcast on top of the hay crop on 6 December.

Alfalfa establishment inside and outside the monolith was good to excellent, with the exception of a couple acres approximately 100 ft west of the lysimeter. In this area, alfalfa stand was spotty due to a heavy infestation of morning glory. The whole field was mowed with a brush hog on 27-28 September above the hay crop to suppress the taller weeds. That is when it became clear that approximately half of the area west of the lysimeter will have to be reseeded in the spring of 2008 to achieve a more uniform stand with the rest of the field. Alfalfa was irrigated on 17 August, 4 September, and 4 October. Water from the irrigation canal was dispensed to each furrow with a siphon.

Irrigation of the Soil Monolith

The monolith was irrigated each time the surrounding area was. The amount of water applied was determined by subtracting the amount that flows (flow x duration) in and out of adjacent furrows, as measured by v-shaped furrow flumes. Water was pumped from the irrigation canal and applied to the monolith through a hose fitted with a flow meter and a valve. The furrows on the monolith were filled with water to simulate normal flood irrigation (Fig. 6).

Future Plans

The reference lysimeter (5 ft x 5 ft x 8 ft) will be installed in 2008 in an adjacent field and seeded to alfalfa. The area of the test lysimeter field that has a poor alfalfa stand will be reseeded in the spring of 2008. Alfalfa in the test lysimeter field will be maintained for at least three more years to calibrate the PME. After that, the field will be planted to corn and other major crops in the Arkansas Valley (corn, wheat, sorghum, onions, etc.) to determine their crop coefficients. It will take at least two years of data per crop to generate reliable Kc estimates. Reference ET will be measured with the reference lysimeter after the results are tested and validated.

The lysimeter project is a joint effort between CWCB, DWR, and CSU. Support has also been provided by USDA-ARS engineers and scientists in Fort Collins, CO and Bushland, TX.

For more information about the lysimeter project at AVRC, please contact Lane Simmons at lane.simmons@colostate.edu or (719) 469-5559.

Detecting Trends in Evapotranspiration in Colorado

by W. Austin Clifford, Colorado Climate Center and
Nolan J. Doesken, Colorado State Climatologist

Abstract

There is increasing evidence that temperatures throughout parts of Colorado and most of the Western U.S. have warmed detectably in the past 20 years and may continue to rise. What this means for Colorado's water resources is uncertain since increased temperatures could be associated with either more or less precipitation, or seasonal changes in the distribution of precipitation. Since precipitation is inherently highly variable in both time and space, it may require many decades to confidently assess systematic changes. The less studied and possibly more answerable question is "What does this mean for evaporation and transpiration rates and consumptive use of Colorado's precious and limited water supplies?" In particular, are we capable, with existing weather data, to detect local and regional differences, year-to-year variations and potential long-term changes in ET and consumptive use?

In the first year of this exploratory study, data from the Colorado Agricultural Meteorological Network (CoAgMet) (www.coagmet.com) were closely examined to determine if they are able to accurately detect spatial and temporal variations in evapotranspiration (ET). CoAgMet is the only statewide network of weather observing sites that measure all of the standard climate elements that directly affect ET rates: temperature, humidity, wind movement, solar radiation, and precipitation. Using the Penman-Monteith model for computing alfalfa reference ET, results show that average May-Sept. ET is highest in the Arkansas River basin where the average seasonal reference ET is 51 inches. and lowest is the North Central region where the seasonal average is 41 inches. At any given station, the difference in cumulative ET from a low ET year to a high ET year is about 7 inches. The highest reference ET values were noted in 2002, Colorado's extreme drought year. 1994 was also very high. Low ET rates were observed 1995-1999. Overall, there is an apparent upward trend in reference ET, but with only 16 years of data these preliminary results are not statistically significant. Comparisons with data from Northern Colorado Water Conservancy District (NCWCD) showed that CoAgMet ET estimates correlate well with data from NCWCD's well-maintained weather station network, but CoAgMet shows systematically higher ET rates and more station to station variability. In summary, CoAgMet has the

Colorado Agricultural Meteorolgical Network (CoAgMet)

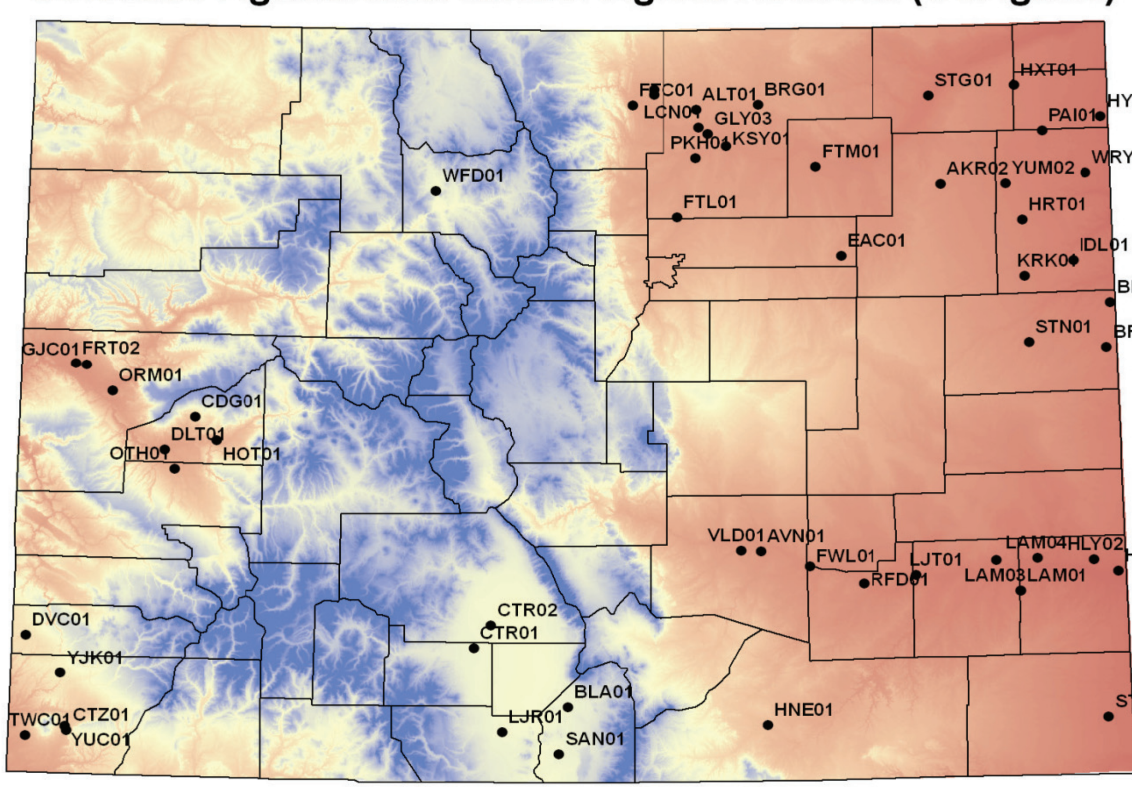


Figure 1. Map of CoAgMet automated weather station network

potential to provide critical information for water resource assessments and decision support. However, periods of missing data, infrequent instrument calibration and potentially unrepresentative locations for some weather stations have compromised CoAgMet data quality for long-term ET applications. Improvements in station maintenance and exposure are encouraged so that the CoAgMet network can be an even more valuable part of Colorado water management and planning for the future.

Introduction

In 1989, two unrelated agricultural research programs in Colorado, both collecting detailed weather data, decided to informally share resources and combine efforts to improve and expand access to timely agricultural weather data (Doesken et al., 1998). This resulted in the establishment of the Colorado Agricultural Meteorological Network (CoAgMet) – a system of automated weather stations that measure and report temperature, humidity, wind speed, direction, solar radiation, precipitation and soil temperatures (examples of stations are shown in Figures 5-6). The majority of the stations are located in areas of intensive irrigated agriculture (Figure 2). These weather stations continuously monitor the weather elements that directly influence the water used by plants – temperature, humidity, wind, sunshine and precipitation. CoAgMet has grown to include 60 active stations. Several new stations were added in 2003-05 in the lower Arkansas River Basin in Colorado as a direct consequence of litigation of the Arkansas River interstate compact with Kansas. The network has never been well funded but is managed as a loose federation of motivated organizations with a shared interest in weather data serving Colorado's diverse agricultural needs.

Colorado water courts have long accepted estimates of consumptive use based upon the Blaney-Criddle (1950) model. The Penman-Monteith model is quickly becoming the accepted standard method, but to be effective long-term detailed meteorological data must be readily available.

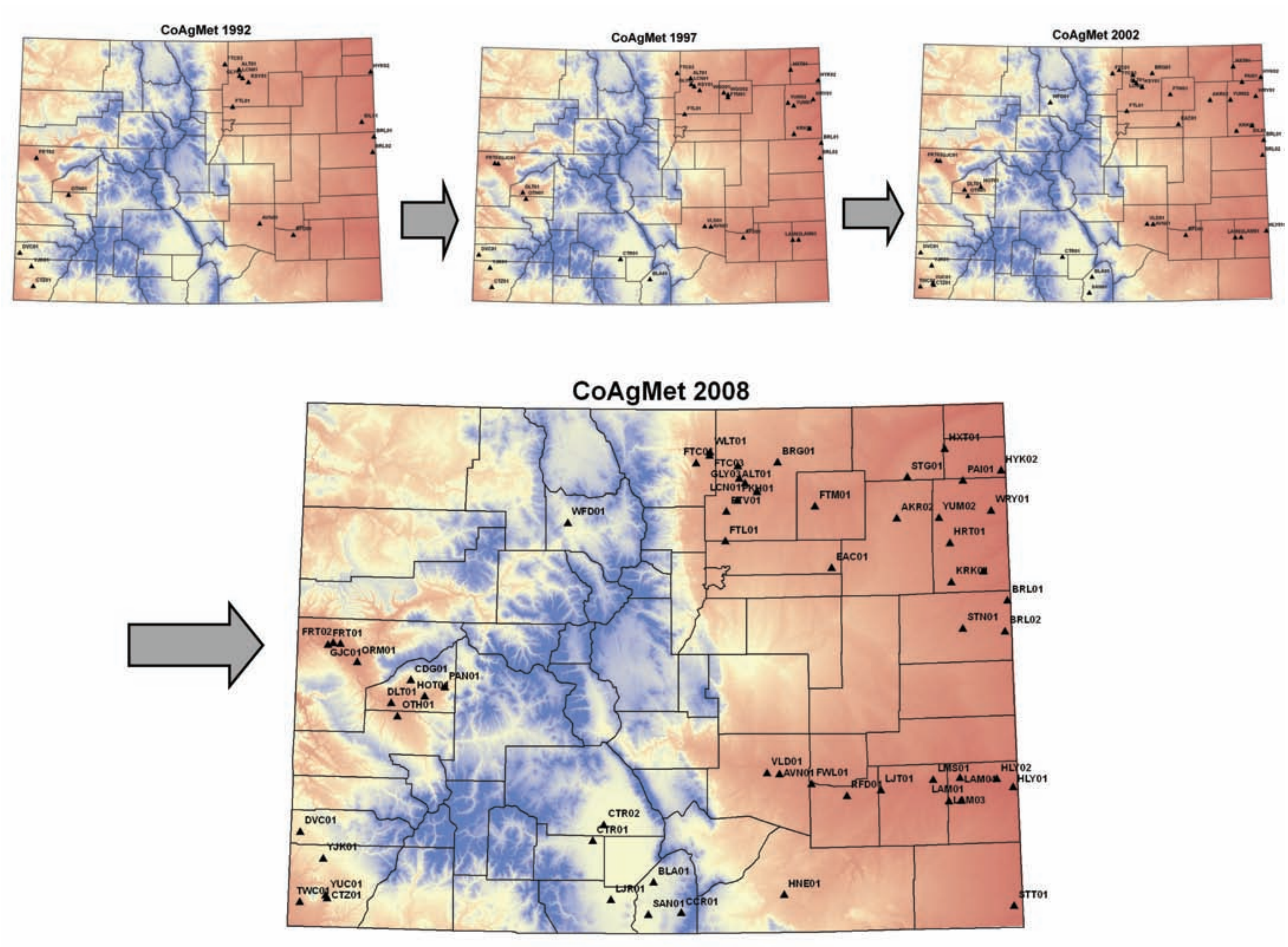


Figure 2. History of CoAgMet (1992-2008)

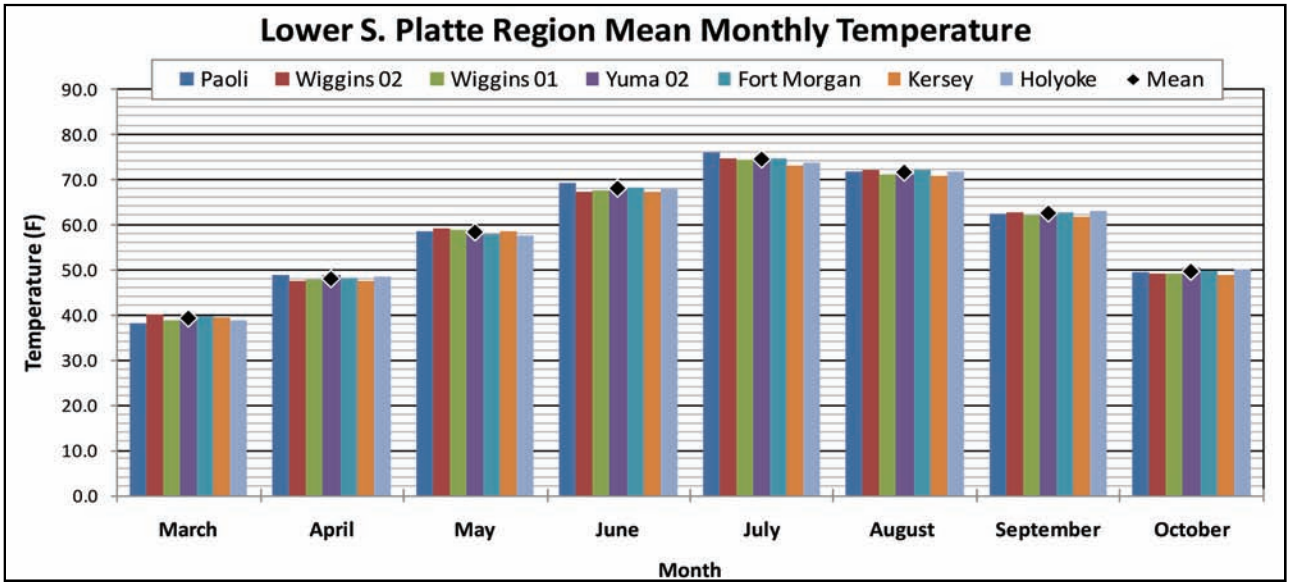


Figure 3. Lower S. Platte Region Mean Monthly Temperature

Methods

After completing the network-wide data quality assessment and comparison, then the Penman-Monteith seasonal cumulative ET was calculated for all stations from the available daily data sets. The growing season was defined as the period from 1 May to 30 September.

Mean cumulative July ET values were compared separately. This aided in determining which stations may have unrepresentative siting. It should be noted the CoAgMet Network has traditionally used the Kimberly-Penman (1982) model for estimating ET. Since the initiation of this study, Penman-Monteith estimates are now co-generated by CoAgMet.

Relatively large differences in monthly and seasonal ET values were noted among stations in each region. To help explain these variations, station locations, elevation and proximity to irrigated land were assessed. Photographs of the CoAgMet stations were examined, and interviews were conducted with CoAgMet collaborators familiar with each station.

Results

Many CoAgMet weather stations are missing significant amounts of data, as seen in Figure 4. There are no stations with serial complete data since 1992. Overall, data are more than 90% complete for many stations. The data quality between regions has varied in the past. The San Luis Valley region overall had the most data gaps, and the North Central Region typically had the most complete data. The Lower S. Platte and the Arkansas River Valley Basin showed

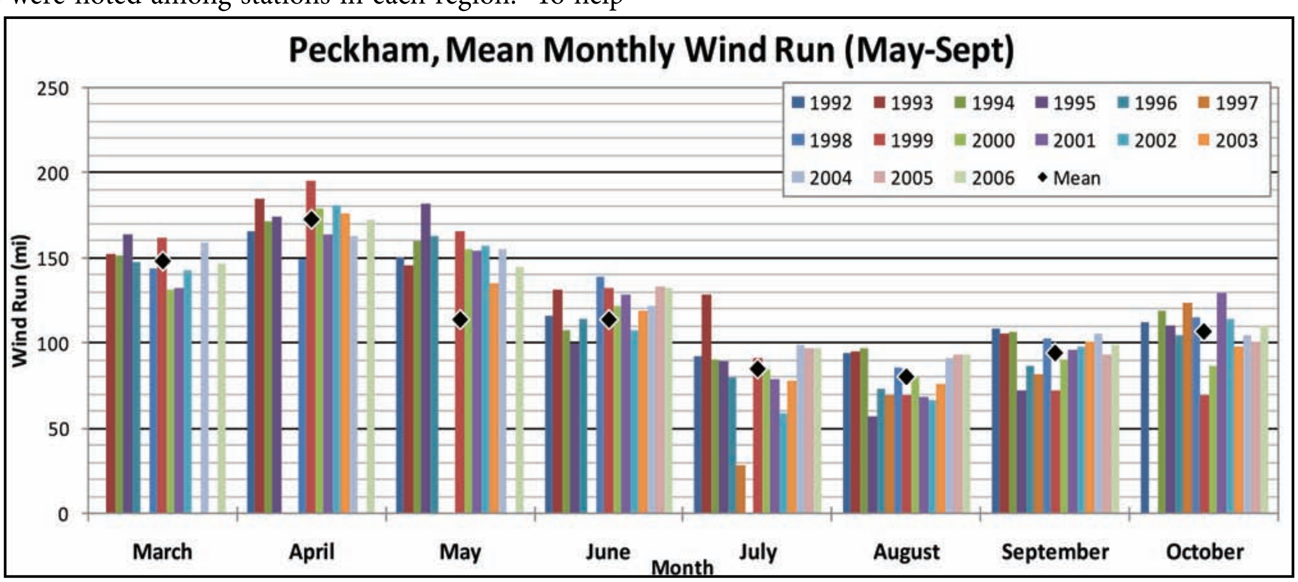


Figure 4. Mean Annual Monthly Wind Run (May-Sept) for Peckham

reasonably complete and consistent data. Unfortunately, for this study, some of the best data in the Arkansas River Valley was measured by stations relatively new to the network, so long time series of high quality data were not yet available based on a large aggregate of stations.

Due to the voluntary nature of CoAgMet and its' ad hoc history, station siting has not been uniform. Some sites are located over or adjacent to clipped grass or alfalfa, while others are in unirrigated areas. Some sites may not fully represent weather conditions observed over irrigated fields so may not be ideal or appropriate for ET applications. Some stations are on the fringe of irrigated areas and some are in dryland areas. Their meteorological data are still valuable for many applications, but the exact local siting affects how suitable each station is for representing ET rates for adjacent cropland. We will be providing a more complete assessment in year two of this project based both on site documentation and computed ET rates.

Figure 5. CoAgMet volunteer Dr. Harold Duke services Dove Creek. Due to the lack of underlying vegetations, sites like this may not be ideal for ET applications

Figure 6. Fort Collins AERC is an example of a clipped grass environment

Conclusions

Close scrutiny of weather data and computed reference ET estimates for seven agricultural regions of Colorado have been completed for the period 1992-2007 using weather data from the Colorado Agricultural Meteorological network (CoAgMet). May-September alfalfa reference ET was shown to be highest in the Arkansas River basin (51 inches) and lowest is the North Central region (41 inches). Year to year variations in computed reference ET are not large (generally less than 15% of the long-term average). At any given station, the difference in cumulative ET from a low ET year to a high ET year is about 7 inches. The highest reference ET values were noted in 2002, Colorado's extreme drought year. ET was also very high in 1994 was also very high. Low ET rates were observed 1995-1999. Overall, there is an apparent upward trend in reference ET, but with only 16 years of data these preliminary results are not statistically significant. Comparisons with data from Northern Colorado Water Conservancy District (NCWCD) showed that CoAgMet ET estimates correlate well with data from NCWCD's well-maintained weather station network, but CoAgMet shows systematically higher ET rates and more station to station variability.

This study shows that CoAgMet has the potential to provide critical weather information to assess year to year variations in reference ET necessary for irrigation scheduling, water resource assessments and decision support. However, periods of missing data, infrequent instrument calibration and potentially unrepresentative locations for some weather stations have compromised CoAgMet data quality for long-term ET applications. Improvements in station maintenance and exposure are encouraged so that the CoAgMet network can become an even more valuable part of Colorado water management and planning for the future.

Future Plans

One more year of work remains under this CWRRI funded project. In 2008, correlation statistics will be developed to provide quality estimates for missing data from stations within each region. CoAgMet station siting will be further assessed. The CoAgMet website will be annotated so that users know which stations are appropriate for reference ET use. Missing data will then be filled in from previous years to create serially complete time series for many stations. This will give a much needed increase in available data for long-term trend analysis. Time series will then be recomputed and evaluated. Further statistical analysis will be completed, including a step-wise regression sensitivity analysis to better understand which weather variables have the greatest impact on computed reference ET here in Colorado. Beginning in early 2008, results from this study will be presented to the CoAgMet advisory team. Efforts to provide reliable funding for CoAgMet and to assure proper instrument siting and consistent maintenance must be given high priority.

For entire report, including site data, please visit http://www.cwrri.colostate.edu/2007_CoAg_Report.pdf

CSU Research Colloquium
Global Water: From Conflict to Sustainability
Tuesday, March 25th, 2008
Hilton Hotel, Fort Collins, Colorado

2005-2015 is the decade designated by United Nations as the International Decade for Action: "Water for Life." 2008 or the "International Year for Sanitation" coincides with many of the issues we are facing today in Colorado including: poor water quality and salinization, wastewater treatment, aging sewer systems, and antiquated policy & institutional frameworks. Historically, international work in water resources has long been a focus at Colorado State University. Today, international water research and development continues and is spread across campus ranging from Engineering, Natural Resources and Agriculture to Sociology, Environmental Health, Business and Biological Sciences.

Environmental and human induced climate changes are effecting natural water regimes world-wide. The Global Water Colloquium aims to present the impact these changes have on decreasing water quality and increasing water scarcity visible across spatial and temporal scales in the hope that the university community will engage in open discussions and collaborative solutions. Many such solutions in the form of technological advances in hydrology and hydraulics will be presented during the 28th Annual Geophysical Union - Hydrology Days being held directly after the Global Water Research Colloquium on March 26-28. Warner College of Natural Resources will be hosting a three day event to celebrate 50 years of the Watershed Science Program beginning March 27th.

The colloquium is designed to benefit investigators with research activities that could be applied to water resources at a local, regional, national and international level as well as researchers with established water resources research programs. Individuals, private consultants, public administrators, managers, policy makers, and those interested in learning more about international research activities in water resources would also benefit from the research colloquium.

The Global Water: From Conflict to Sustainability Colloquium is hosted by the Office of the Vice President for Research. For updates on all these events please visit the Vice President for Research Web site. http://www.vpr.colostate.edu

Contact
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2008 Research Colloquium

Global Water: From Conflict to Sustainability-
Challenges and Opportunities in an Interdependent World

MARCH 25, 2008

HILTON, FORT COLLINS, COLORADO
CHAIR: DR. REAGAN WASKOM
HTTP://**VPR.COLOSTATE.**EDU

Colorado State University

SPRING 2008

INTERDISCIPLINARY WATER RESOURCES SEMINAR
NOON-1:00PM IN THE LORY STUDENT CENTER

31-JAN RM.203	**Luis Garcia** Department Head of Civil & Environmental Engineering, CSU NAS – Study on Colorado River & Climate Change
7-FEB **RM.208**	**David Yates** Hydrologist, NCAR, Research Application Program Incorporating Climate Change Information in Water Utility Planning: A Collaborative,
14-FEB **RM.208**	**Evan Vlachos** Sociology, CSU Managing Transboundary Waters in the context of extreme hydrological events
21-FEB RM.203	**John Stednick** Forest Rangeland & Watershed Stewardship, CSU Effect of Mt. Pine Beetle on Water Quantity and Quality
28-FEB RM.203	**Bill Hansen & Dan McGlothlin** NPS The National Park Service's Experience in Applying Science in Water Rights
6-MAR **RM.226**	**Robert Young** Professor Emeritus, Agricultural and Resource Economics Economic Value of Water
13-MAR RM.203	**Valerie Assetto** Political Science, CSU International Water Governance
20-MAR	**Spring Break**
27-MAR	**Seminar Cancelled** Please participate in Hydrology Days (http://hydrologydays.colostate.edu) Celebrate 50 years of the Watershed Science Program!
3-APR RM.203	**Rodrigo Maia** Civil Engineering, University of Porto, Portugal Water Management Challenges in the Iberian Peninsula
10-APR **RM.208**	**Bret Bruce & Pete McMahon** USGS Denver High Plains Regional Ground Water Study-Current Understanding and Future Directions
17-APR RM.203	**Chris Goemans** Agricultural & Resources Economics, CSU The Medium Term Impact of Natural Disasters in Brazil
1-MAY RM.203	**Bob Raynolds** Denver Museum of Natural Science Climate Change and Issues of Water Availability
8-MAY RM.203	**Roger Pulwarty** NOAA National Drought Information Systems Lori Peak-Hazards, Disasters & the Case of

FY08 Student Water Research Grant Program

Request for Proposals

The Colorado Water Resources Research Institute is pleased to announce a request for proposals for the FY08 Student Water Research Program.

Program Description

This program is intended to encourage and support graduate and undergraduate student research in disciplines relevant to water resources issues and to assist Colorado institutions of higher education in developing student research expertise and capabilities. It is intended to help students initiate research projects or to supplement existing student projects in water resources research. Proposals must have a faculty sponsor and students must be enrolled full-time in a degree program at one of Colorado's nine public universities (ASC, CSM, CSU, CU, FLC, MSC, MSCD, UNC, or WSC).

Funding

Budgets may include, but are not limited to, expenditures for student salaries, supplies, and travel. Funds will not be approved for faculty salaries. Each award is limited to a maximum of $5,000. Awards may be effective as early as April 1, 2008 and research projects should be completed by March 31, 2009. For these research grants, only direct costs are allowed. Facilities & Administrative (F&A) costs may be shown as institutional cost share. Institutions are encouraged to participate in project costs although cost sharing is not required.

Eligibility

Students must be enrolled full-time in a degree program at one of the nine Colorado public universities. Proposals must have a faculty sponsor from the applicant's institution. The faculty sponsor is responsible for ensuring that the proposal has been processed according to their university's proposal submission policies and procedures.

Deliverables

Upon completion of the research project, recipients will be required to submit a final project report, which will include a narrative on research activities and results. **Projects must be completed and results reported by March 31, 2009.** Students may be asked to present an oral report on their work to the CWRRI Advisory Board.

Submission Process

All proposals must be submitted online. Please visit http://www.cwrri.colostate.edu for submission site.

Proposal Deadline

February 29, 2008 at 5:00pm MT

Expected Award/Start Date

Start Date: April 1, 2008

End Date: March 31, 2009

Announcement of Awards

The student applicant and faculty sponsor will be notified as to the status of their application by March 31, 2008 via email.

Program Contact Information

For questions concerning the program, please contact:

Dr. Reagan Waskom, Director
reagan.waskom@colostate.edu

Nancy Grice, Assistant to the Director
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Fax: 970-491-1636

Web: http://www.cwrri.colostate.edu

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	5	2	0	5	12
Masters	2	0	0	4	6
Ph.D.	1	1	0	4	6
Post-Doc.	0	0	0	0	0
Total	8	3	0	13	24

Notable Awards and Achievements

On the first day of the FY08 session of the Colorado Legislature, HB08-1026 was introduced by Representative Randy Fisher to change the name of CWRRI to the Colorado Water Institute. More importantly, this bill removed the longstanding prohibition in our previous authorizing legislation that precluded the appropriation of general fund dollars to the Institute, paving the way for a permanent research authorization in the state's budget. Finally, the language of the bill served to update the Institute's advisory committee and the mission of the Institute to include water resources impacts related to climate change and a charge to serve the state in the area of water policy. The bill passed handily and subsequent funding legislation was submitted for consideration in April 2008. CWRRI will officially become the Colorado Water Institute on July 1, 2008.

Publications from Prior Projects

1. 2007CO149B ("Technology Transfer and Information Dissemination") - Water Resources Research Institute Reports - Brown, Jennifer, ed., 2007, A River of Change, Information Series Report 104, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 24 pp.
2. 2005CO115B ("Colorado's Evolving Irrigated Agriculture: Economic Accounting Impact Analysis") - Water Resources Research Institute Reports - Pritchett, James and Jennifer Thorvaldson, 2007, Some Economic Effects of Changing Augmentation Rules in Colorado's Lower South Platte Basin: Producer Survey and Regional Economic Impact Analysis, Completion Report 209, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 44 pages.
3. 2005CO148B ("Hydrologic Analysis, Forecasting and Simulation of the Upper Colorado River System") - Water Resources Research Institute Reports - Fontane, Darrell and Julia Keedy and Jose Salas, 2007, Impact of Steamflow Variability on the Colorado River System Operation, Completion Report 208, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 86 pages.