Colorado Water Institute
Annual Technical Report
FY 2008

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 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 Introduction

Colorado Water Institute funded nineteen 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.

CWI was fortunate to receive an additional $500,000 in one time funds from the State of Colorado in FY09 to expand the research portfolio in FY09. Under Section 104(b) of the Water Resources Research Act, CWI 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 six new proposals for consideration this year from two 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 CWI Advisory Committee resulted in funding five new projects for FY09.

Active projects and investigators are listed below:

1. **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, Colorado State University. $15,280
2. **Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin**. Stephanie Kampf, Colorado State University. $55,000 ($25,000 in federal funding)
3. **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, Colorado State University. $40,000
4. **Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation**. James Pritchett, Colorado State University. $47,981 ($15,000 in federal funding)
5. **Effects of Pine Beetle Infestations on Water Yield and Water Quality at the Watershed Scale in Northern Colorado**. John D. Stednick, Colorado State University. $50,075 ($11,951 in federal funding)
6. **Occurrence and Fate of Steroid Hormones in Sewage Treatment Plant Effluents, Animal Feedlot Wastewater, and the Cache la Poudre River of Colorado**. Thomas Borch, Colorado State University. $49,944
7. **Detecting Trends in Evapotranspiration in Colorado**. Nolan Doesken, Colorado Climate Center. $47,802
8. **Evaluation of Engineered Treatment Units for the Removal of Endocrine Disrupting Compounds and Other Organic Wastewater Contaminants During Onsite Wastewater Treatment**. Robert L. Siegrist, Colorado School of Mines. $49,746
9. **Direct Determination of Crop Evapotranspiration in the Arkansas Valley with a Weighing Lysimeter**. Abdel Berrada, Colorado State University. $49,995
10. **Refining Water Accounting Procedures Using the South Platte Mapping and Analysis Program**. Luis Garcia, Colorado State University. $22,985
11. **Development of Oilseed Crops for Biodiesel Production Under Colorado Limited Irrigation Conditions**. Jerry J. Johnson, Colorado State University. $60,233

12. **Characterizing Non-Beneficial Evaporative Upflux from Shallow Groundwater Under Uncultivated Land**. Jeffrey D. Niemann, Luis Garcia, Colorado State University. $49,942 ($15,000 in federal funding)
13. **Predictability of the Upper Colorado River Streamflows**. Jose D. Salas, Colorado State University and Balaji Rajagopalan, University of Colorado. $44,859
14. **Simultaneous Water Quality Monitoring and Fecal Pollution Source Tracking in the Big Thompson Watershed**. Lawrence Goodridge, Colorado State University. $49,995
15. **Risk Assessment and Forecasting of Indian Summer Monsoon for Agricultural Drought Impact Planning**. Balaji Rajagopalan, University of Colorado. $86,646
16. **Development of a Correction Function for the 3-Inch, Thin-Walled, Helley-Smith Sampler Deployed on Coarse Gravel Beds**. Steven Abt, Colorado State University. $21,416
17. **Estimating Errors Associated With Calculated Sublimation From Seasonally Snow-Covered Environments**. Douglas Hultstrand, Colorado State University. $5,000
18. **Studies Supporting Sustainable Use of the Denver Basin Aquifers in the Vicinity of Castle Rock**. Kim Lemonde, Colorado State University. $5,000
19. **Flow Device to Assess Biological Water Quality in Colorado Surface Water**. Travis Steiner, Colorado State University. $5,000

For more information on any of these projects, contact the PI or Reagan Waskom at CWI. Special appreciation is extended to the many individuals who provided peer reviews of the project proposals.

Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin

Basic Information

Title:	Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin
Project Number:	2008CO166B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	4th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Water Supply
Descriptors:	
Principal Investigators:	Reagan M. Waskom, Stephanie K Kampf

Publication

Title: Hydrologic analysis and process-based modeling for the upper Cache la Poudre basin

1. Statement of regional or State water problem:

The Cache la Poudre basin exemplifies the many types of water management challenges that exist in Colorado basins. The river has a long history of water use extending back to early settlements in the 1850s, and water is now used to support many agricultural, municipal, and industrial demands. Currently, a common perception among the Poudre River water users is that water has not been available in the quantities it once was (Hoff, personal communication). Even in years with normal or above normal snow pack, users have found that flows are below those that would be predicted from historical conditions. Water users therefore wonder if the river flow regime has changed in some way, and they are interested in exploring new tools that would help predict the timing and quantity of flow under the current hydrologic regime. As a supplement to seasonal statistical forecasts, water planning and management would benefit from models that could simulate possible flow responses to changes in climate, land use, or water use.

2. Nature, scope, and objectives of the project:

The proposed research explores the use of hydrologic analyses and simulation models for characterizing the hydrologic regime and predicting future flows in the upper Cache la Poudre basin. This research will form part of a longer term study trajectory on overall basin hydrology and management. In this context, the present research will focus on how river flows respond to climate variability (precipitation, temperature) in the upper basin (upstream of the canyon mouth).

The research has three major objectives:

1. Conduct a thorough exploration of historical hydrology, particularly spatial and temporal trends in precipitation, temperature, and runoff. Identify timing and magnitude of any changes in land cover or water use.
2. Build a quasi-distributed hydrologic model that converts ground and satellite-derived measurements of precipitation, snow, and temperature into spring-summer runoff hydrographs.
3. Use the hydrologic model to generate possible spring-summer hydrographs for different climate scenarios.

These objectives will be accomplished during the following target timeline:

Semester	*Jan-May 2008*	*Jun 2008 – May 2009*	*Jun-Dec 2009*
Activity	Phase 1, Hydrologic analysis	Phase 2, Model development	Phase 3, Model application
Product	Hydrology database	Hydrologic model	M.S. thesis Journal article

3. Background

3.1. Setting

The Cache la Poudre River is located in northeastern Colorado. From its headwaters in Rocky Mountain National Park, it travels approximately 80 miles down through the Poudre Canyon, eventually passing through Fort Collins and Greeley before reaching its confluence with the South Platte River. The basin covers an area of 1,890 square miles, and it contains elevations ranging from over 13,000 ft above the headwaters down to 4,600 ft at the confluence with the South Platte River. Because of this high elevation range, land cover in the basin extends from tundra in the high elevation areas down to subalpine and montane coniferous forests in middle elevation areas and grasslands at low elevation. The basin geology consists of Precambrian metamorphic and igneous rocks in the upper basin and Cretaceous sedimentary rocks in the foothills and lower basin. The climate in the basin is generally cool and dry, with strong seasonal variation in temperature. Precipitation generally increases while temperature decreases with elevation, leading to significant variability in climate over the basin area.

The Cache la Poudre has long been a source of irrigation water, and diversions from the river for irrigation were well underway in the 1860s (Laflin, 2005). Water shortages were already apparent by the 1870s, so as early as the 1880s, trans-basin diversions were constructed to bring water from the western side of the Continental Divide to supplement Cache la Poudre flows. A number of reservoirs have also been constructed throughout the basin, most on smaller tributaries to the main stem Cache la Poudre. The Colorado-Big Thompson project also brings water into the basin at Horsetooth Reservoir. Numerous diversions take water out of the Cache la Poudre in the lower basin, and these diversions occur in response to water user needs, water availability, and water right priority.

This study will focus on the portion of the basin upstream of the USGS flow gage at the canyon mouth, which is located approximately 3 km downstream of the confluence of the North Fork with the main stem Cache la Poudre. This location has the longest flow measurement record in the basin (going back to 1881), and it is upstream of most of the diversions that take water out of the river. Because the dominant contribution to flow in the river is snowmelt, the part of the basin upstream of the canyon mouth is also the area that contributes most of the river flow. Focusing the study on this upper part of the basin enables us to address primarily the effects of climate on river flows, whereas future study on the lower part of the basin will need to deal more extensively with water diversions, water uses, and irrigation return flows.

3.2 Current Cache la Poudre flow forecasts

Because the Cache la Poudre is a water source for many users, flow forecasts are important for water planning and allocation. Flow forecasts for the Poudre River are currently issued by both the Natural Resource Conservation Service (NRCS) and the Northern Colorado Water Conservancy District (NCWCD). The NRCS issues seasonal forecasts of spring-summer flow. Forecasting begins in January of each year, and until July, the forecasts are updated each month or more frequently if needed. The forecasts are statistical models that primarily incorporate automated data from SNOTEL and streamflow gaging sites as well as snow course data from sites in and near the Cache la Poudre basin (Perkins, personal communication). The NCWCD has explored multiple statistical models for flow forecasting also using SNOTEL and snow course data and in some cases lower elevation precipitation data (Pineda, personal communication). The forecasting success of these data-driven statistical models depends on how well the measurement locations represent the total precipitation input throughout the basin. The NRCS forecaster for the Cache la Poudre has noted that the forecasts work well most years when the majority of the snow is contributed to the basin at high elevation; however, in years where snow cover at low elevation deviates significantly from normal, flow predictions are not as good (Perkins, personal communication).

3.3. Hydrologic modeling

Another potential tool for forecasting is a process-based hydrologic model, which is computer program that simulates stream flow based on some type of conceptualization of the hydrologic cycle. Models have been developed for a wide range of spatial and temporal scales, and they represent components of the hydrologic cycle with varying levels of complexity (see e.g. Singh and Woolhiser, 2002). The statistical models described for flow forecasting are built solely on the measurements available. Process models, on the other hand, assume a set of hydrologic behaviors, and they use the available measurements as inputs to 'force' the simulation of these behaviors. Many newly developed models are spatially distributed, in that they explicitly represent movement of water through space. Some of these types of models divide up the space in a basin by identifying a number of sub-basins, which are connected via a routing network. Other models break up the basin area into a grid or mesh and simulate water flowing between the grid cells either along the ground surface or through the subsurface (more detail in Kampf and Burges, 2007). Models that incorporate significant detail in the way they represent processes tend to require a large amount of input data and incorporate a large number of unknown parameters. Complex distributed models, for example, will require detailed input data (such as spatial patterns of precipitation, temperature, radiation, etc.) and basin characteristics (spatial patterns of soil properties, vegetation characteristics, etc.).

Some hydrologic models incorporate snowmelt processes in varying levels of detail. Of these models, some link snow accumulation and melt routines to other hydrologic process components like surface and subsurface flow, interception, and evapotranspiration (see e.g. PRMS – Leavesley et al., 1983), whereas others simulate primarily snowmelt runoff. The Snowmelt Runoff Model (SRM) (Martinec et al., 1998) predicts streamflow directly from the depletion of snow covered area through the melting season. This type of approach has the significant advantage of using a minimal number of model parameters to predict streamflow, but it is best applied only where nearly all runoff comes from snowmelt, and snow covered area is directly related to elevation. Other snowmelt models range along a spectrum from fully empirical to fully physical and spatially distributed (see e.g. Williams and Tarboten, 1999; Marks et al.1999).

For large-scale analyses (e.g. continental-scale basins such as the Colorado or Columbia Rivers) a new forecasting method has been developed using the large-scale Variable Infiltration Capacity (VIC) model (Wood and Lettenmaier, 2006), which simulates the energy and water balance for 1/8 degree grid cells, connected via a routing network. For smaller scales, however, process models are not yet used extensively in seasonal flow forecasting in the western U.S., in part because of the extensive configuration, calibration, and computational resources required.

3.4. Linking measurements and models

The examples in the previous section highlight just a few of the many hydrologic process models that exist. An important step in modeling is selecting an approach that is most suitable for the processes, scale, and data availability in the area of interest. A major challenge in model selection is the tradeoff between flexibility and parameterization. Models that are comprehensive in their treatment of hydrologic processes tend to suffer from over-parameterization (difficult to calibrate; non-unique results), whereas parameter-parsimonious models are more constrained in application. In a review of snowmelt runoff models, Ferguson (1999) noted that the right level of complexity in a meltwater runoff model is not obvious.

Physics-based models are more challenging to calibrate and not necessarily better than simpler models. A reasonable guiding principle for setting up a process model is that the model should contain only as much detail as the data support.

Even in basins that have extensive measurement networks, hydrologic data used as inputs to models are typically point location climate (precipitation, temperature, etc.) measurements. These point locations may or may not be representative of the larger area to be modeled. Many methods exist for interpolating point measurements to spatial distributions, but the success of all methods is constrained by how well the measurements capture the dominant sources of variability. Some hydrologic variables (e.g. snow covered area, land surface temperature) can be derived from satellite images. These remotely sensed images capture spatial patterns at a larger scale than the point weather station measurements, but they represent only select snapshots in time. The easiest hydrologic variable to get from remote sensing is snow covered area, which depicts the presence or absence of snow (but not the amount of snow). Other climate variables that can potentially be derived from remote sensing include land surface temperature and solar radiation. Satellite products, particularly snow covered area, are beginning to be used more frequently in modeling applications. Snow covered area data can be used as direct inputs to the Snowmelt Runoff Model (see e.g. Gómez-Landesa and Rango, 2002; Tekeli et al., 2005), and snow cover data has been incorporated into other types of models using data assimilation or updating techniques (e.g. Andreadis and Lettenmaier, 2006; Clark et al., 2006; Dressler et al., 2006; McGuire et al., 2006).

3.5. Hydrologic modeling for the Cache la Poudre

From the process modeling perspective, the Cache la Poudre basin is intermediate in scale. The basin is small for representing hydrologic behavior with a large-scale gridded model such as VIC, but spatial data to characterize the precipitation, temperature, soil characteristics, etc. are not available to support a detailed small-scale distributed model. Application of a detailed high-parameter model would require extensive effort in calibration without necessarily producing a unique solution. From the process hydrologic perspective, although the Cache la Poudre basin contains wide variability in topography, land cover, and geology, the flow characteristics are dominated by one primary process: snowmelt. This means that the hydrologic response is low-dimensional, affected primarily by the amount of snow input and the rate of melt. The low dimensionality of the problem partly explains why snow-based statistical forecasts are often suitable for predicting flow in the basin and suggests that a very detailed process model may not be needed for the basin. However, during some years, spring storms (which may be either snow or rain or both) contribute to significant increases in flow; these flow contributions will not be well-predicted by a model that solely represents snowmelt runoff.

A preliminary exploration of flow data for the Cache la Poudre and its major tributaries shows that the bulk of the flow in the river is contributed from high elevation areas, where snow accumulation is highest. Flow is also contributed at lower elevations, but the amount contributed is more variable from year to year. Melt at low elevations contributes flow to the river during the rising limb of the hydrograph in the spring, and melt at higher elevations contributes to peak flow later in the summer. Both low and high elevation snowpack can provide a substantial proportion of flow. Therefore, we hypothesize that a strong predictive model for flow in the Cache la Poudre needs to account for the spatial variability in snow accumulation and melt in the basin. Building on this hypothesis, we propose creating a flow prediction model that combines the predictive strength of a statistical model with the more detailed spatial divisions of a distributed model. The following section describes the steps we will take toward building this model.

4. Methods, procedures, and facilities

4.1. Phase 1: Hydrologic analysis

The first phase of the study will involve characterizing the historical hydrology based on an analysis of the available hydrologic data for the basin. Our particular focus in this analysis will be exploration of how spatial and temporal patterns in precipitation and temperature relate to the magnitude and timing of snowmelt runoff.

a. Point measurements

We will examine historical precipitation and temperature patterns in the basin, supplementing with climate records from other nearby basins and with stations at lower elevations. This analysis will use weather station, SNOTEL, and possibly snow course data. Stream flow measurements at many locations are discontinuous in time, but many parts of the basin have been gaged for some period of time during the last 100 years. Flow measurements at different locations are available from the USGS, Colorado Division of Water Resources, and the NCWCD. The USGS gage at the Canyon Mouth will be our benchmark location for flow prediction. Other stream gages will be used to explore the distribution and timing of flow contributions to the main stem of the Cache la Poudre. During time periods when gage records overlap, we will examine the quantity of flow contributed at each tributary at monthly to annual time scales. To organize this analysis, we will characterize the timing of the flow contribution based on metrics that describe the hydrograph shape such as time of melt initiation, time of peak flow, and time of return to baseflow. For all analyses, stream gage records will be adjusted to naturalized flows, removing both the inputs from ditches and the flow regulating effects of reservoirs. In most cases, sufficient data are available to characterize water transfers and impoundments, and the NCWCD has already developed datasets of naturalized streamflows in the basin at a monthly time step (Pineda, personal communication).

b. Spatial data

We will build a spatial database (in GIS) of the basin characteristics. The database will include a digital elevation model of the topography, stream and reservoir locations, weather and stream gauge measurement locations, geology, soils, and land use. We will also document any known changes in land cover through time, particularly those such as forest cutting and re-growth that may have affected snow accumulation and melt or rainfall runoff.

Spatial snow covered area data are available from multiple sources. Since 2000, the MODIS sensor has collected satellite images in multiple wavelengths, and a snow covered area product is available for processed MODIS data at 500 m or larger resolution. Earlier snow covered area extents can be derived using images from earlier satellite sensors such as Landsat or from aerial photographs. We will examine the snow covered area images that correspond with snowmelt runoff hydrographs and document patterns in snow cover for different parts of the rising and falling limb of the hydrograph. Analyses of remotely sensed data will be partly constrained by cloudiness and product accuracy (see e.g. Maurer et al., 2003), but the available data should be more than sufficient for the exploratory purposes of this study. MODIS images also include data in the thermal infrared wavelength range, which can be used to derive land surface temperatures. A later phase of this research may incorporate land surface temperature product from MODIS into the hydrologic analysis.

We will compile these multiple types of point and spatial data sources into a database tied to the geographic configuration of the basin. Although many data types are available for the basin, the data do not all overlap in time. Therefore, the analysis will involve attempts at reconstructing possible hydrologic responses for locations and time periods when data are not available. Fortunately, we have several time periods with simultaneous flow data for all the major tributaries to the Cache la Poudre (North Fork, South Fork, and others), so these data will help us infer flow scenarios that likely occurred in other years.

4.2. Phase 2: Model development

The components listed in Phase 1 of this project represent steps in using the available data to explore the nature of the flow response both in space and time. These analyses will help identify when and where flow is contributed to the Cache la Poudre. The model we develop for flow prediction at the Poudre Canyon mouth will build directly on the hydrologic analysis. The model will be parameter parsimonious and forced by the data available (station precipitation and temperature and spatial snow covered area). Our preliminary analyses of the basin hydrology suggest that the flow response cannot be captured fully by an index-based snowmelt model (e.g. SRM), and more comprehensive process models (e.g. PRMS) do not fit with our goal of developing a simple, low-parameter model that can link directly with statistical forecasts. Therefore the model developed will be new, but it will draw as needed upon elements introduced in other existing models.

The model will divide the basin into a network of connected sub-elements, which may be defined on the basis of elevation, sub-basin boundaries, or other characteristics (such as in the Hydrologic Response Unit approach in PRMS). A major aspect of model development will involve defining an appropriate number of these model sub-units. Our objective is to keep the model as simple as possible (few sub-basins) while defining enough sub-units to represent the flow response. We will start with large sub-elements then identify smaller sub-elements if needed. Initial delineation of sub-units will be based on observed differences in response between gauged sub-basins. Separate sub-elements will be assigned for areas considered likely to have distinct flow response magnitudes and timing, assessed based on examination of the snow covered area behavior in different parts of the basin.

A preliminary conceptualization of the model involves generating a melt season hydrograph for each sub-unit using a statistical prediction of the total flow volume, peak flow, and timing of runoff. The model will interpolate flow quantities between these predicted points. The method will draw somewhat from existing statistical forecasting models, which predict total flow volume; in contrast to these models, our model will predict both flow timing and volume for a series of connected subunits in the basin. Hydrographs from each model element will enter a routing network that aggregates the subunit contributions, similar to the structure of quasi-distributed models such as HEC-HMS (US Army Corps of Engineers). In this way, hydrograph predictions from the model sub-units will be aggregated to simulate a hydrograph at the Cache la Poudre Canyon mouth. Because naturalized flows can be obtained most easily at a monthly time step, we will calibrate the model to monthly flow volumes. We will divide the canyon mouth gage record into two clusters and use one half of the years for model calibration and the other half to test the model.

4.3. Phase 3: Model application

An increasing concern in the Western U.S. is that climate changes could affect stream flow amounts and timing, and climate trend analyses for the region have been presented in multiple studies (see e.g. Regonda et al., 2005; review in Udall and Bates, 2007). The model developed in this project will offer a structure for exploring effects of possible future climate scenarios. Because our model will be driven by precipitation, temperature, and snow cover, we can generate a range of combinations of these variables that either fit within or extend outside the range of historical climate conditions. In a test application of our model, we will generate hypothetical future climate scenarios by modifying the climate forcing variables and examining the possible effects on the river flow (amount and timing). Because the model will divide the basin into sub-units, we can develop climate scenarios that are spatially variable, changing both precipitation and temperature for different elevations or zones in the basin. This would allow us to account, for example, for up-slope storms that affect the lower portion of the basin but do not contribute snow to high elevations.

Any model, no matter how carefully constructed, will give uncertain flow predictions. Predictions are constrained by the quality of input data and by the ability of the model to capture the important flow contributions. To account for uncertainty in our model, we can develop Monte Carlo routines that generate an ensemble of hydrographs that could occur in a single year within the range of uncertainty of our input data and model parameters. We can also develop a Monte Carlo routine to generate many possible climate scenarios and run the model using each of these scenarios. These climate scenarios could similarly produce an ensemble of hydrographs that might occur under varying climate conditions.

Because most of our effort in the two-year time span of this project will be dedicated to hydrologic analysis and model development, initial applications of the model will serve in part to demonstrate what future research is needed. We also anticipate that the research will help identify new measurement locations (SNOTEL, weather station, or stream gage) that would help improve flow forecasts. The new insights that result from this research will lead to new methods that can be implemented into operational flow forecasting both for the Cache la Poudre and for other Colorado basins.

5. Statement of the results or benefits

This project will generate a range of benefits:

1. Database development for the Cache la Poudre – the compiled station and spatial data will be organized in a database to be made available to any researchers, water users, educators, or other individuals seeking information about the basin.
2. Characterization of historical hydrology in the upper Cache la Poudre basin – the hydrologic analysis will be compiled in a report format to demonstrate the range of flow behaviors that have occurred historically.
3. Improved flow predictions – the hydrologic analysis and model development will provide new insights into the important variables for flow prediction. By including snow covered area in addition to point measurements in the model, we are expanding the possibility to update the forecast reliably. The model can also deliver likely trajectories of flow through the melt season rather than just a seasonal total flow.
4. Tool for exploring effects of different climate scenarios – the model to be developed will be a useful tool for exploring how variability in precipitation and temperature (both spatial and temporal patterns) could affect river flow.

Overall, the hydrologic synthesis involved in this study will form a useful basis for broader understanding of flow processes in the Cache la Poudre basin, fitting in with some of the P.I.'s major research goals of identifying hydrologic process mechanisms at varying spatial scales. Because the model will be developed based on a thorough hydrologic process analysis, the research will lead to new ideas for linking process hydrology with operational modeling and open opportunities for future research on climate-hydrology connections in other Colorado basins.

6. Training potential

The project will serve primarily to train a graduate student, Eric Richer, in hydrologic analysis and hydrologic modeling. Mr. Richer will write an M.S. thesis based on parts of this project. Elements of the project will also be introduced into the P.I.'s courses at Colorado State University, so ~150-200 undergraduate and graduate students will be exposed to current research in their local watershed. An introductory watershed course, WR304 (Principles of Watershed Management), will include assignments based on the hydrologic data and water management issues in the Cache la Poudre basin. This course is currently being re-designed with an emphasis on building knowledge, understanding, and synthesis of issues on the students' local watershed. In a graduate level course, WR524 (Modeling Watershed Hydrology), examples from the Cache la Poudre study will be used in class to stimulate dialogues about different modeling strategies, integration of measurements with models, and issues of scaling in hydrologic modeling.

Acknowledgements

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Wood, A.W. and D.P. Lettenmaier, 2006. A test bed for new seasonal hydrologic forecasting approaches in the western United States. BAMS 87(12), 1699-1712.

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Assistant Professor

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EDUCATION:

***University of Washington**, Ph.D., 2006*

- Department of Civil and Environmental Engineering

***University of Nevada, Reno**, M.S. Hydrogeology, 2002*

- Graduate Program of Hydrologic Sciences

***Williams College, Williamstown, MA**, B.A., 1998*

- Degree with Honors in Geosciences; Concentration in Environmental Studies

TEACHING:

- ***WR 524***: Modeling Watershed Hydrology.
- ***WR420:*** Watershed Practicum. (with other faculty)
- ***WR 440***: Watershed Problem Analysis. (with other faculty)
- ***WR304***: Watershed Management.

RESEARCH:

Distributed hydrologic model testing,** NSF EAR 0537410, **2006-2009

- Developing a framework for testing distributed hydrologic models at the hillslope scale based on detailed numerical simulations of coupled surface-subsurface flow at an extensively measured rangeland catchment.
- Collaborators: P.I., Dr. Stephen J. Burges, University of Washington; Dr. Keith Loague, Ben Mirus, Stanford University

Linking measurements and physics-based modeling for a planar hillslope plot, 2004-2006

- PhD dissertation research exploring how different types of hydrologic measurements collected at varying spatial scales can best inform process-based hydrologic modeling.
- Advisor: Dr. Stephen J. Burges, University of Washington

***Remote sensing of stream temperatures,** 2002-2003*

- Participated in EPA STAR project using in-stream loggers, aircraft (MASTER), and satellite (ASTER) thermal infrared imagery to derive stream temperatures in the Pacific Northwest.
- Collaborators: Dr. Stephen J. Burges, Civil and Environmental Engineering; Drs. Alan Gillespie and Jennifer Kay, Earth and Space Sciences, University of Washington; Dr. Keith Cherkauer, now at Purdue University; Dr. Rebecca Handcock, now at CSIRO, Australia

***Playa evaporation and energy budget,** 2001-2002*

- Examined evaporation and land surface energy fluxes at the Salar de Atacama in northern Chile using eddy correlation techniques and remote sensing (ASTER).
- Advisor: Dr. Scott W. Tyler, University of Nevada, Reno. Collaborators: Dr. José F. Muñoz, Cristian Ortiz, Universidad Católica de Chile

PUBLICATIONS:

Kampf, S.K. and S.J. Burges, 2007. A framework for classifying and comparing distributed hillslope and catchment hydrologic models. *Water Resources Research*. 43, W05423, doi:10.1029/2006WR005370.

Kampf, S.K. and S.J. Burges, in press. Parameter estimation for a physics-based distributed hydrologic model using measured outflow fluxes and internal moisture states. *Water Resources Research.*

Kampf, S.K. and S.W. Tyler, 2006. Spatial characterization of evaporation and land surface energy fluxes at the Salar de Atacama, Northern Chile using ASTER image classification. *Advances in Water Resources* 29: 336-354.

Handcock, R.N., Gillespie, A., Cherkauer, K.A., Kay, J.E., Burges, S.J., Kampf, S.K., 2006. TIR remote sensing of stream temperatures at multiple spatial scales. *Remote Sensing of Environment.* 100, pp. 427-440.

Kampf, S.K., S.W. Tyler, C. Ortiz, J.F. Muñoz, and P. Adkins, 2005. Evaporation and land surface energy budget at the Salar de Atacama, Northern Chile. *Journal of Hydrology* 310, pp. 236-252.

Kay, J.E., S.K. Kampf, R.N. Handcock, K.A. Cherkauer, A.R. Gillespie, and S.J. Burges, 2005. Accuracy of lake and stream temperatures determined from thermal-infrared imagery. *Journal of the American Water Resources Association,* October, pp. 1161-1175.

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Kampf, S.K., M. Salazar, and S.W. Tyler, 2002. Preliminary investigations of effluent drainage from mining heap leach facilities. *Vadose Zone Journal* 1:186-196.

HONORS:

- Fulbright Student Fellowship, 1998-1999
- NASA Earth System Science Fellowship, 2001-2004
- University of Washington College of Engineering Outstanding Teaching Assistant, 2005
- College of Engineering Osberg Family Trust Fellowship, Spring 2005
- Society of Women Engineers Outstanding Female in Civil and Environ. Engineering, 2005
- University of Nevada, Reno Outstanding M.S. Student, Graduate Program for Hydrologic Sciences, 2002

AFFILIATIONS:

- American Water Resources Association
- American Geophysical Union
- Geological Society of America
- NASA Earth System Scholars Network
- Sigma Xi

Eric E. Richer

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Experience

Natural Resource Management and Environmental Consultant
US Peace Corps - Philippines: January 2004 to June 2006

Watershed and coastal resource management, advocacy, project design and management, funding proposals and accounting, information and education campaigns, community organizing, research and data analyses, visual fish census and benthic assessments, training design and facilitation, and marketing development including website design.

Technician

Chadwick Ecological Consultants, Littleton, Colorado: June 2002 to December 2003

Aquatic studies related to water quality, ecotoxicology, stream classification, water development, flow-related impacts, CERCLA/Superfund sites, historic mine activities, mitigation/habitat enhancement planning, watershed monitoring, & nutrient/sediment reduction. Performed research on fish, invertebrates, algae, vegetation, and habitat in rivers, streams, lakes and reservoirs including report writing, data analyses, and field work.

Internship

Illinois Natural History Survey, Center for Aquatic Ecology: May 2001 to August 2001

Watershed monitoring including stream delineation, water quality sampling and analyses, and sampling/identification of fish, invertebrates, vegetation, and zooplankton.

Research Assistant
Kansas Cooperative Fish & Wildlife Research Unit: October 2000 to December 2000

Laboratory work and data entry for project focused on enhancing fisheries management.

Resource Crew
US Forest Service, Spotted Bear Ranger District, Montana: June 1999 to August 1999

Volunteer position through the Student Conservation Association. Assessment and inventory of trail maintenance structures, trail rehabilitation, and visitor contact.

Education

Master of Science in Water Resource Planning and Management
Colorado State University: August 2007 to Present

Bachelor of Science in Fisheries and Wildlife Biology
Double Major in Fisheries Biology and Natural History
Kansas State University: December 2001

Other Qualifications

- Use of computers and software programs including Microsoft Office Professional, SAS, Number Cruncher Statistical Software, Harvard Chart XL 3.0, Corel WordPerfect 8.0, Flowlink 4.0, Freelance Graphics, Adobe Acrobat, Adobe Photoshop 7.0, Photosuite 5.0, Video Impression 5.0, FishBase, ReefBase, Windows, and the Internet
- Use and maintenance of ISCO Flowmeters/Samplers and YSI Data Loggers and Sondes
- PADI Open Water SCUBA Diver
- One-year Non-Competitive Appointment eligibility: June 2006 to June 2007
- Advanced Foreign Language Fluency in Filipino Dialects

Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation

Basic Information

Title:	Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation
Project Number:	2008CO167B
Start Date:	3/1/2008
End Date:	7/31/2009
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	Economics, Models, Water Supply
Descriptors:	
Principal Investigators:	Reagan M. Waskom, James Pritchett

Publication

Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation

Problem Statement: Bioenergy crop production is a potential engine for rural economic growth. Colorado farmers, and especially those in the South Platte River Basin, are well positioned as key energy stock producers for prospective commercial biorefining processes. Farmers in the South Platte Basin are among the most efficient and productive in the United States cropping more than one million irrigated acres.

Bioenergy's bright prospects are in part a result of Colorado's growing cities; however, municipal development is also a significant competitor for crop inputs, especially water and agricultural land. Rapid urban growth increases the competition for water, and agriculture is the primary supplier for increased water demands. Thus, the potential gains from bioenergy cropping must be attractive enough to retain water in irrigated agriculture else the resource will flow to municipal consumption. If profits for bioenergy crop production are limited, then outside investment in bioenergy refining is likely to suffer.

Demand for water is increasing, but supplies in Colorado's South Platte Basin are over-appropriated, meaning that owned rights to water use exceed the actual amount of water in the basin. The Colorado Water Conservation Board's Statewide Water Supply Initiative (SWSI) predicts the South Platte Basin will experience a 61.9 percent increase in water demand by 2030 that will cause an approximately 180,000 irrigated acres to be permanently fallowed. The plans for nearly all South Platte water providers include significant agricultural water right transfers (CWCB, 2004).

Water transfers are likely to reduce the size of the local economic base because fewer irrigated acres are cropped, fewer irrigated crops are sold and fewer crop inputs are purchased. Without other viable, local base industries to generate revenues and provide employment, a reduction in the revenue generated in the agricultural sector will have adverse economic impacts throughout the regional economy. Impacts will be felt by input suppliers and by local governments whose property and sales tax base is eroded. Moreover, downstream users of irrigated crops (e.g., dairies, feedlots, meat packers, cheese manufacturers, sugar processors and ethanol plants) will be forced to seek more costly crops from distant locations.

In contrast, bioenergy crop production may generate many positive economic spillovers for communities; not only through additional crop sales, but also by generating economic activity for local input suppliers (e.g., crop chemical wholesalers) and by downstream users of the crops (e.g., ethanol production facilities). Value-added investment in bioenergy processing is likely to add to a rural community's infrastructure and local supply of labor.

How should community leaders and stakeholders proceed when caught between two rivals – water transfers and bioenergy cropping? Clearly, it is important to weigh the potential economic impact of a growing bioenergy crop industry with increased demands for water resources. Water stakeholders will benefit from a detailed basin level study examining the direct and indirect economic impacts of these rivals, as well as disaggregating these impacts among different industries in the region. This information will be valuable to many water stakeholders including farmers, businesses, water supply administrators, and regional leaders charged with economic development.

Aims/objectives: Can Colorado's agricultural producers meet the challenges of a burgeoning bioenergy industry while still supplying water to growing municipalities? What impacts will be felt by local agribusiness, both suppliers of inputs (e.g., local supply cooperatives) and those who rely on irrigated crops for their livelihood (e.g., sugar processors, dairies and feedlots)? This proposal's overall objective is to provide insights into these important questions. More specifically, the purposes of this study are to:

1. Describe the capacity of South Platte farms to supply bioenergy crops even as the demand for water resources increases. In the context of this study, the South Platte Basin will include farms in Adams, Boulder, Larimer, Logan, Morgan, Sedgwick and Weld counties.

2. Map the existing infrastructure and resources available for bioenergy production in South Platte Basin communities, so that gaps in infrastructure (water, transportation, land, labor) may be identified.

3. Measure the profitability of biofuel crops (e.g., corn for grain) against the profitability of traditional crops (e.g., corn silage, alfalfa, sugar beets) to better understand the farm level tradeoffs of supplying a bioenergy crop to a local purchaser vis a vis a crop designated for local, downstream agribusiness. Likewise, compare the returns from selling water off of the farm to maintaining irrigated agricultural production.

4. Perform extensive in-person interviews with agribusiness managers/owners in the South Platte Basin. The purpose of the interviews will be to collect the managers' assessment of water transfers and returns to bioenergy cropping, a description of the firm's current purchasing behavior with an emphasis on local vs. purchases outside the region, and the proportion of sales that are exported versus those held within the region.

5. Using data collected and validated in Objective 4, along with existing secondary data, create a social accounting matrix (SAM) for the South Platte Basin. The SAM captures the current financial interaction of sectors within an economy including activities, commodities, transactions costs, household income, taxes and government expenditures. The SAM is a baseline against which other economic scenarios might be measured.

6. Create a South Platte Basin computable general equilibrium model (CGE) from the SAM. While the SAM is a snapshot of the current activity within a region, a CGE model explains all of the transactions in the SAM and indicates how important variables (e.g., the price of water, price of land, size of the workforce, capital investment) are altered when resources such as water flow in and out of an economy.

7. Assess the potential regional economic impacts of bioenergy crop production and water transfers to rural economies when measured against a backdrop of current production. Economic scenarios will include incremental bioenergy crop adoption and reduction in irrigated crop acreage. The aforementioned SAM and CGE model will be used to quantify and measure these effects.

8. Interpret and deliver the study's results via meetings with water stakeholders including the South Platte Forum, the Lower South Platte Forum, the Colorado Water Congress, the basin roundtables, etc. Prepare CWRRI completion reports as appropriate and write short study summaries for the CWRRI newsletter.

The proposal's objectives are tightly aligned with the FY 2008 Priority Research Topics identified by the CWRRI Advisory Committee. Specifically, this proposal seeks to answer the question "What are the direct and indirect water related impacts and needs surrounding bioenergy production in Colorado?" To the authors' knowledge, no study has considered both the regional economic impacts of bioenergy crops and expected water transfers on Colorado's rural communities. This research proposal extends previous work on the economic activity generated by irrigated agriculture in Colorado, but now considers the impact of biofuels and biorefining on irrigated cropping profits and rural economic vitality.

Rationale, Significance and Project Benefits:

Without question, a growing population will lead to increased demand for M&I water use. The South Platte and Arkansas Basins represent about 80% of the total projected increase in Colorado's future gross M&I demands. Table 1 indicates the Statewide Water Supply Initiative (SWSI) projections of M&I water use in the year 2000 and for the year 2030.

Table 1. Projected Growth in Municipal and Industrial Water Demand Basins*

Basin	2000 Gross Water Demand (AFY)	2030 proj. Gross Water Demand (AFY)	Projected Increase (AFY)
Arkansas	256,900	373,500	98,000
Rio Grande	17,400	23,100	43,000
South Platte	772,400	1,250,800	409,700

In Colorado, a 68,000 acre foot shortfall exists between projected demands from Table 1 and identified water supplies. Shortfalls are greatest in the South Platte and Arkansas Basins, which supply most growing Front Range communities with water (Table 2). History indicates M&I providers will find avenues to meet customers' needs, and in these basins increasing pressure will be placed on agriculture to urban water transfers

Table 2. Shortfall Between Projected M&I Demands and Firm Supplies in 2030*

Basin	Supply Needed (AFY)	Supply Identified (%)	Shortfall (%)
Arkansas	98,000	82%	18%
Rio Grande	4,300	99%	1%
South Platte	409,700	78%	22%

Agriculture represents approximately 91 percent of water used in Colorado and SWSI projections indicate that it will make up 86 percent of the water use in 2030 (Lower South Platte Forum: Valuing your Water, *Colorado Water, Colorado State University,* April 2005). As population grows, increased M&I demands are met with transfers from irrigated agriculture. Clearly, irrigated agriculture will shrink in Colorado, and SWSI forecasts these reductions as summarized in Table 3.

Table 3. Shortfall Between Project M&I and Firm Supplies in 2030*

Basin	Projected Reduction In Irrigated Acres by 2030
Arkansas	↓23,000-72,000 acres
Rio Grande	↓60,000-100,000 acres
South Platte	↓133,000-226,000 acres

Economic activity is reduced in rural communities as irrigated crop acres are permanently fallowed. The direct and indirect economic activity generated by irrigated cropping has been quantified to a limited extent by Thorvaldson and Pritchett (2006). As indicated in Table 4, irrigated agriculture's economic activity is substantial in the South Platte Basin generating $690 per acre, which includes the direct activity from crop sales; the indirect activity of farm input suppliers; and the induced activity of wages spent by employees.

Table 4. Economic Activity of Irrigated Agriculture in Colorado Basins

Basin	Farm Gate Receipts Relative to Regional Sales	Economic Activity Generated per Acre of Irrigated Cropland
Arkansas	31 %	$ 428
Rio Grande	48 %	$1,127
South Platte	2 %	$ 690

The research by Thorvaldson and Pritchett (Pritchett is PI on this proposal) is an important first step; however, their analysis has several limitations. First, Thorvaldson and Pritchett completed their study prior to recent expansion of bioenergy cropping and the subsequent increased demand for crop inputs. Second, the authors limited their economic activity assessment to irrigated farms and input suppliers, while neglecting downstream agribusiness firms such as sugar processors, dairies, feedlots, and ethanol facilities. As a result, the economic activity generated by these firms is omitted. Finally, the input-output model used in Thorvaldson and Pritchett's research is merely a snapshot of current economic activity. In contrast, the proposed CGE model is dynamic and will trace the flow of resources (e.g., water and land) and their prices as the regional economy responds to increased bioenergy cropping and large scale transfers of water rights. The proposed research is a forecast of likely outcomes rather than a description of existing activity. It should be noted that *the proposed CGE model will be available for future economic analysis of policy change, so the research objectives an important step in building future capacity for answering water related, regional economic questions.*

Importantly, the Thorvaldson and Pritchett effort resulted in more than fifty presentations to stakeholder groups, eight additional requests for impact analysis, a related study focusing on the changing property tax base, two CWRRI completion reports, four articles in popular press, three academic poster presentations and a pair of academic working papers. It is expected that the proposed CGE model will have a similar outreach impact. Stakeholders have asked for, and continue to ask for, information about how agribusiness will be impacted by increasing demands for water resources and the growth of bioenergy cropping. Unfortunately, these questions have yet to be answered concretely.

Bioenergy has the potential to become an important base industry in Colorado. However, the industry's success depends importantly on a local supply of energy crops grown by irrigated agriculture. The number of acres devoted to irrigated agriculture is likely to decrease in the next twenty-five years as water is transferred to M&I use. Will bioenergy crops alter the flow of water resources from rural regional economies? Will a sufficient number of irrigated crop acres be available to support the energy industry? As irrigated agriculture evolves, how will the size and number of irrigated farms change? Moreover, how will the downstream businesses, including feedlots, dairies, meat packers and cheese processors be impacted? This study seeks to provide tools to water resource and community stakeholders confronting these challenges. In particular, a basin level CGE model will be used to generate information for stakeholders. The following section describes the proposed research model.

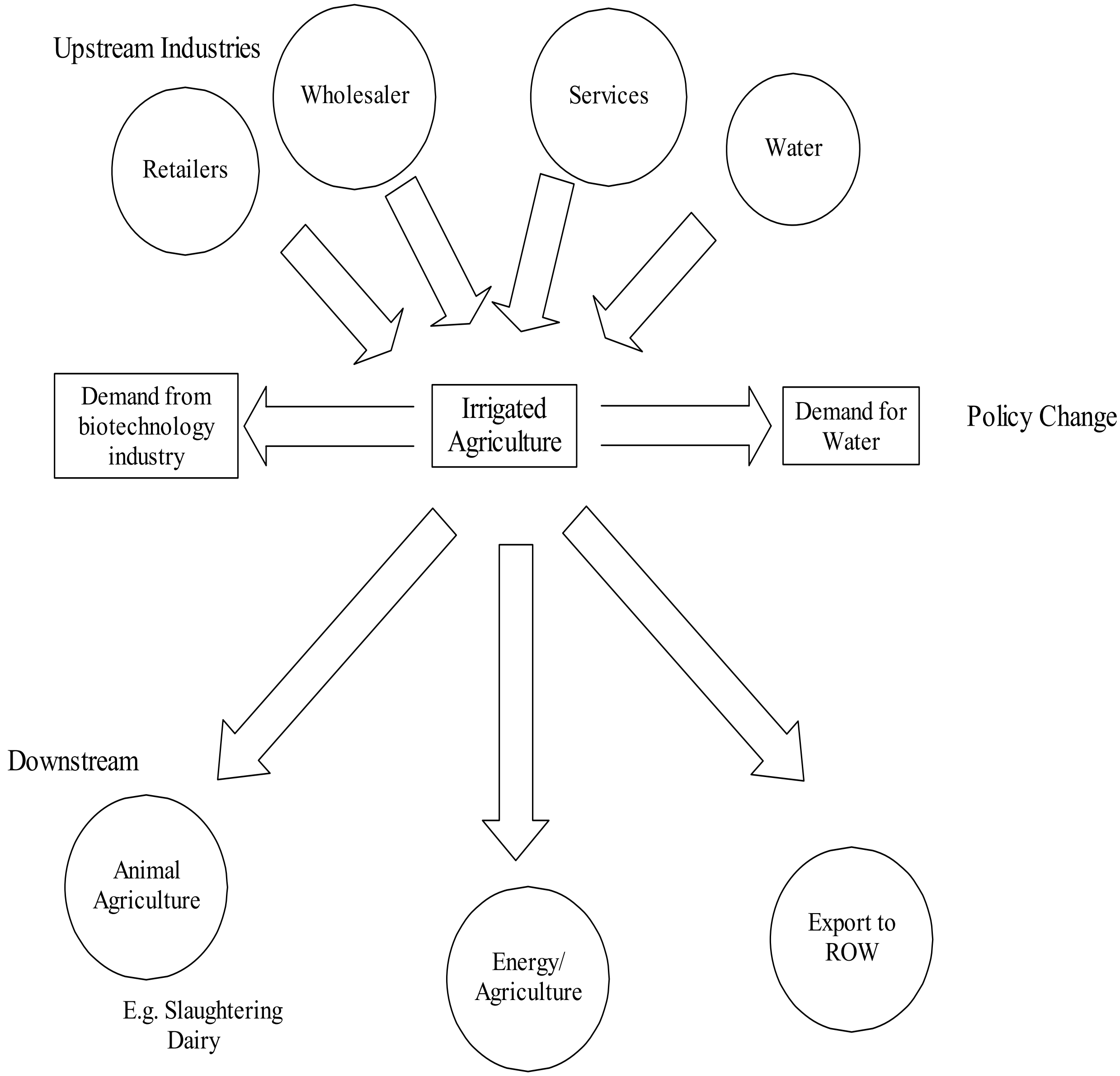
Methodology and Previous/Related Research:

A computable general equilibrium (CGE) model captures the interactions of economic agents as resources are allocated. As illustrated in Figure 1, our South Platte Basin model will first capture the economic interaction of agents in the basin, and then examine how economic activity is altered with additional bioenergy cropping and water transfers. Important players in the upstream portion of the model include retailers that supply farm inputs (e.g., fertilizer, seed, and petroleum products), wholesalers, service providers (crop consultants, real estate services, and banking) and water suppliers. In the next stage of the model, irrigated agriculture represents a production unit that combines factor inputs from upstream businesses to generate products (irrigated crops) that are used by downstream industries. Important downstream industries include animal agriculture (e.g., feedlots, dairies), agricultural energy (ethanol), further processing and fabrication (cheese manufacturers and slaughter plants). Goods are used locally or may be shipped outside the region to the rest of the world (ROW). Likewise inputs may be purchased locally or from abroad. The CGE model will also capture the changing prices of resources as they are reallocated.

In order to construct a CGE model a Social Accounting Matrix (SAM) must be constructed first. A SAM is an all-inclusive, economy-wide data framework, typically representing the economy of a regional unit (e.g., a county or river basin). In practice, the social accounting matrix is a square matrix in which each account is represented by a row and a column. Each cell shows the payment from the account (economic sector) of its column to the account (economic sector) of its row. Thus, the incomes (sales) of an account appear along its row and its expenditures (demand) along its column. The underlying principle of double-entry accounting requires that, for each account in the SAM, total revenue (row total) equals total expenditure (column total). Data in the SAM are expressed in monetary terms.
The variables that will be in the SAM are grouped into the following sectors:

- Activities: The activities sector includes the following sub-sectors: large scale irrigated agriculture, small scale irrigated agriculture, dryland agriculture, industry, transportation, and other services such as utilities, wholesale, and housing
- Commodities: Commodities include crops, farm inputs, processed foods, industrial or manufacturing goods, transportation, and other services' commodities
- Transaction costs: Transaction costs include costs from domestic sales, imports and exports
- Factors: Primary inputs in the production process including water, land, labor and financial capital.
- Household income: households' income and wages in the regional economy, and
- Other institutions: This includes government, taxes, and an agglomerated rest of world.

Figure 1. Illustration of a Computable General Equilibrium Model



An advantage of a SAM is that the researcher can segment important or relevant sectors into different sub-sectors in order to thoroughly describe the impacts of external shocks. As an example, the proposed SAM splits the cropping sector into dryland and irrigated farm subsectors, and then further separates the farm subsector in those that sell water rights and those that retain water rights.

The Social Accounting Matrix is constructed in Microsoft Excel and is the base data that will be used in the Computable General Equilibrium (CGE) model. The CGE model will be constructed within the General Algebraic Modeling System (GAMS) program, and the SAM data will be imported into the model. GAMS is the mathematical optimization software that is typically used to perform CGE simulations.

Since the SAM data is exclusively monetary transactions, other values such as the number of farmers or the number of households have to be added to the SAM to construct the CGE model. The standard CGE model explains all of the payments recorded in the SAM. The model therefore follows the SAM disaggregation of factors, activities, commodities, and institutions. It is written as a set of simultaneous equations, many of which are nonlinear. The equations define the behavior of the different sectors. In part, this behavior follows simple rules captured by fixed coefficients (for example, ad valorem tax rates). Production and consumption decisions are driven by the maximization of profits and utility, respectively. The equations also include a set of constraints that have to be satisfied by the system as a whole but are not necessarily considered by any individual sector. These constraints cover markets (for factors and commodities) and macroeconomic aggregates.

CGE models have been used to assess the interaction of water resources and regional economics in other studies. Chapter 2 of Phil Scott Watson's dissertation "Of Golf and Grains: Three essays of resource use in the new American West (2006) focuses on the effects of increased population growth on water demand in agricultural and urban sectors using a CGE model. The CGE model proposed in this study will use the same methodology as Watson, but will instead represent the South Platte Basin and focus more intently on downstream agribusiness and irrigated cropping.

Goodman's examination of a proposed Pueblo reservoir expansion and temporary water transfers in the Arkansas basin suggest how a CGE model may be used to examine the impacts of water reallocation. Like Goodman, the proposed research considers water transfers, but will also consider the rivalry for resources represented by bioenergy, as well as a more extensive look at downstream agribusiness. In addition, published drought research (Horridge, Madden and Witwer) and a CGE model of agriculture (Adelman and Robinson) are important foundational literature describing the method of creating SAM's and CGE models.

Expected outcomes: A number of deliverable outputs are associated with the project. These outputs include:

- A social accounting matrix that accurately chronicles the economic activity of the South Platte Basin and is calibrated to the latest economic data.
- A computable general equilibrium model capable of examining water resource and bioenergy cropping questions for the South Platte Basin region.
- Presentations to stakeholder groups including the Colorado Water Congress, the South Platte Forum, the Lower South Platte Forum, the Agricultural Water Forum, the Northeastern Colorado Association of Local Governments annual meeting, the annual meeting of Colorado Soil and Water Conservation Districts, basin roundtables, and others.
- CWRRI completion reports and newsletter articles.
- Academic journal articles.

Timeline: Proposed project activities begin on January 1, 2008 and will be completed on July 1, 2009. A PhD candidate, Leonard Gwanmesia, has been identified for the project and has completed all of his academic coursework. The proposed research represents a significant portion of his PhD dissertation. Specific mileposts in the research include:

January 1, 2008 through March 1, 2008

Create the SAM model using secondary data.

March 1, 2008 through June 1, 2008

Validate the SAM model with in-person interview of agribusiness and the Colorado Department of Local Affairs.

June 1, 2008 through September 1, 2008

Create and validate the CGE model. Financial information and flows will be liberated form the SAM, but allocation of water and the flow of crops to bioenergy facilities must be added to the model. Use the CGE model to establish a benchmark of economic activity for the South Platte Basin.

September 1, 2008 through January 1, 2009

Design scenarios to be considered with the CGE model.

January 1, 2009 through March 1, 2009

Simulate scenarios and compile results from the CGE model.

March 1, 2009 through July 1, 2009.

Draft, edit and complete a CWRRI completion report, newsletter article and present results.

Training Potential A PhD graduate student will be trained in regional economic analysis and CGE models in this study. While the student (Leonard Gwanmesia) has completed extensive coursework in regional economics, he has had few opportunities to apply these tools.

Congressional District: Research activities will take place in the 4th Congressional District.

References

Adelman, I and S. Robinson, 1986. U.S. Agriculture in a General Equilibrium Framework: Analysis with a Social Accounting Matrix. American Journal of Agricultural Economics, 68 (5), 1196-1207.

Colorado Water Conservation Board. 2004. Statewide Water Supply Initiative. Available at http://cwcb.state.co.us

Goodman, D.J., 2000. More reservoir or transfer? A Computable General Equilibrium Analysis of Projected Water Shortages in the Arkansas River Basin. Journal of Agricultural and Resource Economics, 25 (2), 698–713

Horridge, M., J. Madden, G. Wittwer, 2005. The impact of the 2002–2003 drought on Australia. Journal of Policy Modeling, 27, 285–308.

Thorvaldson, J. and J. Pritchett. "Economic Impact Analysis of Irrigated Acreage in Four River Basins in Colorado." Colorado Water Resources Research Institute Completion Report # 207. December 2006. Fort Collins, CO.

Watson, P., 2006. Golf and Grains: Three essays of resource use in the new American West. Dissertation, Department of Agricultural and Resource Economics, Colorado State University.

CURRICULUM VITA

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Education

PhD	University of Minnesota, Agricultural and Applied Economics	1999
MS	Colorado State University, Agricultural and Resource Economics	1995
BS	Colorado State University, Agriculture Business	1993

Professional Experience

Colorado State University, Fort Collins, CO July 2007 to Present
Associate Professor, Department of Agricultural and Resource Economics
Applied Research (25%), Outreach (25%), Teaching (50%)

Colorado State University, Fort Collins, CO May 2001 to June 2007
Assistant Professor, Department of Agricultural and Resource Economics
Applied Research (25%), Outreach (25%), Teaching (50%)

Purdue University, West Lafayette, IN October 1999 to May 2001
Assistant Professor, Department of Agricultural Economics
Extension (45%), Research (25%), Teaching (30%)

Relevant Recent Grant Awards

2007. J. Pritchett (co-PI), A Bright (co-PI), R. Waskom, M. Niebauer and T. Bauder. "Public Attitudes and Perceptions Regarding Agricultural Water Use in the West
Water Use/Reuse and Water Security: What Do Households Value?" USDA-CSREES-National Facilitation Project. $171,773.

2006. T. Holtzer (PD) N. Hansen (co-PI), J. Pritchett (co-PI), D. Westfall, M Frasier, E. Schuck, T. Bauder, J. Schneekloth and J. Brummer. "Developing a Model to Sustain Irrigated Agriculture While Meeting Increasing Urban Water Demand in Colorado. Cooperative Proposal with Parker Water and Sanitation District. $984,127

2006. Pritchett, J., R. Waskom, N. Hansen, D. Westfall, C. Bond, E. Schuck, D. Hoag. USDA-NRI-Agricultural Prosperity of Small and Medium Sized Farms. "Developing Economically Sustainable Cropping Strategies for Small and Medium Sized Farms in an Increasingly Scarce Water Environment." $499,113.

2006. N. Hansen, J. Pritchett, D. Westfall, T. Bauder, J. Schneekloth, R. Waskom, and J. Brummer "Sustainable Cropping Systems for Transition from Full Irrigation To Limited Irrigation and Dryland." Natural Resources Conservation Service – Conservation Innovation Grants. $275,000.

Recent Relevant Research

2007. J. Pritchett and J. Thorvaldson. "Some Economic Effects of Changing Augmentation Rules in Colorado's Lower South Platte Basin: Producer Survey and Regional Economic Impact Analysis." Colorado Water Resources Research Institute Completion Report # 209. Fort Collins, CO.

2006. J. Pritchett and J. Thorvaldson. "Economic Impact Analysis of Irrigated Acreage in Four River Basins in Colorado." Colorado Water Resources Research Institute Completion Report # 207. Fort Collins, CO.

2006. Waskom, R. J. Pritchett, and J. Schneekloth. Outlook on the High Plains Aquifer: What's in store for irrigated agriculture?" Great Plains Soil Fertility Conference Proceedings. Denver, CO.

2005. J. Pritchett, P. Watson, J. Thorvaldson, and L. Elingson. 2005. "Economic Impacts of Reduced Acres: Example of the Republican River Basin." *Colorado Water.* February:4-6.

2003. J. Pritchett, M. Frasier and E. Schuck. "Third Party Compensation for Out-of-Basin Water Transfers: Comments on HB 03-1113." Agricultural and Resource Policy Report. APR 03-08. Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, Colorado. August 2003.

Synergistic Activities:

Previous CWRRI fellowship funds have been used in outreach presentations and educational efforts. The focus of these activities is on the regional economic contribution of irrigated agriculture and includes a symposium titled "Enhancing Understanding of Agricultural Water Management" delivered in eleven Colorado locations to clientele including Arkansas River Basin Roundtable, Colorado River Basin Roundtable, Colorado Water Congress, Colorado State University Cooperative Extension, Southwestern Colorado Water Conservation District, South Platte Forum, Lower South Platte Forum, Morgan County Economic Development Corporation, Northeastern Colorado Association of Local Governments, Rio Grande River Basin Roundtable, South Platte Basin Roundtable, Western Association of Rural Conservation and Development Districts.

I'm part of an interdisciplinary team interested in enhancing agricultural production, profitability and sustainability with limited irrigation supplies. We have been successful in creating research and demonstration sites focusing on the techniques. The sites are located near the Colorado cities of Akron, Berthoud, Fort Collins, and Iliff. Field days for stakeholders are planned.

I hold a teaching appointment at Colorado State University and have the opportunity to bring research into the classroom. The classes that I currently teach and/or have been responsible for include: AGRI 192 Orientation to Agriculture Systems, AREC 510 Agriculture Marketing, AREC 428 Agribusiness Management (capstone course), AREC 408 Agriculture Finance, AREC 310 Agriculture Marketing, AREC 305 Enterprise Analysis, BUS 635 World Economics for Business.

Grant No. 08HQGR0142 Development of a Correction Function for the 3-Inch, Thin-Walled, Helley-Smith Sampler Deployed on Coarse Gravel Beds

Basic Information

Title:	Grant No. 08HQGR0142 Development of a Correction Function for the 3-Inch, Thin-Walled, Helley-Smith Sampler Deployed on Coarse Gravel Beds
Project Number:	2008CO199S
Start Date:	7/1/2008
End Date:	7/31/2009
Funding Source:	Supplemental
Congressional District:	4th
Research Category:	Engineering
Focus Category:	Hydrology, Sediments, None
Descriptors:	
Principal Investigators:	Steven R. Abt, Kristin Bunte

Publication

Project Title: **Development of a correction function for the 3-inch, thinwalled, Helley- Smith sampler deployed on coarse gravel beds**

Project Chiefs: **Steven R. Abt and Kristin Bunte**

Project Chiefs' Location: **Colorado State University, Engineering Research Center**
Proposed Start Date: **July 1, 2008**
Proposed End Date: **June 30, 2009**

1) Project Background and goals:

A Helley-Smith type bedload sampler (HS) is often used for measuring transport in coarse gravel-bed streams. However, transport rates and bedload particle sizes obtained from HS samplers can be biased. This study proposes the development of a numerical correction function. The correction function can serve to reappraise existing data sets as well as improve the accuracy of current HS measurements undertaken in river restoration projects. Implementation of a correction function that renders transport rates and bedload particle size measured with HS samplers less biased would greatly improve the credibility of HS samples collected in coarse gravel-bed streams. The improved credibility would reinstate a HS sampler as an instrument that—with the help of correction functions—provides passable estimates of bedload transport in coarse-bedded gravel-bed streams.

Measurements of biased transport rates and bedload particle sizes in coarse gravel-bed streams are caused by the design of the HS sampler and the mode of deployment. When setting the sampler directly onto a gravel bed, the sampler occasionally pushes small to mid-sized gravel particles to the side and dislodges them from their interlock with neighboring particles. The hydraulic efficiency > 1 can then entrain the dislodged particles into the sampler. Setting the sampler repeatedly on the bed (about 20 times per cross-section) increases the opportunity for this process to occur. When transport is low, involuntary dislodgement and entrainment causes oversampling of gravel particles and an overestimation of transport rates by up to several orders of magnitude. The typically short sampling time of 2 minutes or less further overestimates small transport rates while underestimating large transport rates1.

Although bias of transport rates measured with HS type samples is generally known, HS type samplers are currently used for a wide range of applications (e.g., river restoration; monitoring changes in sediment supply) as well as basic research (e.g., bedload dynamics, relationships between transport and flow, incipient motion studies). Alternative samplers that are equally inexpensive and easy to use and do not require wadeable flows are not available. The uncorrected use of biased transport rates measured with HS-type samplers has a variety of detrimental consequences, such as endangering the outcome of river restoration projects and causing misleading conclusions to be drawn about bedload transport dynamics and incipient motion conditions.

2) Objectives:

This study proposes to develop a function that corrects transport rates collected with a 3-inch, thinwalled, handheld HS sampler in coarse gravel-bed streams. During eight years of extensive field studies in coarse gravel-bed streams, we have compiled a substantial data base that allows us to address this task. The correction function will be based on a comparison of sampling results from a HS sampler and bedload traps.

Bedload traps were specifically designed to overcome the shortcomings of the HS sampler in coarse gravel beds and include the following design features: A large sampler opening that accommodates large gravel and cobble particles; A large net for collecting large samples and sampling over a long duration, typically 1 hr; The 4 mm mesh width lets water and sand pass through the sampler, while leaving room in the net to collect gravel rather than sand bedload. Deployment of the sampler on ground plates installed flush with the stream bottom avoids involuntary entrainment of bed particles2; Sampling over a long duration and not disturbing the bed at the sampler entrance, bedload traps can be assumed to provide more accurate measurements of gravel transport rates in coarse-bedded streams than a 3-inch HS sampler. Over eight years of bedload sampling in various coarse mountain gravel-bed streams, we deployed a 3-inch thinwalled HS sampler together with bedload traps, either side by side or immediately before or afterwards, over a wide range of flows and transport rates. At two sites, we also deployed a HS sampler on the ground plates while bedload traps were removed. Bedload traps produced steeply increasing relationships of transport rates and the bedload *Dmax* particle size with flow. By contrast, HS samples collected directly on the bed produced much higher transport rates and larger *Dmax* bedload particle sizes than bedload traps at the lowest transporting flows. Near bankfull flow, transport rates and particle sizes approached those measured with bedload traps3. The overly high and coarse transport rates measured by a HS sampler during low transport are attributed to dislodging and subsequent entrainment of a few particles which nevertheless then make up a large portion of the sample. At high transport, adding a few particles contributes insignificant amounts to the total sample, and transport rates are similar to those obtained from bedload traps. A HS sampler deployed on ground plates had results similar to bedload traps, showing that the majority of the difference in sampling results between the two samplers is attributable to the presence of ground plates that prevent unintended particle entrainment by the sampler. Transport rates that increase steeply with flow in armored gravel streams have been measured in other studies that used samplers that allow long sampling durations and/or prevent bed interactions. A steep increase of transport rates in the armored streams sampled with bedload traps conforms to bedload theory (see the Parker bedload transport equation that increases steeply during low flows) and can be considered another evidence for more accurate estimates of bedload transport rates and *Dmax* particle sizes than those obtained from deploying the HS sampler directly on the bed.

The researchers proposing this work have extensive expertise in field measurements of bedload transport. They collected and analyzed the data to be used in the proposed study.

3) Technical context:

The bias of HS samples has been largely ignored, both in applied and basic research. Emmett's (1981, 1984) endorsement of the HS sampler (that was derived under the special circumstances of a HS deployed on a sill where it collected sand traveling over a stable cobble bed), was considered of general validity for HS samplers on coarse gravel-beds. Subsequently, HS sampling results were used for estimations and analyses of transport rates without much consideration for its accuracy, particularly because there was no other sampler as inexpensive, portable, and easy to use.

Access to our existing, substantial data sets of paired samples from a HS sampler and bedload traps provides an opportunity to quantify the bias and develop correction functions both for transport rates and possibly for sampled *Dmax* bedload particle size. The correction function is likely non-linear, because a much larger degree of correction is required during low flows when transport rates and bedload particles are small than at high flows when transport rates and bedload particle sizes are large. The proposed work needs to clarify whether the correction comprises a single function for gravel bedload or separate functions for each bedload size class and whether correction functions vary with streambed characteristics. Use of a correction function would be beneficial in multiple ways. It would improve the credibility of bedload transport rates currently measured with HS samplers within river restoration efforts and enhance the chance of engineering success. Gravel augmentation and dam removal projects, both of which urgently need reliable information on bedload transport rates and particle sizes during pre- and post-project bedload transport monitoring, would particularly profit from improved accuracy of bedload samples collected with a HS sampler. Use of a correction function would also improve the credibility of the many HS samples collected by government agencies and academia in coarse gravel-bed streams for watershed monitoring and research. The possibility to correct those data sets provides an opportunity to reanalyze bedload samples collected over the past 30 years. Corrected data sets will likely exhibit much smaller transport rates and smaller particle sizes at low flows, but larger particle sizes at high flows. Data sets corrected in that way can resurrect the debate on fundamental questions about bedload transport processes such as equal mobility and selective transport or critical flow for incipient motion in gravel-bed streams that have not been answered satisfactorily so far. A reanalysis of data sets could shed new light onto dynamics of bedload transport and advance our understanding of bedload transport processes in coarse gravel-bed streams. Results of this study are likely to improve the credibility of the HS sampler, expand the instrument applicability to situations when accurate measurements are required, and help sustain sales of the HS sampler.

4) Project Deliverables and Output

A. Technical Requirements: The work is divided in three phases. Phase I will result in the data gathering from existing data sets, collected by the researchers during the past 10 years.

Phase II will include data analysis, including sorting, stratification, evaluation, transformation, and the development of a correction function. Phase II work will also clarify whether the correction comprises a single function for gravel bedload or separate functions for each bedload size class and whether correction functions vary with streambed characteristics.

Phase III results in the completion of a FISP final report that includes the data sets used in the study and the correction function or functions for relating thin-walled Helley-Smith data to bedload-trap data.

Criteria for acceptance of the report is that the report meets the format as supplied by FISP and that it is completed by established delivery date.

B. Deliverables: (Time required for completion of Phases)

Phase I data gathering: Complete

Phase II data analysis: Complete

Phase III report writing and review: In Process

Grant No. 08HQGR0087 Risk Assessment and Forecasting of Indian Summer Monsoon for Agricultural Drought Impact Planning

Basic Information

Title:	Grant No. 08HQGR0087 Risk Assessment and Forecasting of Indian Summer Monsoon for Agricultural Drought Impact Planning
Project Number:	2008CO200S
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	Supplemental
Congressional District:	4th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Agriculture, Drought
Descriptors:	
Principal Investigators:	Rajagopalan Balaji

Publication

Risk Assessment and Forecasting of Indian Summer Monsoon for Agricultural Drought Impact Planning

Balaji Rajagopalan
Cooperative Institute for Research in Environmental Sciences, University of Colorado

Introduction

"The wild monsoon winds blow with abandon, swaying everything in their path...rivers flow and flowers bloom in celebration of the monsoon, as the world is transformed under its spell", notes poet S. P. Kurada in the PBS documentary "Monsoon". The author's sentiments about the monsoon are no exaggeration, for the socio-economic destiny of millions of people in the Indian sub-continent are bound head and tails to the timely arrival and an even spatial distribution of the Indian summer monsoon. Most parts of the sub-continent receive almost all their annual rainfall during the summer monsoon season (June - September). However, the amount of rainfall and its spatial distribution over the sub-continent varies significantly from year to year (also known as inter-annual variability) and also within the season (intra-seasonal variability). The monsoon greatly impacts, agriculture (more than 50% of which is rain fed), power generation (more that 50% of which is hydroelectric from rain fed rivers), and consequently, prices of essential commodities. Thus, it affects the entire spectrum of life - social, political and financial. Hence, understanding the variability of the monsoon (both inter-annual and intra-seasonal), being able to predict its strength and spatial distribution and the associated hydrologic aspects is of crucial importance to the well being of 1Billion of the world's population.

Objectives of the study

Planning for drought and food security is critical for India's economy and societal well being. This fact is greatly underscored by the increasing population, scarce natural resources and significant dependency on the vagaries of the summer monsoon. We propose a study to aid this planning effort by developing tools for intra-seasonal, subnational drought risk forecasting. To this end, the objectives are twofold - (1) to quantify the probability, on average, of the occurrence of agriculturally significant dry spells and (2) to provide a tool for predicting the risk each year based on prevailing conditions of the global climate system.

Methodology

Not much research has been performed on the intra-seasonal variability of the monsoon. Nonetheless" the subseasonal variability is crucial to agricultural and water resources applications. For example, farmers are particularly interested in the rainfall spells in the first couple of weeks of June (the typical sowing period), and, they do not like to see severe rains in August and September when the crop would be matured. While the focus of current practice has mainly been to predict seasonal rainfall totals, clearly, the subseasonal attributes are crucial for sectoral applications. There is a strong need for a systematic analysis of subseasonal variability. Our work will make possible increased specificity of monsoon forecasts in space and time.

Task A - Diagnostics and Risk assessment

The Indian Meteorological Department recently completed a daily, gridded national rainfall data set at 0.5 degree resolution (about 50 km) for the period 1901-2005 (Rajeevan et aI., 2006). These unprecedented data make possible for the first time a spatially continuous and explicit characterization of the frequency of drought and dry spell occurrence over India based on 100+ years of observations. From these daily rainfall data, at each grid location, for each month of the monsoon season, the following set of frequency and probability attributes will be derived:

(i) Number of wet and dry spells (a wet spell being a series of consecutive days with measurable rainfall above a specified threshold, and a dry spell being a consecutive series of days with rainfall below a minimum threshold)
(ii) Probability distributions of wet and dry spells of various lengths
(iii) Probability of transition between wet and dry spells
(iv) Probability of extreme events (both wet and dry)

Additional critical rainfall events can also be investigated along with the above in consultation with partners at the National Center for Drought Monitoring and Mitigation (NDMC) and the Indian Institute of Tropical Meteorology (IITM). The statistics of the above quantities will be spatially mapped to quantify the geographic extent of the risk of these rainfall events. This first-ever mapping of their historical occurrence, in and of itself, will provide a very valuable resource for planners.

The above described key rainfall events will be correlated with the large-scale climate (i.e. oceanic and atmospheric circulation) variables to reveal relationships and, consequently, the causal dynamical links and potential predictive capabilities.

Deliverables

(i) Spatial maps of probabilities (risks) of various agriculturally significant rainfall events from the historical data. This will provide a good sense of the 'static' risk relevent for agriculture planning.
(ii) Similar spatial maps of these rainfall events conditioned on large scale climate features. For instance, if ENSO conditions are found to be a strong driver of these attributes, spatial maps of probabilities of these attributes for EI Nino, La Nina and neutral years will developed. Planners would refer to whichever map corresponds to currently prevailing conditions of the equatorial Pacific.

Task B - Risk Prediction

a. Efficacy of new monsoon predictors

Since the roughly 20-years of operational Indian summer monsoon forecasts issued by the Indian Meteorological Department (IMD), skill has been disappointingly low. The low skill has been blamed upon various candidates, including the ongoing use of purely statistical methods in lieu of incorporating physically-based, dynamical modeling approaches, and a lack of knowledge of the full range of factors that drive monsoon rainfall variations from year to year. The leading predictor has been a single index of El Nino. However, our own recent study indicates that Indian monsoon rains do not fluctuate in concert with a single monolithic index of EI Nino, but that other features of tropical Pacific sea surface temperature (SST) conditions are also important. Our recently published work in *Science* (Kumar et al. 2006) emphasizes that the different so-called "flavors" of El Nino are of major importance for the monsoon. We believe there are now opportunities to improve monsoon forecasts based on such new information.

Also, several recent studies find that the Indian monsoon is within the crosshairs of impacts associated with a surmised weakening of thermohaline circulation in the Atlantic Ocean due to climate change. Our own recent efforts to understand this have pointed to Atlantic SSTs as providing the primary source of the response, and furthermore we are finding that the yearly variations of Atlantic Ocean conditions appear to explain a significant fraction of the yearly Indian monsoon swings.

Methods

We will advance the use of ENSO and Atlantic SST information to improve the capacity of Indian institutions to predict yearly monsoon variations. We will perform both empirical analysis and general circulation model experiments to test the efficacy of new Indian monsoon predictors.

b. Improved regional and temporal specificity of long-lead monsoon forecasts

Most of the focus of current practice has been on the seasonal prediction of all-India summer rainfall. While this is worthwhile, it is of limited usefulness for planning and managing of resources in several parts of India, as the spatial variability of rainfall distribution is quite high. Consequently, forecasting tools are needed for individual regions. To this end, a predictive tool will be developed for forecasting seasonal rainfall and the probability of agriculturally important intra-seasonal rainfall events for planning (as identified in Task A). The resulting ensemble forecasting tool will help provide risk outlooks each year. The steps are as follows:

(i) Identify predictors in the large scale land-ocean-atmosphere system for the variables of interest (e.g., monthly, seasonal, or other rainfall totals), for the desired lead time. This will be done primarily via correlation analysis. The predictor identification will use the recent knowledge of link between ENSO and Indian monsoon rainfall characteristics (Krishna Kumar et al., 2006).

(ii) The identified predictors will be used in a multi-model ensemble forecasting technique (Regonda et al., 2006). In this technique different statistical models (based on nonlinear regression) each with different combination of predictors are identified. Ensemble forecasts are generated from each model which are then combined to provide a multi-model ensemble forecast. It has been shown for ensemble forecasts of streamflow in the Colorado River basin (Regonda et al., 2006a) that this approach performs much better than any single model. The ensemble can provide risk estimates.

(iii) A complimentary approach in which a logistic regression (Regonda et al., 2006b) is used to relate the predictors to the probability of threshold exceedance of the rainfall event of interest will also be developed. This will directly provide the probability of occurrence of the agriculturally significant rainfall events for any year.

Deliverables

An ensemble generation and forecasting software tool that is easy to use will be provided to IMD, a supporting institution of the NCDMM, through IITM, a direct participant in our proposed study. Dr. Krishna Kumar and his associates from IITM will assist and collaborate with the following in both the tasks - (i) compilation of daily rainfall data (ii) identification of attributes relevant for agriculture (iii) predictor selection for improved forecasting tool and skill assessment (iv) interpretation of model outputs and (v) translation and dissemination of the findings from this research to NCDMM The risk estimates and year to year forecasts will be significant new planning tools for decision makers and also for training.

We wish to integrate our products with the existing and ongoing efforts of the NCDMM in developing a robust resource management system.

Time Line

Task A - end of June 2009
Task B and final report - end of September 2009

Collaborators

Dr. K. Krishna Kumar (and his group) at Indian Institute of Tropical Meteorology

Reference

Kumar, K.K, Rajagopalan, B., Hoerling, M., Bates, G. and Cane, M, Science 314: 115-119, 2006.

Rajeevan, M., J. Bhate, J. D. Kale, B. Lal, Current Science, 91, 296 (2006)

Regonda, S.K., B. Rajagopalan, M. Clark, and E. Zagona, A Multi-model Ensemble Forecast Framework: Application to Spring Seasonal Flows in the Gunnison River Basin , *Water Resources Research,* 42,W09404,2006

Regonda, S.K., B. Rajagopalan, and M. Clark, A New Method to Produce Categorical Streamflow Forecasts, *Water Resources Research,* 42,W09501, 2006

Information Transfer Program Introduction

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 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 CWI reports to the web for easier access
- 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:	2008CO171B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	Education, Law, Institutions, and Policy, Management and Planning
Descriptors:	
Principal Investigators:	Reagan M. Waskom

Publication

1. Colorado Water Newsletter, Volume 25 - Issue 2 (March/April 2008), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
2. Colorado Water Newsletter, Volume 25 - Issue 3 (May/June 2008), Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 44 pages.
3. Colorado Water Newsletter, Volume 25 - Issue 4 (July/August 2008), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 32 pages.
4. Colorado Water Newsletter, Volume 25 - Issue 5 (September/October 2008), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
5. Colorado Water Newsletter, Volume 25 - Issue 6 (November/December 2008), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
6. Colorado Water Newsletter, Volume 26 - Issue 1 (January/February 2009), Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 32 pages.
7. Bauder, Troy and Reagan Waskom and Rob Wawrzynski and Karl Mauch and Greg Naugle, 2008, Agricultural Chemicals and Groundwater Protection in Colorado 1990-2006, Special Report 16, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 54 pages.
8. Pritchett, James and Alan Bright and Andrea Shortsleeve and Jennifer Thorvaldson and Troy Bauder and Reagan Waskom, 2009, Public Perceptions, Preferences and Values for Water in the West: A Survey of Western and Colorado Residents, Special Report 17, Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 40 pages.
9. Kryloff, Nicolai and Patricia J. Rettig, 2008, Colorado Water History: A Bibliography, Information Series 105, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 29 pages.
10. Brummer, Joe, 2008, Proceedings, High Altitude Revegetation Workshop No. 18, Information Series 107, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, 519 pages.
11. Brown, Jennifer, 2008, Proceedings, South Platte Forum, 19th Annual, "News, Weather and Water", Information Series 106, Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 33 pages.

Colorado Water Institute Activities

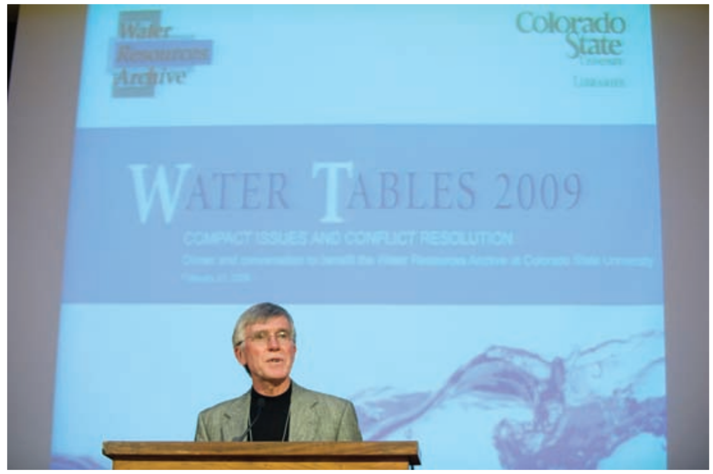
Water Tables Raises $29,000 for Water Resources Archive

by Colorado State University Libraries staff

On February 21, 2009, more than 160 water experts and honored guests gathered to support the Water Resources Archive at Colorado State University Libraries. *Water Tables 2009: Compact Issues and Conflict Resolution* was a huge success, raising more than $29,000. The donation of Maury Albertson's papers to the Water Resources Archive was also announced.

Water engineers, ranchers, lawyers, professors, and students kicked off the event, now in its fourth year, with a reception at Morgan Library and tours of the Water Resources Archive. Dinner and a night of conversation were then hosted at the Lory Student Center ballroom at CSU. Thanks to the generosity of many individual and corporate sponsors, 25 graduate students were able to attend the event and interact with current leaders in the water industry.

The Archives featured two exhibits: one discussed the *Wyoming v. Colorado* court case of 1911, and the other featured highlights from the Maurice Albertson Papers. The first exhibit, *Headlines of History: Exploring the Evolution from Conflicts to Compacts*, contained original Supreme Court documents that led to a change in water law philosophy for Colorado's lead attorney on the case, Delph E. Carpenter. On display from the Delph Carpenter Papers were materials related to the case, which showed his efforts with the 11-year-long court battle and how he came to the conclusion that water compacts would better serve states and water users.



Robert Ward, former director of the Colorado Water Institute and CSU Faculty Emeritus, speaks to attendees at Water Tables 2009.

Ruth and Ken Wright look at an historic water document exhibit at Water Tables 2009.

The second exhibit, a table display of documents and artifacts from the Maurice Albertson Papers, reflected on the former CSU professor's achievements in teaching, research, and international development. Following a moment of silence for Albertson, who passed away in January at age 90, it was only fitting that his widow, Audrey Faulkner, discussed her husband's contribution to water resources at CSU and around the globe. While over 200 boxes had been donated by Albertson before he passed away, Faulkner assured head archivist Patty Rettig that many more boxes will be donated to the archive—a testament to Albertson's contribution to water resources research and education. Faulkner told guests how her husband's passion for water arose during the Great Depression when his father took him on tours of previously drought-ridden areas that were suddenly flooded. Her remarks about his life's dedication to water solutions in the West and throughout the world truly fit the evening's theme of conflict and compacts and were well received by all who attended.

At dinner, esteemed hosts at each table discussed past and current water conflict and compact issues, including topics related to climate, habitat, population, agriculture, law, and management. The hosts' expertise and insight made for lively, entertaining, and enlightening conversation. A tremendous success for both the CSU Libraries and the Water Resources Archive, Water Tables 2009 will provide the Archive with much needed funding for student assistants, supplies, and outreach activities. As a true testament to an enjoyable evening, guests left the event already anticipating Water Tables 2010.

AGU Hydrology Days 2008
March 26-28, 2008
Cherokee Park Room
Colorado State University

Sponsored by

Hydrology Section of the American Geophysical Union

For registration information, visit: www.hydrologydays.colostate.edu

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.

Borland Lecturer in Hydraulics
William E. Dietrich
University of California, Berkeley

Hydrology Days Award Lecturer
Wilfried H. Brutsaert
William L. Lewis Professor of Engineering
Cornell University

Borland Lecturer in Hydrology
Dennis P. Lettenmaier
University of Washington

The Agricultural Water Conservation Clearinghouse A New Resource For Agricultural Producers And Water Managers

by Matt Neibauer and Faith Sternlieb, Colorado Water Resources Research Institute

As we move along in the 21st Century, Colorado and the Western United States (U.S.) are experiencing water shortages as rapid urbanization and limited water resources shape how we farm, manage our water supplies, and create natural resource policies and laws. With production agriculture accounting for about 90 percent of the consumptive use of water in Colorado, it is important to address the needs of producers and water managers living in these areas where critical water resources are limited. Based on the issues and problems agriculture faces with regards to limited water supplies, the Colorado Water Resources Research Institute (http://cwrri.colostate.edu/) and the Northern Plains and Mountains Regional Water Program (http://region8water.org) are currently developing an online regional and national clearinghouse of information, concerning agricultural water conservation, which highlights state of the art research and technology by international experts facing similar water constraints. The Colorado Water Conservation Board has allocated funding beginning July 2008 to build and maintain the website as a resource for Colorado.

The Ag Water Conservation Clearinghouse (http://agwaterconservation.colostate.edu) will ultimately provide current, science-based information on a wide variety of agricultural water conservation issues. The centerpiece of this online clearinghouse is a comprehensive database and library, which identifies current research and educational outreach publications regarding irrigation management, irrigation technology, efficient water delivery systems, agricultural water reuse and recycling, soil moisture and evapotranspiration measurement, cropping systems, as well as agricultural economics and water law/policy. This database will eventually house all of these agricultural water conservation topics in a variety of formats, including refereed journal articles, books, fact sheets, bulletins, reports, theses/dissertations, and conference proceedings

The Agricultural Water Conservation Clearinghouse website will also provide current links to Agricultural Experiment Stations and Land Grant Universities, as well as up-to-date information on agricultural water related research centers, irrigation management curriculum / workshops, and irrigation tools. As development of the website expands, we will also be featuring upcoming events and news related to agricultural water conservation to regional and national audiences. This newly developing resource also contains a comprehensive glossary, frequently asked questions (FAQs), and current news on agricultural water conservation and irrigation efficiency. With a built-in feedback option, this clearinghouse is designed to help build knowledge and connect water resource managers from various local, state, regional, and national organizations providing agricultural water conservation expertise.

We would like to invite you to take a look at this new and developing online resource. We also encourage you to provide us with feedback and contact us with questions, comments, and suggestions as to how this dynamic resource might be improved to optimize its utilization. Please contact the following people for more information about this new online agricultural water conservation clearinghouse:

- Faith Sternlieb, Research Associate, CWRRI
  (970) 491-6328
  faith.sternlieb@research.colostate.edu
- Matt Neibauer, Assistant Regional Water Coordinator, CWRRI
  (970) 491-5124
  matt.neibauer@research.colostate.edu

AgNIC Welcomes the Agricultural Water Conservation Clearinghouse

by Faith Sternlieb, Research Associate, Colorado Water Institute

The Colorado Water Institute is pleased to announce that the Agricultural Water Conservation Clearinghouse (agwaterconservation.colostate.edu) has been invited to join the Agriculture Network Information Center (AgNIC). AgNIC (www.agnic.org) is a voluntary alliance of the National Agricultural Library (NAL), land-grant universities, and other agricultural organizations in cooperation with citizen groups and government agencies. AgNIC focuses on providing agricultural information in electronic format over the World Wide Web. The Ag Water Conservation Clearinghouse is a Cooperative Research Education and Extension Service Western Regional project, spearheaded by the Colorado Water Institute.

Socio-geographic changes in population are placing increased demands on water resources. Population growth is occurring where municipal and industrial demands are already great. Much of the increased demand is occurring in arid regions where water is always scarce. Water resources become even less dependable in years of drought. Numbers of intra- and inter-state controversies are emerging as a result of water shortages.

Agricultural water management is increasingly important in the presence of low water supplies because agriculture in the West consumes approximately 87% of the ground and surface water withdrawals.

When agricultural operations are able to incorporate more efficient methods of using water, more water is made available for use by both the environment and the community at large. The Ag Water Conservation Clearinghouse aims to provide current, science-based information for future collaboration regarding the sustainable use, conservation, and development of water in the agricultural sector.

PUBLIC EARTH DAY EVENTS
April 22, 2008

GARY A. PETERSON AND DWAYNE G. WESTFALL ANNUAL LECTURE

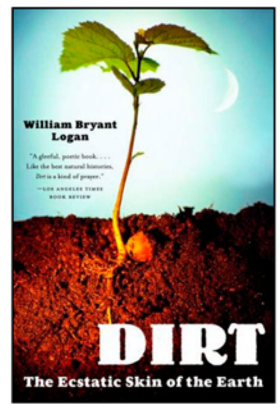
Please join us to celebrate Earth Day and to recognize the importance of our soil and water resources. All events are free and open to the public.

Lectures Presented by award winning nature writer

William Bryant Logan

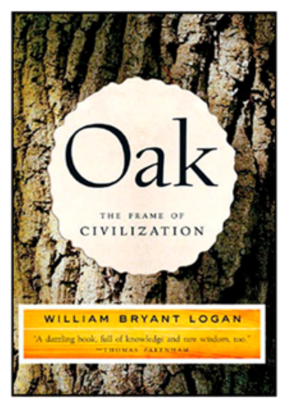
discussing his literary works about natural resources.

Lecture Details



Dirt: The Ecstatic Skin of the Earth
2:00 p.m. – 3:30 p.m.
West Ballroom, Lory Student Center
Colorado State University

Please stay for a reception and book signing from 3:30 - 4:00 p.m.



Oak: Frame of Civilization
7:00 – 8:00 p.m.
West Ballroom, Lory Student Center
Colorado State University

Books will be available for sale before and after the lectures and the author will be available to sign your copy.

William Bryant Logan is an award-winning nature writer. He regularly makes presentations and teaches classes and workshops regarding the care of trees and regarding the natural history of soils, including a lecture to the Soil Science Society of America. He also taught nonfiction writing at the Columbia University Graduate School of Journalism.

DEPARTMENT OF SOIL & CROP SCIENCES

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FY09 Student Water Research Grant Program
Request for Proposals

The Colorado Water Institute is pleased to announce a request for proposals for the FY09 Student Water Research Program.

All proposals must be submitted online by February 27, 2009.
Please visit http://www.cwi.colostate.edu for submission site.

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 fulltime 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, 2009 and research projects should be completed by March 31, 2010. 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.

CWRRI Announces Funded Student Projects

The Colorado Water Resources Research Institute is pleased to announce the funding of 3 undergraduate student projects this year. 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. The FY08 student projects are listed below:

Flow Device to Assess Biological Water Quality in Colorado Surface Water

by Travis Steiner, Department of Animal Sciences, CSU
Faculty Sponsor: Lawrence Goodridge, Department of Animal Sciences, CSU

The World Health Organization estimates that 50,000 deaths per day are due to water related diseases. The detection of waterborne pathogens continues to be difficult. Since most of the pathogens present in water are of fecal origin, the detection of fecal contamination has been the main aim of the testing methodologies. Historically, bacterial indicators have been used to detect fecal contamination. However, there are major problems with the current use of indicator bacteria to detect fecal pollution. Many of these bacteria are routinely isolated from environments that have not been impacted by fecal pollution. In addition, these bacteria are not reliable indicators of the presence of enteric viruses in water. The FRNA bacteriophages (phages) have emerged as indicators of fecal contamination, due to their morphological similarities to human enteric viruses, and the fact that their presence in water typically represents a recent fecal contamination event. Also, the FRNA phages can be differentiated into 4 distinct serogroups, with serogroups I and IV occurring in animal wastewater, and groups II and III typically found in wastewater from human sources. Therefore, if these phages can be detected and simultaneously serogrouped, a new indicator assay will have been developed, that not only detects fecally polluted waters, but also determines the source of the contamination (based on the serogroup of the detected phage).

Studies Supporting Sustainable Use of the Denver Basin Aquifers in the Vicinity of Castle Rock

by Kim Lemonde, Civil and Environmental Engineering, CSU
Faculty Sponsor: Dr. Tom Sale, Civil and Environmental Engineering, CSU

The vision of this project is to advance our understanding of the hydrogeology of the Denver Basin Aquifer in the vicinity of the Castle Rock, Colorado.

The following tasks will be undertaken:

1. Mapping geologic trends to better resolve the long-term capacities of the aquifers to store and release water
2. Further resolution of geologic trends using geophysical logs
3. Collection and interpretation of hydrologic data
4. Further interpretation of water level data
5. Correlation of observations from geologic, geophysical, hydrologic data, and water level data sets

Estimating Errors Associated With Calculated Sublimation From Seasonally Snow-Covered Environments

by Douglas M. Hultstrand, Geosciences, CSU
Faculty Sponsor: Steven Fassnacht, Forest Rangeland & Watershed, CSU

In the mountainous regions of the western United States, a majority of annual precipitation falls as snow and is stored in high-elevation mountain snowpacks. One component of the alpine water balance that is still poorly understood is the amount of water exchanged between seasonal snowpacks and the atmosphere through sublimation. Sublimation losses from the snowpack can constitute a significant component of the water balance in seasonally snow-covered alpine environments. Net sublimation losses from seasonal snowpacks have been estimated to be between 10-50% of the seasonal snow accumulation. Errors associated with snowpack sublimation estimates are crucial for quantifying alpine water balances and estimation of water availability.

Meeting Briefs: Reflections from the Global Water Research Colloquium

by Faith Sternlieb, Research Associate, CWRRI / CSU Water Center

Keynote speaker Brian Richter of The Nature Conservancy confers with colloquium co-sponsor, Jim Cooney and Reagan Waskom.

The CSU Global Water Research Colloquium – From Conflict to Sustainability: Challenges and Opportunities in an Interdependent World, held at the Hilton, Fort Collins on March 25, 2008 was sponsored by the Colorado State University Vice President for Research, the Office for International Programs and the CSU Water Center. The Colloquium's primary goal was to highlight current water research at CSU and bring the university community together to discuss ways in which faculty and students can collaborate on local, regional, national and international water projects. Whether research occurs at a micro or macro scale, implications from such collaborations may have a global impact as communities across the globe become increasingly ecologically and socially interdependent.

A few of the highlights from the Colloquium include: Keynote Speaker Brian Richter, Director of the Sustainable Waters Program for The Nature Conservancy; the Art Poster Competition, directed by graphic design art professors Phil Risbeck and Jason Frazier; and the technical posters from five of eight colleges across CSU. The winners of the art post completion are Elizabeth Schmidt, Amber Crowe and Erin Dubinski. In addition to our keynote speaker, we were very pleased to host two distinguished guests. Professor Rodrigo Maia from the University of Porto in Portugal is a visiting scholar in Engineering at CSU and was able to attend the Colloquium. Eugene Z. Stakhiv from the Army Corps of Engineering participated in our fourth panel discussion and announced the formation of the UNESCO International Center for Integrated Water Resources Management (ICIWaRM). ICIWaRM is a conglomeration of professional organizations, governmental agencies and research institutions working together on interdisciplinary projects towards advanced solutions for global water issues.

The discussion that resulted from the 4th Session Panel led to a series of articulated concerns, questions and possible solutions regarding the future of international water research at CSU. Interdisciplinarity as a fundamental requirement for both curriculum development and experiential learning recurred as a common theme. A few ways to facilitate the internationalization of such an interdisciplinary approach include both top down incentives from the administration and ground up initiatives by faculty as well as direct links to stakeholders. Additionally, fellowships and visiting scholars while revisiting well established partnerships with previous funding sources such as USAID will be instrumental in building relationships with new partners such as non-governmental organizations and learning institutions at large. Finally, encouraging transparent internal communication networks university-wide will foster both collaboration and cooperation while improving academic integrity in research, field work, outreach and education.

Ellen Wohl discusses river health and climate change with fellow panelists, LeRoy Poff and Graham Stephens

As a part of CSU's internationalization strategy, the Global Water Advisory Committee would like to continue the momentum initiated with the Colloquium by offering an outlet for collaboration on potential projects regarding international water research via monthly Global Water Roundtable gatherings. Throughout the upcoming year, the VPR, OPI and the CSU Water Center in cooperation with colleges across campus will organize such venues to connect established water experts and alumni at large with new researchers and faculty at CSU to bring forth a new generation of CSU water professionals.

Art professor Phil Risbeck discusses art student involvement in the Colloquium.

NEWS, WEATHER AND WATER

19th Annual South Platte Forum

Oct. 22-23, 2008 — **Radisson Conference Center, Longmont**

breaking news

extended weather

perspectives

no-spin zone

U.S Bureau of Reclamation photo

sturgeon general report

registration fees

Registration fees include meals, breaks and reception.

Early Registration (by Oct. 1)......................$100

Registration (after Oct. 1).........................$115

Additional invoicing fee (if necessary) $20

payment information

Send this form with check or money order to:

South Platte Forum
c/o Northern Water
220 Water Avenue
Berthoud, CO 80513

forum location & hotel information

Radisson Conference Center - 1900 Ken Pratt Boulevard - Longmont, CO
303-776-2000 - www.radisson.com/longmontco

The Radisson offers a $99 nightly rate to Forum attendees. Call 800-333-3333 by **Oct. 1** to make your reservation. Be sure to mention you're with the South Platte Forum.

news line & information

For general questions, contact
Jennifer Brown, Coordinator
402-960-3670
Jennifer@jjbrown.com

For billing and payment questions, contact
Veronica Gomez, Northern Water
970-622-2322
vgomez@ncwcd.org

For additional information, visit
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Colorado State University Extension
Denver Water

19th Annual South Platte River Forum

by Laurie Schmidt, Colorado Water Institute

"News, Weather and Water" was the theme of the 19th Annual South Platte Forum, held on October 22-23, 2008, in Longmont, Colorado. More than 200 attendees participated in 10 themed sessions during the two-day meeting.

The meeting opened on Wednesday, October 22, with a session titled Weather at the Top of the Hour, in which David Yates, National Center for Atmospheric Research, provided an overview of what we know about local global warming trends and climate models. He discussed the complexities of climate models, particularly with regard to the precipitation variable. Addressing recent news that climate change will lead to much more arid conditions in the Colorado Plateau region, he said, "The assertion that the southwest U.S. will definitely get drier is not a robust finding, and the water vapor variable is very difficult to model."

Tom Perkins, Natural Resource Conservation Service, discussed the dramatic impact that spring weather can have on Colorado snowmelt and runoff. "Extreme spring precipitation —wet or dry—is the biggest source of April 1 forecast errors," he said. Colorado State Climatologist Nolan Doesken talked about the challenges faced by Colorado water resources professionals due to the state's highly variable climate. The final morning session focused on the South Platte Decision Support System and a Judicial Review Forum.

During the lunch break, the Platte River Greenway Foundation was honored with the Friends of the South Platte Award in recognition of its contributions to the South Platte River Basin. Jeff Shoemaker, who accepted the award on behalf of the Platte River Greenway Foundation, was presented with a framed "South Platte Sunset" photo donated by Colorado photographer John Fielder. After the award presentation, former CSU football coach Sonny Lubick gave the keynote presentation, entertaining attendees with colorful anecdotes from his years of coaching.

In an afternoon session titled Letters to the Editor, CSU professor Neil Grigg discussed economic activity in the South Platte Basin and the management measures that will make a difference in economic value, including a more reliable water supply, redistribution, and improved water quality. Next, using South Platte River Segment 15 as an example, Jim Dorsch of Metro Wastewater Reclamation District addressed the importance of water to habitats and biology. The session concluded with a talk by Bruce Bosley, Colorado State University Extension, on the impacts of irrigation dry-ups on land and people.

The final session on Wednesday focused on water quality issues and included presentations by Karl Mauch, Colorado Department of Agriculture; Larry Barber, U.S. Geological Survey; and Laurie Rink, Mile High Wetlands Group, LLC. Barber discussed the fate of consumer product chemicals in surface waters impacted by wastewater treatment plant effluents and presented evidence that a number of these chemicals impact the endocrine systems of fish and other aquatic organisms.

On Thursday, the Forum reconvened with an update from Jerry Kenny on the progress and prospects for the Platte River recovery implementation program. A report on Quagga and Zebra mussels from Mary Fabsiak of the City of Westminster detailed the threat of these invasive species to water systems in the state and the efforts underway to manage and track their transmission from one waterbody to another. CSU professor John Stednick outlined the results of his two-year study on the impact of the pine beetle infestation on forested watersheds. While measurable impact on water yield appears to be variable between catchments, some of the water quality impacts observed across watersheds are cause for some concern.

Nolan Doesken discusses climate at the South Platte Forum.

Highlights of the Thursday sessions included Colorado State Representative Randy Fischer and Department of Natural Resources Executive Director Harris Sherman providing views on the political landscape of water in Colorado and how it might affect South Platte management. The Forum wrapped up with perspectives from members of the South Platte and Metro Roundtables and new state agency directors. The 2008 South Platte Forum, like the previous 18 events, provided participants with an opportunity to network with colleagues and catch up on events and issues related to the Basin.

The 2009 South Platte Forum will be held on October 21-22, 2009. Stay tuned to www.southplatteforum.org for details.

GRAD592
Interdisciplinary Water Resources Seminar

Fall 2008 Theme: Global Water Issues and Challenges
Mondays at 4:00 pm, Room 206A, Clark Building

The purpose of the 2008 Interdisciplinary Water Resources Seminar (GRAD592), through a series of invited speakers, is to examine the state of global water resources and the institutional responses to water shortage, water quality concerns, drought, and climate change. More specifically, the seminar will:

- Examine water resource case studies from a variety of nations and perspectives
- Understand the global environmental challenges of water management and development
- Discuss various approaches employed by governmental and non-governmental organizations to manage water supply and sanitation challenges
- Explore various opportunities to work and serve in international water management

25 Aug.	No class
1 Sept.	*Labor Day*–No class
8 Sept.	**The Looming Global Water Crisis**–Ellen Wohl, CSU
15 Sept.	**Integrated Water Resources Management in South America**–Neil Grigg, CSU
22 Sept.	**Global Change and Global Water**–CSU Atmospheric Scientist (TBA)
29 Sept.	**Water Organizations and the Developing World** - David Freeman, CSU
6 Oct.	**Water for People**–Colleen Stiles, Executive Director
13 Oct.	**Irrigation Water Management and Agriculture**–Terry Podmore & Ramchand Oad, CSU
20 Oct.	**Engineers Without Borders/CSU Global Impact program**–Brian Bledsoe, CSU
27 Oct.	**Managing Trans-Boundary Water Conflict**–Steven Mumme, CSU
3 Nov.	**Water Quality in a Changing Environment**–KJ Reddy, University of Wyoming
10 Nov.	**Water Development in the Peace Corps**–Ben and Kelly Latham, CSU
17 Nov.	**River Basin Decision Support Systems: the Nile**–Larry Brazile, Riverside Technology
24 Nov.	*Thanksgiving Break*–No class
1 Dec.	**Global Natural Resource and Water Management**–Dennis Child, CSU
8 Dec.	**Service/Career Opportunities in International Water**–Peter McCornick, Duke Univ.
15 Dec.	*Finals Week*–No class

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

For more information, contact Reagan Waskom at reagan.waskom@colostate.edu.

Spring 2009
Interdisciplinary Water Resources Seminar

Sponsored by: CSU Water Center, USDA-ARS, Civil and Environmental Engineering, and Forest, Rangeland, and Watershed Stewardship

Thursdays from Noon to 1:00 PM

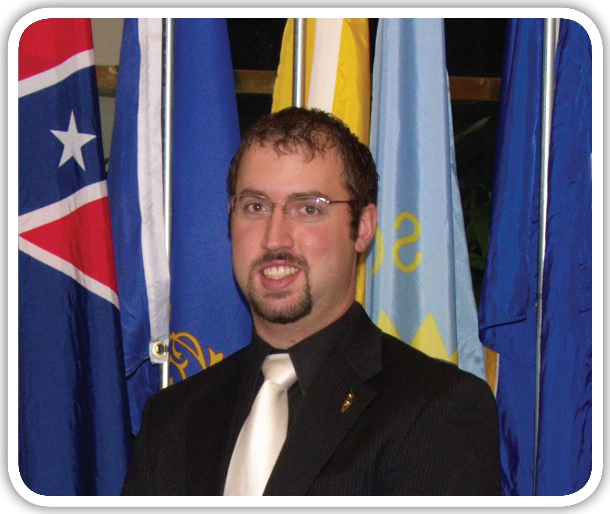
All seminars are held in the Lory Student Center on the main campus of Colorado State University.

February 5 LSC 222	**Benedito Braga**, University of Sao Paulo **Managing Water in the 21st Century: Challenges and Opportunities**
February 12 LSC Virginia Dale	**Perry Cabot**, CSU Extension **Water Quality Issues on Fountain Creek**
February 19 LSC Virginia Dale	**James Pritchett**, Agricultural and Natural Resources Economics, CSU **Survey of Water Attitudes and Values of Western Households**
February 26 LSC 226	**Jeff Neimann**, Civil and Environmental Engineering, CSU **Controls on Soil Moisture in a Semiarid Setting and an Associated Method for Soil Moisture Estimation**
March 5 LSC 222	**Scott Miller**, University of Wyoming **LiDAR in Hydrology: Improving Accuracy or Just Cost?**
March 12 LSC 222	**Mazdak Arabi**, Civil and Environmental Engineering, CSU **Non-point Source Web-based Evaluation Tool**
March 19	*Spring Break*
March 26	*Hydrology Days*
April 2 LSC 222	**Ginger Paige**, University of Wyoming **Rangeland Water Resources: Management Opportunities**
April 9 LSC Virginia Dale	**Mike Ronayne**, Geosciences, CSU **Solute Transport in Fluvial Aquifers**
April 16 LSC 222	**Pieter Johnson**, University of Colorado - Boulder *Topic To Be Announced*
April 23 LSC 226	**Jack Morgan**, ARS **Global Change: It's Essentially About Water**
April 30 LSC 222	**Katie Walton-Day**, USGS Denver **Use of Isotopes to Identify Surface-Groundwater Connections**
May 7 LSC 222	**Marie Livingston**, University of Northern Colorado *Topic To Be Announced*

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

For more information, contact Reagan Waskom at reagan.waskom@colostate.edu or visit the CWI web site.

Upper Yampa Water Conservancy District Scholarship Awarded to CSU Students



The Upper Yampa Water Conservancy District (UYWCD) funds an annual scholarship in support of CSU students preparing for careers in water-related fields. The scholarship program is administered by the CSU Water Center and provides financial assistance to committed and talented students who are pursuing water-related careers at CSU. The UYWCD $3,000 scholarship is open to any major at CSU. Criteria require the recipient to be a full-time student enrolled at CSU with a minimum GPA of 3.0. Financial need may be considered, and preference is given to students from the Yampa Valley area. The scholarship duration is one year.

The Upper Yampa Water Conservancy District Scholarship recipient for the spring semester of 2009 is Michael Macklin. A senior majoring in political science with an interdisciplinary study in water resources, Mike was born in La Junta, Colorado, and raised in Springfield, Colorado. For the past four years, while attending Colorado State University, he has worked at the Colorado State 4-H Office, where he has helped coordinate state and national 4-H youth development events. His studies in water resources and political science led him to Lincoln University in Lincoln, New Zealand, for a semester of study in natural resource and water economics during the spring of 2008. Mike has been active in Alpha Gamma Rho, an agriculturally based fraternity, and has served as an ASCSU Senator for the College of Agriculture for two years. Following graduation, Mike plans to pursue a law degree with an emphasis on water law in the fall of 2009. Mike's love for small towns and rural America has driven his passion to protect the farmers and ranchers of rural America.

The CSU Water Center and Colorado Water Institute congratulate Mike and wish him success in his future academic studies and career. The ongoing support of CSU students by the UYWCD is acknowledged and greatly appreciated.

The Upper Yampa Water Conservancy District (UYWCD) funds an annual scholarship in support of CSU students preparing for careers in water-related fields. The scholarship program is administered by the CSU Water Center and provides financial assistance to committed and talented students who are pursuing water-related careers at CSU. The UYWCD $3,000 scholarship is open to any major at CSU. Criteria require the recipient to be a full-time student enrolled at CSU with a minimum GPA of 3.0. Financial need may be considered, and preference is given to students from western Colorado. The scholarship duration is one year.

The Upper Yampa Water Conservancy District Scholarship recipient for the 2008–09 academic year is Kyle Eitel. A senior majoring in civil engineering at CSU, Kyle was born and raised in Craig, Colorado. During the summers of 2007 and 2008, he participated in an internship at Colowyo Mine in Meeker, Colorado, where he gained valuable experience with GPS and SurvCAD and assisted with project management. His coursework at CSU has stimulated his interest in water-related engineering topics, and he hopes to further his studies and pursue a career in fluid mechanics, hydraulics, and water resources management and securities. Kyle has been a member of the American Society of Civil Engineers (ASCE) Chi Epsilon, the civil engineering honors society, and the National Honor Society. On a personal level, he enjoys the outdoors, particularly activities and recreation involving water.

The CSU Water Center and Colorado Water Institute congratulate Kyle and wish him success in his future academic studies and career. The ongoing support of CSU students by the UYWCD is acknowledged and greatly appreciated.

Colorado Water Institute Reports

Estimating Snowmelt Contribution to an Alpine Water Balance

by Douglas M. Hultstrand, Graduate Student, Geosciences, Colorado State University

Introduction

The annual hydrograph in high-elevation areas is driven primarily by the formation and melting of seasonal snowpacks. In the western United States, stream runoff during the snowmelt season (May-July) accounts for approximately 75% of total annual flow. Snow water equivalent (SWE) is an important input into any high-elevation hydrologic model for flood forecasting and water resource estimates. Spatial and temporal estimates of SWE are limited due to the extreme spatial variability of snow. A challenging problem in snow hydrology is understanding and quantifying winter precipitation in mountain catchments. Typical watershed studies measure both solid and liquid precipitation quantity with a standard precipitation gauge. Precipitation gauges, shielded and unshielded, inherently underestimate total precipitation due to local airflow, wind undercatch, wetting, and evaporation loss. As an alternative to using precipitation gauges, previous studies have had significant success using a combination of slope, aspect, elevation, solar radiation, wind redistribution, and northness as independent variables in statistical models for computing SWE distribution across a watershed.

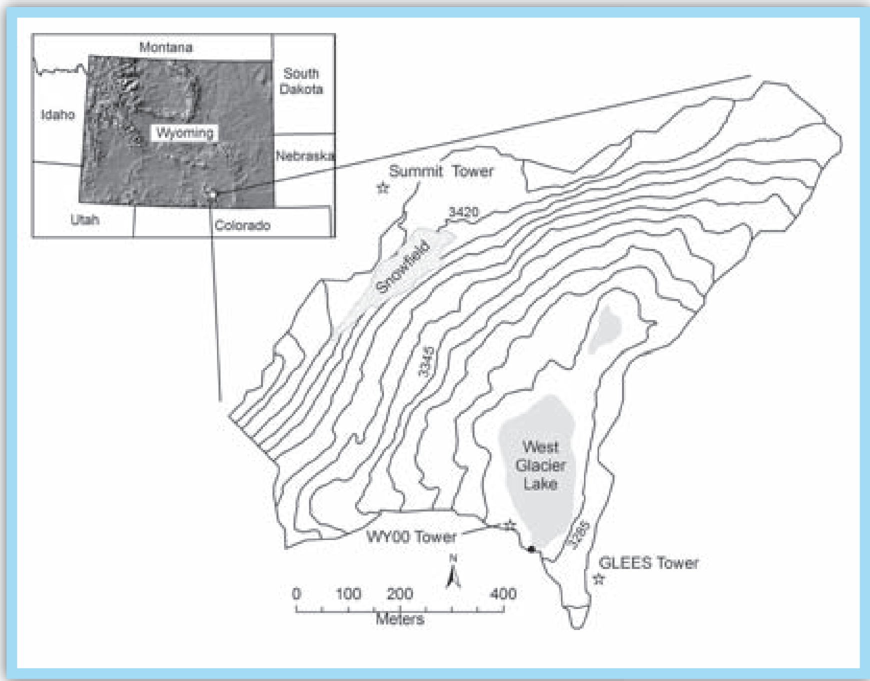


Figure 1. Site map of West Glacier Lake Watershed.

Study Area

West Glacier Lake watershed is located within the U.S. Forest Service's Glacier Lakes Ecosystem Experiments Site (GLEES), an alpine/subalpine research study area located in the Medicine Bow National Forest of Wyoming (Figure 1). West Glacier Lake watershed encompasses 0.61 square kilometers (km), ranges in elevation from 3,200 to 3,500 meters (m), and has a mean annual average temperature of -1°C at the outlet and -2.5°C at the top of the basin. Average annual precipitation is approximately 1.20 m, with 75–85% falling as snow. West Glacier Lake watershed has a unique problem: measured streamflow out of the watershed has been previously estimated at 40% to 130% greater than measured precipitation input. Additional input into the watershed has been attributed to a permanent snowfield in the upper portion of the watershed covering approximately 2.4% of the watershed area. However, the excess output may be a result of inaccurate estimation of water quantities using current precipitation and stream gauging methods.

Methods

Field Methods

An intensive snow survey was conducted on April 20 and 23, 2005, during peak snow accumulation. Snow depths were measured using an aluminum probe pole on an approximate 50-m measurement grid. At each sample location, five depth measurements were collected (one center point plus four points spaced two meters apart in each cardinal direction). The five measurements were recorded to the nearest 0.01 m and averaged to minimize local variation in snow depth at that point. Global positioning systems (GPS) were used to record the location of each center snow depth measurement. A total of 538 snow depth measurements were used for modeling snow depth distribution (Figure 2).

Seven snowpits were excavated and density profiles collected at each site during the intensive snow survey. Snow density was measured with a 1-liter stainless steel cutter and an electronic digital scale with 1-gram resolution. Density profiles were collected at 0.10-m increments and then integrated over total depth to obtain one density value for each snowpit. GPS was used to record the location of each snowpit location (Figure 2).

Independent Variables

Slope, aspect, elevation, solar radiation, and northness were the independent variables used to aid in statistical modeling of snow depth and density. Slope, aspect, and elevation were derived from a 5-m digital elevation model (DEM) using the ArcGIS 9.0®. Northness was calculated as the product of the cosine of the aspect and the sine of the slope. An index of net solar radiation was calculated using methods similar to Elder et al. (1998), using the Solar Analyst extension in the ArcView® software.

Spatial Modelling

Snow Density. The calculated snowpit densities were used to predict density distribution across West Glacier Lake watershed. A multiple linear regression model was applied to point snow densities, along with different combinations of the derived independent variables.

Snow Depth. Using the SPLUS® statistical and mathematical software, snow depths were spatially distributed across the watershed through the following nine spatial interpolation methods: inverse distance weighting, binary regression tree, ordinary kriging, co-kriging with elevation, co-kriging with slope, co-kriging with northness, co-kriging with solar radiation, modified residual kriging, and a combined method using binary regression trees and geostatistical methods. Cross-validation procedures were used to compare the value estimated (without using the observed value) to the observed snow depth value. Residuals from cross-validation procedures were used to evaluate the performance of each model based on the coefficient of determination (R2), the mean absolute error (MAE), and the root mean square error (RMSE).

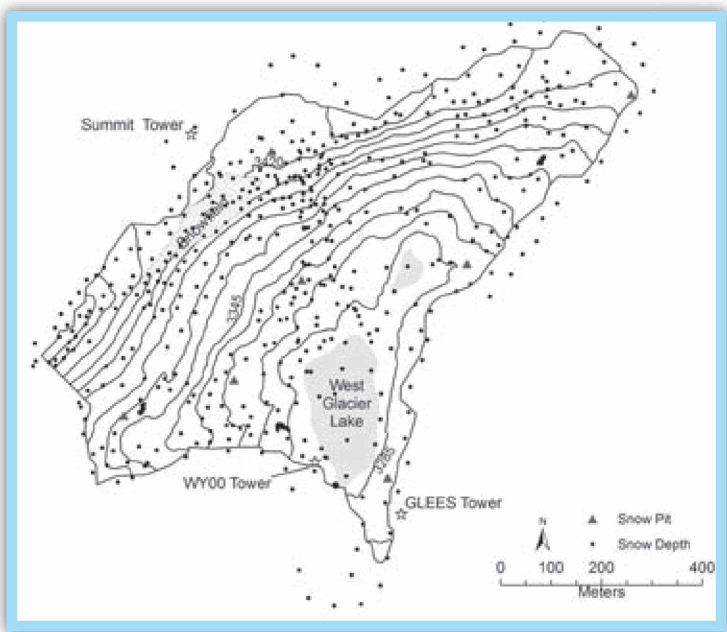


Figure 2. Snow depth and density sample locations for West Glacier Lake watershed.

Snow-Covered Area. Snow-covered area (SCA) was derived from aerial photographs of GLEES taken on April 16, 2005, during peak accumulation. A supervised classification scheme in ArcGIS 9.0 was used to classify aerial photographs into a binary value of zero (0% snow cover) or one (100% snow cover). The SCA for West Glacier Lake watershed was calculated to be 94%.

Snow Water Equivalent

Net winter precipitation was derived by modeling SWE for each 5-m pixel within the West Glacier Lake watershed. The best spatially modeled snow depth layer was used to calculate SWE distribution.

Water Balance

A water balance equation was used to compare annual inputs and outputs for West Glacier Lake watershed:

$$Q = P_s + P_r - E_t - E_s +/- G$$

where Q is stream discharge, P_s is total winter precipitation calculated as estimated SWE plus snowpack sublimation loss, P_r is precipitation as rain, E_t is evapotranspiration, E_s is snowpack sublimation, and G is groundwater. Evapotranspiration was estimated as the difference between precipitation inputs and stream outputs.

Results

Snow Depth Modelling

Cross-validation procedures were used to examine the validity of the snow depth interpolation models. Based on the cross-validation, co-kriging with solar radiation was determined to be the most accurate method for estimating snow depth across West Glacier Lake watershed. Co-kriging with radiation explained 94% of the variance in observed snow depth measurements.

Snow Water Equivalent

Co-kriging with solar radiation model was used along with the snow density and SCA layers to calculate SWE distribution (Figure 3). The modeled SWE distribution resulted in a maximum SWE estimate of 240 centimeters (cm), a mean of 113 cm, and a minimum of 0 cm. Total winter inputs in West Glacier Lake watershed were calculated as peak SWE (1,060 millimeters [mm]) plus snowpack sublimation loss (251 mm), which yielded a total 1,311 mm of winter precipitation.

Water Balance

Calculated inputs and outputs were applied to the simple water balance. Total net input from precipitation as snow (1,311 mm) and rain (170 mm) was 1,481 mm. Annual runoff calculated from the Parshall flume was 1,000 mm.

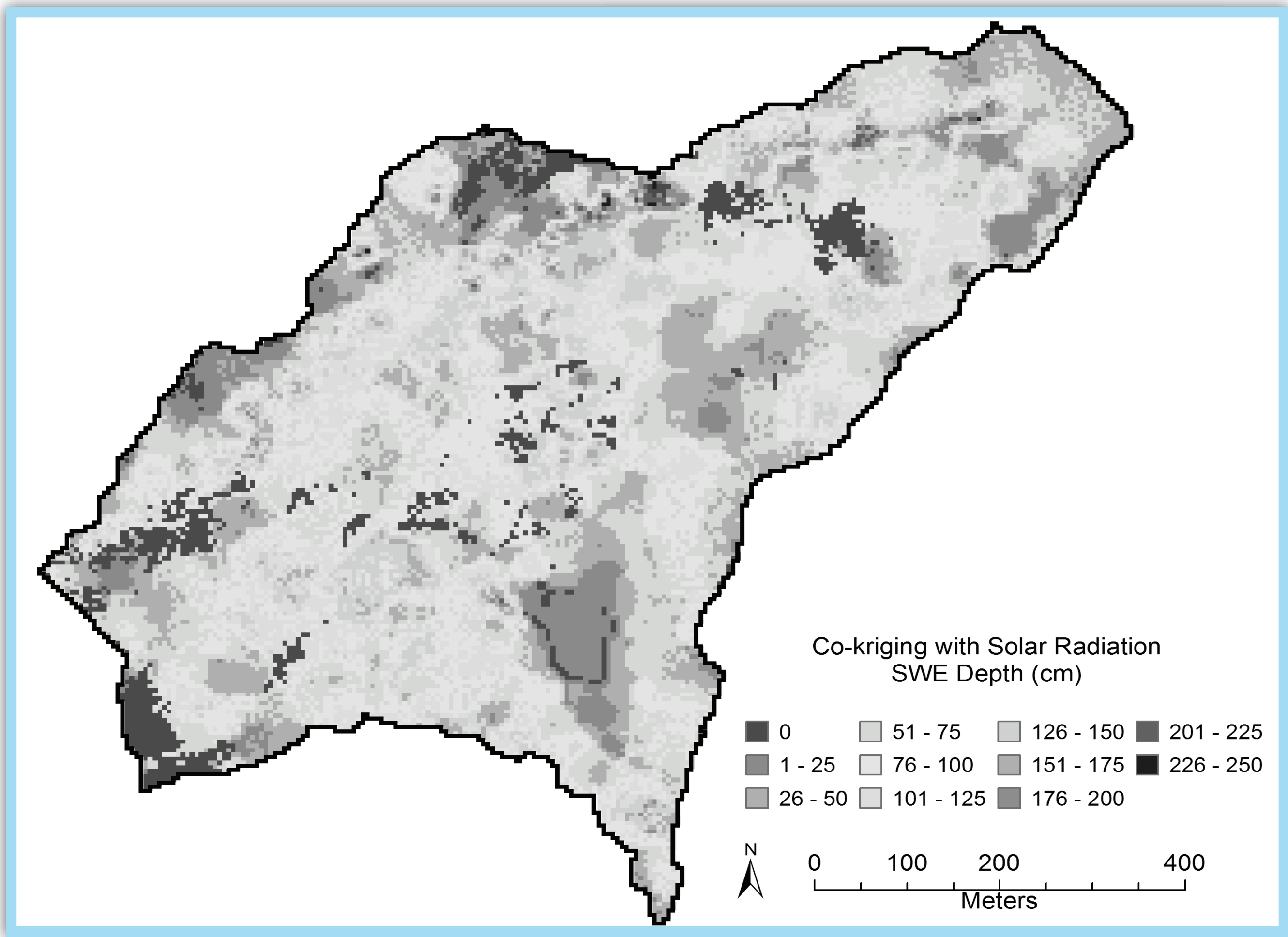


Figure 3. Calculated SWE distribution for West Glacier Lake watershed.

Snowpack sublimation was calculated from mass transfer equations and yielded 251 mm of water lost from the snowpack. The difference between the inputs and outputs yielded an evapotranspiration estimate of 230 mm.

Conclusion

The nine spatial models explained 18% to 94% of the observed snow depth variance, but SWE estimates were within +/- 2% of the best snow depth model. Co-kriging with solar radiation yielded the most accurate estimates of snow depth. The intensive snow survey was able to capture the large-scale and small-scale snow depth variability. The estimated SWE inputs were 67% greater than precipitation gauge estimates, and snowmelt accounted for 85% of the annual streamflow. Summer precipitation was less than snowpack sublimation. These results suggest that snow survey and spatial interpolation methods provide a more accurate representation of precipitation inputs into West Glacier Lake watershed than precipitation gauge estimates. West Glacier Lake water balance was closed without consideration of snowmelt contributions from the permanent snowfield.

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Evaluation of Engineered Treatment Units for the Removal of Endocrine Disrupting Compounds and Other Organic Wastewater Contaminants During Onsite Wastewater Treatment

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Introduction

There has been increased interest and concern in past decades about the occurrence, fate, and adverse effects on ecosystems and human health of trace levels of organic wastewater contaminants (OWCs) in the environment. OWCs include natural and synthetic organic chemicals that are used in industry, agriculture, medicine, and everyday consumer products. Research has shown that the occurrence and incomplete removal of various compounds through municipal wastewater treatment plants can result in discharges of OWCs to the receiving environment (Barber et al. 2000, Glassmeyer et al. 2005). Throughout Colorado, pharmaceuticals, antibiotics, and other OWCs have been identified at low concentrations in streams such as the South Platte River and in ground water (Sprague and Battaglin 2004, Kolpin et al. 2002, Barnes et al. 2002). Adverse effects, some associated with the endocrine system, have been documented in ecosystems exposed to OWCs. For example, in Boulder Creek, Colorado, adverse effects are occurring on fish exposed to effluent-impacted stream water, such as higher proportions of female and intersex fish, gonadal morphology abnormalities, and compromised reproductive potential (Vajda et al. 2006).

In addition to larger municipal wastewater treatment plants, a substantial portion of wastewater throughout the world is treated onsite rather than at a centralized facility. In Colorado there are over 600,000 onsite systems in operation, serving about 25% of the state's population, and 7,000 to 10,000 new systems installed every year. This amounts to over 100 billion liters of wastewater that is treated onsite and discharged to the environment each year. The receiving environments to which these onsite systems discharge often provide the water source for the local community, therefore

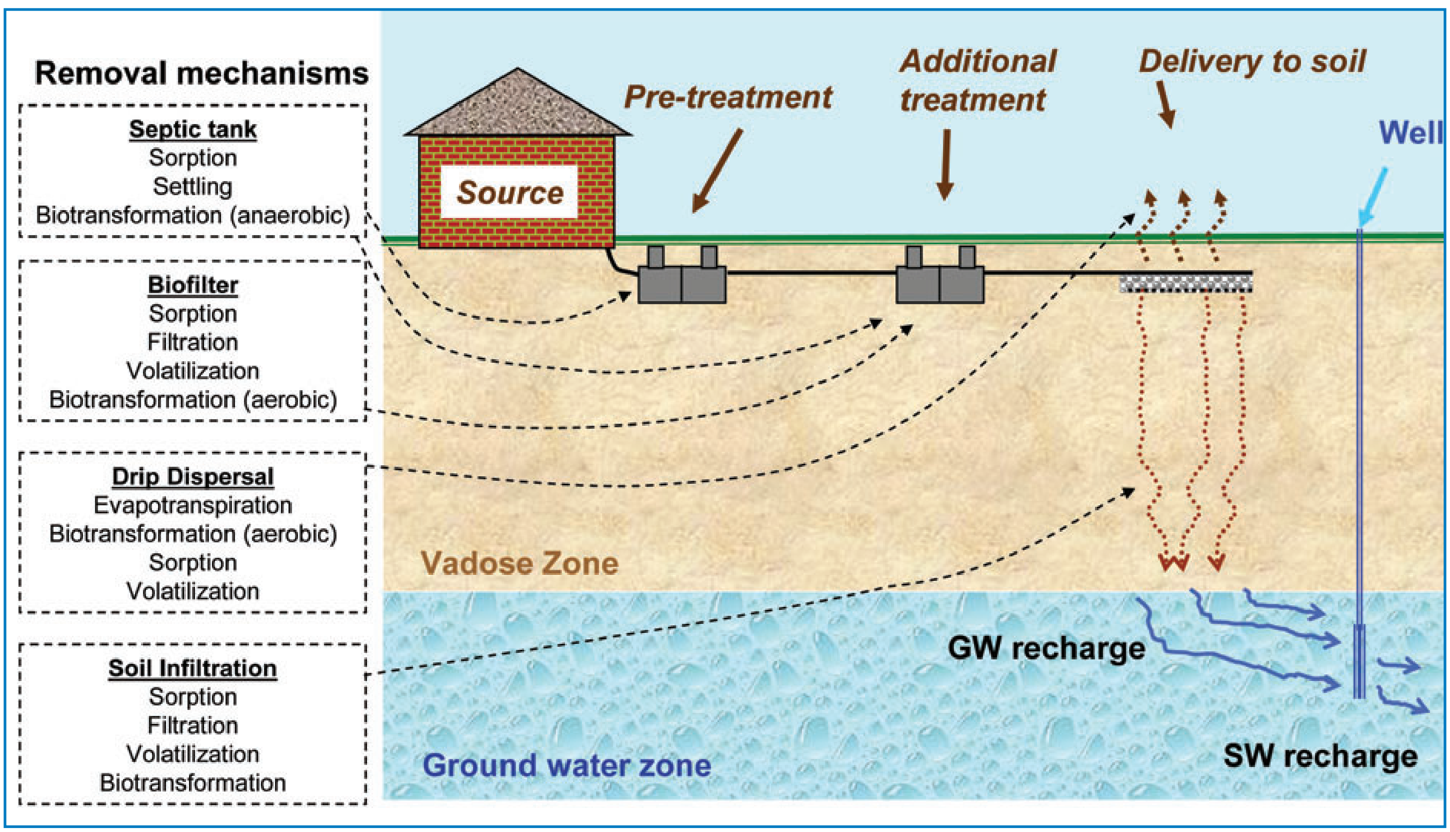


Figure 1. Key components of an onsite wastewater treatment system and relevant removal mechanisms. Above-ground treatment may be through conventional septic tank(s) or additional treatment units such as biofilters. Delivery to the soil may be through conventional soil infiltration or by an alternative treatment such as drip irrigation.

effective removal of contaminants during onsite treatment is important in minimizing risk to ecosystem and human health.

While much is known regarding treatment of bulk parameters such as biochemical oxygen demand, suspended solids, nutrients, and pathogens in these systems (Siegrist et al. 2001, 2005; Van Cuyk et al. 2005, Van Cuyk and Siegrist 2007), the occurrence and fate of OWCs during onsite treatment is less understood. A program of research activities was initiated in 2002 by the Colorado School of Mines (CSM) in collaboration with the U.S. Geological Survey (USGS) to:

1. Determine the occurrence of OWCs in wastewaters produced from varying sources and by different types of onsite wastewater treatment units
2. Assess the treatment of OWCs in engineered treatment units such as septic tanks and packed bed biofilters
3. Assess the fate and transport of OWCs in soil treatment units prior to groundwater and surface water recharge
4. Assess the potential for OWCs to impact receiving waters

Understanding of the occurrence and mechanisms affecting the fate of OWCs in onsite systems and their receiving environments is critical for determining potential adverse affects on humans and ecosystems, and for determining long-term trends of OWC levels in Colorado's water environment (Figure 1).

In March 2007, a research project entitled, "Evaluation of Engineered Treatment Units for the Removal of Endocrine Disrupting Compounds and Other Organic Wastewater Contaminants During Onsite Wastewater Treatment", was initiated at CSM with funding provided by the State of Colorado through the Colorado Water Resources Research Institute (CWRRI). This document has been prepared to highlight the research activities and accomplishments related to this ongoing research project.

CSM Research in Support of the Current Project

Between 2002 and 2005, the CSM/USGS research team sampled septic tank wastewater from 30 Colorado onsite wastewater treatment systems serving different homes, businesses, and institutions. Ten ground water wells and nine surface water sites near the onsite systems were also sampled.

Conn sampling septic tank effluent at the Mines Park test site during a multi-component tracer test

All locations were analyzed for a suite of bulk wastewater parameters using standard methods and 24 OWCs using solvent extraction and derivatization methods. 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 μg/L. Differences in wastewater compositions regarding OWCs may be due to differences in water- and chemical-using activities at the source. For example, a higher proportion of wastewater may originate from cleaning and disinfecting practices in medical facilities as compared to a diluted mixture of wastewaters from a residential source.

Wastewater samples were also collected before and after engineered treatment units (e.g. septic tank, textile biofilter, constructed wetland) to identify potential removal of OWCs during individual engineered treatment units. Results indicate low to negligible removal of bulk parameters and OWCs during septic tank treatment alone. Apparent removal efficiencies during textile biofilter treatment and constructed wetland treatment varied by compound. Removal efficiencies were high for compounds that have been shown to be removed by transformation processes employed in onsite system treatment units, such as anaerobic and aerobic biotransformation, sorption, and volatilization. Apparent removal efficiencies were low for compounds that are resistant to those removal mechanisms, or are degradation products of biotransformed OWCs. Low apparent removal

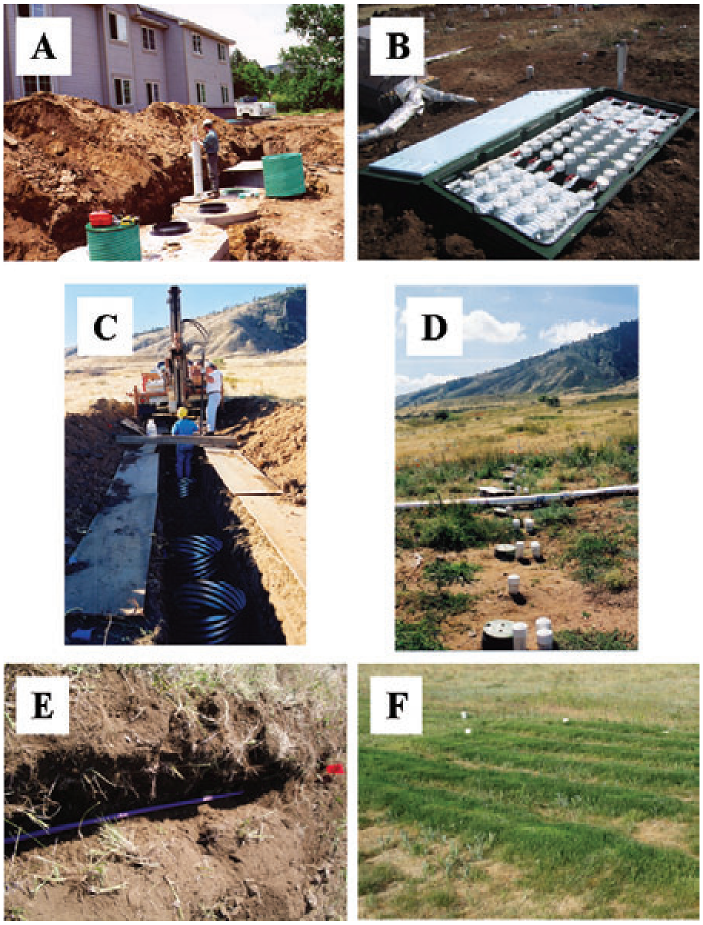


Figure 2 (above) CSM Mines Park Field Site: Wastewater from a multifamily residence is intercepted (A) and managed using pilot-scale unit operations such as a textile biofilter (B), in-ground test cells (C,D), and a drip dispersal network (E,F).

efficiencies and/or high hydraulic loading rates may result in environmentally-relevant loading of some OWCs to the soil treatment unit for further treatment. Complete results of the reconnaissance survey regarding occurrence and fate of bulk parameters and OWCs in onsite wastewater treatment systems have been previously published (Conn et al. 2006, Conn et al. 2007).

Controlled Experimentation into OWC Fate during Onsite Treatment

Research Approach

To further investigate the fate of OWCs during onsite wastewater treatment, a series of experiments are being conducted at the Mines Park Test Site on CSM's campus (Figure 2, http://www.mines.edu/research/smallq/). At the site, wastewater from a multi-unit apartment complex is intercepted and treated onsite by engineered treatment units (e.g. septic tank, textile biofilter) and soil treatment units (e.g. soil infiltration test cells, drip irrigation system) outfitted with monitoring and sampling devices. Forty seven unique locations (Figure 3) along the treatment train including septic tank wastewater, textile biofilter effluent, soil solution at 60, 120, and 240 cm below the infiltrative surface of soil test cells, and ground water monitoring wells were sampled two to fifteen times over one year from November 2006 to November 2007.

Prior to sampling, laboratory experiments were performed to assess the limitations, if any, of measuring OWCs by sample collection methods through stainless steel suction

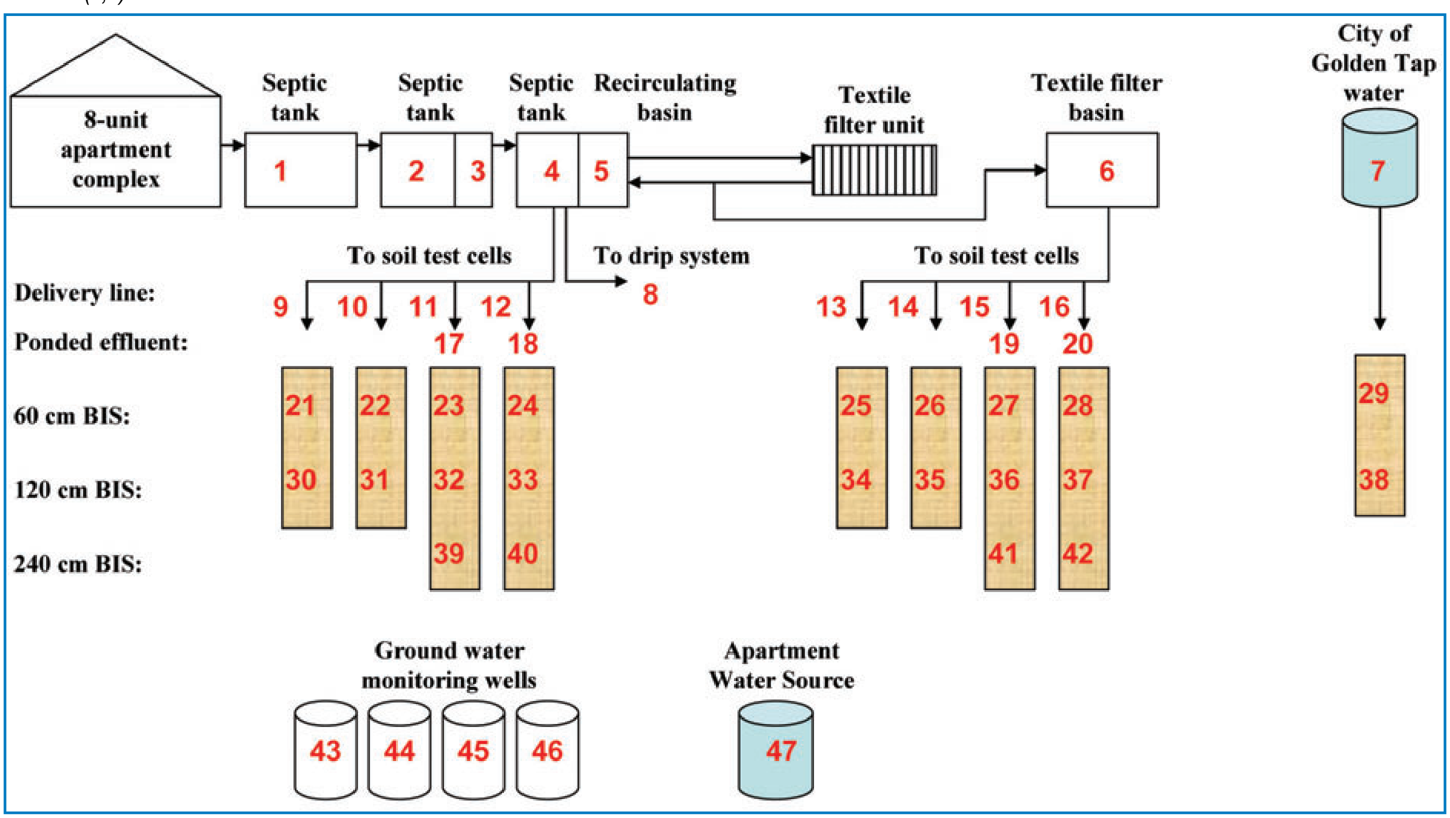
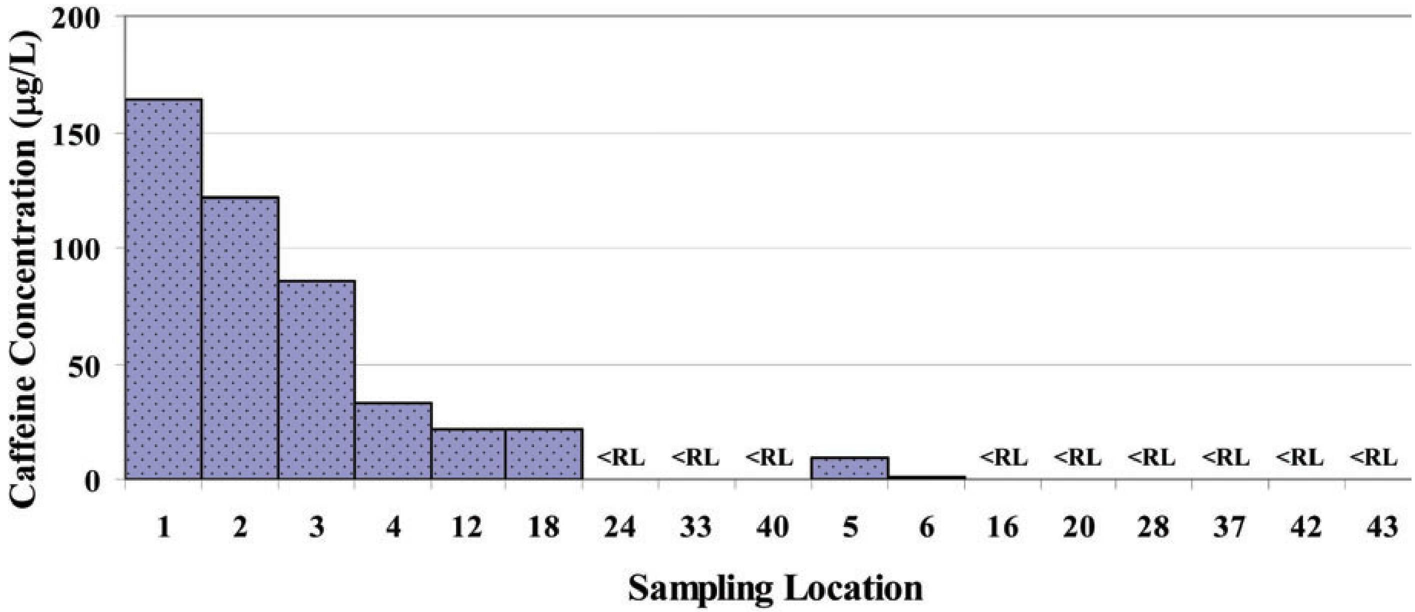


Figure 3. Schematic of the Mines Park Test Site aqueous sampling locations to assess fate of OWCs during onsite wastewater treatment. [BIS = below infiltrative surface]

Figure 4. Concentrations of caffeine in wastewater or treated effluent at various locations in the Mines Park Test Site treatment train. [Sampling location numbers correspond to numbers in Figure 3. <RL = less than the reporting level, 0.2 μg/L.]



lysimeters such as those installed in the soil test cells at the Mines Park Test Site. Analytical methods were modified to quantify a subset of target compounds amenable for analysis through the sampling apparatus, which include caffeine, triclosan, EDTA, NTA, 4-nonylphenol, 4-nonylphenolmonoethoxylate (NP1EO), and 4-nonylphenolmonoethoxycarboxylate (NP1EC). Samples were analyzed for the target OWCs by two methods: a solid-phase extraction and an acetyl-propanol derivatization prior to analysis by gas chromatography/mass spectrometry. A subset of samples were additionally analyzed for bulk wastewater parameters including pH, alkalinity, solids, total and dissolved organic carbon, biochemical and chemical oxygen demand, nitrogen and phosphorus, and fecal coliform. A limited number of samples were analyzed for antibiotics including sulfonamides and tetracyclines by the USGS Organic Geochemistry Research Group in Lawrence, Kansas.

Results from the sampling and analysis aid in assessing:

1. Treatment of OWCs during engineered treatment units (e.g. septic tank, textile biofilter)
2. Treatment of OWCs during soil infiltration as affected by hydraulic loading rate and effluent type
3. Overall onsite wastewater treatment system performance regarding OWCs

Preliminary Results

Treatment Efficiency of Engineered Treatment Units. Preliminary results suggest that septic tanks can provide important primary treatment of some OWCs, likely through mechanisms such as sorption to solids and anaerobic biotransformation. Removal from wastewater of select OWCs including caffeine (Figure 4) was measured during treatment of the Mines Park apartment wastewater through two septic tanks in series (i.e. between sampling locations 1 and 3 in Figure 3). Additional removal of OWCs was achieved during further treatment of septic tank effluent (Location 4, Figure 3) by recirculation through a textile biofilter. Concentrations of caffeine (Figure 4) were reduced to near the reporting level in textile biofilter effluent (Location 6, Figure 3), likely due to aerobic biotransformation. These preliminary results suggest that both types of engineered treatment units studied here- septic tank and textile biofilter- can reduce concentrations of amenable OWCs from onsite wastewater likely through removal mechanisms such as sorption and biotransformation.

Treatment Efficiency Achieved During Soil Infiltration. Removal of bulk wastewater parameters and OWCs during soil treatment was investigated by varying the applied effluent type (septic tank effluent and textile biofilter effluent) and hydraulic loading rate (2 to 8 cm/d) to 8 soil test cells at the Mines Park Test Site. The test cells are located in a sandy loam soil and have been receiving effluent for over three years. The absence of ammonium and presence of nitrate in the soil solution suggests that nitrification is occurring in the vadose zone (Figure 5). Regardless of the hydraulic loading rate, concentration, or form of nitrogen species in the applied effluent (i.e. higher concentrations in the form of ammonium in septic tank effluent vs. lower concentrations mostly in the form of nitrate in textile biofilter effluent), average concentrations of nitrate are greater than 10 mg-N/L in soil solution through 240 cm below the infiltrative surface. After three years of effluent application, concentrations of DOC are less than 10 mg/L in soil solution at all depths regardless of effluent type and hydraulic loading rate, suggesting that organic carbon is being utilized in the subsurface. Similarly, concentrations of total phosphorus are less than 0.3 mg phosphate as P/L in soil solution, suggesting that sorption processes are occurring.

Initial results from the analysis of OWCs suggest that the fate of OWCs during onsite system soil treatment varies by compound. Compounds such as caffeine (Figure 4) that are amenable to processes likely occurring in the vadose zone, such as sorption and biotransformation, were not measured in soil solution at any depth regardless of effluent type and hydraulic loading rate. Other OWCs, such as EDTA and NP1EC, persisted in soil solution to greater depths below the infiltrative surface.

Onsite System Performance. High removal efficiencies of select OWCs during onsite system treatment can be expected. For some compounds, much of the treatment may occur prior to soil application through treatment within engineered units. For example, greater than half of the caffeine concentration measured in influent septic tank wastewater was removed from the Mines Park wastewater during treatment through three septic tanks in series (Figure 4). When septic tank effluent was additionally treated by an aerobic textile biofilter, greater than 99% of the caffeine in the wastewater was removed. Caffeine was never detected in soil solution at 60, 120, or 240 cm below the infiltrative surface of test cells receiving septic tank effluent or textile biofilter effluent. In contrast to caffeine, other OWCs may be partially or negligibly removed during engineered unit treatment and may rely on additional soil treatment for effective removal prior to groundwater recharge.

The water table varies from approximately 3 to 8 m below ground surface near the Mines Park Test Site. Bulk parameter analysis of ground water from four monitoring wells located in and around the test site did not indicate anthropogenic impacts to the ground water with the exception of elevated concentrations of nitrate in one well. Concentrations of OWCs in ground water were near or below the reporting level. These preliminary results suggest that the onsite wastewater treatment system at the Mines Park Test Site has been effectively treating select OWCs found in residential wastewater during septic tank, textile biofilter, and soil infiltration treatment units prior to groundwater recharge.

Preliminary Conclusions and Implications

The occurrence of endocrine disruptors such as surfactant metabolites in wastewater raises concerns about their adverse impacts on the environment following recharge of groundwater and potential recharge of surface waters. The U.S. Environmental Protection Agency has established a toxicity-based water quality criteria for the surfactant metabolite 4-nonylphenol with the 4-day average concentration in freshwater systems not to exceed 6.6 μg/L. The treatment efficiency of 4-nonylphenol and other OWCs may be reduced in onsite systems whose hydraulic loading rates exceed the design loading rate, in onsite systems with marginal soil types, and in onsite systems with a reduced depth to ground water. Additional studies are needed to further assess these and other factors affecting the fate of OWCs in onsite systems. The information from this research will aid in assessing 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. The final report from the ongoing research described herein will be available during 2008.

Acknowledgments

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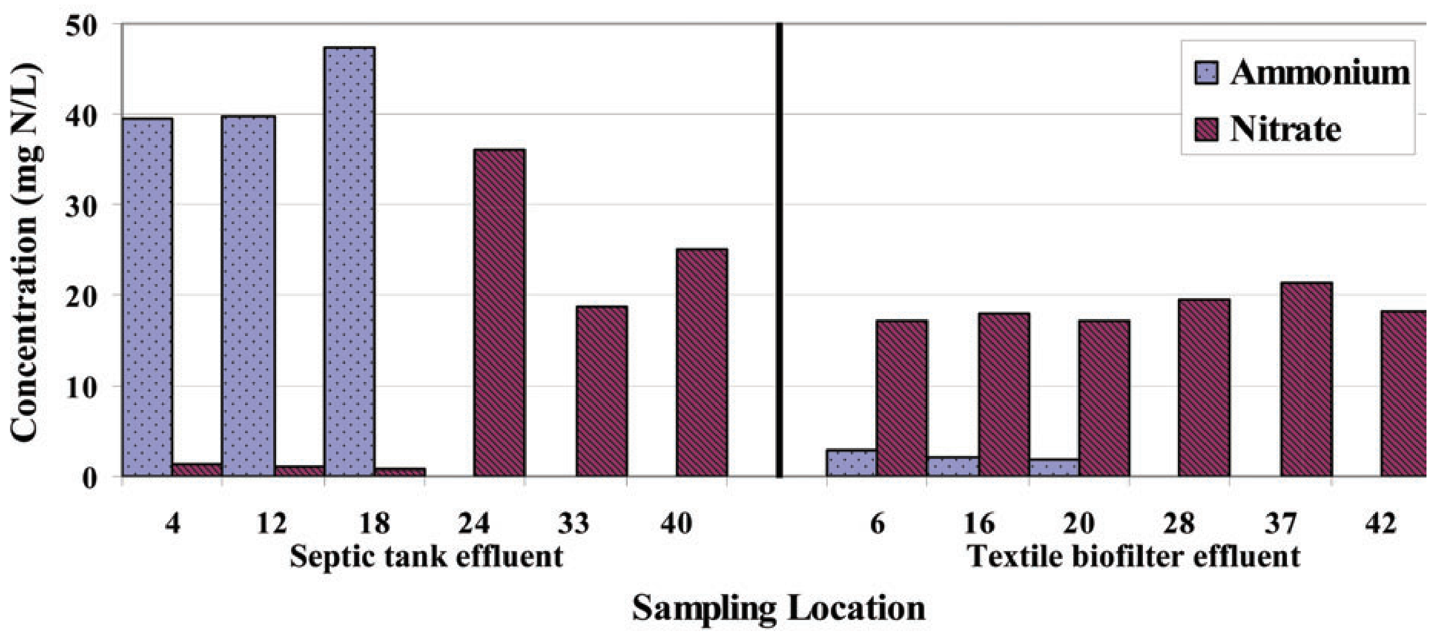
Figure 5. Concentrations of nitrogen species in wastewater and soil solution at the Mines Park Test Site. [Sampling location numbers correspond to numbers in Figure 3. Left side- treatment train using septic tank effluent. Right side- treatment train using textile biofilter effluent.]



Long Range Forecasting of Colorado Streamflows

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Introduction

A key ingredient of water resources management is to make available sufficient amount of water at the time is needed. It is a critical aspect of conservation, development, and management of water resources systems in many regions of the United States, particularly in Colorado because of its semiarid climate. However, water availability may be severely impacted because of extreme hydrologic and climatic events such as droughts. Understanding the variability of such phenomena, and particularly determining their predictability are the main focus of our ongoing research project. This article summarizes the progress made up today.

Water problem

The Colorado River is one of the most important rivers in United States. The water supply provided by the Colorado is critical for a wide range of water users in seven western states. However, the Colorado water resources are under great stress due to the increasing population growth, climate variability, and climate change. There is growing evidence of the effect of large-scale atmospheric-oceanic features on the hydrology of the Colorado basin. Quantifying such effects in the headwaters of the Colorado is difficult because of the varied orography in the Rocky Mountains and because the headwater' rivers lie outside the regions most strongly influenced by large scale climatic forcing such as ENSO. Understanding the variability of the river flows is important to water planners and managers of the system for a number of reasons such as for developing streamflow scenarios that may occur (in the river) in the future and developing efficient procedures for streamflow forecasting.

The Colorado River, being located across semiarid and arid lands, is prone to frequent and often long periods of low flows. The Colorado, being an important source of water supply for may users, has been developed and controlled with many river diversions and dams along the system. Operating such system requires reliable streamflow forecasts. Every year key management decisions for operating the system are made early in the year in anticipation of the forthcoming spring and summer streamflows. Thus long range streamflow forecasting in the Upper Colorado and particularly in the Colorado headwaters are crucial.

Scope and Objectives of the Project

Climatic fluctuations have profound effects on water resources variability and availability in the western United States. The effects are manifested in several ways and scales particularly in the occurrence, frequency, and magnitude of extreme events such as floods and droughts. The scope of the project centers on streamflow variability and predictability at the medium range and long range scales in the headwaters of the Colorado River that originates in the State of Colorado. Specifically we would like to improve the capability of forecasting seasonal and yearly flows. The analysis will include the seasonal and yearly streamflows in the Yampa, Gunnison, and San Juan rivers. For comparison three rivers that drain to the Gulf of Mexico are included, namely Poudre, Arkansas, and Rio Grande. The analysis will be based on seasonal (April-July) and yearly (October-September) streamflows and large-scale atmospheric-oceanic forcing factors such as sea surface temperature (SST), major oscillations indices such as ENSO, PDO, and others, geopotential height, and meridional wind.

Table 1. Basic Description of the River Basins and Stream Gauging Stations Utilized in the Study

River Basin and Site	USGS ID	Coordinates		Elevation (ft)	Drainage Area (mi^2)	April-July mean flow (acre-ft)
		Latitude	Longitude			
Arkansas River at Canon City, CO	07096000	38°26'02"	105°15'24"	5,342	3,117	198,262
Cache la Poudre River at Mouth of the Canyon, CO	06752000	40°39'52"	105°13'26"	5,220	1,056	230,998
Gunnison River above Blue Mesa Dam, CO	09124700	38°27'08"	107°20'51"	7,149	3,453	747,519
Rio Grande at San Marcial, NM	08358500	33°40'50"	106°59'30"	4,455	27,700	391,969
San Juan River near Archuleta, NM	09355500	36°48'05"	107°41'51"	5,653	3,260	747,519
Yampa River near Maybell, CO	09251000	40°30'10"	108°01'58"	5,900	3,410	995,245

Table 2. Some potential predictors for the various study basins

River	Predictor	Time Period	Location	General Description	Correlation Coefficient
Poudre	Snow Water Equivalent (SWE)	Apr 1st		Basin average	0.65
	700 mb Meridional Wind (MW)	Prev. Oct-Dec	32°N-46°N 75°W-95°W	Eastern Canada and eastern U.S.	0.51
	700 mb Geopotential Height (GH)	Jan-Mar	35°N-45°N 120°W-180°W	Over north pacific	-0.45
Arkansas	Snow Water Equivalent (SWE)	Apr 1st		Basin average	0.60
	700 mb Meridional Wind (MW)	Prev. Oct-Dec	35°N-45°N 55°W-60°W	Eastern Canada and eastern U.S.	0.53
	700 mb Geopotential Height (GH)	Prev. Oct-Dec	42°N-50°N 70°W-80°W	Eastern Canada and U.S.	0.47
Gunnison	Snow Water Equivalent (SWE)	Apr 1st		Basin average	0.85
	Palmer Index (PDSI)	Jan-Mar		Climate Division	0.70
	Seesaw SST	Prev. Oct-Dec		SST3-SST4	0.53
Rio Grande	Snow Water Equivalent (SWE)	Apr 1st		Basin average	0.67
	700 mb Zonal Wind (ZW)	Prev. Oct-Dec	25°N-30°N 110°W-120°W	South of U.S.	0.65
	Relative Humidity (RH)	Jan-Mar	30°N-35°N 105°W-118°W	Southwestern U.S.	0.62
San Juan	Snow Water Equivalent (SWE)	Apr 1st		Basin average	0.85
	Palmer Index (PDSI)	Jan-Mar		Climate Division	0.64
	700 mb Geopotential Height (GH)	Jan-Mar	30°N-35°N 115°W-125°W	West coast of U.S.	-0.59
Yampa	Palmer Index (PDSI)	Jan-Mar		Climate Division	0.66
	Snow Water Equivalent (SWE)	Mar 1st		Basin average	0.57
	700 mb Zonal Wind (ZW)	Prev. Oct-Dec	30°N-35°N 105°W-120°W	Southern U.S.	0.56

Approach

Existing medium range and long range forecasting models of streamflow in the Colorado River basin commonly rely on previous records of snow water equivalent, precipitation, and streamflows as predictors. And the typical model has been the well known multiple linear regression. Recent literature have demonstrated the significant relationships between climatic signals and oscillations such as SST, ENSO, PDO, and others on precipitation and streamflow variations (e.g. Cayan and Webb, 1992; Mantua et al, 1997; Clark et al, 2001) and that seasonal and longer-term streamflow forecasts can be improved by using such climatic factors (e.g. Hamlet and Lettenmaier, 1999; Clark et al, 2001; Eldaw et al, 2003; Grantz et al, 2005; Salas et al, 2005). Thus the literature suggests that it is worthwhile examining in closer detail forecasting schemes that incorporate not only the usual predictors (e.g. snow water equivalent, precipitation, and streamflows,) but also climatic factors that may improve the seasonal forecasts of streamflows in the headwaters of the Colorado River.

Furthermore, recent studies suggest that despite the influence of major climatic factors such as ENSO on the hydrology of the Colorado basin, there are significant differences in their effects from basin to basin (McCabe and Dettinger, 2002). This is why we have taken in addition to three major streams in the Colorado headwaters, i.e. Yampa, Gunnison, and San Juan, three other rivers, i.e. Poudre, Arkansas, and Rio Grande so that we can compare their predictability across space.

The approach followed in the study may be summarized as:

- Search for potential predictors
- Reduce the pool of potential predictors by using statistical analysis
- Apply Principal Component Analysis (PCA) and multiple linear regression (MLR) technique for forecasting at individual sites
- Apply Canonical Correlation Analysis (CCA) for forecasting at multiple sites
- Test the forecasting models (fitting and validation)

Table 3. PCs used for the single site forecast models for each river basin

Poudre		Arkansas		Gunnison		Rio Grande		San Juan		Yampa	
PCs	**% var**	**PCs**	**% var**	**PCs**	**% var**	**PCs**	**% var**	**PCs**	**% var**	**PCs**	**% var**
PC1	27.9	PC1	36.7	PC1	29.5	PC1	30.8	PC1	33.2	PC1	29.3
PC2	13.7	PC3	10.7	PC2	9.7	PC2	13.1	PC2	13.6	PC2	12.0
PC4	6.5	PC4	8.2	PC3	7.9	PC3	9.6	PC3	3.8	PC3	10.0
PC10	3.1	PC10	2.4	PC4	7.1	PC6	4.1	PC7	3.2	PC12	1.7
PC12	2.1	PC12	1.2	PC6	5.4	PC9	2.5	PC8	3.0	PC17	0.9
PC27	0.3	PC19	0.2	PC12	2.3	PC11	2.0	PC19	0.7	PC30	0.1
		PC21	0.1	PC20	0.7	PC25	0.4	PC20	0.6		
				PC23	0.5	PC39	0.05	PC22	0.5		
				PC32	0.1			PC24	0.4		
								PC27	0.2		
Total var	**53.7**		**59.6**		**63.3**		**62.5**		**59.0**		**54.1**

In addition to the typical indices such as ENSO as mentioned before, we considered predictors directly identified from sea surface temperature, and other atmospheric circulation features such as geopotential heights (e.g. 700 mb) and zonal meridional winds. Pertinent data have been obtained from http://www.cdc.noaa.gov , NOAA's Climate Diagnostic Center website. Examples of predictors include:

- Snow water equivalent
- Meridional wind (700 mb)
- Geopotential height (700 mb)
- Relative humidity
- Sea surface temperature (SST)
- Air temperature
- Outgoing long wave radiation
- Northern oscillation index
- Pacific decadal oscillation (PDO)
- Southern oscillation index (SOI)
- Palmer drought severity index
- Accumulated flows of the previous months

We used correlation analysis between the predictand (e.g. April-July streamflows for a given site) and the predictor (e.g. average January-March SST for a given area in the Pacific Ocean), tested whether the cross-correlation coefficient was statistically significant, and eliminated the variables associated with not significant correlations.

We applied PCA for the analysis of individual sites (e.g. Yampa). In this method the original variables (predictors) are transformed into a new set of variables that are orthogonal (i.e. no relationship among them). Such new variables are called Principal Components (PCs). Generally only a fraction of the PCs are necessary to account for most of the variability of the data set. And the number of PCs to consider for further analysis can be found by statistical analysis. Then the forecast equation is simply the multiple linear regression model between the predictand (e.g. accumulated streamflows for April-July) and the selected PCs.

We also applied CCA for flow prediction at multiple sites, i.e. a joint prediction for all 6 sites as referred to above. In this approach two sets of variables are considered, the first set consists of the potential predictors and the other set includes the 6 predictands (flows at the referred 6 sites). Each set is transformed linearly, the correlations

Table 4. Model performance for forecasts based on single-site models (PCA)

Method	Statistic	Poudre	Arkansas	Gunnison	Rio Grande	San Juan	Yampa
Fitting	R^2	0.69	0.77	0.87	0.88	0.88	0.86
	adj. R^2	0.65	0.73	0.84	0.86	0.84	0.84
Validation Drop 10%	R^2	0.55	0.68	0.78	0.83	0.82	0.81
	adj. R^2	0.49	0.64	0.74	0.80	0.77	0.79

Table 5. Model performance for forecasts based on multi-site models (CCA)

Method	Statistic	Poudre	Arkansas	Gunnison	Rio Grande	San Juan	Yampa
Fitting	R^2	0.41	0.61	0.70	0.75	0.61	0.76
	adj. R^2	0.33	0.56	0.66	0.71	0.56	0.72
Validation Drop 10%	R^2	0.24	0.48	0.56	0.67	0.48	0.63
	adj. R^2	0.15	0.41	0.50	0.62	0.41	0.58

Table 6. Forecast skill scores (single-site models

Method	Item	Poudre	Arkansas	Gunnison	Rio Grande	San Juan	Yampa
Fitting	*Accuracy*	0.57	0.64	0.58	0.62	0.72	0.72
	HSS	0.42	0.52	0.45	0.50	0.62	0.62
Drop 10%	*Accuracy*	0.49	0.60	0.49	0.60	0.72	0.72
	HSS	0.32	0.47	0.32	0.47	0.62	0.62

Table 7. Forecast skill scores (multiple-site - CCA using PCs)

Method	Item	Poudre	Arkansas	Gunnison	Rio Grande	San Juan	Yampa
Fitting	*Accuracy*	0.43	0.43	0.66	0.55	0.53	0.66
	HSS	0.24	0.25	0.55	0.40	0.37	0.55
Drop 10%	*Accuracy*	0.38	0.45	0.53	0.53	0.51	0.58
	HSS	0.17	0.27	0.37	0.37	0.35	0.45

(canonical correlations) between them are found, are tested to determine their significance, and a prediction equation is established.

The prediction models have been tested in two modes: (a) fitting and (b) evaluation. In fitting mode, the forecast model parameters are estimated using the entire data set, and the forecast and ensuing errors are obtained using the same data (that were used for parameter estimation). On the other hand, in evaluation mode, 10% of the data are not considered, i.e. they are dropped, for determining the forecast model and the remaining 90% are used for parameter estimation. Thus, there are 10 sets of data and 10 forecast models are fitted, one per each data set. Then the forecast errors are determined using the 10 % of data that were dropped as referred to above. We also carried out the analysis dropping each time only one piece of data (instead of 10 %) but the results were essentially similar to the 10 % analysis. Thus we will report only the results obtained based on dropping the 10 % data as noted above. Regardless, once the errors are calculated the so called R2 and adj R2 (adjusted R2) statistics are determined, which quantify how good the model performs. In addition, some measures of accuracy and forecast skill have been utilized.

Brief Description of the Data

The accumulated streamflows for the period April-July at six basins, namely Yampa, Gunnison, San Juan, Poudre, Arkansas, and Rio Grande have been analyzed. The data for the first four sites are naturalized flows and, except for the Poudre data, they were obtained from the data files of the US Bureau of Reclamation (USBR). The data for Arkansas and Rio Grande are data measured by USGS at sites with minimum effect of upstream diversions and storage. Table 1 summarizes the basic features of the streamflow data.

Many hydroclimatic variables such as those listed in section 4 above have been utilized as potential predictors for forecasting the April-July streamflows of the referred six sites. One of the variables is snow water equivalent, a rather obvious predictor since it gives the information of the snowpack that is available in the basin at a given point in time. However, other variables are less obvious such as SST, meridional and zonal wind, geopotential height, relative humidity, air temperature, outgoing long wave radiation, North Atlantic Oscillation (NAO), Pacific North America Index (PNAI), Pacific Decadal Oscillation (PDO), and Palmer Drought Severity index (PDSI). We include many of these variables because it has been reported (e.g. Eldaw et al., 2003; Regonda et al, 2005) that in many places of the globe they play an important role in long range flow forecasting. Note that the data associated with the referred potential predictors are defined at time periods prior to April-July.

Results

For illustration Table 2 lists three potential predictors that gave the highest correlations with the streamflows for each of the study basins. These predictors were obtained from correlation maps such as those shown in Figs. 1 and 2. Figure 1 shows the correlation map between Apr-Jul flows and the previous year Oct-Dec geopotential height (700 mb) and Fig. 2 shows the correlation map between Apr-Jul flows and the previous year Oct-Dec average SST for the San Juan River. They show areas where the correlations are of the order of 0.5 suggesting that these variables may be useful for forecasting the Apr-Jul flows of the San Juan River. Similar maps have been developed from which an array of potential predictors having significant correlations coefficients was selected.

In the case of forecasting at individual sites two types of models were developed, one using a MLR model where the predictors are in the original data domain and the estimation and selection of predictors are based on the stepwise technique, and the other model using a MLR based on PCs as predictors. The second approach gave better results so we will show some results for this case only. For illustration Table 3 summarizes the PCs selected from the stepwise MLR along with the corresponding explained variance. The variance explained for the Arkansas, Gunnison, Rio Grande, and San Juan rivers are in the order of 60 % while for the Poudre and Yampa are about 54 %. In the case of the joint forecast analysis for all sites we considered all the potential

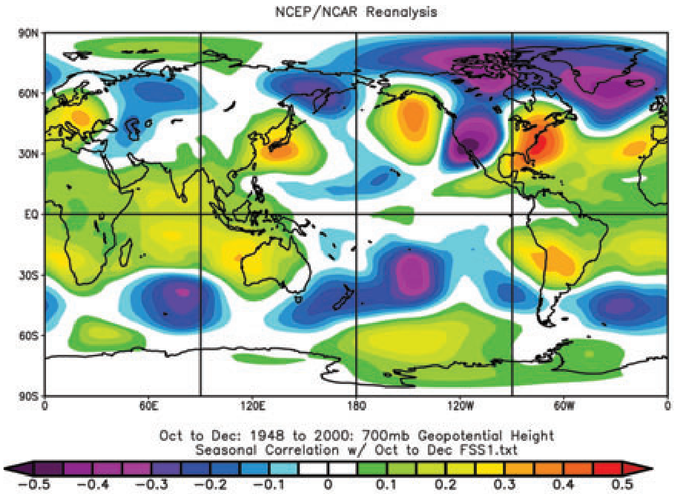

Figure 1. Correlation between the Apr-Jul streamflows of the San Juan River and previous year Oct-Dec mean 700 mb geopotential heights

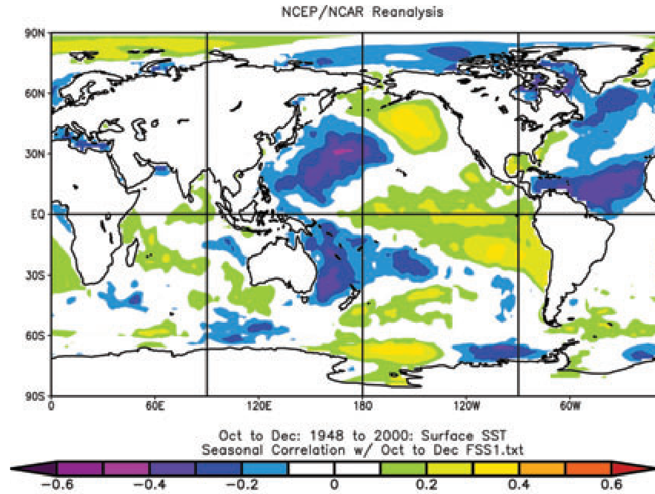

Figure 2. Correlation between the Apr-Jul streamflows of the San Juan River and previous year Oct-Dec mean SST

predictors obtained from the single site analysis, i.e. a total of 262 potential predictors. Then PCA was applied to obtain the corresponding PCs and six PCs were chosen for the CCA.

Tables 4 and 5 show the results of the forecast performances for the single site (based on PCA) and multisite (based on CCA) models, respectively. The tables show values of R2 and adjusted (adj) R2 statistics for fitting and drop 10 % validation. As expected the R2 and adj R2 for validation are smaller than those for fitting. Table 4 results for single site shows that the adj R2 for validation are greater or equal to 74 % for the streams flowing west, i.e. Yampa, Gunnison, and San Juan and south (Rio Grande), while the adj R2 are 49 % and 64 % for Poudre and Arkansas, i.e. for the two streams flowing east. The results for multisite shown in Table 5 indicate similar regional differences as for single site analysis except for the case of the San Juan River. In addition, comparing the performance results for single site

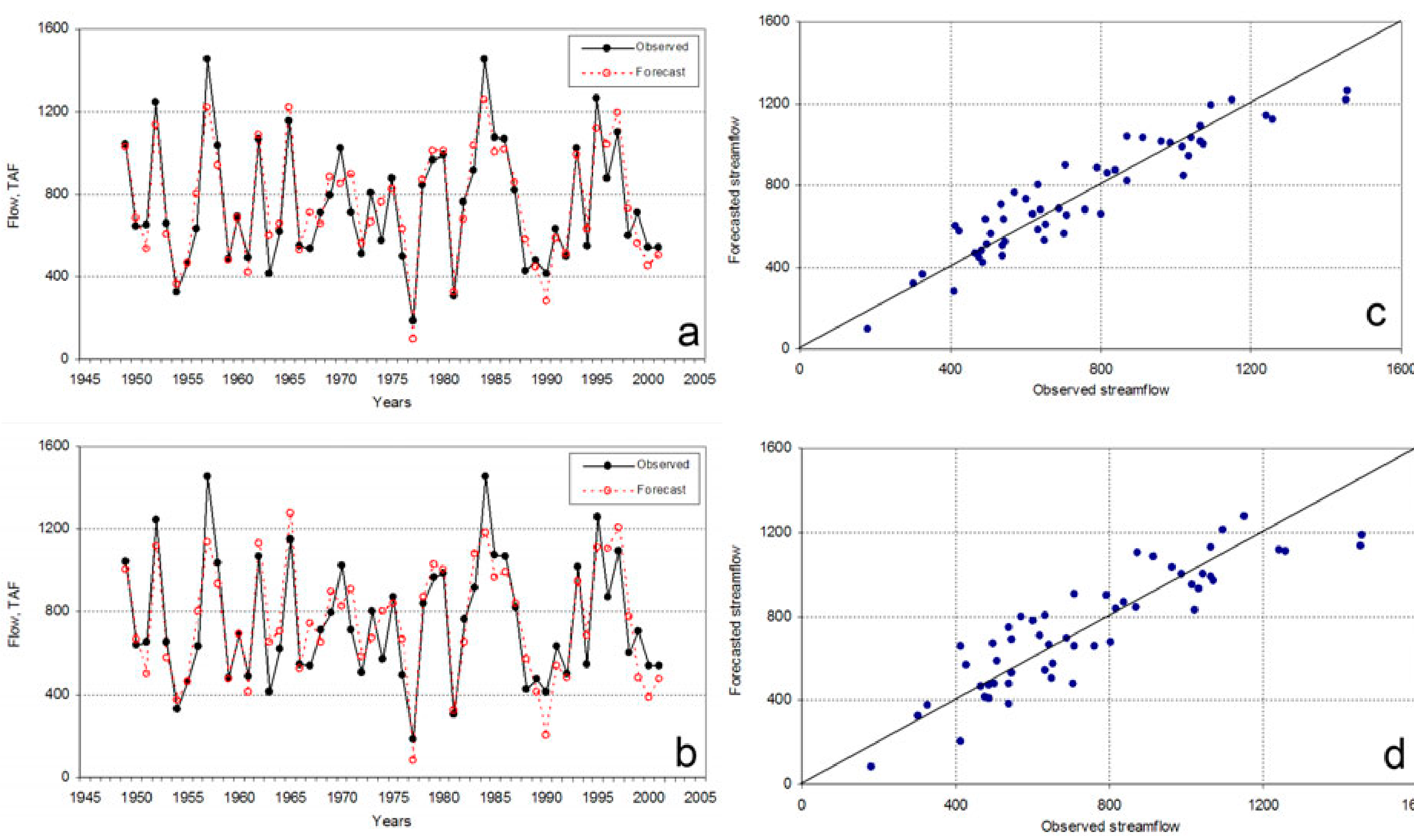

Figure 3. Observed and forecasted flows (based on single site model) for fitting in (a) and (c) and drop 10 % validation in (b) and (d) for the Gunnison River.

Please visit the CWRRI website (http://www.cwrri.colostate.edu) to view this these figures in full color and multisite models it is clear that the performances of the single site forecast models are much better than for the joint multisite models. This result is also expected because the single site analysis will try to accommodate the best predictors for the individual sites, however in the joint analysis, because of the regional differences, those best predictors for a given site may not be necessarily optimal for other sites.

Likewise, Tables 6 and 7 give results of the forecast skill scores obtained from the single site (PCA) and multisite (CCA) models, respectively. Generally the results indicate quite good forecast skills by both models although better results are obtained for the single site models. Again some regional differences in the results are observed especially from those obtained from the multisite models. In addition, Fig. 3 shows a comparison between the observed and forecasted flows based on single site model for the Gunnison River. The figures also indicate the very good forecasts results obtained using the methods described above.

Final Remarks

A major challenge for water planners and managers is finding a reservoir release schedule that can satisfy the demands of the various water users; this requires an efficient forecast of the streamflows in the basin particularly the inflows to the reservoirs. The typical forecasting procedures have been based on multiple linear regression techniques that include past observations of snow water equivalent, precipitation, and streamflows as predictors. However increasing evidence exists of strong connections of large-scale climatic fluctuations on rainfall and streamflow in many parts of the world and in Colorado. In the study reported herein we have shown that significant improvements in long range streamflows forecasting of various rivers in Colorado can be made by using not only snow water equivalent but also a number of oceanic and atmospheric variables as predictors. In the reminder part of the project we will explore further issues related to improving the predictability of the Colorado River flows.

Occurrence and Fate of Steroid Hormones in Sewage Treatment Plant Effluent, Animal Feeding Operation Wastewater and the Cache la Poudre River of Colorado

by Robert B. Young, Ph.D. Student, Dept. Soil and Crop Sciences
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Significance of Steroid Hormones in the Environment

In recent years, scientists have become increasingly concerned about the exposure of humans and wildlife to chemicals in the environment that may disrupt the normal function of their endocrine systems, even at extremely low concentrations. Suspected endocrine-disrupting chemicals (EDCs) include (i) organic chemicals used in detergents, cleaners, plastics, textiles, pharmaceuticals, pesticides, herbicides and other products, (ii) heavy metals such as lead, cadmium and mercury, and (iii) natural compounds such as steroid hormones and phytoestrogens.

The endocrine system controls a number of important biological processes, including the development and differentiation of organs and tissues, sexual reproduction, metabolism, and immune system development. It is the body's chemical messaging and regulation system, and includes hormones, the glands and tissues that produce them, and specialized receptors in organs and tissues that respond to them. Hormones reversibly bind to hormone receptors, and trigger characteristic physical responses. Some EDCs mimic hormones, and trigger physical responses when no hormone is present. Other EDCs reduce hormone effectiveness by competitively binding to hormone receptors, but failing to trigger a physical response. Because extremely small hormone concentrations are sufficient to trigger physical responses, extremely small EDC concentrations may be sufficient to disrupt natural endocrine system functions.

Natural and synthetic steroid hormones, including those administered to humans and livestock as pharmaceuticals, constitute an important class of environmental EDCs. They pose risks to humans and wildlife because of their ability to mix with hormones produced by the body and interfere with natural endocrine functions. Synthetic steroids metabolize and degrade more slowly than natural steroids, and may be more persistent in the environment.

There are three classes of reproductive steroid hormones: androgens, estrogens, and progestogens. Androgens are primarily responsible for stimulating the development of male traits, and estrogens are primarily responsible for stimulating the development of female traits. Among fish, amphibians, reptiles, mammals and birds (vertebrates), the most common natural androgen is testosterone, and the most common natural estrogen is 17-β estradiol. Progesterone, the most common natural progestogen among vertebrates, is involved in the female menstrual cycle, pregnancy and embryogenesis.

Dr. Thomas Borch and Yun Ya Yang sampling water at the Cache la Poudre River.

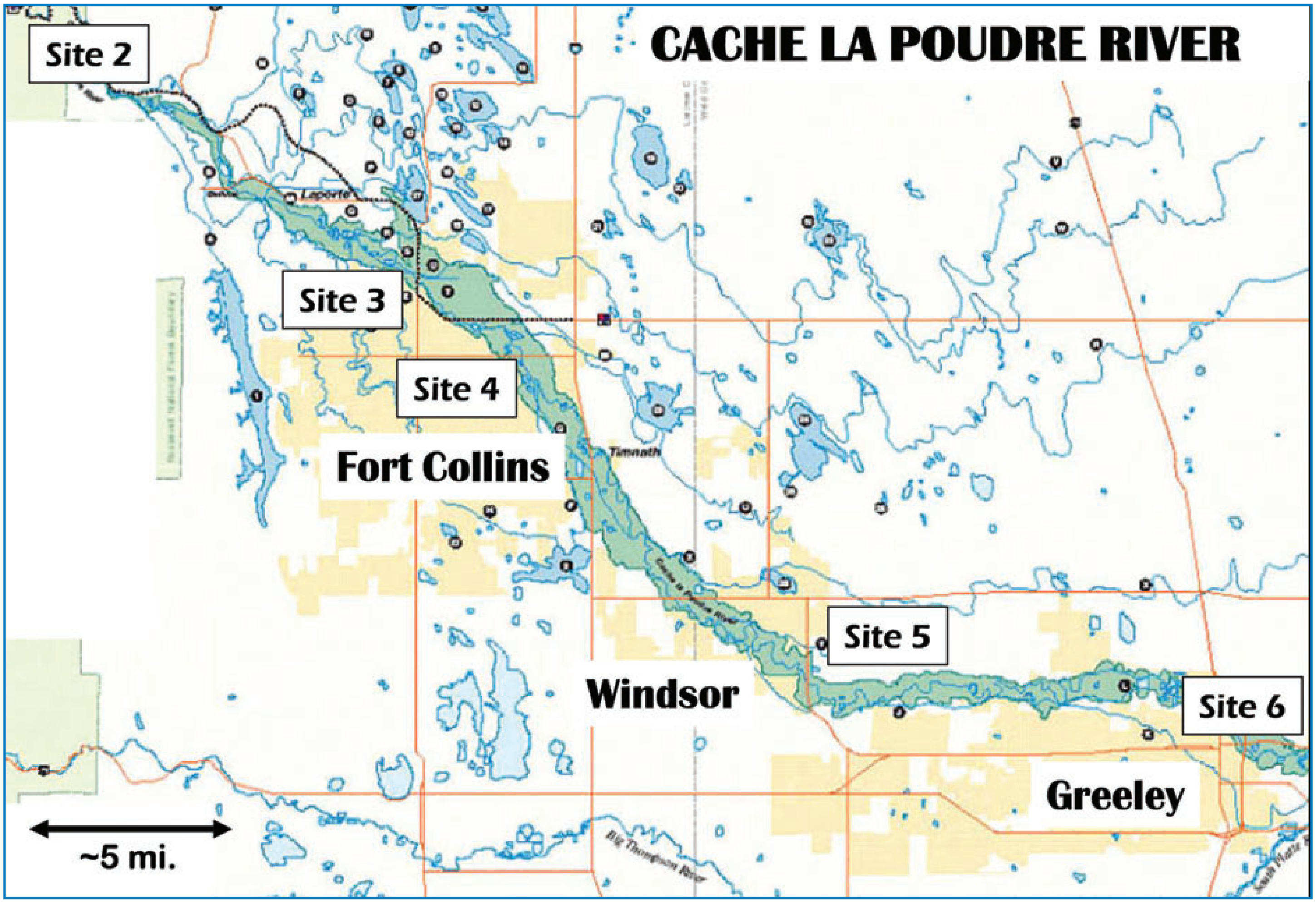


Figure 1. Approximate sampling sites along the Cache la Poudre River.

Different EDCs can have different affinities for the same hormone receptor, and different potencies for the responses they generate. For example, the binding affinity of 17-β estradiol for estrogen receptors isolated from a sheep uterus was approximately 40,000 times greater than testosterone and 400 times greater than bisphenol A, a suspected EDC commonly used to make plastics. Similarly, the binding affinity of testosterone for androgen receptors isolated from rainbow trout brains was approximately 43,000 times greater than 17-β estradiol, and 300 times greater than bisphenol A. As a result, EDCs with lower binding affinities must be present in higher concentrations to occupy the same number of hormone receptors as EDCs with higher binding affinities, and EDCs with lower potencies must occupy more hormone receptors to trigger the same physical response as EDCs with higher potencies. The disruptive effect of EDC mixtures is not well understood, but the presence of multiple EDCs could have a combined disruptive effect, according to the concentrations, binding affinities and potencies of the EDCs present in the mixture.

Androgens, estrogens and progestogens are given to livestock to increase muscle mass and regulate hormone cycles. The most widely used veterinary steroids are testosterone (androgen), trenbolone (synthetic androgen), 17-β estradiol (estrogen), zeranol (synthetic estrogen), progesterone (progestogen), and melengestrol (synthetic progestogen). Melengestrol is commonly administered to cattle with food, and the others are commonly administered as implants.

Steroids are prescribed to people for many purposes, including hormone replacement therapies, anti-inflammatories, asthma treatments, and oral contraceptives. Ethinyl estradiol, a potent synthetic estrogen, is the most commonly used active compound in oral contraceptives for women.

Table 1. Sampling Sites along the Cache la Poudre River.

Site Description	Location
Site 1- Pristine	Below Poudre Falls at Hwy 14 Bridge
Site 2- Minimal Residential	Greyrock Trail
Site 3- Light Agriculture	Shields Street Bridge, Fort Collins
Site 4- Urban; Wastewater Discharge	Below Mulberry Wastewater Treatment Plant
Site 5- Heavy Agriculture	Frank State Wildlife Area Bridge (CR13), Windsor
Site 6- Urban; Heavy Agriculture	Fern Avenue Bridge, Greeley

Steroids can enter surface waters in discharges from septic systems and wastewater treatment plants (WWTPs), runoff from animal feeding operations, and runoff from agricultural fields where manure or biosolids have been applied as fertilizers. Steroids may also enter groundwater through leaching. A 1999 to 2000 national reconnaissance study conducted by the United States Geological Survey (USGS) measured concentrations of 95 organic wastewater contaminants, including steroids, in water samples from 139 streams across 30 states. 17-β estradiol was found in 10% of the streams sampled, and the median concentration was 9 ng/L (parts per trillion). Testosterone and progesterone were found in 2.8 and 4.3% of the streams sampled at median concentrations of 116 and 110 ng/L, respectively. Ethinyl estradiol was found in 15.7% of the streams sampled at a median concentration of 73 ng/L.

Although these concentrations appear extremely low, they are sufficient to have dramatic effects on wildlife exposed to them. In a 7-year, whole-lake experiment in northwestern Ontario, Canada, chronic exposure of fathead minnows to ethinyl estradiol at concentrations ranging from 5 to 6 ng/L (more than ten times smaller than the median concentration detected in the 1999-2000 USGS national reconnaissance study) adversely affected gonadal development in males and egg production in females, and led to a near extinction of fathead minnows from the lake.

To date, little is known about the occurrence, transport and fate of steroid hormones in the environment. For example, very few studies have examined microbial degradation and photodegradation of steroids under environmentally relevant conditions. As a result, little is known about the mechanisms and optimal conditions for degradation under such conditions, or about the identities and risks of the resulting degradation products. As our understanding of environmental steroids improves, wastewater treatment processes and agricultural management practices can be modified to minimize inadvertent increases of steroid hormones in the environment.

Our Research

Our research group includes Dr. Thomas Borch (principal investigator), an assistant professor of environmental and analytical chemistry, Dr. Jessica G. Davis (co-principal investigator), a professor specialized in environmental impacts of animal agriculture, and two graduate students. Robert B. Young (Ph.D. student) joined the research group in the summer of 2007 to study the photodegradation of steroids. Yun Ya Yang (Ph.D. student) joined the research group in the fall of 2007 to study the microbial degradation of steroids.

The major goals of our research are to study the potential occurrence and means of removal of steroid hormones in the Cache la Poudre River. Specifically, we want to investigate the potential for biodegradation, photodegradation and runoff. In addition, we hope that our data will aid in the development of best management practices to enhance the degradation and reduce the mobility of steroids. These data will be available to water managers and the general public through a webpage hosted by Colorado State University, scientific publications, and presentations at scientific conferences.

Presence of Steroid Hormones in the Cache la Poudre River

We are analyzing water samples from the Cache la Poudre River in northern Colorado to determine whether steroids and their major metabolites are present, and in what quantities. The Cache la Poudre River originates near the continental divide and flows through steep mountainous terrain for approximately 43 miles before entering the city of Fort Collins, Colorado. After traveling through Fort Collins, the river flows through mostly agricultural landscape for approximately 45 miles before joining the South Platte River in the city of Greeley, Colorado, a major center of the meat-packing industry. Potential sources of steroids along the Cache la Poudre River include agricultural operations, WWTPs in the cities of Fort Collins and Greeley, and septic tanks in the mountains.

In July 2007, one to two liter samples were collected in the center of the stream from six locations along the Cache la Poudre River. The sampling locations, described in Table 1, range in character from pristine to urban to heavy agricultural environments. Between sites 4 and 6, for example, there are over 90 confined animal feeding operations (CAFOs), dairies and ranches. A map of the sampling locations is set forth in Figure 1.

The collected water samples were filtered through glass fiber filters, and a solid phase extraction (SPE) process was used to concentrate and remove any steroids from the samples. Then, the samples were analyzed with gas chromatography and mass spectrometry (GC/MS) to determine steroid presence and concentrations. The preliminary results of this analysis are set forth in Table 2.

The detection limits varied from site to site, but all were in the low parts-per-trillion (ng/L) range. 17β-estradiol was present at every site except Site 5. Interestingly, estrone, a typical degradation product of 17β-estradiol, was only observed at Sites 5 and 6. This may be due to limited degradation of 17β-estradiol in the Cache la Poudre River, or due to higher concentrations of 17β-estradiol at Sites 4 and 6. Progesterone was not detected in the current study, but also was not detected in 95.7%

Table 2. Detection of steroid hormones and potential degradation products in the Cache la Poudre River. D = detected; BD = below detection limit.

	17β-estradiol	estrone	progesterone	testosterone	androstenedione	cis-androsterone
Site 1	D	BD	BD	*	D	BD
Site 2	D	BD	BD	*	BD	BD
Site 3	D	BD	BD	*	BD	BD
Site 4	D	BD	BD	*	D	D
Site 5	BD	D	BD	*	BD	BD
Site 6	D	D	*	*	D	BD

** Unknown due to sampling, sample preparation, or analysis related problems*

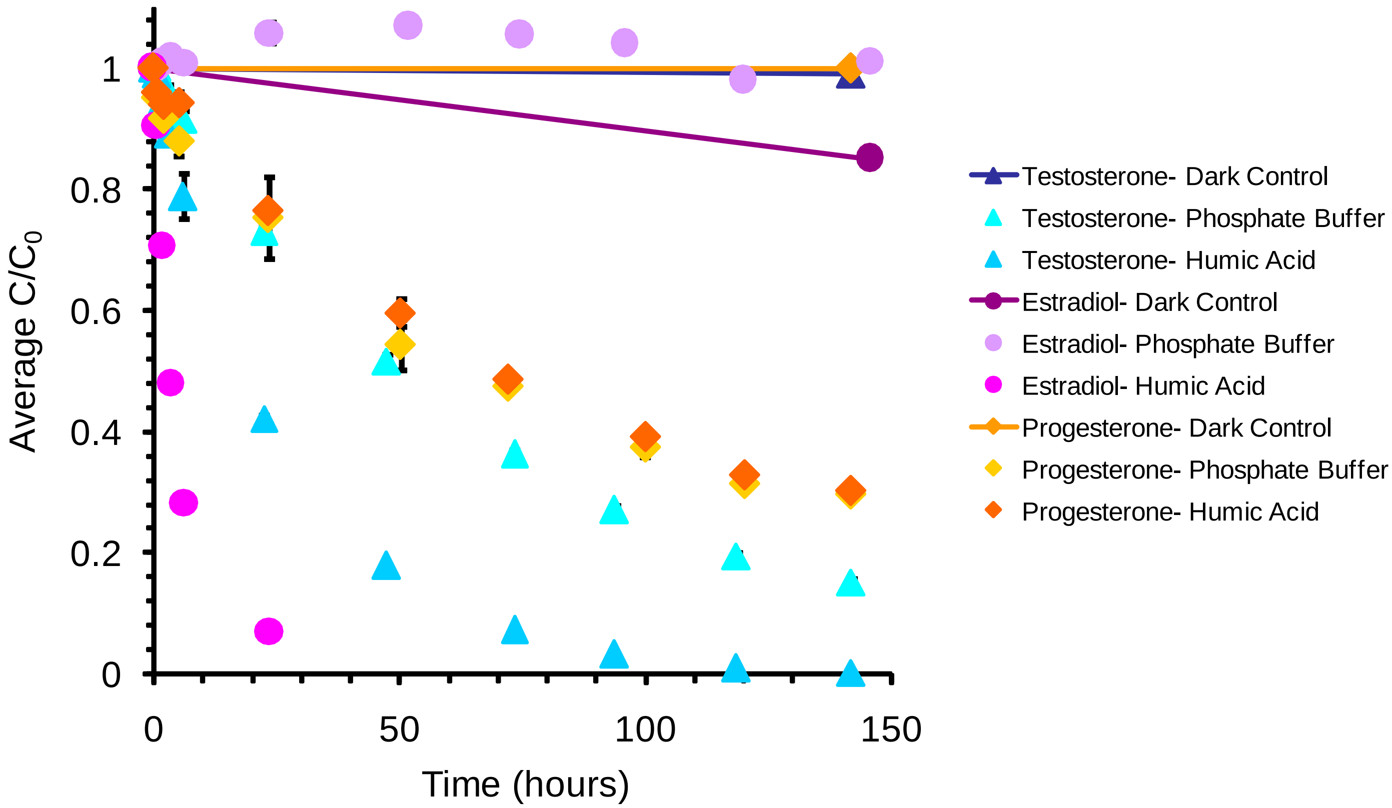


Figure 2. Direct and Indirect Photodegradation of Testosterone, 17β- Estradiol and Progesterone by UV-A light in Phosphate Buffer and Humic Acid. Error bars represent ± one standard deviation. Where not visible, error bars are smaller than symbol size.

of the streams sampled in the 1999-2000 USGS national reconnaissance study. Due to sampling, sample preparation, or analysis related problems, no data are currently available for testosterone. However, androstenedione, a potential degradation product of testosterone, was observed downstream of the Mulberry WWTP (Site 4) and in Greeley (Site 6). Cis-androsterone, a potential testosterone metabolite, was only observed at site 4, suggesting that this compound is either retained in the sediment or being rapidly degraded.

We intend to study steroid occurrence in water samples from the Cache la Poudre River across seasons. To this end, a second set of samples, collected in November 2007 from the six locations described in Table 1, are under analysis as of the time of this writing. We also intend to analyze sediment samples from the same locations, to determine whether hormones are binding to river sediments instead of being transported downstream.

Photodegradation of Steroid Hormones

Multiple laboratory experiments were conducted to study the potential photodegradation of steroids under ultraviolet light at wavelengths found in sunlight, and the possibility of reactions with nitrate, dissolved organic matter and other natural compounds made reactive through exposure to sunlight ("photosensitizers").

Ninety-nine percent of the sun's ultraviolet radiation that reaches the Earth's surface is in the UV-A range from 320 to 400 nm. For this reason, the laboratory experiments were conducted in a photochemical reactor using ultraviolet lamps whose approximate wavelengths ranged from 330 to 405 nm. One mg/L samples of testosterone, progesterone and 17-β estradiol were prepared in deionized water, a phosphate buffer solution (pH 5.5), and buffer solutions containing 10 mg/L nitrate, 5 mg/L humic acid, and a mixture of 10 mg/L nitrate and 5 mg/L humic acid. The buffer solution was intended to eliminate potential effects from changes in pH. The humic acid was used as a model compound for dissolved organic matter, and the nitrate and humic acid concentrations were chosen to represent concentrations commonly found in surface waters. The mixtures were placed in the photochemical reactor, and samples were collected at periodic intervals for analysis by high performance liquid chromatography (HPLC) using a UV absorption detector, and by GC/MS. The results are summarized in Figure 2.

Each of the tested steroids reacted differently, despite the fact that they are closely related chemical compounds. Testosterone degraded under UV-A light, and the rate of degradation increased by approximately 200% in the presence of humic acid. Progesterone degraded under UV-A light, but the rate of degradation was unaffected by the presence of humic acid. Finally, 17-β estradiol did not degrade under UV-A light, but degraded rapidly in the concurrent presence of humic acid. The effect of nitrate was insignificant compared to the effect of humic acid. However, nitrate appeared to enhance the effect of humic acid on the photodegradation of 17-β estradiol, and diminish its effect on testosterone. The rates of degradation in deionized water and the phosphate buffer were approximately the same, suggesting that pH and the phosphate buffer did not significantly affect the degrada-

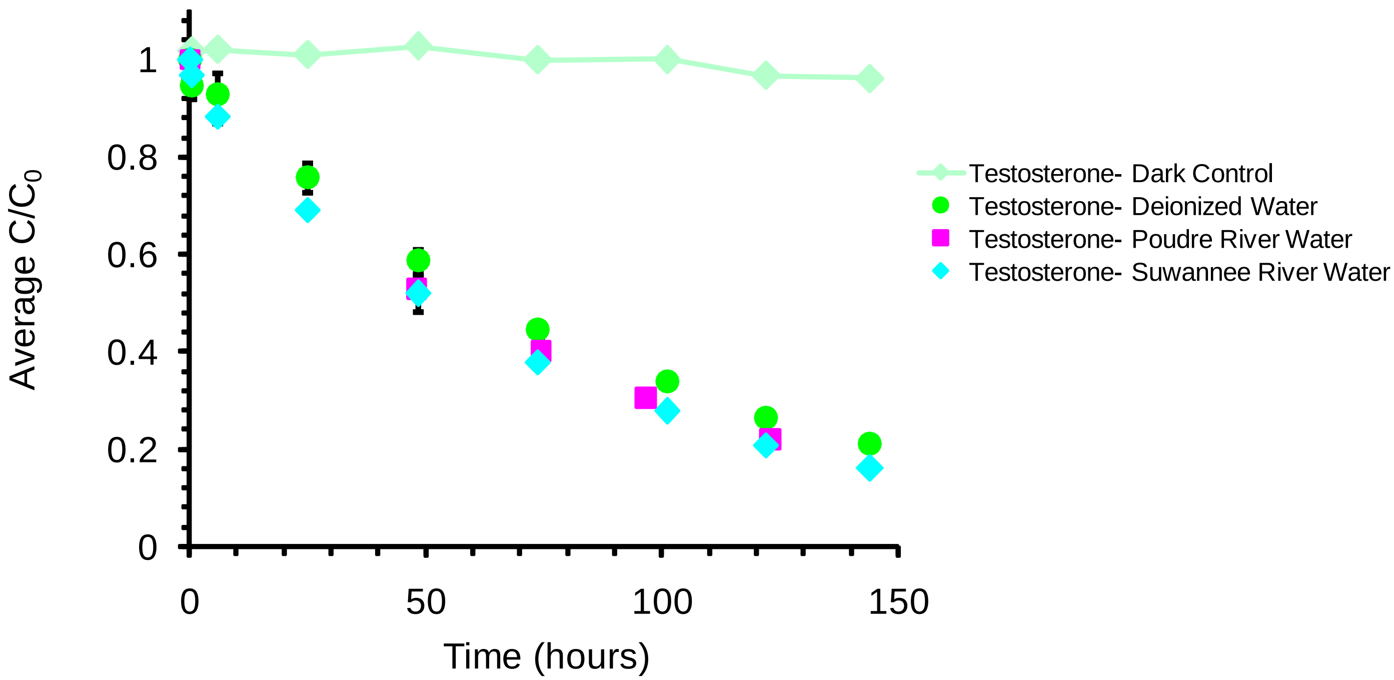


Figure 3. Photodegradation of Testosterone by UV-A light in Deionized Water, Poudre River Water (site 6) and Suwannee River Water. Error bars represent ± one standard deviation. Where not visible, error bars are smaller than symbol size.

tion rate of any steroid tested. Additional research is needed to understand the mechanisms that are involved.

The photodegradation of testosterone was also studied in humic acid concentrations ranging from 1 to 150 mg/L, and in water samples from the Cache la Poudre River (site 6) and the Suwannee River (in the southeastern United States). In the humic acid study, the rate of testosterone degradation increased as humic acid concentrations increased, but appeared to reach a maximum at approximately 50 mg/L. In the river water study, Figure 3 illustrates that testosterone in deionized water degraded more slowly than testosterone in water samples from both rivers, which are high in organic matter.

Because each of the tested steroids reacted differently, the photodegradation of other steroids, such as trenbolone and melengestrol, may be difficult to predict until the phototransformation mechanisms are better understood. Nevertheless, each of the tested steroids degraded under UV-A light, either directly or in the presence of humic acid, suggesting that photodegradation might be important for removing environmental steroids from surface waters.

We intend to identify the products of steroid photodegradation, and to analyze water samples from the Cache la Poudre River to determine the presence and concentrations of these products. To this end, one testosterone degradation product, which was detected with absorption spectroscopy, is being analyzed by mass spectrometry as of the time of this writing to determine its identity. Once these products are identified, they can be analyzed to determine whether the risks of endocrine disruption have been eliminated.

Potential for Biodegradation of Steroid Hormones

Biodegradation is the transformation of organic contaminants via microorganisms into other compounds. It's a key process in natural attenuation or remediation of contaminants at hazardous waste sites. Although a few studies have focused on degradation of estrogens by E. coli, little is known about the degradation pathways. Therefore, we will examine the degradation pathways of 17β-estradiol, testosterone and progesterone via microorganisms commonly found in manure and soils and determine the half-life (persistence) of these steroids in laboratory and field experiments. In addition, because many environmental factors, such as oxygen concentration (aerobic vs. anaerobic conditions), temperature, and the presence of solids, can influence the potential for biodegradation of hormones, we will study how the interaction of bacteria, manure, and environmental factors affects the degradation rates and pathways of steroid hormones.

Hormone Mobility and Management Practices

We intend to conduct a rainfall simulation study in the summer of 2008 to examine the mobility of steroid hormones from agricultural fields following the application of manure or biosolids as fertilizers. At the conclusion of the field and laboratory studies, we will attempt to develop management practices to enhance the degradation and reduce the mobility of steroid hormones.

Acknowledgements

We gratefully acknowledge financial support from the Colorado Water Resources Research Institute and The SeaCrest Group. We also thank Dr. James L. Gray of the USGS National Water Quality Laboratory in Denver, Colorado, and Adriane Elliott, Coordinator of the Colorado State University Interdisciplinary Program in Organic Agriculture, for their technical support.

Development of Oilseed Crops for Biodiesel Production Under Colorado Limited Irrigation Conditions

by Dr. Jerry Johnson, Research Scientist, and Mr. Nicolas Enjalbert, Graduate Research Assistant, Department of Soil and Crops Sciences, Colorado State University

Since 2001, Colorado State University's Crops Testing Program, in collaboration with many other university and USDA ARS researchers, extension agents, farmers, private companies, and a non-profit organization, has undertaken oilseed-for-biofuel crop research and extension. Collaboratively, this work has been undertaken with the objective of testing and adopting oilseed crop species (and varieties) to dryland, limited irrigation, and fully irrigated cropping systems prevalent in eastern Colorado, eastern Wyoming, western Kansas, and the Nebraska Panhandle. Regional applied research has focused on crop variety and agronomy trials, interaction with first-adopter farmers, weed control experiments, insect pest observations, crop water use experiments, crop response to variable climatic conditions, and has resulted in a strong collegial relationship among researchers, farmers, private company representatives, and extension agents within the Great Plains area.

This multifaceted limited irrigation oilseed research project is an integral contributor and benefactor of our overall efforts to provide cropping alternatives that are agronomically sound, economically feasible, and environmentally sustainable to eastern Colorado producers, specifically those needing to adapt to limited irrigation due to water depletion or by regulation.

Camelina experiment in the greenhouse

Target Species Variety Performance Trials Results and Analyses

In 2007, five target oilseed crops were studied: soybeans, safflower, sunflower, canola and camelina. Performance trials were conducted at nine locations within Colorado: Fort Collins, Akron, Walsh, Dailey, Idalia, Yuma, Brandon, Julesburg and Rocky Ford. Oilseeds crops were tested under three environmental conditions: dryland, limited irrigation and full irrigation. Crop data collected yields, percent grain moisture, plant height and pod shattering. Safflower, canola and camelina were studied with greater detail. The oil profile was evaluated for canola, camelina, and safflower.

The five target oilseed crops are being studied in three Colorado cropping systems (Table 1). Sunflower, soybean and safflower are summer annual broadleaf crops. Late fall harvest of these crops make it difficult to get back to winter wheat in Colorado cropping systems the same year. Soybean is primarily an irrigated crop. Sunflower is both a dryland and an irrigated crop. Safflower is primarily a dryland crop. Winter canola and winter camelina can be either integrated into the dryland wheat cropping system or into an irrigated cropping system. However, canola should be considered as an irrigated crop whereas camelina is competitive in dryland conditions.

Spring canola and camelina provide opportunity crops that can be integrated into the dryland wheat rotation predominant in eastern Colorado, planted in early spring, harvested in July and followed by wheat planting in September. Spring canola may be limited by high summer temperatures which reduce pollination and pod filling. Camelina is more drought tolerant and less sensitive to high temperature during pollination and pod filling

Table 1. Cropping Systems Adaptable Oilseed Crop for Colorado

Crops	**Months**										
	August	September	October to February	March	April	May	June	July	August	September	October
Soybean						Planting Date				Harvesting	
Sunflower							Planting Date				Harvesting
Safflower							Planting Date				Harvesting
Winter Canola & Winter Camelina		Planting Date						Harvesting	Planted back to wheat		
Spring Canola & Spring Camelina				Planting Date				Harvesting	Planted back to wheat		

Results of 2007 Crop Variety Performance Trials

In 2007, six variety performance trials of soybean, nine of sunflower, three of safflower, six of canola and three of camelina where conducted. A total of 27 oilseed crop variety trials were conducted in nine eastern Colorado locations.

Soybean

Soybean is presently the primary source of virgin oil for biodiesel in the US. More than 1.5 billions pounds of soybean oil are currently used in the biodiesel industry. The soybean oil profile is in accordance of the US biodiesel standard (ASTM PS 121-99). It has a high level of oleic fatty acid, low level of saturated fatty acid, and medium polyunsaturated fatty acid content (24%), which makes soybean oil a good source for SVO. Soybeans are grown successfully on 62.8 millions acres in the US mainly in the Mid West. Soybean production is well understood, but it is a relatively new crop for Colorado. In the High Plains, soybeans need to be grown under irrigation, and need relatively large amounts of water at the same time as other summer crops. Soybean trials at Yuma in 2006 and 2007 demonstrated soybean yield potential up to 100 bu/ac (Table 2).

Sunflower

Sunflower is native to the High Plains and is well adapted. It is a drought tolerant crop and suitable for dryland production. Average yields for dryland sunflower is 1,100 lbs/ac. Best management practices for Colorado have been established. New cultivars with high oleic content make sunflower oil healthier for human as well as very suitable for SVO. A dryland trial conducted in 2007 demonstrated yields up to 2,445 lbs/ac, and up to 3,474 lbs/ac under limited irrigation (Table 3).

Winter and Spring Canola

Canola is grown on a limited acreage in the High Plains. However, it has the potential to become an important crop. It contains about 40% oil.

Canola yields are limited by temperatures greater than 90°F during the flowering period, as heat reduces pollen fertility. Low moisture profile will reduce yields more than camelina. Canola has a taproot system giving the crop access to deep water and nutrients (Downey et al., 1974). However, when grown in semiarid regions such as the High Plains, the canola roots require adequate subsoil moisture to sustain the crop during flowering and seed filling. Under managed irrigation winter canola is capable of yielding more than 3,000 lbs/ac. Winter and spring canola varieties are being screened to identify promising cultivars for Colorado's limited irrigation and dryland conditions. Trials conducted in 2007 demonstrate yields of 800 lbs/ac under dryland and of 2,400 lbs/ac under limited irrigation (Table 5).

Winter oilseed trails at Akron

Camelina

Camelina is an oilseed crop native to Southeast Europe and Southwest Asia. The plant has been known for about 4000 years as a cultivated crop but there has been relatively little research conducted on it worldwide. Camelina is adapted to more marginal environments and could be a new introduced crop for dryland systems in Colorado. Presently, it is grown on a limited number of acres in the High Plains. Montana is a leading producer of camelina with approximately 40,000 acres in 2007.

Safflower

Safflowers are grown on a limited number of acres in the High Plains. Its center of origin is in Asia where it is used for vegetable oil and dye pigment. In Colorado, safflower production is for bird seed. Safflower is drought tolerant and has high oil content. Safflower has an acceptable oil profile for SVO. 2007 trial results show yields up to 467 lbs/ac (Table 4). But much higher yields have been achieved in different years and with better crop management practices. Safflower oil content can approach 50% in some cultivars.

Table 2. Soybean Trial Performance Summary

Location	Maturity	Water Regime	Average (bu/ac)	Max (bu/ac)	Min (bu/ac)
Akron	Early	Dryland	11.4	18.2	5.9
Fort Collins	Early	Limited Irrigation	20.7	30.3	10.9
Fort Collins	Medium	Limited Irrigation	25.4	33.3	15.4
Rocky Ford	Early	Limited Irrigation	34.5	48.9	20.6
Rocky Ford	Medium	Limited Irrigation	40.4	44.9	36.5
Yuma	Late	Irrigated	78	99.4	66.9

**Soybean oil content can be assumed to be 18%*

Table 3. Sunflower Trial Performance Summary

Location	Type	Water Regime	Average (bu/ac)	Max (bu/ac)	Min (bu/ac)	Oil (%)
Brandon	Oil	Dryland	11.4	18.2	5.9	38.70
Julesburg	Oil	Irrigated	20.7	30.3	10.9	41.15

Table 4. Safflower Trial Variety Performance Summary

Location	Water Regime	Average (bu/ac)	Max (bu/ac)	Min (bu/ac)
Akron	Dryland	430	467	395
Fort Collins*	Limited Irrigation	221	301	182
Walsh	Dryland	208	250	148

Camelina is a drought and cold tolerant crop, resistant to flea beetles and other insect pests. In the past two years, camelina has had higher yield than spring canola under dryland condition at Akron. However, camelina does not have entirely determinant plant growth habit which can lead to significant harvest losses. Moisture received by either rainfall or irrigation at maturity can cause camelina to initiate new growth resulting some green and some shattering pods.

Charlie Rife (Breeder from Blue Sun) observing the Camelina

Camelina is a drought and cold tolerant crop, resistant to flea beetles and other insect pests. In the past two years, camelina has had higher yield than spring canola under dryland condition at Akron. However, camelina does not have an entirely determinant plant growth habit which can lead to harvest losses if it rains in July and new flowers and pods are produced. Camelina uses less water and less nitrogen to obtain good yields than canola. Camelina is suited for the High Plains (Pavlista & Baltensperger, 2006). However, best management practices for sustained camelina crop production are not well understood.

Screening New Alternative Crops

One aspect of the study is to identify new germplasm of targeted crops that will have a better response to limited irrigation. Currently, 140 accessions, 101 Camelina sativa and 39 of Brassica carinata are being evaluated in the CSU greenhouse.

Economic Feasibility

The economic feasibility of these new oil crops must be addressed, specifically two practical economic questions frequently asked about oilseed production for use as Straight Vegetable Oil (SVO) on the farm.

1. What is the break-even price per pound and yield that would make it economically feasible to produce oilseed under limited irrigation conditions?
2. What price per gallon of petroleum diesel, and crop yield, does it become feasible to grow your own fuel under limited irrigation conditions?

There are cropping systems options that can be considered that includes oilseed production for biofuel, but in the interest of answering these two questions as succinctly and clearly as possible, our economic example is based on a hypothetical crop rotation producing three crops in three years and including winter wheat: Corn / Spring Canola / Winter Wheat (as opposed to an alternative four year rotation with three crops that might be Corn / Corn / Winter Wheat). The rotation with spring canola allows the producer to harvest canola in late July and plant back to winter wheat the same year. Our limited irrigation cropping system production costs differ from the costs of full irrigation by lower costs of nitrogen fertilizer and slightly lower irrigation costs. Moreover, the fixed cost per crop is lower in the spring canola/winter wheat rotation because there are three crops in three years as opposed to three crops in four years. Oilseed crops in the Brassicacea family, like canola and Camelina, are good rotation crops because high levels of glucosinolates can effectively break some harmful pest cycles.

Student working on the greenhouse experiment

Benefits of Straight Vegetable Oil (SVO) for Colorado

SVO has many benefits when compared to petro-diesel. Because it requires no refining, it also has advantages over biodiesel and other biofuels. Most importantly, as a renewable resource, it provides an opportunity for farming communities for generations to come.

SVO is not harmful to humans, animals, soils or water. The German Federal Water Act on the Classification of Substances Hazardous to Waters denotes SVO as NWG (non hazardous to water). Biodiesel on the other is slightly hazardous to water while diesel and gasoline are rated as highest toxicity. A North American study on the toxicity of vegetable oil in freshwater also found no harmful effects.

As a fuel, it emits 40 to 60% less soot compared to petro-diesel. It does not contain sulfur and therefore does not cause acid rain. In addition, carbon monoxide and particulate emissions are slightly lower. CO2 emissions are also reduced by 80 to 96% compared to petro-diesel when locally produced and used fuel. Finally, Polycyclic Aromatic Hydrocarbons (PAH) emissions are distinctly lower for all vegetable fuels, reducing risks of cancer.

Table 5. Canola Trial Performance Summary

Location	Source	Water Regime	Average (bu/ac)	Max (bu/ac)	Min (bu/ac)
Akron	Commercial	Limited Irrigation	1891	2397	1458
	Commercial	Full Irrigation	1837	2424	1205
	Cargill	Limited Irrigation	1645	2900	1205
	Cargill	Dryland	401	807	343
	Blue sun	Limited Irrigation	1259	1777	1406
Fort Collins	Commercial	Limited Irrigation	259	761	79

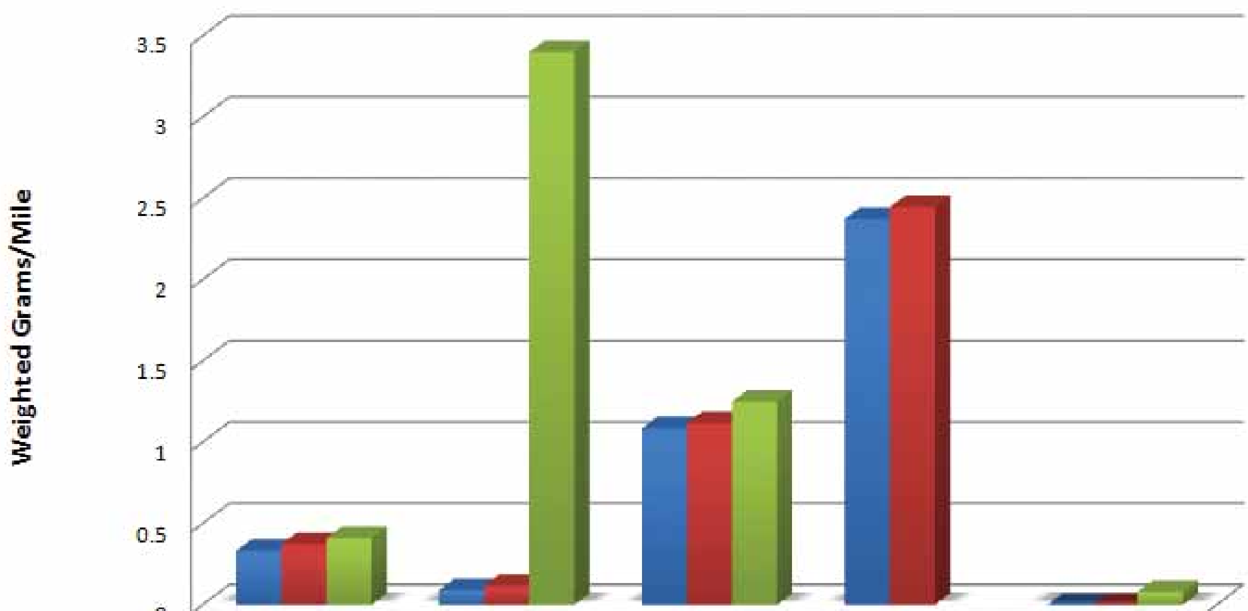
Canola Oil Emissions Testing Results

SVO can contribute to an energy-independent Colorado agricultural system as well as increase food and feed sector security. Gasoline has a 0.873 energy ratio (energy yield/ energy input). If we include distribution and the value of canola meal, the energy ratio number for canola based SVO is 5.45 while for sunflower based SVO, it is 6.33. At average yields of 2200 lb/ac and petroleum diesel at $2.50/gallon, net returns would be expected to be $148/ac. Perhaps equally important is that on-farm production of biofuel (independence from foreign energy) would make Colorado's food and feed supply more secure and less likely to be affected by world affairs beyond local control. In addition, the carbon footprint of Colorado agriculture would be smaller and new crops that require less water could be a new source of farm income.

iCAST Engineering Project Manager Micah Allen presenting to farmer group on how to make fuel

Canola Oil Emissions Testing Results

Testing by Albuquerque Alternative Energies, PlantDrive and VO Control Systems on a 2002 VW Golf TDi at the National Center for Vehicle Emissions Control and Safety (EPA certified) on January 19th, 2007



	THC	CO	NOX	CO2x100	PM
V100 (Canola)	0.333	0.09	1.086	2.37405	0
Diesel (ULSD)	0.373	0.117	1.118	2.44689	0
EPA Limit	0.41	3.4	1.25		0.08

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

by John D. Stednick, Ph.D., Department of Forest, Rangeland, and Watershed Stewardship
Ryan Jensen, Department of Forest, Rangeland, and Watershed Stewardship
Colorado State University

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).

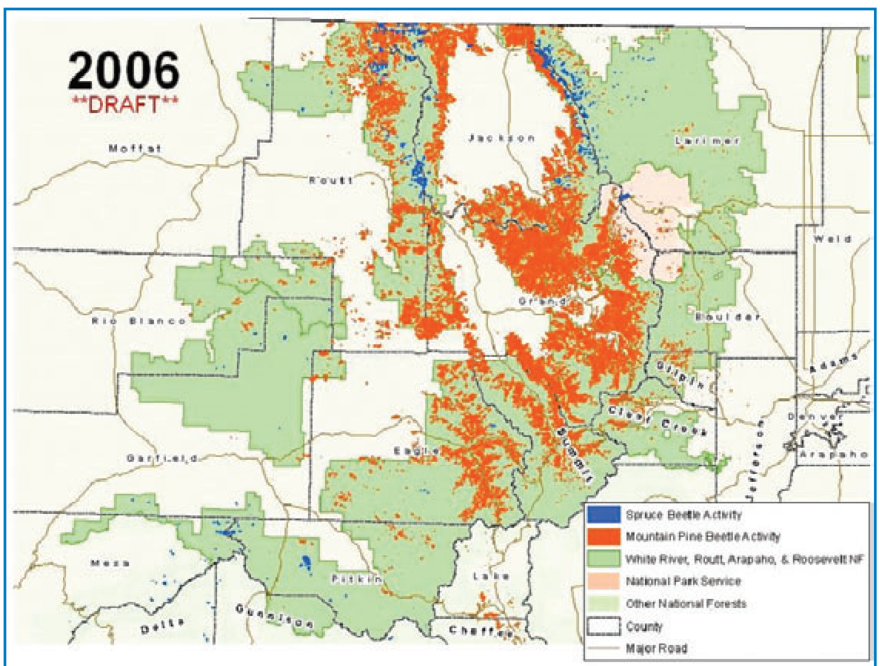


Figure 1. Extent of beetle-killed areas in North-central Colorado (Adapted from Colorado State Forest Service.

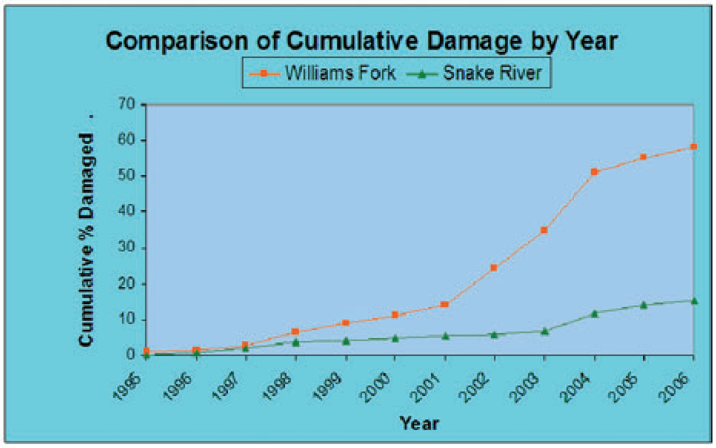


Figure 2. Beetle killed area over time for Williams Fork and Snake River watersheds.

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.

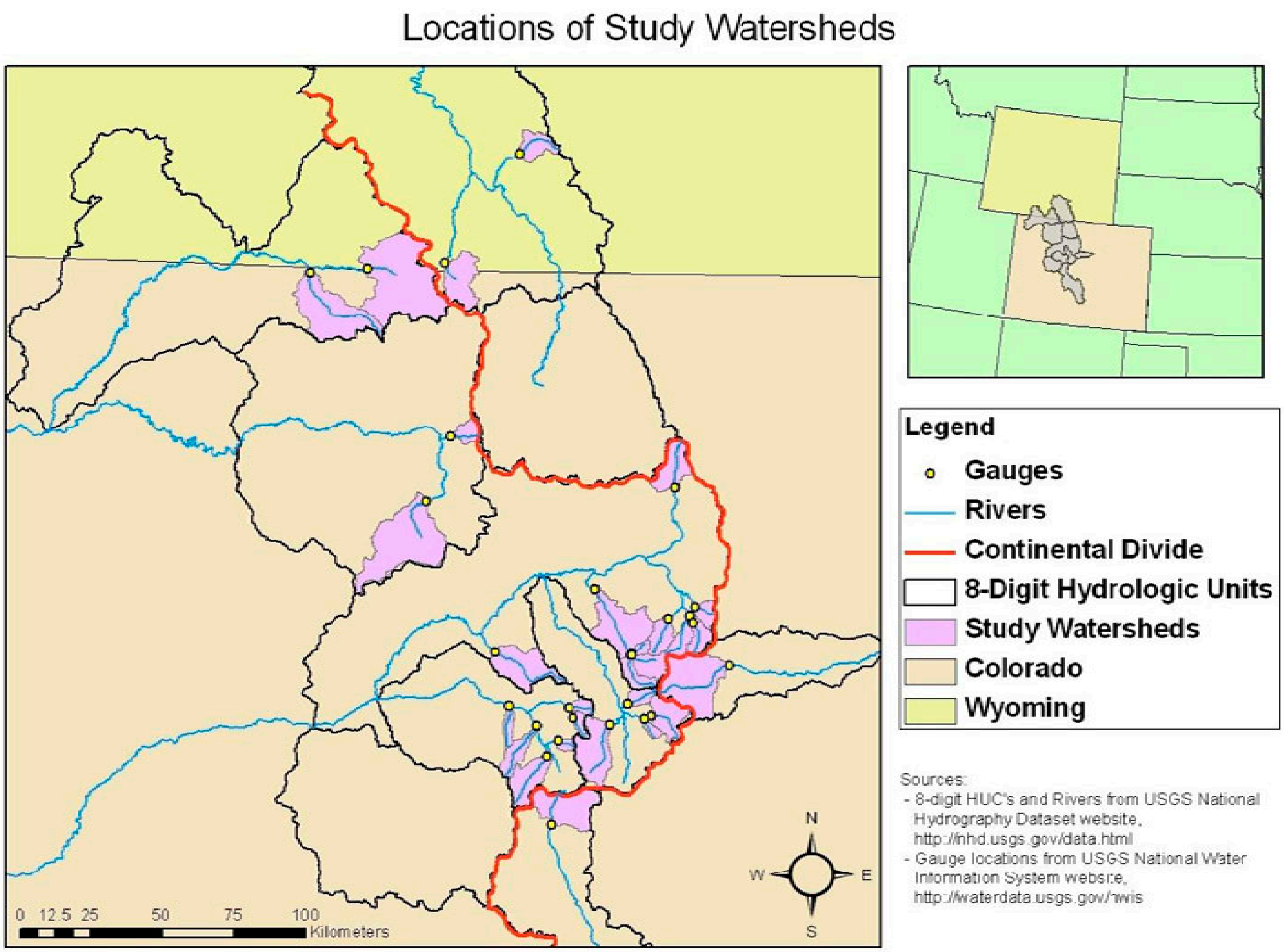


Figure 3. Location of selected watersheds used in this study.

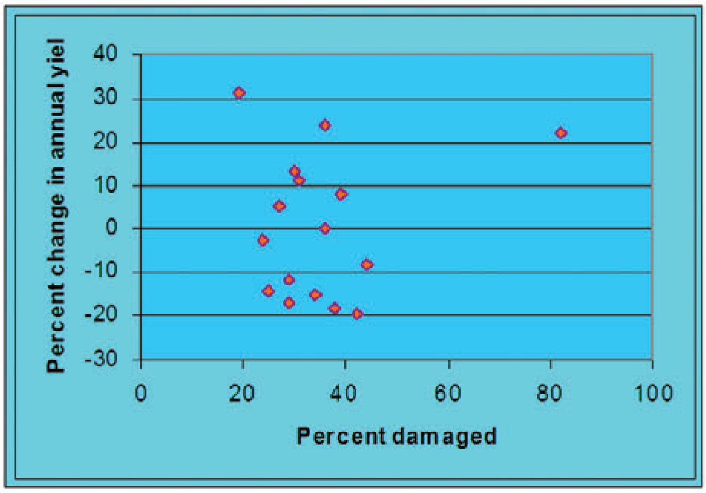


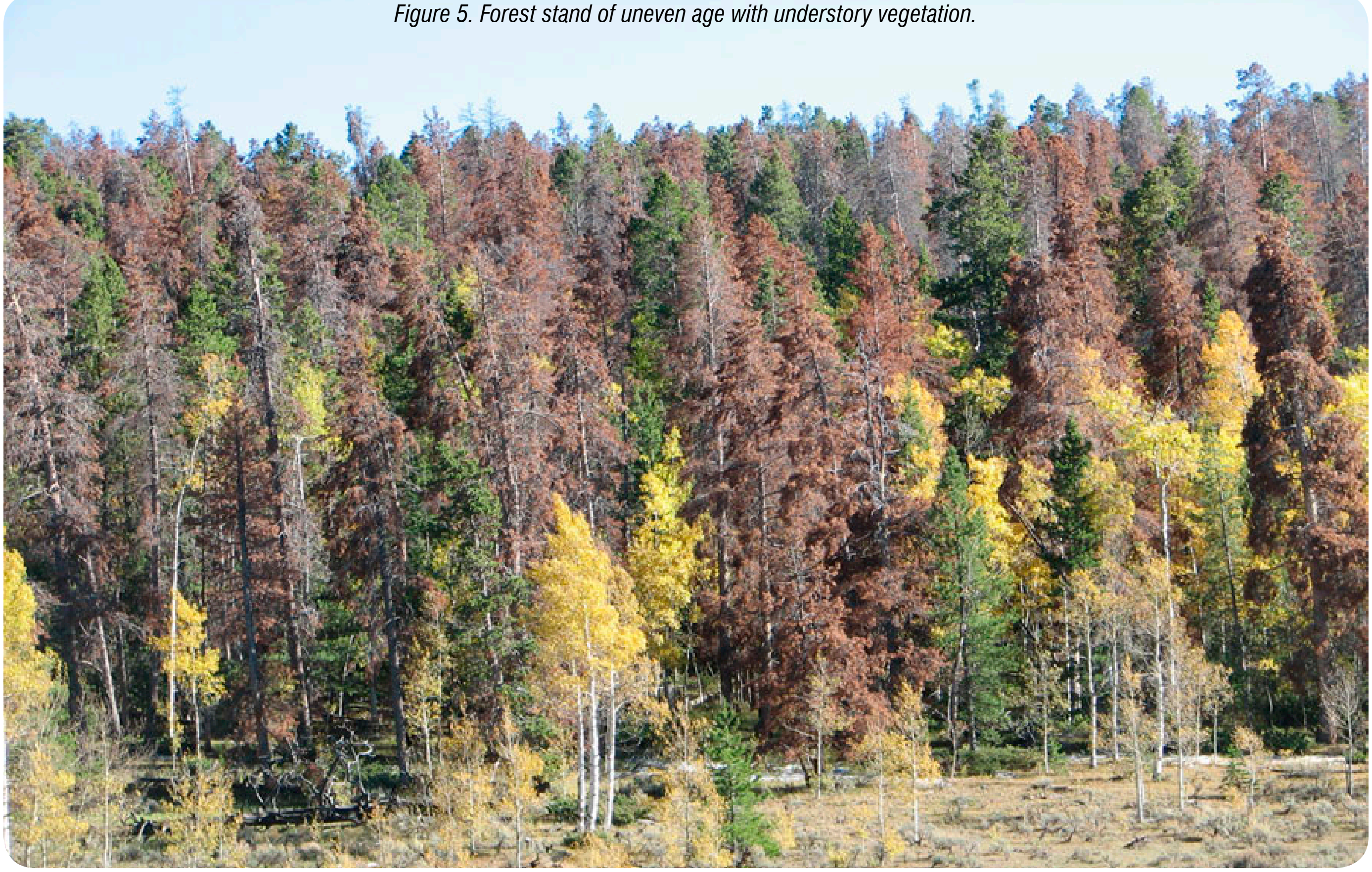
Figure 4. Changes in annual water yield as a function of beetle killed area in the watershed.

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 subalpine and montane settings. The decrease in forest canopy due to defoliation will result in decreased precipitation interception and decreased summer evapotranspiration. Changes in these hydrologic process rates will result in increased soil moisture and increased annual water yield (streamflow). A 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 reduce beetle population viability, but water yield increases can be expected already.

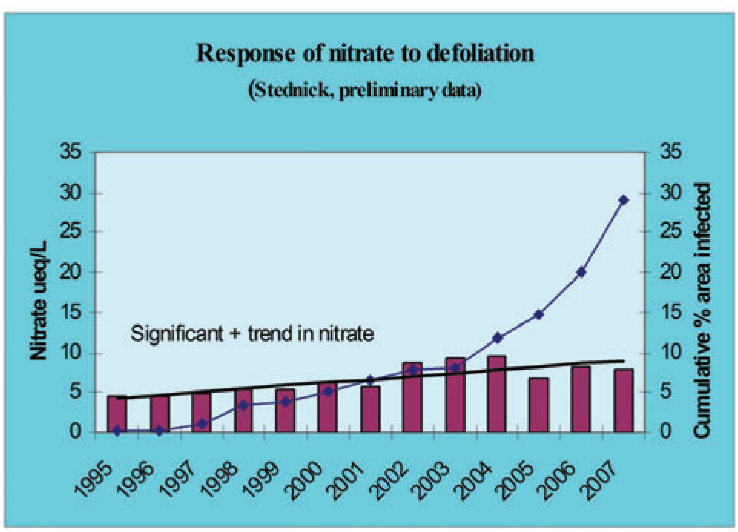


Figure 6. Increases in nitrate-nitrogen concentrations and beetle-killed area over time in Williams Fork.

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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Simultaneous Water Quality Monitoring and Fecal Pollution Source Tracking in the Colorado Big Thompson Water Project

by Lawrence D. Goodridge, Assistant Professor, Department of Animal Sciences
Dr. Claudia Gentry-Weeks, Associate Professor, Department of Microbiology, Immunology and Pathology
Dr. Douglas Rice, Laboratory Director, Environmental Quality Laboratory

Objectives

The overall goal of this project is the development of two integrated detection methods, which will simultaneously determine the presence of fecal pollution and also the source of that pollution, in surface water, within 6 hours. The methods are based upon rapid identification of FRNA bacteriophages (phages), followed by characterization of the phages to determine their source (which allows for an indication of the source of fecal pollution). The specific goals of the project are to: 1) develop a field-ready large volume water sampling device to isolate and concentrate the phages from water; 2) To develop two rapid methods for characterization of FRNA phages (also allowing for identification of the fecal pollution source) based on an immunological method (Lateral Flow Device) and a molecular based method (PCR); and 3) To use the newly developed methods to assess water quality in the Colorado Big Thompson Water Project, and in other watersheds in Colorado.

If successful, this proposal will lead to the development of rapid methods for the simultaneous determination of microbial water quality, and the source of any fecal pollution that may be present. The detection methods will also be evaluated for use in determining the quality of water in large scale transfer projects.

Background information about the need for this research

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. 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

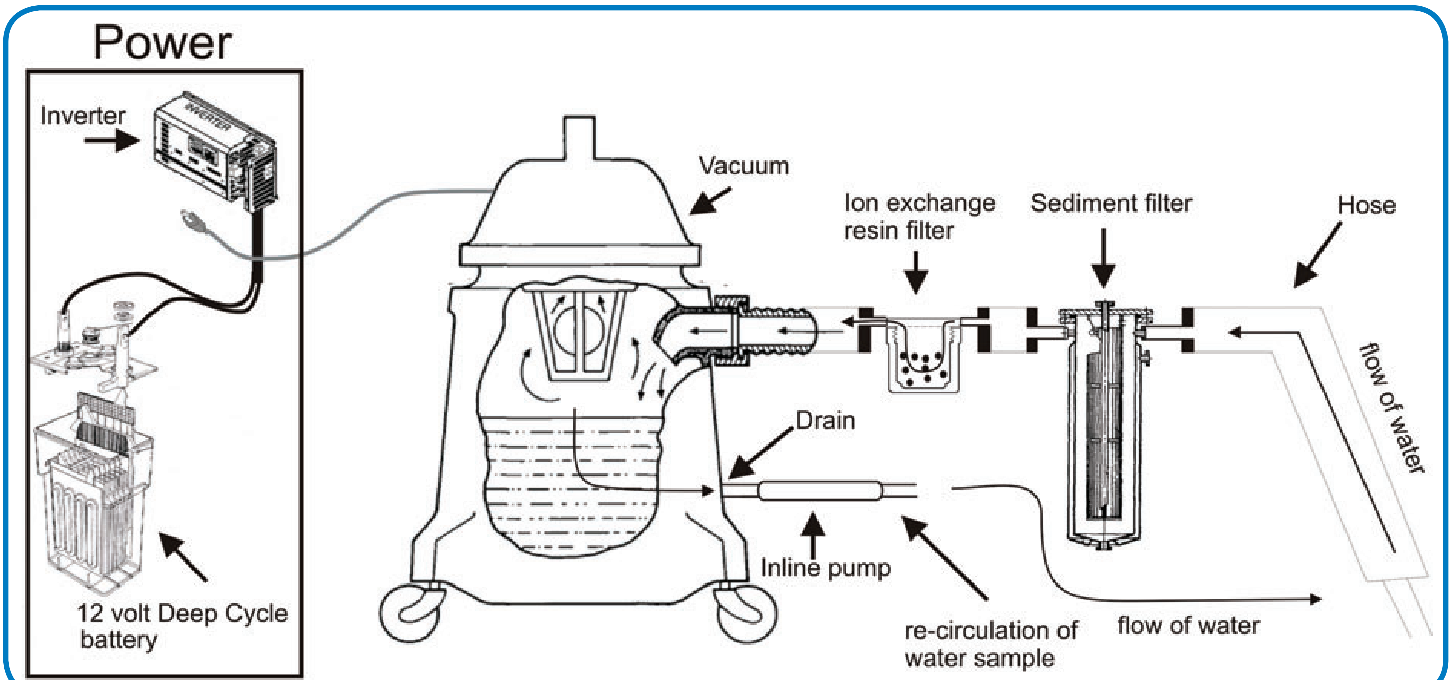


Figure 1. A schematic of the VacBAC. The Vacuum Based Adsorption of Contaminants (VacBAC) device. The VacBAC is a modified wet vacuum that contains a sediment removal filter and an ion exchange resin filter in the hose. Water is sampled (sucked up) via the hose, any particulates or sediment is removed via the sediment filter. Microorganisms (bacteria and viruses) are trapped on the ion exchange resin beads, on the basis of charge. The water is sucked into the vacuum container. After sampling is complete, the hose is attached to the drain, and the water sample is re-circulated (via an inline pump) through the entire system, allowing for more bacteria and viruses to be isolated from the sample. The VacBAC is powered by a 12 volt deep cycle battery, which is attached to a 110 volt AC inverter.

coliform, thermotolerant coliform group, enterococci and *Clostridium perfringens* have been the bacterial indicators used to detect fecal contamination, 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. For example, many of these bacteria are routinely isolated from soil and water environments that have not been impacted by fecal pollution. Another issue to consider is the fact that the bacterial indicators described above are not well suited to tracking the source of fecal pollution when a contamination event is discovered. Obviously, source tracking is extremely important, since it identifies the source of the pollution, which enables containment and a decrease in the chance of waterborne disease outbreaks.

Due to the limitations of the bacterial indicators, and the problems with their rapid detection, it is clear that there remains an acute need to develop water quality test procedures that would identify fecal contamination in a rapid manner, and simultaneously determine the source of that pollution so corrective actions could be initiated.

Achievement of the specific objectives stated in the proposal

Aim 1: develop a field-ready large volume water sampling device to isolate and concentrate the phages from water

We have developed a two stage process, which entails sampling large volumes of water (up to 60 liters) and concentrating the FRNA phages, followed by a detection method to identify the presence of any FRNA phages that were present. In the method, following phage concentration, the phages were detected with the use of a lateral flow assay (field detection) or by PCR.

The sampling and concentration aspect of the process was facilitated through the development of a large scale sampling and concentration device called the Vacuum Based Adsorption of Contaminants (VacBAC) device (Figures 1 and 2).

Aim 2: To develop two rapid methods for characterization of FRNA phages

To test the VacBAC, 20 liter water samples were inoculated with several different concentrations of FRNA phages and the water samples analyzed as described above (Figure 1). After analysis, the ion exchange resin beads (with any bound FRNA phages) were processed by lateral flow assay or RT-PCR to detect the presence of the FRNA phages.

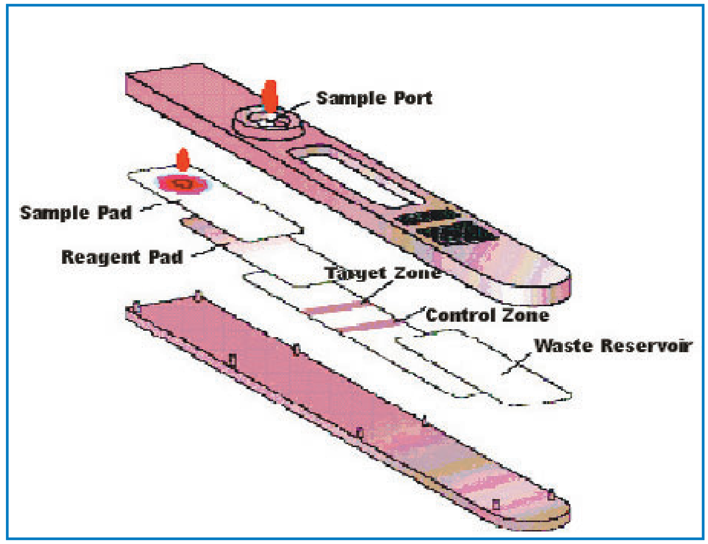


Figure 3. The lateral flow device (LFD). Any FRNA phages that recognize antibodies will be trapped at the target zone. The formation of a line in the control zone indicates that the test has been performed successfully (quality control). If a line at the target zone is present, a positive test is indicated. If all lines at the target zone are absent, a negative test is indicated, while the absence of a line at the control zone at any point indicates that the test did not function properly and should be repeated. The test result should be visible within 5 minutes.

The LFD is a simplified version of the Enzyme Linked Immunosorbant Assay (ELISA) (Figure 3), and these single step immunochromatographic assays utilize similar technology to that used in home pregnancy tests. To demonstrate

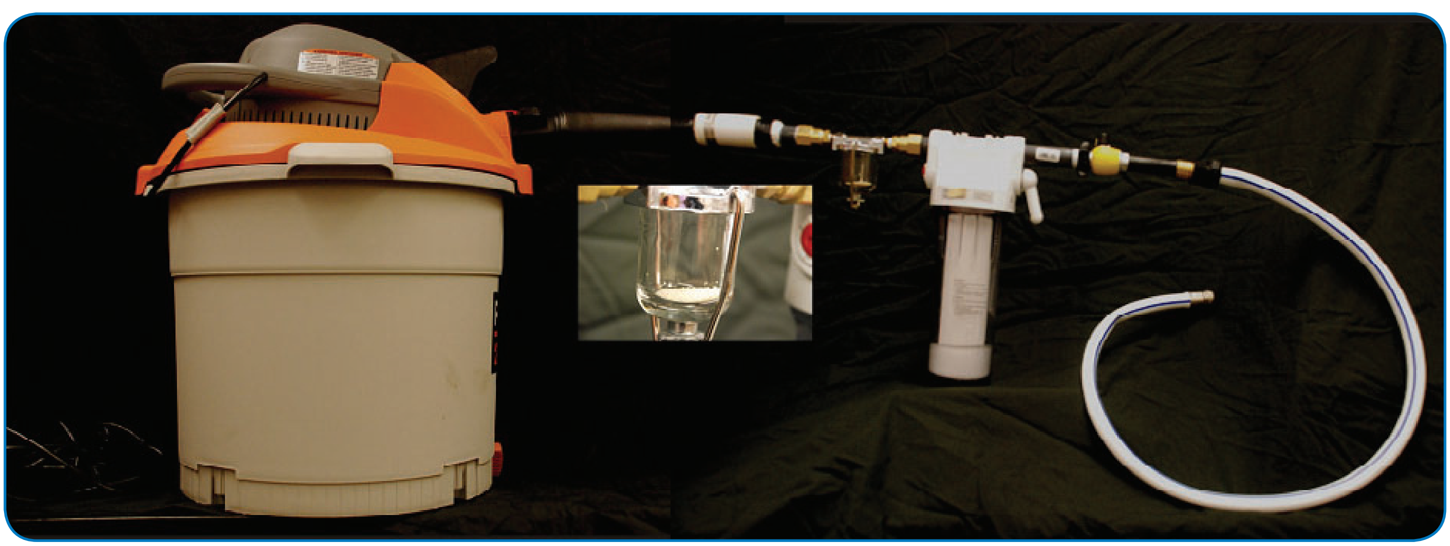


Figure 2. The VacBAC as currently constructed. The ion exchange resin filter is shown inset.

Figure 4. Lateral flow devices (LFDs) used to detect the presence or absence of phage MS2 in water. 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 (< 10^8 phages/ml) (absence of the test line).

the feasibility of using LFDs to detect FRNA phages in water, a LFD based upon FRNA phage MS2 was developed. A series of 10 fold dilutions of MS2 were added to water, and the LFDs were used to determine the concentration at which the MS2 could no longer be detected (Figure 3). The results indicated that less than 10^8 PFU/ml of MS2 was undetectable (Figure 4). This result demonstrates the usefulness of the LFD technique, and also indicated that FRNA phages from large volumes of water samples will need to be concentrated to enable sensitive detection of phages in the water. As described above, the VacBAC device will be used to concentrate phages from up to 60 liters of water.

Even with the large scale concentration of phages from water, as facilitated by the VacBAC device, it is clear that the sensitivity of the LFD will have to be increased in order to develop a viable FRNA field based test. To address the LFD sensitivity issue, we developed an enrichment process, in which the FRNA phages were incubated with their host strain (*E. coli Famp*). In this scenario, the phages infect their host strain and replicate, amplifying themselves to a concentration (10^8 phages/ml) that is detectable by the LFD. We incubated the ion exchange resin beads (with the attached FRNA phage) with the *E. coli Famp* host strain for 3 hours. During that period the FRNA phages that were attached to the anionic beads replicated within the *E. coli* cells and increased in concentration. The results indicated that after the 3 hour incubation, the LFDs were 1,000 times more sensitive, due to the increase in phage concentration. These results indicate that the test method should be able to achieve the sensitivity needed to detect FRNA phages directly, in the field. We are currently optimizing the LFD test to further increase the sensitivity.

In addition to the LFD field test, we were interested in developing a sensitive RT-PCR assay that could be used in the lab, to quantify the amount of FRNA phage from water.

A FRNA RT-PCR assay was developed. Four FRNA phages representing the four serological FRNA groups were evaluated by the RT-PCR assay. These phages included MS2 (serogroup I), GA (serogroup II), Qβ (serogroup III), and SP (serogroup IV). RNA was isolated from each phage with a Qiagen RNA isolation kit, followed by a one step RT-PCR assay. PCR amplicons were resolved on 1.5% agarose gels. We expected bands of 266 bp for phages MS2 and GA, and

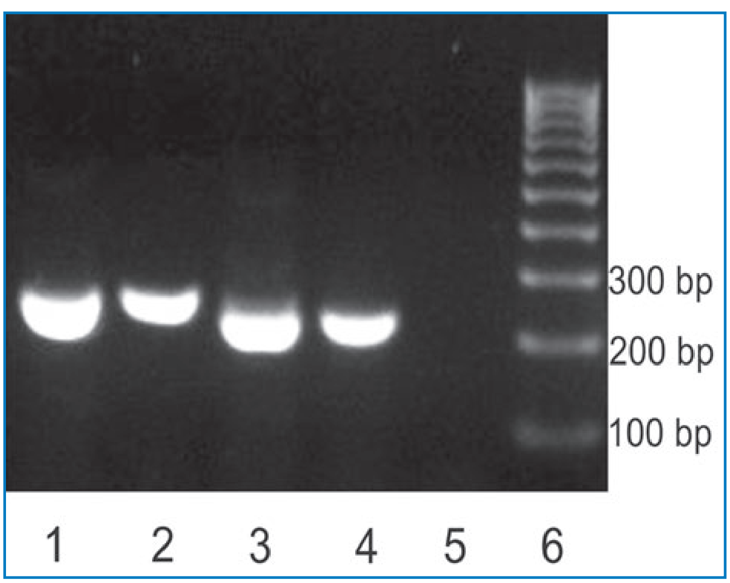


Figure 5. Agarose gel of RT-PCR amplicons of the four FRNA phages representing each of the four FRNA serogroups. Lane 1, MS2 (expected band size 266 bp); Lane 2, GA (expected band size 266 bp); Lane 3, QB (expected band size 225 bp); Lane 4 SP (expected band size 225 bp); Lane 5, negative control; Lane 6, 100 bp ladder.

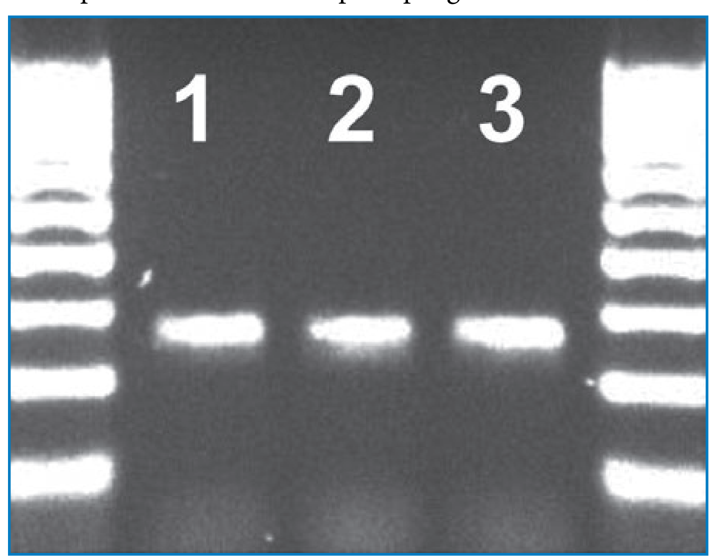


Figure 6. Evaluation of the VacBAC and RT-PCR for rapid detection of FRNA phage MS2. Lane 1 and 5, 100 bp ladder. The lanes identified by the numbers indicated the number of times the water sample was re-circulated prior to detection of the FRNA phages. So for example, in the lane identified as "1" the water sample was sampled once before testing by RT-PCR. In the lane identified as "2" the water sample was re-circulated once before testing for phage, and so on. The results indicate that a similar concentration of phage is bound to the resin beads (30%) each time that the entire volume of water that to be sampled is re-circulated.

226 bp for Qβ and SP. The results indicated that the expected bands were present (Figure 5).

The next step was to evaluate the ability of the RT-PCR assay to detect FRNA phages that were attached to the ion exchange resin beads. We also evaluated the combination of the water sampling and phage concentration ability of the VacBAC, and RT-PCR, to detect FRNA phages in water. For this experiment, 20 liters of tap water were spiked with 105 phages/ml of phage MS2. To concentrate the FRNA phages with the VacBAC, 1 gram of ion exchange resin was added to the on exchange filter in the device (Figure 1), and the 20 liter sample was processed by sucking the water up with the VacBAC hose. The water flowed through the cartridge filter and the second (ion exchange resin-based) filter, and then into the wet vacuum cartridge. The flow rate was approximately 1 liter per minute, so the 20 liter sample was concentrated within 20 minutes. Initial experiments showed that approximately 30% of the MS2 phages were concentrated during the first pass of water sampling. Therefore, the water was re-circulated twice more to evaluate the ability of the VacBAC to isolate more phages from the water sample. Following sampling, the ion exchange resin (with FRNA phage attached) was removed from the filter, and the entire 1 gram sample was tested by the RT-PCR assay as described above. The results are shown in Figure 6.

Finally, we investigated the ability of the ion exchange resin beads to capture phages from water in a manual format by incubating 50 mls of water (inoculated with differing concentrations of phages) with the resin for 1 hour, followed by RT-PCR. The results are shown in Figure 7. The results indicated that as few as 10^0 phages/ml of water are detectable.

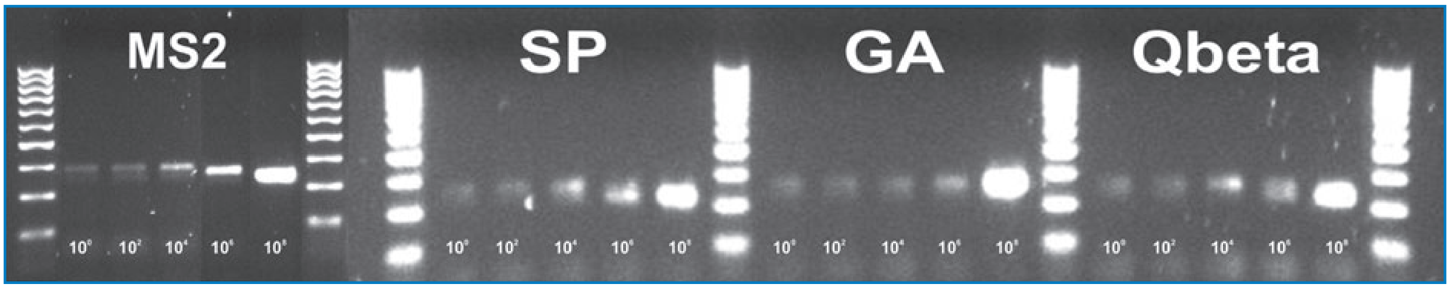


Figure 7. Detection limits of the ion exchange resin capture and RT-PCR assay. The FRNA phage type (MS2, SP, GA or Qbeta) is indicated above each gel. The concentration of phages/ml of water is indicated at the bottom of each gel lane. The results indicated that as few as 10^0 phages/ml are detectable by the assay.

Snowmelt Runoff in the Upper Cache la Poudre River Basin, Northern Colorado

by Stephanie Kampf, *Assistant Professor, and*
Eric Richer, *M.S. Student, Watershed Science;*
Department of Forest, Rangeland, and Watershed Stewardship

From its headwaters in Rocky Mountain National Park, the Cache la Poudre River travels approximately 80 miles down through the Poudre Canyon, eventually passing through Fort Collins and Greeley before reaching its confluence with the South Platte River (Figure 1). The basin covers an area of 1,890 square miles, with elevations ranging from over 13,000 feet above the headwaters to 4,600 feet at the outlet. The river has a long history of water use extending back to early settlements in the 1850s, and water is now used to support multiple agricultural, municipal, and industrial demands. In March 2008, we began a project funded by the Colorado Water Institute to explore runoff generation in the upper Cache la Poudre Basin and develop a model to predict flow in the basin under varying climate conditions. The objective of the first phase of this research is to determine which parts of the basin contribute runoff to the river during the snowmelt season.

Methods

To determine sources and timing of snowmelt runoff in the Cache la Poudre Basin, we compiled a hydrometric database combining climate and discharge data. This database includes point measurements of temperature and precipitation from National Climatic Data Center COOP stations, temperature and snow water equivalent from Natural Resources Conservation Service SNOTEL stations (Figure 1), and snow water equivalents from snow course surveys. These point measurements are located primarily in the highest elevations of the watershed. To estimate the spatial variability in precipitation and temperature, we used PRISM (Parameter-elevation Regressions on Independent Slopes Model; http://www.prismclimate.org), which predicts spatial distributions of precipitation and temperature at monthly time steps. To track the spatial distribution of snow in the basin, we compiled Snow-Covered Area (SCA) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite sensor. SCA data used in our analyses represent the 8-day maximum snow cover extent during each snowmelt season (late March to early June) from 2000-2006.

We compare time series and spatial patterns of these climate variables to discharge at the Canyon Mouth Gauge (Figure 1), which is the flow forecasting point for the Cache la Poudre. Because we are interested in sources and timing of snowmelt runoff in the basin, our analyses are conducted using 'naturalized' flow records in which the effects of diversions and impoundments have been removed. These naturalized flow rates are estimated using a basic accounting method: adding or subtracting diversions and changes in reservoir storage.

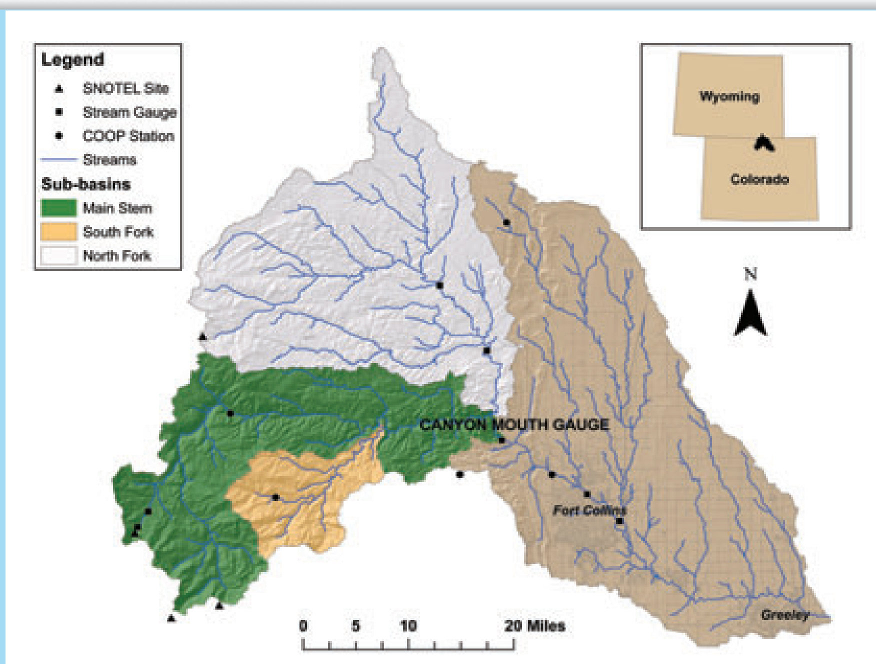


Figure 1. The Cache la Poudre watershed, including measurement locations and sub-basins.

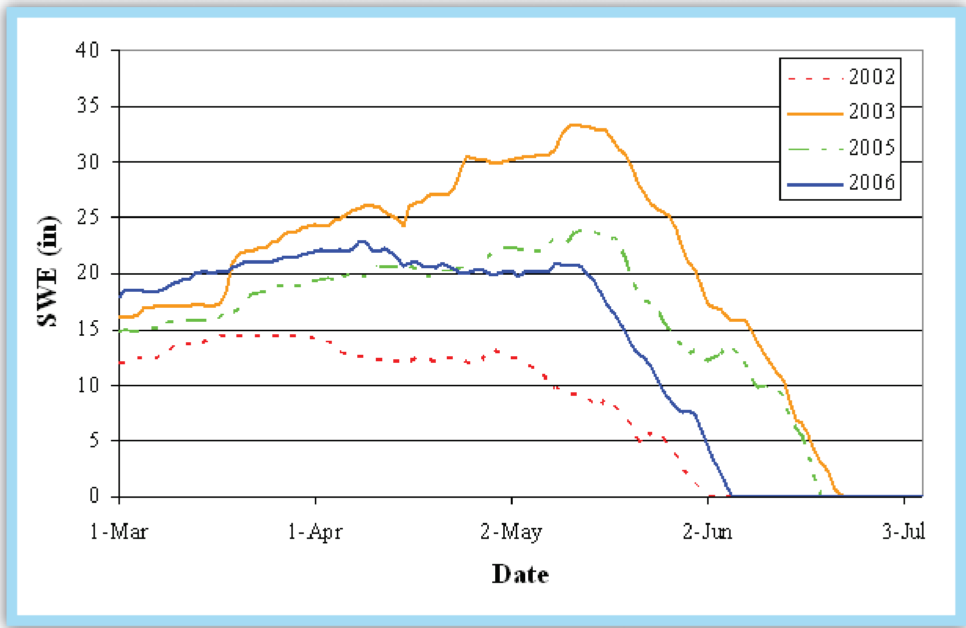


Figure 2. Spring-summer snow water equivalent at the Joe Wright SNOTEL site (10,120 feet). (Data source: Natural Resources Conservation Service)

Results

The upper Cache la Poudre Basin exhibits high spatial variability in temperature and precipitation. According to the PRISM model, average annual precipitation ranges from 13 inches at lower elevations to 53 inches near the headwaters, with a distinct increase in precipitation occurring above 10,000 feet. PRISM-derived average annual temperatures decrease from 50˚F at the lowest elevations to 25˚F at the headwaters. Temperature in the basin follows a seasonal cycle, with minimum temperatures in December and maximum temperatures in July. Average precipitation for the basin is lowest during the winter months and then increases during the spring, with maximum monthly average precipitation occurring in May.

Snow water equivalents measured at SNOTEL sites highlight the importance of spring precipitation. Figure 2 shows example snow water equivalent time series for the Joe Wright SNOTEL site (10,120 feet). During two of the years shown in Figure 2 (2003 and 2005), snow accumulation continued until mid-May. In all years, melt at this high-elevation site began in early to mid-May. In contrast, snow-covered area data show rapid snow melt over much of the basin area in late March (Figure 3), with the snow line gradually rising in elevation throughout the spring. Spring snow storms are evident in the snow cover data for all years except 2006. These spring storms caused abrupt rises in snow cover over the basin, but the additional snow cover typically melted within a week after each event.

These precipitation and snowmelt patterns affect the magnitude and timing of snowmelt runoff in the basin. River flow at the Canyon Mouth Gauge shows a gradual rise during early spring snowmelt, which begins from late March to late April (Figure 4). In most years, a gradual rise in discharge during early spring is followed by a rapid increase in discharge around mid-May. This rapid flow increase corresponds to the time when high elevation snowpack begins to melt (Figure 2). Peak flow occurs in late May to early June, and the river then recedes to baseflow conditions by mid-August.

Discussion

The spatial distribution of precipitation and temperature in the Cache la Poudre Basin implies a moisture surplus in the upper elevations of the basin and a moisture deficit in the lower elevation zones. Analyses of spring snow cover depletion and discharge data indicate that snow melt below around 8,000 feet does not typically result in increased river discharge. As the snow line rises above 8,000 feet, discharge begins to rise gradually, followed by a more rapid increase in flow as the snow line rises above around 9,500 feet elevation. Although each year exhibits a somewhat different relationship between snow cover depletion and discharge, the strong coupling between high elevation melt

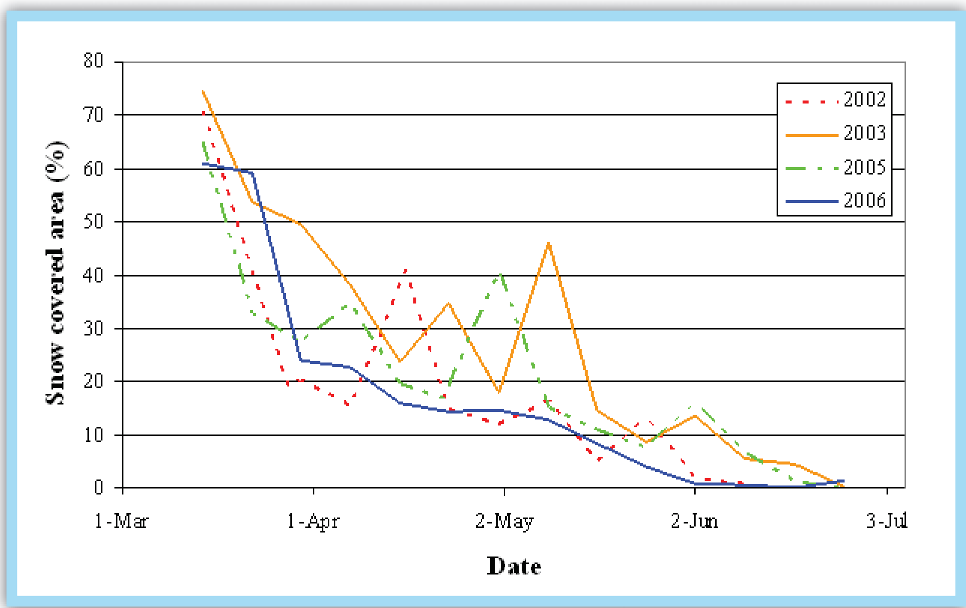


Figure 3. Spring-summer snow covered area depletion for the Cache la Poudre Basin. (Data source: MODIS 8-day composite snow cover, National Snow and Ice Data Center)

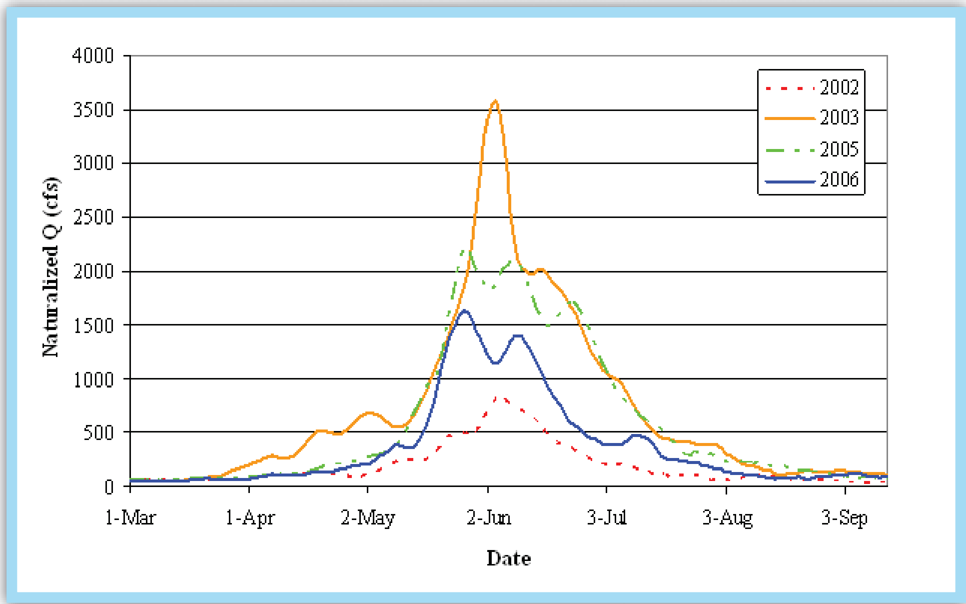


Figure 4. Naturalized discharge at the Cache la Poudre Canyon Mouth gauge. Discharge values represent a 7-day moving average. (Data sources: U.S. Geological Survey, Colorado Division of Water Resources, and water accounting by G. Varra)

elevation tends to result in a gradual rise in Cache la Poudre river flow during April and early May. A rapid rise in the hydrograph occurs around mid-May, when the high elevation snowpack (above ~9,500 feet) begins to melt. Spring months have the highest average precipitation in this basin, and temperatures and precipitation during April and May can have a significant effect on river discharge.

MODIS snow cover data and the PRISM model have been useful for characterizing how and when different elevation zones in the basin contribute runoff to the Cache la Poudre during recent years (since 2000). We are working on quantifying these relationships and expanding the analysis to earlier years by using shape and timing characteristics of the hydrograph. Future work will incorporate snow cover, snow water equivalent, and temperature into a low-parameter model for predicting ensembles of snowmelt hydrographs under varying spring temperature and moisture conditions.

and rapid increase in discharge suggests that high elevation zones contribute much of the snowmelt runoff to the river during high flows.

Under average conditions, the high-elevation moisture surplus is most significant in spring months, when precipitation is high but temperatures are still relatively low. Because precipitation in the basin is highest on average in the spring months, spring precipitation can contribute a significant portion of the annual water yield for the basin. The years 2005 and 2006 highlight the importance of spring conditions for river discharge. These years had similar high-elevation snow water equivalents on April 1 and May 1 (Figure 2), the dates when spring flow forecasts are issued, but the river flow was much higher in 2005 (Figure 4). During 2005, spring precipitation contributed to an increase in the high-elevation snowpack (Figure 2) and additional moisture input at lower elevations (Figure 3). With both high spring precipitation and cool spring temperatures, the 2005 snowpack persisted longer in the spring, and the river had a sustained high flow period lasting from mid-May through late June. In contrast, 2006 had low spring precipitation and warmer spring temperatures. The 2006 snowpack depleted rapidly throughout the basin (Figures 2 and 3), and the river had both lower peak flow and a shorter duration of high flows. With these warmer, drier spring conditions, the recession of the snowmelt hydrograph was already underway by mid-June.

Conclusions and Future Work

The timing and spatial distribution of precipitation in the Cache la Poudre Basin are both important controls on the amount of snowmelt runoff that occurs. Our preliminary results show that snowmelt from around 8,000-9,500 feet

Acknowledgements

This project is funded by the Colorado Water Institute. We acknowledge the support and helpful contributions of Bill Fischer and Shawn Hoff from Cache la Poudre Water Users Association; Andy Pineda, Katie Melander, and Drew Linch of Northern Water; Tom Perkins and Mike Gillespie of the Natural Resources Conservation Service; and George Varra and Mark Simpson of the Colorado Division of Water Resources.

The Cache la Poudre River descends eastward in northwestern Colorado through Roosevelt National Forest in Poudre Canyon. (Image courtesy of Stephanie Kampf)

Refining Water Accounting Procedures Using The South Platte Mapping And Analysis Program

by Luis Garcia, Dept Head, Civil and Environmental Engineering, Colorado State University

Abstract

As growing urban populations, drought and environmental concerns impact water resources in the arid West, it is imperative that efficient use is made of ground and surface waters in Colorado's irrigated valleys. Accurate accounting of groundwater withdrawals is essential for determining efficient use. For 2007, the CWRRI Advisory Committee for Water Research Policy identified the need to refine current augmentation accounting procedures and methods for replacing depletions caused by groundwater pumping. The South Platte Mapping and Analysis Program (SPMAP) has been used successfully to manage data and run models addressing this problem.

The SPMAP project, which started in 1995, is a set of computer tools constructed to enhance water management by matching data acquisition, system design, modeling, and user interfaces with the expressed needs of area water managers. The tools have been developed by the Integrated Decision Support Group (IDS), a research group at Colorado State University. Initially designed for the Lower South Platte River Basin, the popularity of the SPMAP tools has spread so that components of SPMAP are being used throughout Colorado and in other western states. The SPMAP tools include a geographic information system component, SPGIS; a consumptive use model IDSCU; and an alluvial water accounting system, IDS AWAS.

Earlier this year, Hal D. Simpson, the State Engineer, issued a procedures memorandum which declared, "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." Simpson's declaration ensures that more and more water managers, evaluators, and engineers will use IDS AWAS. Now that the IDS AWAS component of the SPMAP tools has become the program of choice for augmentation accounting in Colorado, it is imperative that the program continue to be tested, debugged and refined. In addition, the attention garnered by IDS AWAS will no doubt attract more users to the other SPMAP tools as well, necessitating that these tools continue to be maintained and enhanced.

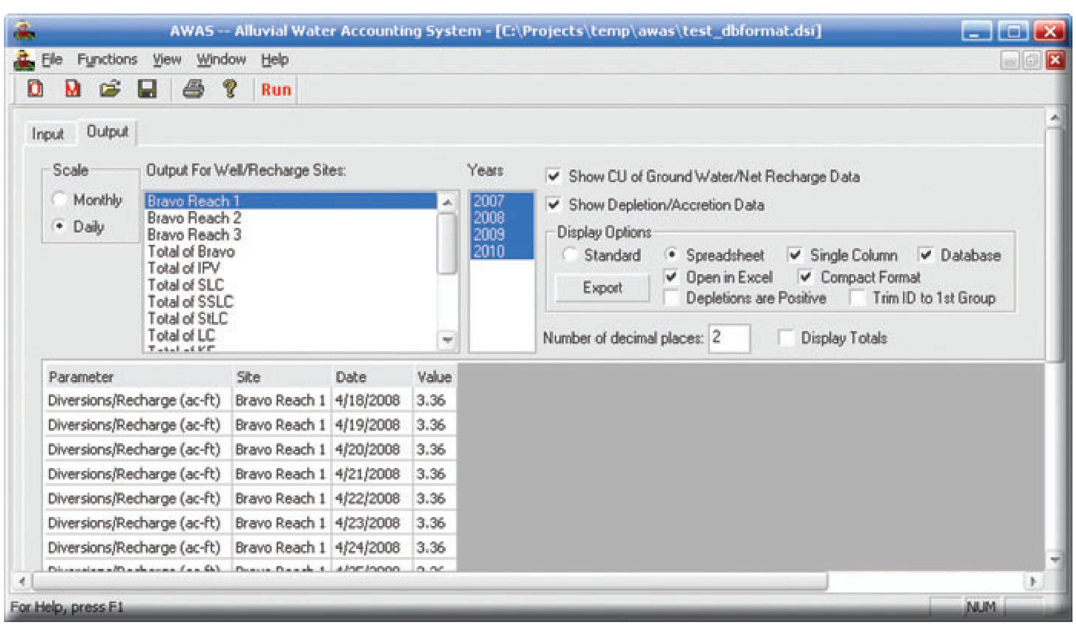
Progress Report for the Following Tasks:

1. Continue to maintain and upgrade the IDS AWAS model to meet immediate needs. Since the model has been adopted statewide, we have received calls and inquiries from parts of the state outside the South Platte Region. The latest was from the Division 2 office of the state engineer in Pueblo asking for a tutorial or quick start guide for IDS AWAS. We will continue to develop minor enhancements to the model.

Major changes to AWAS include output formatting options so help users take tabular data and move it into a spreadsheet or database. Below is an example of diversion output that is suitable for entry into a database. Each row contains a complete data record.

2. Maintain the IDS Website (www.ids.colostate.edu). We use this website for users to download the latest version of all our programs as well as any documentation and a list of all the updates for each version that we release.

IDS continues to maintain a very active website where all the updates to each of our models is posted. This website continues to be used extensively by water users. In addition we have made some upgrades to the GIS component of the website. We have as part of our website a component called the South Platte GIS web site, where users can view well locations, ET imagery, and aerial photographs (www.ids.colostate.edu/projects/spgis/). This year we reprojected all of the GIS layers layers displayed on the website to NAD83 since the state moved from NAD27 to NAD83. We currently have a table with both NAD27 and NAD83 layers so that users using either of the two projections still have access to the data.



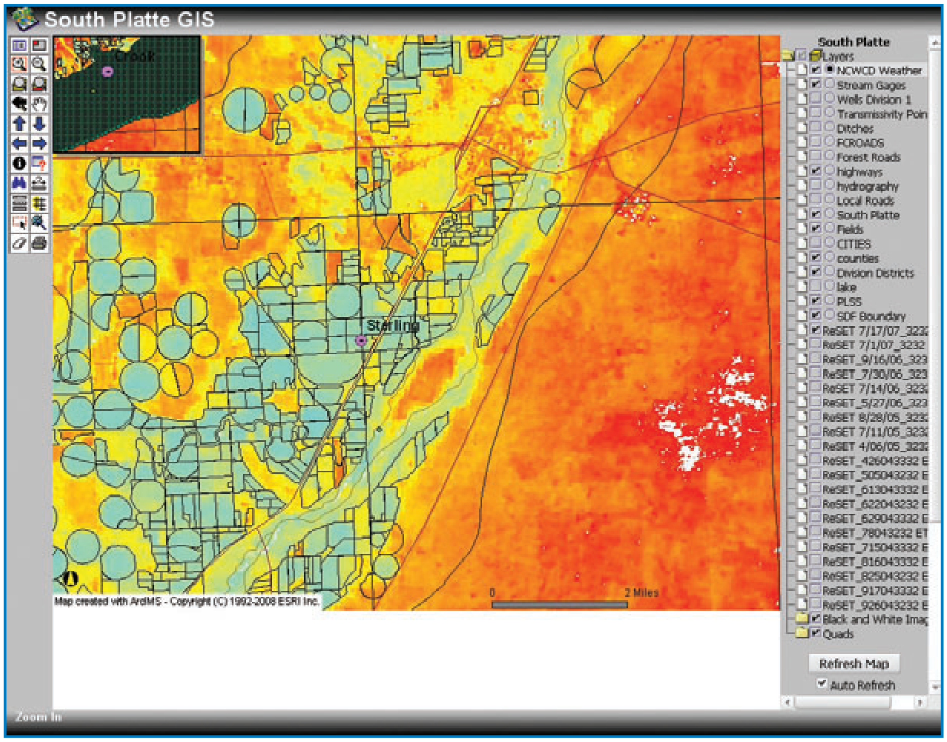
3. Start an effort to update the IDSCU model. While updates to the model have been done over the last few years, including adding several new ET equations, we will focus on working with water user organizations to enhance the capabilities of the model to compute ET estimates for the consumptive use of groundwater which they can then use to determine the demand being met by well pumping. Other enhancements will be to strengthen the capabilities of the model to compute well efficiencies (based on well pumping versus ET consumption) and to provide more detailed water budget results for the users.

We continue to support users with questions regarding the IDSCU. Some of the changes that we have made to the model include the ability to support new weather station formats. We are able to access both NCWCD and CoAgMET and automatically download the data for a user selected weather station. This significantly improves the ability to update weather data for an existing project. We have also included some additional weather station formats such as the Middle Rio Grande Conservancy District (MRGCD), the Arizona Meteorological Network (AzMet), and the California Irrigation Management Information System (CIMIS).

IDS also added monthly field application efficiency, improved importing data from other projects, and added the ability to run the model with shortened periods of record.

4. Continue to document, test and revise all enhancements to SPMAP.

IDS updated its training manual for IDSCU in May 2007 after giving a training session and is working on updating the IDSCU user manual.



Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	1	0	7
Masters	1	0	0	1	2
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	7	0	1	1	9

Notable Awards and Achievements

Department of the Interior awards CSU & Dr. Jose Salas with the Partners in Conservation Award

In Washington D.C. on May 7th, 2009, the Department of the Interior presented the Partners in Conservation Award to several organizations that contributed in developing the "Colorado River Interim Guidelines". Among them, Colorado State University (Department of Civil and Environmental Engineering) along with three other universities were recognized for helping in the effort.

The contribution of Colorado State University, has been through two back to back research projects dealing with Stochastic Hydrology of the Colorado River. In these projects Dr. Salas and graduate students utilized innovative record extension techniques for updating the data base of naturalized flows of the Colorado River system, developed new approaches for reconstructing streamflows of the Colorado River based on tree ring indices, developed potential scenarios of streamflows that may occur in the Colorado in future years, characterized multiyear droughts of the Colorado using simulation and mathematical techniques, and tested the effects of stochastic streamflows on the operations of the Colorado River system, particularly the effects on reservoir levels and outflows of the two major lakes, i.e. Lake Powell and Lake Mead.

Additionally the project helped improving the software SAMS (Stochastic Analysis, Modeling, and Simulation), software developed at CSU for stochastic simulation of hydrological data. Two Ph.D. students T.S. Lee and Z. Tarawneh were funded by the referred projects. Also Ph.D. students C.J. Fu and D.J. Lee and M.S. student J. Keedy collaborated in some parts of the projects.

Publications from Prior Years

1. 2008CO171B ("Technology Transfer and Information Dissemination") - Water Resources Research Institute Reports - Brown, Jennifer, ed., 2008, Proceedings, South Platte Forum, 19th Annual, "News, Weather and Water", Information Series 106, Colorado Water Institute, Colorado State University, Fort Collins, Colorado, 33 pages.