Colorado Water

Newsletter of the Water Center of Colorado State University

May/June 2008 Volume 25, Issue 3

Theme

Water Research Updates

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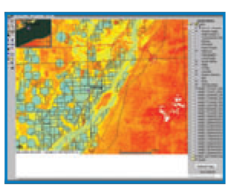

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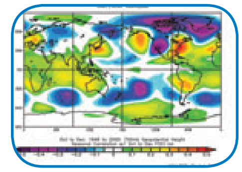

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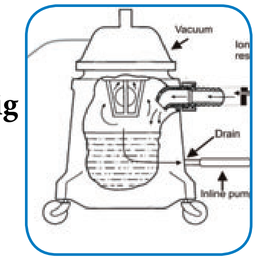

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COLORADO WATER is a publication of the Colorado Water Resources Research Institute at Colorado State University. The scope of the newsletter is devoted to enhancing communication between Colorado water users and managers, and faculty at the research universities in the state. This newsletter is financed in part by the U.S. Department of the Interior, Geological Survey, through the Colorado Water Resources Research Institute. The contents of this publication do not necessarily reflect the views and policies of the U.S. Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

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Colorado Water Resources Research Institute: http://cwrri.colostate.edu
CSU Water Center: http://watercenter.colostate.edu
Colorado Water Knowledge: http://waterknowledge.colostate.edu

Published by: Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO 80523-1033
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Cover Photo: Photos taken by Bill Cotton of CSU at the Global Water Colloquium, held at the Hilton in Fort Collins on March 25th, 2008

Editorial

by Reagan Waskom, Director, Colorado Water Resources Research Institute

Colorado Water Resources Research Institute renamed after 43 years supporting water research in Colorado

In a 1963 speech to the Western Resources Conference, Colorado Senator Gordon L. Allott, in stated that "*It is from the field of research that our hopes really spring… as our society becomes larger and in turn places greater demands upon this limited water resource, only research can be counted on to provide the answers which we must and will have for America.*" A year later on July 12, 1964, President Lyndon Johnson signed into law the Water Resources Research Act of 1964, creating the state water institutes. President Johnson said in his signing speech, "*The Water Resources Research Act … will enlist the intellectual power of universities and research institutes in a nationwide effort to conserve and utilize our water resources for the common benefit.*"

Forty-three years, 400 scientific reports and four Directors later, CWRRI is being renamed the Colorado Water Institute (CWI) as a result of the passage of Colorado House Bill 08-1026. We change our name with some caution, as the history and accomplishments of the Institute are the legacy of many productive partnerships between university faculty and the Colorado water management community working to use scientific research to inform water management and policy decisions. We are indebted to our past supporters, contributors, funders and we thank members of the current Colorado Legislature and water community who have supported the cause of water research. The scope and mission of CWI was slightly updated and expanded through HB08-1026, but remains – a statewide institute with the purpose of "*developing, implementing, and coordinating water and water related research programs in the state, and transferring the results of research to potential users.*"

In this era of shrinking budgets and growing water problems, more is required of the science community if research is to be adequately funded and we are to capture public support in the midst of many other compelling societal problems that require funding. In a perfect world, water management professionals and policy makers should beat a path to the university, seeking science to support decisions. The responsibility for this disconnect is probably rightly shared, but it is incumbent on the research community to communicate the importance and relevance of science in public decision making in order to justify the expenditure of public money. Water and environmental problems are complex and variable systems; uncertainty is intrinsic and complete or perfect knowledge of these systems is unrealistic, often causing decision makers to doubt the value of science. If there is such a thing as "bad science", it is not when the results are uncertain, but when we mix politics or advocacy in the scientific process.

In the process of testifying for four bills over the past three years to fund the Water Institute, I have been fascinated by the astute and critical questioning I have faced from our decision makers. Healthy skepticism of our objectivity, relevance, impact and need to further study every topic have all been expressed to me at the state capitol. Our legislators face the issue of accountability and impact on a daily basis and believe scientists should be no different. So how do we convince policy makers to better fund and use science in decision making, while we remain objective and true to the science?

One strategy involves taking a global issue such as water and making it meaningful to society at the local level. It requires scientists to get serious about measuring the impact of their work at the local level, being accountable for funding, and communicating effectively with non-technical audiences. In a sense we must become advocates, not for scientific outcomes, but for science itself.

Water research has some strong supporters in the Colorado water community and the state legislature who want us to engage in relevant academic inquiry and training programs. The passage of CO House Bill 08-1026 and HB 08-1405 this session speak to that support. Our advocates see the potential for higher education to discover new knowledge and technology through scientific research, but the burden is on us to be more relevant, responsive and timely in order to meet the water information needs and expectations of Colorado.

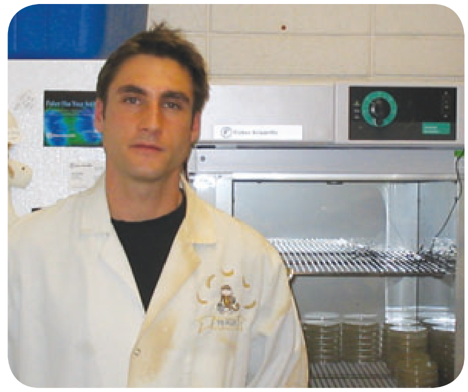
Reagan Waskom

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.

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).

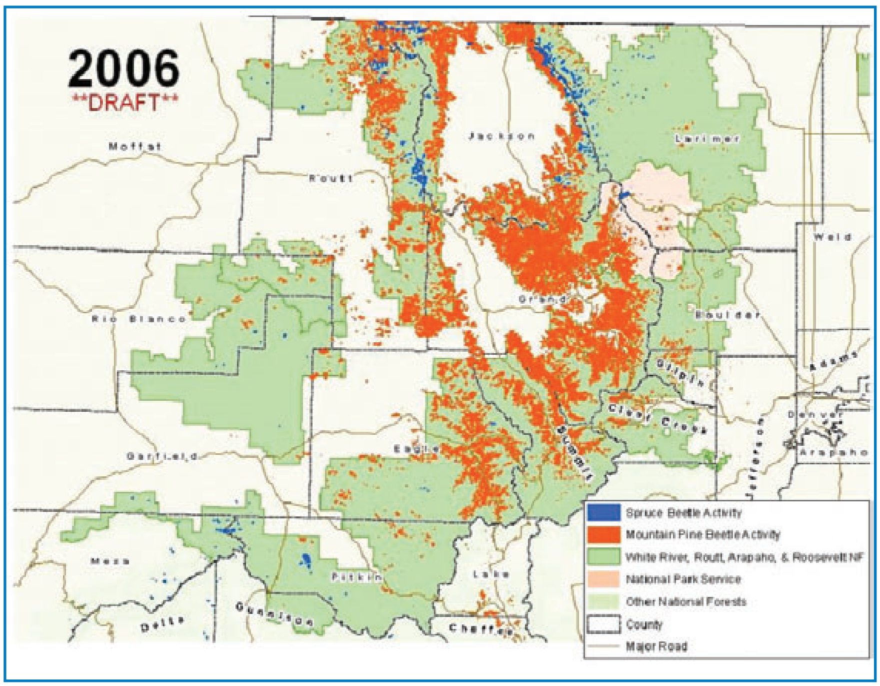


Figure 1. Extent of beetle-killed areas in North-central Colorado (Adapted from Colorado State Forest Service.

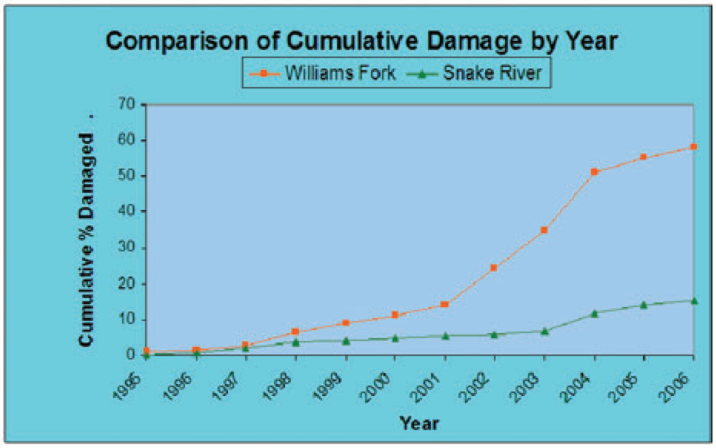


Figure 2. Beetle killed area over time for Williams Fork and Snake River watersheds.

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.

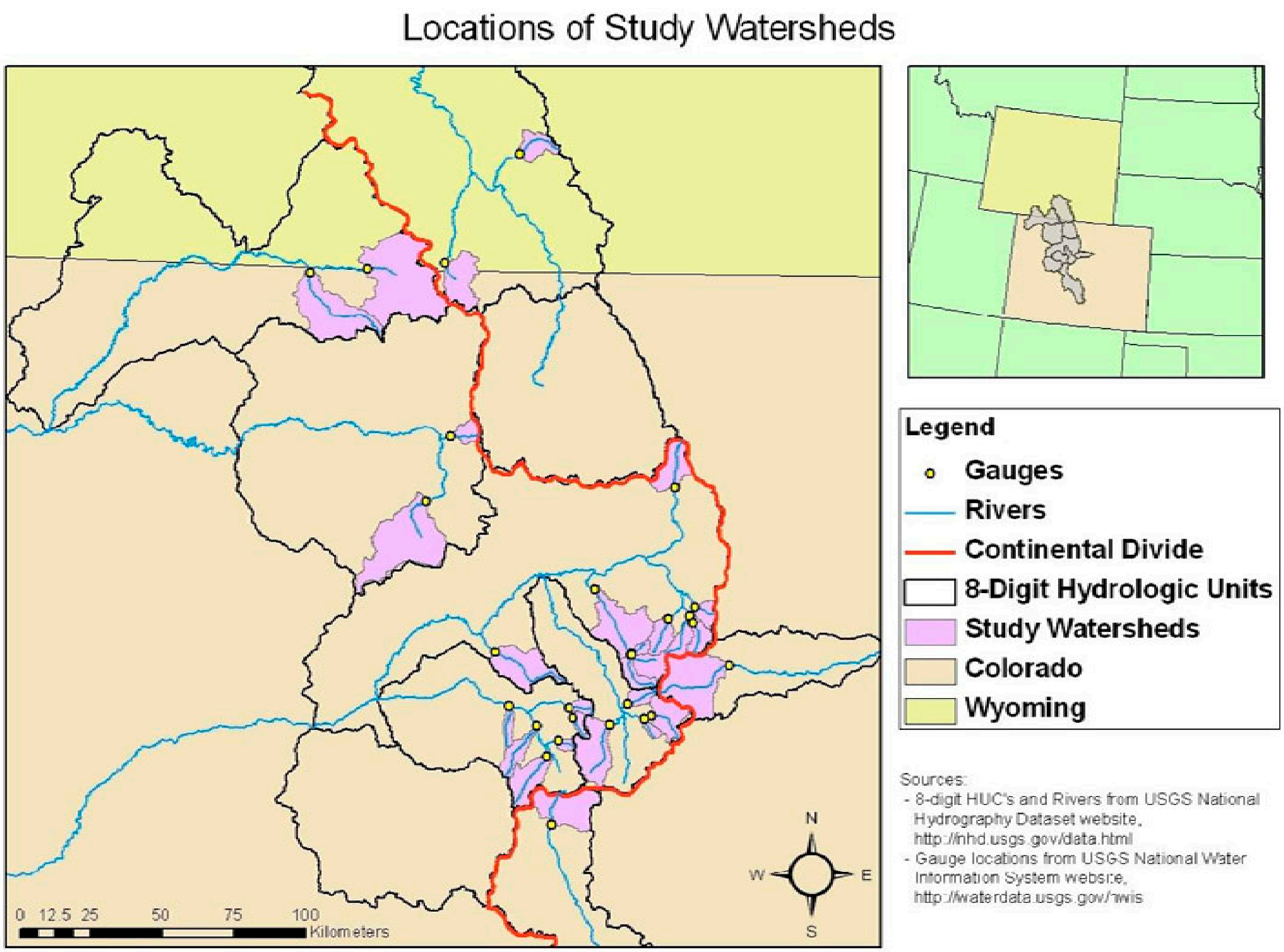


Figure 3. Location of selected watersheds used in this study.

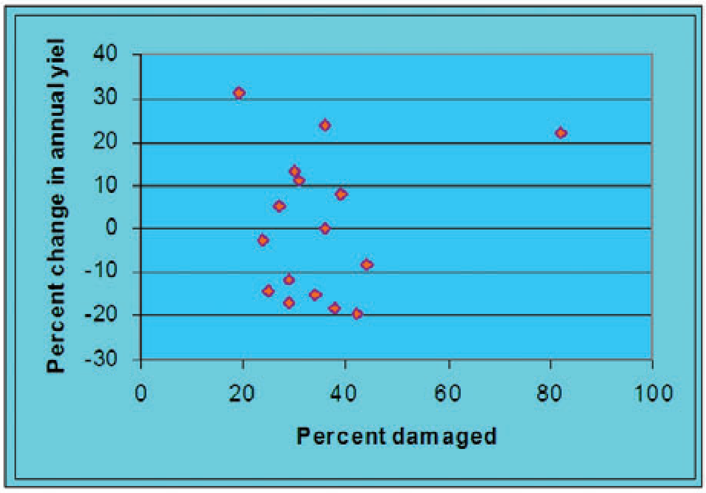


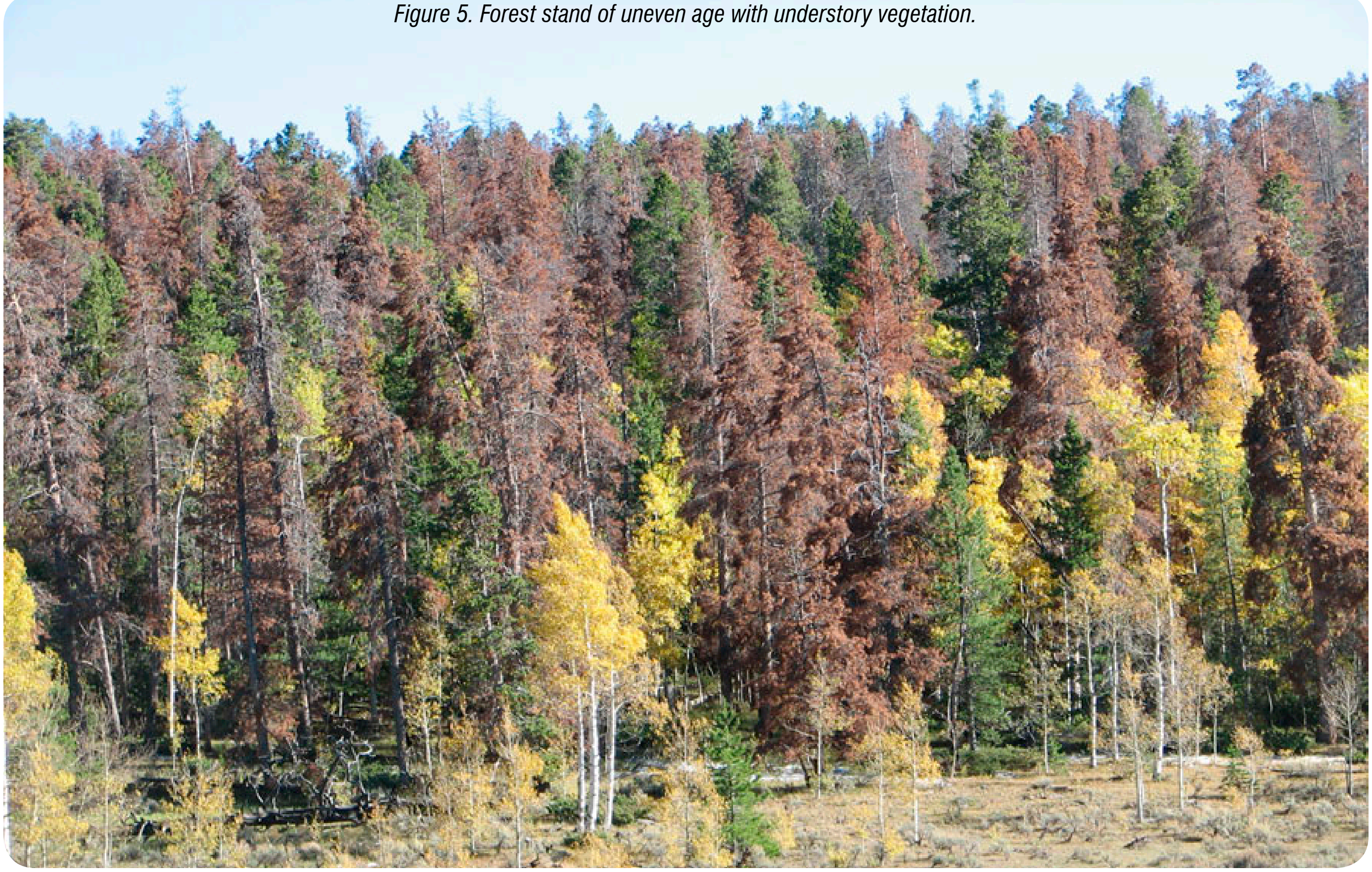
Figure 4. Changes in annual water yield as a function of beetle killed area in the watershed.

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.

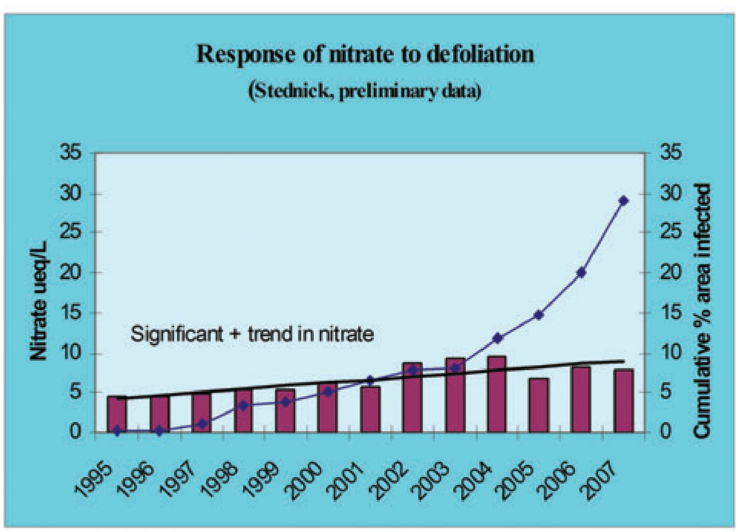


Figure 6. Increases in nitrate-nitrogen concentrations and beetle-killed area over time in Williams Fork.

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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Gov. Ritter Creates Forest Health Advisory Council

by Katherine Timm, Outreach Division Supervisor, Colorado State Forest Service, Colorado State University

On Feb. 12, Gov. Bill Ritter created the Colorado Forest Health Advisory Council, a multi-agency action group that will coordinate and lead efforts to address the mountain pine beetle epidemic and other threats to Colorado's 22 million acres of forestland.

"Colorado's forests are vital to our environment, to our communities, to our economy and to our overall quality of life," Gov. Ritter said. "But our forests are at risk, and one of the biggest risks is the mountain pine beetle. This epidemic has decimated more than 1.5 million acres of mature lodgepole pines over the past decade and could wipe them out in another three to five years.

"Many people have been working on this issue for years," Gov. Ritter added. "The time has come for a unified, coordinated and aggressive action plan that enlists all stakeholders as collaborative partners in this fight. The time has come for state government to lead that effort. The Colorado Forest Health Advisory Council will bring together local, state, federal and private interests to identify and implement short-term actions and long-term forest health strategies."

Harris Sherman, executive director of the Colorado Department of Natural Resources, and Jeff Jahnke, state forester and director of the Colorado State Forest Service, co-chair the council. Other council members include Hamlet "Chips" J. Barry, Denver Water Department; Charles E. Bedford, The Nature Conservancy; Rick Cables, US Forest Service; Robert H. Davis, Forest Energy Corp.; Nancy Fishering, Intermountain Resources; State Sen. Dan Gibbs, Senate District 16; Kara S. Heide, Vail Resorts; James A. Ignatius, Teller County; Suzanne R. Jones, The Wilderness Society; Susan Kirkpatrick, Colorado Department of Local Affairs; James Martin, Colorado Department of Public Health & Environment; Kendrick E. Neubecker, Colorado Trout Unlimited; Joseph T. O'Leary, Warner College of Natural Resources, Colorado State University; Suzanne B. O'Neill, Colorado Wildlife Federation; Tom Plant, Governor's Energy Office; Barry J. Smith, Eagle County Emergency Management Director; Rebecca L. Swanson, Office of Governor Bill Ritter, Jr.; Ronald N. Turley, Western Area Power Administration, Edward C. Wang, Town of Granby; State Rep. Al White, District 57; Sally Wisely, Bureau of Land Management. .

The Council will immediately develop a short-term action plan that:

- Implements priorities identified in Community Wildfire Protection Plans
- Encourages and supports establishment of Forest Improvement Districts
- Coordinates expansion of economic incentives to reduce forest treatment costs
- Implements landscape-scale stewardship projects
- Continues the Community Forest Restoration Grant Program

The Colorado Forest Health Advisory Council will coordinate and lead efforts to address the mountain pine beetle epidemic and other threats to Colorado's 22 million acres of forestland.

The Council also will develop long-term strategies for sustainable forest health, addressing:

- A statewide vision to protect communities from fire and restore forest health
- Guiding principles for the design and implementation of restoration projects
- A method to monitor and evaluate existing projects and share lessons learned
- Ways to increase public awareness about the relationship between healthy forests and clean drinking water, quality wildlife habitat, safe communities, strong economies, and recreational and tourism values

The Council will report back to the Governor and Legislature annually. If recommendations require legislative action, those recommendations will be submitted by Oct. 1 prior to the January start of the legislative session.

"Many healthy-forest efforts are already underway," Gov. Ritter said. "This Council will not reinvent the wheel. It will build a better wheel, a faster wheel that maximizes these efforts. This Council is not another study group. It is an action group.

"This is not just about managing a crisis; it's about getting ahead of it. It's about being proactive as we consider the future of our forests 25, 50, 100 years from now."

During its first meeting on March 27, council members focused on short-term opportunities related to state and federal legislation, as well as the long-term need for a comprehensive vision for Colorado's future forests.

Several representatives of the state's Congressional delegation provided an update on forestry and wildfire legislation, and discussed the potential impacts of program cuts proposed in President Bush's FY 2009 budget. State Sen. Dan Gibbs also provided an update on forestry-related bills at the Capitol. During the coming weeks, the council will make recommendations to the Governor regarding support for key initiatives.

Council members also discussed a new comprehensive state forest resource assessment being developed by the Colorado State Forest Service. The assessment will incorporate several factors, including forest health, wildfire risk, population growth, wildlife habitat and critical watersheds with an eye toward identifying priority forest landscapes in need of management.

Once completed, the assessment and a strategy for moving forward will provide a vision and roadmap for the state's diverse forestry interests — including local communities, land managers and non-profit organizations — to work together to address Colorado's most pressing forest management challenges.

Other topics discussed by the council at the March 27 meeting include:

- Opportunities to further the work of existing local forest collaboratives, such as the Front Range Roundtable and Colorado Bark Beetle Coalition
- The need to reduce the cost of forest treatments through market development, incentives and increased use of prescribed fire
- Strategies for combining wildfire risk reduction in watersheds with the restoration of forest health
- The importance of assisting communities with the development of Community Wildfire Protection Plans (CWPPs) and FireWise building strategies
- Ways to utilize forest biomass as a renewable energy resource as part of Gov. Ritter's Climate Action Plan and New Energy Economy initiative

USGS science for a changing world — Recent Publications

Principal Locations of Metal Loading from Flood-Plain Tailings, Lower Silver Creek, Utah, April 2004 by B.A. Kimball, R.L. Runkel, K. Walton-Day http://pubs.usgs.gov/sir/2007/5248/

Quality of Shallow Ground Water in Three Areas of Unsewered Low-Density Development in Wyoming and Montana, 2001 by T.T. Bartos, T.L. Quinn, L.L. Hallberg, C.A. Eddy-Miller, http://pubs.usgs.gov/sir/2008/5012/

GSFLOW - Coupled Ground-Water and Surface-Water Flow Model Based on the Integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005) by S.L. Markstrom, R.G. Niswonger, R.S. Regan, D.E. Prudic, and P.M. Barlow http://pubs.usgs.gov/tm/tm6d1/

Ground- and Surface-Water Chemistry of Handcart Gulch, Park County, Colorado, 2003-2006 by P.L. Verplanck, A.H. Manning, B.A. Kimball, R.B. McCleskey, R.L. Runkel, J.S. Caine, M. Adams, P.A. Gemery-Hill, and D.L. Fey http://pubs.usgs.gov/of/2007/1020/

The Fate, Transport, and Ecological Impacts of Airborne Contaminants in Western National Parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon by D.H. Landers, S.L. Simonich, D.A. Jaffe, L.H. Geiser, D.H. Campbell, A.R. Schwindt, C.B. Schreck, M.L. Kent, W.D. Hafner, H.E. Taylor, K.J. Hageman, S. Usenko, L.K. Ackerman, J.E. Schrlau, N.L. Rose, T.F. Blett, and M.M. Erway. 2007 http://www.nature.nps.gov/air/Studies/air_toxics/wacap.cfm

U.S. Geological Survey Colorado Water Science Center: http://co.water.usgs.gov

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
Dr. Thomas Borch, Assistant Professor, Depts. Chemistry & Soil and Crop Sciences
Yun Ya Yang, Ph.D. Student, Dept. Soil and Crop Sciences
Dr. Jessica G. Davis, Professor, Depts. Soil and Crop Sciences & Animal Sciences
Colorado State University

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.

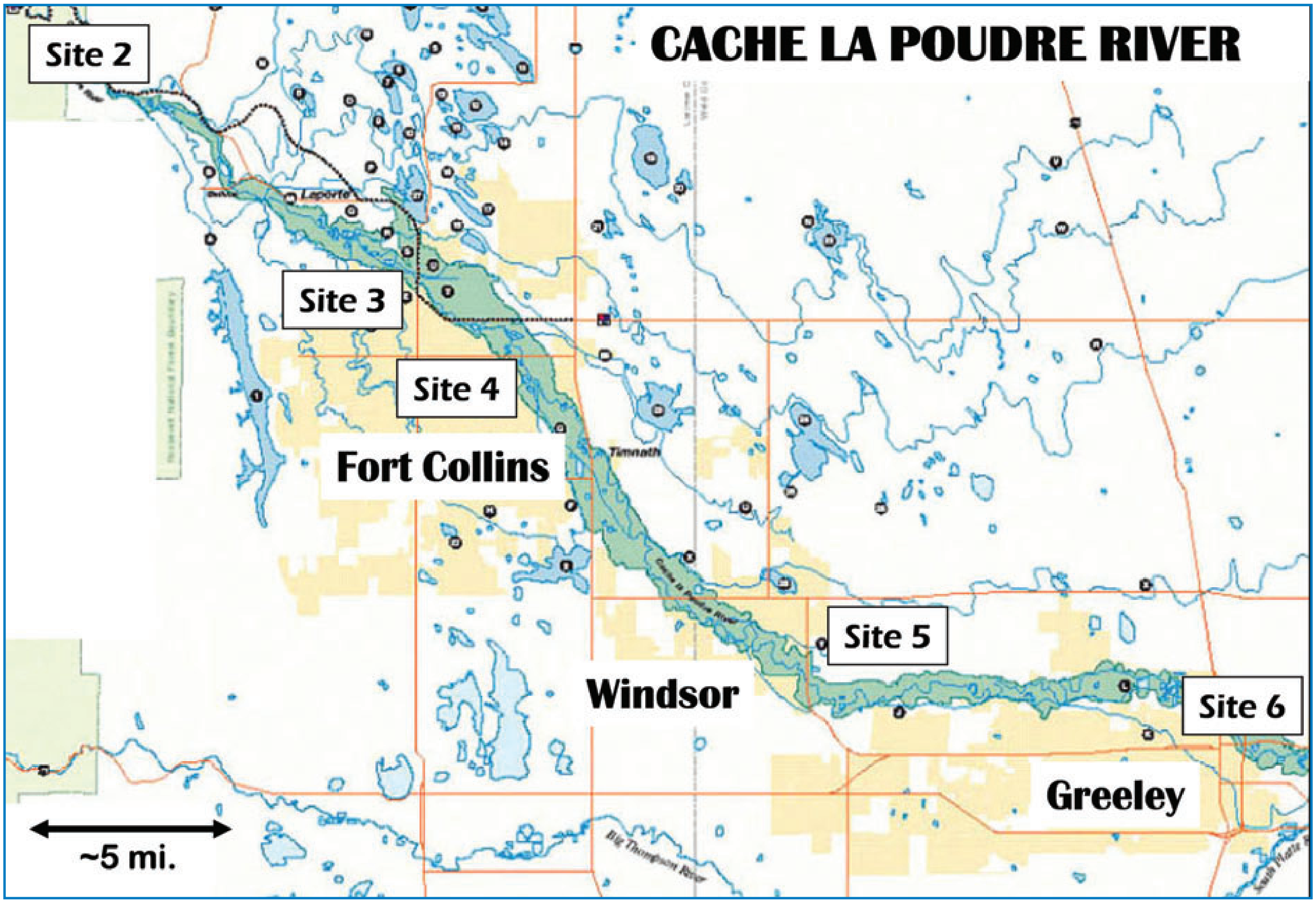


Figure 1. Approximate sampling sites along the Cache la Poudre River.

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*

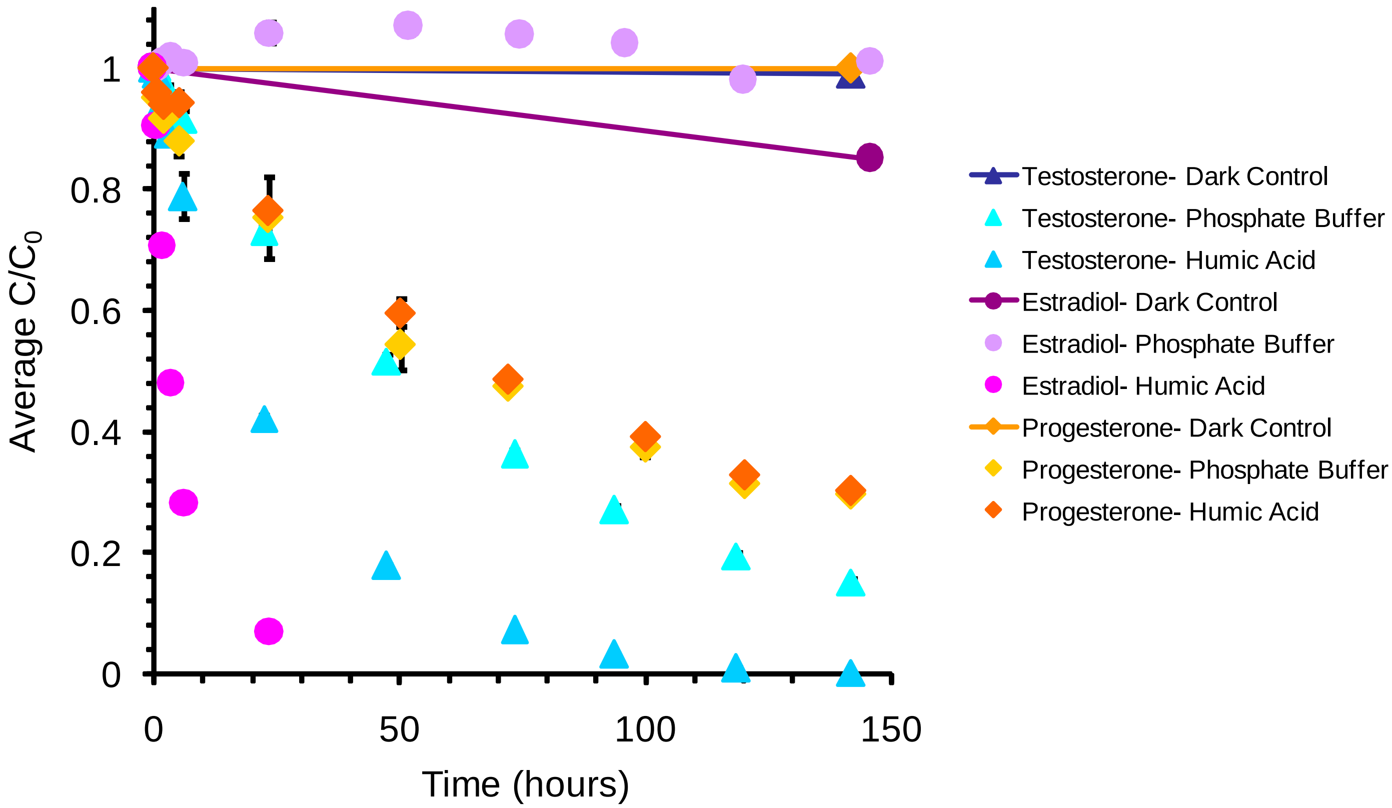


Figure 2. Direct and Indirect Photodegradation of Testosterone, 17β- Estradiol and Progesterone by UV-A light in Phosphate Buffer and Humic Acid. Error bars represent ± one standard deviation. Where not visible, error bars are smaller than symbol size.

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-

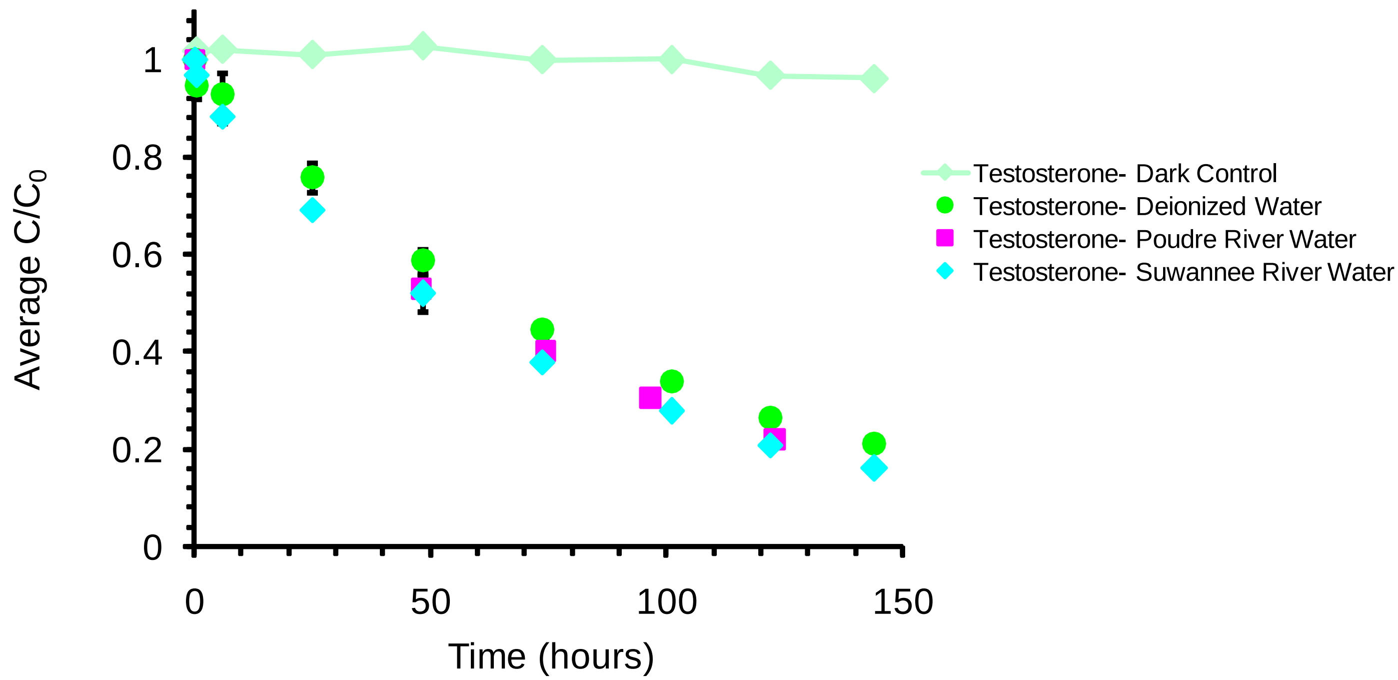


Figure 3. Photodegradation of Testosterone by UV-A light in Deionized Water, Poudre River Water (site 6) and Suwannee River Water. Error bars represent ± one standard deviation. Where not visible, error bars are smaller than symbol size.

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.

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

by Kathleen Conn, Ph.D. Candidate, Environmental Science & Engineering
Dr. Robert L. Siegrist, Professor and Director, Environmental Science & Engineering
Colorado School of Mines, Golden, Colorado

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

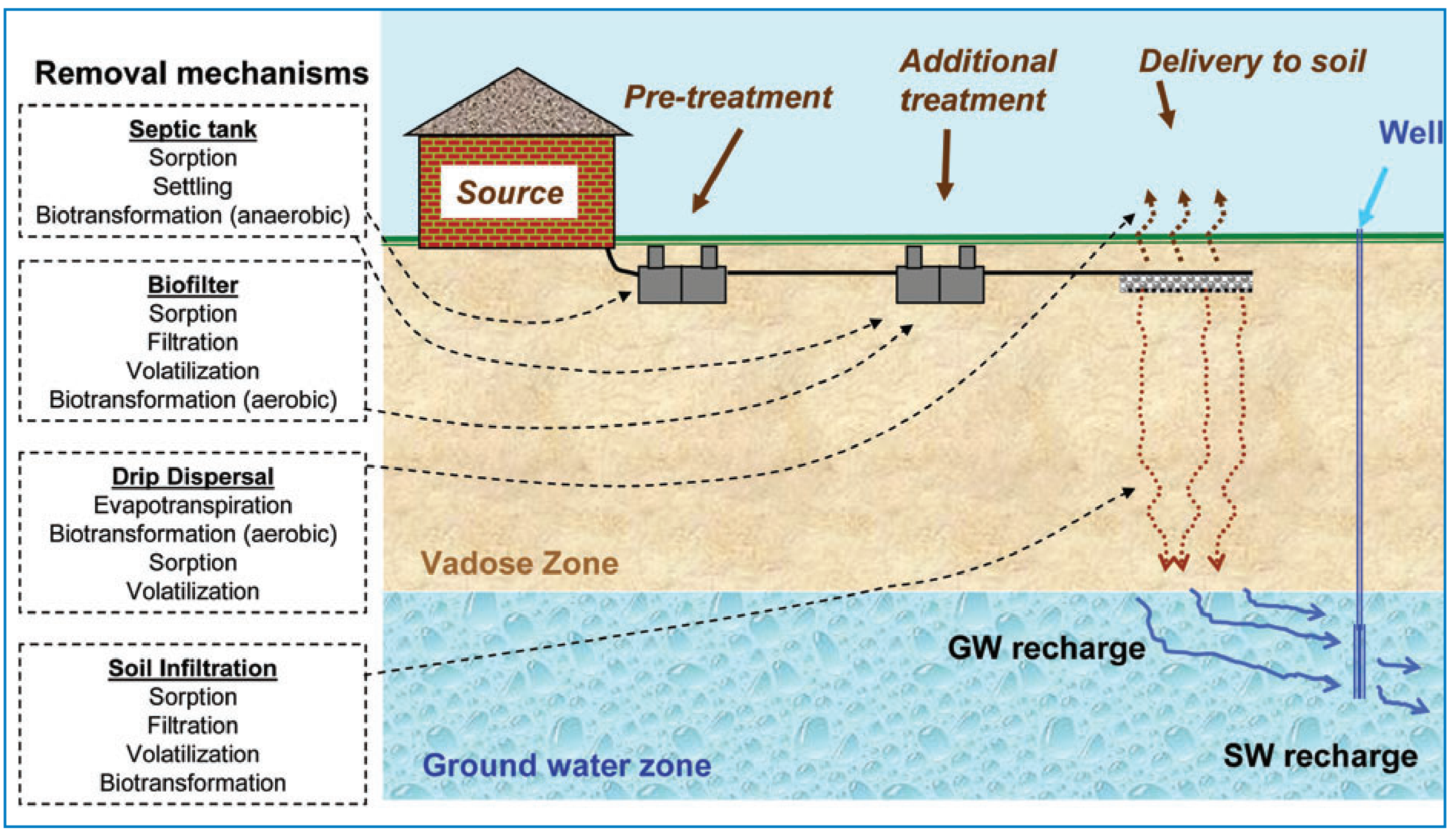


Figure 1. Key components of an onsite wastewater treatment system and relevant removal mechanisms. Above-ground treatment may be through conventional septic tank(s) or additional treatment units such as biofilters. Delivery to the soil may be through conventional soil infiltration or by an alternative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

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

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. 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

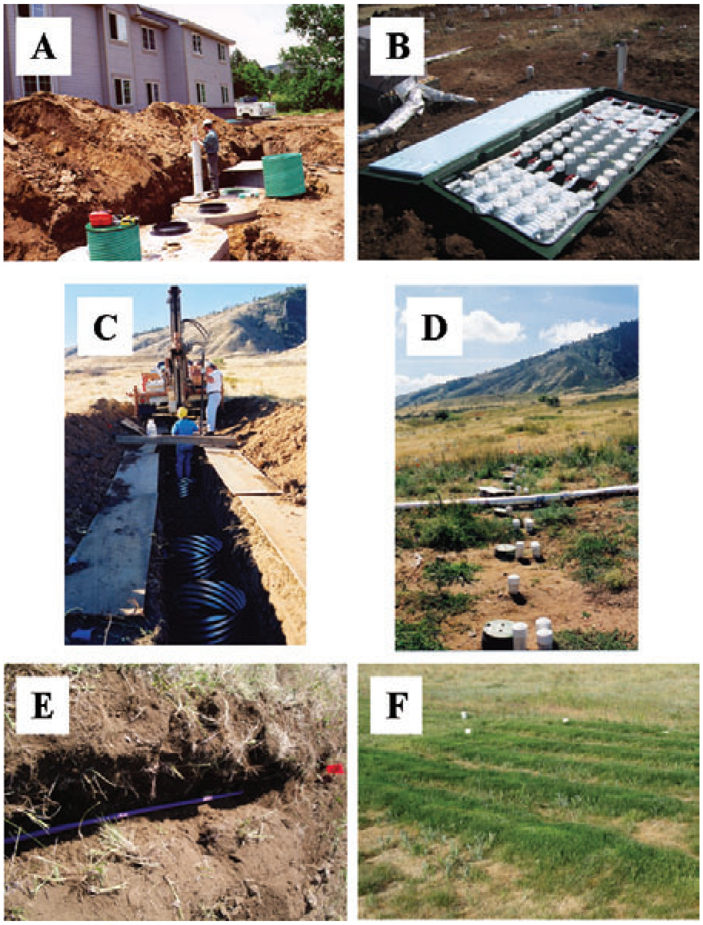


Figure 2 (above) CSM Mines Park Field Site: Wastewater from a multifamily residence is intercepted (A) and managed using pilot-scale unit operations such as a textile biofilter (B), in-ground test cells (C,D), and a drip dispersal network (E,F).

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

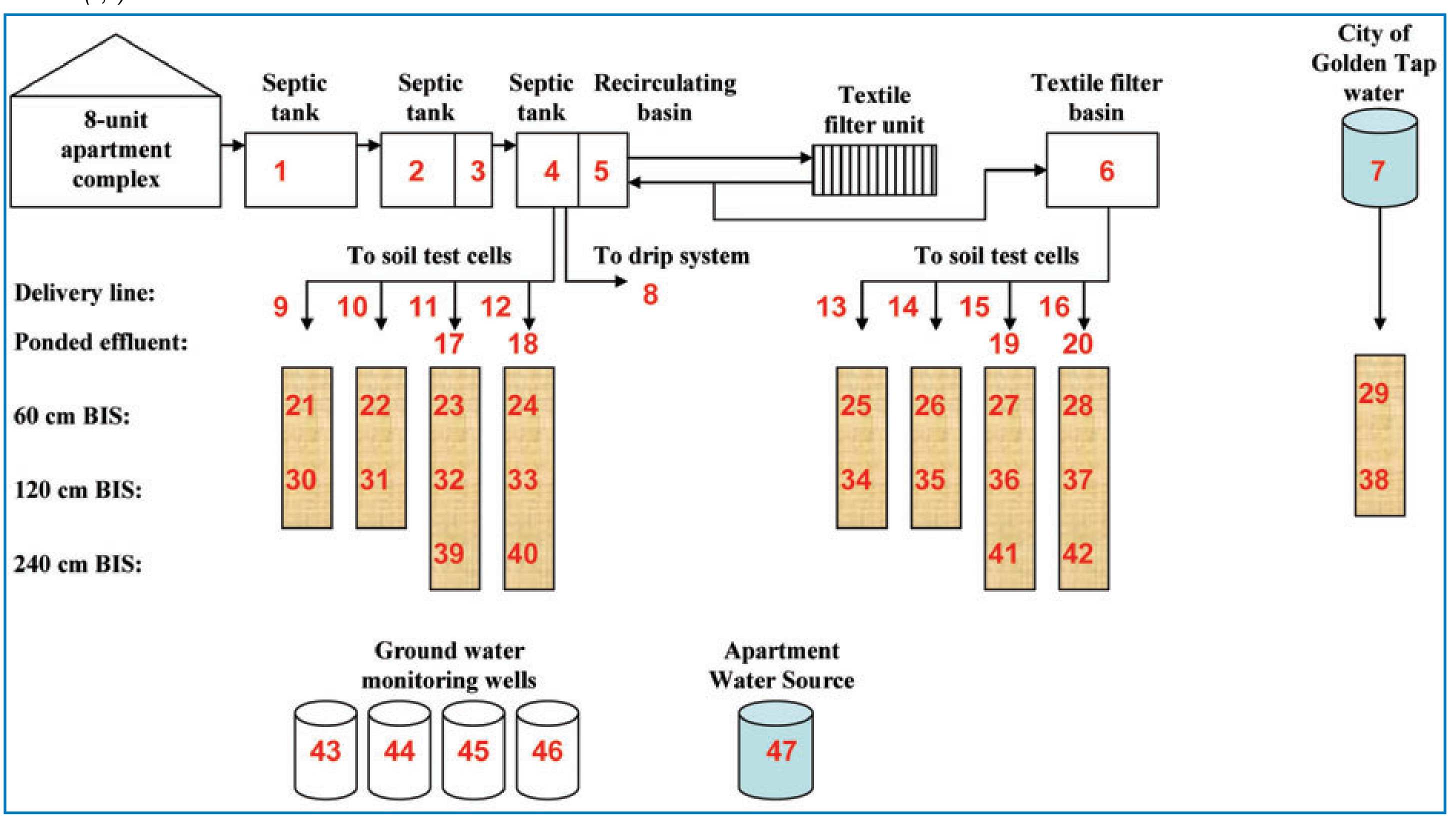
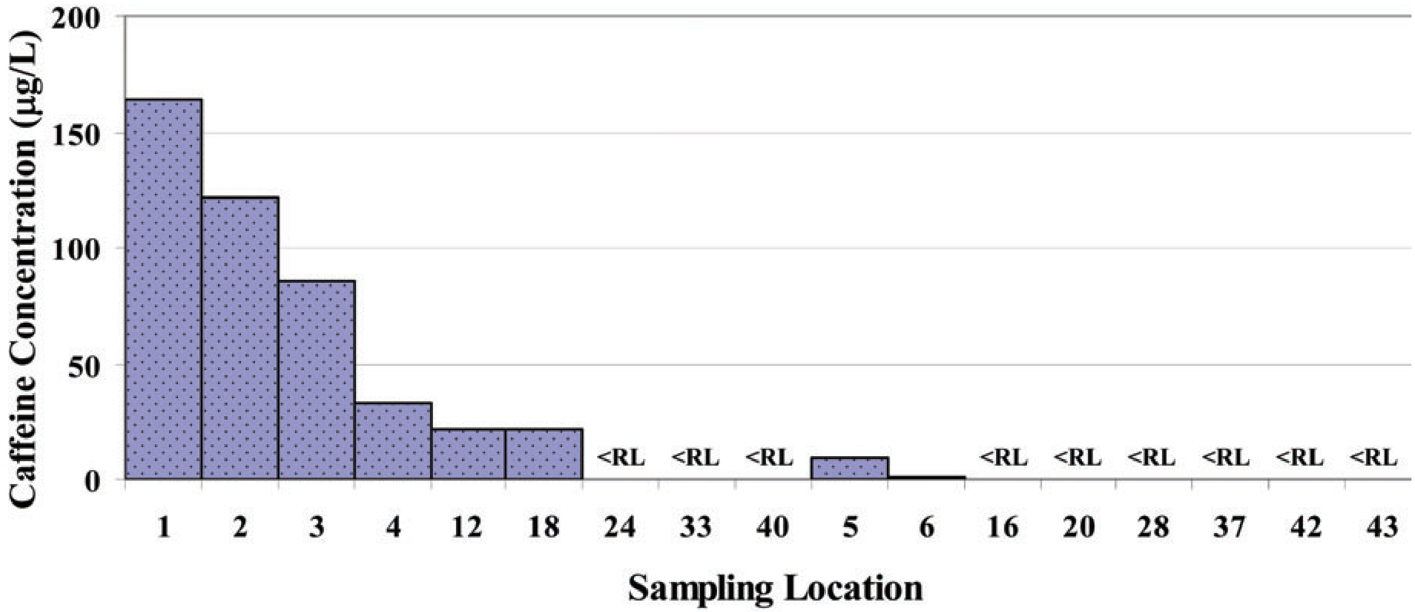


Figure 3. Schematic of the Mines Park Test Site aqueous sampling locations to assess fate of OWCs during onsite wastewater treatment. [BIS = below infiltrative surface]

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.

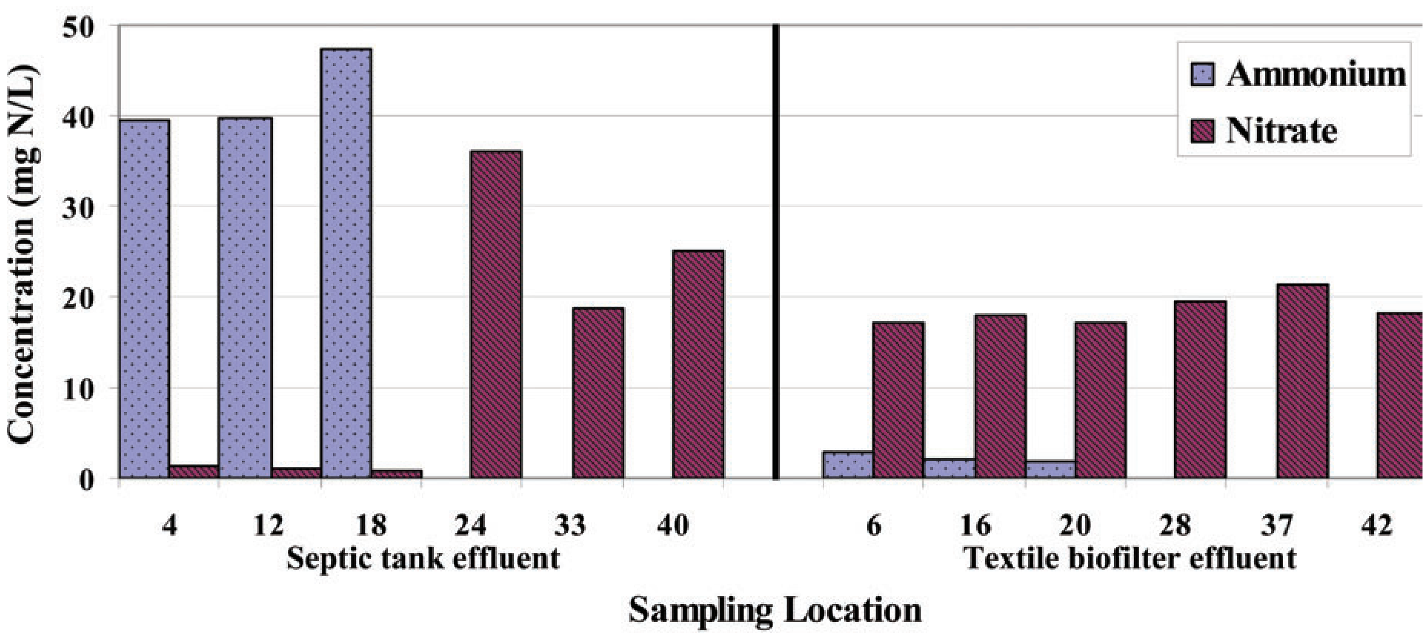
Preliminary Conclusions and Implications

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

The research is funded by the State of Colorado through an Interagency Agreement between the Colorado Water Resources Research Institute and CSM, Subagreement Number G-0042-1. The authors thank the U.S. Geological Survey National Institutes for Water Resources, U.S. Geological Survey Toxic Substances Hydrology Program, and the Colorado School of Mines Small Flows Program for further support. In particular, we thank Dr. Larry Barber, Dr. Mike Meyer, and Greg Brown at the USGS and Kathryn Lowe, Jill Tomaras, and Jim McKinley at CSM for assistance in sample collection and analysis.

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.]



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.

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.

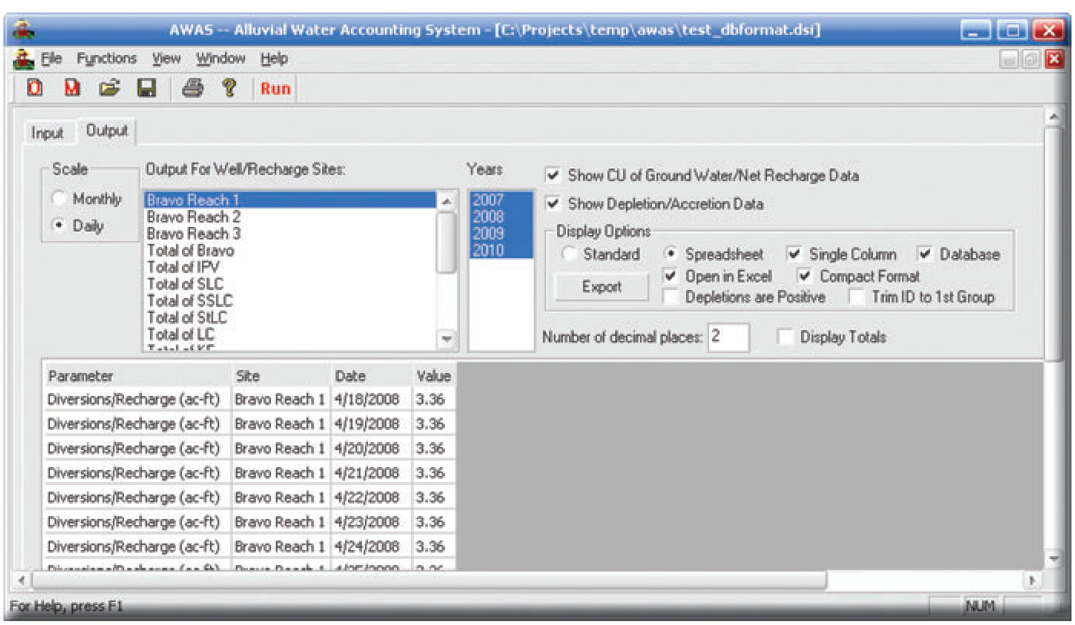
Progress Report for the Following Tasks:

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.



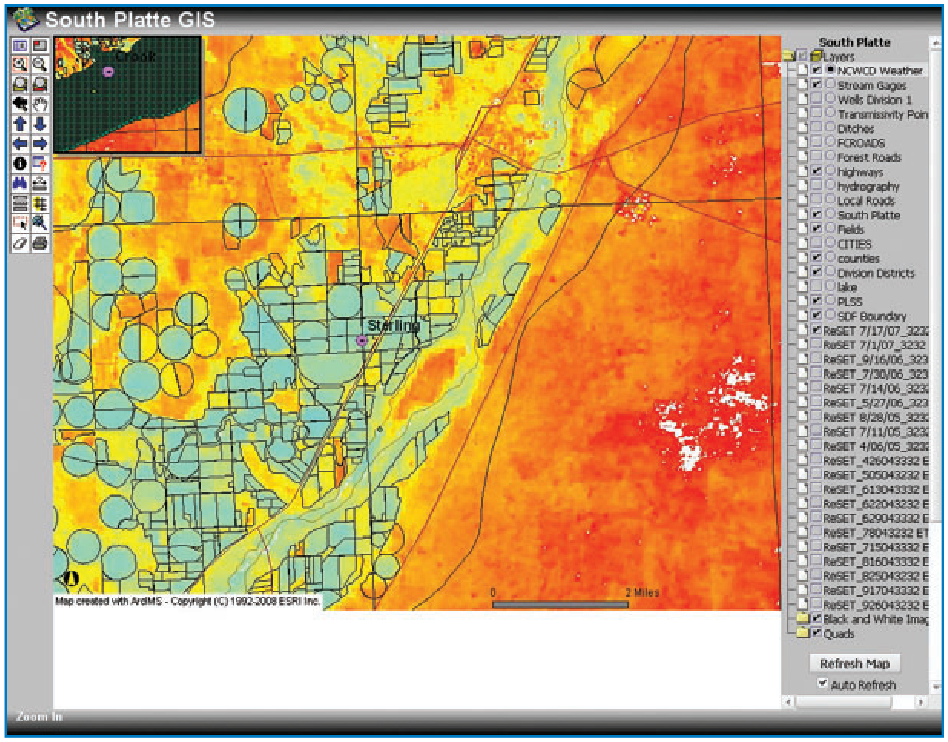
3. Start an effort to update the IDSCU model. While updates to the model have been done over the last few years, including adding several new ET equations, we will focus on working with water user organizations to enhance the capabilities of the model to compute ET estimates for the consumptive use of 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.



Long Range Forecasting of Colorado Streamflows

by Jose D. Salas, Professor, Civil and Environmental Engineering, Colorado State University
ChongJin Fu, PhD, Civil and Environmental Engineering, Colorado State University
Balaji Rajagopalan, Associate Professor, Civil Engineering, University of Colorado

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

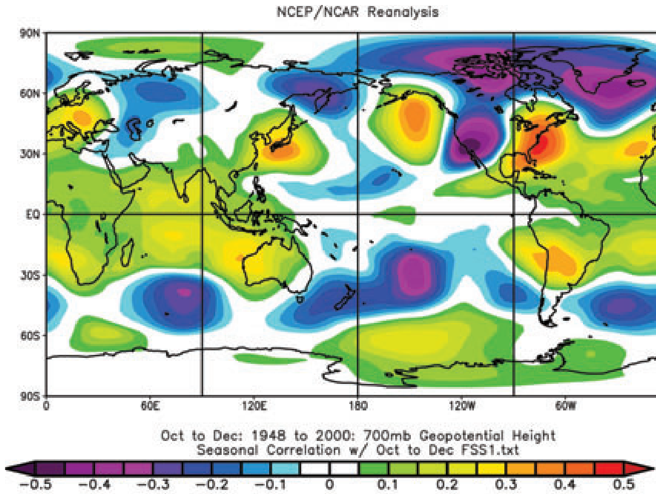


Figure 1. Correlation between the Apr-Jul streamflows of the San Juan River and previous year Oct-Dec mean 700 mb geopotential heights

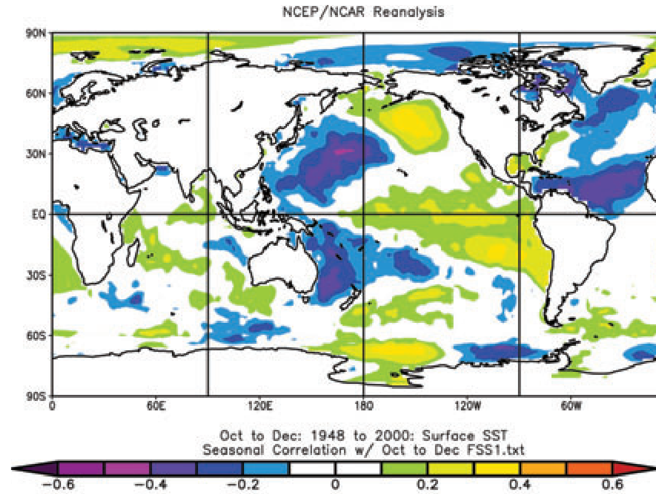


Figure 2. Correlation between the Apr-Jul streamflows of the San Juan River and previous year Oct-Dec mean SST

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

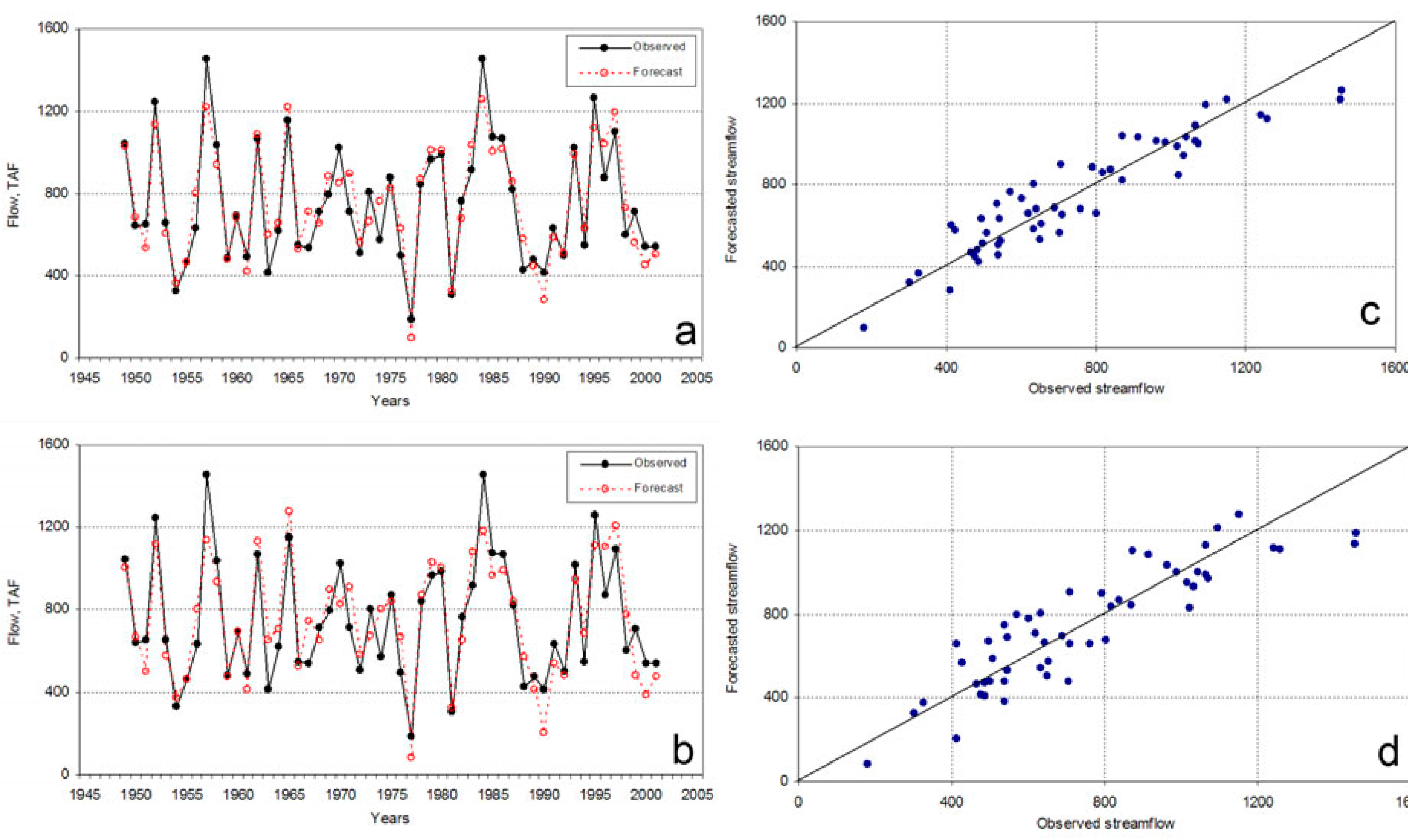


Figure 3. Observed and forecasted flows (based on single site model) for fitting in (a) and (c) and drop 10 % validation in (b) and (d) for the Gunnison River.

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.

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

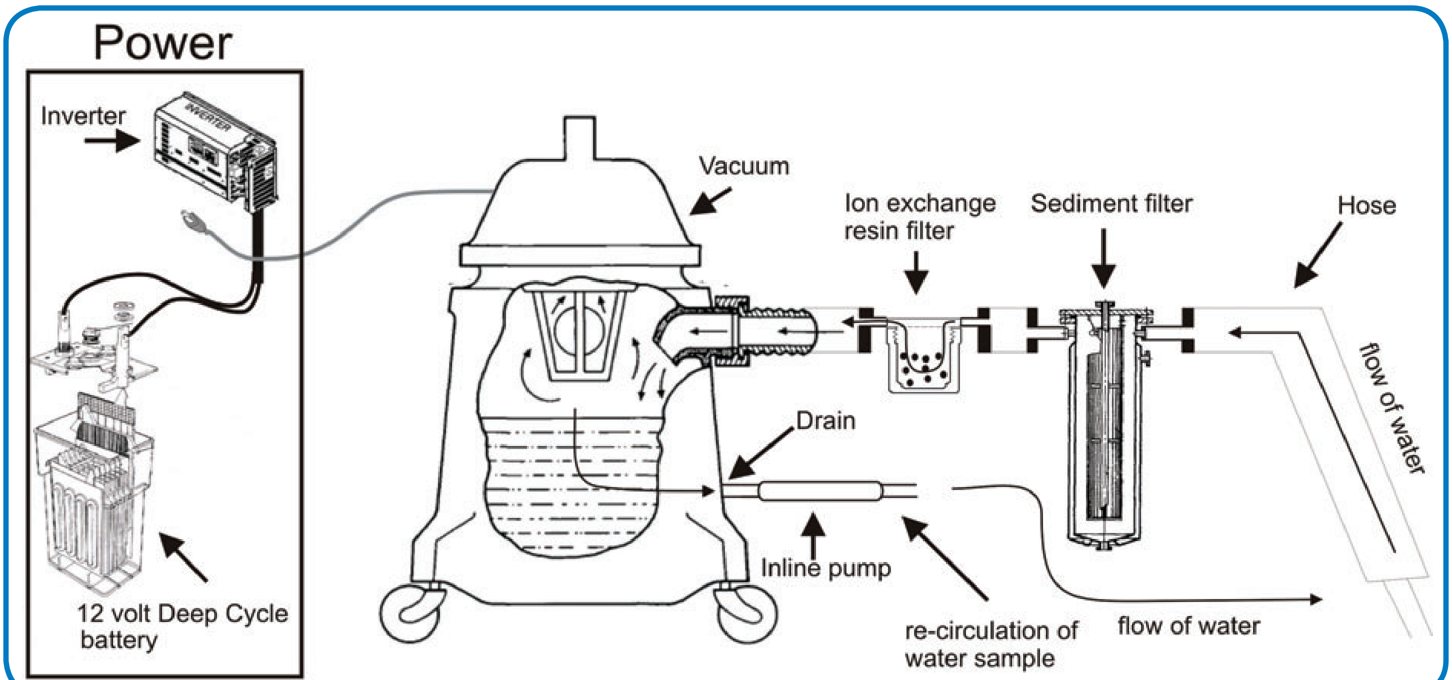


Figure 1. A schematic of the VacBAC. The Vacuum Based Adsorption of Contaminants (VacBAC) device. The VacBAC is a modified wet vacuum that contains a sediment removal filter and an ion exchange resin filter in the hose. Water is sampled (sucked up) via the hose, any particulates or sediment is removed 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.

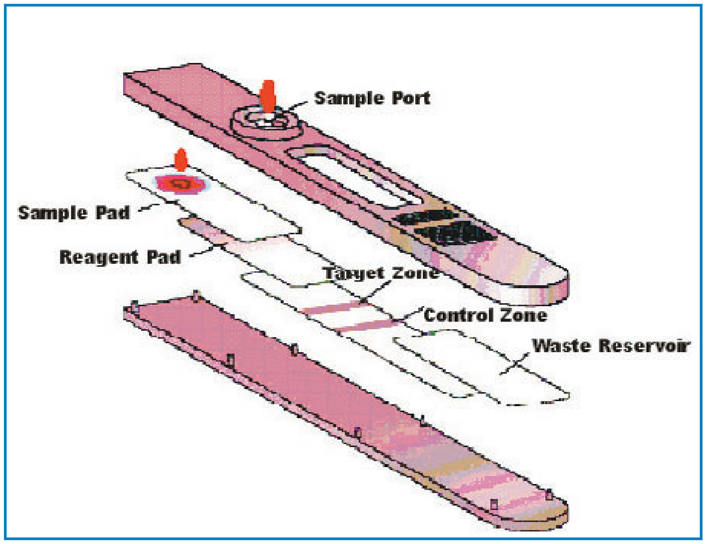


Figure 3. The lateral flow device (LFD). Any FRNA phages that recognize antibodies will be trapped at the target zone. The formation of a line in the control zone indicates that the test has been performed successfully (quality control). If a line at the target zone is present, a positive test is indicated. 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

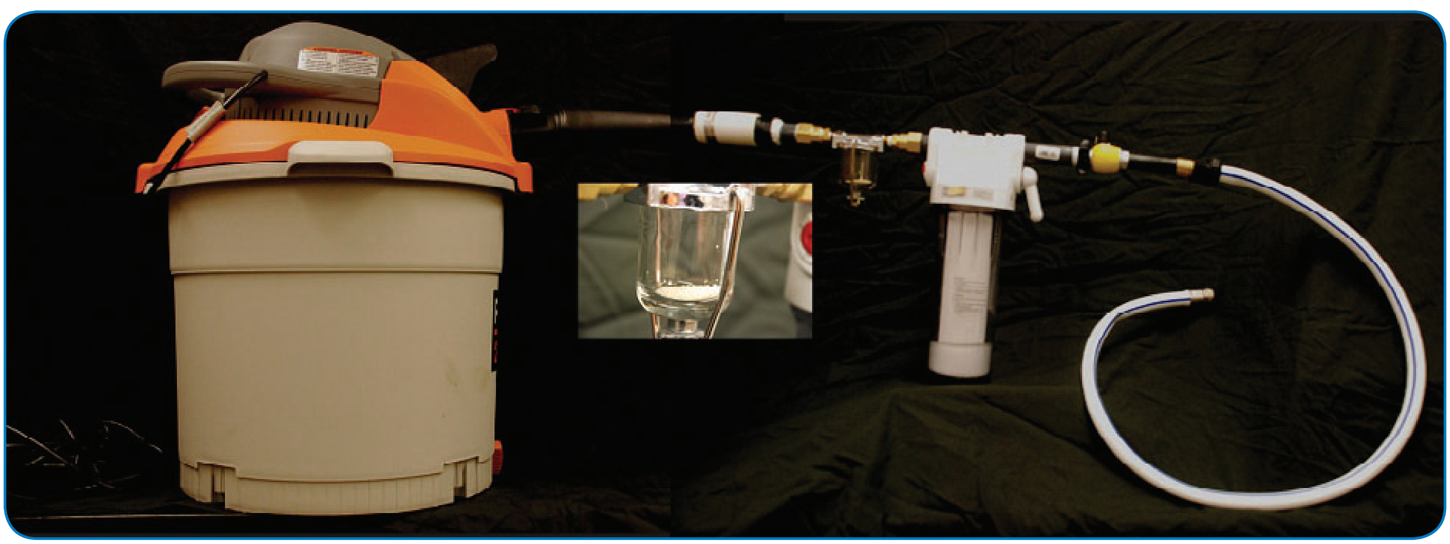


Figure 2. The VacBAC as currently constructed. The ion exchange resin filter is shown inset.

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

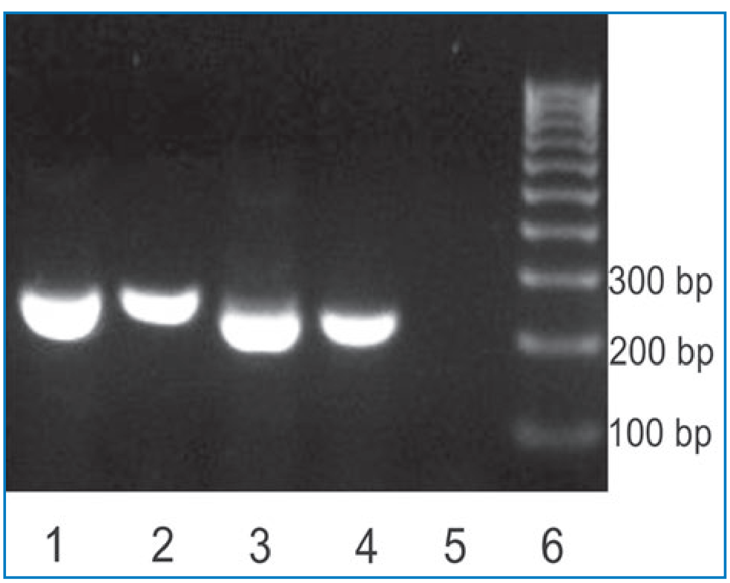


Figure 5. Agarose gel of RT-PCR amplicons of the four FRNA phages representing each of the four FRNA serogroups. Lane 1, MS2 (expected band size 266 bp); Lane 2, GA (expected band size 266 bp); Lane 3, QB (expected band size 225 bp); Lane 4 SP (expected band size 225 bp); Lane 5, negative control; Lane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

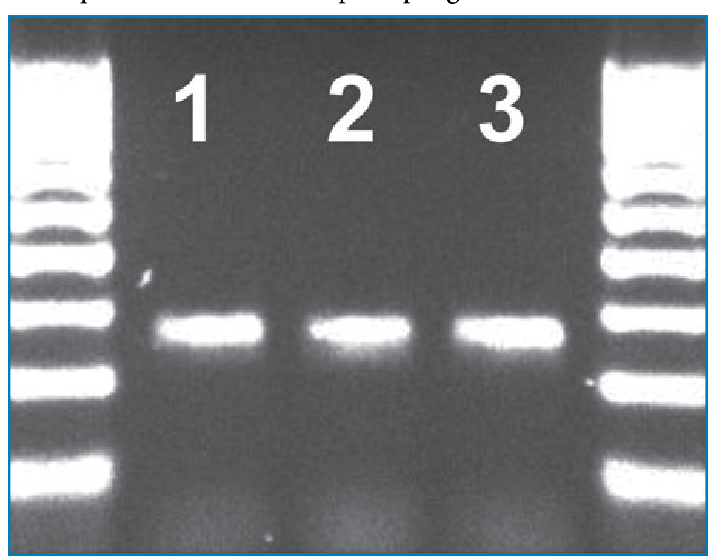


Figure 6. Evaluation of the VacBAC and RT-PCR for rapid detection of FRNA phage MS2. Lane 1 and 5, 100 bp ladder. The lanes identified by the numbers indicated the number of times the water sample was re-circulated prior to detection of the FRNA phages. So for example, in the lane identified as "1" the 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.

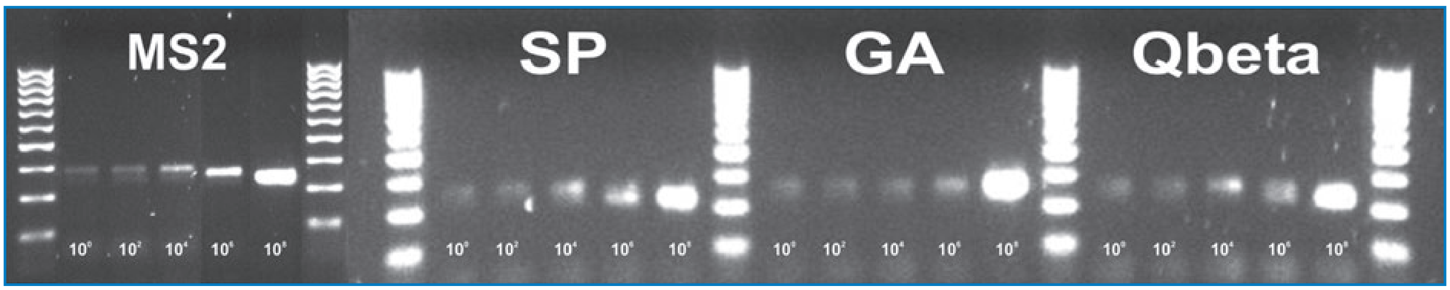


Figure 7. Detection limits of the ion exchange resin capture and RT-PCR assay. The FRNA phage type (MS2, SP, GA or Qbeta) is indicated above each gel. The concentration of phages/ml of water is indicated at the bottom of each gel lane. The results indicated that as few as 10^0 phages/ml are detectable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

Universities Council on Water Resources announces Water Policy and Socioeconomics Award

Dr. Miriam Masid has been selected as the first place recipient of the Ph.D. Dissertation Award in the field of Water Policy and Socioeconomics. The title of Mariam's dissertation is "Reforming the Culture of Partiality: Diffusing the Battle of the Experts in Western Water Wars". Her research explored some of the complexities of the water court process in Colorado.

The award consists of a certificate, a $750 check, reimbursement up to $1,000 for travel expenses, and waived conference registration for the 2008 UCOWR/NIWR Conference being held at the Marriott at the Civic Center in Durham, NC, July 22-24. This award will be presented at the Awards Banquet, to be held from 7:00-9:00pm on Wednesday July 23.

We are pleased to speak for the entire UCOWR delegation in congratulating Dr. Masid and have every confidence that her contribution to the field of Water Resources will be a significant one in the future.

For more information please see Mariam's article in the Volume 25, Issue 2 Colorado Water Newsletter. To view the dissertation in its entirety, please visit: http://www.courts.state.co.us/supct/committees/waterctcomm.htm

New Additions to the Water Resources Archive

By Patricia J. Rettig, Head Archivist, Water Resources Archive, Colorado State University Libraries

More individuals and organizations have recently taken steps to help preserve Colorado's water history by giving materials to the Water Resources Archive at Colorado State University.

Most significant is a new donation from the Colorado Climate Center. Nolan Doesken, state climatologist, notified the water archive of the Center's cache of historic climate data. Storing the boxes in an airplane hangar was not doing any favors for the long-term preservation of the materials or their accessibility. By bringing the 61 boxes into archival custody, the data sheets will be stored in a clean, climate-controlled facility and will be available to all researchers. The majority of the data was collected by local weather stations as part of the National Weather Service Cooperative Observer Program; the remainder was collected by the Mountain States Weather Network. The data largely covers Colorado and surrounding states over a 100 year period starting in 1893. While these materials are available digitally on the National Climatic Data Center website, the irreplaceable originals have now found a good home.

Other recent additions to the water archive have come from two individuals. Marvin Jensen, civil engineer and consultant, had already given the archive a portion of his professional output: files from his work on the Lower Colorado River Accounting System. He recently added to the collection by donating six boxes concerning his work for the Bureau of Reclamation on assessment of water use by the Imperial Irrigation District of California. These materials reveal the study he conducted and its outcome.

Also new to the Water Resources Archive are biographical materials about Harvey Johnson, former president of the Water Supply and Storage Company and onetime mayor of Fort Collins. The one box of materials documenting Johnson's life and work was brought to the water archive by his son, Gordon Johnson of Greeley. Making these materials available to researchers will help tell the story of a significant figure in northern Colorado's water history.

A forthcoming addition to watch for is several thousand digitized items from Water Resources Archive collections. This is being made possible by a $20,000 grant from the Colorado Water Conservation Board. Materials to be digitized include groundwater data, Larimer County reservoir and ditch maps, slides of various water projects, and more. The digitized materials will go online later this summer and fall.

For more information about the Water Resources Archive or donating materials or money, see the website at:

http://lib.colostate.edu/archives/water/

Or contact the author:

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Natural Resources students work in El Salvador with Engineers Without Borders

by Ryan Jenson, Forest, Rangeland and Watershed Sciences and Charlie Ferrantelli, Geosciences, Colorado State University

About EWB-CSU

Engineers Without Borders USA is a nonprofit organization founded in 2000 to help improve the lives of people in disadvantaged communities around the world through environmentally and socially sustainable development projects. In 2004, interested students at Colorado State University officially formed a student chapter, EWB-CSU. Since that time, the chapter has worked on water supply and treatment projects in India, Tanzania, and El Salvador. Currently, there are two active potable water supply projects ongoing in El Salvador, one in the neighboring villages of La Laguneta and El Chile, and the other in the community of San Antonio Abad. Both projects have involved interdisciplinary teams including students studying Geosciences, Watershed Management, Civil and Environmental Engineering, and Sociology.

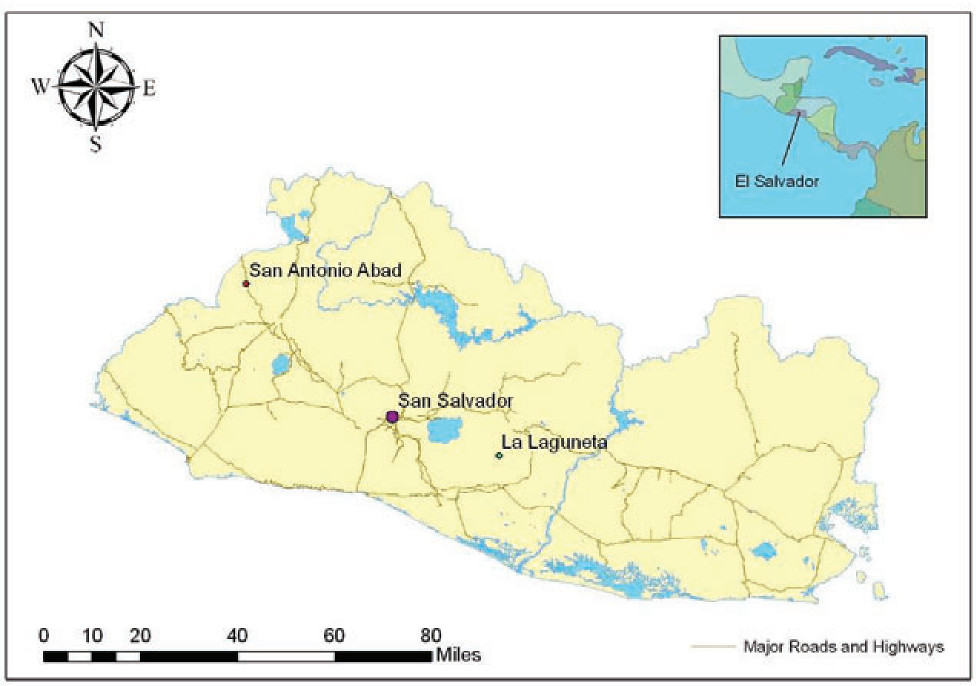
La Laguneta and El Chile

In 2005, EWB-CSU became involved with the communities of La Laguneta and neighboring village, El Chile. These two communities are located in south central El Salvador (about 40 km southeast of San Salvador) in a majestic setting high on the west flank of San Vicente Volcano. This EWB project team has involved the active participation of students from varying departments including the departments of Geosciences and Forest, Rangeland and Watershed Stewardship, both a part of the Warner College of Natural Resources.

The primary problems and goals associated with this project are related to the availability and quality of drinking water. Groundwater, which constitutes the primary drinking water supply in both villages, is obtained from nine local wells in La Laguneta, whereas El Chile citizens get water from a nearby spring. The main problem is that groundwater production rates are significantly reduced during the four-month dry season, when each family may only receive 25 to 100 liters per day. Additionally, the water in La Laguneta requires treatment for fecal bacteria contamination before it is safe to drink. In response to these water issues, EWB-CSU's main objective has been to help develop a sustainable drinking water supply for the 700-800 citizens of each of these villages. This includes the acquisition, treatment, and distribution of water.

In 2006, EWB-CSU conducted a hydrogeologic analysis in La Laguneta, which indicated that the La

Location of Engineers Without Borders - CSU Projects, El Salvador



One of the six public wells in La Laguneta.

Laguneta basin contains sufficient groundwater to act as a water source for the proposed La Laguneta water supply, and possibly enough water to augment the El Chile supply. Two wells were drilled in La Laguneta in 2006; however, these wells were unsuccessful at providing water at sufficient rates. This was theorized to be due to complex and unknown geologic conditions in the subsurface. At this point, EWB-CSU began to consider the use of geophysical methods to better characterize the geology beneath La Laguneta before additional wells were drilled.

Geophysical techniques are noninvasive methods of acquiring large amounts of subsurface data in a rapid and economic manner. In this project, a combination of ground penetrating radar (GPR) and electrical resistivity (ER) were selected for use, with all equipment being supplied by the Department of Geosciences. The geophysical design and analysis was conducted primarily by Charles Ferrantelli of the Department of Geosciences as part of a Master's thesis.

The GPR method provides two-dimensional subsurface images of stratigraphy, whereas ER is often used to determine permeability and water content of the subsurface. When correlated with well data, these techniques were proposed to define the extent and thickness of aquifers, and determine future drilling locations.

In Spring 2007, with local help of all ages, EWB-CSU conducted a geophysical survey of the La Laguneta Basin. This consisted of 11 GPR transects, ranging from 40 m to 450 m in length, and 6 ER transects ranging from 240 m to 540 m. Upon return to CSU, the geophysical data were processed and analyzed.

By correlating the GPR results with the geologic data known from the first two EWB wells and geologic maps of the area, there appear to be two main rock units in the basin: one deeper unit consisting of older consolidated volcanic rock, and a shallow unit consisting of much younger unconsolidated material. Based on its unlithified nature and literature information, the upper unit most likely acts as the aquifer in the basin, whereas the lower unit consists of bedrock. Geophysical maps generated of these two units indicate that the thickest amounts of the upper unit (10 to 14 m) are contained within two bedrock sub-basins (depressions in the

Locals assist in extending the electrical resistivity cables and measuring out electrode spacing in La Laguneta.

Locals help control fiber optic cables during the collection of GPR data in La Laguneta.

bedrock surface), whose presence beneath the surface were previously unknown. These two sub-basins may contain the greatest aquifer thickness, and were identified as prospective well locations. Although the ER-survey results were less conclusive, they generally support these conclusions and indicate that the sub-basins may contain groundwater.

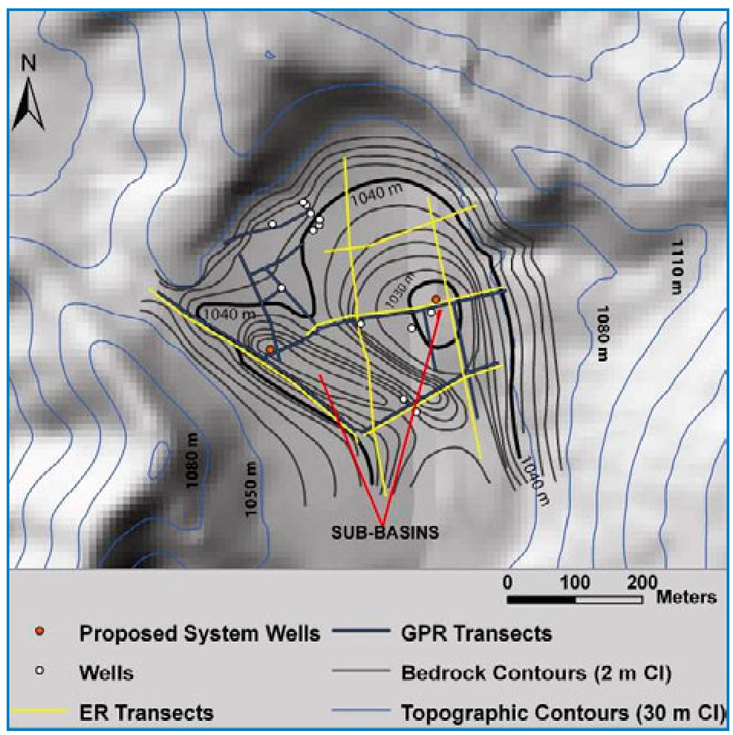
These results will be tested in Spring 2008 when the La Laguneta community will have a well hand-dug in each sub-basin. Naturally, everyone involved hopes for optimal results; nevertheless, this project has been a positive learning experience for all participants; foreigners and locals, young and old. It could not have been done without all of them.

San Antonio Abad

In early 2006, EWB-CSU took on its second water supply project in the community of San Antonio Abad, El Salvador. A peripheral subdivision (colonia) of the town of Candelaria de la Frontera, in the northwestern province of Santa Ana, San Antonio Abad is home to roughly 600 people. Denied service by the national water provider due to lack of system capacity, the community was left to fend for themselves in order to obtain a domestic water supply. Many of the homes in the colonia have shallow, hand-dug wells which the residents use to access the local water table. Unfortunately, a number of these wells dry up during the six month dry season, and due to the lack of sanitation infrastructure, all are badly contaminated with bacteria from household latrines and septic pits. The only other option is to purchase relatively expensive water from outside the community.

In order to address this problem, EWB-CSU obtained funding from Colorado and Salvadoran Rotary Clubs to drill a 48 meter deep community well and develop well-site infrastructure for treating and dispensing potable water. Fortunately, the aquifer test indicated that the new well, drilled in January 2007, was highly productive and will be adequate to meet the community's current and foreseeable future needs. Water quality testing showed that the well was chemically safe, but still would require biological treatment.

On a return trip in January 2008, the well-site infrastructure was installed. This included a ¾ horsepower submersible well pump, a pump house with three water taps, two rooftop water tanks, and a chlorination system installed by a Salvadoran NGO. This infrastructure is



Bedrock surface topographic map derived from geophysical surveys showing the location of sub-basins, current and proposed well locations, and geophysical survey transects.

Community members carrying water in San Antonio Abad

owned and operated by the community's development association, which has begun using a truck with a water tank to deliver water to the homes of community members.

As a result of EWB'CSU's involvement in the community, a number of additional related community needs are being addressed. A rain gauge donated by the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) was installed, and an improvised well sounder left with the community in order to monitor local water supplies. The area around the community well has also been designated as a wellhead protection zone in order to prevent further contamination of the water supply. Finally, a number of EWB students are designing a system for mitigating erosion, a serious and costly problem during the monsoon season, and for improved disposal of gray water.

In addition to the well-site infrastructure, the EWB team has been working to design an expansion to the

The EWB-CSU team with community members and the local Peace Corps Volunteer during the January 2007 aquifer test in San Antonio Abad

Students and community members installing plumbing to the rooftop tanks for the San Antonio Abad pump house in January 2008

system which will deliver treated water to several community taps located throughout the colonia. It is hoped that this expansion can be completed by the end of 2008. Furthermore, a final design is being completed for a community-wide water distribution network which the community can use to solicit additional funding from government and international sources in order to provide water taps to every household within the colonia. With luck, all the water needs of San Antonio Abad can be met in the coming years as a result of their collaboration with EWB-CSU.

A student installing a rain gauge in San Antonio Abad as faculty mentor Bill Sanford looks on

Faculty Profile

Denis Reich, Extension Specialist, Colorado State University

After enjoying Perry Cabot's essay in last month's newsletter, I am coming to fully appreciate the good fortune of being a member of Colorado State University's Water Team and Extension family. Along with Joel Schneekloth, in the Northern Region, I believe we make a diverse and talented trio of Water Resource Specialists that complement each other well.

This is my first time as a resident of Colorado, but as a native of Australia I am no foreigner to water issues. My father in fact, was a civil engineer who cut his construction teeth building the dams and reservoirs that today allow the hinterland of Eastern Australia to fulfill its agricultural potential. I myself pursued Chemical Engineering at the University of Sydney with little idea of my calling in the water arena until an internship with a home grown membrane filtration company set the course for my professional career.

Upon graduating, I took a Development Engineer position with the same company, Memcor Research, in 1996. My most memorable assignment was traveling to the arid North Western region of Australia to pilot a membrane plant for the millions of liter per day Harding River project. The journey involved 150 kilometers on sand and gravel roads, some across aboriginal tribal lands – needless to say the only vehicles for rent at the airport were Hiluxes and Land Cruisers. I remember the first time I stood on the crest of Harding Dam and being over-whelmed by what was effectively an inland sea trapped behind this man made wall. Water that filled this massive reservoir came from monsoonal rains between November and April, without which the lucrative mineral and gas industries in the vicinity would be virtually non-existent. Prior to the dam, water had been little more than a curse in this region: either completely lacking or wreaking havoc in torrential floods. Water was now plentiful and accessible to the point that quality had become the primary if only water concern. As I took in that dramatic view, there is no way I could have known I'd be living and working here on the other side of the world, in the Colorado River basin, some 10 years later, an area that also relies on similar precipitation timings and reservoirs for life to flourish.

My career in water treatment was good to me. After a couple of years in Australia, I received a placement in England with responsibilities throughout Western Europe and Scandinavia. Then in 2000 I took an opportunity to be based in the U.S. working throughout North America. Another career highlight was commissioning the first microfiltration stage of a large water recycling and aquifer reinjection project in Orange County, California. The theme that emerged from working with such a variety of communities and cultures was that prosperity was a double edged sword. With growth, competition for natural resources was inevitable and for water, a commodity with no economic substitute, this was particularly pertinent.

After four years working in the Unites States, Memcor was bought out for the third time and I saw this as an opportune time to pursue my graduate school aspirations. In the meantime, my parents had successfully consolidated a second career as cattle ranchers in the New England plains of New South Wales. I was inspired by their ability to weather

the parochial hostility of their neighbors as they transitioned from urban professionals to savvy cattle "cockys" (as producers are affectionately known in Australia). I took this growing interest in agriculture with me into a Masters of Science at Iowa State University. In the summer of 2004 I began a major in Sustainable Agriculture, a degree that's title alone was causing tense discussion within the College of Agriculture at the nations first Land Grant University. While I found the controversy surrounding my chosen major somewhat educational it wasn't what attracted me to the degree. The curriculum was rooted mediating solutions for the challenges that plagued the human food chain in Iowa, throughout all 50 states, and the world. This was reflected by the large percentage of international students enrolled, far larger than any other agricultural graduate degree at ISU.

The first class was a two week "ag boot camp" throughout the Corn Belt of the Midwest. We must have been quite a sight to the wide variety of farmers we visited as we piled out of our dusty minivans and religiously pulled on our disposable plastic booties for bio-security purposes. While I'm sure I learnt a lot from that class about hog genetics, milk yields and tile drainage, the nugget I took away was that at every level of food production people were involved; someone's livelihood was always on the line. For things to change pain would not be easy to avoid. It was an observation that has stayed with me long since my thesis defense.

Since acquiring my Masters I feel blessed to have landed a job that allows me to reconnect with my first calling, water and still be intimately involved with producers. I have been made to feel at home very quickly in Western Colorado thanks to an exceptional group of Extension colleagues who have never hesitated to put themselves second in helping me get my bearings. It is an example that I am anxious to follow. In the four short months I have been traveling the West Slope, visiting with water stakeholders, I am humbled by the passion that Coloradans have for improving their state. The future that will be left for the next generation is clearly something that occupies minds. I recently observed a great example of this at the April Colorado River Roundtable meeting: while critiquing the "vision document" for the watershed, presented by the Colorado River District, a roundtable member refused to let the chairman move on to the next agenda item, declaring "the topic of vision just too important to let drop".

I also see it as part of my role not to let the issue of a sustainable water future for Colorado "drop." As the competition for water in Colorado escalates, it seems the pain of change is proving increasingly difficult to avoid, one need only pick up a newspaper from the Front Range to confirm that. While dilemmas of such a scale are yet to hit the West Slope, few here pretend that it isn't possible if steps aren't taken now. I am focused on assisting those invested in taking such steps achieve this in an inclusive and scientific manner. Whether it is via a water management program for small acreages, facilitating river stakeholder partnerships or online education I see such a goal as being highly rewarding in addition to positively achievable. I look forward to working with all involved.

JTAC Presentation Denver Water GIS Applications May 15, 2008 at the Embassy Suites Hotel in Denver

Denver Water, the largest municipal water provider in the Rocky Mountain region, provides water to approximately 1.2 million customers. The utility's water transmission and distribution system consists of over 2,600 miles of pipe ranging from 4-inch to 108-inch in diameter, over 18,000 fire hydrants, 34 water storage tanks, and 19 major pumping stations. In the early 1990's, Denver Water initiated a major undertaking of developing a geographic information system (GIS) as a management tool for their facilities. The system has grown tremendously since its infancy and on-going management and significant enhancements of the system are planned in the future.

Brenda Reum, Denver Water's Manager of Geospatial Information and Technology, will provide an overview of Denver Water's GIS system, including lesson learned during its development, what features have found to be most effective and an overview of the significant plans that Denver Water has for its continued development and utilization. She will cover how the data is currently stored in the database and the future plans of how Denver Water will use the data for Mobile Workforce, Water Rates analysis, aging infrastructure predictive maintenance, and Customer Service applications. Cartographic output is still a major method of distributing the data, Brenda will discuss some of the problems encountered in producing maps for field staff and other interested parties.

The luncheon will be held at the Embassy Suites Hotel, 7525 E. Hampden, on the north side of the road about a half-mile east of I-25 at Roslyn Street (behind the "On the Border" restaurant and west of Tamarac Square). Luncheon check-in will be from 11:30 am to noon, at which time lunch will be served. The presentation and tour will follow lunch. The luncheon cost is $22 for AWWA or WEF members, $27 for nonmembers, and $15 for students. Please pay at the door either by cash or check, and make checks payable to "RMSAWWA".

For more information visit: http://rmwea.org/rmwea/committees/Joint/jt ac_luncheon_schedule.htm or contact Steve Polson at jtac@ch2m.com or 720-286-5376

Research Awards

Colorado State University, Fort Collins, Colorado
Awards for February 2008 to April 2008

Arabi,Mazdak, Purdue University, Multi-Criteria Optimization of Watershed Management Practices for Sediment, Nutrient, and Pesticide Control, **$103,369**

Arabi,Mazdak, Purdue University, Watershed-Scale Evaluation of BMP Effectiveness: Eagle Creek Watershed, Indiana, **$53,125**

Christensen,Dana K, Golf Association/U.S. Green Section, Development of Stress Tolerant, Turf-Type Saltgrass Varieties, **$26,274**

Collett,Jeffrey L, NSF - National Science Foundation, Cloud Chemistry Measurements in the Southeast Pacific during VOCALS-REx, **$105,480**

Cooper,David Jonathan, DOI-NPS-National Park Service, Data Collection & Wetland Mitigation Design for Two Rodeo Lagoon Wetlands, **$9,000**

Fassnacht,Steven, State of Colorado, Estimating Errors Associated with Calculated Sublimation from Seasonally Snow-Covered Environments, **$5,000**

Fassnacht,Steven, University of California-Los Angeles, Scaling Snow Observations From the Point to the Grid Element: Supporting NOHRSC's National Snow Analysis System, **$23,237**

Garcia,Luis, DOI-Bureau of Reclamation, Subsurface Drainage Research, **$20,000**

Garcia,Luis, Various "Non-Profit" Sponsors, Developing a Decision Support System for the South Platte Basin, **$10,000**

Gates,Timothy K, DOI-Bureau of Reclamation, Identification, Public Awareness, & Solution of Waterlogging & Salinity in the Arkansas River Valley, **$50,000**

Goodridge,Lawrence, DOC-NOAA-Natl Oceanic & Atmospheric Admn, A Bacteriophage Linked Immunosorbent Assay for Rapid Detection of Pathogenic V. parahaemolyticus, **$105,794**

Goodridge,Lawrence, Colorado Water Resources Research Institute, Development of a Multiplex Lateral Flow Device to Assess Biological Water Quality in Colorado Surface Water, **$5,000**

Hansen,Neil, DOI-Bureau of Reclamation, Demonstrating Limited Irrigation Technology as an Approach to Sustain Irrigated Agriculture While Meeting Increasing ..., **$71,436**

Kampf,Stephanie K, DOI-USGS-Geological Survey, Hydrologic Analysis and Process-Based Modeling for the Upper Cache la Poudre Basin, **$15,000**

Parkinson,Bruce Alan, Dreyfus Foundation, A Distributed Combinatorial Search for Water Splitting Photocatalysts, **$45,000**

Prieksat,Mark, USDA-USFS-Rocky Mtn. Rsrch Station - CO, Clean Air, Dust Monitoring and Safe Drinking Water Compliance Study Schofield Barracks, HI, **$138,578**

Pritchett,James G, DOI-USGS-Geological Survey, Water Reallocation and Bioenergy in the South Platte: A Regional Economic Evaluation, **$15,000**

Qian,Yaling, Golf Association/U.S. Green Section, Multiple Stress Tolerance, Seed Dormancy Breaking, and Establishment of Seeded Saltgrass, **$22,852**

Qian,Yaling, Golf Association/U.S. Green Section, Salinity Management in Effluent Water Irrigated Turfgrass Systems, **$26,864**

Ramirez,Jorge A, NSF-EHR-Education & Human Resources, REU Site: Research Experiences for Undergraduates: Program in Water Research at Colorado State University, **$105,824**

Theobald,David M, The Nature Conservancy, Attribution of Colorado-Wide Hydrography, **$5,000**

Thornton,Christopher I, Americast, Inc., Roof Drain Testing, **$61,115**

Thornton,Christopher I, DOI-Bureau of Reclamation, Investigation of Alphabet Wiers, **$100,000**

Thornton,Christopher I, Hydrau-Tech, Inc., Valenciano Dam Spillway, **$42,316**

Thornton,Christopher I, Norris Screen Manufacturing Inc, Coanda Intake Weir Flow Testing, **$32,953**

Waskom,Reagan M, DOI-USGS-Geological Survey, Program Administration Project, **$10,000**

Waskom,Reagan M, DOI-USGS-Geological Survey, Technology Transfer & Information Dissemination, **$52,335**

Wohl,Ellen E, NSF-GEO-Geosciences, Wood Loading in Headwater Neotropical Forest Streams, **$80,232**

Calendar

May

14-16 **33rd Colorado Water Workshop: Mining, Energy &Water in the West, Gunnison, CO**
A look at water quality and supply issues from the revival of mining & energy production
www.cfwe.org or www.western.edu/water

15 **JTAC Presentation Denver Water GIS Applications, Denver, CO**
Seminar discussing development of Geographic Information System (GIS)
http://rmwea.org

19-21 **MODFLOW and More: Ground Water and Public Policy, Golden, CO**
Presentation of applications of ground water models throughout hydrologic work
http://typhoon.mines.edu/events/modflow2008

28-31 **USCID Water Management Conference, Scottsdale, AZ**
Share experiences to learn more about Water transfers and urbanization issues
http://www.uscid.org/08conf.html

June

5 **Water Conservation Planning and Implementation Training for Water Conservation Professionals, Denver, CO**
http://www.greatwesterninstitute.org

8-12 **AWWA Annual Conference & Exposition, Atlanta, GA**
Learn more about safe water practices and innovations
www.awwa.org

17-19 **Workshop: Status of Drought Early Warning Systems in the US, Kansas City, MO**
Bringing together drought planners from watersheds, agriculture, energy, and others
http://drought.gov

19-20 **South Platte Basin Tour, Denver, CO**
Two day tour highlighting the lower portion of the river through Northeastern Colorado
www.crwe.org

27 **Combating the Yuck Factor, Technologies & Philosophies of Reclaimed Water**
PWO Seminar, Rocky Mountain Water Environment Association, Boulder CO
http://www.rmwea.org/rmwea/committees/PWO/Boulder/Boulder2008.htm

30-2 **AWRA Summer Specialty Conference Riparian Ecosystems and Buffers: Working at the Water's Edge, Virginia Beach, VA**
www.awra.org

July

22-24 **UCOWR/NIWR 2008 Conference, Durham, North Carolina**
Going over topics such as International water, education, climate change and more!!
http://ww.ucowr.siu.edu

August

3-7 **7th Annual StormCon, Orlando, Flordia**
Join in for education and training for anyone involved in surface-water quality!
www.stormcon.com

20-23 **CWC Summer Convention 2008, Vail, CO**
The Colorado Water Congress is putting on a convention this summer in Vail
http://www.cowatercongress.org

November

17-20 **2008 AWRA Annual Water Resources Conference, New Orleans, LA**
A multidisciplinary water conference for all participants in the water community
www.awra.org

COLORADO WATER

Newsletter of the Water Center of Colorado State University

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