Colorado Water

Colorado State University

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Theme
Student Research

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Highlights

In Every Issue

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Editorial

by Reagan Waskom, Director, Colorado Water Institute

Raising the general public's level of "water literacy" is a laudable goal that CSU and a number of partner agencies in Colorado work diligently and sincerely on every year. Of course, the "public" is actually made up of many disparate audiences that tend to be highly distracted by an almost infinite array of information opportunities, making water education a long-term, if not Sisyphean, task. The April 2010 *National Geographic* special issue on water showed the incredible bully pulpit an international organization such as the National Geographic Society has for bringing awareness to global issues such as water. A number of laypeople have commented to me on how eye-opening aspects of the recent magazine story on water was to them. For those who have not yet read it, you might not be surprised that the only real mention of Colorado (other than a great photo of the People's Ditch near the end) was a sidebar article on rainwater harvesting and those in defiance of current state law. The challenges of providing public information and education are embedded in our recent attempts to clarify the revised rainwater harvesting rules in Colorado, reminding us of how repetitive and persistent we must be in educating the public.

Public education has been much in the news lately, unfortunately because of state budget shortfalls and cuts rather than society's appreciation of the intrinsic value education creates. However, it would be much less painful for the state legislature to cut K-12 and higher education if we were not so keenly aware of the role an educated populous plays in a democratic society and the modern workforce. Our global competitive advantage has to a large degree been a function of our creativity in science, mathematics, and engineering fields, and the future portends even more rapid change and complexity that should encourage society to put a greater premium on a robust, publicly funded system of education. As a land grant university, Colorado State University has a mandated public outreach and education role that we serve through extension, distance education, and other means; however, our primary mission has always been resident education of undergraduate and graduate students.

This issue of *Colorado Water* is focused on the primary mission of water education at CSU—training the next generation of water managers and scientists. One of the ways we do this is through classroom teaching, but perhaps an equally important component is through experiential education, internships, and research projects. The Colorado Water Institute at CSU has recently been

providing competitive seed money grants to help students get started on their research projects and internships. As a result of annual calls for student proposals, we've received an interesting mix of project proposals from students across disciplines and Colorado universities. Several of these projects are described in this issue in articles written by funded students. These projects help satisfy degree requirements, but they also give students practical skills to build upon in their professional careers. Not only are the students getting research experience, but they are required to prepare reports for this newsletter, exposing them to the process of publishing results and communicating their research findings to a general audience. Learning how to communicate to the public is critical for successful science and engineering students. Also in this issue, undergraduate students in Melinda Laituri's "Geography of Water Resources" class report on their semester projects comparing Colorado rivers to other international rivers. Again, the purpose is for students to not only acquire information and new skills, but also to learn how to effectively communicate what they have learned to other audiences.

The job market for new graduates is highly competitive now, and although our student placement remains reasonably good, we are always looking to improve the product. What preparation and skills are most valuable for new hires just out of college? How can higher education do a better job of preparing students for careers in water resources? Clearly, these are not rhetorical questions, and we encourage our readers to offer their experience and insight on what they look for and need in new graduates. Let us hear your input at cwi@colostate.edu. If I receive enough responses, we will publish these insights in an upcoming issue of *Colorado Water*.

Bear Creek Watershed Partnership Project

by Kimberly Gortz-Reaves, MS Candidate, College of Architecture and Planning, University of Colorado Denver
Faculty Sponsor: Charlie Chase

The headwaters of Bear Creek in the Mount Evans Wilderness. (Courtesy of Kim Reaves)

The purpose of the Bear Creek Watershed Partnership (BCWP) research was to identify stakeholders and potential partners operating in the Bear Creek watershed and suggest ways to create a system that aids the coordination of watershed-wide projects. The upper reaches of the Bear Creek watershed stretch from the Mount Evans Wilderness to the Bear Creek Reservoir between Morrison and Lakewood, Colorado. The final eight miles of Bear Creek flows through the dense urban environments of Lakewood, Sheridan, and Denver before joining the South Platte River. This diverse watershed has high altitude streams to heavily impacted reaches. The land and water is being managed by a multitude of land use agencies. This research aimed to identify all stakeholders in the upper watershed and the 8-mile reach below the Bear Creek Reservoir.

Initially, the research was facilitated by the BCWP, a volunteer collaboration between the City of Denver Parks and Recreation, University of Colorado at Denver, National Park Service Rivers, Trails, and Conservation Assistance (RTCA) Program, AmeriCorps, FrontRange Earth Force, and Groundwork Denver. The research was initiated by the facilitating partners for several reasons. First, it was believed there were various organizations and plenty of opportunities to create conservation experiences within existing programs. Yet, no one knew the extent of programs being implemented to meet regulatory requirements or of outreach events by community groups. Also, is it has been shown that partnerships create favorable circumstances to develop and support a watershed-based stewardship effort and improve management strategies. Furthermore, the Bear Creek watershed is unique in its stewardship learning opportunities for youth and communities because it physically encompasses a variety of environments and uses.

To forward the efforts, graduate students in Landscape Architecture and Planning at the University of Colorado at Denver were recruited to help answer the question of whom and to what extent stakeholders are operating in the watershed. With the help of a faculty advisor, a questionnaire was drafted to guide interviews for data collection. Organization representatives and program leaders were contacted to inform them of the burgeoning partnership and to collect the following information: contact information, organization mission, and the extent of their involvement in the watershed and interest in the partnership. The initial call list was compiled from names and contact information collected at a Young Conservation Stewards meeting held on December 12, 2007, and hosted by the National Park Service RTCA. Additional contacts were gathered as phone interviews were conducted. The long-term intent of the BCWP was to use the collected data to create a vehicle in

This aerial photo shows the pressure on Bear Creek from urban development in the lower reaches of the watershed. (Edited from Microsoft LiveMaps by Kim Reaves)

which partners would be able to share or coordinate their objectives and improve management strategies.

The 57 respondents represented various nonprofit community groups, volunteer organizations, and jurisdictional land management agencies. Of the 57 respondents, 41 were in favor of being involved in a partnership, 6 said no, 6 said maybe, and 4 did not indicate a preference. Several regulatory activities occurring in the watershed offer opportunities for collaboration, including promoting environmental health, safety, and water quality education. Sources for creating "on-the-ground" stewardship activities include stormwater awareness, mitigating pollution and erosion, and reducing environmental impacts from human activities.

Many of the public agencies already work with volunteer groups and individuals, but they usually do not coordinate with efforts outside of their jurisdiction. However, there is a marked consensus that the lack of cross-jurisdictional coordination related to management strategies or volunteer service opportunities needs attention. It was also recognized that creating cross-jurisdictional opportunities may economize and make management efforts more efficient. As a result, a few key agencies believe that a partnership could help organize conservation efforts and educate the public on watershed issues. Interest in a partnership is high, and many respondents wanted to come together to have a "roundtable" discussion.

After the initial identification of stakeholders, the facilitating partners discussed options for creating a system that aids the coordination of watershed-wide projects. Several possibilities were explored, including a web-based forum/map for posting projects. Data were used to create a model of a web-based map, which employed flash script to make roll-over buttons for highlighting contact information. Using this technique would also locate project sites. Other options explored included the formation of a funded entity similar to Cherry Creek Stewardship Partners, which would act as a guiding board of volunteer members.

Logistics or substantial commitment to the formation of a partnership has not currently manifested. The research concluded with the open-ended possibility for various stakeholders to have a "roundtable" meeting to establish the collective interest in a partnership and to set objectives. Currently, further research is being conducted to determine and document the extent and type of public/private "on-the-ground" youth and community projects. Further data on regulatory mandates will also be collected to find area agencies that can coordinate efforts to make programs more efficient and economical. It is the goal of those continuing to work on the partnership to have the roundtable gathering in June and facilitate a meeting between land managers and community groups to discuss the findings and move the partnership to the next level. The next level will involve creating a partnership model that has a mission befitting to the Bear Creek Watershed. It is hopeful that through the research efforts, watershed stakeholders will further efforts in solidifying a partnership that will coordinate "on-the-ground" youth and community projects and create a system for watershed-wide stewardship.

Hydrologic Control of the Nuisance Diatom, *Didymosphenia Geminata*

by James Cullis, PhD Candidate, Civil, Environmental and Architectural Engineering, University of Colorado at Boulder
Faculty Sponsor: Diane McKnight

In recent years, particularly since the 2002 drought, have you noticed your favorite mountain stream in Colorado becoming less pristine? Have you noticed a thick brown algal mat coating the streambed that looks horrible and snags your fly when you are fishing? In some places it is particularly troublesome, with mats 1-2 centimeters thick and long white streamers resembling wet toilet paper. Does it feel gritty like wet cotton wool? Chances are that your stream is another victim to an emerging nuisance algal species called *Didymosphenia geminata,* otherwise known as "didymo" or "rock snot."

James Cullis holds a rock covered with didymo in South Boulder Creek. (Courtesy of James Cullis)

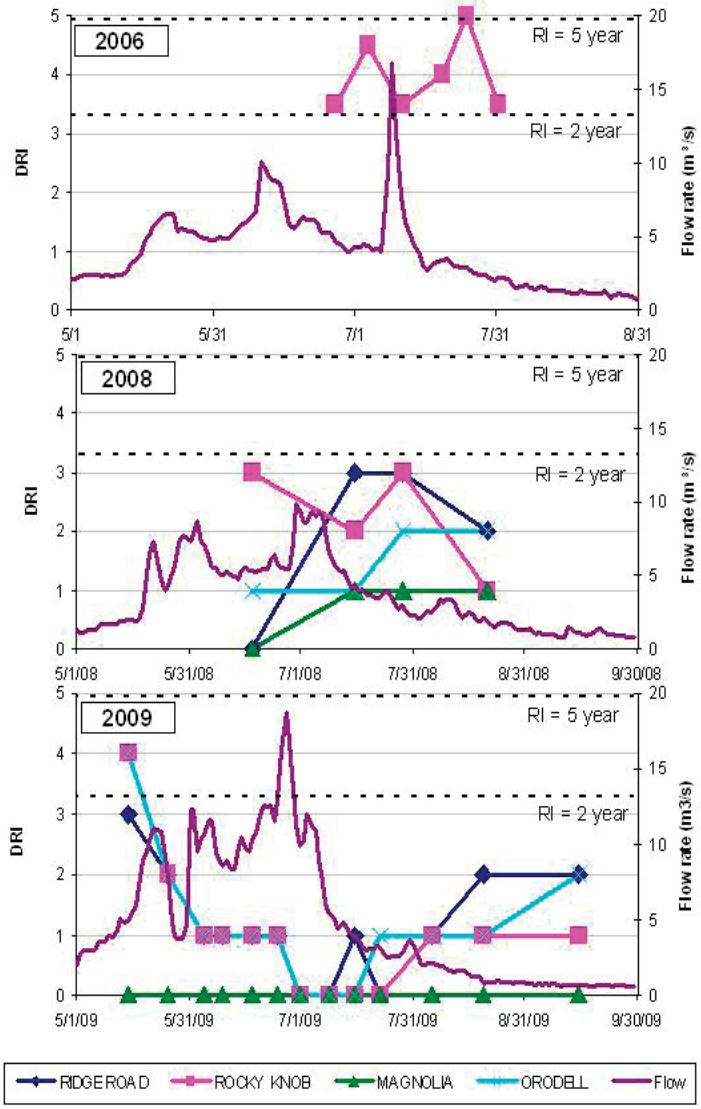
An Emerging Nuisance Species

Traditionally, algal blooms in rivers and lakes can be associated with increased nutrient loading. This is often due to human impacts downstream of wastewater treatment plants or agricultural runoff. Not so with didymo. This type of diatom is uniquely adapted to grow in low-nutrient conditions typical of many otherwise unimpacted mountain streams. Didymo is not new to Colorado; this diatom has always been a part of the natural environment of mountain rivers in North America and northern Europe, and periodic blooms have been part of the natural cycle. In recent years, however, the tendency of this nuisance species to bloom and spread to new watersheds has increased. Most significantly, in 2004 it was first detected in streams in the South Island of New Zealand. The conditions in these streams were ideally suited to its growth, and it quickly spread to other watersheds and resulted in algal mats many centimeters thick. It now represents a significant threat to local economies and stream ecosystems in these areas.

Controlling Factors and Ecological Impacts

The invasion of streams in New Zealand sparked an interest in determining the factors contributing to the growth of this nuisance species. Studies have been conducted in New Zealand, the United Kingdom, Canada, and the United States. These studies have confirmed the tendency to bloom under low-nutrient conditions, specifically in streams with

These two photos of the stream bed in Boulder Creek show the impact of high-flow events in the spring of 2009, which resulted in significant removal of didymo coverage.



This graph shows observed didymo coverage, as measured by the Didymo Rating Index (DRI) at four study sites in Boulder Creek in relation to stream flow. Note that flows above 10m3/s result in a reduction in the coverage, but that the reduction depends on the time that the high flow occurs. The rate of recovery depends on the subsequent flows and can be rapid when high flows are not maintained.

a relatively high proportion of organic phosphorus in the total dissolved phosphate (TDP) concentration. Flow rate is also an important factor. High flows, and particularly the physical scouring and disturbance of the stream bed, are considered to be a primary control on didymo growth. The regulated flow regime downstream of dams and reservoirs provides a hot spot for growth. The thick algal mats have a significant impact on benthic macroinvertebrates, increasing the abundance of small worms and reducing the overall species diversity. It is unclear, however, what the resulting impact is on larger species such as fish.

Recreational users, such as fishermen, are one of the main contributors to the spread of this nuisance species. Individual cells can remain viable on the felt soles of wading boots for many days, facilitating the transport from one stream to another. This has resulted in a massive public awareness campaign in New Zealand, where felt-soled waders are now banned and wader wash stations have been established at popular fishing spots. There is mounting pressure in Canada, Alaska, and other parts of the United States to implement similar cleaning and disinfection control and to phase out the use of felt-soled waders.

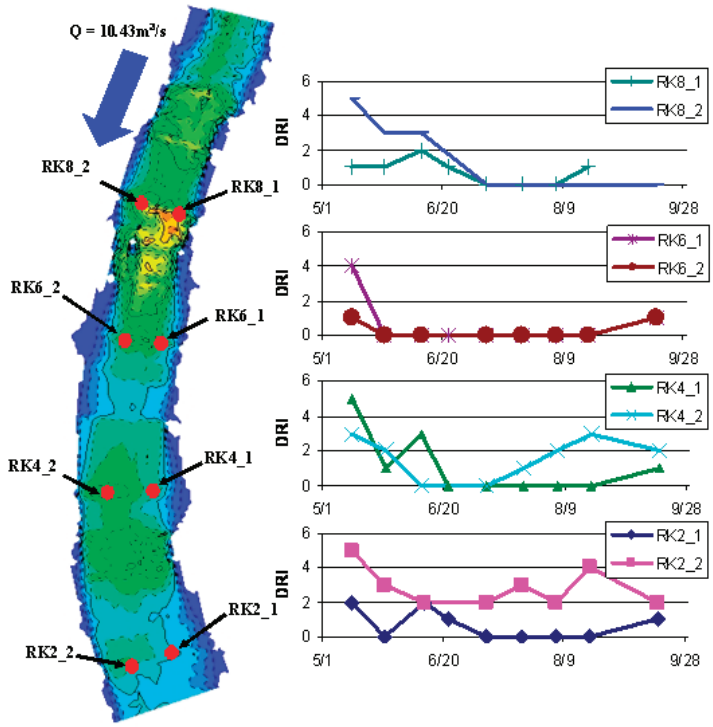
Studies in Boulder Creek, Colorado

For the past several years, students at the University of Colorado at Boulder have been studying *D. geminata*. This species represents an excellent subject, as it is relatively easy to identify both in the field and under the microscope, is abundant in nearby streams, and can be used as the basis for discussions of stream ecosystems, human impacts, and watershed management. A particular area of ongoing research is to investigate the role of flood events, with the objective of determining the critical flow requirements necessary to remove the didymo mats from the streambed.

Preliminary data were collected during the summer of 2006, and further monitoring was conducted in Boulder Creek in 2008 and 2009. The primary metric for monitoring the growth of didymo was a qualitative Didymo Rating Index (DRI). The DRI takes into account the extent of the coverage and the thickness of the algal mat. It ranges from zero, representing no obvious signs of didymo growth, to a maximum of ten, representing 100% coverage and mats greater than 5 cm thick, as have been observed in New Zealand. The maximum for Boulder Creek was 100% coverage with a mat thickness of 1 to 2 cm, representing a 6 or 7 on the DRI scale. In addition to the DRI, physical samples from individual rocks were taken and analyzed in terms of the ash-free-dry-mass (AFDM), chlorophyll concentration, and didymo cell densities.

Determining the Critical Flow Requirements

The results of monitoring the growth of didymo at four study sites in Boulder Creek are shown in Figure 2. The coverage is measured in terms of the DRI on the left axis and is compared to the average daily flow rate on the right axis. The dashed lines represent the estimated 1 in 2-year and 1 in 5-year annual maximum flow, based on 100 years of flow records. The results show the importance of high flows in controlling the growth of didymo. In 2006 the spring melt was relatively low, but a heavy rainstorm produced a late-season flood, resulting in a significant reduction in the didymo coverage. 2008 was an average flow year with limited impact on the didymo coverage. In contrast, 2009 was a very high flow year. The result was almost complete removal of didymo from the streambed at all study sites and limited recovery due to the sustained high flows.



The figure on the left shows the spatial variation in bed shear stress at the maximum flow rate of 10.43m3/s for the Rocky Knob site. The yellow and orange areas indicate higher shear stress, and the red dots indicate the sampling locations. The figures on the right show the change in the Didymo Rating Index for each sample location. Note that for 2009, the maximum flow resulted in very high shear stress values and potential for bed disturbance over most of the study site. There is still, however, some difference in the impact at the different sampling locations

The results indicate that a flow of $10m^3/s$ is a critical level for the removal of didymo in Boulder Creek, which is about the average annual maximum flow. Analysis of the average shear stress associated with this flow suggests that it is similar to the flow required to initiate significant bed disturbance. This supports the hypothesis that flows need to be high enough to result in the physical scouring of didymo due to bed disturbance rather than just elevated bed shear stress. It is unclear at this stage if these findings can be applied to other streams where didymo is a problem, and this should be a focus of future research using data from other locations and countries. Further studies to be conducted during the summer of 2010 will also determine the shear resistance of the didymo mats directly using flume experiments.

The Importance of Spatial Variation

One goal of the research being conducted in Boulder Creek is to quantify spatial variation within a stream habitat. During a flood event, shear stress is not evenly distributed across the stream bed. This results in spatial variations in the potential for bed disturbance and the removal of algae such as didymo. The resulting patchiness is considered important in maintaining the diversity of stream ecosystems. Spatial variation in the removal of didymo is being studied at the four study sites in Boulder Creek by developing a two-dimensional hydraulic model of each site. Preliminary results from the Rocky Knob site are shown in Figure 4, which illustrates the spatial variation in shear stress resulting from the maximum flow rate observed in 2009 of $10.43m^3/s$. The result of this spatial variation in shear stress is apparent in the difference in the observed DRI at eight specific locations within the study site. By studying this spatial variation in shear stress and the impact on the removal of didymo, we hope to better determine the critical shear stress needed for removal.

Using Managed Flood Releases for Future Control

The overall objective of this study is to determine the critical flow requirements necessary to remove didymo in streams. This information will be useful in considering the potential to use managed flood releases from reservoirs to control future growth. This approach is already being used in New Zealand, where a number of flood releases have flushed the didymo out of impacted streams. In New Zealand, this approach is supported by an awareness of the negative impact of didymo on local economies and stream ecosystems, as well as the availability of spare water. In other parts of the world, such as Colorado, there is neither the level of awareness of the threat nor the availability of spare water. It is therefore important to not only better understand what the impact of didymo is in these areas, but also to improve our quantitative understanding of the magnitude, duration, and timing of flood events that would be most efficient in controlling future growth. The aim of this study is to provide this quantitative understanding that will enable water resources managers to consider the trade-offs between making flood releases with the objective of controlling didymo growth and considering the many other current and future demands on this precious resource.

Acknowledgements

Funding for this research is provided by the Colorado Water Institute, the Boulder Creek Critical Zone Observatory, the University of Colorado, the American Society of Civil Engineers, and the Aurecon Group.

For more information on the ecology and impact of *Didymosphenia geminata* and on what can be done to control the spread and future growth of this nuisance species, visit the Environmental Protection Agency web site at: http://www.epa.gov/region8/water/didymosphenia.

Developing Barriers to Prevent the Upstream Migration of the New Zealand Mudsnail

by Scott Hoyer, MS Candidate, Fish, Wildlife, and Conservation Biology, Colorado State University
Faculty Sponsor: Christopher Myrick

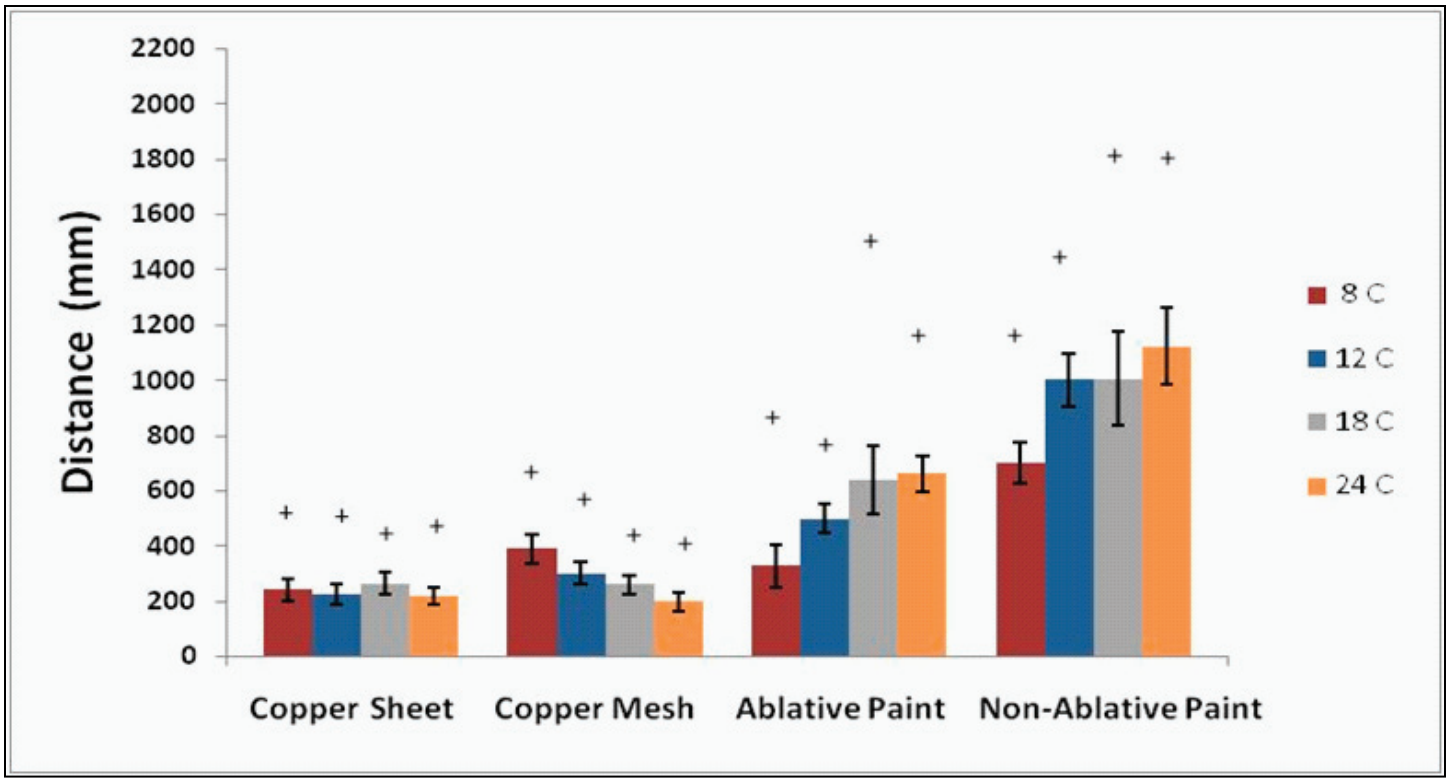
Waterways and aquaculture facilities throughout the western United States are at risk of invasion by the New Zealand mudsnail (*Potamopyrgus antipodarum*) (Figure 1). Originally endemic to New Zealand, mudsnails were first discovered in the United States in 1987 near Hagerman, Idaho, and have since spread to all the western states, excluding New Mexico. The mudsnail's high reproductive capacity allows them to reach extremely high densities in some situations (> 500,000 snails per square meter), leading to concerns that native aquatic communities and valuable sport fisheries could be negatively impacted. Several recreational fisheries have already suffered in California and Colorado by the closure of popular stretches of streams following mudsnail invasion. Additionally, several western aquaculture facilities have been invaded by mudsnails, resulting in revenue losses associated with the costs of facility disinfection to eradicate this organism and declines in fish produced for fisheries enhancement and restoration. The mudsnails' wide range of physiological tolerances and lack of effective native predators or competitors raises the possibility that it could spread to the majority of western waterways unless positive steps are taken to limit further invasion.

The New Zealand mudsnail is a small (< 6 mm at maturity) freshwater snail endemic to New Zealand that has rapidly spread across western North America. The snail's high reproductive potential, lack of natural predators, and broad environmental tolerance range have raised concerns about its potential impact on native aquatic communities and valuable sport fisheries. (Courtesy of Scott Hoyer)

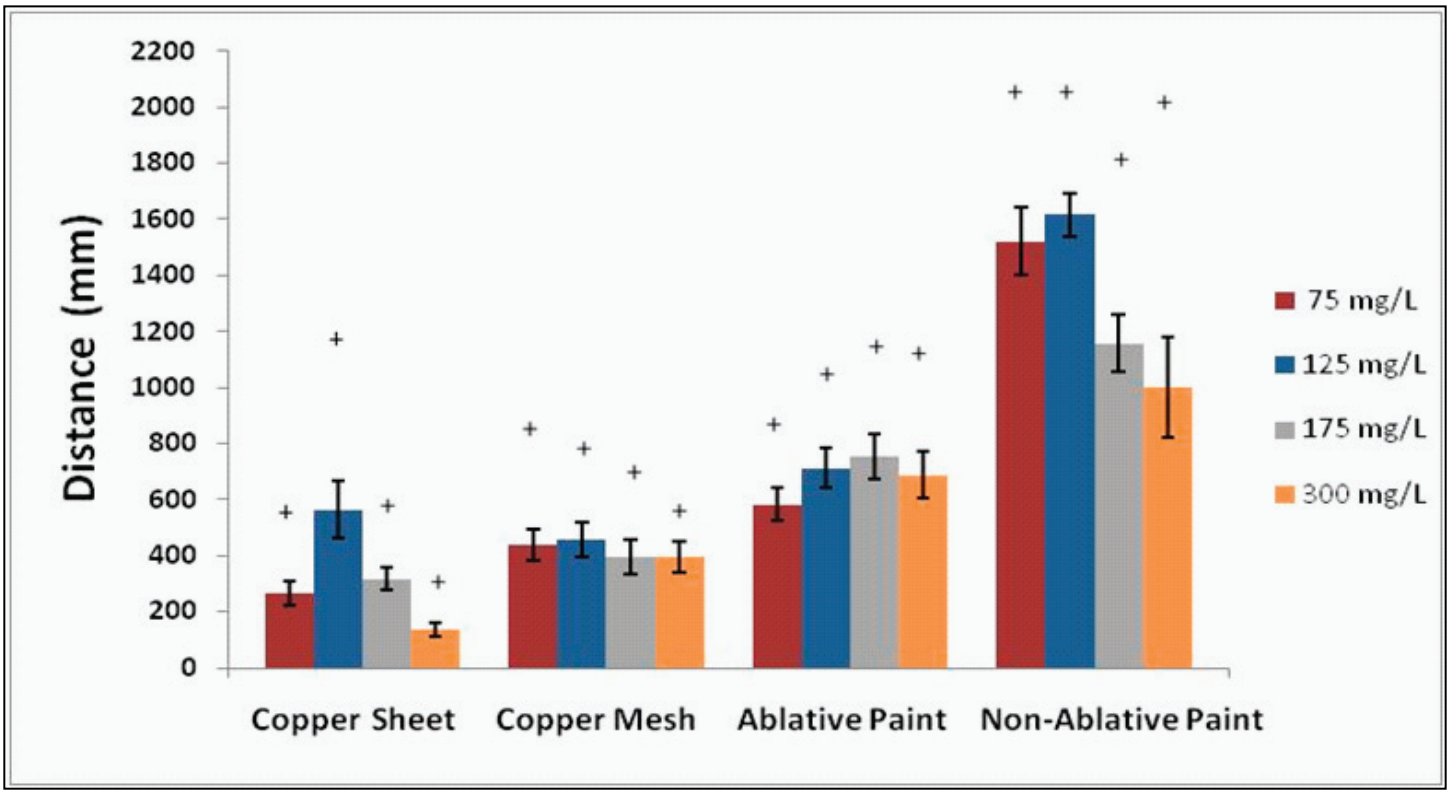
This image shows a 21.5-cm diameter PVC arena that was used to evaluate the New Zealand mudsnails' response to various copper-based materials. (Courtesy of Scott Hoyer)

The New Zealand mudsnails' rapid and wide-ranging invasion across four continents over the last 150 years can partly be attributed to the ease in which it can be inadvertently spread by humans. Mudsnails are quite small (< 6 mm at maturity) and can survive long periods of desiccation, thus allowing them to "hitchhike" between waterways on gear such as boots, waders, and rafts. Management agencies are now working to eliminate this pathway by educating fisherman, biologists, and other recreational water users on the proper ways to disinfect gear. However, infested gear is not the only way in which mudsnails find their way into novel habitats; fish hatcheries are now being carefully monitored to ensure that their activities do not lead to further spread. Because an infested aquaculture facility could easily spread mudsnails through normal stocking, it is no surprise that facilities that are found to harbor mudsnails face harsh restrictions by management agencies. In some situations, a facility may be quarantined until all of the mudsnails have been eradicated, which can be very costly in terms of both time and money and may lead to bankruptcy for some small private operations.

To protect these operations, it is important to find ways of preventing invasion in the first place. Mudsnails find their way into hatcheries in several ways, including crawling upstream through effluent pipes that connect a facility to an infested waterway. To eliminate this pathway, we



Average and maximum crawling distance of the New Zealand mudsnail on four copper-based substrates at various water temperatures. Averages are shown with standard error bars; + indicates the maximum distance traveled by any single snail within a treatment group.



Average and maximum crawling distance of the New Zealand mudsnail on four copper-based substrates at various water hardness levels. Experiments were conducted at 18° C. Averages are shown with standard error bars; + indicates the maximum distance traveled by a single snail within each treatment group.

need to develop a barrier system for these pipes. One potential class of barriers is copper-based substrates such as copper sheeting or marine anti-fouling paints. Copper-based materials are commonly used to control mollusk colonization on boat hulls and other submerged structures, so there is some possibility that they could also be used in this application. To test this hypothesis, Dr. Christopher Myrick and Sarah Conlin conducted a pilot study in 2007-2008, in which they exposed mudsnails to several types of copper-based materials. When compared to movements on bare PVC control surfaces, Myrick and Conlin found that the mudsnails' crawling distance was up to 7 times less on the copper surfaces, suggesting that these materials could indeed function as a barrier to mudsnails.

Over the last several years, some at-risk hatcheries have installed these copper materials in their effluent pipes, and while in some situations they were successful, in others they were not. There could be several reasons for this difference in effectiveness, perhaps most notably—differences in the physical and chemical characteristics of each hatchery's water supply.

It is well known that copper toxicity (and perhaps barrier efficiency) is affected by several variables including water temperature, water hardness, pH, and organic carbon concentration. The purpose of my current research is to determine the conditions under which copper-based materials function best as barriers to New Zealand mudsnails. Below I describe the findings of the first two phases of this project, in which we attempt to determine how water temperature and water hardness affected the mudsnails' response to potential copper barrier materials.

To address these questions, we conducted two separate experiments to test the barrier efficiency of the following four copper-based compounds: copper sheeting (99.9% pure), copper mesh (99.0% pure), ablative anti-fouling paint (25% cuprous thiocyanate as the active ingredient), and non-ablative anti-fouling paint (39% cuprous oxide as the active ingredient). All experiments were conducted at the Colorado State University Foothills Fisheries Laboratory.

For the water temperature experiment, mudsnails collected from Boulder Creek (Boulder, CO) were acclimated to 8, 12, 18, or 24°C for a period of two weeks before the initiation of the experiment. This temperature range was chosen to cover most of the mudsnail's temperature tolerance range and the range of temperatures likely to be discharged from a hatchery. For the water hardness experiments, we acclimated the mudsnails to one of four hardness levels (75, 125, 175, or 300 mg/L as $CaCO_3$) for a period of two weeks at 18° C. Following the acclimation period, we conducted experiments in circular PVC arenas (Figure 2), in which we covered one-half of the surface with a copper substrate and left the other half bare to serve as a control. At the beginning of a trial, a single mudsnail was placed in the center of the arena, and its movements were recorded for a two hour period. We later analyzed and compared movements on each the copper surface types.

After analyzing the data from these two experiments, we found that crawling distances were reduced on the copper sheet and mesh in both experiments (Figures 3 and 4). The non-ablative paint did not seem to limit the snails' movements in either experiment, which strongly suggests that substance would not be an effective barrier. We also determined that water temperature did not have a strong effect on the barrier ability of the four copper-based materials, although we did notice an increase in movement with increased temperatures (Figure 3). This observation was expected considering that the metabolic and activity rates of most cold-blooded organisms increase with temperature. Finally, water hardness did affect mudsnail movements across the copper surfaces, with crawling distance being the greatest in the 125 mg/L water hardness group (Figure 4).

Conclusions and Future Work

In both experiments, copper sheet and copper mesh consistently reduced the crawling distance and velocity of the mudsnails, suggesting that these materials have the ability to function as effective mudsnail barriers across a broad range of temperatures and water hardness levels. In contrast, the non-ablative anti-fouling paint did not appear to limit the mudsnails' movement under any of the experimental conditions. Upon considering the amount of copper in each of these materials, it appears that in order for a copper-based substrate to function as an effective barrier, it must contain a high percentage of copper. Furthermore, the maximum crawling distances that we observed in these experiments suggest that barriers must be at least 1.5 meters in length to stop 100% of the mudsnails. This last point is very important, because it is crucial to ensure that not a single mudsnail gets into a hatchery since the mudsnails reproduce asexually (i.e., it only takes one snail to start an entirely new population).

In 2010 we will continue to evaluate the performance of these copper-based compounds by testing each of them in a variety of conditions. We are currently evaluating barrier efficiency across a range of pH values. We will also determine how water velocity and the buildup of organic biofouling affect the mudsnails' response to these materials. Finally, to reduce the negative effects of copper on non-target species, we will evaluate the amount of copper that is leached from the materials. By doing so, we can determine the optimal barrier length that will block mudsnails, while also preventing unnecessary harmful effects to nearby aquatic communities.

Innovative Strategies for Sharing Water in the Colorado River Basin

by MaryLou Smith, Policy and Collaboration Specialist, Colorado Water Institute

What are the chances of getting farmers to sit down with urban water managers and environmentalists to talk about ways they can share their water? Increasingly, the writing on the wall is that some of the water needed for urban growth in the West and some of the water needed to keep water in streams for environmental purposes will come from agriculture.

A recent grant to the Colorado Water Institute from the Walton Family Foundation is funding not just talk among these three stakeholder groups, but roll-up-your-sleeves, delve-into-the-details dialogue that is expected to lead to action by Western policy makers.

Leaders from Family Farm Alliance, Western States Water Council, Western Urban Water Coalition, Environmental Defense Fund, The Nature Conservancy, Western Governors' Association, and others met for a year before they formulated a work plan they could all agree on. Convinced that creativity, innovation, and a strong motivation to preserve common values can lead to mutually beneficial water-sharing strategies, the group will stage a two-day retreat in August convening leading water innovators throughout the West.

Findings will be presented this fall to the Western States Water Council, the water arm of the Western Governors' Association, which has set as a prime policy issue the question of how agricultural water supplies can help meet the anticipated needs of urban growth in the West while maintaining the economic and social integrity of agriculture and rural communities. The work group's intent is to cut through jargon and wishful thinking to focus on and showcase real opportunities for policy improvement.

Group members are interviewing key individuals throughout the West to find out what we can learn from past transfers of water from agriculture, as well as what they are hearing and seeing in the way of innovative water-sharing concepts. What are the obstacles standing in the way of wide-spread use of those concepts and experiments? From these interviews, they hope to find the 20 most innovative thinkers for the summer retreat.

Work group members include:

- Colorado Water Conservation Board—Todd Doherty
- Colorado Water Institute—Reagan Waskom
- Environmental Defense Fund—Jennifer Pitt
- Family Farm Alliance—Pat O'Toole
- Metropolitan Water District—Bill Hasencamp
- The Nature Conservancy—Taylor Hawes
- Tumbling T Ranches—Ron Rayner
- Western Governors' Association—Tom Iseman
- Western Urban Water Coalition—Mark Pifher
- Western States Water Council—Nathan Bracken
- WestFAST Western States Federal Assistance Team—Jonne Hower

Facilitating the group's work is MaryLou Smith, policy and collaboration specialist at the Colorado Water Institute.

MaryLou Smith, formerly vice president of Aqua Engineering, Inc., has joined the Colorado Water Institute as Policy and Collaboration Specialist. In this role, she will secure and implement a variety of grants to convene stakeholders throughout the West for collaborative dialogue leading to improved water policy. Her work presently includes the Agricultural/Urban/Environmental Water Sharing Initiative discussed here, convening of rural communities in the Arkansas River Valley to cooperate on development of a regional water conservation plan, and design and implementation of a national conference for the Irrigation Association on how the irrigation industry can best face the challenge of diminishing water supplies for agriculture and urban landscapes. She is currently convening panels for presentations at statewide meetings on the topics of how to incorporate water-conserving landscape irrigation innovations into local water policy, and the paradox of growth and its effects on the statewide conversation about looming water shortages. She can be reached at the Colorado Water Institute at 970-491-5899 or 491-6308, and at MaryLou.Smith@colostate.edu.

Potential Changes in Groundwater Acquisition by Native Phreatophytes in Response to Climate Change

by Julie Kray, MS Candidate, Forest, Rangeland, and Watershed Stewardship, Colorado State University
Faculty Sponsor: David J. Cooper

Introduction

Across the arid intermountain regions of western North America, precipitation is limited, yet much of the natural landscape supports plant communities. Some plants in these near-desert environments are able to thrive in spite of drier surface soil conditions by developing roots deep enough to tap into a more stable water source: groundwater.

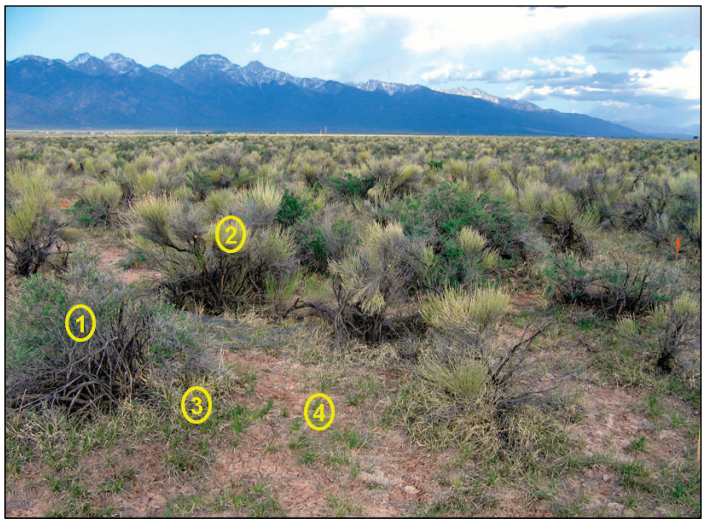
Phreatophytes, or plants that can use groundwater, cover vast areas of our western landscape. Native plant communities dominated by phreatophytes are ecologically valuable for soil stabilization, wildlife habitat, and forage for domestic livestock. However, phreatophyte communities can substantially influence total water outflow on a basin scale through groundwater evapotranspiration (ET). Groundwater resources in the West are essential to human populations, sustaining regional agriculture and municipalities by providing a reliable water supply in arid regions with unpredictable climates. Accurate estimates of groundwater use by native phreatophyte communities are therefore critical to managing groundwater in arid intermountain basins. Additionally, we need to understand how phreatophyte water use may change in response to climate variability. Changes in the timing and amount of precipitation are likely throughout western North America, and warming temperatures are expected to increase ET by native plant communities and agricultural crops. It is unknown whether different species of phreatophytes will vary in their sensitivity to altered precipitation patterns, and how these differences will affect groundwater use at the plant community scale. Changes in plant community composition and water acquisition patterns may in turn influence water availability for agriculture and other human uses.

Study Area and Questions

This study took place in the San Luis Valley (SLV), a high-elevation intermountain basin located in southern Colorado. The SLV is the most arid region in Colorado, receiving only 180-250 mm of precipitation annually; yet, a shallow unconfined aquifer recharged by snowmelt runoff from the surrounding mountains supports over 600,000 acres of irrigated agriculture, substantial water transfers out of the valley, and more than 1.2 million acres of native rangeland plant communities (Figure 1). The dominant native plant species in the SLV are phreatophytes, and evapotranspiration by phreatophyte communities accounts for nearly one-third of the total annual groundwater consumption.

The four most common native plant species in the SLV are the shrubs greasewood (*Sarcobatus vermiculatus*) and rabbitbrush (*Ericameria nauseosa*), and the grasses alkali sacaton (*Sporobolus airoides*) and saltgrass (*Distichlis spicata*). These four species are generally regarded as facultative phreatophytes, able to acquire both groundwater and soil water recharged by precipitation.

The rainfall manipulation experiment compared control plots receiving ambient rainfall with one of two treatments: (a) decreased rainfall using rain-out shelters and (b) increased rainfall through addition of rain captured by shelter roofs. (Courtesy of Julie Kray)



Native phreatophyte communities occupy over 1.2 million acres in the San Luis Valley, Colorado. These include the shrubs Sarcobatus vermiculatus (1) and Ericameria nauseosa (2), and the grasses Sporobolus airoides (3) and Distichlis spicata (4). (Courtesy of Julie Kray)

Between 50-70% of the total annual precipitation in the SLV occurs from mid-July through September, through rain events generated by the North American monsoon system. Some SLV phreatophytes may be adapted to use predictable pulses of late summer monsoon precipitation to reduce or supplement their groundwater consumption. However, current precipitation patterns are likely to vary with climate change. Existing climate model projections for the SLV are inconclusive, with some suggesting an increase and others projecting a decrease in monsoon rainfall. The goal of our study was to understand the interactions between precipitation and plant water use patterns for both wetter and drier futures.

Our study addressed the following questions:

- How do water acquisition patterns (groundwater versus rain-recharged soil water) vary among native phreatophyte species under the current climate? Are some species more dependent on groundwater than others?
- How will phreatophyte water acquisition patterns respond to a change in growing season precipitation? Will increased monsoon rainfall lead to increased plant use of soil water and reduced use of groundwater?
- Conversely, if growing season precipitation decreases, will plants become more reliant on groundwater?

Methods

We conducted a rainfall manipulation experiment at our long-term study site near Crestone, Colorado. The experiment compared plants in control plots receiving natural rainfall with plants receiving one of two treatments: (1) decreased rainfall using rain out shelters ("rain out"), and (2) increased rainfall by applying rain captured from shelter roofs ("rain add") (Figure 2).

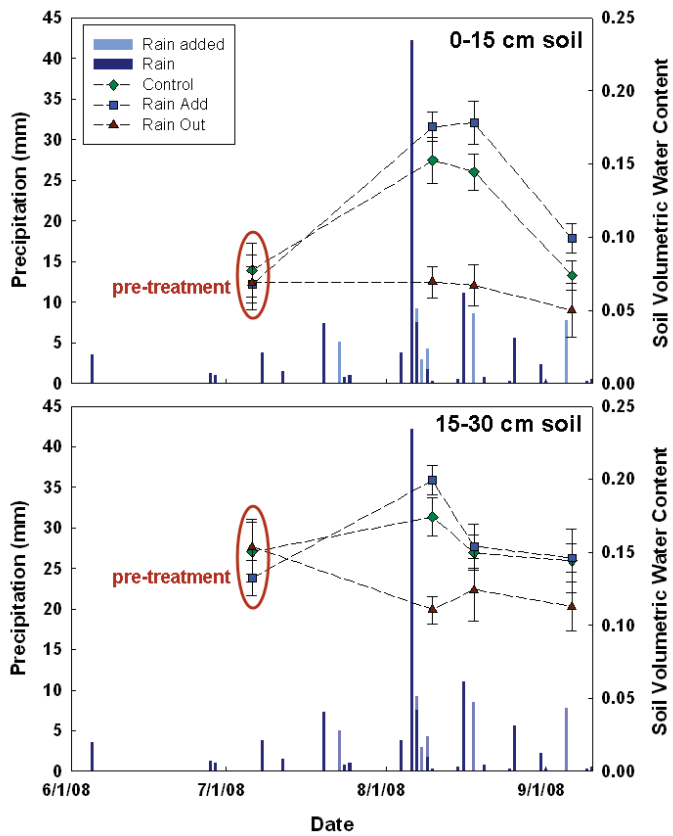
To identify plant water sources, we compared the stable oxygen isotope signature of water taken up by each plant species with soil water from 0-15 cm and 15-30 cm depths, and groundwater. The isotopic signature (the ratio of ^{18}O to ^{16}O, or $\delta\,^{18}O$ value) of water in plant xylem tissue reflects the signature of the water source(s) a plant acquires. In the SLV, groundwater carries the isotopic signature of winter precipitation and varies little over time. Soil water picks up the signature of rain immediately following an event, but as rainwater evaporates, heavier isotopes are concentrated in the soil, and the signature of soil water becomes more enriched. We used these naturally occurring differences in source water isotopic signatures to determine the relative contributions of soil water and groundwater to total plant water uptake.

Results

Precipitation during the 2008 growing season followed a typical pattern, with minimal rainfall in June and early July (Figure 3). The majority of the rainfall occurred in August during the peak of the monsoon season, including one large event of 42 mm on August 6. In the top 15 cm of the soil profile, our rainfall manipulation treatments effectively altered mean volumetric soil water content. Pre-treatment soil water content was similar in all plots (7-8%) (Figure 3). After treatments took effect in early August, mean soil water content increased to 15% in control plots and 18% in rain addition plots, but was limited to 7% in rain out plots. In the 15-30 cm soil layer, treatment effects were reduced, and soil water content in all plots was both higher and more stable than in the 0-15 cm layer throughout the growing season (Figure 3b). Water table depth increased during the growing season, dropping from 119 to 143 cm below the soil surface.

The isotopic signature of groundwater ($\delta\,^{18}O$ = -14.2 ‰) did not change over the growing season, while soil water $\delta\,^{18}O$ values in the upper 30 cm varied from -9.9 ‰ to -2.3 ‰, as a function of rain inputs or evaporation. Comparing the mean stable oxygen isotope signatures of plant xylem water with these potential sources showed clear differences in water acquisition patterns between the four phreatophyte species. Both grasses (*Sporobolus* and *Distichlis*) used water only from the upper 30 cm of the soil profile and accessed little or no groundwater. Grasses that received rain (control and rain add treatments) acquired water from both sampled soil layers, while grasses in rain out plots relied heavily on soil water in the 15-30 cm layer.

The two shrubs (*Sarcobatus* and *Ericameria*) had different water acquisition strategies (Figure 4b). Early



This graphic illustrates growing season precipitation in 2008 and comparison of treatment effects on mean volumetric soil water content in: (a) the 0-15 cm soil layer and (b) the 15-30 cm soil layer.

in the growing season, *Sarcobatus* used primarily groundwater. However, as monsoon rain events recharged the upper 30 cm of the soil profile, *Sarcobatus* responded by increasing its uptake of water from this source. This pattern suggested that while *Sarcobatus* may be able to persist using groundwater exclusively, it also responds rapidly to acquire precipitation inputs to surface soil. In contrast, *Ericameria* primarily acquired groundwater throughout the growing season, including periods when soil water was abundant. *Ericameria* plants did incorporate some surface soil water in plots that received rain, though much less than *Sarcobatus*. Of the two shrubs, *Ericameria* relied more heavily on groundwater and was relatively insensitive to precipitation inputs in the surface soil.

Implications and Future Research Directions

Our results indicate that distinct differences occur in the water acquisition patterns of four common native phreatophytes in the SLV. These phreatophytes will vary in their sensitivity to changes in soil water availability, which may affect basin-scale groundwater use by native plant communities over time. An increase in rainfall may benefit both grass species and *Sarcobatus*, as these plants are either partly or entirely dependent on rain-recharged surface soil water. However, it does not appear that a moderate increase in rainfall will dramatically change current plant water acquisition strategies or greatly alter plant community composition and groundwater ET. Conversely, a decrease in rainfall will likely increase water stress in grasses, which could lead to a reduction in grass cover and a plant community dominated by shrubs over time. Because both shrub species use groundwater, a slight increase in both abundance and individual plant use of groundwater could result in a large increase in groundwater ET on a watershed scale. This may further alter the balance of groundwater available to sustain regional agriculture and other human uses in the SLV.

Future research should focus on quantifying the total annual groundwater use by each phreatophyte species and understanding how variations in soil water availability affect plant production. Results from our work and future research on phreatophytes in the SLV will be incorporated into the Rio Grande Decision Support System (RGDSS) groundwater model that is used to manage the SLV aquifer.

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Colorado Water Science Day 2010

New Challenges, New Science For Managing Colorado Water

Wednesday, June 23, 2010
9:00 am – 3:30 pm
University Memorial Center, Room 235
University of Colorado
Boulder, Colorado 80302

Keynote Speakers

Matt Larsen, Associate Director for Water, USGS — *USGS Water Science Program Priorities & Directions*

Mike Sullivan, Deputy State Engineer, Colorado — *Using Science To Manage Colorado's Water*

Speakers

Ken Leib, USGS
Impacts Of Land Use Change On Water Quality

Thomas Borch, Colorado State University
Emerging Contaminants

Alisa Mast, USGS
Mercury Deposition

Noah Molotch, University of Colorado
Remote Sensing of Snowpack

Sarah Spaulding, USGS
Nuisance Alga

John McCray, Colorado School of Mines
Carbon Sequestration

Brad Udall, University of Colorado
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Impact of Limited Irrigation on Health of Four Common Shrub Species

by Jason Smith, MS Candidate, Horticulture and Landscape Architecture, Colorado State University
Faculty Advisor: James Klett

Throughout much of Colorado, the demand for water has increased and the available water supply has decreased. It is increasingly important to conserve water wherever possible. One way to conserve water in planted landscapes is to plant low water use plants. Unfortunately, little scientific research has been conducted on determining the water use of common plant species that are used in urban landscapes and distributed throughout nurseries and garden centers in the Rocky Mountain region. Most plant species' responses to limited irrigation are based solely on opinion or visual observation, and as a result, a shrub water study was conducted during the 2009 growing season at the W.D. Holly Plant Environmental Research Center at the Fort Collins Colorado State University campus (Figure 1). The purpose of the study was to determine the growth response of four shrub species that are commonly marketed throughout Colorado nurseries and growing centers for planting in Colorado landscapes. The shrubs were subjected to progressively decreased amounts of irrigation based on the Evapotranspiration (ET) of a short reference crop, and the resulting responses were assessed. The species that were tested were: *Cornus sericea* (redosier dogwood), *Hydrangea arborescens* 'Annabelle' (Annabelle hydrangea), *Physocarpus opulifolius 'Monlo'* (Diablo® ninebark), and *Salix pupurea* (arctic blue willow); one cool-season grass was used as a control: *Poa pratensis* (Kentucky bluegrass).

The experiment consisted of two separate components. The first was an in-field component in which the shrubs and turf were planted in the ground. This in-field component tested all four species of shrubs and the turf using four separate treatments (0%, 25%, 50%, and 100% of ET). The second part of the experiment was a lysimeter component, in which two of the species were grown in a pot-in-pot system and received 25%, 50%, or 100% of ET. Only the redosier dogwood and Annabelle hydrangea were tested in the lysimeter component due to space limitations. All plants (in both components) were planted during the 2008 growing season and were provided with 100% of ET so that the shrubs could establish. In 2009, irrigation treatments were implemented weekly, and the average amounts provided are depicted in Table 1. Data collection included soil moisture, plant heights and widths, predawn leaf water potentials, daily water use (using the plants grown in the lysimeter component only), visual ratings, end of season leaf areas, and end of season leaf fresh and dry weights.

Some difficulties were encountered in the 2009 season due to the weather. Data collection was limited during June and most of July as a result of heavy hail damage incurred on June 7, 2009 (Figure 7). Data collection effectively ceased until plant foliage returned. After the shrubs had re-leafed, data collection resumed from the end of July until mid-September. Further, during the experimental period the total rain fall was above normal, the number of days that precipitation occurred was approximately 35% of the total experimental period, and the summer month temperatures were milder than in previous years (specifically 2008). These conditions are all examples of the difficulties in trying to maintain an outside study testing the effects of drought response when the weather is not similar to drought conditions. As a result of these difficulties encountered from the hail damage, ample rain, and cooler temperatures in 2009, the experiment will continue during the 2010 season, with data collection focusing on the same four species studied during the 2009 season. The 2010 data will supplement the data already collected and to further quantify the shrub species' responses to progressively decreased amounts of irrigation.

Despite the difficulties mentioned, the 2009 results still suggest that all four species will survive in all treatments. All of the tested species (redosier dogwood, Annabelle hydrangea, Diablo® ninebark, and arctic blue willow) will probably ***survive*** without supplemental irrigation when planted in the ground as long as they receive about 10 inches of precipitation and an average temperature of 64°F from May-September, since none of the tested plants in any of the in-field repetitions died due to insufficient soil moisture. However, despite all plants surviving, performance can vary depending upon the amount of water given to them. For example, redosier dogwood and Diablo® ninebark were both wider in the 100% treatment than the 0% treatment,

Shrub Water Study at Colorado State University. (Courtesy of Jason Smith)

From left to right, clockwise: Cornus sericea (redosier dogwood), Physocarpus opulifolius 'Monlo' (Diablo® ninebark), Salix pupurea (arctic blue willow), Poa pratensis (Kentucky bluegrass). Center: Shrub Water Study after hail storm. (Courtesy of Jason Smith)

but there was no difference in height at the end of the season. Redosier dogwood and Annabelle hydrangea were visually more appealing (having more lush growth, less leaf scorch, etc.) in the 100% treatment than the 0% overall during the season. Diablo® ninebark had leaves that had a greater fresh and dry weight per square centimeter in the 100% treatment than the 0%, 25% and 50% treatments at the end of the season. However, quite surprisingly, no statistical differences existed for the seasonal means for the predawn leaf water potential data for any one species in any particular treatment. Essentially what this means is that no one plant species in any particular treatment was more stressed than another member of the same species in a different treatment. All members of one species were equally water stressed in the 0%, 25%, 50% and 100% treatments. These results probably occurred due to the fact that soil moisture levels did not vary significantly in any treatment over the season. Abundant precipitation and cooler temperatures incurred during the testing period most likely kept the soil and plants sufficiently hydrated for survival.

The plants in the lysimeter component were more responsive to treatments. As a result of the plants being in pots, and thus a restricted rooting zone, a smaller reservoir of soil was present to store water. Further, since there was a limited water-holding capacity available to the plants, all tested plants in the lysimeter component dried at a faster rate than the in-field plants. In short, the lysimeter plants were more conducive to drought stress since they could dry out

Table 1: Approximate Gallons of Irrigation Water Applied per Shrub per Week (2009)

	In-field Trials (5/12 - 9/29)	Lysimeter Trials (5/12 - 8/14)	Lysimeter Trials (8/15 - 9/29)
0%	0	N/A	N/A
25%	0.17	0.16	0.36
50%	0.34	0.31	0.73
100%	0.69	0.62	1.46

at a faster rate in between natural precipitation events. The lysimeter component of the experiment showed that both redosier dogwood and Annabelle hydrangea lost more weight (due to water loss) on a daily basis in the 100% treatment than in the 50% treatment, and more in the 50% than in the 25% treatment. What this means is that both species will use more water on a daily basis if more water is provided to them. The redosier dogwood had the same trend and the Annabelle hydrangea had a similar trend, up to a point, with the predawn leaf water potential data and the leaf area data. The redoiser dogwood and Annabelle hydrangea had reduced stress and larger leaves in the 50% than in the 25%, but only the dogwood had further reduced stress and larger leaves in the 100% when compared to the 50%. In other words, more water will reduce stress and create larger leaves in redosier dogwood, but more water will only reduce stress and create larger leaves up to a certain point for the Annabelle hydrangea.

Although only one growing season of data was collected, and troubles were encountered during the 2009 growing season, some interesting conclusions resulted from the experiment. Redosier dogwood, Annabelle hydrangea, Diablo® ninebark, and arctic blue willow appear to be able to survive in the ground with no supplemental irrigation as long as they receive approximately 10 inches of precipitation and an average temperature of 64°F from May-September, assuming they've had at least 1 year for establishment. It is imperative to remember that even though these plants will survive with lower irrigation amounts, they may not necessarily thrive. Further, redosier dogwood and Annabelle hydrangea in pots will use more water when provided with more water, and more water will reduce stress and create larger leaves for both species.

Dr. Jose Salas Awarded the Prestigious Ven Te Chow Award

Dr. Jose 'Pepe' Salas, a Colorado State University civil and environmental engineering professor, was recently awarded the prestigious new Ven Te Chow award from the American Society of Civil Engineers. The award is presented annually to individuals in recognition of a lifetime spent on "...exceptional achievement and significant contribution in research, education, and practice" in the field of hydrologic engineering. The award, which will be presented May 16-20 in Providence, Rhode Island, is the most visible and prestigious award given in Salas' chosen field of hydrology.

Salas is being recognized for his 35 years of experience and significant contributions to hydrology in the areas of probabilistic and stochastic characterization of hydrologic processes, flood forecasting, regional drought analysis, frequency analysis, and education efforts through books and publications, as well as his modeling of the Colorado River, the Nile, and the Great Lakes Basin.

Geography of Water Resources: Comparing International and Colorado River Basins

by Melinda Laituri, Associate Professor, Forest, Rangeland, and Watershed Stewardship Department and Faith Sternlieb, Research Associate, Colorado Water Institute

The water crisis, defined by geographical, political, physical, social, and economic parameters, is both a global and local phenomenon. To demonstrate the relationship between water issues throughout the world and those in our own backyard, students in GR 342 (The Geography of Water) were assigned the task of comparing one of the eight major Colorado river basins with an international watershed (Figure 1). GR 342 is a course offered by the Department of Forest, Rangeland and Watershed Stewardship in the Warner College of Natural Resources at Colorado State University. Students were asked to examine five critical aspects of integrated river basin management: transboundary water issues such as transbasin water transfers and transboundary conflict management, dams, climate change, privatization, and water quality. This article presents the results of their research efforts during the fall semester of 2009. The course instructors chose the most effective comparisons, which cover three of the five themes and seven of eight basins.

The purpose of this article is to examine how the impending water crisis is affecting two seemingly dissimilar basins—geographically located in different hemispheres and exhibiting diverse habitats in a range of climates. While the area and scale of each watershed is quite different (Table 1), the student projects demonstrate that these water issues and solutions reveal many of the same characteristics. Major rivers, such as the Amazon, Nile and Congo, were purposefully not examined in this study; instead, emphasis was placed on basins that have not been as extensively studied. The main challenge students faced was comparing water resource information and data across international boundaries based upon quantitative data that lack standardization.

Evaporation and Water Supply in Arid Regions: Rio Grande and Tigris-Euphrates River Basins

by Hillary Murray

Areas of the world in which an arid environment dominates often present unique water management challenges. In an arid region, the water loss through evaporation can be considerable. The Tigris-Euphrates Watershed and the Rio Grande Watershed are similar in that they both lie in extremely arid regions geographically. Evaporation of water occurs quickly from soil, trees, and wetlands and reservoirs. The Rio Grande Watershed includes numerous reservoirs engineered as water storage systems. These reservoirs are especially important in an arid climate for water insurance in times of scarcity and for irrigated agriculture. In the Tigris-Euphrates Watershed, large storage systems have been built primarily in Turkey. They not only provide water security in a time of drought, but also protect against flooding, which can devastate the agricultural industry. The Euphrates' tributaries converge in the uppermost part of the basin, allowing for a single dam located in the upper portion of the basin to control virtually all of the water flowing through the Euphrates River. Turkey has done just that with the engineering of the Ataturk Dam completed in 1990. Syria, Iraq, and Kuwait rely on these rivers for irrigation; the water lost through evaporation becomes more important with each passing year. Currently it is estimated that the loss in evaporation from the various dams along the Euphrates River is 1083 MCM per year, and evaporation from the reservoirs is estimated to be 630 MCM each year. Similarly, evaporation from the Tigris' nine reservoirs is significant. These reservoirs make up a surface area of 693 square kilometers, and their evaporation is estimated to be 624 MCM per year. While the waters held in storage systems assist in times of plenty, they will only compound a shortage due to high evaporation rates as environmental and social factors change in the coming years.

Issues have arisen in the Rio Grande Watershed over water being lost through evaporation off reservoirs built for storage. In 1979, the U.S. Court of Appeals prohibited certain bodies of water in a desert setting from being kept in reservoirs due to the water loss associated with this practice. To demonstrate the need to address evaporated waters, a Canadian enterprise attempted to purchase unappropriated water lost through evaporation from the Cochiti, Elephant Butte, and Caballo Reservoirs in New Mexico. The enterprise proposed purchasing water from the Gila River before it entered the reservoirs, thereby avoiding the amount of water being lost to evaporation. This water would be diverted to underground storage facilities, thus diminishing the amount of water lost to evaporation. The State Engineer of New Mexico denied the application for water rights.

Studies that can be applied to both the Rio Grande and the Tigris-Euphrates Watersheds indicate that evaporation

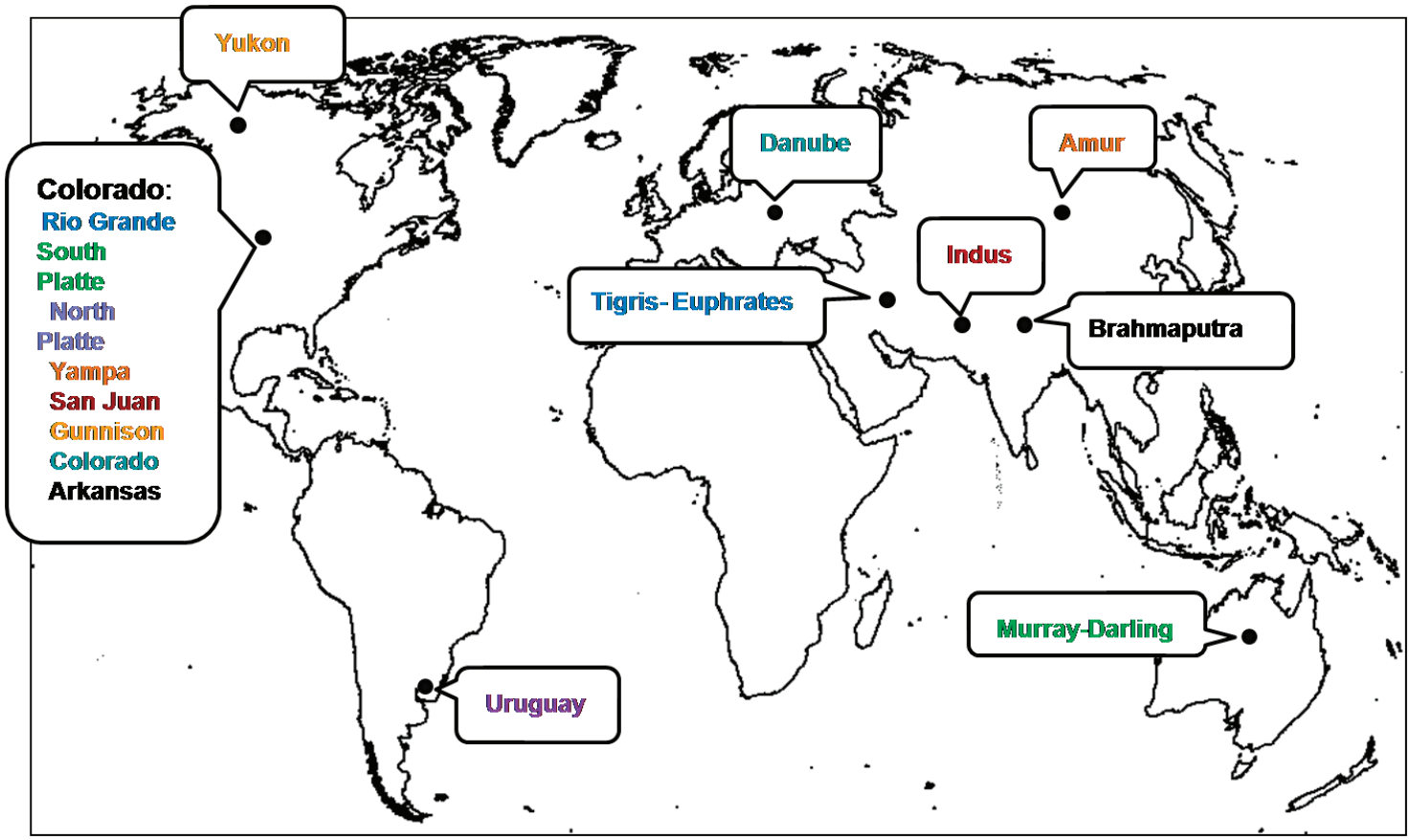

Figure 1: *International river basins compared to Colorado river basins*

from reservoirs in arid regions must be managed. Evaporation rates can be difficult to measure because they differ with temperature, seasonality, and wind rate. Advanced techniques in measurements of evaporation will assist in transboundary issues between nations and the amount of water allocated to downstream users.

Water Rights Transfers: South Platte/Republican and Murray-Darling River Basins

by Kira Puntenney

The Murray-Darling River Basin (MDRB) and the South Platte River Basin (SPRB) are major agricultural producers. Water in both river systems is completely allocated and population levels are predicted to increase in the future. The amount of available water is finite and managers need to find ways of allocating more water in order to support development. The emphasis in these basins is on determining innovative plans to ensure that the transfer and allocation of water will provide an adequate supply and quality of water to support all water needs. The MDRB has initiated a Basin Plan that prioritizes environmental concerns in securing water for the basin's future. This plan includes a "Cap" system on the amount of water that can be diverted. A comparison of the SPRB's water diversion practices to the Murray-Darling's might present possible solutions for both basins. Water supply within the MDRB is based mainly on precipitation. Diversions and storage within the basin through a system of dams, weirs and channels is crucial in maintaining flows and are further supplemented with transbasin diversions from the Snowy River.

In 1988, the five states within the MDRB came together to form the Murray-Darling Basin Commission which allowed for the management of the natural resources on a basin-wide scale. The formation of this political infrastructure made it possible to coordinate joint natural resource management and integrated basin management policies while still giving power to the states to manage their portion of their basin. As salinity issues and land degradation continued to increase, the Murray-Darling Basin Commission and the Murray-Darling Basin Ministerial Council chose to implement a cap on surface water diversions limited to 1993-1994 levels. By putting a cap on the amount of water that can be diverted, the flows within the river can be kept at a much more sustainable level for environmental needs. All future growth in water use must come from water trading and increasing efficiency. This basin-wide management plan aims to set environmental objectives and create measures to secure water for all uses within the basin. This will be accomplished by taking advantage of the best and latest scientific, social, cultural and economic knowledge available so that basin-wide

Table 1. Paired Watersheds

Colorado River Basins	Area	International River Basins	Area
Rio Grande	608,000 km²	Tigris-Euphrates	765,000 km²
South Platte	71,639 km²	Murray-Darling	1,061,475 km²
North Platte	72,520 km²	Uruguay	380,000 km²
Yampa/White/Green	27,195 km²	Amur	2,127,700 km²
San Juan/Dolores/San Miguel	26,338 km²	Indus	561,253 km²
Gunnison	20,720 km²	Yukon	847,621 km²
Colorado	637,000 km²	Danube	795,656 km²
Arkansas	505,000 km²	Brahmaputra	1,664,700 km²

collaboration will be effective in taking steps towards securing the future of the Murray-Darling River Basin.

Halfway across the world in the northeast corner of Colorado is the SPRB. Relying on precipitation as its main water source, this basin is subject to variable water flows that make allocating and diverting water difficult. The SPRB is one of the most over-allocated basins in Colorado supplying water to urban, recreational, environmental, industrial, and agricultural usages. The Murray-Darling and the South Platte are similar in that agriculture is an important factor in water allocation, which is instrumental for trading agricultural water rights to municipalities. The South Platte River differs from the MDRB in terms of how water is allocated. The Prior Appropriation System or "first in time, first in right" recognizes senior and junior water users where senior water rights to beneficial use must be filled before the junior rights holders.

The SPRB has been attempting to assess what is needed to address future problems through the creation of such groups as the South Platte River Basin Task Force and the South Platte Basin Roundtable. Within the SPRB, the South Platte Decision Support System is currently being developed. This is a comprehensive database that integrates modeling systems to help make decisions as to how the water in the basin can be allocated to it maximum potential (Brown and Caldwell, 2002). Would the cap system and basin-wide water resources management initiatives being formulated in the MDRB be appropriate in the South Platte River Basin? If the cap system was implemented in the SPRB, the focus would be on greater water efficiency and water trading to supplant the creation of more transboundary diversions. A key aim of the cap system is to improve methods to calculate flows and water uses within the basin. The MDRB's basin-wide initiative is an example of basin-wide collaboration that identifies major goals for economic and environment stability from which the SPRB could benefit. Due to the difference between water right appropriation systems and political infrastructures, the MDRB Basin Plan could not be applied to the South Platte. However, South Platte managers could work towards creating a collaborative unit to better implement water allocation initiatives.

Water Quality: South Platte and Murray-Darling Basins

by Josh Voorhees

The Murray-Darling River Basin (MDRB) in Australia and the South Platte River Basin (SPRB) in the United States both suffer from water quality issues stemming from natural, agricultural, and urban effects. The MDRB is considered Australia's "bread basket," yet agricultural production in the region is under constant threat from surface and groundwater salinity levels. The basin also faces algal blooms caused by high nutrient loads in rivers. The SPRB sees the possibility of dryland salinity invading its fields and impacting agricultural production in the future. The large concentration of urbanized landscape in Denver and the surrounding area have an adverse effect on water quality in the SPRB and contribute to large nutrient and pesticide levels farther downstream.

The MDRB's most serious problem concerning water quality is increasing salt loads in the Murray River, which are expected to increase as river flows decrease due to climate change. Low flow conditions in the basin cause higher concentrations of nutrients and salts because there is less water in the river to dilute the concentrations. The construction of locks, weirs, and reservoirs in the early 1900s helped keep more water available throughout the year

to dilute these constituents and provide irrigation water during low flow conditions. Global climate change in this region is expected to decrease precipitation and increase evaporation rates, leading to less water available to dilute salts and nutrients in the basin's waterways. To reduce salinity in the basin's rivers, farmers were encouraged to divert irrigation return flows away from the river and into artificial and natural saline-water disposal basins. About 200 of these basins throughout the MDRB are used to store salts that would otherwise be deposited into rivers.

Though these basins are now commonplace in the MDRB, there are still questions as to the long-term effects of such basins on surrounding aquifers and rivers. High nutrient levels in the basin cause the accelerated growth of blue-green algae in lakes and streams. Blue-green algae naturally occur in the basins' ecosystems but can form large algal blooms when given favorable conditions, such as high nutrient levels and adequate sunlight. Through improved management practices, both total phosphorous and total nitrogen levels must be decreased to help limit blue-green algae growth in the basin. The use of riparian vegetation strips has been shown to reduce the addition of non-point source nutrients carried into river systems by runoff and erosion.

High levels of nitrogen and phosphorous are delivered into the South Platte River by groundwater, agricultural runoff, and wastewater treatment plant effluent. While the largest urban areas in the MDRB are located towards the end of the basin, urban areas in the SPRB are located along the Front Range of the Colorado Rocky Mountains and affect river and groundwater quality downstream. A study by Sprague in 2002 shows that storing water from the South Platte in off-stream reservoirs can be used to lower nitrogen concentrations in the water for the irrigation season, but this practice also increases algal growth in the reservoirs. In addition to nutrient loads, the SPRB also has increasing salt concentrations. Though high salinity is not yet widespread in the SPRB, it will likely become an issue in the future due to water reuse, elevated water tables, and evaporative concentrations of salts. The Northern Colorado Water Conservancy District and the U. S. Bureau of Reclamation are working together to compile a salinity database for the South Platte River to assess its current condition.

Land use has an effect on water quality in both of these regions. In both the MDRB and the SPRB, agricultural practices contribute to salinity, nutrients, and turbidity in surrounding waterways. Urban influences alter water quality downstream of large cities due to the runoff of fertilizers and chemicals into city sewer systems. As global climate change causes changes in weather patterns and seasonal water runoff, both the SPRB and the MDRB are likely to be facing similar water quality issues. Political boundaries, corporate interests, economics, and water demand will make the implementation of new policies very challenging. A basin-wide approach will be needed to move towards better management policies and regulations aimed at preserving water and its uses in these basins.

Transboundary Water Issues: North Platte and Uruguay River Basins

by Jenna Meeks

The physical properties of water pose several complications related to regulation of usage and allocation; most notably, water does not follow political boundaries but rather flows across counties, states, and countries. The North Platte River Basin and the Uruguay River Basin face problems with water transfer (Table 2). The water rights of the states involved in the North Platte River are highly complex and intricate. However, in the developing region where the Uruguay River runs, water rights are still being established and are open to interpretation. Issues facing the two basins illustrate the complexity of water rights and ownership.

Table 2. Transboundary Conflict

Commonly Caused By:	Resolution Tactics:
• Withdrawal of water from river basin • Dams • Limited water availability • Population growth • Balance of power between boundary countries • Politics of involved countries • Religious and cultural differences • Difference in water law	• Basin-wide cooperation • Awareness of basin limitations • Acknowledgement of all involved parties • Balance between flexibility and enforcement in management options

The North Platte River Basin, with headwaters located in Colorado and flowing into Wyoming and Nebraska, is located in the western half of the United States, which is considerably more arid than the eastern part of the country. Most western states follow the Doctrine of Prior Appropriation, which usually applies to surface water as well as to groundwater. The Doctrine of Prior Appropriation is a right to the use of water and is appropriated by the act of diverting water from its source and putting it to beneficial consumptive use. Only water that is actually used can be claimed, while the excess water must remain in the stream. Also, once the water has been beneficially used, the waste and return flow must be returned to the original source.

While there have not been recent transboundary conflicts in the North Platte River Basin, historically there have been disputes between Wyoming, Nebraska, and Colorado. In 1922, the case of Wyoming versus Colorado settled by the U.S. Supreme Court ruled that the Doctrine of Prior Appropriation applies across interstate boundaries if both states rely on same water allocation system. Since the North Platte Basin feeds water to the most heavily populated area of Wyoming, this ruling entitles the most senior water right holder in either state to their share. The case also limited total water diversions in Colorado from the Laramie River. A second Supreme Court case of Nebraska versus Wyoming in 1945 equitably divided water allocations between Colorado, Wyoming, and Nebraska. In general, transboundary water issues in the western United States focus around allocation and entitlement.

The Uruguay River basin contributes 12 percent of the total flow into the La Plata River Basin, which is the fifth largest basin in the world. About 43 percent of the river's watershed is in Brazil, and 41 percent is in Uruguay. Argentina, Bolivia, Brazil, Paraguay, and Uruguay all signed the Plata River Treaty, which designated the Uruguay River Management Commission to oversee and manage transboundary development of the basin. In the Uruguay River Basin, the main conflict involves a pulp mill being built along the Uruguay River. Argentina has appealed to the International Court of Justice, claiming that Uruguay has breached the transnational agreements due to construction of pulp mills along the river. The water treaty between Argentina and Uruguay prioritizes water uses: domestic and sanitation purposes, navigation, production of electric power and irrigation. The pulp mills have the potential to compete with the other water uses, with particular respect to water flow and water quality.

The North Platte Basin and the Uruguay Basin face similar water rights issues in that downstream users have an investment in the management of the entire watershed. Solutions to transboundary management must ensure that water is of adequate supply and quality for downstream uses.

Dams and Endangered Species: Yampa and Amur River Basins

by William Carron

While the Yampa and Amur River Basins are very different in terms of water storage reservoirs and dams, upon closer examination there are some key similarities (Table 3). The Amur is the longest undammed river in the world. Additionally, it is the longest boundary river in the world, which makes this basin a prime example of a transboundary watershed in need of joint environmental management between China and Russia. This river is the site of Asia's largest salmon run, where each year salmon and sturgeon migrate from the sea of Okhotsk in Russia. The Yampa River Basin has seven major storage projects, with the largest dam holding 33,275 acre-feet. However, a 250-mile stretch of the Yampa flows through Dinosaur National Park and is unimpeded by dams. The Yampa is home to the humpback chub, bonytail, Colorado pikeminnow, and razorback sucker, which are listed as endangered species under the Endangered Species Act.

Water extraction and impoundment and the antecedent effect on species at risk are present in both watersheds. There have been several demands placed upon the Yampa River: the reconstruction of the Taylor Draw Reservoir in 1997, consideration of diverting Yampa flows to water hungry Front Range communities in 2006, and extraction of water by Shell Frontier Oil and Gas for a proposed oil-shale

Table 3. Climate Comparisons of the Amur and Yampa River Basins

River Basin/Climate Characteristic	Amur River Basin	Yampa River Basin (includes the White and Green River Basins)
Temperature extremes	-25.6° - 122° F	25°F - 54° F
Rainfall	16 – 32 in/year	10 – 60 in/year
Storms	Monsoon	Summer thunderstorms
Runoff	40% due to snowmelt	35 - 69% due to snowmelt
Disturbance	Drought	Drought

Figure 2: *This map of the Yukon watershed overlain on a map of the contiguous United States illustrates the river basin's vast scale.*

project in 2008. Concerns with the Taylor Draw Reservoir and at-risk species has led to a proposal to de-commission the dam as a better way to preserve endangered fish species.

Resolution of these issues demands cooperation between different agencies of the federal government, private industry, and local communities and is a challenging undertaking. Since the 1950s, a series of nine dams have been proposed on the main stem of the Amur River. These dams will have critical effects on wildlife such as the Oriental White Stork, Chinese Softshell Turtle, Red-Crowned Crane, and the migrating salmon and sturgeon. They will be responsible for the relocation of ethnic minorities due to inundation and will impact local and commercial fishing activity. However, development of these dams will require extraordinary binational cooperation. While these two watersheds differ dramatically in size and population, they are both experiencing the same issues of providing people of the region with clean energy and water supply while protecting the environment.

Transboundary Water Treaties: San Juan/Dolores/ San Miguel and Indus River Basins

by Katherine Condon

The Dolores/San Juan/San Miguel River Basin and the Indus River Basin are regulated through established treaties and compacts that govern water sharing and cross-boundary transfers, but history in both regions has shown that disputes still arise and persist in spite of these documents. Although these are two very different watersheds, there is an underlying tension that is present in both cases: the question of when (and to what extent) environmental concerns should take precedence over established legal rights to water. The Dolores/ San Juan/San Miguel River Basin spans parts of Colorado, Utah, Arizona, and New Mexico, and also encompasses the Ute Mountain and Southern Ute Indian Reservations.

In 1988, the Colorado Ute Indian Water Rights Settlement Act resolved the claims of the Southern Ute and Ute Mountain Tribes to their water rights on streams crossing the reservations. As part of the settlement, the state of Colorado agreed to partially fund the Animas-La Plata Project, which had been postponed due to environmental concerns. With the 1988 Water Rights Settlement Act, renewed opposition to the Animas-La Plata project arose, focusing in large part on the potential impacts that reduced flow in the San Juan River would have on the endangered pikeminnow and razorback sucker populations. The U.S. Fish and Wildlife Service found that the pikeminnow population downstream in the San Juan would not be able to recover from the decreased flow in the Animas tributary. Ute proponents of the project felt that this was an unjust

limitation placed on their established long-standing water rights, due to the results of development carried out in the past for the benefit of others. The project was eventually allowed to proceed after the Bureau of Reclamation agreed to operate the San Juan River in a closer approximation of the river's natural hydrology. The project was scaled down in size, which eliminated the irrigation component while still fulfilling the water rights of the Ute tribes. These changes to the project allowed construction to move forward, although continued environmental opposition to the dam remained.

Present-day water rights in the Indus River Basin, which straddles the India-Pakistan border, are determined by the Indus Waters Treaty of 1960 (IWT). In this agreement, India was allocated exclusive use of water in the three eastern rivers (the Sutlej, Beas, and Ravi). Pakistan has the right to water in the three western rivers (the Indus, Jhelum, and Chenab). Disputes are settled through third-party mediation by a neutral expert appointed by the World Bank. One project at the center of recent controversies is the construction of the Baglihar Dam, a hydroelectric project on the Chenab River in India. Pakistan opposed the project, contending that the dam gives India too much control over water and electricity for Pakistan, that the project design exceeded the limitations set by the Indus Waters Treaty, and that it would provide India with a potential weapon in the form of floodwaters in times of conflict. After Pakistan appealed to the World Bank to intervene, a neutral expert was appointed in 2005 to evaluate the Baglihar project and propose a resolution. In 2007, the mediator's report approved the project with a lowered dam height and storage capacity. Although both India and Pakistan, as per the requirements of the Treaty, have abided by the final mediated decision, there have been reports of dissatisfaction. The question that remains is whether the dam's design conforms to the IWT.

These two disputed projects illustrate two of the many ways in which environmental concerns can conflict with the fulfillment of the water rights specified by legal treaties and compacts. In the Animas-La Plata case, the legal claim of the Ute Indians to previously unused water to which they were entitled had to be reconciled with environmental concerns regarding the impact of lowered flows on river health and endangered fish species. The Baglihar Dam was approved in part because its construction was deemed environmentally sound and, therefore, non-threatening to Pakistan's water rights. In both cases, although opposing sides disputed the importance of environmental issues versus established water rights, a settlement was reached through extensive negotiation and compromise.

Climate Change: Gunnison and Yukon River Basins

by Ryan Gamble

Climate change has affected the hydrologic cycle in the Yukon and Gunnison River Basins (Figure 2). Of particular concern in the Yukon River Basin is the thawing of the permafrost layer, which will impact the hydrology of the Yukon River and residents in the Alaskan Panhandle. In 1988, the U.S. Geological Survey conducted a study on climate change and water resources of the Gunnison River Basin and found that changes in temperature primarily affected the temporal distribution of runoff throughout the year. Changes in temperature affected the timing of snowmelt and the ratio of rain to snow, with the effects of temperature change being particularly significant during the spring and summer seasons. The issue of an altered snowmelt and rain ratio not only affects Colorado, but also downstream states to which the Gunnison River Basin supplies water.

The effects of climate change are being experienced in both of these watersheds. Researchers note that changes in stream flow characteristics of the Yukon from 1944 to 2005 are linked to the Pacific Decadal Oscillation (PDO), due to sea level, temperature, and wind pattern change. The effects of a warmer PDO due to climate change has the potential to alter the hydrologic system because of increased melting of the permafrost and the polar ice caps. The Environmental and Hydrologic Overview of the Yukon River Basin states that climate in the Yukon River Basin has been undergoing significant long-term change, causing warmer temperatures and earlier snowmelt and permafrost thawing. Increases in stream flows in the Yukon River Basin affect the wildlife, land, and communities within Alaska and Canada that rely on the river system.

The Gunnison River Basin is an important river basin not only for Colorado but for all the states that rely on the water that flows through the basin. The effects of climate change on the basin are an important aspect when deciding on how the water is shared between the different users and uses between states. Research indicates that the Upper Gunnison River Basin will have a significant drop in snowpack due to climate change, and that the upper basin will lose more than the lower basin due to the constraints of the Colorado Compact of 1922, which require flow levels to be maintained.

Human activities have been linked to increased greenhouse gases that cause climate change. Human intervention and management strategies will help resolve changes in the climate and the hydrological cycle patterns in the Yukon and Gunnison River Basins. With drought looming over the western states and early melting of the permafrost in the Yukon, water stewards have a challenging job in managing the water resources in both the Yukon and Gunnison River Basins.

Hydropower versus Environmental Flows: Comparing Dams in the Colorado and Danube River Basins

by Forrest Dorsey

The Glen Canyon Dam in the Colorado River Basin and the Gabcikovo Dam in the Danube River Basin have had major influences on the western United States and Central Europe, respectively, concerning hydro-electric power generation and effects on environmental habitat. Glen Canyon Dam is located on the Colorado River in Page, Arizona. Dams in the U.S. Southwest generate electricity for the fast-growing region and provide water recreational opportunities. Glen Canyon Dam's hydropower generates 6 percent of the total electricity in Arizona and 13 percent in Utah. The damming of the Colorado River has resulted in a reliable source of energy, as well as tourism opportunities. However, there have been significant harmful ecological outcomes due to the dam: changes in the river's natural flow regime, loss of species of both flora and fauna, natural scouring of the river basin, and the exchange of a free-flowing river for a large lake.

The upper Danube River is an ideal place for building hydropower plants due to the river's natural gradient and the need to supply energy to a growing population. The second largest dam system on the Danube River is located at Gabcikovo, near an area that used to form one of the region's largest wetlands. The Danube River Commission states that the river channel only receives 10-20 percent of the total flows, due to the 80-90 percent of water channeled towards the turbines to generate 10 percent of the electricity used in Slovakia.

The dams were constructed for the benefit of the populations along these major rivers; however, serious environmental effects have resulted. The Glen Canyon Dam traps sediments that create buildup in Lake Powell, which impacts fish and wildlife populations. The Gabcikovo Dam is facing similar environmental problems, as the original channel no longer receives a sufficient amount of discharge. Research shows that in some areas, surface water and groundwater levels have dropped by up to 4 meters, or 13 feet, adversely affecting the area's wetland ecology. Migratory fish, such as the sturgeon, are indicators of the ecological conditions of the entire Danube River Basin. Sturgeon use tributaries of the Danube as migration routes and spawning grounds, but the hydropower plants in central Europe create migration barriers. The Gabcikovo Dam has resulted in sharp declines in most Danube sturgeon species, leading to regional economic impacts on the productivity of fisheries. In response to the ecological changes on the river, an International Commission for the Protection of the Danube River has been established.

Glen Canyon Dam near Page, Arizona, generates 6 percent of the electricity in Arizona and 13 percent in Utah. (Image from Wikimedia Commons)

To counteract impacts from the Glen Canyon Dam, an experiment to improve the river for wildlife was launched in 2008. Opening the jet tubes at Glen Canyon Dam would release Colorado River water into the Grand Canyon, pushing sand built up at the bottom of the river's channel into a series of sandbars and beaches downstream with the aim to improve habitat for the humpback chub fish species. This experiment was implemented, and research recorded the highest sediment deposits in a decade, which has led to improved habitat and increased camping beaches for tourists.

Dam management includes not only management of flow regimes, but also efforts to address issues of habitat change. Dam issues are similar throughout the world, and countries can benefit from the experiences in different locations to create improved water resource management for both humans and the environment.

Conclusion

GR 342 is designed to give students a broad background in spatial and temporal issues involving water resources around the world. In addition, the class offers students the opportunity to develop critical thinking, writing, and research skills by expanding their perspective to the global arena while examining some of the most pressing local challenges. Findings from the above studies show that despite significant differences in area, climate, and physical attributes, several crosscutting themes were revealed, including adequate supply and quality of water for multiple uses, the transfer and allocation of water from one use to another and from one jurisdiction to another, water rights, and water supply for human populations versus the natural environment. As was noted by each excerpt, the lessons learned in one river basin can very well translate to solutions in another.

High-Resolution Soil Moisture Retrieval in the Platte River Watersheds

by Chengmin Hsu, Ph.D. Candidate, Civil Engineering, University of Colorado Denver
Faculty Sponsor: Lynn E. Johnson

Research Question and Objective

Hydrological and other applications require soil moisture data at high spatial and temporal scales. Of the various methods to obtain soil moisture data, satellites hold promise of providing data at the appropriate scales. Currently, there are only two sources of operational global soil moisture data from satellites: (1) Advanced Microwave Scanning Radiometer (AMSR-E) aboard NASA's Aqua satellite, and (2) the Soil Moisture and Ocean Salinity (SMOS) satellite operated by the European Space Agency.

However, neither is a high-resolution product. The AMSR-E surface soil moisture product has a 25-km resolution, whereas SMOS can create only 50-km resolution products. Motivated by the urgent need for high-resolution soil moisture data, the purpose of this research is to develop an algorithm for disaggregating the 25-km AMSR-E daily soil moisture to a 250-m resolution product.

Study Site

The study site encompasses areas within the South and North Platte River watersheds and the Republican River watershed (Figure 1). The total study area is approximately 45,000 square kilometers. Most of the area is composed of open grassland and agriculture areas.

Data

Data used include: (1) X band (centered at 10.7 GHz) derived soil moisture from the AMSR-E sensor, (2) Moderate Resolution Imaging Spectroradiometer (MODIS) data, (3) data from the Soil Survey Geographic (SSURGO) database, (4) station data from the NRCS Soil Climate Analysis Network (SCAN), (5) wind speed measurements, (6) in-situ soil moisture data collected from the Automated Weather Data Network (AWDN) of the High Plains Regional Climate Center (HPRCC), and (7) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery collected over parts of Weld and Larimer Counties in Colorado.

The MODIS data used are version 5 MODIS/Terra and MODIS/Aqua 1-km resolution daily surface temperatures and MODIS/Terra 250-m resolution 16-day Enhanced Vegetation Index (EVI). The observations from the 16-day EVI product were cloud free and were used to generate fractional vegetation cover (Figure 3). Seven MODIS Version 5 surface temperature images with the least amount of cloud cover were acquired (July 13, 19, 20, 30, 31 and August 1 and 20, 2008). The ASTER image was captured on August 19, 2008. Land surface temperature was estimated from 90-m resolution L1B thermal radiances using the emissivity normalization method implemented in ENVI (ENvironment for Visualizing Images image processing software, http://www.ittvis.com/ProductServices/ENVI.aspx).

Disaggregation Algorithm

The soil moisture downscaling algorithm is composed of three sequential stages:

Stage 1: Downscaling of a 25-km resolution AMSR-E soil moisture to a 5-km resolution product. In this stage the basic concept is that the evaporation rate of the sub-pixel at 5-km resolution should be higher than the average evaporation of the pixel at 25-km resolution if the soil temperature of the sub-pixel is greater than that of theAMSR-E pixel. Thus, soil moisture of that sub-pixel will be drier than that in the 25-km resolution pixel.

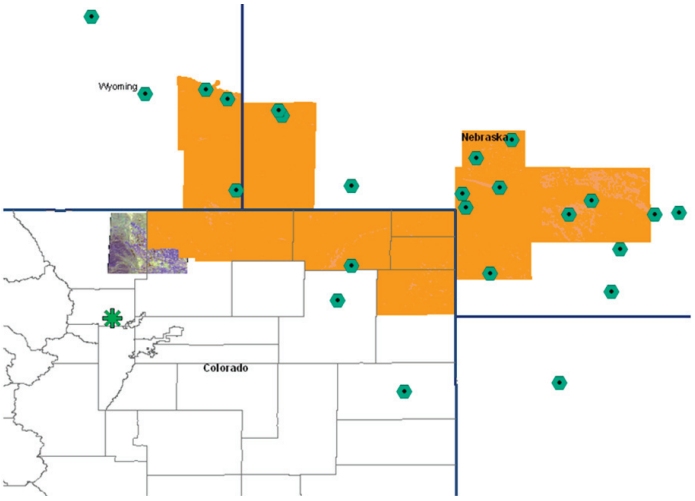

Figure 1: The study site (in orange) is located across Colorado, Nebraska and Wyoming, comprising the areas within the North and South Platte River Basin and the Republican River Basin. The malachite green points are Automated Weather Data Network (AWDN) stations from the High Plains Regional Climate Center (HPRCC).

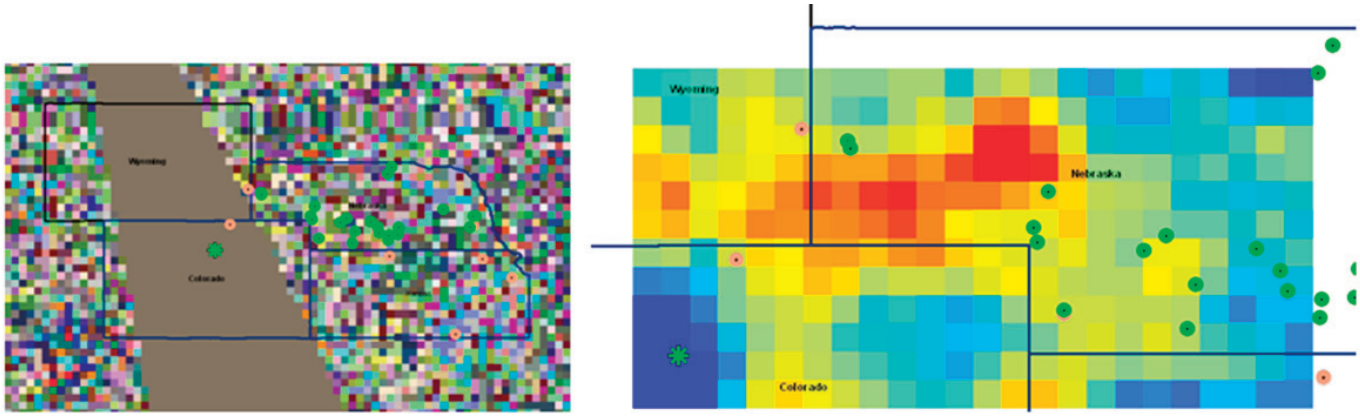

Figure 2: The graph on the left is the AMSR-E soil moisture imagery on July 20, 2008. It shows that a large area without data occupies the left edge of the study site. The graph on the right is the magnified interpolated soil moisture data, seen after using Krigirg interpolation method.

Stage 2: Downscaling of 5-km resolution soil moisture to 1-km resolution soil moisture. In the second stage, the Percent Clay from SSURGO data and the fractional vegetation cover derived from EVI are used for downscaling. This operation's purpose is to account for the lower soil moisture sensitivity of the MODIS surface temperature and the poor capability of AMSR-E to differentiate soil and vegetation signals.

Stage 3: Downscaling of 1-km resolution soil moisture to a 250-m product. The method applied in this stage is similar to that in Stage 1 but uses ASTER derived surface temperature and Normalized Difference Vegetation Index (NDVI).

The equations below represent the philosophy used for the first stage of downscaling AMSR-E soil moisture using MODIS data. Notice that all equations are also appropriate for disaggregation using ASTER data in Stage 3. This brings together soil properties and the philosophy mentioned above. The downscaling relationship for the first stage can be represented by:

$$SM_{MODIS,\ 5km} = SM_{AMSR\text{-}E,\ 25km} + \theta c * SMD_{MODIS,5km}$$

with SMD as the MODIS-derived soil evaporative efficiency estimated based on the difference of soil temperatures between the 5-km resolution and its average within the AMSR-E pixel. The equation also integrates the lab findings of Komatsu (2003) by adding a downscaling coefficient, θc. θc is a semi-empirical parameter that depends on soil properties and boundary conditions of soil layers. In this research, the data extracted from the SSURGO database was used. SMD is assumed to be linear and can be defined as:

$$SMD_{MODIS,\ 5km} = \frac{T_{MODIS,\ 25km} - T_{MODIS,\ 5km}}{T_{MODIS,\ 25km} - T_{min,\ 1km}}$$

Here, $T_{MODIS,\ 5km}$ is the soil temperature at the 5-km resolution. It is derived by using MODIS derived EVI and surface temperature aggregated at the 5-km resolution. $T_{MODIS,\ 25km}$ is its average within the AMSR-E pixel, and $T_{min,\ 1km}$ is the minimum MODIS derived soil temperature at the 1-km resolution. The assumption for the minimum soil temperature is that it is equal to the minimum MODIS surface temperature. The soil temperature can be estimated by using a simple equation developed by Merlin et al. (2008). The equation can be defined as:

$$TMODIS,\ 5km = \frac{T_{surf,\ MODIS,\ 5km} - f_{v,\ MODIS,\ 5km} * T_{v,\ 5km}}{1 - f_{v,\ MODIS,\ 5km}}$$

Table 1: 5-km Resolution Soil Moisture Downscaling Validation

	Nunn Station		Johnson Farm Station	
Date	Observed Soil Moisture (%) at 5-cm depth	Estimated Soil Moisture (%) at 5-cm Depth	Observed Soil Moisture (%) at 5-cm depth	Estimated Soil Moisture (%) at 5-cm Depth
7/13/2008	0.113	0.119	0.072	0.091
7/19/2008	0.101	0.109	0.197	0.094
7/20/2008	0.100	0.110	0.105	0.095
7/30/2008	0.108	0.096	0.252	0.101
7/31/2008	0.105	0.101	0.153	0.106
8/01/2008	0.101	0.101	0.107	0.093
8/20/2008	0.320	0.112	0.235	0.089

with $T_{surf,MODIS,5km}$ as the MODIS-derived surface temperature, $T_{v,5km}$ as the vegetation temperature, and $f_{v,MODIS,\ 5km}$ as the fractional vegetation cover at the 5-km resolution. In this research, $T_{v,5km}$ was estimated to $T_{min,\ 1km}$. fv can be estimated using EVI directly. The coefficient θc, is calculated using von Karman wind turbulence models and SSURGO soil database. Detailed steps are described in a paper published by Komatsu (2003).

In Stage 2, a variable produced by multiplying the percent clay of SSURGO and f_v was used for downscaling. The equation is represented by:

$$SM_{1km} = SM_{5km} + 0.025 * \frac{f_v * P_{clay,\ 1km} - f_v * P_{clay,\ 5km}}{f_v * P_{clay,\ 5km}}$$

where "P_{clay}" is the percentage of clay extracted from SSURGO. The concept is that clayish soil can retain a large percentage of water, but it is not good for vegetation growth. The pixels that have high fractional vegetation cover and also a high percentage of clay must be wetter than the pixels that do not have them.

Results

The results of downscaling at the 5-km and 1-km resolutions are quite good in the dry phase, based on the comparison of observed and downscaled soil moisture (Table 1). One day's result of the downscaled 5-km resolution soil moisture is shown in Figure 4.

However, in wet phases, downscaling results do not reflect the true soil moisture. For example, the in-situ soil moisture data on August 20, 2008, for the Nunn station is 0.32, while the downscaled soil moisture data for that specific pixel shows it as only 0.112. Further examination of the original AMSR-E soil moisture data finds that soil moisture in that specific pixel is only 0.104. This indicates that the AMSR-E sensor cannot capture the true soil moisture variability in wet phases.

The 5-km soil moisture data of July 13, 2008, was further downscaled to the 1-km resolution using the method depicted in the second stage (Figure 5). The derived soil moisture for the pixel where the Nunn station is located is 0.113, which is exactly the same as the soil moisture observed at the station. This is an encouraging sign for the second stage of downscaling. The 1-km resolution soil moisture data of July 13, 2008, was also downscaled to the 250-m resolution. But because the downscaling was based on the only available ASTER data of August 19, 2008, large amounts of error can be expected. Therefore, validation has not yet been executed.

Conclusion

The developed downscaling algorithm seems satisfactory, based on the limited analyses conducted. The problem of AMSR-E indicating soil moisture that is too dry compared to reality during the wet phase suggests that AMSR-E data are not adequate for downscaling. However, this deficiency can perhaps be overcome by integrating SMOS data, because

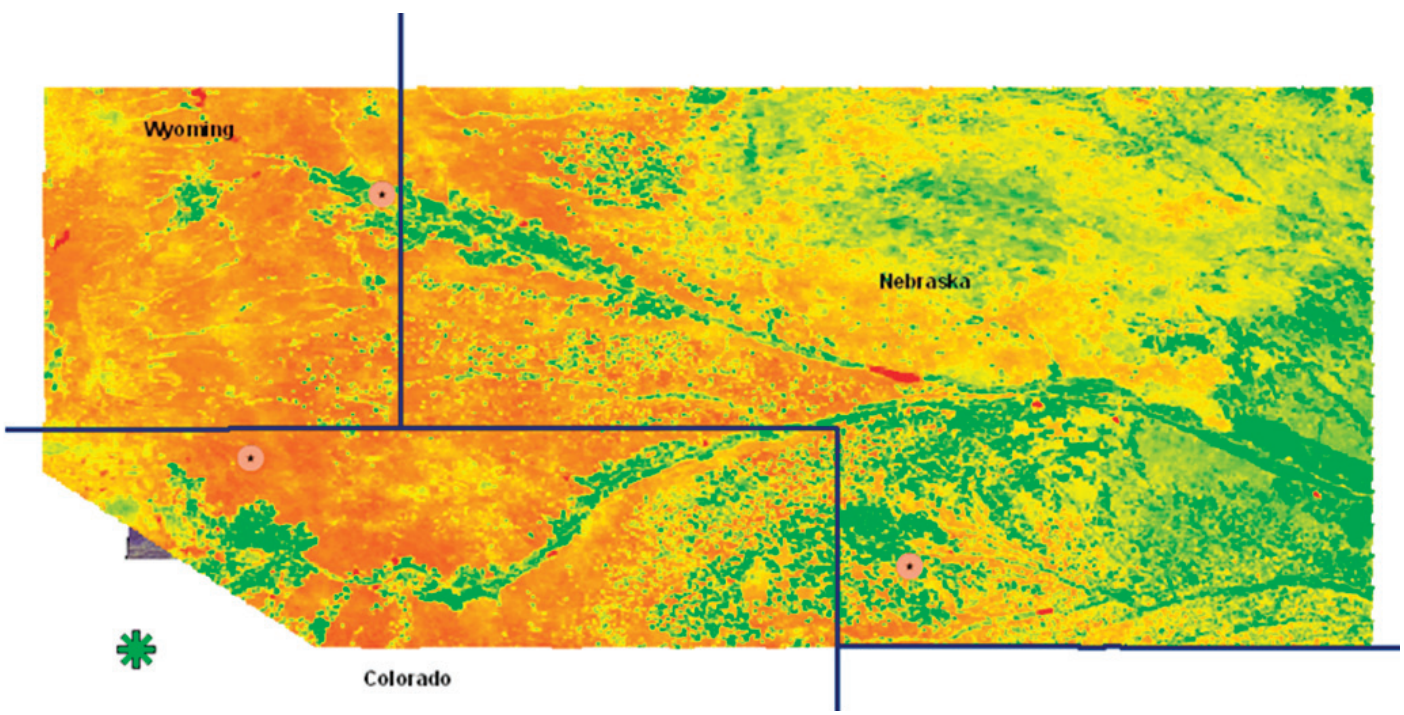

Figure 3: The EVI of the period between July 27, 2008 and August 11, 2008 represents the factional vegetation cover of that period of time. The greener the color is, the higher the percentage of vegetation cover.

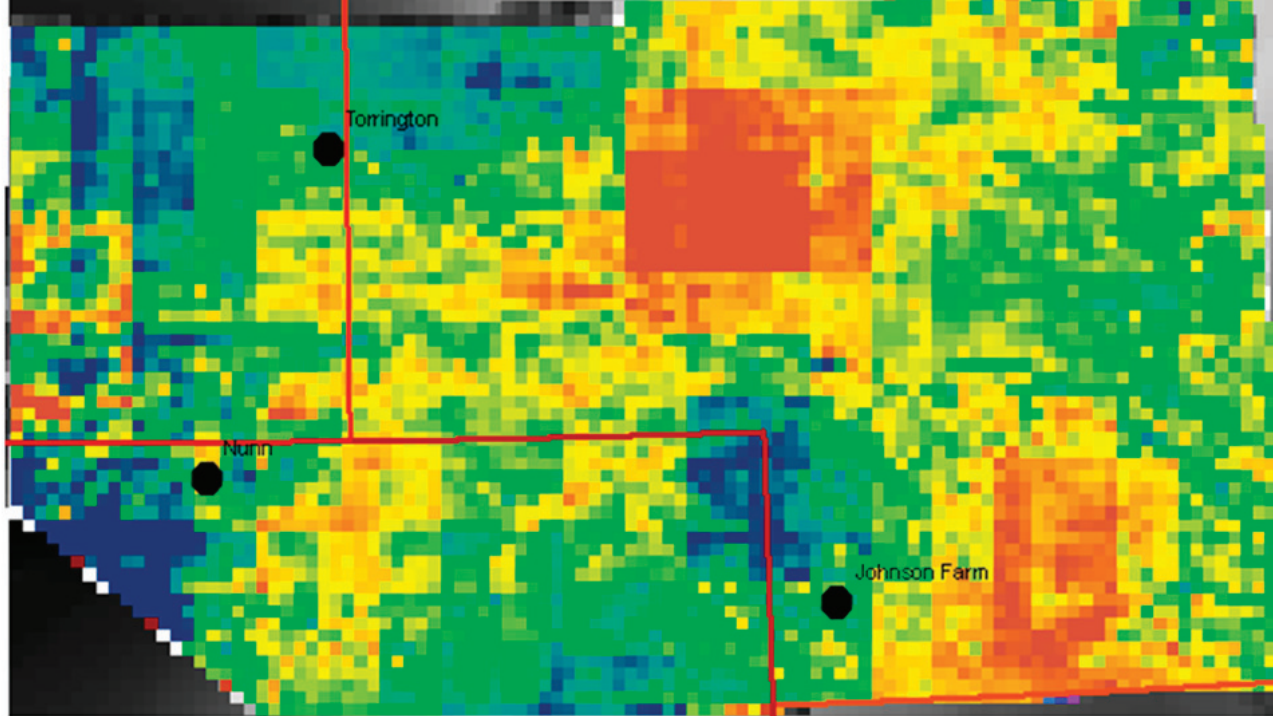

Figure 4: The downscaled 5-km resolution soil moisture data on August 1, 2008.

the SMOS satellite equips sensors that can detect L-band energy emitted from the Earth. This will reduce the problem of vegetation canopy forming an opaque layer that hinders the signal from the soil as detected by AMSR-E sensor. Another way to improve this downscaling model is to make adjustments to the second stage. In this research, a constant value of 0.025 was used. In fact, it can be shaped as a parameter integrating the dynamics of precipitation. Improvement of the second phase of the downscaling algorithm deserves additional attention.

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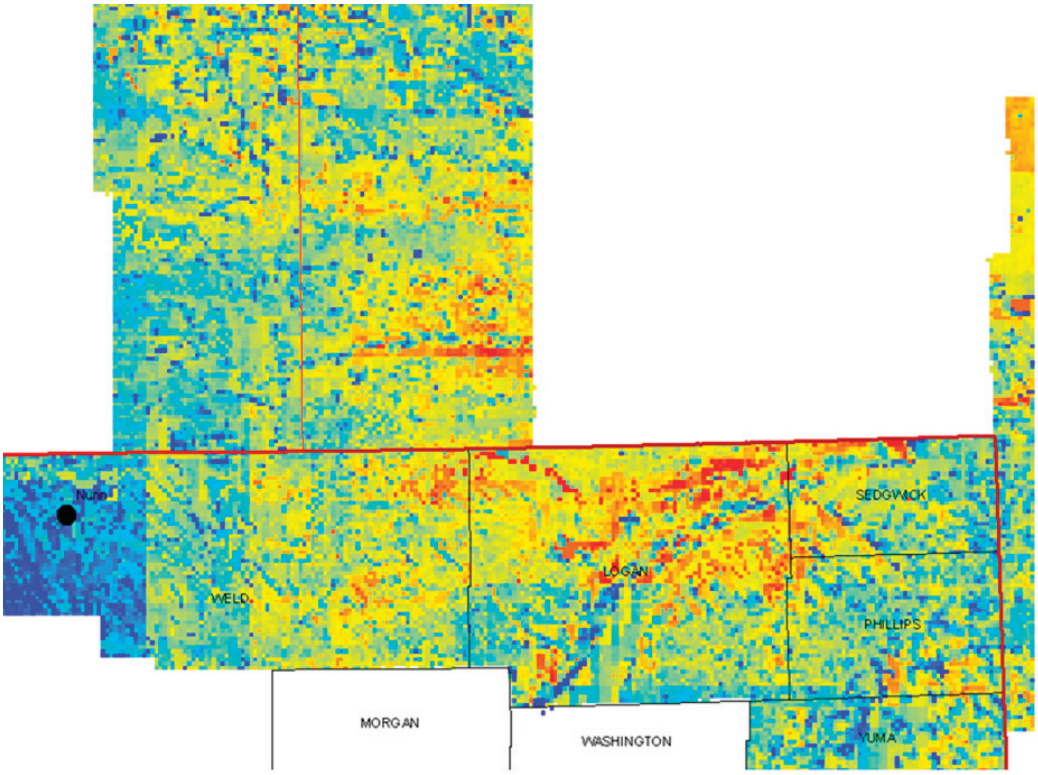

Figure 5: The downscaled 1-km resolution soil moisture data of July 13, 2008. The black spot in the left corner is the Nunn station of the Soil Climate Analysis Network.

Archivist Patricia J. Rettig Receives Faculty Award for Excellence

Colorado State University Libraries Assistant Professor Patricia J. Rettig has been selected as the recipient of the 2010 Colorado State University Libraries Faculty Award for Excellence. This award recognizes a member of the Libraries faculty for outstanding contributions to the Libraries, to the University, and/or to the library profession.

Rettig, the Head Archivist for the Water Resources Archive since 2005, has been recognized not only for her practice of librarianship, but also for her many scholarly and creative contributions to the profession. Rettig joined the University Libraries as a Project Cataloger in 2000 and became an Archivist in 2001. During her years of service with University Libraries Archives and Special Collections, she has built the Water Resources Archive from a small assortment of boxes to a premier collection of archival records documenting all aspects of water in the Rocky Mountain West. Following her initial efforts to arrange and describe the existing archival collections, Rettig created a display to showcase the Water Resources Archive and took it on the road to water conferences, ditch company meetings, and other gatherings, introducing Colorado's water community to the Archive's holdings.

Through careful cultivation of relationships with civil engineers, historians, water lawyers, and other key individuals in the water community, Rettig has facilitated the donation of dozens of new collections to the Archive, most notably the highly significant Papers of Delph E. Carpenter and Family. She has worked tirelessly to make these unique materials available to a worldwide research community through online finding aids and digitized materials

In addition to her articles for peer-reviewed journals, Rettig has contributed to the *Colorado Water* newsletter on a regular basis, educating members of the water community about the holdings and activities of the Water Resources Archive. Finally, her thorough planning, visually pleasing and informative exhibit design, and successful execution of the annual Water Tables fundraising event have resulted in higher visibility for the Water Resources Archive, donation of new archival collections, and funding to assist in the preservation of these collections. Rettig deserves recognition for excellence in building and making accessible unique holdings of the CSU Libraries to water researchers throughout the world.

Rettig is a member of the American Library Association, the Society of American Archivists, and the Society of Rocky Mountain Archivists.

A Good Flood: New Donations to the Water Resources Archive

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

Floods can be good, at least when they are floods of historical documents coming to an archive. The month of March brought a flood of new donations to the Water Resources Archive. The three waves of new materials are significant for documenting Boulder ditches, Fort Collins weather, and the work of one of the Colorado water community's most important legal minds.

Boulder Ditches

The city of Boulder, Colorado, celebrated its sesquicentennial (150th anniversary) in 2009. As part of the celebrations, local artist Elizabeth Black brought together historians, scientists, and other artists to examine the history of Boulder's irrigation ditches. This effort, called the Ditch Project, took the form of three extensive exhibits featuring artwork, photo essays, and educational materials about ditches, as well as a public symposium and a web site (http://bcn.boulder.co.us/basin/ditchproject/).

Black compiled substantial information and numerous photographs of Boulder-area ditch companies—more than would fit on the web site. To share this wealth of information, he loaded the digital files onto flash drives and donated them to the Water Resources Archive. This makes it the second all-digital donation to the Archive. In the coming months, archivists will inventory and catalog the files to make them easily accessible through an online database.

Fort Collins Weather Data

In modern times, automated collection of weather data is the norm, but this was not the case 30 years ago. When Jim Wirshborn, founder of Mountain States Weather Services, began collecting hourly temperature, precipitation, and wind data in Fort Collins back in 1976, he observed the weather directly and recorded those observations by hand. His set of data is continuous since that year, making it remarkable for its time span, consistency, and completeness.

Wirshborn's 15 boxes of chronological Fort Collins weather data will be added to the Water Resources Archive's existing Climate Data Collection, which contains observations from weather stations across the state, dating back to 1893. The new addition also contains a small cache of information about Fort Collins' most recent significant weather event, the 1997 flood.

Bob Carlson, Water Commissioner for District 6. (From the Records of the Ditch Project, Water Resources Archive, Colorado State University)

Justice Gregory J. Hobbs

May 2010 will mark the beginning of Justice Gregory J. Hobbs' 15th year on the Colorado Supreme Court. Prior to his service there, Justice Hobbs practiced law for 25 years, specializing in water, environment, land use, and transportation. He has also actively participated in wide-ranging professional activities, including service as vice-president of the Colorado Foundation for Water Education and as a co-convenor of Dividing the Waters, a Western Water Judges project.

The 30 boxes Justice Hobbs has donated to the Water Resources Archive largely contain files from his days as a law partner, at a time when he was doing a lot of work for the Northern Colorado Water Conservancy District.

In addition to this work, the boxes contain a number of Justice Hobbs' speeches, articles, and books, including his poetry. Files relating to his professional service are included as well. This volume and variety of material will require significant time and attention from an archivist, but once it is organized and inventoried, it will provide a valuable resource detailing the career of this important legal mind.

The Water Resources Archive is pleased to have this type of flood of information coming in its doors, and more is welcomed at any time. For more information about the collections in the Archive or to find out how to donate materials, please visit the Water Archives web site at: http://lib.colostate.edu/archives/water/ or contact the author at 970-491-1939 or patricia.rettig@colostate.edu.

Alpine Dust Deposition and Associated Continental Winds

by Morgan Phillips, *Undergraduate Research Assistant, Colorado Climate Center*

A visible layer of desert dust coats the snows of Mount Sopris in Colorado's Elk Range in 2007. (Courtesy of National Snow and Ice Data Center/Penn Newhard)

During the late winter and early spring, mid-latitude cyclones and their associated fronts moving through the southwestern United States often generate intense regional dust storms which then deposit large amounts of airborne sediment in alpine mountain areas (McBride, 2007). Aeolian sediment deposition on alpine snow packs in the western United States is becoming a subject of greater concern as a larger percentage of the population continues to depend on mountain snow as a source of municipal water supplies. The accumulation of dust on mountain snow packs has the potential to alter the snowmelt regime and thus the rate and timing of snowmelt discharge (Painter et al. 2007). The primary goal of this study was to investigate potential origins of dust found in the San Juan snow pack by using a combination of data analysis and atmospheric models, while at the same time attempting to quantify the frequency of high wind periods capable of generating dust storms.

The study began with visual analysis of time series data for all Remote Automated Weather Stations (RAWS) in the western United States. Stations with periods of high winds that best corresponded to known dust events in the San Juan Mountains were then identified. The locations of these weather stations indicate where conditions were favorable for dust entrainment during a dust event, and were concentrated in northeastern Arizona. This information, along with satellite imagery, provided a good indication of where most of the dust originated. The frequencies of such high winds were then evaluated on a monthly basis for RAWS in Arizona, Nevada, Utah, and western New Mexico for the last 20 years. Results from this analysis showed a marginal correlation between the frequency of high wind periods and the El Niño/Southern Oscillation (ENSO), particularly in the January-April months.

In order to properly manage water supplies impacted by the effects of wind-blown dust, it is important to have a thorough understanding of the underlying mechanisms which bring about such situations. Considering the findings of this investigation, along with the results of other work, this study concludes that most of the dust accumulated on the San Juan Mountains in 2009 originated from the arid basin areas of the Colorado Plateau. As far as the correlation between increased frequency of high wind periods in the southwestern United States and the El Niño Southern Oscillation (ENSO), more research is necessary before any concrete conclusions can be made. It is clear that some underlying relationship does exist between the ENSO and continental winds; however, the exact magnitude and timing of this effect is still unknown.

Water Resources Extension around the State

by Perry E. Cabot, Extension Water Resources Specialist, Colorado State University

After a wet winter in the Arkansas Basin, the ditches are again flowing bank-full down here, and Lake Pueblo is almost at capacity. These fortunate circumstances were the topic at the recent Arkansas River Basin Water Forum (April 6-7), for which the CSU Southern Regional Extension Office provided a healthy share of leadership and organization. The Forum was attended by about 160 stakeholders and interested citizens in Cañon City, covering topics such as supply, quality, and economic impacts of water resource management in the Arkansas Basin. With the Forum now behind us, Extension Water Resources work in the Arkansas Basin is turning its focus to our numerous field projects. Front and center is one study of canola cropping under different irrigation regimes. Our objective is to evaluate whether this particular oilseed crop has broad appeal to the arid southern Colorado plains. Our work is funded by the National Winter Canola Variety Trial Program and the Lower Arkansas Valley Water Conservancy District. While we may not grow record-breaking yields in this area, the idea of growing canola in conjunction with water leasing arrangements is gaining appeal. Through our partnership with the Arkansas Valley Research Center and local cooperators, we are gathering useful information for producers to consider this alternative farming and irrigation strategy.

USGS science for a changing world — Recent Publications

Assessing Groundwater Availability in the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming by S.L. Qi, and S. Christenson http://pubs.usgs.gov/fs/2010/3008/

Changes in Streamflow and the Flux of Nutrients in the Mississippi-Atchafalaya River Basin, USA, 1980-2007 by W.A. Battaglin, B.T. Aulenbach, A. Vecchia, and H.T. Buxton http://pubs.usgs.gov/sir/2009/516A/

Development and Application of Regression Models for Estimating Nutrient Concentrations in Streams of the Conterminous United States, 1992-2001 by N.E. Spahr, D.K. Mueller, D.M. Wolock, K.J. Hitt, and J.M. Gronberg http://pubs.usgs.gov/sir/2009/5199/

Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado by J.P. Capesius, and V.C. Stephens http://pubs.usgs.gov/sir/2009/5136/

Health Effects of Energy Resources by W. Orem, C. Tatu, N. Pavlovic, J. Bunnell, A. Kolker, M. Engle, and B. Stout http://pubs.usgs.gov/fs/2009/3096/

One-Dimensional Transport with Equilibrium Chemistry (OTEQ) – A Reactive Transport Model for Streams and Rivers by R.L. Runkel http://pubs.usgs.gov/tm/06b06/

Mechanisms for Chemostatic Behavior in Catchments: Implications for CO2 Consumption by Mineral Weathering by D.W. Clow, and M.A. Mast http://co.water.usgs.gov/publications/non-usgs/Clow09onecha.pdf/

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

Faculty Profile

Karan Venayagamoorthy, Assistant Professor, Department of Civil and Environmental Engineering, Colorado State University

I joined the Department of Civil and Environmental Engineering at Colorado State University as an assistant professor in January 2008. I received my bachelor's degree in civil engineering (summa cum laude) and master's degree in civil engineering (cum laude) from the University of Kwazulu-Natal (formerly known as University of Natal) in Durban, South Africa, in 2000 and 2002, respectively. I then came to the United States to pursue my doctoral studies in civil and environmental engineering at Stanford University. I earned my PhD in 2006, specializing in environmental fluid mechanics and hydrology. I then spent an additional year as postdoctoral research fellow at the Environmental Fluid Mechanics Laboratory at Stanford University.

I have been fortunate to have received numerous honors and awards, such as the merit medal from the Engineering Council of South Africa for the most outstanding performance in engineering at the University of Natal (2000), the S2A3 medal for the most outstanding MS thesis from the South African Association for the Advancement of Science (2002), Offshore Mechanics Scholarship from International Society of Offshore and Polar Engineers (ISOPE) for outstanding performance at Stanford University (2006), and the Lorenz G. Straub Award from the St. Anthony Falls Laboratory at the University of Minnesota for my 2006 PhD dissertation at Stanford University.

I first heard about the Department of Civil and Environmental Engineering at CSU when I was an undergraduate student in South Africa; my hydraulic engineering professor spoke highly of CSU's impressive water engineering research program. I have excellent impressions about the capabilities of the faculty in the civil and environmental engineering program and the College of Engineering as a whole. The opportunity to carry out innovative and cutting-edge interdisciplinary research in water engineering, as well as wind engineering and fluid mechanics, was an important factor in my decision to join CSU.

Research

My primary research expertise and activities are in the field of environmental fluid mechanics, geophysical fluid dynamics, and hydraulics, with an emphasis on the use of computational fluid dynamics (CFD) simulations in conjunction with theory and lab/field experiments to study fundamental problems in natural and engineered environments. Example problems include mixing and dispersion of pollutants/contaminants, nutrients, sediment, etc., which involve the atmosphere, rivers, estuaries, lakes, coastal and open oceans, and ground water. It is crucial to address these problems to ensure sustainability of our environmental resources. Some examples of my recent research projects include modeling the effect of aquaculture wastes on coastal water quality, nonlinear internal waves in the coastal ocean, fundamental aspects of mixing and dispersion in stably stratified turbulent flows, modeling mixing in disinfection drinking water tanks, and water quality modeling. Some of my research in environmental fluid mechanics has been published in prestigious journals such as the *Journal of Fluid Mechanics*, *Geophysical Research Letters*, and *Physics of Fluids Journal*.

At CSU, I am slowly building a nice computational fluid dynamics research group (currently comprising five graduate students) to work on a number of externally funded research projects. I am working on a research project funded by the Colorado Department of Public Health and Environment (CDPHE) to optimize the hydraulic efficiency of drinking water systems. The main objective of this study is to provide design guidelines for effective disinfection in small public drinking water systems

(in Colorado, about 75% of drinking water systems are classified as small—servicing less than 3000 people).

I am the PI on a project addressing the dynamics of turbulent mixing in oceanic flows funded by the Office of Naval Research (ONR), and I also conduct research on turbine dynamics in wind engineering in collaboration with a colleague in solid mechanics, Professor Paul Heyliger. Our focus in this project, funded by the Center for Research and Education in Wind (CREW), is to investigate the turbulence-induced aeroelastic and structural response of multiple turbines in large wind farms, with a special thrust towards discovering influences of large deformation mechanics of large flexible turbine blades. I am also setting up a high-performance computing facility to enhance the computational research capabilities in environmental fluid mechanics, water engineering, and wind engineering in the Department of Civil and Environmental Engineering.

Teaching

Teaching is an integral part of my academic life, and I have a strong inclination to awaken the curiosity and critical thinking skills in my students. At CSU, I have taught a number of courses at the undergraduate and graduate levels, including Fluid Mechanics (CIVE300), Engineering Dynamics (CIVE261), and a new graduate course in Computational Fluid Dynamics (CFD–CIVE581A2) that I developed from scratch in Spring 2009. I am also currently developing a new course entitled "Models and Computational Methods in Civil Engineering (CIVE580A3)" to both provide a solid background in math models and numerical methods for civil engineers and serve as a prerequisite to the CFD course that I have already developed. This new course emphasizes the fundamentals of numerical methods for the solution of differential equations (both ordinary and partial) encountered in the different disciplines in civil and environmental engineering. I have also taught review sessions in dynamics and fluid mechanics for the Fundamentals in Engineering (FE) exams for the past two years at CSU.

I am blessed to be married to my lovely wife, Lumina Albert. We have a three-year-old daughter (Diya) and are expecting our second child in June. We have been planning to learn to ski and hope to do so soon! I am currently in my third year at CSU and I am still getting to know people. I look forward to meeting many of you and collaborating on potential research projects in the near future.

Karan Venayagamoorthy
Assistant Professor

Colorado State University

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Water Research Awards

Colorado State University (February 15 to April 15, 2010)

Abt, Steven R, Civil & Environmental Engineering, USDA-USFS-Rocky Mtn. Research Station-CO, Bedload Transport in Gravel-bed Rivers & Channel Change, $74,313

Berrada, Abdelfettah, Southwestern Colorado Research Center, National Sunflower Association, Evaluation of Sunflower in Dryland Crop Rotations, $10,450

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Floodplain Inundation & Entrainment Studies (Project No. FR-BW TOPO), $30,870

Bestgen, Kevin R, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Yampa & Middle Green CPM & RBS Larval Survey (Project No. 22f), $94,219

Cabot, Perry Edmund, CSU Extension, Southeast Colorado Resource Conservation & Dev, Oilseed Cropping as a Strategy for Sustained Farming in a Region Impacted by Agricultural Water Transfers, $20,500

Chavez, Jose L, Civil & Environmental Engineering, Central Colorado Water Conservancy District, Irrigated Agriculture Water Conservation Tool, $29,242

Culver, Denise R, Fish, Wildlife & Conservation Biology, EPA-Environmental Protection Agency, Tools for Colorado Wetlands: Essential Information for Identification, Assessment, and Conservation, $198,001

Doesken, Nolan J, Atmospheric Science, Colorado Water Conservation Board, Evaluation and Integration of Selected Drought Triggers and Indices—Their Role and Use in Colorado's Drought Mitigation and Response Plan, $50,000

Fausch, Kurt D, Cooperative Fish & Wildlife Research, DOI-USGS-Geological Survey, Tools to Assess Effects of Uncertain Climate Change Scenarios on Colorado River Cutthroat Trout, $70,000

Hawkins, John A, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Middle Yampa Smallmouth Bass & Northern Pike, $264,413

Hobbs, Nicholas Thompson, Natural Resource Ecology Lab, DOI-USGS-Geological Survey, Development of a River Ecosystem Forecasting Framework, $14,332

Klett, James E, Horticulture & Landscape Architecture, DOI-USGS-Geological Survey, 2010CO220B-Impact of Limited Irrigation on Health of Four Common Shrub Species, $5,000

Liston, Glen E, CIRA, NSF - National Science Foundation, IPY: Collaborative Research: A Prototype Network for Measuring Arctic Winter Precipitation and Snow Cover (Snow-Net), $93,000

Maloney, Eric D, Atmospheric Science, NSF - National Science Foundation, Intraseasonal Variability of the West African Monsoon, $214,165

Pearson, Calvin H, Soil & Crop Sciences, Flux Farm Foundation, Evaluation of Plant Species and Production Inputs for Sustainable Biomass and Bioenergy Production in Western Colorado, $30,690

Poff, N LeRoy, Biology, State University of New York, Impact of Climate Change and Variability on the Nation's Water Quality and Ecosystem State, $43,333

Qian, Yaling, Horticulture & Landscape Architecture, USGA-US Golf Association/Green Section R, Salinity Management in Effluent Water Irrigated Turfgrass Systems, $28,420

Snyder, Darrel E, Fish, Wildlife & Conservation Biology, DOI-Bureau of Reclamation, Identification & Curation of Larval & Juvenile Fish (Project No. 15), $116,679

Thornton, Christopher I, Civil & Environmental Engineering, Urban Drainage & Flood Control District, Hydraulic Model Study: Type C and D Grate Inlets for Highway Median Storm Drainage, $29,705

Venayagamoorthy, Subhas K, Civil & Environmental Engineering, DOD-NAVY-ONR-Office of Naval Research, Dynamics and Modeling of Turbulent Mixing in Oceanic Flows, $43,910

Venkatachalam, Chandrasekaran, Electrical & Comp Engineering, NASA, Global Observations and Precipitation Microphysics: Interpretation, Precipitation Estimation, and Application to GPM and TRMM, $150,247

Waskom, Reagan M, Colorado Water Institute, DOI-USGS-Geological Survey, Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management, $82,400

Waskom, Reagan M, Colorado Water Institute, DOI-USGS-Geological Survey, Program Administration Project, $44,235

Waskom, Reagan M, Colorado Water Institute, DOI-USGS-Geological Survey, Technology Transfer and Information Dissemination, $38,100

Waskom, Reagan M, Colorado Water Institute, EPA-Environmental Protection Agency, Colorado State University/FY 10 Water Pollution Workshop, $56,065

Calendar

May

16-21 **ASFPM 34th Annual National Conference; Oklahoma City, Oklahoma**
Largest and most comprehensive floodplain management conference.
www.floods.org

21-24 **National River Rally 2010; Snowbird, Utah**
This annual event brings together river conservationists to discuss watershed protection.
www.rivernetwork.org/programs/national-river-rally

24-25 **14th Annual Water Reuse & Desalination Research Conference; Tampa, Florida**
The latest results of water reuse and desalination research.
www.watereuse.org/foundation/Research_Conf/14

June

2-4 **Natural Resources Law Center 2010 Martz Summer Conference; Boulder, Colorado**
Celebration of the 40th anniversary of the Public Land Law Review Commission Report.
www.colorado.edu/law/centers/nrlc/events/upcoming.html

3 **Water Matters! Global Water Conference; Pittsburgh, Pennsylvania**
Learn about the future of water protection.
www.pittsburghwed.com/watermatters/

9-11 **2010 CFWE River Basin Tour; Southwestern Colorado**
Join legislators, professionals, and educators for a tour of the Dolores and San Juan Basins.
www.cfwe.org

15-18 **63rd Canadian Water Resources Association National Conference; Vancouver, BC**
Share ideas on building a water legacy to sustain a healthy environment.
www.cwra.org/News_Events/National_Conference_2010/Default.aspx

16 **Chatfield Watershed Summit; Denver, Colorado**
A day of idea sharing and networking at the Denver Botanic Gardens at Chatfield.
www.chatfieldwatershedauthority.org

20-24 **AWWA 2010 Annual Conference and Exposition; Chicago, Illinois**
Workshops, webcasts, and programs on all aspects of water stewardship.
www.awwa.org/ACE10/

July

13-15 **2010 UCOWR/NIWR Annual Conference; Seattle, Washington**
"HydroFutures: Water Science, Technology & Communities"
http://water.montana.edu/ucowr/default.htm

18-21 **2010 Soil and Water Conservation Society (SWCS) Conference; St. Louis, Missouri**
"Ecosystem Services: Applications for Conservation Science, Policy, and Practice"
www.swcs.org/en/conferences/2010_annual_conference/

21-23 **35th Annual Colorado Water Workshop; Gunnison, Colorado**
"Scarcity, Conflict, and Cooperation: Meeting Future Demands Through Innovation Today"
www.western.edu/academics/water

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The Gunnison River drops an average 43 feet per mile as it descends through the Black Canyon in western Colorado. (Photo by Laurie J. Schmidt)