Colorado Water

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Colorado State University

Theme: Energy and Water

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Highlights

In Every Issue

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Front Cover: A hydroelectric power plant atop Bridal Veil Falls in Telluride, CO. Photo by Ethan Lofton

This Page: Upstream of the John Martin Dam on the Arkansas River, a site currently under proposal with the Department of Energy for a hydroelectric project. Courtesy of Tim Gates

Editorial

by Reagan Waskom, Director, Colorado Water Institute

Oil and water may not mix, but they seem to be closely associated of late. In Colorado, residential communities and energy producers appear to be the ones having trouble mixing well. Perhaps an upside of these conflicts–they are helping inform the public of the linkage between energy and water. In spite of public distaste for energy production near our homes, it is widely agreed that we do not want utility service interrupted or for energy to become too expensive.

Energy related water withdrawals account for a significant amount of society's water use, but they are still a distant second to agricultural consumptive use. Even in this drought year, it is rare to hear of energy providers that cannot deliver their commodity due to lack of water. On the flip side of this relationship, water utilities are often the largest single energy user in their service areas, and facility operators are pressured to reduce the amount of energy used to transport and treat water. Utility managers are expected to keep the power on and the taps flowing 24-7, and a power outage like the recent one in India that affected 700 million people during the heat of summer is not acceptable here.

U.S. electricity demand is presently growing at approximately one percent annually, just slightly above our population growth rate. Since virtually all of Colorado's rivers and aquifers are fully appropriated, the growth in our energy related water demand can only be satisfied through reallocation, conservation, transbasin diversion or substitution of potential new technologies such as dry-cooling, waterless fracturing, or closed loop systems through treatment and reuse.

The future of West, at least over the next several decades, looks like continued expansion of about two dozen large metropolitan areas—each needing significant new water and energy resources transmitted from elsewhere. These metropolitan areas are the major economic centers of the West and generate most of the economic activity and tax revenue. In many ways, an increasingly urbanized West is the most efficient way to accommodate new growth, if we do it right. The economies of scale associated with large urban areas are often the best way to provide utilities to the greatest number of people at the lowest unit cost and impact. Folks often move to Colorado and the West because of a desired quality of life, yet they rarely call ahead to determine if there is adequate water and energy to sustain the lifestyle they envision. Those beautiful

landscapes that seem like a perfect place to live and play also often contain natural resources that someone has a legal right to develop.

Conventional energy sources produced in Colorado include coal, oil and gas, thermoelectric generation, and hydropower. Natural gas is currently Colorado's largest energy commodity on a Btu basis. Unconventional energy sources include oil shale, shale oil, shale gas, and coalbed methane. Colorado is positioned to become a leading energy producer as new drilling technologies promise up to 1.5 billion barrels of recoverable oil from the Niobrara formation alone. West Slope oil shale deposits promise even larger reserves of oil but may require significant amounts of water in the process–the exact amount is unknown and depends upon the extraction method eventually used. Water used for energy extraction holds very high value, but for only for a specific period of time until energy reserves in a given field are recovered.

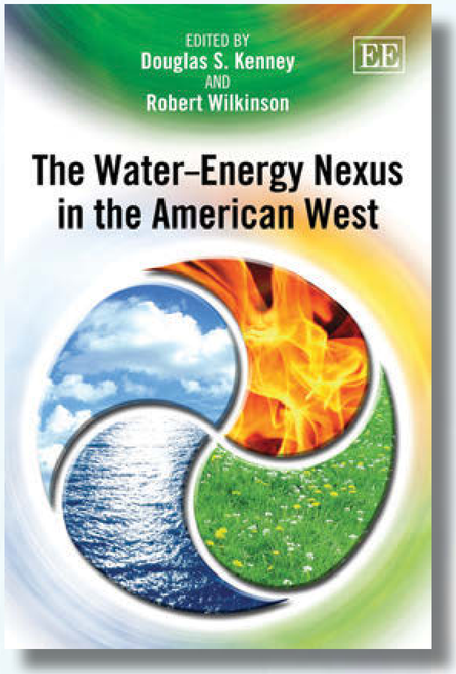
The university has a role in developing science and technology to address energy production challenges, but we have also become deeply engaged in related community issues through Extension and our other externally focused units. CSU has several new initiatives in energy, a few of which are mentioned in this issue of Colorado Water newsletter. CSU has recently started a Natural Gas Initiative, a Colorado Water Energy Consortium, and the Center for the New Energy Economy that complement our existing Clean Energy Supercluster. We invite you to join us on campus on October 1-3 for the Natural Gas Symposium 2012 to learn more about what the university is doing to address these important issues.

The Water-Energy Nexus: A Problem or an Opportunity?

Douglas S. Kenney, Director, Western Water Policy Program, University of Colorado School of Law

The energy and water sectors are areas characterized by highly trained professionals making billion dollar infrastructure decisions implicating virtually all aspects of our lives, from economic development to environmental protection. In a variety of ways, they face similar challenges—such as growing populations, climate change adaptation and mitigation, budgetary limits, aging infrastructure, and competing societal demands. And the two sectors are intimately connected, as energy development is usually highly water intensive, and water management is often highly energy intensive. Several aspects of the relationship are explored in The Water-Energy Nexus in the American West (Edward Elgar Publishing, 2011), a recent product of the University of Colorado's Western Water Policy Program (School of Law), prepared with support from the University of Colorado (CU)'s Renewable and Sustainable Energy Institute (RASEI) (a collaboration with the National Renewable Energy Lab) and the Western Water Assessment (a joint program of CU and the National Oceanic and Atmospheric Administration).

Perhaps the most striking conclusion arising from this broad overview of the water-energy "nexus" is that, given the many points of overlap of the two sectors, it is disconcerting that they operate largely in isolation, and the opportunities for coordinated management—and the costs of fragmented decision-making—are consistently underappreciated. While the water needs of some Front Range "fracking" operations have received significant public attention lately, it is the larger trends in the energy sector that most significantly implicate water



resources. Some trends are generally "water friendly," including the increasing popularity of photovoltaic (PV) and wind energy generation; while others can have a significant water cost, such as the expanded use of biofuels (such as ethanol), the prospect of a large-scale West Slope oil shale industry, and, of course, the aforementioned fracking operations and other forms of natural gas development. Precisely determining which specific projects are problematic for the water sector and which are not is deceptively complex, as each case raises its own issues associated with facility siting (and land-use) and transmission, among many others, and these concerns must be weighed against other considerations, including larger-scale objectives such as national security, economic development, and climate change mitigation.

Throughout Colorado and the West, the water implications of a changing energy sector are increasingly gaining the attention of researchers, advocacy groups, and public officials (including Public Utility Commissions (PUCs)). And in a few cases, water considerations are influencing decisions about the siting and fuel choices of new energy generation and transmission facilities. Lagging further behind, however, is a recognition that the energy needs of the water sector are significant and growing. Already, roughly 13 percent of energy use nationally is associated with water, and in many western states, including California, Arizona, and Nevada, water agencies are the single greatest users of electricity. The case of California is illustrative, as 19 percent of the state's electricity and 33 percent of its non-powerplant natural gas consumption is associated with water management and use. To a large extent, these numbers derive from the large number of water users served by systems that pump water long distances to consumers. It is not unusual for the energy costs of raw water delivery in some parts of California to exceed 3,000 kWh/af (kilowatt-hours per acre-foot). Given this, water conservation in California has taken on a new urgency and a new role—as a vehicle for energy conservation, and likewise, for limiting greenhouse gas emissions.

With few exceptions, the energy demands of water management has been a minor issue in Colorado, as the delivery of mountain snowmelt to most urban and rural users has been accomplished without need of extensive pumping nor water treatment. But that era that largely passed. Most new and proposed Front Range water projects—including Prairie Waters, the Northern

Integrated Supply Project (NISP), the Southern Delivery System, and the "mega pipelines" (including the so-called "Flaming Gorge Pipeline" and "Big Straw," and their many derivatives that would draw water from Wyoming or western Colorado)—require extensive pumping and water treatment. These projects use, roughly, five to 20 times the energy as most existing Front Range gravity-fed systems. The Southern Delivery System, for example, will require 4,630 kWh/af—a value normally only seen in pockets of California, the terminus of the Central Arizona Project (in Tucson), or in ocean desalination projects. Many of these projects already raise concerns regarding cost, environmental impact, and water availability; adding energy demands to the mix only further suggests that, like California is increasingly doing, perhaps Colorado should use the water-energy nexus as the impetus for much more aggressive water conservation.

Many of the most basic tools of demand management applicable to the water sector, such as metering and dynamic pricing structures, first found acceptance in the energy sector. The next set of transferrable lessons may be found in energy planning processes that aim to evaluate and balance the costs of developing new supplies with demand management opportunities, or the redesign of utility business models to decouple utility revenues from the volume of water sold. Importantly, the energy sector's regulated, long-term planning approach often includes a broader spectrum of stakeholders and review processes, including a strong PUC role, than does the water sector, which may explain the slower adoption of demand management principles in the water arena. The fortunate reality is that actively suppressing demands not only has benefits in both the water and energy sectors independently, but it has benefits that bleed over to the other sector. Additional societal benefits include reduced public expenditures on both water and energy infrastructure, reduced environmental and social disruptions, and the political harmony that only elusive "win-win" solutions can offer. If there is one aspect of the water-energy nexus that is most underappreciated, it is that it offers an opportunity unlike any other, and the key to capitalizing on that opportunity is through an enhanced commitment to conservation in both sectors.

Water and Energy: Colorado State Studies the Issues

Neil Grigg, Civil and Environmental Engineering, Colorado State University

Water and Energy for the Future

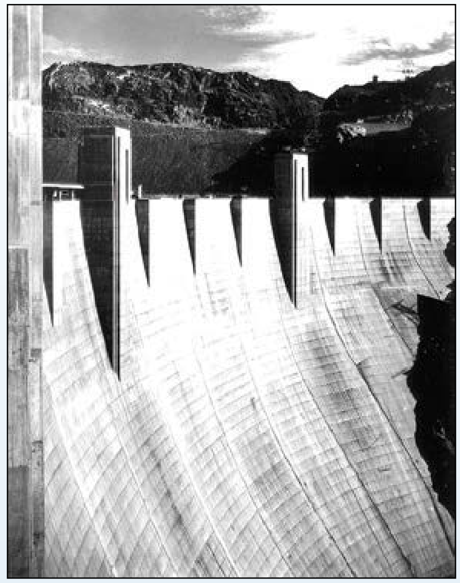
Access to sustainable and affordable energy resources is a high-profile issue, and the production, transmission, and distribution of most forms of energy have strategic interfaces with the management of water resources. Prominent examples of energy-water issues in Colorado include shale gas and fracking, produced water, thermoelectric cooling water, hydropower, biofuels and competition for irrigation water, wastewater from energy production, and use of energy by water utilities.

Given the convergence of two critical issues of such central interest to Colorado State University (CSU), a group of faculty worked with the Water Center, the School of Global Environmental Sustainability, and Provost Rick Miranda to include water and energy among working sessions (called "Water Cafés") on major water topics during Spring Semester 2012. The sessions identified issues, determined where CSU can contribute to solutions and obtain resources, and identified the CSU participants and partners.

The panel on energy and water issues met on February 9, 2012 and included Governor Bill Ritter, Jr., Director Center for the New Energy Economy; Ken Carlson, Co-Coordinator, Colorado Water Energy Consortium, Civil and Environmental Engineering; John Labadie, Professor, Civil and Environmental Engineering; Sally Sutton, Department Head, Geosciences; James Pritchett, Agricultural and Resource Economics; and Mark Paschke, Shell Endowed Chair in Restoration Ecology, Forest and Rangeland Stewardship. It was moderated by Neil Grigg, Professor, Civil and Environmental Engineering.

Framing the Water-Energy Issues

It was clear at the event that energy is a giant economic sector linked in many ways to the world economy by complex financial stakes and investments. The water-energy nexus has multiple poles created by intersecting issues involving energy sectors, water management concerns, and environmental impacts. It also creates technological opportunities, such as a partnership with the natural gas industry, the need to handle produced water, learning to understand the underground environment to evaluate long-term impacts, and



Hoover Dam—an example of multiple disciplines working together on a water project that incorporates hydroelectric generation.
Courtesy of the U.S. Bureau of Reclamation

opportunities inherent in combined wind-hydroelectric systems. Natural gas is of special interest due to rapidly-changing technologies and global demands.

In Colorado, limited water supplies could be the main constraining factor in developing the potential for energy development. Supplies must be balanced across the water demand sectors and legal obligations must be satisfied. There is a need for much greater emphasis on water efficiency

to get more use from existing supplies without further environmental degradation. Security and resilience of water supplies is very important, and drought is an ever-present threat. The ongoing drought has had major impacts on energy, the economy, and on agriculture and livestock. Environmental issues loom large across the water-energy nexus. Every source of energy production has its own environmental impacts. The water-energy footprint can be reduced, but the cost will be significant.

As a result of limited water and environmental impacts, energy development requires focused attention on developing win-win conditions for the many necessary trade-offs in water and energy development and management. It is important to understand the positive and negative spillovers at the interfaces of energy and water issues.

Given its diversity and many scenarios, the key aspect of the energy-water issue for CSU is to focus on important contributions via its capabilities in the joint energy-water-environmental arena. Resources can be available from government agencies, businesses, and foundations, and faculty will need to join partnerships and become involved with ventures across the development-to-regulation spectrum. Areas of convergence that were discussed by the panel include activities of the natural gas industry, management of produced water, electric power utilities and water management, evaluation of impacts on subsurface conditions from energy development, and water management across the categories of energy production and use.

How Colorado State Can Respond

By focusing on the interfaces in the energy-water-environmental arena CSU can be an honest broker, do research at the boundaries of the issues, and vet issues for the benefit of the public. These activities fit the land grant mission but can be risky because people see the issues differently and hold strong opinions. Also, financing research at the boundaries of the development-regulation interface may involve new types of partnerships. CSU faculty and researchers working in energy production and use, water management, and environmental impact assessment may find partners in energy companies, government regulators, and public interest organizations.

The next steps should focus on defining areas of convergence and developing strategies for team-building and proposal development. Faculty members often work in separate focused areas; to create broad interdisciplinary teams will require new initiatives. This is an ongoing problem in a university setting comprised of departments and specialties.

Leadership to define the areas of convergence might come from the energy side of the equation, rather than the water or environmental side. For example, a program to aid the oil and gas industries to minimize their footprint could draw in water and environmental expertise. A focused program to understand the underground environment might draw in geologists, geospatial, and groundwater researchers. A program to consider needs of wind and hydroelectricity could focus on the electric power industry.

The faculty group noted that Colorado State's strong reputation in water is an asset, but attention by faculty and university leaders can be diverted by other priorities. During Fall Semester 2012, new activities will be taking place to strengthen the Water Center and to work through SOGES to create new approaches to interdisciplinary activity and development of funding for large projects. A new focus on the Water Center will engage faculty in water events more effectively and help define needed areas of curriculum development.

Evaluating Micro Hydropower Potential in Colorado's Irrigation Infrastructure

Brian Campbell, M.S. Candidate, Civil Engineering, Colorado State University
Daniel Zimmerle, Mechanical Engineering, Colorado State University

The John Martin Reservoir along the Arkansas River, proposed site of the potential John Martin Reservoir Hydroelectric Project.
Photo by Bill Cotton, CSU Photography

Every irrigation manager knows there are "lots" of structures in irrigation systems—and on a bad day, they all seem to need repair. Ongoing research at Colorado State University (CSU) is attempting to count and categorize these structures to identify how they could be utilized to develop Colorado's micro hydropower potential.

Colorado's Existing Energy Generation Assets

Colorado's energy generation assets have the capacity to produce approximately 13.8 GW of electrical power. Colorado's energy generation asset matrix is summarized in the following figures:

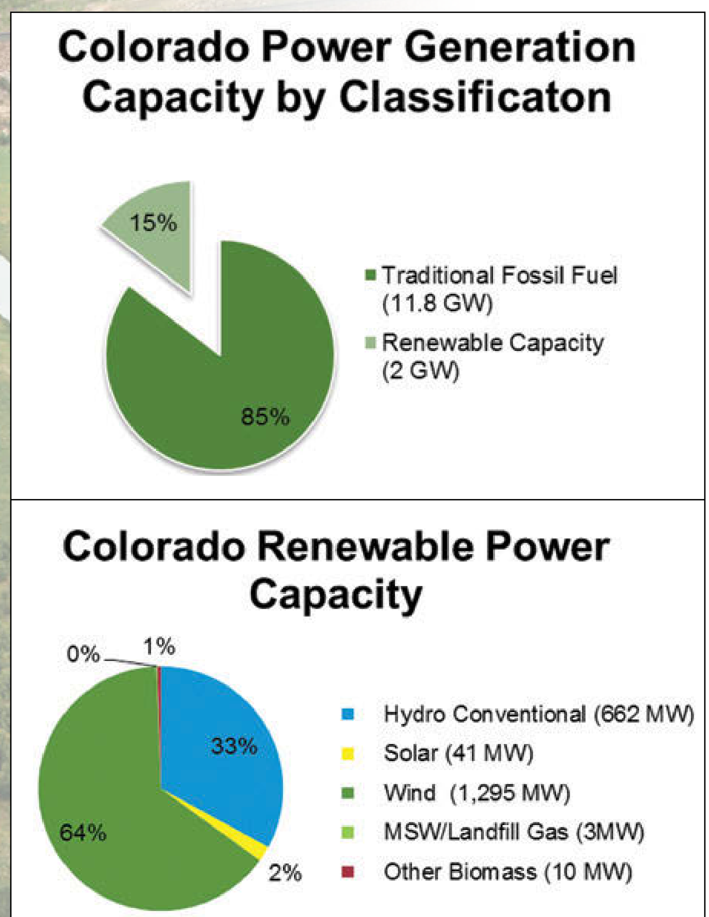


Figure 1. *Colorado Generation Assets, U.S. Energy Information Administration, 2010*

Renewable energy assets make up 15 percent of Colorado's electrical generation capacity and are capable of providing two GW of electrical power. Renewable energy is mandated to increase to 30 percent by the year 2030. Of the renewable energy generation, hydropower is the second largest, next to wind, and produces approximately one third of Colorado's renewable energy using 662 MW of capacity.

There are 53 hydropower sites in Colorado. More than half of these sites, 30, are rated at five MW or less, and have a combined capacity of 64.6 MW, one tenth of the hydropower total. The other nine tenths are produced by the 23 sites over five MW, which have a combined capacity of 597.2 MW.

Regulatory approval has long been the bane of small hydropower development. A recent agreement between the Federal Energy Regulatory Commission (FERC) and The State of Colorado seeks to streamline regulatory review of small, low-head hydropower (micro hydropower) projects located in constrained waterways: Memorandum of Understanding Between The Federal Energy Regulatory Commission and The State of Colorado Through the Governor's Energy Office to Streamline and Simplify the Authorization of Small Scale Hydropower Projects, 2010. The streamline program focuses on low-head hydropower sites that meet FERC's five MW and existing conduit exemption programs. This regulatory change will likely encourage the development of micro-hydropower projects, primarily as upgrades to existing water system infrastructure.

The first project to successfully navigate the new streamlined process was an irrigation pipeline in Meeker, Colorado. The project will produce 100,000 kilowatt-hours of energy annually from one generating unit with a capacity of 23 kW. FERC approved the project in a two-month time span compared to a three year timespan, the historical timeline for this type of project.

Investigating Upgradeable Irrigation Infrastructure in Colorado

A just-released USBR study hints at the potential for micro-hydropower. The U.S. Bureau of Reclamation (USBR) conducted an investigation, Site Inventory and Hydropower Energy Assessment of Reclamation Owned Conduits, 2012, evaluating potential hydropower assets in USBR canals. USBR analyzed canal sites if elevation changes were greater than or equal to five feet with a minimum of four months of flow per year.

The study identified 28 sites in Colorado with a combined power potential of approximately 27 MW. For Colorado, the largest site was approximately five MW, and the total gross head of all the sites combined included was 2,103 feet. The report identified that the list was not conclusive and additional sites within USBR's infrastructure may exist. Despite these limitations, development of these sites would theoretically increase Colorado's micro hydropower capacity by nearly 50 percent.

In 2011, researchers at CSU conducted a field study in which 36 different canals were investigated to document the type of hydraulic structures used within the canals in the various geographic regions of Colorado. The research documented 233 specific structures including 79 weirs, 12 gated structures, six flow measurement structures, and 136 drop structures. Data collected included geometric properties of the structures and distances to electric utility lines. Using the same five foot drop requirement as USBR, 70 of the 136 drop structures were identified as

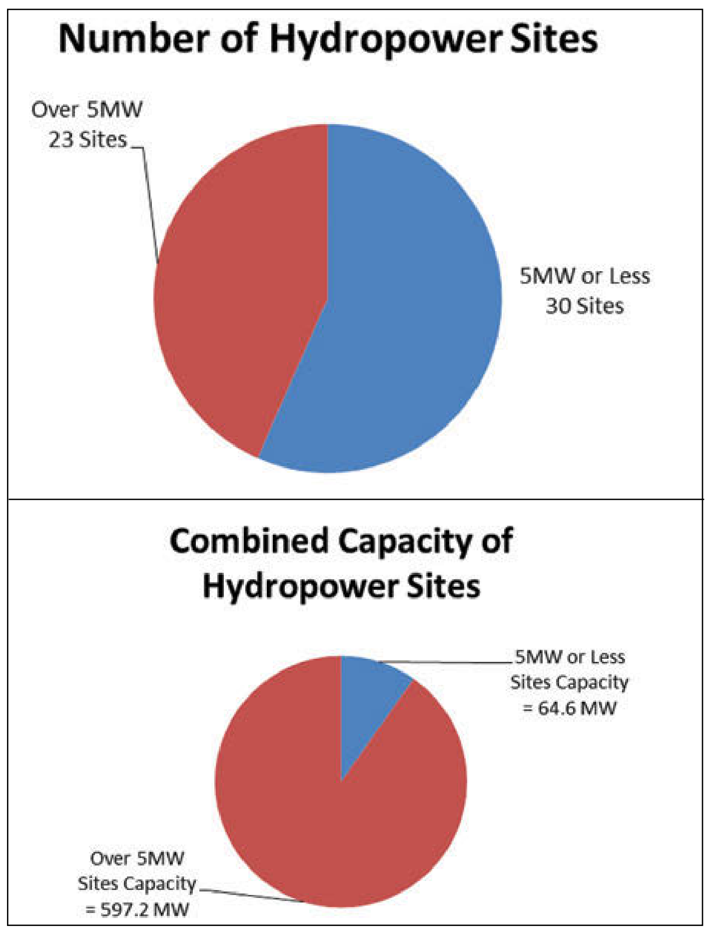


Figure 2. *Summary Hydropower Sites*

Table 1. *Survey site subcategories*

			
Vertical Drop*	Chute*	Pipeline*	Check Drops*
Vertical drops are structures that enable a change in elevation over a very short length of canal alignment.	Chutes are typically used where water is conveyed over long distances and along grades that may be flatter than those for drops but steep enough to maintain supercritical velocities.	A pipeline is a closed conduit structure used to convey water.	Check drops are vertical drop structures with a check structure integrated on the upstream end.
			
Gate Drops	Siphon	Steep Grade Change	Engineered Drop Structure
A gate drop incorporates a gate structure on the upstream end of the change in elevation of the canal thalweg.	Siphons (sometimes referred to as inverted siphons) are closed conduits that convey water under existing infrastructure, usually with the headwater and tailwater above the lowest point in the siphon alignment.	This classification was used to identify a section of canal defined as a "steep" slope with normal depth below critical depth. Examples of this type of grade change were generally analogous to short chutes.	An engineered drop structure is used to define a specific energy dissipation function, such as baffle chutes, spillways with stilling basins, and general structures that were either cast in place or constructed offsite and placed within a canal alignment.

*Definitions as listed in *Site Inventory and Hydropower Energy Assessment of Reclamation Owned Conduits, 2012*

potentially hydropower sites. (These sites did not include sites listed in the USBR study.) The gross head of the combined 70 potentially upgradeable sites approximated 2,400 feet.

These two studies indicate that substantial capacity for micro hydropower exists in Colorado's irrigation systems. The question is: Can they be developed successfully? To help answer this question, CSU's research also divided surveyed sites into sub-categories to begin looking at how sites would be upgraded. Site categories included those found in Table 1.

Where Next?

It has long been recognized that the custom engineering work required to design micro hydropower sites represents a significant barrier to their development. Unsurprisingly, field survey work indicates that there is significant commonality between sites within a category. The commonality could be exploited to reduce development costs for each site. The question remains, however: Are there enough similar structures within any category to justify the investment in a flexible, generic design?

CSU's ongoing work will identify site categories which are (a) promising for hydropower production, and (b) common enough to justify the system investment. If there are forty or fifty similar sites, developing a standard hydropower solution makes sense. If there are four or five sites, the investment in standardization is difficult to justify. By quantifying the number of sites, the research team hopes to attract investment into the necessary equipment, design, and installation technologies.

While the field survey produced excellent results—including photographs and measurements—it is impractical to survey every canal system in detail. Therefore, CSU is exploring methods to identify and quantify the micro hydropower resources in irrigation infrastructure using geographic information system (GIS) data. Field survey data will be utilized to develop and validate methods, which can then be applied to other canal systems. Using available field data and incorporating sites listed in the USBR study, the team has identified geospatial profile signatures which appear promising for identifying sites using GIS data, digital elevation models and pattern matching methods. In parallel, the team is exploring methods to identify the seasonal flow values to combine with GIS resources. Power potential estimates will be conducted by incorporating flow values through the structures.

Table 2. *Summary of Field Data*

Colorado Hydrolic Division	Canal Names	Number of Structures	Length of Canal (km)*
1	Boulder Feeder Canal	13	4.8
	Boulder Supply Canal	7	21.1
	Dixon Feeder Canal	1	N/A
	Hanson Feeder Canal	6	20.5
	Hanson Supply Canal	10	9.4
	Larimer and Weld Canal	32	92.4
	Poudre River	1	N/A
	St. Vrain Supply	8	16
2	Arkansas River	2	N/A
	Catlyn Canal	1	11.4
	Fort Lyon Canal	16	175.4
	Rocky Ford Highline	6	59.1
3	Costilla Canal	2	8.4
	Monte Vista Canal	8	41
	Prairie D	9	17.6
	Rio Grande Canal	8	27.3
	Rio Grande Canal Lateral No. 1	11	13.6
	San Luis Canal	12	25.7
4	East Canal	7	23.3
	Ironstone Canal	3	18.4
	Loutsenhizer Canal	1	N/A
	Montrose & Delta Canal	9	39
	Selig Canal	10	37.1
	South Canal	7	19.5
	Uncompahgre River	4	N/A
5	Grass Valley Canal	2	10.5
	Harvey Gap Reservoir Outlet	1	N/A
	Leon Park Feeder Canal	1	1
	Park Creek Ditch	1	0.6
	Pump House	1	N/A
	Rifle Gap Reservoir Outlet	1	N/A
	Southside Canal	12	48.6
	West Lateral	2	9.8
7	U Lateral	4	6.5
	Canal 1	12	16.3
	Canal 2	2	1
TOTAL		233	775.3

*N/A structures represent point measurements. Entire canal reach was not investigated
*Length of canal represents the length of the canal alignment in which sites were investigated

Regulatory and Environmental Considerations of Produced Waters from Coal Bed Natural Gas Development in Colorado

John D. Stednick, Watershed Science, Colorado State University

Introduction

The increase in coal bed natural gas (CBNG) production in Colorado over the last few years has resulted in increased environmental concerns related to natural resources, particularly water resources. As for other natural resources, we have managed energy resources separately from water resources, and thus often have to depend on legal decisions for guidance in water resources management. Colorado has separate bodies of law governing water (Water Act, C.R.S. § 37-92-101, et seq.) and gas (Oil and Gas Act, C.R.S. § 34-60-102, et seq.).

Water is pumped from the coal bed to reduce the hydrostatic pressure and release the natural gas trapped in the coal. Produced water is defined as any water produced during the extraction of oil and gas. Produced water has historically been exempt from Colorado's prior appropriation doctrine and was previously regulated solely by the Colorado Oil and Gas Conservation Commission (COGCC) as exploration and production waste under Rule 907. Recently, the state of Colorado developed new regulations for administration of produced waters and as a result of Vance v. Simpson (Case No. 05CW63). Produced water associated with natural gas production in southern Colorado was being reinjected. The produced water was presumed to be tributary and was not located within a designated groundwater basin. No permit was applied for, based on the State Engineer's Office statutory interpretation that a permit is not necessary unless the produced water is subsequently put to beneficial use. Several ranchers filed the case, claiming produced water was injuring springs with senior water rights. The Court granted summary judgment for the ranchers and declared that the Colorado State Engineer must exercise regulatory and administrative authority over groundwater diversions associated with CBNG development. The Court ruled that the Colorado State Engineers Office had the authority to regulate produced water, that CBNG produced water is a beneficial use, and that CBNG produced water shall be considered to be tributary unless proven otherwise (Colorado State Engineer's Office, 2012).

Coal bed methane (CBM)-produced water pumped from several wells is brought together to one outfall for disposal and management. This photo illustrates a CBM outfall releasing water into a constructed pond.
Courtesy of Suzanna Carrithers Soileau

The case was appealed to the Colorado State Supreme Court (Case No. 07SA293) by BP America Production Company. The Colorado Supreme Court upheld the lower court's findings in April 2009. Because the extraction of water is necessary to access CBNG, the Supreme Court ruled that the presence and extraction of CBNG produced water are integral components to the entire CBNG process. They elaborated that its extraction is thereby a beneficial use and that the State Engineer's Office is required to permit oil and gas wells that produce water and that produced water extraction is subject to Colorado's Prior Appropriation Doctrine, because extracting the water makes it inaccessible to other water rights holders. Surface water discharge, evaporation ponds, and reinjection into deeper geologic formations all cause injury to senior water rights in a tributary ground water system.

The Supreme Court ruling led to Colorado State Legislature House Bill 09-1303 and Senate Bill 10-165, which gave the State Engineer's Office the authority to initiate rule-making for produced water regulations. The issues of administering produced water are yet to be resolved. For example, petitions for nontributary (no surface to groundwater connection) produced water status is ongoing. Future produced water management and administration will be subject to the technical and legal rigor common to all water well pumping in Colorado.

Under Colorado water law, all groundwater is presumed to be tributary to the waters of the stream. Recent stream depletion studies commissioned by the Colorado Geological Survey indicate that in some basins, the aquifers and coal seams are tributary. Studies in the

Piceance Basin have led to conflicting conclusions; in one scenario, models of groundwater pumping suggested downstream streamflow depletions, but another study using a different model suggested no streamflow depletion (see Stednick et al. 2010).

CBNG Water Use

Water is held in fractures or cleats in coal beds—the deeper the coal bed, the less water is present, but the more saline it becomes. In general, there is an inverse relationship between the total dissolved solids (TDS) and the water production rate due to the coal seam hydrology, permeability, and water chemistry relationships. Large amounts of water are produced from CBNG wells, especially in the early stages of production. Coproduced water composition has been related to specific coal bed formations, and water quality changes little with duration of pumping (Stednick et al., 2010). The primary water composition in the western United States is a sodium chloride or sodium bicarbonate water type. Produced waters from permeable and shallow coal reservoirs that are close to meteoric recharge are often quite fresh, as in the Powder River basin (WY) and the San Juan basin (CO) (Stednick et al., 2010). Formation waters with longer residence times with the coal formation, low permeability or longer contact times (connate waters) may dissolve more solids and more insoluble constituents.

Commonly, the produced water may contain significant levels of salts and may require treatment and/or disposal. Water disposal options that are environmentally acceptable and yet economically feasible are sought. Water can be discharged on the surface if it is relatively low in total dissolved solids (TDS), but often it is reinjected to a depth where the quality of the injected water is less than that of the host rock (USGS, 2000). In Colorado, disposal of produced water includes underground injection wells, surface evaporation, or discharge to surface waters with or without downstream uses. The Clean Water Act requires permits for all surface water discharges, specifying volumes of water, TDS content, and the body of water receiving the discharge. After discharge, the water becomes part of the "waters of the state" and is subject to all regulations applicable to surface water.

Another common use of produced waters is for irrigation, but water quality is not suitable for irrigation under all conditions (Ganjegunte et al., 2008; Stednick et al., 2010). The suitability of a given water source needs to be evaluated based on three factors that when considered in combination will provide soil condition that will not negatively affect crop growth. These factors are (1) salinity (2) infiltration/permeability, and (3) nutritional imbalance/toxicity. In addition, it is important to consider the leaching fraction because the soluble salts need to be leached in order to maintain an acceptable root-zone salt balance (Oster and Rhoades, 1990; Stednick et al., 2010). The occurrence of high salts in the produced waters often precludes sustainable irrigation use and reinjection is used.

Perhaps the largest issue of coal bed methane development is hydraulic fracturing or fracking—the injection of water, sand, and proprietary chemical formulation in the completed bore hole to increase cleat or fracture volume. Fracking fluids are used to increase the cleat size to facilitate the migration of natural gas from the coal bed. The success of fracking has increased and is common in CBNG drilling. Although the U.S. Environmental Protection Agency (EPA) regulates injection wells, fracking fluids are specifically exempt via the Safe Drinking Water Act. A report by the EPA concluded fracking posed no risk to groundwater used as drinking water (USEPA, 2004), although a more recent investigation of CBNG production and groundwater contamination around Pavillon, Wyoming suggested otherwise (USEPA, 2011). The latter report is now under an outside technical review. There remains considerable debate about hydraulic fracturing fluids. The potential migration of fracking compounds moving into other groundwater bodies that may be used as potable or agricultural sources is of concern. The degree of connectedness between the gas bearing strata and groundwater sources is often unknown or unclear, hence potential migration of fracking compounds is often unknown. The human health effects of low level chronic exposure to coal derived organic compounds are currently unknown. Some of these organic compounds are potentially toxic, but at the measured levels unlikely to have acute health effects. To help keep the public informed, the Colorado Oil and Gas Commission's website offers voluntary disclosure of these compounds by energy development companies (COGCC, 2012). Increased concerns about water quality related to fracking fluids suggest additional water quality monitoring is needed.

Yet another concern is the availability of water supplies for fracking. Some municipalities currently sell their drinking water to oil field service providers for fracking water purposes, even in our current drought conditions. Logically, examination should be made of using produced waters for fracking waters.

Spring Semester 2013, GEOL/ENGR 480 Fundamentals of the Natural Gas Industry will be offered and will cover the geology, exploration, production, transportation, and environmental issues, including how those topics relate to coal bed natural gas.

Water Intensity of Shale Oil and Gas Development in Northern Colorado

Stephen Goodwin, PhD Candidate, and Ken Carlson, Associate Professor,
Civil and Environmental Engineering, Colorado State University

Water resources in Northern Colorado and the Western United States are constantly strained given the historical agricultural needs, burgeoning development, and the semi-arid environment. With continued population growth, development of unconventional oil and gas resources, and the importance of agriculture in the region, the pressure on water resources in the region is expected to intensify. The oil and gas industry has long been a part of Northern Colorado's economy, but recent advances in technology have stimulated considerable growth in the region that has increased concern about the industry's future demand on water resources.

Competition over water resources between agricultural, municipal, and industrial demands including oil and gas operations continues to escalate and there is increasing concern about where all of the water will come from. In October 2011 the State Review of Oil and Natural Gas Environmental Regulations (STRONGER) organization issued a report on rules developed by the Colorado Oil and Gas Conservation Commission (COGCC) related to hydraulic fracturing. One of the five recommendations of the report included the following:

> *The review team recommends that the COGCC and the DWR jointly evaluate available sources of water for use in hydraulic fracturing. Given the significant water supply issues in this arid region, this project should also include an evaluation of whether or not availability of water for hydraulic fracturing is an issue and, in the event water supply is an issue, how best to maximize water reuse and recycling for oil and gas hydraulic fracturing.*

The Natural Gas Subcommittee of the Secretary of Energy's Advisory Board (SEAB) stated in a November 2011 report, "At present neither the EPA or the states are engaged in developing a systems/lifecycle approach to water management." They recommend that new partnerships or mechanisms be developed to study the lifecycle of water resources as one approach to protecting the quality of water resources in the future.

Colorado State University, along with the Colorado Water Institute and Noble Energy, Inc., has established the Colorado Energy-Water Consortium (CEWC) to bring together industry, academics, agriculture, government, environmental, and consulting stakeholders to address water issues through research and related activities

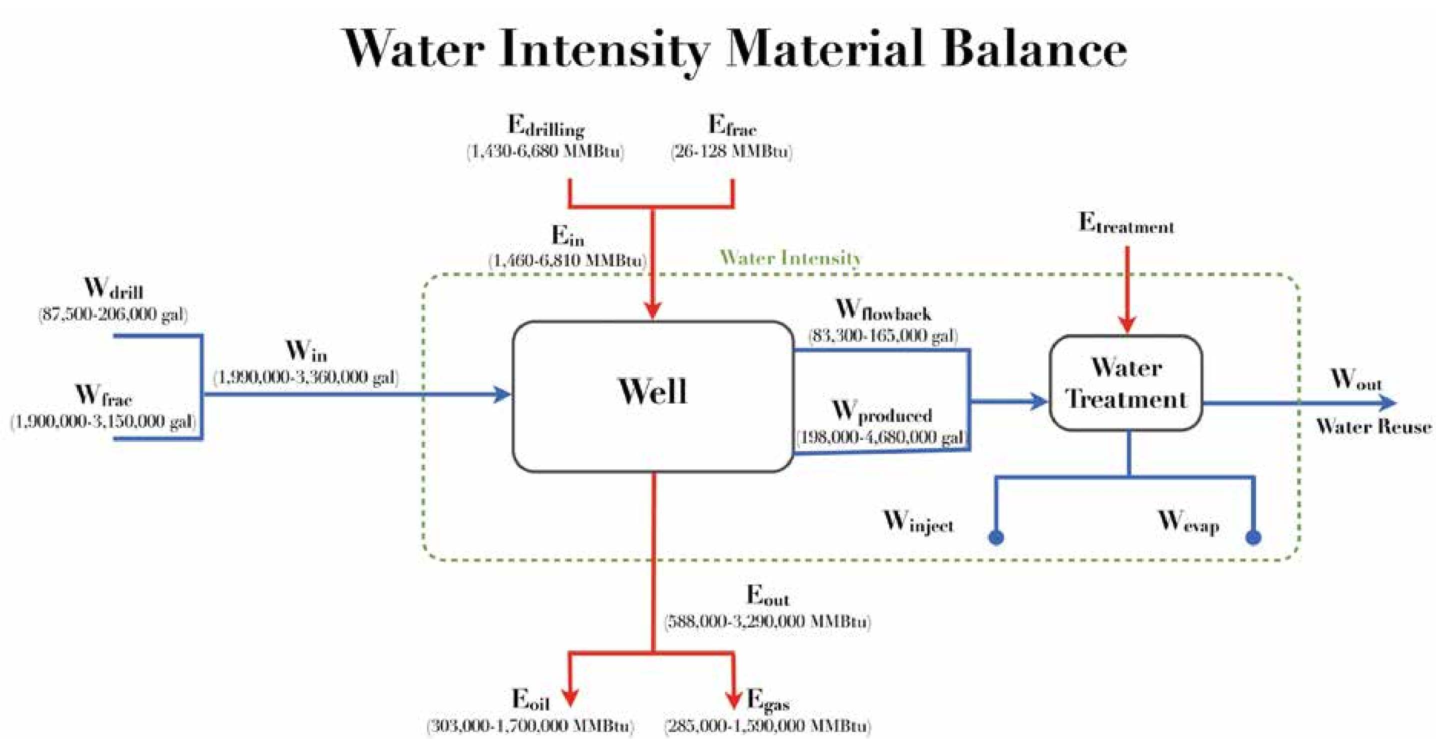


Figure 1. *Material balance used to define the water intensity assessment of Noble Energy oil and gas wells in the Wattenberg field*

$$\text{Water Intensity} = \frac{\left[\text{Volume of Drilling Water} + \text{Volume of Hydraulic Fracturing Water}\right] - \left[\text{Volume of Flowback Water} + \text{Volume of Produced Water} - \text{Volume of Injected Water} - \text{Volume of Evaporated Water}\right]}{\left[\text{Energy from Oil} + \text{Energy from Natural Gas}\right] - \text{Energy Used for Drilling} - \text{Energy Used for Hydraulic Fracturing} - \text{Energy Used for Water Treatment}} \quad \text{Eq-1}$$

Equation 1 is reduced to:

$$\text{Water Intensity} = \frac{[W_{drill} - W_{frac}] - [W_{flowback} + W_{produced} - W_{injection} - W_{evap}]}{E_{recovered} - E_{drilling} - E_{drilling} - E_{treatment}} \Rightarrow \text{Water Intensity} = \frac{[V_{in}] - [V_{out}]}{E_{net}} \quad \text{Eq-2}$$

$$q(t) = \frac{q_i}{(1+D_i t)^{1/b}} \quad \text{Eq-3}$$

where

$q(t)$ = Future production rate
qi = Initial production rate
Di = Initial decline rate
t = Time
b = Degree of curvature

(see article on page 20). One of the first research projects assessed the amount of water required to drill and hydraulically fracture a well in Northern Colorado and compared the efficiency with other energy sources including coal, nuclear, solar, wind, and biofuels.

The water efficiency, or water intensity, is measured with a ratio of the water consumed and the total energy developed with the water. For the first research project 13 horizontal wells operated by Noble Energy, Inc. that were drilled and hydraulically fractured in 2010 and 2011 were used for the assessment of horizontal wells. Horizontal wells in Northern Colorado are initially drilled vertically for 6,000 to 7,500 feet before the wellbore turns horizontally to follow the shale formations. The formation is then hydraulically fractured to increase the porosity of the formation and allow oil, gas, and water to return to the surface back through the wellbore.

The combination of horizontal drilling and hydraulic fracturing has created a resurgence of oil and gas drilling in the United States by broadening the number of profitable oil and gas formations, including Northern Colorado. However, horizontal wells are more expensive and require nearly ten times more water than traditional vertical wells to complete. Horizontal wells are the focus of the study to best assess potential impacts on water resources.

Figure 1 shows the water and energy flows of a typical well and the control volume used to define the water intensity. Using a 95 percent confidence interval, the lower and

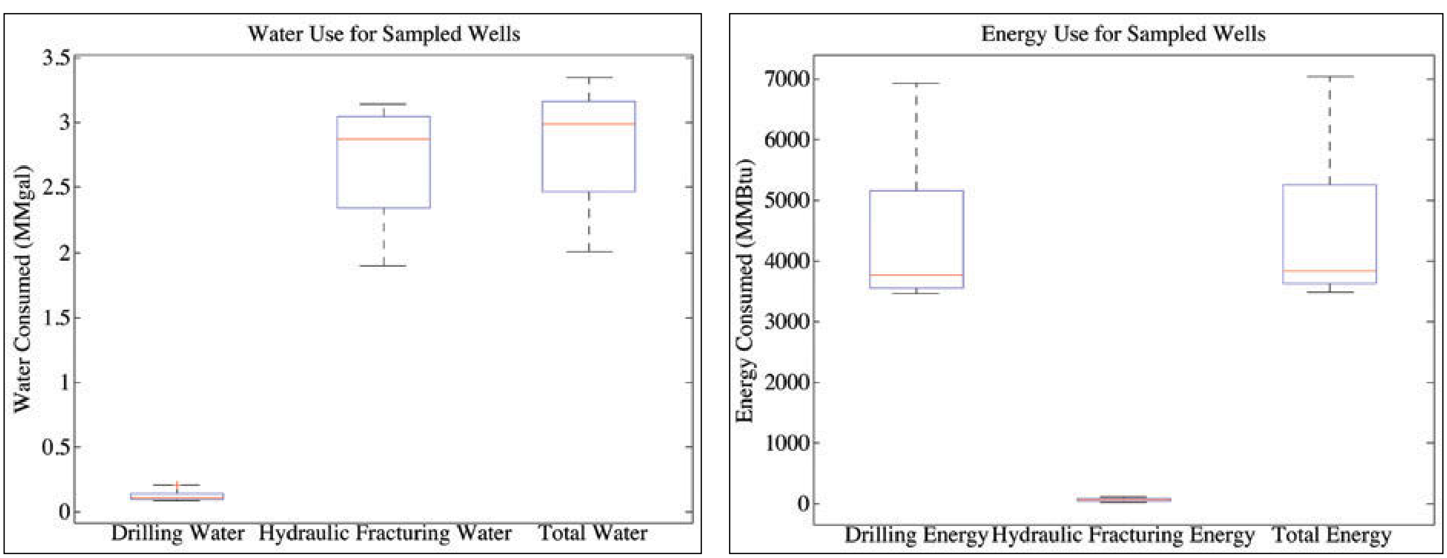


Figure 2. *Water and energy use of the sampled wells*

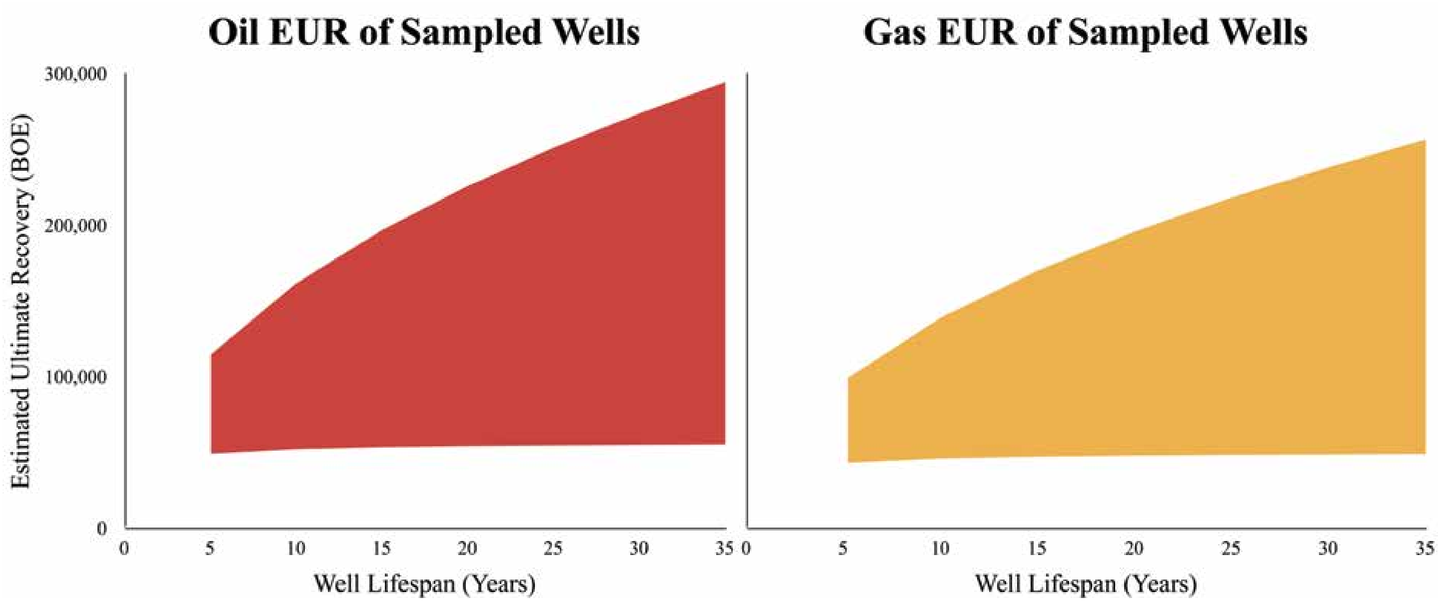


Figure 3. *Projected estimated ultimate recovery of oil and gas for the sampled*

upper limits of the sampled data are shown in parenthesis. The water intensity is defined using Equations 1 and 2.

A decline curve analysis is used to estimate the ultimate oil, gas, and water production from each well. Without extensive historical production data available, a variety of future scenarios are modeled from existing, current production data for a sensitivity analysis of water intensity values. The Arps equation model, shown in Equation 3, is used with the varying degrees of curvature (b-values) ranging from 0.8 to 1.6, based on more established shale formations (0.8 is based on the Fayetteville and 1.6 is based on Eagle Ford). Similarly, the projected well life spans ranged from 5 to 35 years. The existing production data was filtered to remove initial production noise and to smooth existing production data before it was fit to the models using a least squares fit.

Water and Energy Input

Sampled horizontal wells use nearly three million gallons of water to drill and hydraulically fracture a single well. The majority of the water (96 percent) was used for hydraulic fracturing and the rest was used for drilling. A typical well uses 115,000 gallons of water for drilling and 2,870,000 gallons of water for hydraulic fracturing. In contrast, drilling requires the most energy (98 percent of the total energy required for a single well). The typical well required 3,180 million Btu of energy for drilling and 78 million Btu of energy for hydraulic fracturing.

Water and Energy Recovery

Sampled horizontal wells are estimated to recover between 587,000 to 3,290,000 MMBtu of energy. Slightly more of the total energy recovered is predicted to come from 52,300 to 294,000 barrels of oil and the rest will be recovered from 259,000 to 1,540,000 thousand cubic feet (mcf) of gas (43,100-257,000 barrels of oil equivalent). The low estimate for both oil and gas was modeled by extrapolating current production data using a b-value of 0.8 and a well lifespan of 10 years. Similarly, the high value was modeled with a b-value of 1.6 and a well lifespan of 35 years. Figure 3 shows the estimated ultimate recovery of oil and gas as a function of the well lifespan.

The total water recovered, which includes both flowback and produced water, is estimated to be between 330,000 and 4,810,000 gallons of

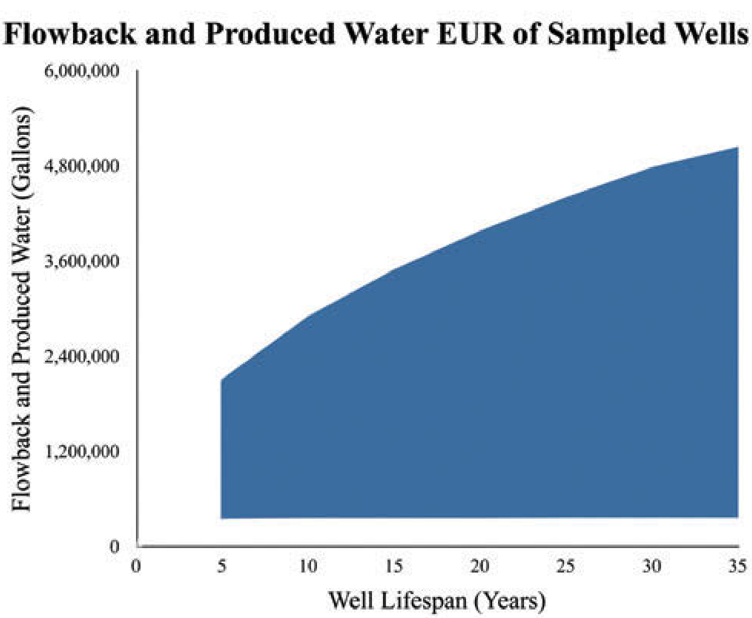


Figure 4. *Estimated flowback and produced water of the sampled wells*

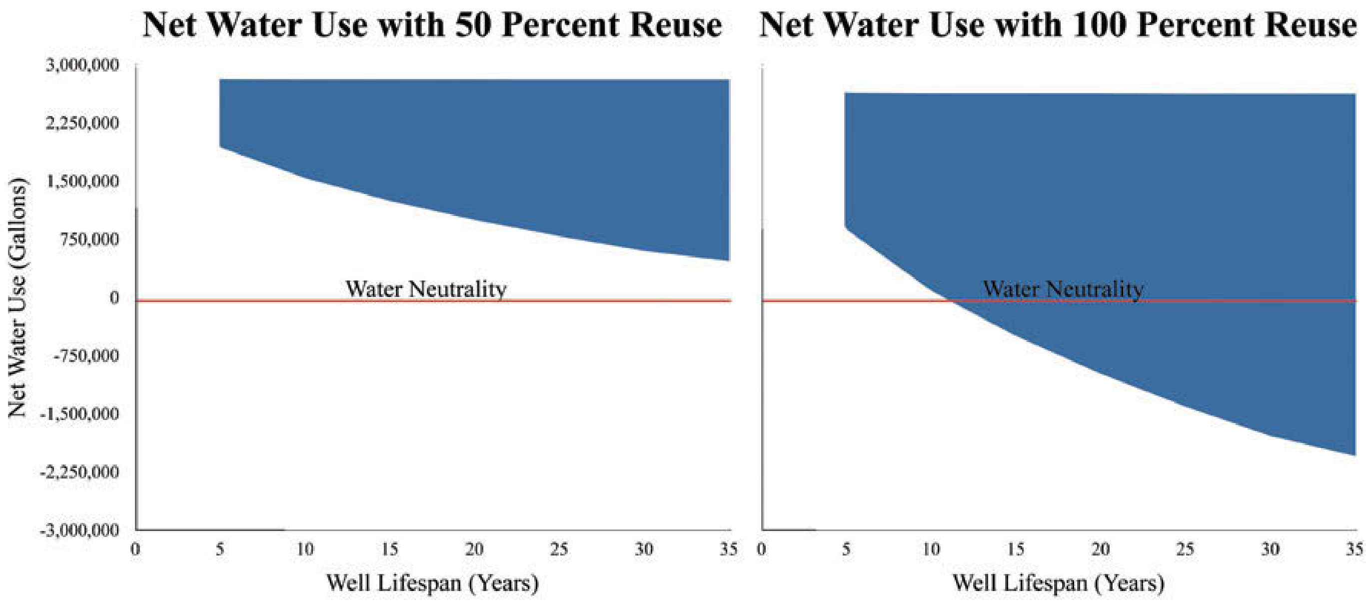


Figure 5. *Estimated net water use with 50 and 100 percent reuse*

water. Produced water predictions associated with unconventional oil and gas development is not well understood and is difficult to estimate, which is reflected in the large uncertainty in the water recovery value.

Potential for Water Reuse

The impact of treating the flowback and produced water to fracture new horizontal wells and reduce the net impact on water resources in Northern Colorado is assessed despite large uncertainties in water recovery prediction values. Figure 5 shows two water reuse scenarios: a 50 percent water reuse and 100 percent water reuse scenario. Although the net water use can be dramatically reduced with 50 percent water reuse, it is unlikely a 50 percent reuse scenario will be able to reach net water neutrality. The 100 percent water reuse scenario shows it may be possible for unconventional oil and gas development to reach net water neutrality depending on the ultimate water recovery value and the degree of treatment required for reuse.

The water intensity of the sampled horizontal wells is estimated to be between 0.9 and 7.8 gal/MMBtu without any water reuse. A 50 percent water reuse scenario reduces the water intensity to between 0.2 and 4.8 gal/MMBtu. The high oil and gas production scenario with 100 percent water reuse predicts a negative water intensity value (i.e., a net water producer), and the low production scenario reduces the water intensity estimate to 4.5 gal/MMBtu.

The water intensity value estimated for unconventional oil and gas

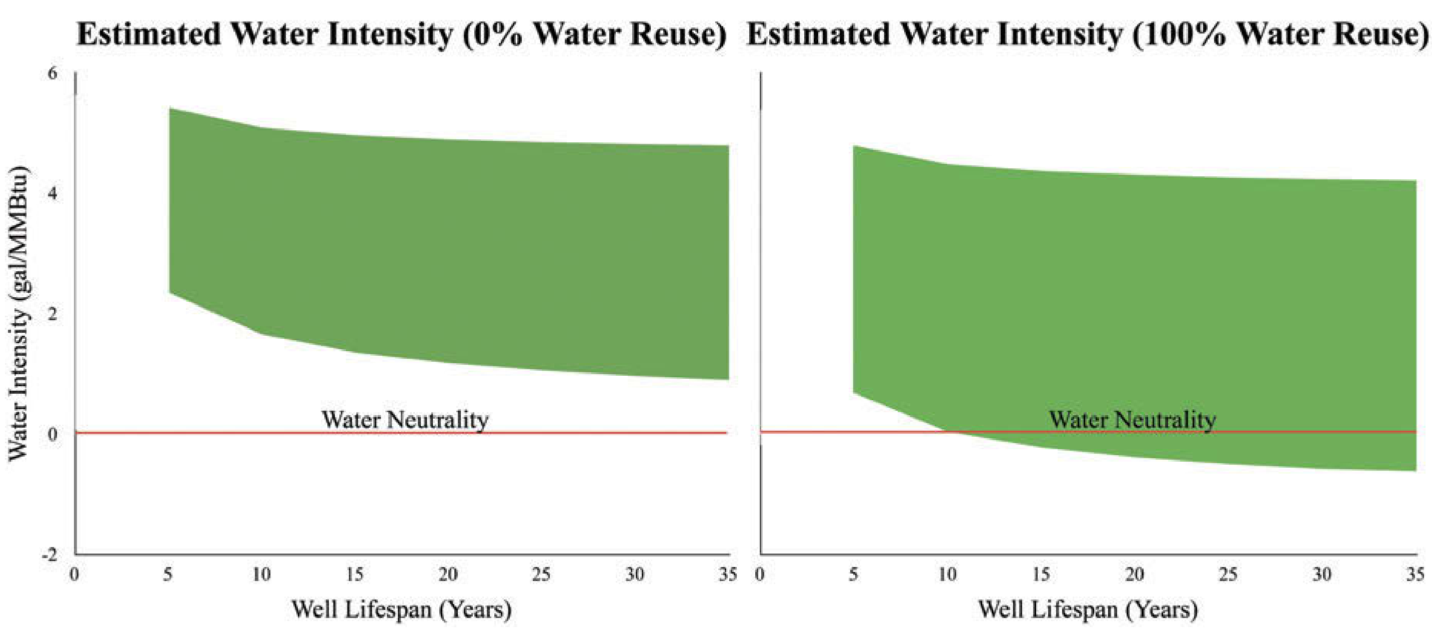


Figure 6. *Estimated water intensity*

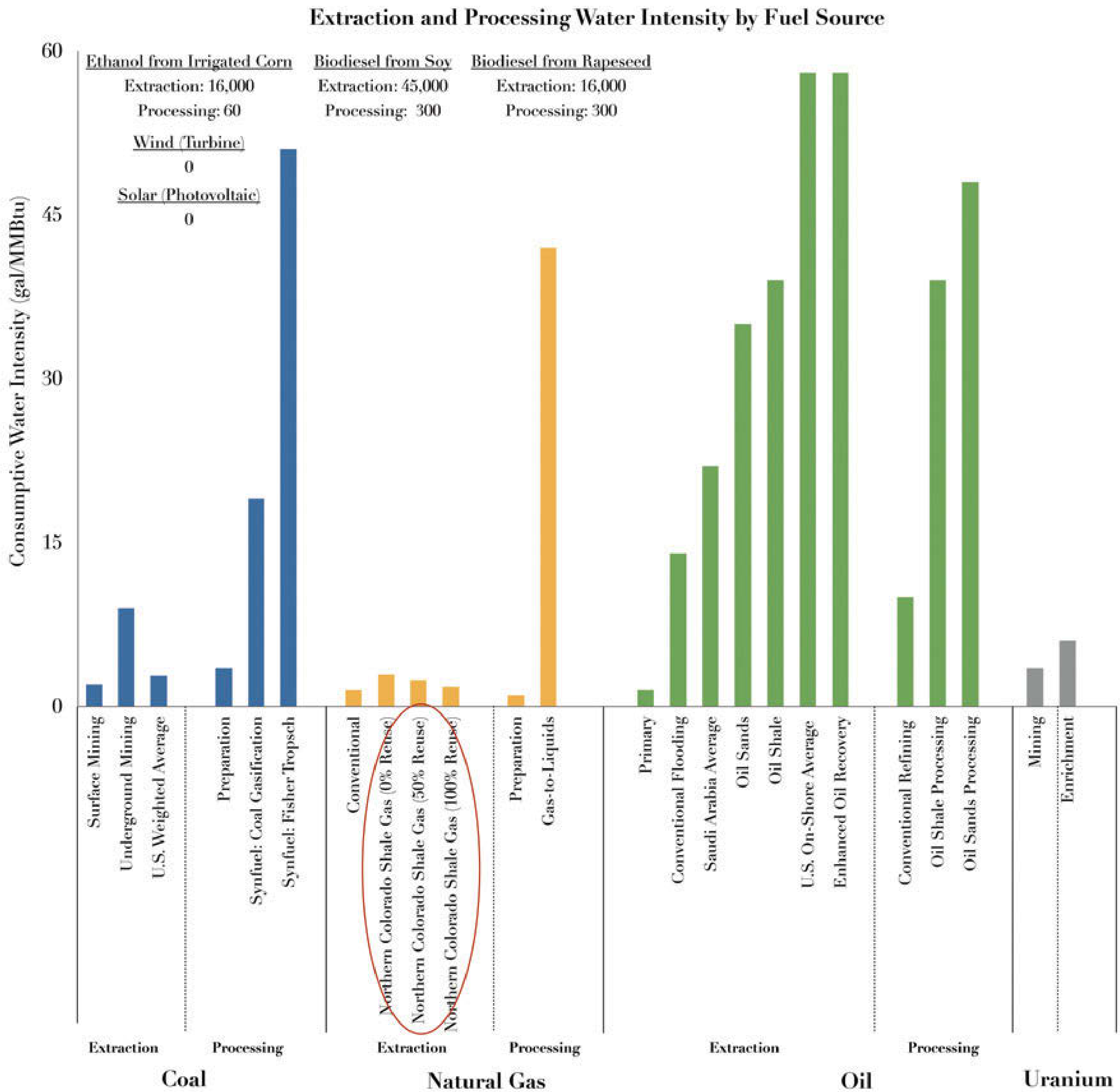


Figure 7. *Water intensity comparison of a variety of energy for extraction and processing*

drilling and hydraulic fracturing in Northern Colorado is compared with water intensity estimates of other energy sources, including coal, nuclear, solar, wind, and biofuels in Figure 7. Biofuels require the most water for extraction and processing, particularly when irrigation is required. Other renewables, such as solar and wind, do not require water for extraction and processing and are not included in Figure 7. The water requirements for coal, oil, natural gas, and uranium vary substantially by region. Water requirements for coal and uranium mining depend local geology, mining methods, and available water resources. Oil and natural water requirements depend on local geology, recovery methods, and reservoir depletion.

Although unconventional oil and gas drilling in Northern Colorado requires nearly three million gallons of water to drill and hydraulically fracture a single well, the water intensity value is comparable to the water intensity value of other energy sources when the entire extraction and processing lifecycle is considered. Future research to develop, refine, and optimize water treatment and reuse methods will be essential to protect Northern Colorado's water resources as unconventional oil and gas development continues to demand more water.

New Water Education Center Springs to Life at Metro State College in Denver

Tom Cech, Director, One World One Water Center for Urban Water Education and Stewardship, Metropolitan State University of Denver

Water resources education has long been a part of Colorado's legacy in higher eucation. According to CSU Water Archivist Patty Rettig and former Director of the Colorado Water Institute, Dr. Robert Ward, Elwood Mead served as the first professor of irrigation in the United States at what was then Colorado Agricultural College in Fort Collins. Other universities have followed suit, and later added majors and minors in water resources management, policy, engineering, law, and other disciplines. However, Metropolitan State College of Denver (Metro State) is embarking on a new endeavor to create water stewards for the future.

Metro State is located in downtown Denver, west of Speer Boulevard and virtually across the street from the Pepsi Center. Formed in 1964, Metro State currently is home to 24,000 undergraduate and graduate students on the Auraria Campus. Also clustered around the Tivoli area are two other sister institutions—the University of Colorado-Denver and the Community College of Denver. Combined, they form what is known as the Auraria Campus, with a total of 45,000 undergraduate and graduate students.

With the help of a $1 million donation from an anonymous benefactor, Metro State is now home to an exciting new water institution in our state—the One World, One Water (OWOW) Center for Urban Water Education and Stewardship. (Faculty and students are already referring to it as the "Oh, Wow" Center.) Its purpose is to develop "urban water stewards" from diverse backgrounds and a wide range of disciplines. Students who study hydrology, history, politics, water law, industrial design, art, music, theater, engineering technology, nutrition, and a host of other majors will be guided toward internships and other volunteer opportunities to help shape new solutions for local and statewide water issues.

The first phase has involved development of new courses for the pilot water studies minor, including "Water

The One World One Water sculpture was created by artist Rik Sargent and donated by Valerie Gates. It is located in front of the new Student Success Building, on the Auraria Campus, at Metropolitan State University of Denver.
Courtesy of Tom Cech

Essentials," a water 101 course, "Introduction to Water Law and Water Rights Administration," "Conflict Resolution," and "Multicultural Water Issues." Instructors for the four initial courses are: 1) Penn State and University of Colorado alumnus Dr. Tom Davinroy, a hydrologist in the Department of Earth and Atmospheric Science; 2) Dr. Elizabeth McVicker, a practicing water attorney who is also President of the Center of Colorado Water Conservancy District in Fairplay, a member of the South Platte River Basin Roundtable, and earned her degrees at the University of Texas, Johns Hopkins, New York University, and the University of Denver School of Law; 3) Carla Schnitker, a practicing attorney and conflict resolution expert who previously served on the faculties at the University of Leiden (Netherlands) and Indiana University; and 4) Amber Tafoya of Nuestro Rio (Our River) who earned her law degree from the University of Colorado – Boulder.

Tom Cech, Director of the One World One Water Center at MSU Denver.
Courtesy of Tom Cech

The pilot water studies minor will also include required internships at water organizations and a capstone project. Numerous electives are also available, and will include water-related field trips around the state. In addition, a water speakers series has already be initiated, as well as an innovative water seminar series—film screenings, art/photography, and music events will begin in the coming year.

The effort to bring the OWOW Center to Metro State was led by Dr. Sandra Haynes, a Denver native who received her Ph.D. in Counseling from CSU in 1990. Haynes was an American Council on Education (ACE) Fellow in 2009-2010, and used that time to develop and create the new water program at Metro State. It currently includes a 21-credit hour pilot Water Studies minor developed for all majors on campus, including art, music, industrial design, nutrition, earth and atmospheric science, theater, teacher education, engineering technology, and many more. "Part of Metro State's mission as an urban institution is to help the community solve community-related issues. Clearly, water is a huge issue in the West, and our new One World One Water Center will help address those needs."

Tom Cech was hired as the first Director of the OWOW Center, and will lead the development of undergraduate water resource courses, awareness and teambuilding on the Auraria Campus, and community and statewide outreach efforts. Tom was the Executive Director of the Central Colorado Water Conservancy District in Greeley for many years and an adjunct instructor at the University of Northern Colorado and Colorado State University. He has also written college-level water resources textbooks with John Wiley & Sons, Cambridge University Press, and the University Press of Colorado. Erika Church is the Assistant Director of the OWOW Center. Erika is a Metro State graduate, obtained her Master's Degree in Adult Education in 2010 from Regis University, and has been on the Metro State staff for the past ten years in the offices of the Institute for Women's Studies and Services and the most recently in the Center for Individualized Learning.

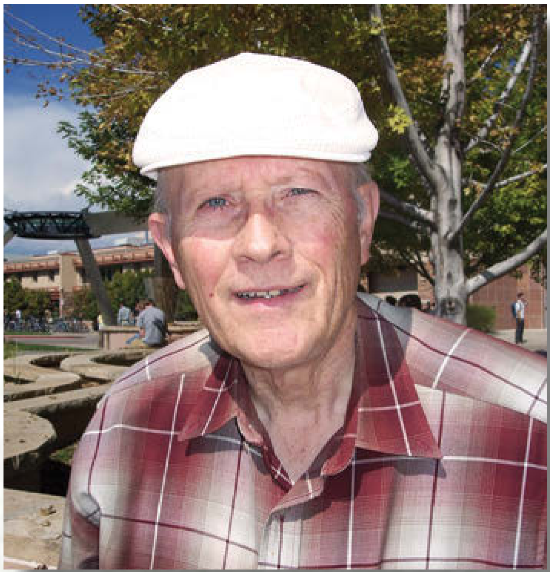
The OWOW Center Advisory Council has begun its work, and includes Jesse Altum, President, Metro State Student Government Assembly, Denver; Amy W. Beatie, Executive Director, Colorado Water Trust, Denver; Peter Binney, P.E., National Director, Sustainable Infrastructure, Merrick & Company; Rob Buirgy, Buirgy Consulting, Inc., Lafayette; Hope Dalton, Water Specialist, Tri-County Health Department, Greenwood Village (Metro State graduate); Dr. Jörg E. Drewes, Professor, Environmental Science & Engineering, Director of Research, NSF-ERC ReNUWIt, Colorado

School of Mines, Golden; John Echohawk, Executive Director, Native American Rights Fund, Boulder; Elizabeth V. Gardener, Special Projects Coordinator, Denver Water, Denver; Jennifer Gimbel, Director, Colorado Water Conservation Board, Denver; Barbara J.B. Green, Partner, Sullivan Green Seavy LLC, Boulder; Gregory J. Hobbs, Jr., Justice of the Colorado Supreme Court, Denver; Antonio Esposito, Water Resource Engineer, CH2M Hill/DEN, Englewood (Metro State graduate); Tom Iseman, Program Director, Water Policy & Implementation, Western Governor's Association, Denver; James E. Kircher, Director, Colorado Water Science Center, U.S. Geological Survey, Lakewood; Eric Kuhn, General Manager, Colorado River Water Conservation District, Glenwood Springs; Paul W. Lander, Geography, Continuing Education & Sustainable Practices Program, University of Colorado, Boulder; Dan Luecke, Boulder; Adams Price, Rotary Club of Denver, Denver; Nicole Seltzer, Executive Director, Colorado Foundation for Water Education, Denver; Amber Tafoya, Colorado Coordinator, Nuestro Rio, Denver; Kenneth Wright, P.E., Chief Engineer, Wright Water Engineers, Inc., Denver; Dr. Sandra Haynes, Dean, School of Professional Studies, Metropolitan State College of Denver, Denver; Susan Noble, Director of Development, Major and Planned Gifts, Metropolitan State College of Denver, Denver.

The project was officially dedicated on May 2nd with the unveiling of artist Rik Sargent's One World, One Water bronze sculpture in front of Metro State's new Student Success Building on campus. For further information, please contact Tom Cech at tcech@mscd.edu or Erika Church at churche@mscd.edu.

Platte River Basin Habitat Recovery Program: Presentation By David M. Freeman to the National Research Council On Lessons Learned

On April 12 in Omaha, Nebraska, David Freeman, Emeritus Professor of Sociology presented an analysis of lessons learned from his study of Platte Basin negotiations that, over the course of 12 years (1994-2006) put in place a river basin scale habitat recovery program designed to serve the needs four species listed under the Endangered Species Act—the whooping crane, piping plover, interior least tern, and the pallid sturgeon. Parties to these negotiations included the U.S. Fish and Wildlife Service, the Bureau of Reclamation, representatives of Colorado, Nebraska, Wyoming water users, and the environmental community. The outcome was a habitat recovery program that is now in the process of re-organizing an annual average of about 11 percent of Platte river flows as measured near Grand Island.



Dr. Freeman's study, just re-released this July in paperback book form, provided background for use by the NRC Committee on Sustainability Linkages. Committee members examined the Platte basin habitat recovery program and negotiations to gain insight into the means by which federal agency personnel can better transcend their bureaucratic and disciplinary silos, establish accountability, and sustain effective inter-organizational linkages in support of cooperative efforts in the water-agriculture-energy sectors. Professor Freeman's presentation centered on critical lessons drawn from the Platte basin negotiating experience.

David M. Freeman. *Implementing the Endangered Species Act on the Platte Basin Water Commons.* University Press of Colorado: hardback, 2010; paperback 2012.

Colorado Energy Water Consortium Formed to Address Water Issues Related to Oil and Gas Development in the State

Ken Carlson, Civil and Enviormental Engineering, Colorado State University

Huishu Li, Civil and Environmental Engineering graduate student, collects water samples from oil and gas operation in Weld County.

Courtesy of Ken Carlson

Colorado State University (CSU), a worldwide leader in water resource planning and management, and Noble Energy, one of the nation's largest independent oil and gas producers with operations in Colorado, have created the Colorado Energy Water Consortium—a partnership to address water issues associated with oil and gas production, including hydraulic fracturing, through empirical research and scientific investigations (http://cewc.colostate.edu).

Goals of the partnership include identification, understanding and development of solutions for water issues related to oil and gas development in the Colorado and the Rocky Mountain west. In addition, the consortium will focus on communicating that research with the public and growing CSU's curriculum to prepare students for an increasingly critical industry to Colorado and the western U.S.

The consortium is governed by a nonpartisan board of directors comprised of leading members of the agriculture, consulting, environmental, government, industry, and academic communities (Table 1).

The consortium was formed in 2011 with initial funding from both CSU and Noble Energy. The CEWC is currently working on water issues related to oil and gas development and has been designed to:

- Provide research and information relevant to the quantity of water resources available and used in

Table 1. *CEWC Board of Directors*

Don Ament	Former State Agriculture Commissioner
Bill Bellamy	Fellow and Senior VP of Water Technologies at CH2M Hill
Tom Iseman	Water Policy Director at the Western Governor's Association
Barb Kirkmeyer	Weld County Commissioner
Ken Knox	Sr Adviser and Water Program Director, Noble Energy
John Sanderson	Co-director of the Center for Conservation Science and Strategy at the Nature Conservancy
Reagan Waskom	Director of the Colorado Water Institute at CSU
Bryan Willson	Director of Engines and Energy Conversion Lab at CSU

the development and production of energy in Colorado and the intermountain region of the western United States

- Provide research and information relevant to the quality of water resources available and used in the development and production of energy in Colorado and the intermountain region of the western United States
- Discover and develop practical solutions to water related problems relevant to the development and production of energy
- Promote the development of an educational structure designed to train scientists, engineers, and technicians to work in the energy industry on issues related to water and the environment
- Provide accurate and timely information to the public related to energy-water quantity and quality concerns

Since water resource availability in Colorado can be strained given the historical agricultural needs, burgeoning development, and the semi-arid environment, the CEWC has initially focused on water use and water intensity. Since competition over water resources will continue to escalate to meet expanding municipal and industrial demands, including those associated with the oil and gas industry, water use is an issue that will be important for the foreseeable future.

The initial projects undertaken by the CEWC include a water intensity study (see related article in this issue) and a project to development advanced geographic information system (GIS)-based water management tools for the shale oil and gas industry. Researchers from CSU have partnered with Noble Energy on both of these projects, developing information and tools that will lessen the impact of oil and gas development on water resources in the state.

In the future, additional partners will collaborate with the CEWC including Halliburton, a leading service company, and potentially other operators. Issues such as recycling fracking flowback and produced water and effective environmental monitoring will be significant focus areas for CEWC researchers.

Collection tank for storing produced water (on left) before disposal or recycling.
Courtesy of Ken Carlson

Guiding Landowners and Agencies Dealing with Domestic Energy Development in the Northern Plains and Mountains

Julie Kallenberger, Assistant Regional Water Coordinator, Colorado Water Institute
Troy Bauder, Water Quality Specialist, Department of Soil and Crop Sciences, Colorado State University
Reagan Waskom, Director, Colorado Water Institute
Jim Bauder, Professor Emeritus/Adjunct, Montana State University
Ginger Paige, Professor, University of Wyoming

As recently as a decade ago, the impacts of oil and natural gas development on water resources were mainly confined to issues related to off-shore drilling for oil, ruptured pipelines, and grounded oil tankers. Today, new terms, like coalbed methane (CBM), coal seam natural gas, and drilling and extraction practices, like horizontal drilling and fracking (formally known as hydraulic fracturing), are gaining a lot of attention, particularly in the Northern Plains and Mountains (NPM) Region. Much of this attention is due to better understanding of the potential for oil and gas resource development to affect land and water resources by industry, society, and regulatory agencies.

Regarding the current thrust of unconventional oil and gas development in the NPM Region, landowners frequently voice concerns about whether fracking can or will contaminate their domestic water supplies. Irrigators wonder whether discharge of CBM-produced water will cause changes in irrigation water quality and regulatory, and governmental agencies need to know what values should be assigned to water quality parameters to assure protection of water resources.

The NPM Regional Water Program, a USDA sponsored partnership of six land-grant universities, initiated a project to help guide landowners and agencies dealing with the impacts of domestic energy development on their land and water supply. The activities performed in this project have led to the development of a widely-viewed informational video documentary, online educational tools, stakeholder forums, conferences, regional workshops, and productive collaborative partnerships among landowners, governmental agencies, and oil and gas companies.

Sodicity and salinity impacts to corn crop irrigated with river water downstream of CBM discharge area.
Photo by Troy Bauder, Colorado State University

Advances in Oil and Gas Extraction Technologies and Impacts on Regional Water Supplies

In the mid-1990s, the natural gas industry developed efficient processes for locating and extracting CBM from shallow coal deposits throughout the Intermountain West. A significant increase in natural gas prices prompted the drilling and development of nearly 31,000 CBM wells in the NPM Region by 2010. Concurrently, the increase in crude oil prices prompted expanded exploration and drilling for oil and natural gas reserves. This expanded drilling was complemented by new drilling techniques and improved methods for withdrawing natural gas and crude oil from underground oil reserves.

The two most noteworthy advances have been horizontal drilling and improved hydraulic fracturing, a process whereby industry-proprietary chemicals, mixed with large volumes of water and sand, are injected into underground geologic formations to open and expand pores and channels so that oil and gas can more readily flow to the well cavity. Additionally driving the oil and gas development industry has been the discovery of large, prolific oil and gas reserves contained in the Niobrara and Bakken shale deposits, underlying southeast Wyoming, northeast Colorado, northeast Montana, and northwest North Dakota. Extraction of CBM requires pumping and disposing of often large volumes of water from coalbeds. This water ranges in quality from nearly fresh to brackish and saline. Pumping and discharge of water from CBM operations onto the landscape and into storage impoundments and rivers has increased dramatically in the past decade.

The discharge and disposal of CBM produced water was found to alter the quality of some streams, rivers, and groundwater. Research has documented that CBM production water can often negatively alter soil properties as well. Each of these circumstances can pose a threat to the quality of water used for irrigation, livestock watering, range land, and aquatic habitat sustainability. Additionally, severance of mineral rights from surface rights often means that landowners, whether dealing with CBM or unconventional oil/gas drilling, have little control over drilling operations and must rely on surface use agreements and negotiations with gas and oil production companies to guide operations on the landscape.

Sampling CBM discharge water in the Raton Basin of Colorado.
Photo by Troy Bauder, Colorado State University

Educational Resources

The NPM Regional Water Team responded to needs of landowners, concerned citizens, and governmental agencies and administrations by:

- Researching impacts of CBM produced water discharges on irrigation water quality and management alternatives on semi-arid landscapes and irrigation water
- Developing educational resources for landowners, regulatory and natural resource management agency personnel, litigants, attorneys, consultants, scientists, students, the media, educators, and policy makers
- Transferring science-based information to the general public, media, landowners potentially impacted by CBM extraction, and other decision makers

The team and their partners developed a *Land & Water Inventory Guide for Landowners in Areas of CBM Development* which has been used to educate landowners concerning CBM issues and assist with monitoring and assessment of impacts to land and water resources. Team members also produced *Prairies and Pipelines*, a public television documentary that addresses the science and social issues behind CBM recovery and associated water management. Also, inquiries from private well owners, Extension field staff, and EPA Region 8 staff prompted the development of a comprehensive website on the hydraulic fracturing extraction processes and potential implications for water resources. This website provides information about drilling and hydraulic fracturing techniques, water quality testing, surface use agreements, perspectives on water quality and quantity, and potential health issues related to hydraulic fracturing.

For additional information about the NPM Regional Water Program and these resources please visit www.region8water.org and http://waterquality.montana.edu/docs/methane.shtml.

Potential Effects of Wildfires on Water Quality

John D. Stednick, Watershed Science, Colorado State University

Streamflow generation mechanisms and flow routing processes are the largest determinants of water quality. Forested watersheds are usually associated with excellent water quality. Infiltration rates are rarely exceeded by precipitation rates and thus streamflow generation occurs via subsurface flow routing. Forests provide stream shade, which moderates water temperatures, and provide a source of organic material and nutrients, which are used by aquatic organisms. Forests also modify the chemistry of incoming precipitation as a result of vegetation and soils interactions. Thus, natural disturbances such as wildfires that remove or disturb forest vegetation or alter hydrochemical flow paths may change water quality.

Wildfires remove vegetation, downed woody materials, and soil organic matter, exposing mineral soil surfaces. This exposure to raindrop impact and splash can seal or fill soil pores at the surface with finer soil particles. This may be compounded by water repellency, and may result in decreased infiltration and increased overland flow. Especially during high-intensity rainfall events, overland flow leads to increased runoff and dramatic changes in peak streamflows and timing. The overland flow also carries ash, fine debris, and eroded soil to receiving waters.

Often a wildfire results in the formation of a water-repellent or hydrophobic layer below the soil surface as a result of condensation of long-chain aliphatic soil organic compounds that are volatilized by the fire heat. During a wildfire, temperatures at the soil surface can approach 900° C. High-temperature fires may completely consume the surface organic layers, with the organic material mineralized or volatilized. Specific fire temperatures are controlled by such factors as fuel loads, types, and moisture contents, and fire weather. At higher temperatures, much of the mass of organic matter can be transformed into carbon dioxide and water vapor, with nutrients lost as gases or converted (mineralized) into forms more readily transported by surface runoff or drainage water. The nutrient most vulnerable to gaseous losses is nitrogen, which can be volatilized at relatively low temperatures (e.g., 200–500° C). Phosphorus can be volatilized at high burn temperatures (e.g., 770° C), whereas other mineral nutrients such as calcium, magnesium, and potassium are typically converted to oxides (often a major component of the light-colored ash remaining after fire) that are relatively soluble. These volatilized organic compounds condense on cooler soil particles associated with steep temperature gradients below the soil surface. Because dry soil is a poor conductor of heat, even a few centimeters below the soil surface the temperature is not likely to exceed 150° C. This results in hydrophobic layers that repel water, thereby reducing infiltration (water movement into the soil surface) or percolation (water drainage within the soil). Reductions in the infiltration rate can be significant (e.g., one to two orders of magnitude). Coarse textured soils are more prone to water repellency than finer textured soils. These hydrophobic layers persist from six months to three years in Colorado, depending on soils, fire severity, and forest vegetation regeneration rates. To a lesser extent, hydrophobic soil layers also occur naturally.

Because soil and water resource effects are influenced so much by fire severity, a system for classifying burn areas has been developed that characterizes results of the burn, thus integrating burn intensity, duration, and site conditions. A Burned Area Emergency Rehabilitation effort (BAER) lead by the U.S. Forest Service will start with a fire severity inventory to prioritize areas needing immediate restoration efforts to address soil erosion potential. The soil classification system has four categories:

- **Unburned to very low.** Fire has not entered the area, or has very lightly charred only the litter and fine fuels on the ground; soil organic matter, structure, and infiltration are unchanged
- **Low.** Low soil heating or light ground char occurs, mineral soil is not changed, leaf litter may be charred or partially consumed and the surface of the duff may be lightly charred, original forms of surface materials such as needle litter may be visible, very little to no change in runoff response
- **Moderate.** Moderate soil heating with moderate ground char, soil structure is usually not altered, decreased infiltration due to fire-induced water repellency may be observed, litter and duff are deeply charred or consumed, shallow light colored ash layer and burned roots are usually present, increase in runoff response may be moderate to high
- **High.** High soil heating, or deep ground char occurs, duff is completely consumed, soil structure is often destroyed, decreased infiltration due to

After the High Park Fire: From Greyrock to Seaman Reservoir. Photo by Michael Menefee

fire-induced water repellency is often observed, top layer of mineral soil may be changed in color (but not always) and consistency and the layer below may be blackened, deep and fine ash layer is present (often gray or white), all or most organic matter is removed, essentially all plant parts in the duff layer are consumed, increase in runoff response is usually high

High burn severity areas are primary treatment candidate sites if there are downstream values at risk. Treatments often attempt to provide soil cover and include mulching, grass seeding, wood straw, and erosion control structures such as straw waddles or other overland flow filtering structures. This classification scheme assumes that soil conditions are the primary influences on hydrologic functions after wildfire. Weather events (e.g., antecedent conditions, storm size, rainfall) also influence hydrologic functions (e.g., interception, evapotranspiration) and water quality functions (e.g., root strength, nutrient cycling, shade). Such a focus may be suitable for screening for immediate site rehabilitation needs, but it may not capture more subtle or complex watershed responses, such as changes in stream temperature or nutrient concentrations. Specific burn locations, patterns, and extents are also important in determining watershed responses. If riparian areas remain intact, for example, key functions of sediment storage, evapotranspiration, and shade may persist to some extent. Extensive wildfires that consume both upland and riparian sites create conditions conducive to severe hydrologic responses and associated water quality effects.

Wildfires have the potential to increase stream temperatures through the reduction of shading vegetation in riparian areas and the widening of the channel because of the loss of channel bank strength. Many studies have reported increased nutrient movement through soils and into streams following fire. The extent of nutrient movement into streams following fire depends on the buffering capacity of soils, the proportion of a watershed burned, the rate of vegetation regrowth, streamflow generation mechanisms, and streamflow regime. Fire could be expected to cause a greater duration and magnitude of water quality effects than forest harvesting partly because of the greater loss (death) of vegetative cover and the conversion of insoluble chemicals within organic matter into readily soluble chemicals in ash, which are more quickly and easily transported into streams; however, there are many confounding factors. For example, net nitrification in the soil may be greater after harvesting than after fire. This may happen if nitrifying bacteria are more adversely affected by fire or if greater immobilization of nitrate occurs in the soil after a fire, in which case less nitrate nitrogen could be expected to leach into streams. Fire often enhances nitrification because of the increased ammonium levels, stimulation of nitrifying bacteria, or sorption by charcoal of nitrification-inhibiting phenolics. The charred material left by fire can be a chemically active heterogeneous mixture of compounds containing nitrogen, sulfur, and oxygen functional groups, which can be quickly oxidized, attacked by microbes, and rendered soluble, thereby facilitating nitrate and sulfate additions to streams. Furthermore, dissolution of smoke gases directly into streams may also enhance stream water nitrate nitrogen levels. Dissolution of smoke gases into freshwater would yield relatively more nitrate for a well-ventilated fire, and relatively more ammonium for an incomplete combustion or poorly ventilated fire.

Although sometimes overlooked because much of it may occur during or shortly after burning, the loss of surface and binding organics from severe fires contributes to dry ravel. This erosion process is the downhill movement of soil, organic material, and rocks in response to gravity. In western Colorado, we found soil erosion following forest road construction was greater as dry ravel erosion than as precipitation/overland flow generated soil erosion.

One of the puzzles about watershed response to fire is the apparent increase in slope failures, which generally are thought to result from positive soil pore pressures. This occurs when water creates buoyancy that separates and floats soil particles, often at a discreet failure zone. Fire may promote slope failures by reducing evapotranspiration and root strength, but a dominant effect is the diversion of water from infiltration to overland flow or surface runoff, which tends to lower water pore pressures. A fire and flood sequence with landslides or debris torrents has often been observed.

The increased inputs of sediment to the channel proper may take years to move through the system. The flux of this sediment depends on the sediment size, location, and streamflow energy needed to transport the sediment. Summer low flows carry little sediment, thus we must wait for higher spring snowmelt flows to transport the sediments through the watershed. The current water quality in the Cache la Poudre River is not suitable as a drinking water source, since the water is colored by organic compounds leaching from the burned area and transport of ash and sediment directly to the river. Although sediment itself is relatively easy to remove via sand filtration, the removal of color requires expensive carbon filtration, and such an expense precludes its use as drinking water. Even with the sediment and color, the river water is usually acceptable as irrigation water, although pumping or other mechanical transport would not be recommended. The fine textured sediment carries nutrient sorbed to the particle, and can have a fertilizer value.

The persistence of adverse water quality effects is a function of watershed recovery rates, often influenced by management activities related to increasing soil cover, either as mulch, grass seeding, or vegetation regeneration. The recently formed High Park Restoration Cooperative will help direct these efforts.

A variety of information on watershed rehabilitation methods and other fire related resources is available at the following websites:

http://www.co.nrcs.usda.gov/news/pas/2012_Fires/2012_Fires.html

http://www.co.nrcs.usda.gov/programs/ewp/ewp-index.htm

http://larimer.org/highparkfire/

Fuelbreaks in High Park Fire Area Aided Firefighters, Protected Watershed

Ryan Lockwood, Public and Media Relations Coordinator, Colorado State Forest Service
Katherine Timm, Outreach Division Supervisor, Colorado State Forest Service

Greg Zausen, a forester for the CSFS Fort Collins District, builds a slash pile while completing mitigation work in the Borden Memorial Forest. The piles are burned in the winter.
Courtesy of the Colorado State Forest Service

As the High Park fire bore down on the northwest corner of Lory State Park west of Fort Collins, Colorado, on June 11, foresters who'd spent three years thinning out a 375-acre fuelbreak in the area held their breath wondering if it would work.

The crown fire roared through the treetops, pushed by high winds and devouring swaths of unbroken canopy made up of bone-dry, highly flammable pine needles and branches. But when the fire hit the fuelbreak—an area where trees had been thinned out, but not removed altogether—it could no longer jump from tree to tree, so it dropped to the ground, just as foresters hoped it would.

Later inspection revealed that the flame front became a much more benign ground fire as it burned through the fuelbreak, where it merely torched some individual trees or patches of trees until it hit a control line established by retardant drops from aircraft. And there it was stopped, sparing not only the park, but a large section of the watershed for Horsetooth Reservoir.

"So many variables affect fire behavior that it's difficult to point to one factor and say that this is what stopped that portion of the fire," said Diana Selby, assistant district forester, Fort Collins District of the Colorado State Forest Service. "But we can say that the fire behaved like we wanted it to and that firefighters took the opportunity to stop the fire in the park using retardant drops."

Forestry Measures Provide Watershed Protection

High-severity fire was prevented within fuels treatment areas in Lory State Park, where stand thinning occurred, and as a result, the watershed for Horsetooth Reservoir was not as significantly threatened by post-fire runoff. In contrast to treated areas, approximately eight percent of all burned acreage within the 87,200-acre fire area burned at high severity, which causes flooding and erosion in storm events.

In severely burned areas, a wildfire vaporizes ground cover that normally would intercept rainfall and creates water-repellent soils. As a result, there is a significant risk for dangerous flooding, extreme erosion and heavy sedimentation downstream that may endanger life, damage property and degrade water quality.

"Fuels treatments like those in Lory State Park are specifically intended to help reduce the risk of severe fire intensity," Selby said.

Many areas within the High Park burn footprint had not been treated, however, and some burned at a higher severity. Protecting the barren, water-repellent soils in these areas from intense rainstorms has been the principal goal of an interagency Burn Area Emergency Response (BAER) Team. The team includes representatives from the U.S. Forest Service, Natural Resources Conservation Service, Colorado Department of Transportation and Larimer County. The team's objectives include aerial mulching of 5,600 acres of National Forest System lands and the possible mulching and seeding of an additional 5,700 acres of private land; only areas of moderate to high burn severity on steep slopes will be addressed.

An Ounce of Prevention…

For the past decade, Colorado Parks and Wildlife has been working in tandem with the Colorado State Forest Service to actively manage hazardous fuels, including beetle-killed stands, in 20 state parks. CSFS provides technical forestry assistance and helps plan and implement treatments.

The Lory State Park project was funded by a $250,000 FEMA pre-disaster mitigation grant from the Colorado Division of Emergency Management, matched by $120,000 from Colorado Parks and Wildlife through Great Outdoors Colorado. Treatments included shaded fuelbreaks on ridge tops, which firefighters used for retardant drops during the High Park Fire. The fuelbreaks also helped prevent erosion in the area from monsoon rains that occurred immediately after the fire.

"The value of fuels mitigation treatments at Lory State Park during the High Park Fire underscores the successful partnership that Colorado Parks and Wildlife and the Colorado State Forest Service have developed over the decade since the Hayman Fire," said Matt Schulz, Colorado Parks and Wildlife forest management coordinator.

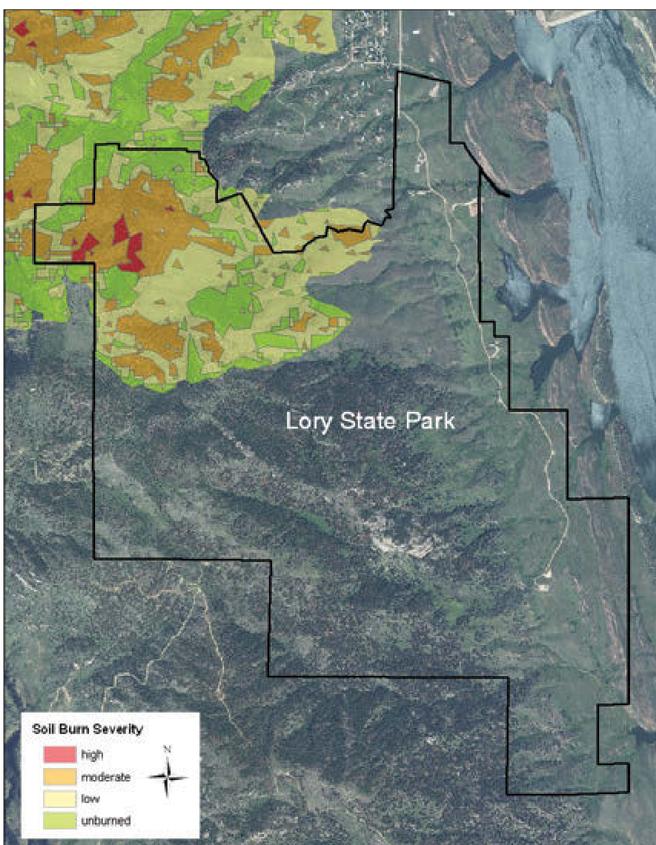
Additional Fuels Mitigation in Nearby Communities, CSU Property

Complementing the fuels treatments implemented in Lory State Park was work done by landowners in neighboring Redstone Canyon and by CSFS personnel in the Borden Memorial Forest, an education-oriented forest property owned by Colorado State University.

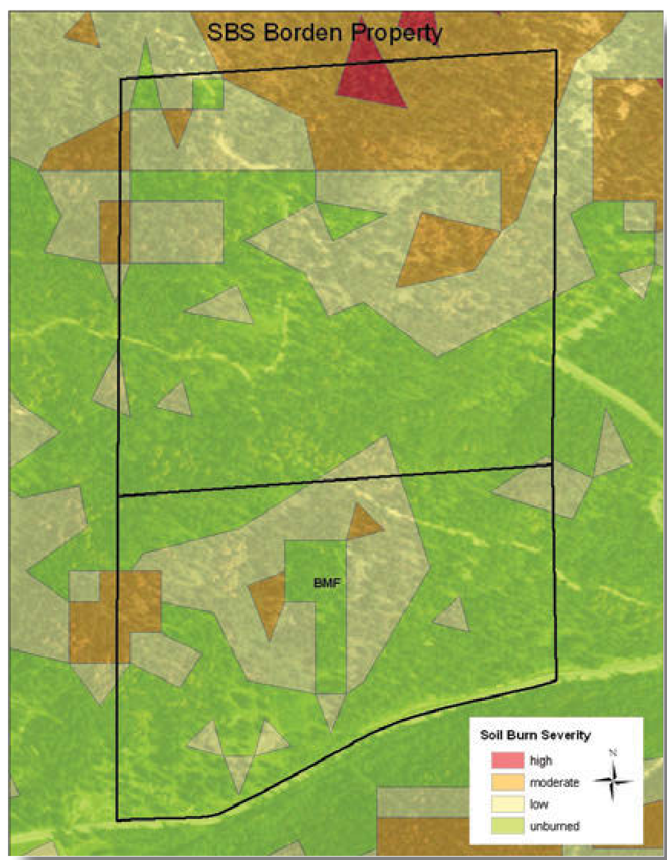
In Redstone Canyon, community members met every Saturday for four months to thin trees along community roads, creating a shaded fuelbreak and safer conditions for entry and exit during a fire. The group's sweat equity reduced the cash cost of the overall project, resulting in more areas being treated. During the High Park Fire, Redstone Canyon fuelbreaks also were used for retardant drops and fire perimeter work.

Further north in Rist Canyon, fuels mitigation work helped keep the fire on the ground in the Borden Memorial Forest, potentially saving homes and minimizing damage to the forest. The 70-acre private forest, a certified Tree Farm that was donated to CSU to be used as a living classroom, is used for experiential learning opportunities for CSU students. Wood used for the university's annual homecoming bonfire comes from forest thinning projects completed on the property.

"In addition to protecting Lory State Park, Redstone Canyon and



A burn severity map of Lory State Park. Areas where mitigation work was done in the park did not experience the high-severity burning.
Courtesy of the Colorado State Forest Service



A burn severity map of the Borden Memorial Forest. Although the fire passed through the forest, much of it remained unburned or burned at low intensity due to mitigation work.
Courtesy of the Colorado State Forest Service

The High Park Fire burned 87,200 acres before containment more than three weeks after ignition.

Courtesy of the Colorado State Forest Service

surrounding communities from wildfires, these fuelbreaks also established safe zones for firefighters to battle the blaze," said Selby. "These treatments would not have been possible without the partnerships, funding, and collective will of everyone involved, and they are a testament to the importance of coordinated efforts to mitigate hazardous fuels."

The Lory State Park, Redstone Canyon, and Borden Memorial Forest fuels mitigation projects are part of a larger forest management effort aimed at reducing hazardous fuels, mitigating the impacts of mountain pine beetles and restoring forest health in an area stretching from the lower Poudre Canyon south to Masonville. Smaller fuelbreaks like the 375-acre fuelbreak at Lory may be dwarfed by massive fires like High Park, but they underscore the benefits of what can be accomplished with partnerships and well-placed fuels treatments that can keep a large fire from becoming even more damaging and dangerous.

Seedling Trees Provide Long-Term Erosion Solution

Although immediate soil stabilization measures have been the primary concern for the fire's interagency BAER Team, CSFS is encouraging area landowners to think about long-term goals. Planting seedling trees is one of the best long-term solutions to rejuvenate burned forests and control erosion, because as the trees grow, their spreading roots trap and retain soil, while their canopies intercept falling rain to further reduce erosion.

The CSFS Nursery has provided hundreds of thousands of inexpensive tree seedlings to accelerate forest regeneration in burned areas, including portions of the area burned by the 2002 Hayman Fire. Many species native to the High Park area, such as ponderosa pine, lodgepole pine, Rocky Mountain juniper and Douglas-fir, are available for reforestation, soil retention and wildlife habitat improvement. CSFS personnel are available to provide technical advice and seedling survival tips to landowners planting seedlings.

Those living outside burned areas who want to help with reforestation efforts to protect local watersheds can make monetary donations to the CSFS-administered ReForest Colorado fund. The fund, established through the CSU Foundation, allows corporations and private citizens to make donations to help plant trees in fire-scarred areas of Colorado.

For more information about wildfire mitigation, the CSFS Nursery or donation opportunities, go to http://csfs.colostate.edu/.

Defend and Develop: Why the Colorado Water Conservation Board Was Created

J. William McDonald, Owner, McDonald Water Policy Consulting, LLC
Tom Cech, Director, One World One Water Center for Urban Water Education and Stewardship, Metropolitan State University of Denver

2012 is the 75th anniversary of the 1937 laws creating the Colorado Water Conservation Board (CWCB) and the Colorado River Water Conservation District, as well as the law enabling the formation of water conservancy districts. To mark its anniversary, the CWCB commissioned a brief history. Written by the authors of this article, it will be published this fall. The following is adapted from two chapters of the forthcoming book and briefly highlights the events which led to the CWCB's creation.

Colorado's oldest decreed water rights are in the Rio Grande Basin with priority dates between 1852 and 1854. With the gold rush in 1858-59, private irrigation development expanded to the Arkansas and South Platte River Basins.

Initial individual developments were confined to river bottoms. To move onto higher elevation benches along rivers required community efforts. The earliest of these, in 1860, was the Denver City Ditch. Horace Greeley and Nathan Meeker followed with their unabashed national promotion of Union Colony (now Greeley) in the 1870s and the construction of four major ditches from the Cache la Poudre River serving over 100,000 acres.

There were, however, limits on the viability of private irrigation developments. In Colorado, investors in corporately financed efforts often did not see a return on their investment, and the companies and corporations formed to pursue developments often foundered.

Prominent among these developers was T. C. Henry, "champion promoter of irrigation projects" in Colorado. In 1883, Henry arrived in Colorado a wealthy man. He formed the Colorado Loan & Trust Company—as President and primary stockholder—and went to work creating and financing irrigation companies. Although Henry was aggressive in his irrigation schemes, many failed due to inadequate water supplies. His fortune dried up by the time of his death.

The state itself fared no better.

> *… from 1890 to 1893 the state invested a considerable part of its income fund in the construction of reservoirs. Unfortunately these were poorly located as to cost, as to water supply and as to capacity. Of the canal construction … [two] were undertaken. The use of convicts on these works was … tried. Here again the location was not good, the water supply uncertain and a general scheme of development inadequate. The result … was that practically all the money spent was without result.*

Likewise, what became one of Colorado's original federal water projects was started by the state in 1901 with $25,000. After only 900 feet of the Gunnison Tunnel were driven, funds were exhausted and the project abandoned.

The failure of private ventures began to mount in the late 1880s and 1890s throughout the West, although not for lack of promotional efforts. In October, 1873, the first Irrigation Convention in the U.S. was held in Denver. One of the promoters was Rocky Mountain News editor William Byers, with the goal to draw attention to railroad lands he and others were peddling. Governors and delegates attended from surrounding states, and promoters orated about building a 550-mile long canal from Denver, across Colorado's Eastern Plains, and into Kansas. Much of the land along the route was owned by a railroad company.

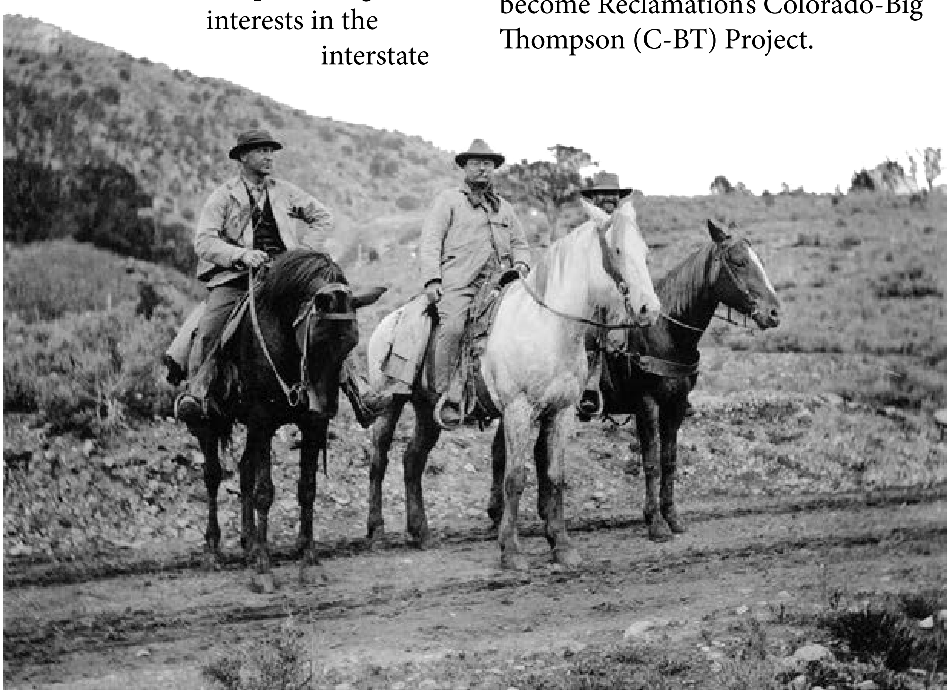
Theodore C. Henry was an Abilene, Kansas pioneer businessman and wheat entrepreneur before he arrived in Colorado.
Courtesy of Kansas State Historical Society

It was against this backdrop that the westwide "irrigation movement" of the 1890s took hold. When Theodore Roosevelt became President in 1901, the movement gained a strong advocate for federal irrigation development. With his support, the movement achieved its goal of obtaining Congressional enactment of the Reclamation Act of 1902, a program to reclaim the arid West run by the U.S. Bureau of Reclamation (Reclamation).

This new federal program got off to a promising start in Colorado with the early approval of two Reclamation projects—the Uncompahgre Project around Montrose (authorized in 1903) and the Grand Valley Project in the vicinity of Grand Junction (authorized in 1911). Despite this early success, Colorado was concerned about federal reclamation projects going forward in downstream states in the face of decisions by the U.S. Supreme Court which applied the doctrine of prior appropriation across state lines, to Colorado's detriment. This prompted the state, led by water attorney Delph Carpenter from Greeley, to embrace the negotiated interstate compact as a means of protecting its interests in the interstate rivers which arise in and flow from Colorado.

The first such compact was the seven state 1922 Colorado River Compact. But it was a double edged sword in that the compact's allocation of water between the Upper and Lower Division states of the basin enabled California to obtain, in 1928, the Congressional authorization of Hoover Dam and the All-American Canal. This made possible the very development which Colorado feared despite the protection afforded by the compact.

By 1935, at the height of the Great Depression, Colorado had received only $14.4 million out of a total of $381 million invested in, or allotted to, Reclamation projects. The lion's share had gone to Arizona, California, Idaho, Washington, and Wyoming. Furthermore, the state was embroiled in its first debate over transmountain diversions from the West Slope to the East Slope. The source of that controversy was what would become Reclamation's Colorado-Big Thompson (C-BT) Project.



President Theodore Roosevelt, pictured here (center) near Glenwood Springs, Colorado in 1900 or 1905, rode to the rescue of those who had long sought the creation of the federal reclamation program. Source: Denver Public Library, Western History Collection.

Photo by Harry C. Stewart

With the New Deal's emphasis on public works projects to create jobs during the depression, Colorado saw the opportunity to obtain federal funding for water projects from the newly created Public Works Administration (PWA). But it was ill prepared to advance its cause and deeply divided over the proposed C-BT Project. Colorado needed to identify and survey potential projects and resolve its "sectional differences" before funding would be forthcoming from the PWA or Reclamation.

To serve as a coordinating agency at the state level, the Colorado State Planning Commission (CSPC) was created by the Governor in 1934. It was statutorily authorized in 1935. Its task was to evaluate statewide needs for natural resources, highways, public buildings, public lands, recreation, sanitation, mining, and other public works that might qualify for federal funding.

Water developments were high on the CSPC's list of projects to promote. To this end, Governor Edwin C. Johnson convened a meeting of water users from throughout the state on June 3, 1935. At that meeting, a committee was selected to advise the CSPC on which new irrigation projects to propose to the PWA. This Advisory Committee on Water Resources consisted of seven people from the West Slope, seven from the East Slope, and three from the San Luis Valley.

The "Committee of Seventeen" met just ten days later and unanimously adopted, over the course of three days, 17 resolutions. These identified the high priority water projects and investigations for which the committee recommended that PWA funding be sought.

Despite the progress made by the "Committee of Seventeen" in 1935, a second statewide water conference

Governor Edwin C. Johnson worked to get the state organized to pursue funding from the Public Works Administration. It is perhaps no accident that he is seen here playing with a yoyo in the governor's office, pulled as he was between the competing interests of the East and West Slopes. Source: Denver Public Library, Western History Collection.

Photo by Harry M. Rhoads

called by the CSPC in February, 1936, indicated that much remained to be done:

> *"If we ... don't wake up to the situation which confronts us we will realize before long that development and growth in Colorado are at an end," said J. M. Dille, … Chairman of the … [Committee of Seventeen and a proponent of the C-BT Project]. "On every side the lower states have perfected and are perfecting irrigation rights which we cannot contest except by actual construction in this state. We have spent hundreds of thousands of dollars in defending lawsuits aimed at our water rights, but what we need is a positive program of construction rather than a negative defensive attitude" A similar view was expressed by W. S. Aupperle, Western slope leader and president of the [Western Slope] Protective Association [which opposed the C-BT Project] …. "It is our job to perfect a comprehensive and just plan of water development in Colorado ...."*

Against this backdrop, the bill creating the CWCB was drafted in late 1936. Despite lingering differences over the C-BT Project, there was broad agreement on both sides of the Continental Divide that the state needed to act aggressively to protect its interests in interstate rivers. The need for and the work of the Committee of Seventeen and the CSPC in 1935 and 1936 informed, in part, the thinking that led to the introduction of the CWCB legislation in the 1937 General Assembly.

The bill had the strong support of the new Governor, Teller Ammons. Ammons had been elected in the fall of 1936 and the creation of the CWCB was "a principal plank in the Governor's platform and of his initial message to the Legislature." A newspaper referred to the bill as the "Governor's water defense commission," terminology indicative both of the Governor's support for the bill and of the prevailing view that Colorado needed a new state agency to promote the development of its water resources and to defend its interests in interstate streams from attack by downstream states.

Governor-elect Ammons had called a meeting for December 22, 1936, to consider plans for the legislation in the upcoming session. While the nucleus of the gathering was reportedly the CSPC's Committee of Seventeen, others were expected to be there as well. The next day, the press reported that Ammons had:

> *… obtained the unanimous approval … of 43 officials, legislators and representatives of water interests thruout [sic] the state for his bill to establish a state water conservation commission [consisting of 11 members]. After the approval was given, Ammons voiced his willingness to ask the Legislature for any appropriation conferees deemed necessary to carry out the program. …*

Despite his strong support, what had become House Bill No. 6 did not pass until the last day of the legislative session. Ammons signed it into law on June 1, 1937. As the statutory chairman of the CWCB (a provision which was removed from the statute in 1967), the Governor convened the first Board meeting on July 13, 1937.

By statute, the CWCB was created "for the purpose of aiding in the protection and development of the waters of the state." As Clifford Stone, the CWCB's first attorney and director

Vena Pointer, Pueblo water attorney and original member of CWCB, was also director of the Caddoa Reservoir Association (later named John Martin Reservoir, on the Arkansasa River) and was a member of the Colorado State Planning Commission.
Courtesy of Pueblo City-County Library District

said, the new law provided "a state instrumentality whereby interstate river questions, defensive as well as promotional, may be handled and maximum utilization of water rising in the state attempted …. After all, the chief defense of our waters is their utilization …."

Defend and Develop aptly summarizes the CWCB's first 30 years. In fact, it was exclusively devoted to that cause. The water community and the general citizenry shared the views expressed by Stone, environmental concerns were non-existent or in their most nascent stages, and the political leadership of the day was united in seeking to maximize the utilization (read as the beneficial consumptive use) of the state's water resources.

Defend and Develop: A Brief History of the Colorado Water Conservation Board's First 75 Years will trace those formative years, the transition decades of the 1970s and 80s when the CWCB was given its first new statutory responsibilities (floodplain designations, appropriation of instream flows, and water project loans), and the transformation of the last 20 years—even as the CWCB has continuously been devoted to its original mission of defending the state's interests in interstate rivers and developing its scarce water resources. We invite you to share in the rich history of this state agency when this anniversary book is published.

Author J. William McDonald was Director of the Colorado Water Conservation Board from 1979-1990, and author Tom Cech was Executive Director of the Central Colorado Water Conservancy District from 1982-2011.

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Quality of water in the White River and Lake Tapps, Pierce County, Washington, May-December 2010; 2012; SIR; 2012-5022; Embrey, S. S.; Wagner, R. J.; Huffman, R. L.; Vanderpool-Kimura, A. M.; Foreman, J. R.

Peter Nelson

Lindsey A. Middleton, Editor, Colorado Water Institute

This fall, Colorado State University (CSU) will be introducing a handful of new faculty members, including Peter Nelson. Nelson will be joining the Department of Civil and Environmental Engineering as an Assistant Professor.

Originally from Washington State, Nelson attended Princeton University for his Bachelor of Science in Engineering (2003) and holds a Ph.D. in Earth and Planetary Science from the University of California Berkeley (2010). During his years as a student, Nelson served as a graduate student instructor and earned several awards for his teaching and research. Most recently, he was a National Science Foundation International Fellow in Environmental and Civil Engineering at the University of Genoa, Italy.

Nelson has been to CSU before—in 2002 as an undergraduate student, he worked under the advisement of Tim Gates in a summer research program. Now he says he looks forward to working at CSU. "The Civil Engineering Department is very well suited for the type of research I plan on doing," says Nelson.

Nelson's work will primarily focus on how fluid mechanics and sediment transport interact to shape the landscape. He explains his work in Genoa, Italy, where he studied their more theoretical methods of understanding and predicting river channel evolution. For example, he says, beginning with a straight channel and introducing a bend, one can mathematically predict the eventual change in curvature the stream channel undergoes.

Also while he was in Italy, Nelson says he was able to work in the field assessing damage from the winter 2011 floods. They worked to measure

high water marks and collect data to be used to characterize flood wave propagation and evaluate effects on geomorphology, and eventually to predict and avoid such disasters in the future.

For fall semester 2012, Nelson will be teaching one class—Hydrometry, a graduate level lab-based course with field components, where students will learn techniques for river and stream measurements and experimental data analysis. "Working as a teaching assistant in graduate school was very rewarding," he says, explaining that teaching is one of the main reasons he chose to stay in academia.

Nelson's past research has included studying the spatial organization of sediments in riverbeds, which was the topic of his dissertation. He used observations collected in physical experiments to guide the development of a model that simulates the evolution of riverbed topography and bed surface sorting. Overall, he found that complicated interactions between spatially-varying hydrodynamic forces, size-selective sediment transport rates, and streambed topography control the development of these bed surface patches. Such research could be applied to predicting bed characteristics and potentially to restoring habitat and ecosystems.

At CSU, Nelson is already working with Lee MacDonald of the Department of Forest, Rangeland, and Watershed Stewardship and others in the College of Natural Resources to study the effects of the High Park Fire. "Since it just happened this summer, we're trying to work quickly," he says of the effort to characterize changes in runoff, erosion, and deposition. He says they're currently trying to connect the effects of the fire to changes in landscape, such as changes in the structure of the channel network, the formation or filling in of gullies, and the location of sediment deposition.

Nelson says he looks forward to working more in river morphology as well, which he says is still moving toward more of a quantified field as opposed to the more descriptive field it was a few decades ago. He looks forward to interesting field work and the opportunities that CSU has to offer.

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Water Research Awards

Colorado State University (June 16, 2012 to July 15, 2012)

Aldridge, Cameron, DOI-NPS-National Park Service, Identification of Critical Winter Habitat Requirements for Gunnison Sage-Grouse, $7,000

Bestgen, Kevin R, DOI-Bureau of Reclamation, Monitoring Effects of Flaming Gorge Dam Releases on the Lodore and Whirlpool Canyon Fish Communities, $80,211

Binkley, Daniel E, USDA-USFS-Rocky Mtn. Rsrch Station – CO, Impacts of Mountain Pine Beetle & Spruce Beetle on Forest Carbon & Water Balance, $25,850

Carlson, Kenneth H, DOE-NREL-JISEA-Joint Institute for Strat, JISEA NG Study - Water-related Data and Analysis, $5,000

Cooper, David Jonathan, DOI-NPS-National Park Service, Wetland Ecological Integrity Monitoring in Glacier National Park, $62,013

Fiege, Mark T, City of Fort Collins, Fort Collins Water Utility History Update, $13,000

Jacobi, William R, DOI-USGS-Geological Survey, Impacts of Mountain Pine Beetle Infestations on Forested Ecosystems Along the Colorado Front Range, $47,000

Johnson, Brett Michael, Colorado Department of Public Health & Enviorment, Characterizing Bioaccumulation of Mercury in Sport Fish: Informing TMDL Development & Modeling Mitigation Strategies in Front Range Reservoirs, $286,353

Johnson, Brett Michael, DOI-Bureau of Reclamation, Chemically Fingerprinting Nonnative Fishes in Reservoirs (Project No. C-18/19), $6,000

Johnson, Jerry J, Syngenta, Influence of Agrisure Artesian water-optimization alleles on hybrid performance and response to plant density, $29,915

Laituri, Melinda J, Environmental Defense Fund, Colorado River Basin Governance Geospatial Layer for Agricultural Water Users, $34,505

Matsumoto, Clifford R, DOC-NOAA-Natl Oceanic & Atmospheric Admn, Hydrologic Research and Water Resources Applications Outreach Coordination, $99,196

Myrick, Christopher A, University of Washington, Cost-Effective, Alternative Protein Diets for Rainbow Trout that Support Optimal Growth, Health, and Product Quality, $2,600

Omur-Ozbek, Pinar, City of Loveland, Colorado, BIOWIN Modeling/Simulation for Biological Nutrient Removal Expansion Improvements to the Loveland WWTP, $19,293

Reich, Denis A, Colorado Water Conservation Board, Ag Transfers: Investigation of Water Savings, Water Quality Benefits and Profitability of Sub Surface Drip on Alfalfa in Grand Valley, $8,841

Reich, Denis A, Colorado Water Conservation Board, Agricultural Weather Data Delivery Improvements to Uncompahgre Valley Irrigators, $112,000

Reich, Denis A, Colorado Water Conservation Board, WSRA: Investigation of Water Savings, Water Quality Benefits and Profitability of Sub Surface Drip on Alfalfa in Grand Valley, $46,894

Sale, Thomas C, DOD - US Department of Defense, Basic Research Addressing Contaminants in Low Permeability Zones, $249,978

Sale, Thomas C, Town of Castle Rock, CO, Extended Studies Supporting Sustainable Use of the Denver Basin Aquifers, $25,000

Schneekloth, Joel, Monsanto, DroughtGard Irrigation Timing - Reproductive Growth Stages, $75,600

Schorr, Robert, DOI-USFWS-Fish & Wildlife Service, Preble's Meadow Jumping Mouse Populations at the USAF Academy, $53,791

Vieira, Nicole K M, Colorado Division of Wildlife, Developing Flow Recommendations for Turquoise Reservoir and Establishing Riparian Monitoring Points for the Upper Arkansas River and the Lake Fort, $42,023

Calendar

September

13 **Colorado River District Annual Water Seminar; Grand Junction, CO**
Featuring a presentation on the history of the Colorado River District from George Sibley
www.crwcd.org/page_115

19-20 **2012 CWCB Statewide Drought Conference; Denver, CO**
Building a Drought-Resilient Economy through Innovation
cwcb.state.co.us/Pages/CWCBHome.aspx

20 **Northern Colorado Water Conservancy District 75th Anniversary; Berthoud, CO**
Open house celebration for the 75th Anniversary
www.northernwater.org/AboutUs/75thAnniversary.aspx

October

9-11 **2012 Sustaining Colorado Watersheds Conference: Water2012; Avon, CO**
This annual conference expands cooperation and collaboration throughout Colorado in natural resource conservation, protection and enhancement by informing participants about new issues and innovative projects and through invaluable networking.
www.coloradowater.org/Conferences

19 **The Fourth Annual Water Conservation Summit; Denver, CO**
This Summit is to learn more about what is happening at the state and local level relating to water conservation and water efficiency in general.
coloradowaterwise.org

24-25 **23rd Annual South Platte Forum; Longmont, CO**
Water 2012: Celebrating along the way
www.southplatteforum.org/2012_fourm.html

31-2 **NWRA Annual Conference; Coronado, CA**
National Water Resource Association 81st Annual Conference
www.nwra.org

November

8-9 **Upper Colorado River Basin Water Conference; Grand Junction, CO**
The Water Center provides an opportunity for water experts focused on the Upper Colorado River Basin to share information about current projects and ideas for future projects.
www.coloradomesa.edu/watercenter/

14-15 **Business Models for the Future: American Water Summit 2012; Chicago, IL**
This financial water conference provides a rare opportunity to meet the water industry's key executives and leading thinkers, gathering here to define the future of America's water.
www.americanwatersummit.com/

28-29 **Colorado Aquifer Management: Groundwater and river flow connections; Denver, CO**
American Ground Water Trust is organizing a two-day conference for water managers, end users, and thier scientific and legal advisors on river accretions due to artificial recharge, stream depletions due to well pumping, and thier impact on water management policy.

December

12-14 **Colorado River Water Users Association Annual Conference; Las Vegas, NV**
www.crwua.org/

January

12-14 **Colorado Water Congress Annual Convention; Denver, CO**
www.cowatercongress.org/

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Bridal Veil Falls near Telluride, Colorado.

Photo by Theodore Moniodis