# Produced Waters Workshop

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## CWRRI

## Colorado Water Resources Institute
## Colorado State University



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# Forward

Ranil Wickramasinghe, Proceedings Editor

Reagan Waskom, Director, CWRRI

Domestic production of oil, natural gas, and coal bed methane are essential to the United States economy. The large volumes of variable-quality water that are co produced during the course of extracting these fossil fuels are commonly referred to as 'produced waters.' While there is a need for energy production, there is also a need to enhance water supplies in the West while avoiding the environmental degradation resulting from release of these impaired waters.

Ranil Wickramasinghe

Technology and economics exist today to treat impaired waters to meet beneficial-use standards. To make produced water a viable and reliable source of water, the energy industry, water industry, water-user interests, environmental interests, and Federal, State, and local governments must come together to overcome the constraints hindering development of this resource. The various parties must reach common definitions of terms, agree on the issues at stake, and collaborate to overcome the impediments to obtaining energy and producing water.

The Produced Waters Workshop was held in Fort Collins, Colorado, on April 4-5, 2006 to explore the potential opportunity for beneficial use of produced waters and the obstacles to making this a reality. The overriding goal of the workshop was to enhance our understanding of opportunities and challenges involved in converting produced waters to beneficial use. The workshop attempted to:

- Identify the key opportunities and capabilities of state-of-the-art treatment technologies for produced waters;
- Initiate discussions regarding public policies to facilitate the development of this valuable resource; and,
- Define a course of action to further evaluate and pursue these opportunities.

Reagan Waskom

Nearly 200 participants from government, energy companies, water users, water supply planners, government agency staff, researchers, industry representatives, and other interested parties met to discuss these topics. The conference planning committee used the metaphor of turning lemons into lemonade to put the tone of the conference into perspective. Readers of this proceeding will note that the speakers addressed the problem from a wide range of perspectives including policies that can be fostered to realize enhanced water supply in the West from energy development-related 'produced waters.' The workshop did not delve deeply into the scientific and technical details of impaired water treatment. A poster session was used to describe some of the ongoing technical efforts. Abstracts of these posters are found at the back of this proceedings.

A number of common issues were apparent through the talks and audience discussions. These include:

- The most promising opportunities to convert produced waters to beneficial use occur where produced water sources geographically align with markets for water.

- Water markets and the costs of disposal versus treatment will drive the value of produced waters and will be the fundamental factor in determining if produced waters are converted to beneficial use.
- The end users of the produced waters need to be willing to significantly offset the cost of treatment, storage, delivery, and management.
- States play the key role in water management and administration and must be in the lead on changing laws and policies to facilitate beneficial uses of produced waters.
- The federal role is in some respects simpler and subordinate to the states. However, federal agencies should provide leadership in helping to solve these problems as much of the production occurs on federal lands.
- A significant amount of produced waters is being generated in the Powder River Basin in Wyoming. Advocates for converting this water to a beneficial use could not explain why the cities of Sheridan and Gillette do not seem interested in exploring the option of using this water to help meet their municipal demands. It was stated that both cities need new supplies of water.
- The estimated quantity of produced waters varies widely based on who provides the estimate and how the available quantity is characterized. The state representatives for Wyoming and Colorado generally characterize the quantity of produced waters available within their state as a small drop in a big bucket compared to the total quantity of tributary waters available within their state. However, it was noted that the vast majority of anticipated produced waters in the Rocky Mountains are yet to be brought to the surface.
- The quality of the water is another factor in determining the quantity of produced waters that is feasible for converting to beneficial use. Extremely impaired produced waters will typically not be viable as a practical alternative water source.
- Studies that look at the potential alternative uses of produced waters need to be done well in advance of the gas and oil drilling permit process. The permit process takes 30 days and energy companies are generally not willing to wait for the long planning processes involved in evaluating alternative uses for the water.
- The water and energy businesses operate within different markets and, consequently, within very different incentives and timeframes. Oil and gas producers react quickly to swings in the energy market while water suppliers enjoy a more steady market without large swings in price (unless there is a drought). As a result, energy companies work quickly in accessing their non-renewable supplies while raw water suppliers (generally government organizations) work over long time scales in planning new water projects. Energy companies often work with high risk, while water utilities/districts try to reduce risk to the lowest possible levels. The business culture in the energy and water industries are very different, a point which came out over and over again in the workshop.
- The Department of Interior emphasis on rapid energy development processes is in conflict with the longer time frame to plan and implement water projects. One can't wait until the water is flowing out the gas wells to start thinking about alternatives. Planning should occur in advance of energy production on a watershed scale.
- Current water purification technology is generally adequate to treat produced waters where it is economically feasible. There is a portfolio of technologies available to apply depending on site-specific factors. Managing the concentrated waste was mentioned a couple of times as a problem that needs a better solution.
- The National Energy Technology Laboratory (NETL) devotes on the order of $10 million annually toward advanced water treatment technologies application for produced waters and other sources of impaired waters associated with energy development. This is split between internal and external R&D. NETL is a government owned/government operated facility.
- The most significant void in capabilities where research could help is in the area of social sciences to help remove institutional and social barriers.
- Science and data gaps also need to be addressed in understanding and managing the long-term adverse impacts to lands, ground waters, and ecosystems. A presentation by Montana State University, and pictures from other presentations, of the adverse impacts in the Powder River Basin helped drive this point home to the workshop participants.
- Sustainability is a concern. The water will only last as long the oil and gas development lasts. Produced water volumes at a given well head also fluctuate with time. However, the water produced over the next two decades may buy time for water conservation measures and infrastructure to be developed.
- Better interagency coordination was a common suggestion.
- More and earlier engagement in the NEPA process by stakeholders and others that can bring innovative solutions to the problem would help.

Several logical follow-up actions were proposed, which will be pursued by the workshop organizing committee. An important suggestion involves the USGS and Bureau of Reclamation developing a map indicating where quantities of potentially useable produced waters geographically align with factors that could indicate the feasibility of use such as Water 2025 hot spots and existing water infrastructure that could potentially be used to transport the water.

The economic costs and returns of current water purification technologies for various qualities of produced waters needs to be evaluated. Management of the concentrated waste brine from treatment methods also needs to be addressed in order to determine disposal options.

Pilot and demonstration projects are needed to provide proof of concept from treatment to beneficial use in key basins. One avenue for pursuing this action would be for the National Energy Technology Laboratory and the BOR to explore joint projects.

A formal interagency state and federal cross-cutting work group is needed to enhance communication among agencies and provide a point of contact for the industry. There were also suggestions of expanding the workgroup composition to include stakeholders, oil industry, and private sector.

Ranil Wickramasinghe
Proceedings Editor
Associate Professor
Department of Chemical and Biological Engineering
Colorado State University

Reagan M. Waskom
Director
Colorado Water Resources Research Institute
Colorado State University

*Produced Waters Workshop –*

# Welcome

Welcome Speaker: Dr. Robert Ward

Can produced waters be used to enhance Western water supply, or are they simply waters that are to be disposed of? Is there a missed opportunity at this juncture?

These are the questions we will look at during the next few days Answering questions such as these is not going to be straightforward. Produced waters occur at the complex interface of land management, energy management, water management and environmental management. One hundred years ago, our society, unfortunately, decided to divide up the landscape and divide up the resources in order to "professionally manage them." The result: we have a large number of agencies that manage certain aspects of our environment.

The university system followed right along and began to produce disciplines that could feed the professionalism that was required. We have majors in forestry that often work for the forest service. We have majors in fisheries and wildlife biology that work at the US Fish and Wildlife Service. We have range scientists that work for BLM. We have hydrologists that work with the USGS. We have water engineers that work for the Bureau of Reclamation. We also have a state-based participatory water rights system that manages the right to use water in the West that has juxtaposition against it: a federally based, regulatory-driven water quality management system.

You begin to see this is complex. We're working at the interface of all of these issues. Today's workshop is just that, a workshop. We're going to try to explore some of these problems and look at where we can find agreement and where we can't, through our dialogue of the next two days.

For example, we'll look at what agencies, with what authority, with what missions, address what aspects of this interface surrounding produced waters. What technological developments, at what cost, can we employ to convert the produced water 'lemon,' if you will, into enhanced water supply lemonade? You'll see that theme running through our program here. If we have a problem, what can we do to make that problem into something beneficial?

I also want to point out that this workshop is the result of the cooperation of a large number of people. I'd like to recognize very quickly some of the people who have been involved. We had an organizing committee that put the program together, and the complexity of the issue demanded a lot of effort from this committee. Therefore, I hope you'll appreciate their efforts. The members of that committee are:

- Pat O'Toole, president of Family Farm Alliance
- Dave Stewart, president of Stewart Environmental Consultants
- Chuck Hennig, with the Bureau of Reclamation
- Steve Kasower, with the Bureau of Reclamation
- Katie Benko, with the Bureau of Reclamation
- Earl Cassidy, with USGS
- Jim Otten, with the USGS
- David Burnett, with the Global Petroleum Research Institute at Texas A&M University
- Harold Bergman, director of the William D. Ruckelshaus Institute at the University of Wyoming
- Gregg Kerr, director of the Wyoming Water Resource Research Institute
- Gretchen Rupp, s director of the Montana Water Center
- Carl Wood, director of the New Mexico Water Resources Research Institute
- Ranil Wickramasinghe, professor in Chemical and Biological Engineering here at CSU, and
- Reagan Waskom, the Interim Director of the Colorado Water Resources Research Institute here at CSU

I'd also like to acknowledge that, while they were doing a lot of the politics, there's a number of other people who were doing a lot of the organizational detail: Marilee Rowe; Gloria Blumanhourst; Sandy Sorensen, and Matt Neibauer. These people worked hard to make sure that all the details and organizational arrangements operate as expected. I want to thank them all for their efforts.

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# Keynote Address

**Mark Limbaugh**
**Assistant Secretary of Water and Science**
***U.S. Department of Interior***

Good morning, all. I'll begin with a little bit about what I do in the Department of the Interior (DOI). The Assistant Secretary for Water and Science is responsible for two bureaus in the Department, the United States Geological Survey (USGS) and the Bureau of Reclamation (BOR). Both of those bureaus have about $1 billion each in budget authority.

The USGS provides science to the nation and to the federal and state agencies that contract with it. Those folks have some tremendous challenges ahead, one of which is dealing with hazards. We heard about tornadoes the other day, and we've had hurricanes this past year that have not been rivaled for many, many decades. We have a 100th anniversary of the 1906 earthquake in San Francisco. Looking at the state of science and earthquakes, it's incredible what they're doing with technology, and we're talking about bringing all the disciplines of the USGS – science, water, geography, geology, and biology – all together to help people deal with these natural hazards. Dealing and managing the technology in geo-spatial mapping and managing data over those kinds of new venues is an incredible challenge, one that needs to be coordinated through the government. USGS is at the forefront of that.

For Reclamation, water is the biggest issue in the West. Reclamtaion is smack-dab in the middle of that issue in all 17 Western states. It operates dams like Hoover and Grand Coulee; and the CBT – the Colorado Big Thompson Project here in Colorado – was developed by Reclamation.

About the goal of this conference: when Pat O'Toole came to us and wanted us to convene a conference where we could talk about produced waters, I said, "What's that?" We don't have much energy up in Idaho other than some hydropower and some geothermal, so I didn't really understand the proposed topic. Be assured, I learned a lot in the past few weeks getting ready for this conference!

Pat wanted to get people together to talk about it, because communication seems to have been a barrier. The water's there, the produced water's being brought up and, in many cases, put back down into the ground with no discussion about how we could beneficially use some of that water. Bringing people together – that's what government should be doing – facilitating solutions that deal with these issues, on the ground where it makes the most difference in people's livelihoods. Reclamation and USGS got together with Colorado State University and the Colorado Institutes and I'd like to thank Dr. Ward and also Reagan Waskom for helping us put this thing together.

Just a word about energy and water: one of the things we need to focus on is energy production. Energy is the economic driver of our national economy. Recognizing the price of oil and gas and the issues overseas, we need to do as good a job as we can in helping to develop this country's own resources and meeting the needs and challenges of today while looking forward to tomorrow.

The same goes for water. When I was growing up on the farm, I learned that oil and water don't mix. Yet, now it looks like maybe they do. The water side is not too different than the energy issue; especially in the West. We've got water issues in the West that have pitted neighbor against neighbor, farmers against fish, urban communities against rural communities – and that way of thinking has got to stop.

Secretary Norton addressed it early after entering office, when she had to deal with the Klamath crisis on the border of Oregon and California. This issue involved shutting off 200,000 acres of farmland to protect species that were listed under the Endangered Species Act, and then the National Academy of Sciences determined that the science used was flawed – a tough situation. She said, "How do we get ahead of these issues and problems before they become crises?" We developed what we call Water 2025, an initiative that looks forward, identifies tools with which we can deal with these issues, and has some federal funding behind it to provide on-the-ground success stories – on-the-ground help to keep these crises from developing.

Water 2025 is based on the premise that droughts come and go in the West. We know a drought will happen. Every year there's a drought someplace. Couple that with the emerging population growth, the challenges of the Endangered Species Act, the ineffectiveness of crisis-style management, the aging infrastructure involved in delivering water in the West – those are the things that are going to cause us problems in the future if we don't get ahead of them. With shrinking federal budgets, how do we deal with all these problems? We have to leverage federal dollars with our partners to solve problems at the ground level.

Water 2025 focuses us on trying to get ahead of some of these water issues before they disrupt the lives of more communities, in other parts of the West. It's critical when we start talking about produced waters that we remember we're trying to solve a problem: adding water supply that is usable, that can be treated and replace existing water supplies to help communities grow – or simply to deal with drought and shortages. The water community is interested in looking at new ideas, looking at new technologies, and trying to get ahead of these problems.

It's in the context of Water 2025 that I'm here today to challenge you to try to find ways to work together. As a former Water Master in the state of Idaho, I dealt with water laws in the state. I dealt with federal agencies that had to abide by those water laws. What you have is a lot of bureaucracies coming together, and you think, "Well, which one is in charge, and how do we work together?" You get one permit, and then another agency takes another bite of the apple with additional requirements.

We need to focus our efforts to coordinate those activities. That's something the federal government can do better. Certainly we would be committed to rolling up our sleeves to coordinate activities within the Interior Department, at least; maybe with the Department of Energy if we need to, and especially with the states and local governments that have control over the water resources in the West. That's where the decision should be made, and that's where we need to be working – at the local level.

Very few good, effective decisions come out of Washington D.C. They come from people just like you, working at the ground level to meet these challenges. One of the tools of Water 2025 is the use of the marketplace. The marketplace can bring to bear a balance. Yes, we have to have regulation to make sure we're not fouling the waters and impacting other people and wildlife. On the other hand, the marketplace is what brings these challenges to the forefront and brings solutions. If we can continue to work with the marketplace – as with the Colorado River basin looking at water banking – to provide water, meet needs, and make people whole in the process, that's the approach we need to be looking at to create our own destinies in the West. Thank you; I wish you all well.

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**Mark Limbaugh** was nominated last year by President Bush, confirmed by the U.S. Senate, and sworn-in as the new Assistant Secretary for Water and Science at the Department of the Interior. Prior to taking this post, Mark served as Deputy Commissioner for the Bureau of Reclamation in Washington, D.C., where he was responsible for external and intergovernmental affairs for the agency. Mark was born and raised in Idaho, graduating cum laude from the University of Idaho with a B.S. in Accounting. Mark has worked as a Certified Public Accountant with the firm of Deloitte Touche, as an Idaho family farmer, and as State Water Master for Idaho's Payette River Basin. He was also the Executive Director for the Payette River Water Users Association and the Lake Reservoir Co. Mark has served as President of the Family Farm Alliance, a grass-roots organization representing Western irrigated agriculture, and was an active member of the National Water Resource Association and the Idaho Water Users Association. Mark also served as a Director for the U.S. Committee on Irrigation and Drainage. He is married, and has four children and five grandchildren. Contact him at the Department of the Interior in Washington, D.C., phone (202) 208-3186.

# List of Figures/Photos/Tables

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# Opportunities and Constraints

Moderator: Reagan Waskom
Colorado State University
Fort Collins, Colorado

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# Opportunities and Constraints

## Lemonade Stands Are Good for the Local Economy: *Produced Waters Are an Additional Water Supply for the West!*

by Pat O'Toole, Rancher, Savery, Wyoming

We're at the crest of a wave on this issue. We have the opportunity to talk about it in the customary manner, with respect to water issues and the energy crisis in America. Yet, this is an opportunity to talk about it in the context of today: crisis management.

I came to Fort Collins in 1970 to go to school. At that time, Fort Collins was described to me as the prettiest town in the United States. I still think it's a beautiful place, but at that time it was a relatively small community surrounded by farms. East of here is Weld County, which has the reputation of being one of the most productive agricultural counties in the United States. The number-one production county in the United States used to be Los Angeles, which is now all paved over. Since 1970, Fort Collins, Denver, and Boulder have been paved over. Some of the most productive agricultural land in the United States is being paved over.

I want to talk about energy and the production of gas and oil and produced water in the context of what I think it is: a national security issue. Food also is a national security issue. If you don't like what's going on in the Middle East right now, wait until we have a third-world country extort us on food production – we are moving rapidly in that direction.

The Family Farm Alliance represents farmers in 13 western states. Over the last few years, we've been trying to analyze what it means to us, this 'reaching of limits.' Settling the West was America's post-Civil War release from fighting one another, to, instead, develop new lands and realize the opportunity and the wonderful things we know about the West. What the drought has shown us is that we've reached our limits in terms of water. We do not have the options we thought we would have. Water managers around the West believe the drought threw us 20 years into the future, forcing us to make decisions that we didn't think we were going to have to make for a while. Now we have to make those decisions.

### The need for water storage

Our family's ranch is on the Colorado/Wyoming border on the Western Slope. This year we have 117% snowpack, so we're going to have the luxury of having water this year, and that's wonderful. If you've been a farmer or rancher and lived through drought, you know it is a most-grinding experience: you wake up in the morning and go to bed at night thinking about drought. In Northern Wyoming where the snowpack numbers are 80%, they still are in drought. They're dealing with restrictions in the Powder River Basin and Gillette.

I talked to a fellow in New Mexico yesterday who said the snowpack in parts of his state is 0%. When Mr. Yates talked about the 653 million bbls of water being produced, I thought, "Wouldn't it be something if maybe some of that water would help the Elephant Butte Irrigation District, to help alleviate cutbacks this year?" The New Mexico delegation is looking at some way to hold their farmers together through this drought period so their livelihood doesn't disappear.

In this New West, drought-induced reality, we are transferring our ag lands. And that's what the Family Farm Alliance – of which I've been fortunate enough to preside over the past couple of years – has taken on as our main mission. How do we deal with drought? How do we articulate what it means to the general public? Last year, I presented to Congress a study that our Alliance had done on storage. As you all know, the popular perspective of the last few years is that storage is a bad thing, that we need to tear down dams. That perspective is not realistic.

The drought has shown us is that, not only is such a perspective not realistic, it's also not reasonable, and it's not the way that we're going to move forward. We are going to have to use storage. Thank God we have storage; otherwise, we wouldn't have the West that we have today. It's been our perspective at the Alliance that if there is no new water, ag water will be taken out of production. Analysis of a study currently underway in Colorado indicates that, over the next 20 years, 2.7 million people are expected to move into the Eastern Slope of Colorado – for those of you who don't live here, that's where you see that brown-should-be-green color. The Eastern Slope doesn't have the water for that.

That water is going to come from agriculture. The projections are 150,000 to 450,000 acres of agricultural production in Colorado will disappear in that period of time in order to fulfill the needs of the population growth. That brings us to the subject at hand: produced water.

### Wyoming as an example

In our valley at the Colorado/Wyoming border, we're anticipating a major coalbed methane play occurring. The initial work has already begun. Many of us ranchers and local residents use that land, and you have to analyze what it's going to mean to us. Over the last year, we've come to a lot of realizations, and number one is that Wyoming is an example for the rest of the West. I'll talk a lot about Wyoming and Colorado because that's the area I know the best. However, you can extrapolate the situation there to a lot of other places in the West.

The Powder River Basin has taught us lessons about unplanned water production, which is happening in thousands of wells that are not coordinated and that our governor Dave Freedenthal said we needed to have, back when I was in the legislature years ago. We were finding pots of money then from the last boom to keep going. (We were joking last night that perhaps an income tax was a possible way to fund our state government.) Now we've got the biggest surplus in the country because of this incredible production in the Powder River.

In terms of water, however, no one anticipated the volumes that have been involved. Ironically, the City of Gillette is looking at water restrictions at the same time millions and millions of gallons are being released. Montana is suing the state of Wyoming because of the release of water through the Powder River Basin.

When we started thinking what can we do to anticipate what obviously would be a major issue in other locations, we started doing basic multiplication to estimate how many mcf of gas is related to how many bbls of water. (Understand, this was an interesting exercise for us, because agriculture guys multiply everything by acre-feet, or similar formulations, while the oil field guys cite barrels. We use completely different languages.) What we know is, that if we do not understand how much water and how much gas are going to be there, we can't plan.

We started doing some multiplication and quickly came up with numbers that boggle the mind. I won't go through the numbers here that were verified by the State Engineer, but they were huge numbers – numbers that talk of major rivers that were going to be released through the gas process. We started asking questions of the companies and of the state of Wyoming: what is it going to mean to us? What are we going to do with this water?

Right now there's an Environmental Impact Statement (EIS) process going on in what's called the Atlantic Rim, a geologic feature that runs north-south, north of the Colorado border. In the spring, I trail livestock from north to south along the Atlantic Rim. In the fall, I trail from south to north. I know from horseback about every inch of it, one way or another. It's high-desert country, and its very beautiful country. It has incredible livestock capability. It has incredible wildlife capability. It has the best sage grouse habitat anywhere. In our part of the country, we value those attributes. What we're trying to figure out is: how does this massive influx of gas, which resulted in the Powder River experience, going to affect us? The EIS process going on right now indicates all that water is going to be reinjected. I'm telling you right now, that isn't going to happen. Not geologically, not economically; it's not going to happen. It's going to happen other ways.

### New needs, new technologies

The beauty of having a conference like this is having the opportunity to talk about what those other ways are. I recently spoke at a conference of people who were doing treatment of water. We've all heard that there are technologies to turn seawater into potable water. What's happened is that relative values of all kinds of commodities have come together. In Wyoming, we used to flare $CO_2$ and natural gas – burn it, just to get rid of it. You'd be driving along the highway and see flames going up in the air – natural gas that we were burning to dispose of. We don't do that anymore. We build multi-billion-dollar pipelines to take that gas to service our national security needs in terms of energy.

The same kinds of technology matrices are starting to happen in the water world. Here is a staggering statistic: 19% of California's total energy consumption is used to transport clean water. What an incredible reality, that the relative value of water has increased from about $5-$7 an acre-foot – the worth to a farmer producing hay or alfalfa – to about $1,100-$1,200 an acre-foot, the cost that California's coastal communities find affordable compared to the cost of transporting that water from somewhere else. That's how the relative value of water has changed in not just our lifetime, but in the last decade.

Consider that, along with Mr. Yates' information. Our own interpretation of how much water is in the Green River Basin is higher than what Mr. Yates indicated, but I think that's because we don't know yet. When you talk to individual companies, when you look at the oil and gas records on the internet, you start making your extrapolations. The numbers are phenomenal: the water that's going to be produced in the Green River Basin will have interstate implications, just like the water in the Powder River Basin and Tongue River has implications in the state of Montana.

If you understand water, you understand all the fascinating interplays, the relationships that Dr. Ward has spent his career analyzing, and one of them is that 'water belongs to the states.' There are going to be debates. There are court cases going on right now regarding who owns the water. Do companies own the water? Do they want to just get rid of it? The reality is, the states own the water. The beauty of Western America is its resounding affirmation of private property rights. That's what we believe. Perhaps, to an extent, that's why there are red states and blue states.

An important part of the debate in the next few years is embracing the reality that there's going to be water produced, and that water can be cleaned at reasonable cost where it fits within the context of the economies of the western states. When there's a drought, wasting water is considered by the general public to be a negative. We need the water, and the drought is going to force us to do the right thing; instead of flaring gas and burning it into the air, we're going to use that resource because we need it. Everybody who understands western politics, western interstate relationships, recognizes that water is a valuable commodity. When I spoke at the Ruckelshaus Institute in Wyoming, my comment was this: water and disposal should not be in the same sentence. Water is much too valuable a commodity. Certainly we won't use every acre-foot or every barrel of it in a beneficial way. 'Beneficial use' is a term that people in the water world use; we won't beneficially use every bit of it, but we're darn sure going to start using more than we're using today – because we have to.

The beauty of a conference like this is that it brings people with different mindsets – some speaking in barrels and some speaking in acre-feet – together in a room to allow them to start talking about how we deal with this. As Mr. Yates said, this is one of the all-time fun things because it can be a win-win. We must use the technology that's emerging in our country and worldwide. I always heard the Israelis were the greatest water managers in the world because water is a root source of political differentiation in the Middle East – and a cause of conflict. Water exacerbates the religious differences. All those names that you hear on the news are about water and who controls the water. If you're an Israeli, you get to take a shower; but if you're a Palestinian, you get a bucket every so often and that's all there is. Some of the largest projects in the world right now involve cleaning water in Israel and in the Middle East, primarily because the people there look to some sort of new matrix of using water to solve political situations.

### American resourcefulness

We have the opportunity in the West to have that new water. We're going to build the storage. We're also going to use produced water in a beneficial way, applying technology and our own brains to figure out how a situation that has become such a conflict in the Powder River can become a great opportunity in other places in the West. Senator Domenici of New Mexico heads a produced-water subcommittee, and the subject is going to be debated in the Senate and the House. I think that's a discussion we all ought to be looking at because there might be ways to use that vehicle to enhance the technology and the demonstration capability.

It's been a revelation how much technology is happening and how many companies in the US are taking the lead over the last year. I think Dow just built a major plant to do membrane technology, and GE has new water-cleaning technology – because it's needed technology. It's going to be exciting to apply it in the context of these crises.

Perhaps you're aware of the Two Forks Dam decision in Colorado in the early 1990's. The Environmental Protection Agency (EPA) had dominance over permitting of this project, intended to be Eastern Colorado's long-term water supply. Hundreds of millions were spent on the Environmental Impact Statement. Eventually it was vetoed, so that the dam did not get built. The decision took ag land out of production instead of constructing water storage. The long-term implications of that decision are very similar, in my mind, to what the federal and state agencies have in front of them right now: delivering water, from the Colorado River Basin, for example, requires a storage component.

And, moving water through the system will require that we mimic natural hydrology – there will be multiple federal and state oversights involved. Permitting will be required from the Fish &Wildlife Service, the Corps of Engineers, and the EPA. All of those players, especially since most of this is going to happen on federal land, are going to have some decision-making capability and need to facilitate good thinking.

One of the things that will hopefully come out of this conference is a message to these agencies. We have to have some interactions between the different agencies. In Wyoming, it took us 25 years to permit a water project that we saw for the first time last fall – imagine, 25 years! I can tell you that Mr. Yates and a major oil company can't wait 25 years for permits to get the job done.

At the same time we must exercise environmental responsibility. We have grazing permits on the Colorado/Wyoming line, and when I go to some well areas where there've been pipelines, I can see the little grooves where the seeder has passed over but there's no grass, no seed because the reclamation wasn't done, or – if it was done – it wasn't done with thought. My wife and I were driving out to one of the sheep camps, and we saw a guy doing some pipeline work and staking. When we asked what he was doing, he told us he was getting ready to seed the area in the fall. In the worst drought in 500 years, this guy was planning on putting seed in the fall with some expectation that there was going to be grass there right away.

American farmers are the greatest farmers in the history of the world. If we can't figure out a way with water and seed and using our heads to do reclamation, that's our fault. However, the beauty of BLM/Fish & Wildlife Service/EPA interaction is: if people put their heads together, we can find magic in this opportunity of produced water.

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**Patrick F. O'Toole** is a cattle and sheep rancher from the Little Snake River Valley near Savery, Wyoming. He served three terms in the Wyoming House of Representatives, including service on the Select Water Committee. Pat was a Presidentially-appointed member of the Western Water Policy Review Commission and wrote the minority report to protect Western and states' water rights. He is presently President of the Family Farm Alliance, a group that works for the interests of irrigators in 13 Western states. He speaks extensively on water, land use, and natural resource issues. Patrick has a B.A. in Philosophy from Colorado State University. He and his wife Sharon have three children and one granddaughter. Contact him at (phone) 307-383-2418.

## The Industry Grows a Lot of Lemons:

### *Produced Waters Are a Cost to Be Minimized!*

by Frank Yates, Yates Petroleum Corporation

Yates Petroleum Corporation has been looking for treatment alternatives for several years in an effort to find economically competitive alternatives to down hole disposal. Several factors must be taken into account in order to effectively pursue these potential options. Economics; available technologies; new technologies; legal, regulatory and environmental concerns; and internal company and industry politics have had an influence on progress made in this arena.

### Economics

Down hole disposal has been the long-time acceptable method of dealing with waste water associated with oil and natural gas production. Reinjection of produced water is expensive and can represent 50% of the direct operating costs of many oil and gas wells. In order to do comparative economics between down hole disposal and treatment, we must first get our arms around what our down hole disposal costs are. This may prove more difficult than one might think because of how the various costs of disposal are accounted for by different companies.

There are three components to reinjection costs that must be quantified: capital expenditures, direct operating costs, and gathering costs.

- Initial capital expenditures are those associated with drilling a disposal well, or more commonly, converting an existing dry hole to a disposal well – an approach that can be considerably less expensive.
  Costs vary considerably across the country. In Southeast New Mexico, a 7,000-foot Delaware dry hole can be converted to a disposal well for about $600,000. It may be possible to inject as much as 6,000 bbls of water per day (1 bbl = 42 gal) into a well like this. This scenario calculates to $100 / bbl / day of capacity, a ratio used for comparative economics. Another example in SE New Mexico is a Devonian disposal well in the Dagger Draw field. A typical dry hole is deepened from about 8,300' to about 11,000' and prepped for injection for about $1.4M. These wells can typically accommodate injection rates of 25,000 bbls / day initially. This equates to only $56 / bbl / day of capacity. Conversely, in Wyoming, the subsurface strata available for injection are very low in porosity and permeability. It can cost $4M to drill a disposal well that will only take 4,000 bbls / day. Now you're up to $1,000 bbl / day of capacity.
- Direct operating costs for a disposal well include costs for electricity for pump operations, filters, and chemical treatments for well bore protection. These costs can add up to between $0.03 and $0.07 / bbl for some areas, more in others.
- The third component of cost is gathering, or getting the produced water from the production facility to the disposal facility. Gathering is accomplished either by pipeline or by trucking, depending on the daily volumes of water to be transported. These costs can range from a few cents per barrel – when moving larger volumes through pipelines – to several dollars per barrel to truck smaller volumes of water that do not economically warrant laying gathering lines.

All of these components need to be considered when analyzing a company's produced water disposal costs. Once capital costs are amortized, and gathering considered, total disposal costs can vary widely – from about $0.12 / bbl in SE New Mexico to more than $5.00 / bbl in the Green River or Wind River Basins in Wyoming. Disposal in other parts of the country could cost even more.

Water volumes can vary widely from region to region and can have a huge impact on economics of disposal options. The New Mexico Oil Conservation Division (MNOCD) reports that produced water is estimated to be 653 million barrels in 2005. This includes water from East Indian Basin where one well can produce 3,000 bbls / day of water, but only costs about $0.17 / bbl for disposal. This low disposal cost is a result of the tremendous investment in disposal infrastructure made by operators to accommodate the larger volumes of water produced per well in this region.

Operators in this area are fortunate to have a highly porous and permeable Devonian formation to dispose into at approximately 11,000 ft depth level.

MYCO Industries, Inc. operates five wells east of Carlsbad that produce a total of only about 120bbl/day of water. With no disposal gathering infrastructure available, disposal costs for these wells run $2.70/bbl. This price is a combination of hourly trucking rates to haul produced water to a commercial site and a disposal fee of $0.50/barrel to actually dispose of the water. Also worth considering is the fact that the cost of converting a dry hole is not going to change just because there is less water available for disposal. Using the $600,000 example above to dispose of only 120bbl of water per day drives capital expenditures up to $5000/bbl/day of capacity.

Technological and Logistical Hurdles

Wyoming and New Mexico produce similar quantities of water, but volumes vary widely from region to region. For example, produced water volume from coal bed methane (CBM) production in the Powder River Basin (PRB) is about 1.5 million barrels per day from about 15,000 wells, or an average of 100 bbls/day/well. The gas production from the area is about 900 mmcfd. These figures indicate that, for each mcf of gas produced, there is also 1 2/3 bbl of water produced. Conversely, in the Green River Basin (GRB) in Southwest Wyoming, there is an average of only about one-tenth of a bbl of water produced per mcf of gas. The high volume of water produced in the PRB – more than 16 times the volume produced in the GRB – has raised many controversial questions about producing gas from the PRB.

Produced water quality will present technological hurdles. Produced water quality varies as widely as quantity from area to area and has a tremendous impact on treatment options available. Table 1 presents a brief summary of typical produced waters encountered in the oil field, illustrating the challenge related to treatment.

**Table 1. Water Quality of Various Produced Waters**

| All units mg/L | Pecos River | Disposal well | Well 1 | Well 2 | Well 3 | Well4 | Well 5 |
|---|---|---|---|---|---|---|---|
| **State** | NM | NM | NM | WY | WY | NM | NM |
| **Bicarbonates** | 127 | 705 | 488 | 3,318 | 1,680 | 39 | 464 |
| **Hardness ($CaCO_3$)** | n/a | n/a | 11,000 | n/a | n/a | 88,000 | 15,000 |
| **Arsenic** | 0.082 | 0.078 | n/a | n/a | 0.036 | n/a | n/a |
| **Calcium** | 620 | 582 | 3,600 | 404 | 70 | 30,000 | 5,200 |
| **Chlorides** | 2,020 | 3,100 | 48,000 | n/a | 9,360 | 182,000 | 80,000 |
| **Sodium** | 1,064 | 2,010 | 27,261 | 444 | 6,250 | 78,398 | 45,591 |
| **Sulfates** | 2,040 | 1,160 | 1,800 | 212 | 4 | 600 | 400 |
| **TDS** | 6,350 | 8,070 | 81,629 | 5,977 | 15,700 | 294,167 | 132,135 |

## Treatment Technologies

Five years ago, Yates Petroleum knew nothing – zero, zip, nada – about water treatment technologies. After considerable time and money, we've moved along that learning curve. There is still a lot to learn and a way to go before we are treating meaningful volumes of water, but we believe that we are at the forefront of New Mexico producers who see the value to the state, our industry, and our company in pursuing produced water treatment options.

Four different types of technical solutions have evolved in the oil and gas produced water treatment arena: membranes, evaporative technologies, ion exchange, and thermal compression.

- Thermal compression requires expensive pressure vessels, and the operator must still dispose of a concentrate stream. It does not appear to be as economic as other technologies.
- It appears the key to any membrane technology will be pretreatment. Conventional reverse osmosis (RO)

membranes are easily fouled by bacteria, hydrocarbons, heavy metals, and other suspended solids such as calcium sulfates. Ozone pretreatment, for example, can be effective against bacteria and marginally effective against hydrocarbons and heavy metals, but it is nearly ineffective in reducing suspended solids. New technologies such as hydrocarbon-resistant micro- or ultra-filtration membranes, operating at low pressures, may offer cost effective solutions to pretreatment for RO.

- Ion exchange treatment techniques have become the application of choice in the Powder River Basin where water qualities are fairly good with the exception of elevated sodium levels.
- Evaporative technologies have evolved from using simple misters dependent on ambient conditions to more sophisticated systems that recover much of the latent heat of vaporization. Altela Inc., an Albuquerque-based company, is developing such a product. The company's treatment tower promises to be effective at economically treating water up to 100,000 Total Dissolved Solids (TDS). There are no metal parts, so corrosion problems are practically eliminated. If waste heat is available from flash gas or a compressor, then direct operating costs are nearly zero. An operator can produce as much as four pounds of water from 1,000 BTUs of heat input, or four times as much as simple boiling.

Yates Petroleum currently is working with three proprietary variations of these technologies that suggest promise for specific applications. We have plans to apply a membrane technology and an ion exchange technology. We currently have an operating pilot using Altela's technology to treat a few barrels per day of about 40,000-TDS produced water. There are a host of treatment companies in the marketplace experimenting with, and building, pilots that incorporate variations of these technologies. The key will be the economics.

### Regulatory and Legal Considerations

The question has been raised several times, "Who owns treated produced water? Who has jurisdiction over treated produced water?"

In January of 2004, an engineering, legal, and logistical study was prepared for the Lea and Carlsbad Soil and Water Conservation Districts in New Mexico. The study's purpose was to evaluate the feasibility of treating and using produced water in that region. Luebben Johnson & Young LLP in Albuquerque did the legal research and observed that "wastewater from oil and gas production is generally treated as part of the real property's mineral estate, which is originally owned by the landowner, conveyed to the producer in the oil and gas lease, and transferable by the producer as personal property."

While there are no specific laws in New Mexico or other states directly dealing with the "appropriation" of wastewater found in conjunction with oil and natural gas (with the exception of shallow coal bed methane water), there are indications in statutory, administrative, and appellate law that produced water is not publicly owned water, but part of the privately owned mineral estate conveyed to the oil and gas operator.

New Mexico law is quite clear with regard to the Oil Conservation Division's jurisdiction over produced water. OCD has the responsibility to hold producers accountable for the proper disposition of their wastes, which include produced water. In addition, the New Mexico legislature recognized the operator's ownership when it passed a tax credit bill of $1,000 per acre foot to operators who could deliver clean produced water to the Interstate Stream Commission at the Pecos River in SE New Mexico.

### Conclusions

The economic treatment of produced water is right around the corner from being widely utilized throughout the oil field. It will be a win-win for the oil and natural gas industry and the environment, especially in the arid West. In order for this to happen, companies must overcome the current paradigm – the single-minded thinking – that any produced water requires a disposal well. Further, companies must do a better job of quantifying their disposal costs: they must not assume the cost of owning and operating a disposal well is zero merely because the company has sunk capital into a well.

The companies that overcome these hurdles will be the companies that will develop new oil and natural gas reserves in areas previously considered not economically feasible because the wells made too much water. This is actually a win-win-win scenario because it allows our country to produce more of our own domestic hydrocarbon resources.

**Frank Yates Jr.** was raised working in the oil field around Artesia, New Mexico, from the age of fifteen. He earned a Bachelor of Science degree in Mechanical Engineering from New Mexico State University in 1979. He is currently registered as a Professional Engineer in the states of New Mexico and Arizona. Frank has continued extracurricular studies in environmental science and policy, geosciences, and business administration.

Frank is currently President of MYCO Industries, Inc. and a Vice President of Yates Petroleum Corporation. He is past President of the Independent Petroleum Association of New Mexico and past member of the Executive Committee of the New Mexico Oil and Gas Association. In addition Frank has served on many other boards and committees including the boards of First National Bank of Artesia and the Community National Bank of Midland Texas.

Frank is an accomplished multi-engine, instrument-rated pilot with 20+ years of experience and over 2700 hours of total time. He enjoys many outdoor sports; primarily snow skiing, but also hiking, golfing, and bicycling. His wife, Mary, is also an accomplished business professional. He has three adult children: Tyson, Tao, and Tevis. Contact him at dorothyr@ypcnm.com; phone (505) 748-4407.

*Produced Waters Workshop –*

# Opportunities and Constraints

## How Do We Squeeze Lemons, and What Do We Do with the Peels?

## Can technology transform produced waters into new supplies, at a competitive cost and without environmental damage or added liability?

**by Lynn Takaichi, Kennedy/Jenks Consultants, San Francisco, CA**

The question I'm going to try to address is: can technology transform produced water into new supplies, at a competitive cost and without environmental damage or added liability? That's quite a task. Clearly there are individual projects that can meet these criteria. I think the real question at hand is: Can we make produced water reclamation live up to its full potential? I have served as the engineer for a suburban water supplier for 22 years. It's from that perspective that I'm going to talk about potential produced water development.

### CLWA Overview

First I'd like to provide some background on this particular water agency, the Castaic Lake Water Agency (CLWA). It has a service area of approximately 195 square miles. It's located predominately in northwest Los Angeles County. It includes a little bit of the uninhabited area of eastern Ventura County. The service population is currently approximately 240,000 people. This particular agency is a wholesaler of State Water Project water. That's the imported water that serves much of Southern California and the Central Valley. It also is a wholesaler of recycled water. In addition to its wholesale responsibility, it is the owner of one of four retail water agencies in the Santa Clarita Valley. It currently has approximately 25,000 retail connections.

Current water demands are approximately 90,000 acre-feet per year, of which 50,000 acre-feet is the imported water of the State Water Project supplies. It's growing rapidly. New housing units are 2,500 per year, which translates to about 2,200 acre-feet per year of new demand. It is also the home to one of the largest subdivisions in Los Angeles County called Newhall Ranch. Newhall Ranch has planned for 21,000 housing units, and it's just beginning.

Because of this growth rate, the agency has been very active in seeking out new water supplies. Over the last ten or 15 years, it has executed water transfers totaling some 65,000 acre-feet per year. Unfortunately, much of this water has come from agricultural areas in the Central Valley. It participates in two water banks because the state water project has a high degree of variability. It uses banking to stabilize those water supplies. It's also implementing a recycled water program, which is going to total some 17,000 acre-feet per year. Figure 1 shows the location of the water agency and the extensive number of water projects in California.

**Figure 1. Castaic Lake Water Agency and Other Water Projects Statewide In California**

California is fortunate in that these large water projects allow a lot of movement of water across its vast geographic areas. You can see that the Castaic Lake Water Agency is at the terminus of the state water project called the West Branch; in Los Angeles County.

Figure 2 shows the CLWA service area, predominantly in Los Angeles County. The blue area in the eastern part is the retail portion of the state-led water agency's service area and also the site of the Placerita Oil Field. The green areas are the oil-producing areas within the service area. Figure 3 better shows the Placerita Oil Field in the eastern part of the service area. Placerita Oil Field has been pumping since the 1940's. It produces a very heavy crude, so the reservoir is steam flooded. It produces approximately 50,000 barrels per day of produced water, which is reinjected, except for the small amount that's used to generate the steam.

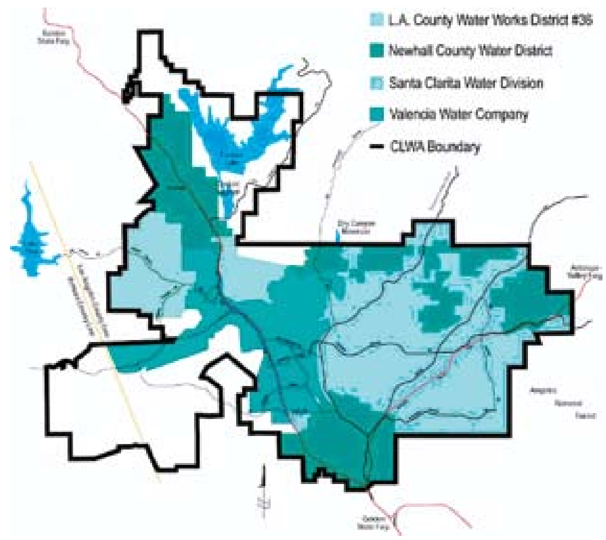


**Figure 2. Santa Clarita Valley and CLWA Service Area**


**Figure 3. Location of Oil Fields in CLWA Service Area**

## History of Produced Water Reuse at CLWA

Produced water reuse at the water agency began in the early 1990's when I received a phone call from someone at ARCO Western Energy who said, "You guys are working on a recycled water plan; we've got some water that you guys might be interested in." I asked this young engineer to send me over some water quality analysis, which I examined immediately. For those of us who are in the potable water business, this is something that we would almost run away from. But she was persistent, so we started exploring some concepts for how this might be used. We toured a number of produced water facilities in the Central Valley. Then she mobilized ARCO, which itself was an interesting process.

We identified a potential grant opportunity with the Department of Energy (DOE) that we applied for successfully.

During the time that we were undertaking this research project, oil prices declined dramatically. Interest in produced water reclamation fell off proportionally. Towards the mid-to-late 1990's ARCO sold Placerita Oil Field to a fairly large independent oil company. Because of the price, and the staff resources available, nothing much happened until the early-2000 period. Berry Petroleum, who was the purchaser of the oil field, called up and said, "Remember that reclamation program? We're now interested again." We reinitiated discussions and, fortunately for the oil companies, anyway, prices recovered. In 2003, we updated our recycled water master plan to incorporate produced water as a potential water source. In 2004 we initiated an Environmental Impact Report – the California equivalent of an Environmental Impact Statement.

For the last two years we've been working on this particular Environmental Impact Report, which is due to be completed in the fall of this year. The long time frame for the Environmental Impact Report has really nothing to do with produced water. This particular area happens to be ground-zero for growth issues, and nearly everything that happens there is litigated, usually with multiple lawsuits. Every document has to go through a litany of attorneys before it's issued; that's what takes most of the time.

### Project Funding

I'd like to talk a little bit about the research project because it's interesting in both its scope, results, and the interaction between the petroleum industry and the water industry. The project participants included:

- Department of Energy
- ARCO Western Energy
- Kennedy/Jenks Consultants
- Southern California Edison
- Electric Power Research Institute, Chemicals and Petroleum Office
- Castaic Lake Water Agency
- National Water Research Institute

Most of the funding came from the DOE. ARCO contributed quite a bit of in-kind services, as did Kennedy/Jenks. Interestingly; Southern California Edison Company participated. They are the power provider for this area. Along with the steam that's produced, they produce power and electricity – a cogeneration client. Edison, as the purchaser of that power, was interested in all things that were produced water. We also had the participation of EPRI – the Electrical Power Research Institute – through their chemicals and petroleum office. My client, the Castaic Lake Water Agency participated, and a research group called the National Water Research Institute. We had a pretty broad spectrum of people interested both in the petroleum and water industries in this particular project.

### Project Benefits

The objectives of the project were multiple:

- First, we wanted to **improve thermal recovery efficiencies.** We do that by producing higher quality steam
- **Lower the produced water handling costs.** The produced water that doesn't go to steam production is reinjected at very high pressures.
- **Reduce water circulation** in the reservoir, because when you reinject the water back in to the formation it eventually shows up as produced water again.
- Reduce the potential for reservoir damage from the reinjection process
- Recover more oil, because produced water reclamation has the side benefit of actually increasing the amount of oil that can be extracted from the reservoir.
- Finally, but not least, we wanted to see if we could develop a **new water resource.**

### Produced Water Flow Estimates

Placerita, in one sense, is not unique. It's really important that we get some perspective about some of the potential. During the process, we made estimates of the amount of produced water in some of the adjacent areas. In Los Angeles County, we identified approximately 64 million gallons per day of produced water. The coastal area, which is predominantly Ventura and Santa Barbara Counties, sees 27 million gallons per day; and Kern County, which is a very active oil producing area, 129 million gallons per day. Clearly not all of this is recoverable, some because of the quality, some because it's reinjected for subsidence and mitigation.

There is some substantial potential here in an area that is seeking water from every source it possibly can. Clients like mine, suburban water agencies, just happen to be in the marketplace; they are the ones willing to pay the highest prices.

### Parameters of Concern

We were concerned about certain primary water quality parameters during the treatment process. Here is an example of water that was, actually, reasonably good:

| | |
|---|---|
| TDS | ~5500 mg/L |
| Temperature | 150 to 175° F |
| Boron | ~17 mg/L |
| Silica | 255 mg/L |
| Hardness | ~1100 mg/L |
| Ammonia | ~9 mg/L |
| Total Organic Carbon | 120 mg/L |

It had a total dissolved solids (TDS) level of approximately 5,000-6,000 mg/L. Because the reservoir is steam flooded, the temperature of produced water is high, 150 to 175° F. Boron is very high, making the farmers cringe. Silica also was high, and that restricts the industrial reuse potential. There is moderate hardness – potable ground waters in the area typically have hardness of about 500, so this is not too bad. Ammonia is high, which affects corrosion rates, among other things. As a water purveyor, we were especially interested in the total organic carbon, or TOC. For potable water sources, we're typically looking at 2 to 10 mg/L, not 120 mg/L, so that really causes some concern.

### Irrigation Water

In the project, we actually looked at a variety of endpoints. This figure (Figure 4) happens to be the flow schematic for the irrigation train which is consistent with its use as recycled water.

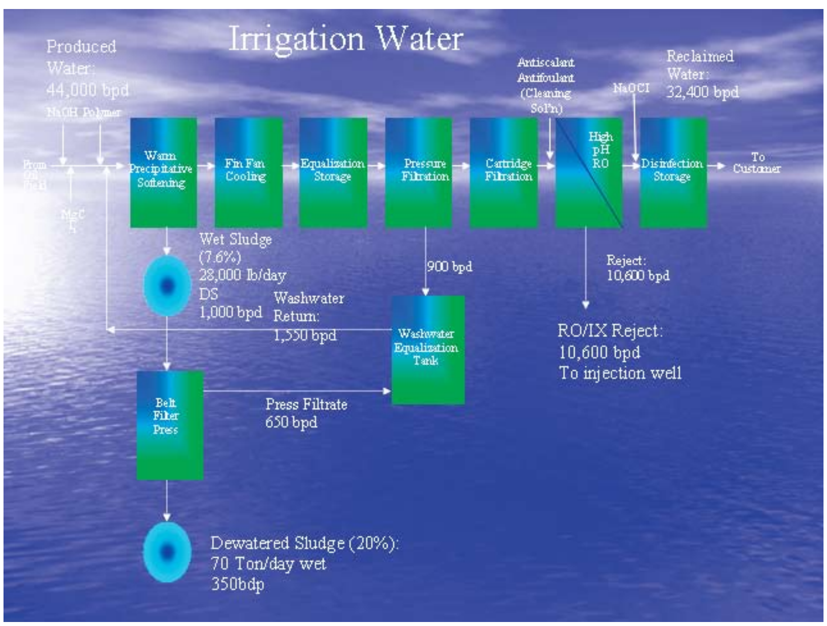


**Figure 4. Flow Schematic of Irrigation Water Train**

The production that was available was approximately 44,000 barrels per day. We go through a lime softening process that removes the hardness and silica. It goes through a cooling process to reduce the temperature, filtration, a high-pH reverse osmosis system, and, finally, disinfection. Through the process, we lose quite a bit of the water to residuals, so the output would be estimated to be 32,000 barrels per day.

### Water Quality Results

These are the actual water qualities determined in the pilot study; they differ from the historical numbers:

| Parameter | Initial (mg/L) | Final (mg/L) |
|---|---|---|
| TDS | ~6000 | 145 |
| Temperature | 150 to 175° F | 90 |
| Boron | ~16 | 1-2 |
| Ammonia | 9.3 | 2-11 |
| Silica | ~10 | not detectable |
| Hardness | 1-5 | not detectable |
| TOC | 120 | 2 |

Water quality with respect to TDS, at least for Southern California, is excellent. Our State Water Project water has a TDS usually of about 300. Ground waters can be anywhere from 500 to 1,000. Temperature has been reduced, boron removed. Ammonia is still high, but we think we can address that through some alternative cooling mechanisms. Silica was removed, hardness was removed, TOC is down to 2 mg/L. The technology is clearly there to meet our objectives.

### Total Project Costs

Based on this particular project, we estimate the plant would have a capital cost of about $10.6 million. The treated produced water would cost about $0.16 per barrel. These figures reflect use as recycled water and do not reflect the potable or industrial reuse options that we looked at.

### Technical Conclusions

- We clearly **can meet the water quality objectives.** The technology is there to do that –it's improved quite a bit since the time this research was done.
- The cost **for treatment is comparable** – slightly higher than the disposal cost that the oil field is currently experiencing.
- The cost of the water is **more expensive than imported water but only slightly higher than local recycled water supply.** Right now, when we go out to seek additional state water project entitlements – predominately from agricultural areas – we can acquire and confirm that water supply at over $500 an acre-foot. The recycled water that we're developing tends to be about $1,000 an acre-foot when we include the long term development of the program. The earlier phases are more expensive than that.
- Just as important, this supply could **avoid some of the environmental issues associated with our other supplies.** We get our state water from a very fragile area called the Sacramento San Joaquin Delta, fraught with environmental issues. We're not clear that we can get any more additional water supplies; whether from agriculture, but certainly from the project as a whole.

Recycled water has its own issues. The wastewater is discharged to a water body; an ephemeral stream called the Santa Clara River. It is a critical habitat for a number of endangered species, including the unarmored three-spined stickleback, pond turtle, red-legged frogs, least Bells vireo, and a number of others. There are requirements for us to leave water in the river, and that issue is currently under negotiation with some of the other resource agencies.

### So, why has it taken us so long?

We've gone more than a decade now trying to discuss with the oil field operator a produced water reclamation plan. We've shown through research that the technology is available. The costs seem to be in line; and yet, the project still languishes.

This analysis is based on my limited experience in California, with this project and others I've been involved with. I've broken down the causes for delay into three basic reasons:

| Cause | Water | Petroleum |
|---|---|---|
| Priority | • Relatively Small Supply | • Oil Price Fluctuations |
| | • Competing Issues | • Competing Issues |
| | • Local Focus | • National Focus |
| Expectations | • Not Familiar With Produced Water | • Not Familiar With Water Supplies |
| | • Long Time Frame | • Short Time Fame |
| | • Perception of Value | • Perception of Value |
| | • Risk Adverse | • Willing to Take Risk |
| Communication | • Little Outreach to Petroleum | • Little Outreach to Water |
| | • Prior Relationship Based on Contamination Issues | • Prior Relationship Based on Contamination Issues |
| | • Primary Federal Agencies BOR & ACOE | • Primary Federal Agency: DOE |
| | • Primary State Agency: Health | • Primary State Agency: Resources |

First is the priority that the parties seem to place on produced water reclamation. Secondly, there are differing expectations of the oil and water industries. Finally, there've been some prior illusions to some of the communication difficulties that the oil and water industry have.

With respect to **priority**, for an urban water supplier, this is a pretty small supply. We're dealing with 2000 acre-feet, where our smallest transaction to date has been 11,000 acre-feet. The transaction costs for any of these supplies are fairly high, so we tend to focus on some of the larger opportunities rather than the smaller ones.

Water utilities have a lot of competing issues. When you're a State Water Project contractor, you deal with all the issues in the Bay Delta. We're dealing with perchlorate contamination from a former munitions manufacturer. It's an unadjudicated ground water basin, so we have a lot of ground water issues. This small supply is not the highest priority for an urban water supplier. Our growth issues are just tremendous and take a tremendous amount of time, particularly during litigation.

Lastly, water agencies tend to be locally focused. They respond primarily to the rate payers, the taxpayers and the voters. They pay a lot of attention to some of the local political issues that exist. My observations of the petroleum industry, based on our experiences, suggest their interests clearly follow the price of oil. When the prices for oil from Placerita went from $20 to $4 a barrel, interest quickly fell off. When they're at $40+ as they are now, interest picked right back up. The result when you're looking at long time horizons: it's always a start and stop – a mode of operation that tends to delay the development of a long-term project. The petroleum industry also has a lot of competing interest. Discussions with the Western Oil and Gas Association suggest that produced water reclamation was not a high priority. They had interest, but it was not a high priority. There are energy, environmental, and tax policy issues that tend to dominate that agenda.

Then, we should mention **expectations** of the players involved. Water agencies clearly are not familiar with produced water; when you mention produced water in most water districts, they'll turn their back and run. They'll pretty much react the way I did in the early 1990's: with the comment, "Yuk!"

Water agencies tend to have to have a long time frame; particularly the ones established early. This characteristic has two aspects to it. First, when you're approving houses, you need supplies that are going to last a long time. Oil field life is a key issue. Back in the 1990's, a lot of wells were being shut down because of the price. That doesn't give a water agency a lot of confidence that the supply is going to be here 50 years from now – even though Placerita Oil Field has been operating for 60+ years. The second aspect of the time frame characteristic is the fact that most public water agencies are accustomed to having a long development period. It is not unusual for us now to have five, seven, even ten years for the most routine projects, because of the environmental process, the permitting process, the deliberations that our public bodies go through, and litigation.

The water agencies have a different perception of value than the oil companies. When I talk to water agencies about produced water, their attitude is, "Why should we do a favor for the oil companies? We'll take it off their hands as long as they're willing to give it to us."

Finally, water agencies, because they come primarily from a public health perspective, are very risk-adverse. They want some security that the supply is not going to cause problems for their consumers, whether it's ingested or used for irrigation. Many of the irrigation uses tend to be on schools, playgrounds, parks, and other public places where there's exposure. The petroleum industry situation is somewhat reversed. I've come to realize they do not understand how water supply is developed, transported, treated, and served to the public. Their time frames tend to be much more short-term. I had one oil company come in and say, "OK, we're ready to move. Can you have this thing up and running next year?" That's not the way public water agencies operate. They wanted to reinvest money because they had capital that year. They didn't want to wait three, five, seven years to do a project.

Their perception of value is somewhat different than that of the water industry. They see the water crisis that's occurring all across the West and think that water is going to be the next oil and that the value of water is the highest-price-quoted. That isn't the way we do water transfers. By the way, water transfers are an interesting process. There are prices that are quoted, for example, for seawater desalination, but that's not the whole story; there are many transactions that occur at half or less than the price of desalting seawater.

Finally, oil companies are accustomed to taking risks. They are in an exploration business, where risk is part of everyday life. They don't see why we have to provide redundancy and reliability in our treatment processes – a notable difference that affects some of the treatment facilities.

The last reason why I think some of these deals haven't come to fruition is simply **communication.** The water and oil industries have very little outreach to each other. Most of the interactions have dealt with contamination issues like MTBE or BTEX. They fight in court, they do everything but try to cooperate on common issues. And, that's why I think one of the benefits of this forum is bringing some of those issues together.

They also look at the governmental infrastructure differently. Water agencies are going to turn to the Bureau of Reclamation (BOR) or U.S. Geological Survey (USGS), or the Corps of Engineers for water development projects; whereas, the DOE is the primary resource development agency for the oil industry. All of us are regulated, unfortunately, by the Environmental Protection Agency (EPA) and the resource agencies. When we in the water industry look for either technical support or funding or even hand-holding, we tend to turn to the BOR or the Corps of Engineers. On the state level, urban water suppliers turn to the health agencies, the agencies we see all the time and deal with the most. In the petroleum industry, it tends to be the resource agencies – those that are responsible for permitting and developing the oil resources.

### What Should Be Done?

Clearly, research is going to help. Senator Domenici's Bill 1860, is, I think, a real good start. It funds some of the technology; it will research things that exist in this particular area. We need to expand our horizons about what areas are considered research. In my observation, problems are as much transactional as they are technology. We need to improve the social sciences and how we can better and more quickly come to agreements about the issues at hand. The social sciences have a lot to contribute here.

Secondly, I would suggest that we start to develop state-by-state implementation plans. Senate Bill 1860 calls for some research roadmaps, but that's different than having implementation road maps. To me, it's unconscionable that every project has to start from scratch and not learn the lessons from those that preceded it. These kinds of implementation road maps can be used to educate other projects in other, smaller, communities that don't necessarily have the resources to start the project from scratch.

Thirdly, I think we need a set of demonstration projects that are visible and accessible. I would suggest that the DOE and Department of Interior (DOI) get together to both develop, fund, and acquire different technologies to get a series of demonstration projects that we can bring both the water industry and the petroleum industry to view.

Lastly, we need some leadership. Right now, we in the West turn to the DOI, for the most part, for water leadership. Petroleum industry turns to the DOE. Water agencies aren't used to going to the DOE, and I'm sure the petroleum and oil industry is not accustomed to going to the BOR. We need a point of contact. The federal agencies ought to try to get together to, at least, provide the initial reissuing. The only other alternative is for the two industries to get together – a process that could be very slow to develop from where we are now.

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**Lynn Takaichi** is currently Chairman and Vice President of Kennedy/Jenks Consultants, a 500-person environmental engineering firm. He has served as a consultant to water industry clients for 34 years and has served as Agency Engineer for the Castaic Lake Water Agency for 22 years. He practices in the area of water resources, water treatment, and utility management. He is a registered civil engineer in California and received his B.S. and M.S. from the University of California, Berkeley. Contact him at (phone) 805-658-0607.

*Produced Waters Workshop –*

# How Much Water Are We Talking About?

Moderator: Katie Benko,
Bureau of Reclamation,
Denver, CO

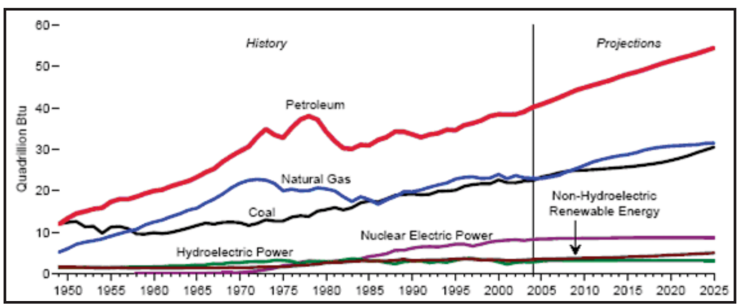
## Energy Outlook in the West Relative to Extractive Industries and Disposition of Produced Waters

by Gary Bryner, Natural Resources Law Center, University of Colorado at Boulder

Natural gas provides 24% of the energy used in the United States and represents 27% of total domestic production. The United States produces 85% of the gas it uses and imports the rest from Canada. Since virtually all of the gas used in the United States is supplied either domestically or from its northern neighbor, it contributes to national energy security. It is also a major source of revenue for all levels of government, particularly in the Rocky Mountain States where much of the natural gas is developed on federal and state lands and private property.

Demand for natural gas is currently growing at about 1 trillion cubic feet (tcf) per year. The U.S. Department of Energy (DOE), whose data are used to project the national energy policy, suggests that natural gas use will increase between 2000 and 2020 from 22.8 to 34.7 tcf; another estimate suggested consumption will climb to 31 tcf by 2015. Others project an even more rapid increase in consumption.[1] Natural gas is the cleanest burning fossil fuel, releasing less CO2 and other pollutants than coal or oil, making it an attractive fuel and, for some energy analysts, the key to the transition from fossil fuels to alternative energy sources. Figure 1 illustrates the history of U.S. reliance on natural gas and projects steady growth in the demand for natural gas.

**Figure 1. U.S. Energy Consumption History and Outlook, 1949-2025**




*Source: U.S. Department of Energy, Energy Information Agency, "Energy Perspectives." http://www.eia.doe.gov/emeu/aer/ep/ep_frame.html*

### Coalbed methane development in the western United States

Coalbed methane (CBM) is a source of natural gas that is of growing importance as a domestic source of energy at a time when demand is rapidly increasing and output from some conventional sources of natural gas has peaked. CBM accounts for seven percent of total natural gas production and eight percent of gas reserves in the United States:[2]

CBM from the intermountain states has played a significant role in meeting U.S. demand for natural gas, particularly the states of Colorado, New Mexico, Utah, and Wyoming, and that role is expected to grow in importance. Some 80% of the total CBM production in the United States has come from the Rocky Mountains. The San Juan Basin in southern Colorado/northern New Mexico has been the major regional source of CBM. The Powder River Basin in northwest Wyoming is the area of CBM production that is growing the most rapidly. CBM resources are also being developed in the Uinta Basin in eastern Utah, the Raton Basin in south-central Colorado, and the Piceance Basin in northwest Colorado, and major expansions of coalbed development are expected in Montana, the Green River basin in Wyoming, and perhaps other areas in the West. There is little agreement over the size of the natural gas resources remaining in the interior West, but given the exploding demand for natural gas, there will be pressure to find and develop as much of the region's gas as possible.[3]

While CBM development has produced important energy and other economic benefits to many communities in the West, it has nevertheless been quite controversial. Environmental impacts associated with CBM development include the construction of roads, drill pads, water disposal sites and related facilities; noise from pumps, compressors, and traffic that disturbs residents and wildlife; the creation of air pollution; the disruption of areas that were previously isolated from development or valued for undisturbed vistas and solitude; and the impact of water quality and supplies. Much of the conflict is rooted in widely discussed changes in the population of the West as recreational and preservationist interests increasingly clash with traditional extractive industries.[4]

### CBM and produced water

CBM is trapped within coal seams. Methane attaches to the surface areas of coal and is held in place by water pressure. Methane remains in a coalbed as long as the water table is higher than the coal. When the water is released, the gas flows through the fractures into a well bore or migrates to the surface. Drilling initially produces primarily water; gas production eventually increases and water production declines. When the CBM is extracted, the water must be separated, the gas is sent to pipes, and the water is dumped into ponds or injected back into the ground. In order to develop the resource, companies must first pump large quantities of water from the ground, about 12,000 gallons a day on average for each well, to release the methane. Here's the average water production from CBM wells, in gallons per well per day:

- Powder River 16,800
- Raton 11,172
- San Juan 1,050
- Uinta 9,030
- San Juan Basin: 1,200 wells have produced 36 billion gallons of water
- Wyoming portion of the Powder River Basin: in the next 15 years, approximately 51,000 wells will have produced over 1.4 trillion gallons of water

The development transforms the landscape with pipes, roads, compressor stations and power lines, and discharged water that is often not useable for irrigation and, in some places, is reinjected into underground regions (Figure 2).

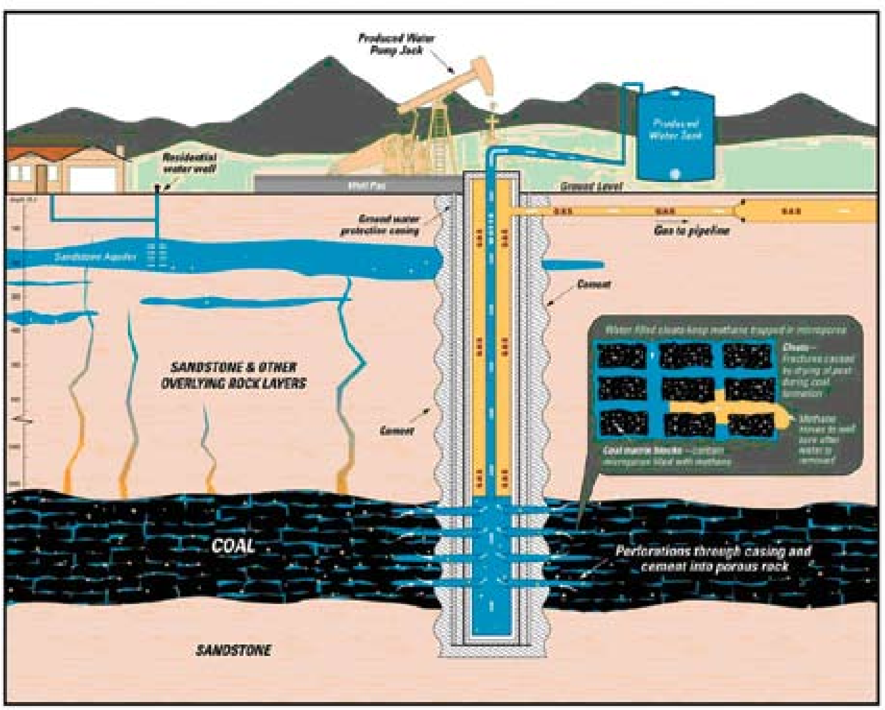



**Figure 2. Coalbed Methane Development Avoids Contamination of Water Supplies**

## Managing produced water

The development of CBM has sometimes pitted energy developers against other users of the affected water. Issues surrounding CBM development and water include: (1) underground water quantity and the possibility that drilling for CBM contaminates aquifers with water of lower quality; (2) water rights and underground water supplies that may be diminished as dewatering occurs; (3) groundwater that may be contaminated by discharged water that is polluted; and (4) aquatic areas, stream beds, and local ecosystems that are unaccustomed to receiving such large volumes of water.

The options for dealing with the large quantities of water released include the following (costs generally increase as one moves down the list):[5]

- Traditional surface discharge: water is allowed to travel downstream and be absorbed or evaporate as it moves.
- Irrigation: water released to agricultural areas.
- Treatment: water is treated to improve quality.
- Containment with reservoirs: water is piped to a surface impoundment where it is absorbed or evaporates, or may be used to water cattle.
- Atomization: water evaporates more quickly than normal through the use of misters placed in surface impoundments.
- Shallow injection or aquifer recharge: water is pumped into freshwater aquifers.
- Deep injection: salty water is typically reinjected deep into the ground.[6]

Because of differences in water quality, CBM-produced water governance differs across basins:[7]

| | | |
|---|---|---|
| • San Juan: | 99.9% of produced water is injected | |
| • Uinta: | 97% injected, 3% evaporation | |
| • Powder River: | 99.9% surface discharge | |
| • Black Warrior: | 100% surface discharge | |
| • Raton Basin: | Colorado: | 70% surface, 28% injected |
| | New Mexico: | 100% injected |

The quality of produced water varies considerably across and even within basins, depending on the depth of the methane, geology, and environment of the deposition. In general, the deeper the coalbed, the less the volume of water in the fractures, but the more saline it becomes. In the San Juan Basin, for example, water quality can vary from 20,000 ppm total dissolved solids (TDS) in the southern portion of the basin to 500 ppm (potable) near the outcrops. Water quality is also high in the Huerfano County region of the Raton Basin's CBM fields. Produced water in the Powder River Wyoming basin is largely useable for a variety of purposes, but the quality of produced water varies across the basin.

## Landowner concerns

In general, water quality is highest in the Southeast, and diminishes to the West and North, where total dissolved solids increase. A major challenge in a semiarid landscape is managing the tremendous increase in produced water. Even if water quality is high, salts may concentrate during evaporation or may overwhelm the semi-arid environment, inundating vegetation and causing erosion. Stock reservoirs have been created, and while some ranchers have wanted the water source, others do not since the reservoirs take land out of production.[8] Ranchers are faced with soils damaged by the salts and metals remaining after evaporation; less grass is available for cattle; clay soils become hard pan; and dead cottonwood trees, dead grass, and weeds result from CBM development.[9]

In some areas where water quality is good, such as some parts of the Raton Basin, CBM companies and landowners have negotiated agreements to provide produced water for stock. Company officials report that there is more demand for water than they can supply. Produced water in the Powder River and Raton Basins has contributed to municipal water supplies. Such examples are evidence that CBM development can occur in partnership with landowners in ways that profit both. But conflicts frequently arise between land owners, especially when they do not own the gas leases under their property. Transporting water from where it is produced to where it can be used may be expensive in many cases, and that is a significant limit to efforts to ensure beneficial use of the produced water.

## Water quality regulation[10]

Under the Clean Water Act, as administered by states, CBM development is governed by water quality standards to protect designated uses of water such as drinking water, agriculture, or fisheries.[11] Standards include pollution limits to protect state water quality standards, anti-degradation requirements beyond water quality standards, and total maximum daily loads – maximum daily pollutant discharges that are assigned to point and non-point sources to ensure total pollution levels are not exceeded. The standards consist of numeric pollution limits as well as narrative or descriptive standards that are typically applied to each category of use. If a body of water has more than one designated use, the more stringent standard applies.[12]

Section 401 of the Clean Water Act requires CBM companies to apply for and receive a National Pollution Discharge Elimination System (NPDES) permit if they are discharging produced water into surface waters of the state. Clean water regulations provide that "there shall be no discharge of waste water pollutants into navigable waters from any source associated with production, field exploration, drilling, well completion, or well treatment (i.e. produced water, drilling muds, drill cuttings, and produced sand)" without an NPDES permit.[13]

If technology- based limitations are insufficient to ensure water quality standards are met, states must develop "total maximum daily loads" (TMDLs) for each pollutant for which standards are being violated.[14] The TMDL determines the maximum amount of the pollutant that the water body can receive daily; states apportion the total load point and non-point sources. Once the TMDL is fully allocated, no further discharges of pollutants into the water body are allowed.

The Safe Drinking Water Act (SDWA) governs reinjection of water produced from CBM extraction.[15] No underground injection is allowed without a permit. Regulations define five classes of injection wells according to the type of fluid they inject and where the fluid is injected. With CBM, most reinjection is done into Class II wells that address fluids that are either brought to the surface in connection with oil and gas development or are used to enhance the recovery of oil and gas.[16]

## State water law governing CBM produced water

Given the importance of clean water in the arid West, no environmental issue has been more contentious or critical to the future of CBM development than that of the impacts on local water. One of the most important challenges surrounding CBM development is finding beneficial uses for the produced water. As indicated above, transportation costs and issues are a major issue, since produced water is often located far from good sites for beneficial use.

Given the aridity of the West, the region's water is at least as valuable as its natural gas. Water law is tremendously important in shaping water use, but the legal framework surrounding the use of CBM-produced water is not well developed. All states require that appropriated water be put to beneficial use, but the assumption underlying each state's regulation of water produced from CBM development is that it is waste and that state oil and gas commissions have jurisdiction over the produced water. While this may have made sense when the produced water was largely the brine resulting from conventional deep oil and gas drilling, it does not make sense for CBM water. Many of these statutes were passed in Utah, New Mexico, Colorado, Montana and Wyoming in the 1950s and early 1960s, when the produced water was highly polluted. CBM production did not start until the late 1980's, with the real boom occurring in the mid-1990s.

The Rocky Mountain states have all adopted the prior-appropriation approach to water law. Under prior appropriation, ownership of land does not result in ownership of water, but water rights are created when water is diverted and used or appropriated for a beneficial purpose. The main provisions of prior appropriation include the following:

- First, the water right is the amount of water put to a beneficial use; there are no limits to the quantity used such as reasonable use, but state statutes typically require right-holders to show that all the water will be beneficially used and not wasted.
- Second, the date of the original appropriation established the water right priority date; the holder of the oldest or most senior priority right is entitled to delivery of the full right; junior right-holders are entitled to whatever water is available after senior rights-holders have withdrawn their water.
- Third, rights are acquired by use and may be lost by non-use: abandonment occurs when the right-holder intends to relinquish the water right.

- Fourth, water rights are "perfected" when an applicant receives a certificate or decree from the state water engineer or court recognizing that the water is being put to beneficial use and belongs to the applicant.
- Fifth, beneficial use generally includes domestic, municipal, industrial, commercial, agricultural, hydropower production, stock watering, and mining; recreation, fish and wildlife maintenance, and preservation of environmental and aesthetic values have also been defined as beneficial use.
- Sixth, water rights are passed to new land owners when land is conveyed unless the grantor expressly reserves those rights, and water rights may be transferred separately from the land if allowed by state law.
- Finally, the prior appropriation doctrine is primarily applicable to surface waters. Water that occurs as a result of human labor is not subject to appropriation but belongs to those responsible for producing it. [17]

### Addressing CBM challenges

Given the lack of water in many areas of the Rocky Mountain West, it is important to explore whether the existing water management uses are optimal. Companies and landowners may find fruitful opportunities to work together to capture produced water, and, if quality permits, sell it to users. Existing water law can help ensure produced water is put to beneficial use, but the current legal framework does not create incentives for companies to take such actions. State statutes governing CBM development and produced water differ in terms of the standards they provide to oil and gas commissions in governing extraction and related activities:

In Wyoming:
- CBM produced water is defined as a beneficial use
  - Applications for withdrawal granted as a matter of purpose; can deny if not in the public interest
  - 2006: Powder River Basin Council (PRBC) petition to require produced water be put to measurable beneficial use
  - State district court, 2006: water not discharged into natural watercourse, so surface owner has more control over it
- CBM permits take 3 to 6 months to process
- 2005: Split Estates Act to give surface owners more rights
  - BLM studying the issue; does it apply to federal minerals?

In Montana:
- Board of Environmental Review decided not to require industry to reinject produced water but to require no degradation of stream water quality
- Environmental council is studying split estate issue
- CBM permits take up to 2 years to process
  - Montana moratorium on CBM development

In Colorado:
- CBM produced water is considered exploration and production waste
  - No beneficial use is required, no withdrawal permit is required
  - Permit is required for disposal
  - Surface owners can use water and get beneficial use permit Colorado
- Considering split estates bill

In Colorado, CBM produced water is considered exploration and production waste, and producers are not required to show a beneficial use of the water or to obtain a withdrawal permit. Producing water through CBM development is, itself, defined as a beneficial use in Wyoming, and applications for withdrawal are granted as a matter of purpose; but this has not required water owners to take specific steps to ensure the water is used productively.

There are considerable advantages that can come as states clarify the ownership of produced water and owners take responsibility for ensuring that it is put to beneficial use. In 2006, the Powder River Basin Council petitioned the state to require produced water be put to measurable beneficial use. A 2006 state district court decision also strengthened the control of surface owners over produced water in ruling that if produced waters are not discharged into natural watercourses, surface owners have more control over what happens to the water. Wyoming also enacted a split estates act in 2005 that gave surface owners more voice in the development of resources under their property, and other states are considering similar legislation. The Montana Board of Environmental Review has established a no degradation of stream water quality resulting from discharged water. These are important first steps in developing state laws that clarify the ownership of produced waters and ensuring that these waters are used carefully and productively.

Finally, stakeholders in CBM basins can come together to develop guidelines for the development within their regions. Watershed groups and other community-based initiatives have been developed in the West to bring parties together to overcome political fragmentation, reduce litigation, and encourage innovative and cooperative solutions to natural resource problems.

This model could be applied to addressing CBM problems. Stakeholders can meet together to fashion plans to produce accurate baselines for water quality and quantity, review compliance with testing and monitoring requirements, develop water management plans to ensure beneficial use, negotiate best management practices that minimize adverse impacts, ensure surface owners are involved in decisions affecting their lands, integrate CBM with other water management and ecosystem planning, and aggregate experience and lessons and communicate those with those in other CBM basins.

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[1] NATIONAL ENERGY POLICY DEVELOPMENT GROUP, NATIONAL ENERGY POLICY: RELIABLE, AFFORDABLE, AND ENVIRONMENTALLY SOUND ENERGY FOR AMERICA'S FUTURE 1:7 (May 2001).

[2] Matthew R. Silverman, *Coalbed Methane in the Rocky Mountain Region: Yesterday, Today, and Tomorrow,* in COALBED METHANE DEVELOPMENT IN THE INTERMOUNTAIN WEST 125, AT 125 (Natural Resources Law Center, University of Colorado School of Law CD-ROM, July 2002, hereinafter NRLC CD-ROM).

[3] Walter B. Ayers, Jr., *Coalbed gas systems, resources, and production, and a review of contrasting cases from the San Juan and Powder River Basins,* 86 AAPG BULLETIN 1855 (Nov. 2002).

[4] See Gary C. Bryner, *Coalbed Methane Development: The Costs and Benefits of an Emerging Energy Resource,* 43 NAT. RES. J. 519 (Spring 2003).

[5] C.A. Rice and T.T. Bartos, *Nature and Characteristics of Water Co-Produced with Coalbed Methane with emphasis on the Powder River Basin* (presentation at the U.S. Geological Survey Coalbed Methane Field Conference, May 9-10, 2001).

[6] Peggy Williams, *Western Coalbed Methane,* OIL & GAS INVESTOR 34 (Nov. 2001).

[7] Steve de Albuquerque, *An Overview of CBM Exploration and Production,* NRLC CD-ROM.

[8] Hal Clifford, *Drilling method pumps up floods of conflict,* THE CHRISTIAN SCIENCE MONITOR (January 3, 2002) hppt://cs-monitor.com/2002/0103/p3s1-usgn.html, last visited January 4, 2002.

[9] Jill Morrison, *CBM Development, Ranching, and Agriculture,* NRLC CD-ROM.

[10] The discussion in this section is based on Kate Zimmerman, Federal, State, and Local Regulatory Framework for Permitting of CBM Development, NRLC CD-ROM.

[11] 33 U.S.C. ‘ 1313(c)(2)(A); 40 C.F.R. ‘ 131.11(a)(1).

[12] 40 C.F.R. ‘ 131.11(a)(1).

[13] 40 C.F.R. ‘ 435.32.

[14] 33 U.S.C. ‘ 1313(d)(1)(C).

[15] 42 U.S.C. ‘ 300hh-8.

[16] 42 U.S.C. ‘ 300(h)(b)(2).

[17] This summary is based on Jan G. Laitos, NATURAL RESOURCES LAW 384-99 (2002).

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**Gary Bryner** is a professor in the Political Science department at Brigham Young University, where he teaches courses in public policy, American politics, constitutional law, international development, and environmental and natural resources policy. He is also a research associate at the Natural Resources Law Center, University of Colorado School of Law, and has been a research fellow at the Natural Resources Defense Council, the National Academy of Public Administration, and the Brookings Institution. He has B.S. and M.A. degrees in Economics from the University of Utah, a Ph.D. in Government from Cornell University, and a J.D. from Brigham Young University. He can be contacted at (phone) 303-492-1287.

*Produced Waters Workshop –*

# How Much Water Are We Talking About?

## Estimated Volume and Quality of Produced Water Associated with Projected Energy Resources in the Western U.S.

by Jim Otton, U.S. Geological Survey, Denver, CO

Current information about the volume and quality of produced waters that are and may be used to supplement available water supplies in the arid western U.S. is reviewed in this report, covering these general topics:

1) The current energy and water production from conventional oil and gas resources and from unconventional resources, especially coalbed methane (CBM);
2) The potential for future water production from western U.S. energy production, especially CBM.

As these topics are discussed, some helpful conversions include (1) one barrel of water is 42 U.S. gallons, and (2) one acre-foot of water is 7,760 barrels.

Conventional oil and gas is defined as oil and gas held in structural and stratigraphic traps where a water-petroleum interface has formed. Most historical production in the U.S. is from conventional oil and gas fields.

Unconventional oil and gas is that held in broadly disseminated or continuous form in the host formations, usually with richer sweet spots or fairways. More recently, unconventional fields have become very important. CBM is an example of unconventional or continuous gas. Another example is the tight gas sandstones such as those that are being extensively drilled in western Colorado today.

Conventional oil and gas production and CBM production differ in water production history. Early in the production history of a conventional gas or oil well there is substantial oil or gas production, and minimal water production due to the natural segregation of those components in a conventional oil or gas reservoir (Figure 1).

As time progresses, gas and oil production decreases and the amount of water that is introduced into the well bore during production greatly increases. The "water cut" in a conventional well can be as much as or more than 100 barrels of water per barrel of oil. In contrast, in an idealized CBM well the water pressure in the coal bed first must be reduced to allow the gas to desorb from the coal and flow to the well bore. This requires pumping out a large amount of water before much gas is produced. Over time, gas production is stable and the water production gradually declines. Eventually both gas and water production decline. The initial development of CBM thus requires significant effort and expense to dewater the coal before gas is produced.

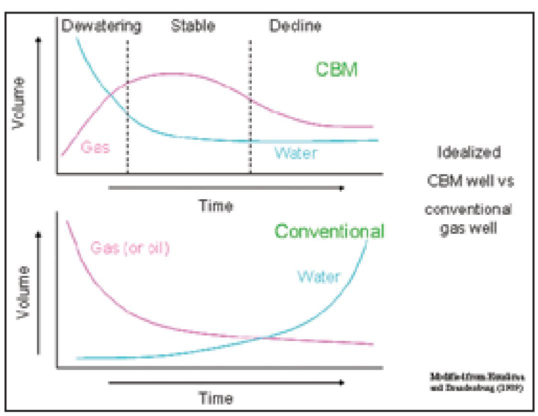


**Figure 1. Water Produced During Gas Well Life Cycle. Modified from Kuuskraa and Brandenburg, 1989.**

### Water production from conventional energy operations

Figure 2 shows the distribution of oil and gas wells in the U.S. They are numerous in some arid portions of the western and southwestern U.S. Thus there are many areas in that part of the country where co-produced water could be used for irrigation and possibly other purposes.

The colored areas represent 0.25-mile-square cells, with green indicating oil production, red gas production, and yellowish-orange mixed production. Gray squares are dry holes. The 98th meridian drawn on the map has regulatory significance. 40CFR Part 435 states that produced waters may be released west of the 98th parallel for the beneficial use of agriculture and wildlife, whereas regulations stipulate reinjection east of this line except for stripper wells. In all cases, State effluent guidelines must be met and permits received for releases. Wyoming is the only State with a significant number of permits for release of produced waters.

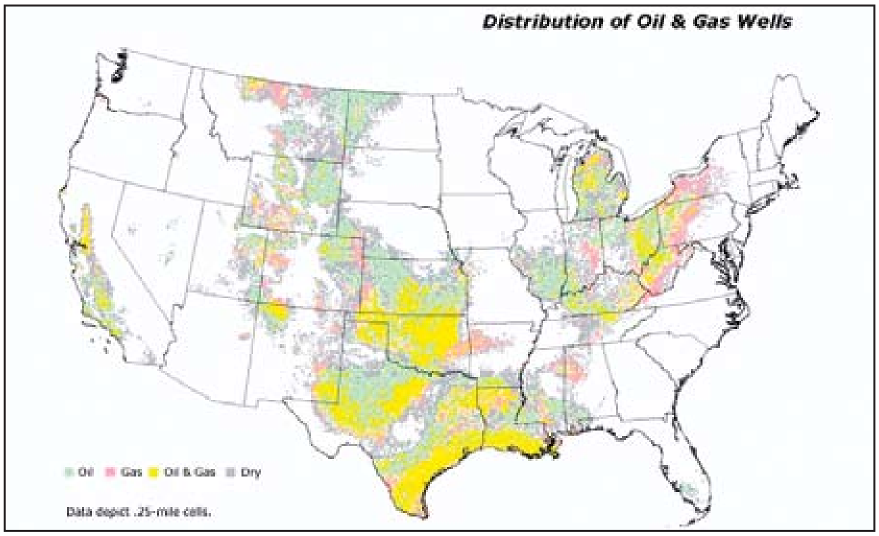


**Figure 2. Distribution of Oil and Gas Wells in the U.S.**
**Derived from a USGS map by Mast et al, 1998**

Data on the volume of water produced from conventional oil and gas wells are difficult to obtain because reporting requirements vary from state to state, and there are no Federal reporting requirements. However, individual States are improving their reporting requirements, so it is possible to obtain data on produced water volumes nationally although national estimates vary widely. For example, Mr. Yates, a participant in this workshop, commented that there are 30 billion barrels of produced water generated annually in the U.S., whereas our estimates (U.S. Geological Survey) indicate a smaller volume in the range of 20 to 21 billion barrels. The latter numbers are based on 2005 production figures of 1.9 billion barrels of crude oil and about 23.4 trillion cubic feet of gas, and the estimated ratios of water to oil and water to gas; sources of information include the Department of Energy (DOE), the National Energy Technology Laboratory (NETL), and the Energy Information Administration (EIA).

Presently, conventional oil production generates more produced water than gas production. Ratios are typically 8 to 10 barrels of water per barrel of oil. Table 1 provides produced water volume data for 1985, 1995, and 2002, in thousands of barrels, for 31 oil and gas producing states.

| State | 1985[a] | 1995[b] | 2002[c] | Source |
|---|---|---|---|---|
| | | | | |
| Alabama | 87,619 | 320,000 | 99,938 | State |
| Alaska | 97,740 | 1,090,000 | 813,367 | State |
| Arizona | 149 | 100 | 88 | Estimate |
| Arkansas | 184,536 | 110,000 | 90,331 | Estimate |
| California | 2,846,078 | 1,684,200 | 1,290,050 | Estimate |
| Colorado | 388,661 | 210,600 | 133,005 | Estimate |
| Florida | No data available | 76,500 | 48,990 | Estimate |
| Illinois | 1,282,933 | 285,000 | 212,098 | Estimate |
| Indiana | No data available | 48,900 | 34,531 | Estimate |
| Kansas | 999,143 | 683,700 | 1,174,641 | State |
| Kentucky | 90,754 | 3,000 | 2,411 | Estimate |
| Louisiana | 1,346,675 | 1,346,400 | 1,079,805 | State |
| Michigan | 76,440 | 52,900 | 33,207 | Estimate |
| Mississippi | 318,666 | 234,700 | 286,532 | State |
| Missouri | No data available | 100 | 1,200 | State |
| Montana | 223,558 | 103,300 | 104,501 | Estimate |
| Nebraska | 164,688 | 61,200 | 51,191 | State |
| Nevada | No data available | 6,700 | 2,765 | Estimate |
| New Mexico | 445,265 | 706,000 | 112,934 | State |
| New York | No data available | 300 | 844 | State |
| North Dakota | 59,503 | 79,800 | 78,236 | Estimate |
| Ohio | No data available | 7,900 | 6,416 | State |
| Oklahoma | 3,103,433 | 1,642,500 | 1,252,870 | Estimate |
| Pennsylvania | No data available | 2,100 | 5,842 | State |
| South Dakota | 5,155 | 4,000 | 3,293 | State |
| Tennessee | No data available | 400 | 275 | Estimate |
| Texas | 7,838,783 | 7,630,000 | 5,031,945 | State |
| Utah | 260,661 | 124,600 | 84,791 | Estimate |
| Virginia | No data available | 300 | 550 | Estimate |
| W. Virginia | 2,844 | 6,000 | 4,284 | Estimate |
| Wyoming | 785,221 | 1,401,000 | 2,119,394 | State |
| | | | | |
| TOTAL | 20,608,505 | 17,922,200 | 14,160,325 | |

[a] 1985 produced water volume (barrels) from API (1988).
[b] 1995 produced water volume (barrels) from API (2000).
[c] 2002 produced water volume data from state oil and gas agencies/websites unless estimated based on historic water-to-oil ratio.

State-by-state PW volume data 1985, 1995, 2002 (1000 bbls)

Declines

Increases

Source: ANL/DOE, 2004

**Table 1. State-by-state produced water volumes. The source of the reported water volumes are either state data or estimates based on hydrocarbon production. Source for the table: ANL/DOE, 2004.**

In Table 1 States with significant production and steady or recent declines include Alabama, Alaska, Arkansas, California, Colorado, Florida, Illinois, Indiana, Kentucky, Louisiana, Michigan, Nebraska, New Mexico, Oklahoma, Texas, and Utah,. These are States where conventional oil and gas production dominates. There are a few States where there have been significant increases in produced water volume. In Wyoming, for example, increased CBM production accounted for large amounts. In Kansas, there was a dramatic expansion in natural gas production, combined with some new CBM production.

### Quality of water in conventional oil and gas fields

Figure 3 portrays data for total dissolved solids (TDS) in conventional oil and gas derived from an online database published by the U.S. Geological Survey (USGS) (http://energy.cr.usgs.gov/prov/prodwat/).

West of the 98th parallel, many of the conventional produced waters in Montana, Wyoming, northern Utah, Colorado, and northwestern New Mexico are relatively fresh (less than 10,000 ppm TDS, purple squares). These waters potentially could be of beneficial use without having to be treated to lower the TDS. Other areas in the western U.S. – for example, the Williston Basin in western North Dakota and the Texas and Oklahoma panhandles – have high-salinity waters. The Permian Basin of West Texas and southeastern New Mexico has mixed water quality; primary constituents are sodium chloride or sodium/calcium chloride and TDS ranges from a few thousand ppm TDS to about 350,000 ppm. There are some produced waters in the U.S., largely in the Michigan Basin, that are as high as 410,000 ppm TDS. With respect to the Appalachian Basin, there is only a limited amount of data from producing areas in that region

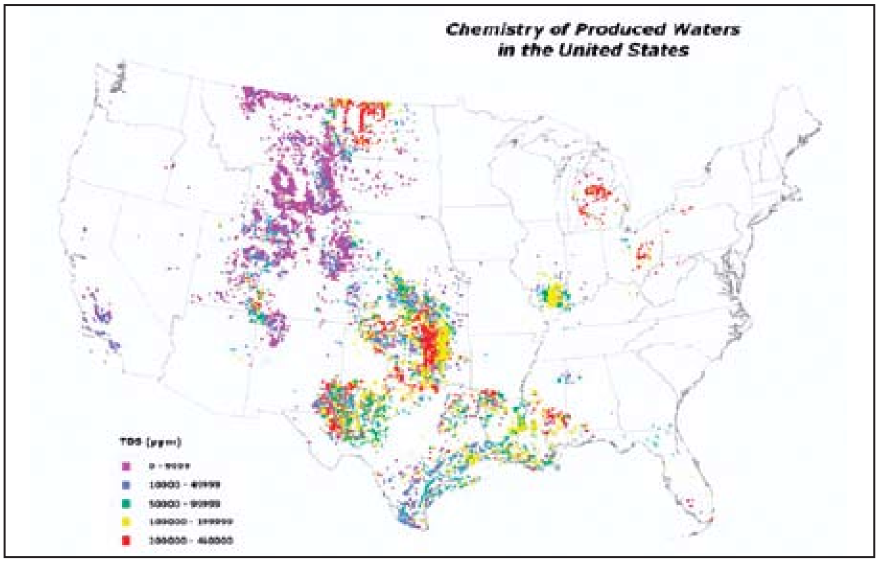


**Figure 3. Chemistry of Produced Waters in the United States, Source: online USGS database (http://energy.cr.usgs.gov/prov/prodwat/)**

### Water production from unconventional energy operation

CBM-produced water is the dominant source of water from unconventional hydrocarbon accumulations. There are other unconventional oil and gas resources, specifically tight gas sandstones, that generate produced water, but the data indicate that much less water is generated per thousand cubic feet of gas from these sources than from CBM production. Figure 4 shows where there is CBM production across the United States.

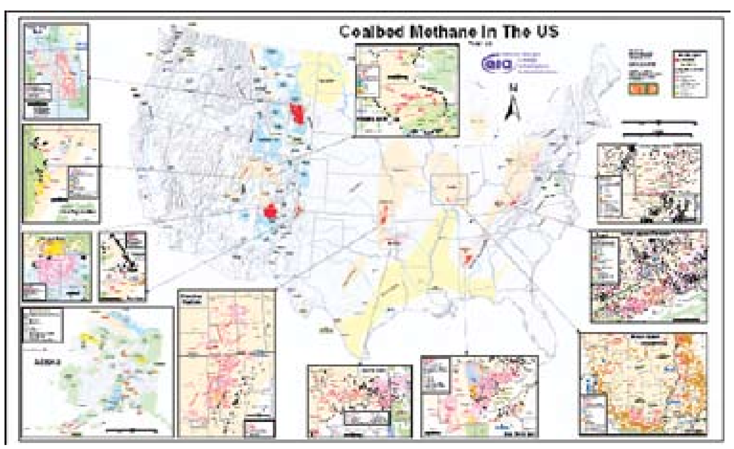


**Figure 4. Areas of coalbed methane production in the United States. Source- http://www.eia.doe.gov/oil_gas/rpd/cbmusa1.pdf**

The Black Warrior Basin in north-central Alabama and the San Juan Basin in northern New Mexico and southern Colorado are the oldest areas of CBM production in the U.S., with production from the 1980s. Presently, the four big areas of production in the western U.S. are the San Juan Basin, the western Uinta Basin, the Powder River Basin (PRB), and the Raton Basin. There are other areas under development and consideration, including the Piceance Basin in western Colorado and the eastern Washakie Basin in south-central Wyoming, as indicated by Mr. O'Toole in an earlier discussion. Most coal-bearing basins in the western U.S. have been explored for potential CBM production.

Volumes of produced water in the major CBM basins are shown in Table 2. These are based on 2005 data, with a U.S. total from 2003. The Black Warrior Basin in Alabama, during 2005, had an average of about 4,400 wells with

| Basin | State | No. of Wells | Avg. water bbl/day/well | Water/gas bbl/Mcf |
|---|---|---|---|---|
| Black* | AL | 4,369 | 41 | 0.58 |
| Powder* | WY | 15,200 | 103 | 1.66 |
| Raton | CO | 1,892 | 234 | 5.90 |
| San Juan | CO | 1,671 | 42 | 0.44 |
| | NM | 3,621 | 12 | 0.33 |
| Unita* | UT | 488 | 58 | 0.20 |
| **USA CBM total for 2003 ~one billion bbl @ 500 bbl / MMcf** | | | | |
| * data are for 2005 from state sources. Powder River Basin CBM wells generated 548 million bbls of PW in 2005. (Source for PRB data: Wyoming Oil and Gas Conservation Commission webpage.) | | | | |

**Table 2. Volume of produced water in major western CBM basins. Table is modified from Rice, 2000 (http://pubs.usgs.gov/fs/fs-0156-00/)**

relatively modest water production in barrels per day per well – and a water-to-gas ratio that is relatively low at about 0.58 barrels per thousand cubic feet of gas (Table 2). Contrast that to the PRB in Wyoming, where, at the end of 2005, there were some 15,200 producing wells and about 3,500 shut-in wells. Substantial quantities of water are produced out of these wells on an average per well basis – about 2.5 times that of the much more mature CBM-developed Black Warrior Basin. The Raton Basin occupies a smaller area with considerably fewer wells, but has more than twice the water production per well (234 vs. 103 bbl/day/well), and a much higher water-to-gas ratio (5.90 vs. 1.66) than the PRB. The San Juan Basin exhibits a relatively mature CBM water-production profile. This basin, which peaked in gas production a few years ago, has two sections, in Colorado and in New Mexico, with slightly different characteristics in terms of the average water production per well per day. The Uinta Basin has modest water production per well, producing an average of 58 bbl/day/well.

In 2003, all these CBM-producing areas generated about 0.85 billion barrels of water, with an average of about 500 barrels per million cubic feet of gas. For 2005, calculations show that about 0.5 billion barrels of produced water were generated from the PRB's CBM wells alone, equivalent to about 73,600 acre-feet of water.

### CBM Water Quality

CBM waters of the five major basins listed in Table 3 are predominantly sodium-bicarbonate waters with lesser amounts of chloride and TDS values are shown to range widely. For comparison, the EPA secondary drinking water standard is 500 ppm TDS and seawater is approximately 35,000 ppm TDS.

| Basin | State | Type | Total Dissolved Solids (mg/L) | pH |
|---|---|---|---|---|
| Black | AL | $Na\text{-}Cl\text{-}HCO_3$ | 160 to 31, 000 | 5.4 to 9.9 |
| Powder | WY | $Na\text{-}HCO_3$ | 270 to 4,000 | 6.7 to 8.0 |
| Raton | CO | $Na\text{-}HCO_3$ | 530 to 6,000 | No data |
| San Juan | CO | $Na\text{-}HCO_3\text{-}Cl$ | 410 to 170,000 | 5.2 to 9.2 |
| Unita | UT | $Na\text{-}HCO_3\text{-}Cl$ | 6,350 to 43,000 | 7.0 to 8.2 |

Conventional production water: 5,000-410,000 mg/L TDS; Na-Ca-Cl (http://energy.cr.usgs.gov/prov/prodwat/).

**Table 3. Composition of Water in Major CBM Basins**
**Table is modified from Rice, 2000 (http://pubs.usgs.gov/fs/fs-0156-00/)**

The PRB waters exhibit modest TDS concentrations overall, which is one of the reasons why PRB water seems suited for beneficial use. In other basins, the quality of the water is not as good and beneficial use is more problematic. The San Juan Basin waters, for example, have highly varied TDS, and most operators simply reinject it. Likewise, most operators reinject Uinta Basin waters. In the Black Warrior Basin, the TDS concentrations are bimodal and operators are allowed to release the lower TDS waters to surface streams.

Listed below are components of CBM-produced water that may present some water quality issues when beneficial use is considered:

- Dissolved inorganic species
  - Major ions—Na, K, Ca, Mg, HCO3, Cl, SO4
  - Minor species—NH4, B, Li, F
- Dissolved trace elements
  - Fe, Ba, Mn, Se, Zn, Cu, Cd, Mo, Cr, As, Pb
- Dissolved organic species
  - Phenols and volatile aromatic compounds
- Dissolved and dispersed hydrocarbons (far more common in conventional produced waters)
- Dissolved and suspended radionuclides
- Drilling and workover additives

Major cations and anions are the most typical parameters measured to assess water quality and to determine water type. Of the four minor inorganic species listed, ammonium is significant because of nitrogen limits to surface and ground waters; the other minor species can impact plant growth. Several of the listed dissolved trace elements have primary drinking water standards established by the USEPA. Other impacts of the dissolved constituents include effects on water transmission equipment, cleanup technologies, pastureland or cropland being irrigated, and aquatic life; many aquatic life standards are lower than drinking water standards. If produced water is to be treated for drinking water, all of these components of CBM waters need to be evaluated; as are many of the same constituents in conventional produced waters.

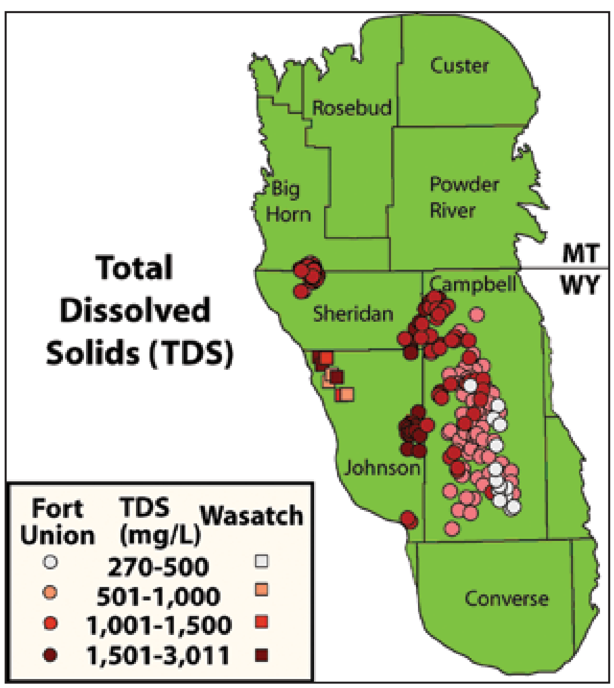


**Figure 5. Total Dissolved Solids in Waters throughout the PRB. Modified from Rice and others, 2003. http://ipec.utulsa.edu/Conf2003/Abstracts/rice.html**

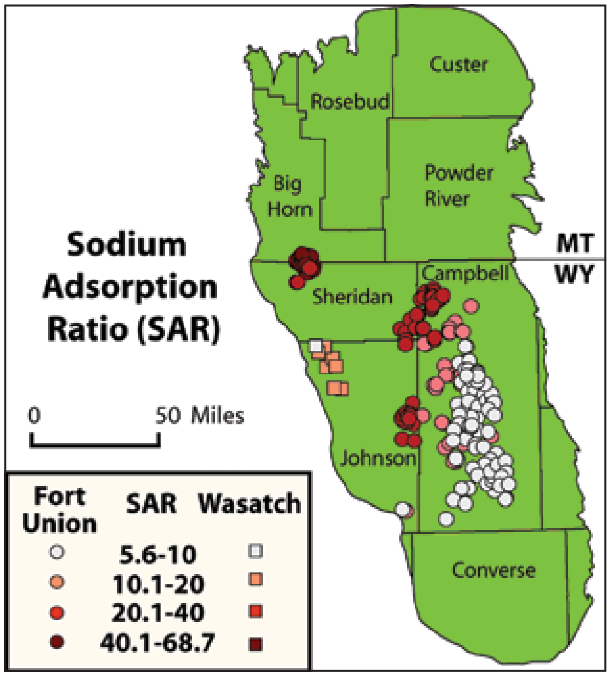


Figure 6. SAR in Waters throughout the PRB. Modified from Rice and others, 2003. http://ipec.utulsa.edu/Conf2003/Abstracts/rice.html

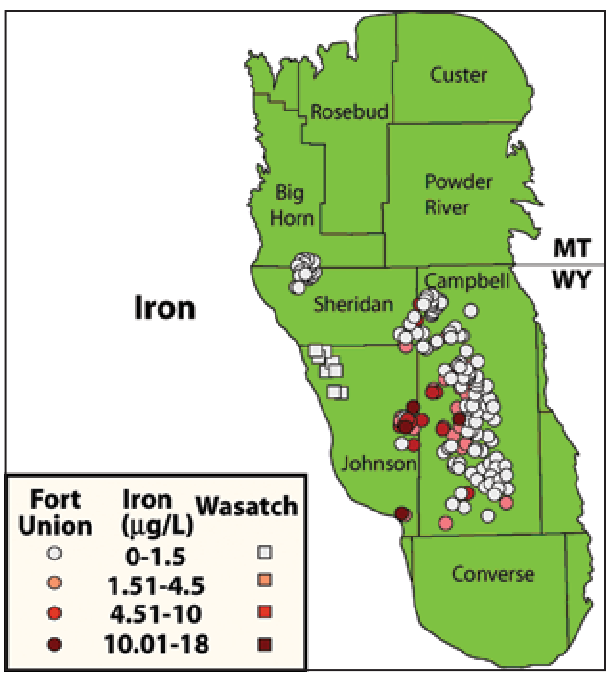


Figure 7. Iron in Waters throughout the PRB. Modified from Rice and others, 2003. http://ipec.utulsa.edu/Conf2003/Abstracts/rice.html

In some basins, such as the PRB, water quality may vary across the basin, with the result that water in some areas may be useful for certain beneficial uses, but in other areas it may not. Three different water quality parameters in PRB waters illustrate this. The waters exhibit TDS values that range over an order of magnitude, from 270 to about 3,000 ppm (Figure 5). Waters are generally fresher on the southeast side of the basin and become more saline toward the west and northwest. TDS becomes important because of the 500-ppm secondary drinking water standard; and there is a 6,000- to 10,000-ppm rule-of-thumb limit, roughly, for stock watering, depending on which part of the country you're from. A TDS of 10,000 ppm is considered as an upper limit of "useable water" by many authorities; see, for example, the discussion in http://www.kgs.ku.edu/Dakota/vol1/hydro/hydro20.htm . Tolerance of irrigated agriculture to waters with high TDS depends on crop type, but ranges from about 1,200 ppm to as much as 10,000 ppm. Some of the waters in the PRB therefore may not be suitable without treatment for some purposes, based on TDS concentrations.

Although PRB CBM water has relatively low TDS, its sodium-bicarbonate water type raises issues for irrigation. The Sodium Adsorption Ratio (SAR), calculated from the ratio of dissolved sodium to dissolved calcium and magnesium, is a water quality parameter that measures the potential of the applied water to degrade soil structure in soils rich in smectitic clay. This degradation hinders the infiltration of water and the ability of plants to take up that water. The SAR values of CBM waters in the PRB commonly attain values that are a cause for concern in irrigation (>~8, compare with values in Figure 6). Many operating companies in the PRB are actively working to reduce the CBM SAR value either through a variety of water treatments or by applying soil amendments to irrigated fields.

Dissolved iron is present in PRB waters (Figure 7) as predominantly ferrous ($Fe^{+2}$) iron. Upon exposure to air, the iron is oxidized and forms iron oxyhydroxide precipitates that can foul many systems, especially treatment systems. Ferric iron can be an issue in aquatic habitats. It affects fish gills, coats and smothers substrate, reduces pH, and increases turbidity.

Water quality limits the uses of the untreated CBM water and dictates the treatment necessary for a particular beneficial use. If drinking water is the goal, treatment will need to address strict standards for major and minor salts, trace elements, and organic compounds. For irrigation, requirements for TDS are less stringent. SAR is important because of its impact on soil quality. Similarly, eliminating or minimizing phytotoxic trace elements like boron and lithium is important if water is used to irrigate crops that are sensitive to them.

### Potential water resources

Putting produced waters to beneficial use requires some understanding of their future availability. Figure 8 gives an overview of DOE projections for produced water from various oil and gas resource types.

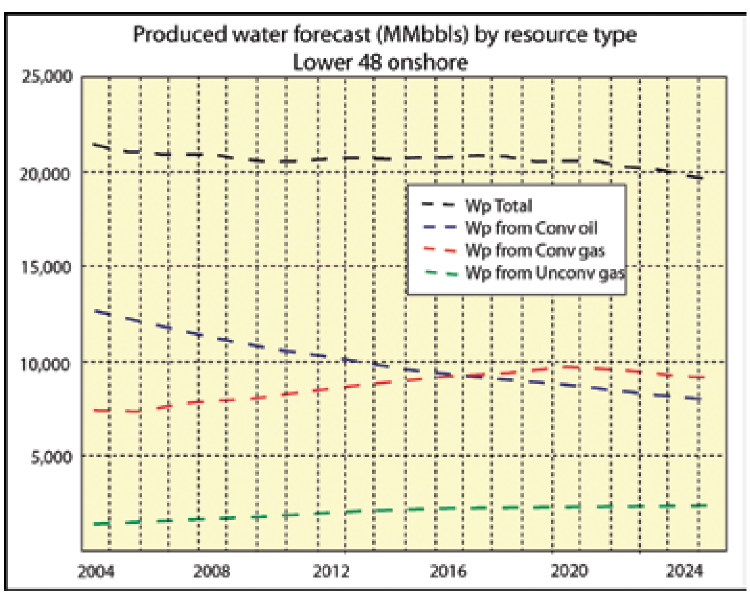


**Figure 8. DOE projections for produced water volume. Source: National Energy Technology Lab, DOE, 2005**

DOE projects a gradual increase nationwide in the amount of water available from unconventional gas production, largely from CBM production. For conventional gas, DOE projects a steady increase in water production for the next 15 years, followed by a slight decrease thereafter. A steady decrease is predicted for water production from conventional oil. Although there tends to be more water production as oil fields mature, the amount of oil and water actually being produced is expected to continue to decrease in the U.S.

This projection provides a national perspective, but predicting water availability on a regional or local scale requires much more location-specific information. Such predictions are important because the water is commonly only used locally, due to the cost of moving it any significant distance. Thus there is a need to closely examine the projected oil and gas production in specific areas and then estimate, as accurately as possible, the likely volumes of co-produced water from development of these resources.

The USGS, in a 2002 report, estimated a 50% probability that 16.5 trillion cubic feet of economically recoverable natural gas from CBM and 1.5 billion barrels of economically recoverable oil are yet to be discovered in the PRB. To arrive at these numbers, (1) each formation and each structural setting in the basin was examined; (2) the natural system that generated oil or natural gas was evaluated, and (3) the expected volumes of oil and gas that remain trapped in the formations present in the subsurface were estimated. Projecting estimates of undiscovered, economically recoverable oil and gas volumes to calculate produced water volumes, however, cannot be done linearly, because water-to oil and water-to-gas ratios vary from formation to formation, and even within a formation. In addition, the production history of each field changes with time. A simplistic approach in the case of the PRB is to use the 2005 reported water-gas ratio of 1.66 barrels of water per thousand cubic feet of gas from Table 2 and the 16.5 trillion cubic feet of CBM gas resource estimate cited above, and project that about 28 billion barrels of water would be available in the PRB over the period of CBM production. Oil production could be an additional significant contributor to PRB water supply. We cited about 1.5 billion barrels of projected undiscovered oil in the basin. Using a reasonable range of water-to-oil ratios of 3.3-10, some 5 to 15 billion barrels of water could be provided by oil production to supplement that coming from CBM production.

The error bars on these estimates, however, could be substantial. For example, many companies in the PRB are shifting development to the deeper Big George coal, an attractive resource because it is gassier, but the water-to-gas ratios are higher; therefore there may be an upward shift in the amount of water being generated in the PRB compared to current estimates. Such a circumstance is difficult to predict as are other natural factors and changes in the natural gas price which may affect future production.

Similar estimates of CBM resources in other producing basins throughout the U.S. are indicated in Figure 9. A total U.S. CBM gas resource is estimated at 163.3 trillion cubic feet.

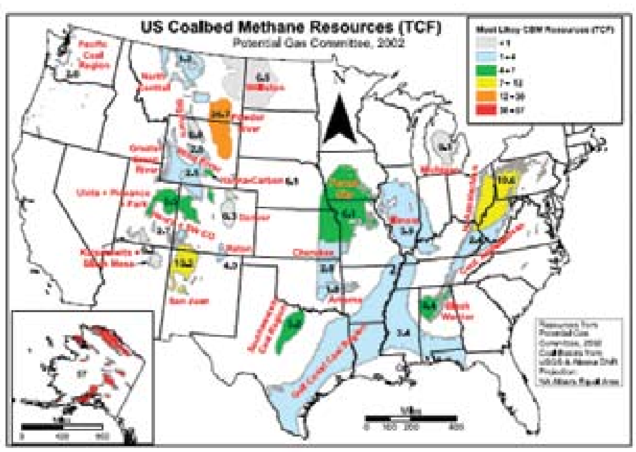


**Figure 9. U.S. CBM Resources**

### Future Water Resources from western energy development

Other potential hydrocarbon energy resources, such as basin-centered gas, exist in western energy basins that will generate varying amounts of produced water. The Denver Basin has had extensive development in the Wattenberg gas field; however, there are other basin-centered gas resources where development is new. For example, in western Colorado, the Unita-Piceance Basin has experienced development only over the past few years. There, the water-to-gas ratios are low, so water from this source will apparently be limited.

There has been limited shale gas development in Montana and North Dakota, but water production is virtually nil. If oil shale, a major potential oil resource, is retorted in place, the result will be a large, but unknown, volume of water of likely poor quality. If mined, brought to the surface, and retorted at the surface, the shale will be a net consumer of water (2-5 barrels of water per barrel of shale oil generated).

### Conclusions

Produced water resources are substantial in many western basins, and are potentially important additional sources of water for beneficial use. In the PRB of Wyoming, about 73,600 acre-feet of water was generated in 2005. CBM waters are generally fresher than conventional oil and gas waters in the same basin and require less cost to process for use. CBM waters are generally dominated by sodium and bicarbonate with lesser chloride; the sodium content creates adverse soil changes where these waters are used for irrigation. Precautions must be taken to conduct thorough geochemical analyses of any produced water to identify potential problems and to establish the appropriate treatment technologies for a particular proposed use. Because of the spatial and temporal variability of water production and water quality, the planning and development of systems to effectively treat, deliver, and use the water are difficult. Development and production in oil and gas fields is subject to geologic and geotechnical variability and to price fluctuations that influence the pace and location of production. Water users expect a steady water supply through time with consistent quality.

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**James K. Otton** has been a research geologist with the U.S. Geological Survey since September 1974. He received a Ph.D. from Penn State in 1977. His project work for the last 12 years involves studies of produced water releases at oil and gas production sites and their effects on soil, surface water, ground water, and the ecosystems they support. Project work has included sites in OK, IL, KY, MI, MT, WY, and CO. Since 1998, he has been a member, and, more recently, chair, of the Science Advisory Committee of the Integrated Petroleum Environmental Consortium, an EPA-funded, four-university consortium designed to fund research to assist oil and gas operators in meeting environmental regulations in a cost-effective manner. Jim is presently chief of the environmental impacts of energy production project and is involved in developing simple oil and gas production site assessment screening techniques for land managers and companies acquiring leases. He also is involved with assessing the susceptibility of watersheds and aquifers to historical and ongoing releases of produced water from oil and gas operations using GIS techniques. Finally, he leads long-term, multi-disciplinary research site investigations at two oil production sites on the Osage Reservation (Oklahoma) since 2001, in collaboration with the Osage Tribe, Corps of Engineers, BIA, EPA, DOE's National Petroleum Technology Office, and nearby Oklahoma universities. He can be contacted at 303-236-8020 or jkotton@usgs.gov.

*Produced Waters Workshop –*

# How Much Water Are We Talking About?

**Opportunities and Liabilities for Produced Waters**

by Jeff Cline, Anadarko Petroleum Co.,
The Woodlands, TX

The water I'm going to be discussing is both coalbed natural gas (CBNG) produced waters as well as conventional oil and gas produced waters. It's low in dissolved solids and by location is called "beneficial use water." The title of this talk suggests that I will present some answers. You may hear more about the difficulties of using a resource that is treated like a waste.

Before we go further, I'll say something about who we are. Anadarko Petroleum Company is actually the largest private landowner in the state of Wyoming. I will be talking about resource development in Wyoming. I'll be talking about the history of both traditional and coalbed natural gas beneficial-use types of waters, oil and gas development as an investment, and some perspectives on the beneficial produced waters and the options and feasibility of managing produced water. That of course is a forum discussion unto itself. In fact if we want to get into a formal discussion unto itself, we could just take water treatment as a whole forum discussion, so it's going to be very brief. And we're going to be discussing the feasibility of management options and solutions, moving forward.

Figure 1 shows the basins in the state of Wyoming. Coalbed natural gas produced water discharges began fairly recently, around 1990, in the Powder River Basin. You've heard all about this. Water will be produced from a given well for about ten years. It diminishes about 1/3 per year from the start of the well. Water production must be maintained in order to produce gas. I'll show you more on that in a minute. The NPDES permit under the Clean Water Act allows management as beneficial-use water. Typically the water quality profile of this type of water exhibits zero salts, low chlorides, no sulfates, and TDS from about 1,500 to 3,000 mg/L. This water usually is very low in heavy metals as well.

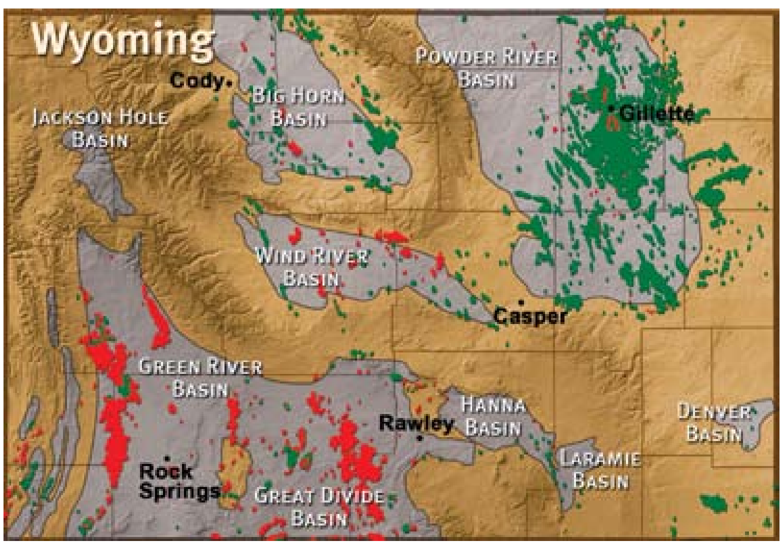


**Figure 1. Wyoming Areas of Interest**

You can see water volumes from zero up, that is, you can turn on some wells, and they produce gas right away; however, that's the exception. You can turn on other wells that produce about 1,500 barrels a day for two years and then finally the gas appears – if it's there. A very important point here: this water is used for ranching and agriculture. It's used extensively for irrigation. In spite of the SAR ratios, it can be managed in agriculture irrigation very readily.

Figure 2 shows a typical water production in a coalbed natural gas field. This looks somewhat strange, doesn't it? This curve actually reflects water production for a particular field; however, any given well will have a production curve that comes down like this. You bring on a certain section and it declines, bring on another section and it declines, then a few more wells come on, then you bring on a whole set of wells and fields, and finally the field itself has a decline. When you enter into discussions about potential opportunities – like water for communities or for cooling – and you show them curves like this, they ask for this guaranteed amount for 50 years. We can't do that, so the discussions stop.

The next photo (Figure 3) shows water being produced into a tire tank in Wyoming, one of thousands of these. This

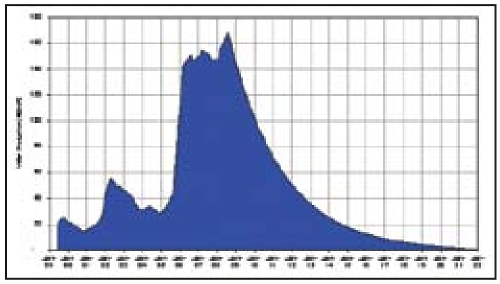

**Figure 2. Typical Water Production in CBNG Field**

is discharge at our Wardern ranch near Gillette, Wyoming – a very arid area. You can see some iron staining here, but it's actually clean-looking water. You see the wildlife in the background. Cattle use the water, drink in it, bathe in it, cool down in it – they tend to like it. Even in this very arid environment, there is lots of growth near the water, some of that can actually be consumed by cattle and wildlife (Figure 4). A set of ducks was seen nesting on this particular impoundment, for the first time ever (Figure 5). Interestingly, with the Powder River one half mile away, the great blue herons come to the pure coalbed natural gas produced water to feed on frogs and fish (Figure 6). Once you have this water, a great variety of life will come.

**Figure 3. Ranch near Gillette, Wyoming**

**Figure 4. Cattle at Wyoming Impoundment**

**Figure 5. Ducks at Wyoming Impoundment**

**Figure 6. Great Blue Heron at Wyoming Impoundment**

### Salt Creek Traditional Produced Water

We've been discharging traditional produced water in our Salt Creek Field for about 65 years. It is discharged under an NPDES permit and Clean Water Act and Beneficial Use Waters regulations. Water quality is similar, with TDS less than 5,000; sulfate levels from 300 to 3,000 mg/L; and chlorides from 200 to 2,000 mg/L. These numbers are not limited to Salt Creek but reflect the oil industry waters in general that are discharging throughout Wyoming. The water quantity slowly increases as oil decreases.

Ranching and many agricultural operations are dependent on the produced water. If we cut back on production of water for a short time in Salt Creek, these people will be in our office demanding that water. They don't own it, but they like it and depend on it. Figure 7 is a picture of a Salt Creek Field in winter, a very arid environment.

**Figure 7. Salt Creek Field in Winter**

**Figure 8. Water Discharge Brings Wildlife**

Figure 8 was also taken in the winter, a bit closer to spring, and it shows what happens where we discharge the water – a dramatic change, hardly detrimental. There is vegetation and ample fish, the water is filled with ducks, and there are beaver and other wildlife. The water quality differs from CBNG produced water, with total dissolved solids being similar: TDS<5,000 mg/L, sulfates 300 to 3,000 mg/L, and chlorides 200 to 2,000 mg/L.

### Investment and Risk

Oil and gas development is an investment. That's important to keep in perspective. These wells are developed to bring energy products to the market economically. What about the development costs?

One thing that's very difficult and costly is the time required – years – to obtain the authorizations. Time is money. It can take sometimes several years to get an NPDES permit, and then the permit requirements change because of moving regulatory requirements. What do we shoot for? What do we build? We can invest millions to build infrastructures, pipelines, compressors, water facilities; and then, if requirements change, what do we have? It's a risky business for us.

High price volatility for the product equals high economic risk. For coalbed natural gas, for example at Warden Ranch, the price has varied from $0.80 to $7.00 per thousand cubic feet during the last three years. That's high risk. You have to make all this investment up front, well before you know what price you're going to get for your product. CBNG competes with other investment opportunities; therefore, if the gas risk/reward is too high, we go to other investments with lower risk/reward.

### Options for Managing Produced Water

Injection is the most commonly applied management practice for any produced water. Infiltration impoundments are the next most common practice for managing coalbed natural gas produced water. This includes infiltration and evaporation mechanisms. Irrigation is then the next most common application. Minor treatment and discharge to draws is also a common management practice and includes aeration to remove heavy metals like iron, adsorption to get the barium out, and gypsum treatment to manage the SAR. Managing SAR with reverse osmosis, ion exchange, or other aggressive treatments is very expensive and very risky business because the technologies are in pilot phase of development.

Typically there are transportation issues with the water. We've already heard many times in this morning's discussions that transportation issues are glossed over. They're huge. When wells are being installed and begin producing water for a short time, the area where the water is producing is relocating. Meanwhile, older wells are "drying up." As producing wells move, pipelines must be moved or built to transport to a city or power plant for cooling, and they cost millions per mile. Transportation of water is very difficult and costly.

### Perspectives on Produced Water Use

Traditional oil and gas produced waters are usually considered necessary for ranching and agriculture communities. This water has been discharging a long time; and wherever it is, the ranchers are dependent on it. The coalbed natural gas produced water is used and sought by most ranchers, yet is disliked by some – and those are the people heard from most often. Here's an example situation: we installed a pipeline 50 miles long past and over the properties of 20 landowners. Nineteen wanted the water.

The environmental effects of traditional and CBNG produced water is similar. Water begets life. Drainages will change from intermittent to perennial, and vegetation becomes wetlands/riparian. Yet, is the subsequent use by fish, waterfowl, big game, and livestock a good thing? Some think it is; some think it's not.

What's the feasibility of produced water management options? First we have regulatory changes that cause a risk to our investment. A high risk to our investment really changes our feasibility. Traditional oil and gas produced water feasibility changes; for instance, at one point in our Salt Creek Field we went down to 0.5% oil content – 99.5% of the fluid produced is water. Consider what overhead costs are in such an operation. And imagine if someone says to you, "We want you to change what you do, to start treating all that water." We cannot feasibly do that. We could start injecting, but reinjection just doesn't pay for itself. So, in many cases the field shuts down. In the case of our Salt Creek Field, we're injecting $CO_2$, and. we're getting an increase in oil production – which can start to pay for some other water management options.

For coalbed natural gas produced water, continued discharge straight to a draw is more feasible than discharge to ponds, irrigation, or aggressive treatment. Injection may not be feasible in the Powder River Basin – although we are considering transporting water from there to inject in formations outside the basin.

### Water Management Options Compared

Let's compare the costs and risks of water management options:

| Option | Cost | Economic Risk |
|---|---|---|
| Injection | Med-High | Low |
| Impoundment | Low-Med | Med-High |
| Irrigation | Med | Med |
| Minor treatment/discharge | Low | High |
| Major treatment/discharge | Very High | Low-Med |

Let me comment on why I consider minor treatment and discharge as a high economic risk. Simply, the regulations are changing constantly. We don't know if we're going to have to install new facilities, so it's a high economic risk. Major treatment and discharge offers low-to-medium economic risk. Something stands out here that operations people like – low risk.

What are the solutions? A production engineer will first opt for injecting the coalbed natural gas produced water and conventional produced water when it's feasible. That's the lowest risk option. It's the only thing he can take advantage of. We want to support the local community and help out ranchers by giving them water, we really do. But, it must be a low-risk strategy. If the regulatory environment makes it higher risk, it does not make sense to do it.

Our goal for water injection is storage in a formation of a similar class. For instance, we are moving our coalbed natural gas produced water in the Gillette area (a Class III water for livestock) by pipeline to be injected and stored in an aquifer having Class III Water – the Madison formation.

And, we look for solutions in improved regulatory certainty. We need to really have certainty here. Finally, let's manage beneficial use water as a resource, not a waste; maybe states should manage excess produced water.

**Jeff Cline** currently is the Water Programs Manager at Anadarko Petroleum Corporation, with current emphasis being produced water management in Wyoming. In 1976, he obtained a doctorate in Geochemistry at Michigan State University, with thesis work in water chemistry. Dr. Cline has over 50 publications/presentations, with emphasis in environmental applications studies such as produced water treatment and management, waste management, and waste fate and effects in the environment. He was a professor of environmental science at Wilkes College, and has worked within the oil industry for the last 25 years. Contact him at (phone) 832-636-2611.

*Produced Waters Workshop –*

# How Much Water Are We Talking About?

## Environmental Considerations in Utilizing Produced Waters for Beneficial Use

*Tuesday Luncheon Speaker*

by Jim Bauder, Extension Specialist,
Montana State University

What are some of the environmental implications of produced water management? As we heard from Jim this morning, there are potential opportunities for nearly a billion barrels of water out there someplace. The answer to the questions of water quality tolerance, management solutions, and environmental implications really depends on which audience you're talking to and where you are in the spectrum of things. It really depends on what your venue is and whether you're the natural resources manager, or the regulatory agency, or one of the downstream users of the industry. You've seen a lot of those perspectives this morning.

### Location, Location, Location

Figure 1 illustrates the magnitude of energy extraction in Wyoming. Each of these sites is an energy extraction site. You can see in most of these cases there is some provision for some type of produced water management.

I was pleased to hear this morning that produced waters management can be likened to a train; we really don't know how long the train is, we don't know where it's going, we don't know the length of the tracks. But, clearly the train is there, and it's time we need to start thinking collectively about how to deal with that particular set of circumstances.

**Figure 1. Wyoming Energy Extraction Sites**

### How much water are we talking about?

From the perspective of CBM, each of those wells in Figure 1 produces some water. Generally, the big challenge is that the water is in a lot of different locations on the landscape, that wells in close proximity are managed together, but that all the locations are not managed collectively. We heard that piping water is expensive. Treating water is expensive. Sometimes other options are expensive. Consequently, that water is not necessarily collected and put someplace. For one project in the Powder River Basin, an average coalbed methane well pumps five gallons of water per minute, averaged over ten years. That's about 7.5 acre-feet per well per year. The obvious question is what do you do with all kinds of water that are close to the surface and easy to use? Figure 2 is a sky-high look at central Kansas. Each of the circles in this photo represents an irrigation center pivot. The red ones show circles of healthy vegetation, the white ones reflect a different response, and the green ones yet another. This is an example of where a lot of water relatively close to the surface has been put to some kind of beneficial use.

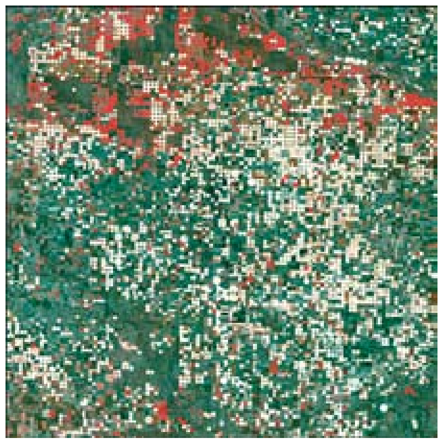

**Figure 2. Aerial Image of Croplands near Garden City, Kansas**

Contrast that with situations in the Powder River Basin or in the San Juan or Raton, or some of the other CBM developments or other kinds of produced water applied on landscape. We don't see this kind of scenario evolving. One has to ask why not. If it's such readily available water and easy to get to, why haven't these scenarios evolved? Obviously, landscape is a factor. Another is that water is very dispersed across the landscape. If ten million acre-feet of water – maybe 40 million acre-feet – are readily available at relatively shallow depths in locations that are, for the most part, short on water already, then why isn't this water being used in these schemes of beneficial use? I'm not being an adversary of beneficial use. It might be that much of the water is so dispersed across the landscape that it's not consolidated in sufficiently large enough volumes to be economically manageable in any way other than what the manager sees as right.

### No Single Solution?

I want to get back to the lemonade story. I like the idea of that theme, and I think you've done a great job of developing it. I started to think about lemonade and tried to follow through with that analogy. Here's yet another spin: a little bit of lemonade and a lot of sugar and a lot of water make really good lemonade when they're all mixed together and chilled. Even Reagan made the comment this morning at 11:00, "It's too early for lemonade," – very appropriate. On a cold winter day in central Montana, or before dinner on Saturday night, or especially right after you got off work on a tough day, you might not want to be drinking lemonade. You might have some other beverage that you prefer. It may not be your first drink of choice. Squeezing a lemon into the iced tea or on a fresh salmon filet is desirable, but it doesn't take a lot of those lemons for this benefit. And I think that is one of the issues that we're struggling with right now.

This observation applies to my own situation as well. I have some fairly major research projects looking at beneficial use of CBM product water, and part of the problem is I've got too many lemons. There are a number of opinions about the reality of putting the energy extraction-related produced water to beneficial use. There are a couple of major questions from an environmental perspective. What are the potential realized beneficial uses, and what are the potential consequences? I could probably walk away right now, based on everything I've heard this morning, and conclude there isn't a single solution to put all this water to beneficial use.

Part of the reason is that our attention is so spread out in so many different directions. We've tried to identify some of the beneficial uses that would be appropriate for the landscape. I'm going to go through some of the challenges faced not only by the industry folks but also by the regulatory folks – that the academics, landowners, everyone on the landscape, faces – when it comes to the idea of beneficial use.

I'll use the example of livestock water to start with. We heard this morning that ranchers like it. There are several ranchers in the room whose property I've visited; and, yes, I think they probably do like that water to some extent. But in other cases they say, "I've got too much of it." You can develop a 'plus-and-minus' list for any one of these beneficial uses. I've tried to do that here with the livestock water example:

- Theoretical Plus: We have a lot of water on the landscape, and it's good for livestock. Livestock dispersal on the landscape is important.
- Hypothetical Deterrents: Long-term water access. How long does the play last? How long can we depend on it? How long can I manage for one particular set of circumstances, knowing that there's some degree of uncertainty down the road?
- Reality: You've got a 1,000-head herd that might use 50,000 acres of rangeland. It only takes the water from two or three wells to supply those livestock. The problem is getting that water over 50,000 acres of land becomes a very expensive endeavor for the industry. The point is, we must look at all sides of the particular circumstance; there is no one-size-fits-all solution out there for all situations.

Figure 3 shows data from the USGS database for records of produced water. Obviously, our five-state region is the area of greatest interest.

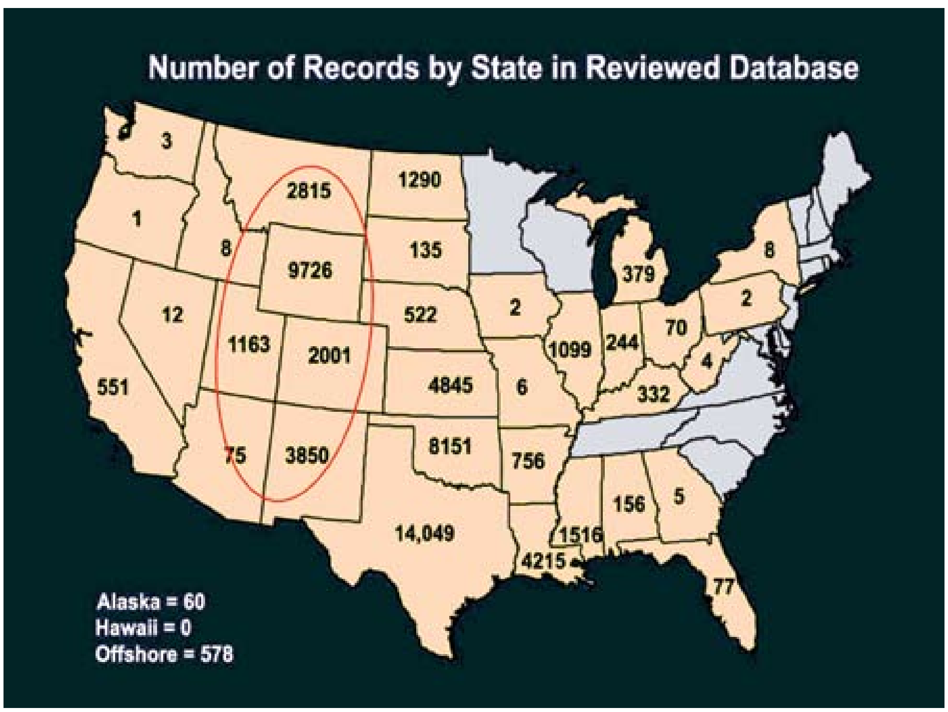


**Figure 3. Records by State of Produced Water in USGS Database**

While there are various ways to manage produced water, the reality is that, historically, most co-produced water has been managed as a waste product. Consider the situation in Figure 4, where there are small amounts of water with very impaired water quality – disposal is probably the best option. Figure 5 shows a lot of dispersed water, but not enough water in any one location to do anything with it other than figure out how to get rid of it.

Figure 4. When Disposal is the Best Option

Figure 5. Dispersed Water

### Infiltration Ponds as an Option

We took this picture (Figure 6) a few years ago, and I want to use it to introduce infiltration ponds as a management option. Infiltration ponds provide the wetland habitat, wildlife enhancement, or ephemeral channel recharge. Understand that this is not the sole occurrence of the water in that pond. It does something. It goes somewhere. Either the pond gets full and another pond has to be made, or the pond drains to some other place, dries up, and requires management. To each of these possibilities there is a consequence.

Figure 6. Infiltration Pond

Let me comment on the impact of the infiltration ponds we see in Figure 5 on the landscape. That particular photo shows the Tongue River drainage from Wyoming, at the right in the photo, moving into Montana, at the left in the photo. When I first showed this picture, someone asked if this was the land of 10,000 lakes. I replied that it's the land of 10,000 ponds. It's estimated that there are currently between 8,000 and 12,000 of these produced water evaporation ponds and infiltration ponds in the five-state region -between 4,000 to 5,000 in Wyoming. We heard this morning that the statistics are changing aggressively.

Collectively these ponds may be interacting with surface water hydrology, the shallow and deep hydrology of the basins, and may be cumulative to down-stream flow and quality – with unknown benefit. A benefit may be increased flow; a detriment may be altered water quality. When we begin to take a look at surface and ground water hydrology, it doesn't take long to discover that it may be a significant period of time before we see the impacts, and those impacts may be fairly subtle at times. In any case, the use of infiltration ponds requires a significant amount of surface space footprint, engineering and construction costs, and some degree of management. These pivot sites take roughly 1/3 of the area intended for irrigation to store the water to be used.

At times, getting a picture of what it looks like is helpful. Nothing is implied here other than it's time to realize that there are some consequences. In the alluvial valley shown in Figure 7, water flow is primarily through the shallow alluvium. Here, there is irrigation along the river bottom, and most of the impound sites you can see are off the river bottom are fairly significant. In many cases, they have potential to interact with drainage into the surface channel or the potential to begin to feed into other geologic sources that we've known about for long periods of time.

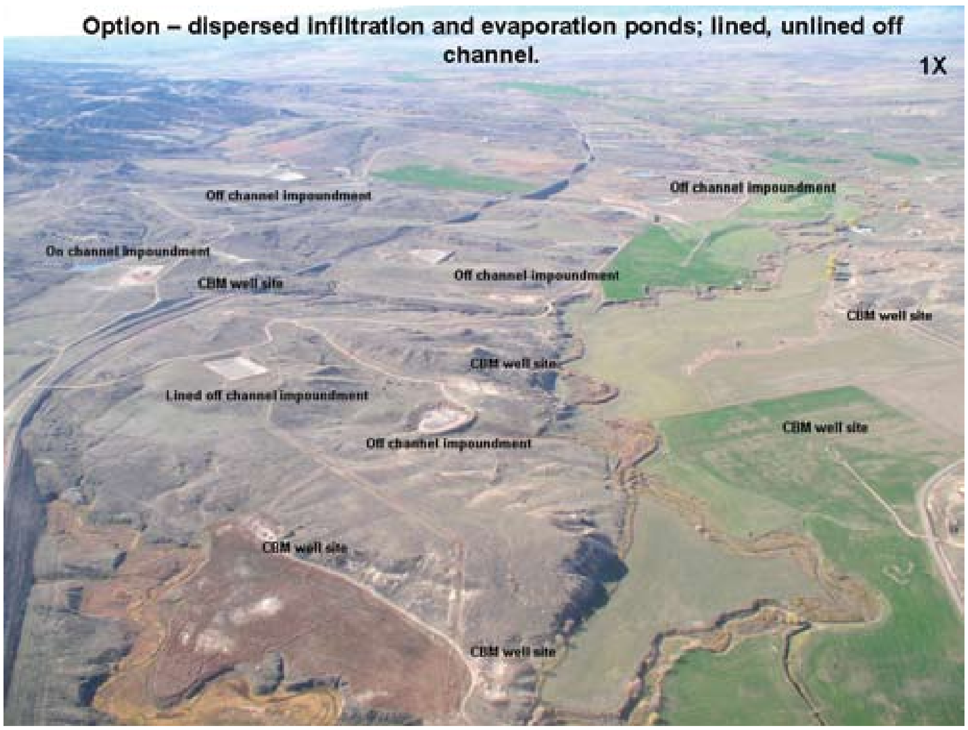


**Figure 7. Impoundments in Alluvial Valley**

What are the potential environmental consequences here?

- recharge of shallow alluvium
- leaching of salts from soils and return flow to surface water resources
- down gradient and geologic interface saline seep sourcing
- reduced rangeland acreage
- enhanced wildlife habitat
- intercepted runoff and down stream water rights if in-channel
- long-term rangeland production capacity limitation
- future site reclamation needs
- others identified in the research journals and environmental arena: site disturbance, re-vegetation needs, weed seed transport, West Nile virus, etc

Now, which of these consequences are benefits? We know there is recharging of the shallow alluvium; however, is that desirable? We know that there's leaching of salts from some of the soils in return flow to surface water; again, you have to ask yourself if that's something that's desirable or not. You can go through the list and identify for every one of these potential beneficial uses, one or more potential detriments. There's more than one side to each consideration; there are multiple venues that need to be looked at. Some of those we're just beginning to understand and develop management plans for.

I want to show you the bigger picture now in Figure 8, which shows the Tongue River in 1999, and Figure 9, the same in 2003.

**Figure 8. Tongue River 1999**

**Figure 9. Tongue River 2003**

The green area in these aerials is the alluvial stream feed to the river corridor . The dark green line is the river corridor. The blue spots are areas of surface water. Someone mentioned this morning this impact is happening very quickly. You can see immediately how quickly it has happened in this area. These areas of surface water are all either infiltration or evaporation ponds. If they're infiltration ponds, the intent is the water is going somewhere. If they're evaporation ponds, the intent is the water is not going somewhere. Eventually this site needs to be managed.

### Consequences Clear As Mud

There are some very broad implications to each one of these various opportunities. The question is, and I still don't think we have all the answers here: what are the environmental, regional, hydrologic, or legal consequences? You heard a little of those this morning, and I'm going to talk just a little bit about them. The issue of national security has got to be important to us. The issue of economic development has got to be important to us as we look at some of the other issues and attempt to strike a balance.

The legal issues are really focused around environmental consequences. I'll give you just a taste of what we've learned in Montana and Wyoming and what I think some of the other states are going to experience. In 2002 it was ruled that CBM production water was not a pollutant. That ruling was overturned by an appeals court that stated "ground water produced in association with methane gas extraction, and discharged into the river, is a pollutant" under the Clean Water Act, and states cannot create exemptions. The legal system is struggling with what this water is.

Recently, Montana passed what's called the non-degradation standard which says that there are certain limits or allowances within-stream. Those streams and rivers are originating in Wyoming and flowing into Montana, which now means we've got state-to-state issues. Now, the judicial and regulatory systems are wondering just what constitutes beneficial water. There are some petitions out there asking the states to establish statutes that define beneficial use. We used to have to deal with landowner-to-landowner issues, and now we're dealing with state-to-state. I think, eventually, we're going to be dealing with water moving out of the intermountain basins and moving everyplace else. We are actually in the headwaters, and I don't think all of us realize the implications of this fact.

Obviously if one had the option, one would go to irrigation, because you can use a large amount of water on land areas to get rid of that water or put it to beneficial use. Where the land is available, there needs to be some thought about what's going to happen over a long period of time. Generally, the limitation is that there's just not a suitable enough area to get rid of a billion barrels of water, or even a million barrels of water, in any given location. It's a fairly significant area, so to think of it as an opportunity is not very likely in the immediate future. Consider this example of irrigation as the opportunity at a development site. A 130-acre pivot will allow for beneficial use of 325 acre-feet. If you've got 60 wells pumping ten gallons a minute, you get your water supply in 130 days. The well has to keep pumping for 365 days. I used it for 360 days which leaves me 260 days that I need to store that water. You soon realize that the storage pond will require 1/3 of all of the acreage that you're planning to irrigate.

Limited CBM produced water quality information exists, particularly in the new development areas in southern and southwestern Wyoming and some locations in Colorado. What information is available suggests that the quality is significantly impaired compared to water in the Powder River Basin. I was encouraged by information that I saw today suggesting most of the water that we deal with in the Powder River Basin would be accepted by California in a hurry. It's just a matter of how we're going to get it moved over there; don't forget we heard earlier about the expense of moving it. Most of the data suggests that the water is of better quality than in other areas where development is going to occur. This water likely can be put to beneficial use in irrigation.

Figure 10 shows photos from a project we've been involved with for several years, funded by the Department of Energy and the Montana Department of Commerce. We've been looking at various means of using CBM water for beneficial use. Water management progress in the Middle East inspired us to look at using saline water for irrigating barley intended for beer brewing. We picked over a bunch of barley lines that are good for beer producers and have been grown very successfully. The photo on the left shows barley irrigated solely with simulated CBM product water from the northern portion of the PRB; the photo on the right is barley irrigated solely with non-saline, non-sodic water comparable to the Yellowstone River at Terry, Montana. Together, they illustrate that it's possible to use this water under the right types of management conditions.

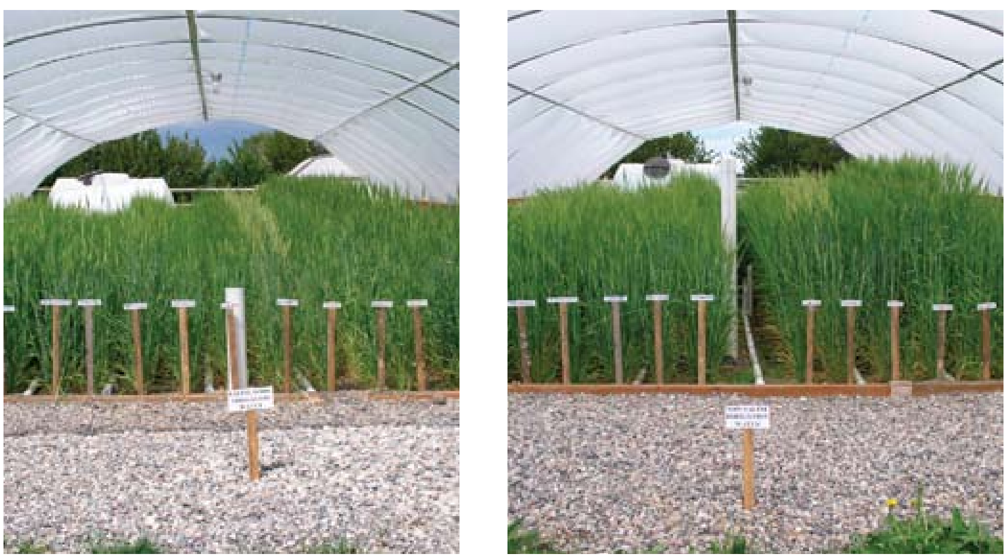

**Figure 10: Barley Growth Using CBM Product Water (on left) and Non-Saline, Non-Sodic Water (on right).**

Yet, there is another side to that coin and consequences to be paid. Researchers at the University of Wyoming looked at how soils behaved under actual operator industry-managed CBM irrigation sites.[1] They looked at six different sites and the change in chemistry of those soils over time with irrigation with CBM water. Their data show that the soil begins to take on the characteristic of the water that's there. The authors stated that CBM water was different than the soil being irrigated, yet the soil began to take on characteristics of the water – there were significant accumulations of sodium in the soil. Sodium is one of the problem issues that we deal with in irrigation.

Product water is not a good candidate for sole-source irrigation. Modestly saline-sodic water needs to be mixed, used in a conjunctive manner, if it is going to be used for irrigation. The lesson learned, and we know that lesson from a lot of different places now, is that chemistry of the soil dictates some of the opportunities and some of the beneficiary uses of that water.

The other thing that we looked at is what happens below those fields, below those sites where you used CBM water or water of impaired quality. Figure 11 shows what we found looking at changes in shallow ground water chemistry over a period of time. We're looking at changes in salinity within ground water that, not surprisingly as salinities go up over time, eventually have potential to bear on the downstream.

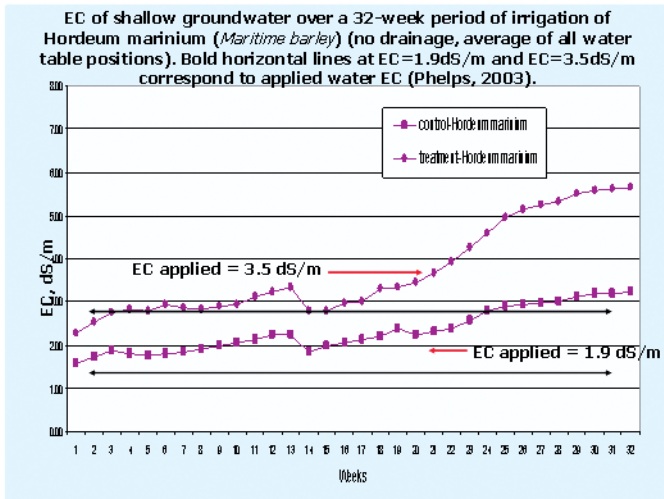


**Figure 11. Changes in Ground Water After Irrigation**

We also looked at soil responses to accidental spills, intentional long-term discharges, and ponding. I spoke to a couple of ranchers this morning and they assured me that what we had predicted had happened: we had ponds that had stopped taking water. I was not surprised, and I can explain. Figure 12 shows soil pH and Exchangeable Sodium Percentage (ESP) responses to periodic flooding/inundation with produced water from a northern PRB CBM well. The blue lines represent what the soils were like before CBM development, or before the discharge. The pink lines represent what the soils looked like after a period of time with water being applied. From a soil science perspective, they're not a surprise to us.

The threshold generally used for ESP is about 15. If the ESP exceeds 15, the soil will begin to disperse, or lose its

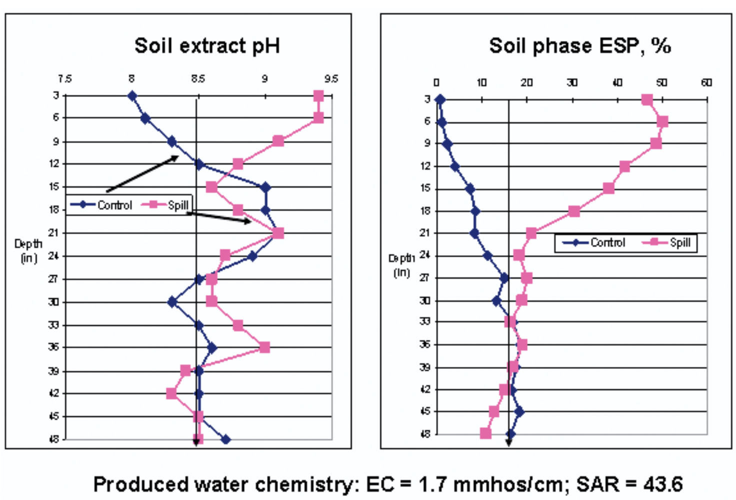


**Figure 12. Soil pH and ESP Response to CBM Water**

structure. Once it loses its structure, it loses its drainage characteristics. Once it loses its drainage characteristics, it becomes a saline site. The threshold that we use for salinity is somewhere in the range of 3 mmoles/cm; however, threshold depends on which plants you're looking at. Some of our plants are sensitive at 2 mmoles/cm or less. More-tolerant plants will tolerate EC up to 8 or higher; this means you need to know what plants you're dealing with and how to accommodate the soils.

If we look at the SAR (Figure 13), the threshold we identify is somewhere in the neighborhood of 12, but we now have data that substantiate a threshold could be as low as 4 or 5.

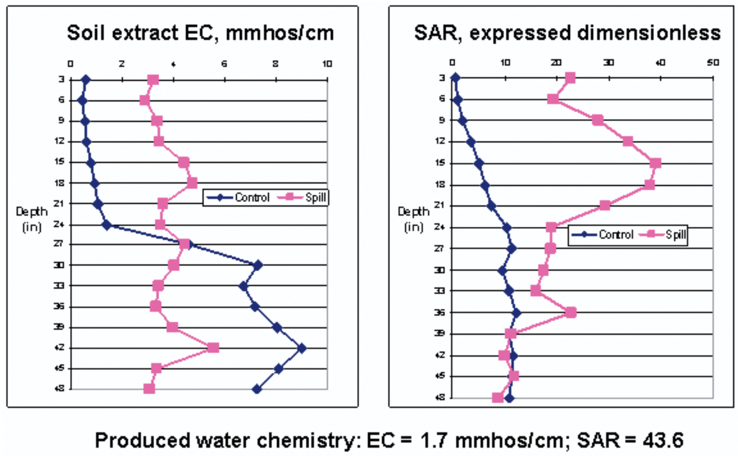


**Figure 13. Soil EC and SAR Response to CBM Water**

You can begin to see the consequence of water disposal, at the site itself or when that water gets into the channel or begins to go someplace else. The lesson learned reinforces what we knew: Produced water is not a good candidate for sole-source irrigation. The modestly sodic and saline water needs to be mixed or used in some conjunctive fashion.

### Augmentation

Let's consider the potential of using water to augment streamflow during periods of drought or low streamflow. The posters included in this workshop have done a good job of describing chemical changes of this water and produced water

Produced water that's sodium bicarbonate rich tends to behave in a certain way when it is exposed to the atmosphere or when put in a stream:

- The salt concentration generally increases, because the water is evaporating.
- Soluble calcium concentration will decrease, causing some of these infiltration ponds to stop taking water or begin to lime in the bottom.
- The SAR will increase.

These predictable chemical changes mean one needs to follow the discharge all the way through the chain of potential impacts down gradient. The chemistry is likely to change as one moves downstream.

We monitored three different waters – one sourced from the Powder River, a CBM produced water, and a saline sodium water – over a nine-day period. Table 1 shows how the waters changed.

| | Initial vs. Final pH | Initial vs. Final EC (dS/m) | Initial vs. Final SAR | % Change EC | % Change SAR | % Change pH |
|---|---|---|---|---|---|---|
| Powder River | 7.4 / 8.1 | 3.07 / 3.75 | 3.7 / 4.4 | 22.15 | 18.92 | 9.5 |
| CBM | 7.7 / 8.4 | 3.36 / 4.01 | 12.5 / 18.0 | 19.35 | 44.00 | 9.1 |
| Saline-sodic CBM | 7.5 / 9.1 | 5.42 / 6.71 | 20.7 / 33.8 | 23.80 | 63.29 | 21.3 |
| | | | Average % Change: | 21.77 | 42.07 | 13.3 |

**Table 1. Change in Water Chemistry for Three Water Qualities Over a Nine-day Time Period (Subject to Evapoconcentration)**

Changes in the salinities are not unexpected. The salinities increase significantly, and they are a function of water quantity and evaporation conditions. The SAR values changed very dramatically. This is a detrimental parameter with respect to irrigation water management, and this dramatic change warrants close monitoring. The pH also changed, predictably. Again, some faculty members at the University of Wyoming looked at produced water when it's discharged into a stream.[2] They observed the pH of the CMB discharge increases significantly, from 7.1 to 8.88. Specifically, pH increased in the downstream channel before that water reached the receiving stream. Dissolved calcium concentration decreased as expected, and the SAR increased as the water moved downstream. It now becomes a matter of not just managing that water onsite but managing that water all the way through the chain.

Yet another issue to consider: what are some of the other impacts within the stream? Researchers in Bozeman looked at water discharges into the Powder River in Wyoming as it flows into Montana.[3] The authors observed that the dissolved solid concentrations were in excess of historic values in the USGS database for the receiving stream. Another finding that's getting much more attention is the removal of non-desirable species within stream channels. Lesson learned: product water is not a good candidate for large contributions to stream flow without expecting some measurable impacts on the aquatic environment.

We're learning some things that will help us manage this water without some expectation of environmental impact on aquatic environment. In terms of sites where water is withdrawn, a study reported by the Montana Bureau of Mines and Geology[4] looked at the impacts of large scale CBM energy extraction and water extraction within the northern part of the Powder River Basin. One of the conclusions of that study was that there were significant drawdowns in the aquifer, ranging from 220 to 550 feet within the field of active CBM recovery. A lot of the coal seams serve as domestic water supplies; so as you begin drawing down the wells, those domestic water supplies become less and less available. Those drawdowns were projected to extend as much as five to ten miles outside the CBM development/recovery field. One conclusion: flows from springs and wells supplying water for livestock, domestic, and wildlife uses, and sourced from coal seam aquifers from which CBM is being extracted will be diminished and may be eliminated within the areas of drawdown. The authors concluded that there may be some effect on base flow if all the water was going into infiltration impoundments. The lesson learned: withdrawals of large volumes of produced water are likely to have measurable impact on the local ground water hydrology; this impact may possibly translate to alterations in surface water hydrology.

### Wetlands

We saw this morning that we have been successful at targeting wetlands for using water for beneficial purposes. The hypothesis that we started with was that we could use specific plant species in communities that would be tolerant of the water. We quickly learned that, while the hypothesis is good, there weren't enough plants out there to use the water; and we needed to look at what the implications were. One of the things we did see was there were certain species that performed very well; native species have established hydrologically distinct communities in ephemeral channels now running with produced water (Figure 14). The question becomes: are these species desirable? The livestock manager may be pleased with the water, but he or she may find plant species establishing that aren't necessarily desirable.


**Figure 14. Native Species Populating Wildcat Creek, Running Produced Water, Campbell County, WY**

I want to summarize with a couple of different points:

- There are many small amounts of water in many different places out there on the landscape, a situation that offers a real challenge to us in terms of beneficial use management. Those water resources are too dispersed to be easily managed collectively.
- It's debatable about the quality of that water and its suitability exclusively for single uses.
- There are questions about long-term availability. I can understand the reluctance on behalf of an operator to make major investments in infrastructure or equipment, knowing it's only a short time in the scheme of project development.
- There are questions about the short and long-term environmental implications.

I want to share a few statistics that illustrate how we could be looking down the road. Cumulative production between 1987 and December, 2004, in the Powder River Basin was estimated by the Ruckelshaus Institute of Environment and Natural Resources at the University of Wyoming to be about 300,000 acre-feet of water pumped. Annually that is about 65,000 to 75,000 acre-feet. That water represents 1.5 times the storage of Lake DeSmet, one of the headwater reservoirs of Wyoming just south of Buffalo and Sheridan, or one half the annual storage in Buffalo Bill Reservoir, also in Wyoming. If one was to assume that all the CBM produced water in Wyoming could be blended with the combined storage of Lake DeSmet, Buffalo Bill Reservoir, and Glendo Reservoir, the co-produced water volume would constitute only about 1.5% of the aggregate storage of these three reservoirs during the past 17 years. If we're in a drought, having 1.5% more water may not be significant, but it's certainly something we'd be interested in. On an annual basis, all the CBM water that was being produced in Wyoming amounts to only about 4.5% to five percent of the combined storage of those three water bodies.

Most likely, the question will not be one of what to do with this new-found good fortune but rather one of how to work it into the system presently in place, how to identify and amplify the benefits and opportunities that might be there, and how to minimize the adverse impacts. I'll end emphasizing a statement I heard this morning that I think is very appropriate. We've learned how to co-mingle and develop conjunctive water management practices, but we're still learning about the legal system and environmental regulations and how those things have to be blended together. That's the new area we need to work on if we're going to figure out how to put this water to beneficial use.

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**Jim Bauder** is a professor and Extension Soil and Water Quality Specialist in the Department of Land Resources and Environmental Sciences at Montana State University, where he has been employed since 1980. He has a B.S. in forest management, M.S. in watershed science, and Ph.D. in soil physics with emphasis on irrigation and drainage science. He earned his Ph.D. at Utah State University. He currently directs the MSU Extension Water Quality research and education program, which includes teaching, research, and outreach. He is a Fellow of the Soil Science Society of America, the American Society of Agronomy, and the Soil and Water Conservation Society. He is also a recipient of the U.S. President's award for Outstanding Environmental Stewardship. Contact him at (phone) 406-994-5685.

*Produced Waters Workshop –*

# Water and Energy Policies: Old Obligations Up Against New Needs?

Moderator: Dave Stewart
Stewart Environmental
Fort Collins, Colorado

## Who Owns the Right to Treated Produced Waters?

by Steven Bushong,
Porzak, Browning & Bushong, LLP, Boulder, CO

My talk today is about produced water. The only way to talk about ownership of produced water in Colorado is to talk about how we get the right to use water in Colorado. The reasoning is this: the lands in Colorado and most western states were principally owned at one time by the United States government. When the federal government opened up the western states for private ownership, they did it through various mining acts and homesteading acts and the like. The law is clear that, when you acquire private ownership of the land, you did not acquire the right to the water. Ownership of the water was left to the local rules and customs.

### Prior Appropriation

Accordingly, in order to understand who owns produced water, we have to look at the local customs and laws. In Colorado, the laws on how we distribute water started forming before statehood. When the early pioneers came out here, they realized pretty quickly that the riparian doctrine that is applied in the eastern U.S. wasn't going to work. That's a doctrine declaring if you own the riparian land, you are entitled to a share in the water flowing past your property. But in the dry landscape of the western states, it was clear early on the water needed to be taken from the stream to where the use was needed.

Colorado and most of the other western states developed what we call the prior appropriation doctrine. That doctrine allows anyone, whether you own the stream bank or not, to appropriate the right to use water on a first-come, first-served basis. In fact, that basic doctrine was established so early that when Colorado first adopted its constitution; it provided that the water of every natural stream is the property of the public and dedicated to the use by the people of the State, subject to appropriation (Art. XVI, Section 5). In fact, the constitution provides that the right to appropriate that water shall never be denied (Art. XVI, Section 6). Not only does the constitution essentially recognize the prior appropriation doctrine, it even goes so far as to give you a private right of condemnation. If you need to get the water from the stream through different people's property to your property, you can go in and condemn a ditch right or flume right to get the water there (Art. XVI, Section 7).

### Requirement for a Water Right

The requirement for a water right, in its simplest form, is just diversion or control of water for beneficial use. Diversion means, for example, a ditch diverting water out of a stream; but it can also mean a well that diverts water out of the ground water.

Beneficial use is really an evolving concept in Colorado. In addition to very traditional concepts like irrigation and mining and domestic use, we now know that snowmaking, recreation, wildlife, all sorts of uses – even dust suppression – have been deemed beneficial use. It comes down to a question of fact. If you are putting that water to some type of use and getting a benefit out of it, you have a pretty good argument that it's beneficial use. It's not really that simple, however, because even in the statutory definition of beneficial use, we have other concepts like reasonableness and efficiency. These are the two primary elements of getting a water right.

Once you've diverted the water and placed it to beneficial use in Colorado, you actually have a water right. The problem is, you may be the only one who knows that you have it. That's not usually enough. What you have to do is get a priority for the water right. That priority then fits into the prior appropriation doctrine. The way we did that previously in the state was to have what were called 'general stream adjudications,' and from time to time the state would come in and figure out who had water rights and organize the relative priorities. The oldest right got the number one priority, the second oldest right got the number two priority, and so on. That law was changed in 1969 and, no doubt, changed by a water lawyer, because now what you have to do is go to water court to get a priority in Colorado.

Figure 1 shows the seven different water court divisions that correspond to the different major drainage basins in Colorado. Right now, we are located in Division 1, which is the South Platte River Basin. Once you file an application in water court, it's really somewhat a free-for-all, because the whole world gets notice of your application, and anyone who wants to come in and file statement of opposition can do that. We may end up with no objectors in your case.

The priority date of a water right is now based on the year that you file the application in water court. You could've been using that water for 100 years, but if you filed this year, it's a 2006 priority water right.


**Figure 1. Colorado's Seven Water Divisions**

For water rights that are filed in the same year, we then look to what's called the appropriation date. That's the date in which you had the intent to divert the water and actually took some actions that were consistent with that intent. For water rights filed in the same year, the earlier the appropriation date the more senior the priority.

### Components of a Water Right

If you're successful in water court, you'll get a water court decree. It will provide definition to your water right. It will provide the point of diversion, the quantity of flow rate – or the diversion rate, the place of use, period of use, time of use, and also explain the type of beneficial use.

In Colorado, you can also go in and get what's called a conditional water right even though you're not actually diverting and putting the water to beneficial use yet. In this manner, you can get a priority date that will relate back to the date of your application. This allows the appropriator to develop the infrastructure to divert the water and put it to beneficial use over time, with the comfort of already having a priority date for the water right. Conditional water rights have additional elements of proof that must be satisfied in addition to diversion and control.

### Water Rights Priority System

What does it mean to have a water right? Let's say you've gone through water court and you have your water right. In Colorado, that water right is like a real property right. It allows a one-time use of the water for whatever beneficial uses you have decreed. Any return flows that come off of that use go back to the stream and becomes available for diversion and re-diversion and re-diversion by other users. There are exceptions to this rule, and they are important to produced waters because one of those is non-tributary water. For non-tributary water and other sources of imported water, you can use it and reuse it to extinction.

Having a water right also means that you have a right to divert the water in priority. If you are in priority, which I'll describe here in just a minute, then you can insist that upstream water rights not divert their water if that action is going to injure your diversions.

Let's talk a little bit about administration. In Colorado, the State Engineer's Office is ultimately the entity responsible for administering water rights. The State Engineer has a division engineer for each of those water divisions illustrated in Figure 1. Each of those division engineers has water commissioners. Those are the people who are, essentially, policing water rights and deciding who gets to divert and who doesn't. Administration is based on the prior appropriation system, which is basically the first-in-time, first-in-right system. This means a senior water right has to be fully satisfied before the next most senior water right gets to divert. If that right is fully satisfied, then the next most senior right gets to divert, and so on. Those most-senior water rights get to divert their full entitlement before the more-junior water rights get to divert, without preference among beneficial uses. Figure 2 is a simple diagram that shows how the priority system works.

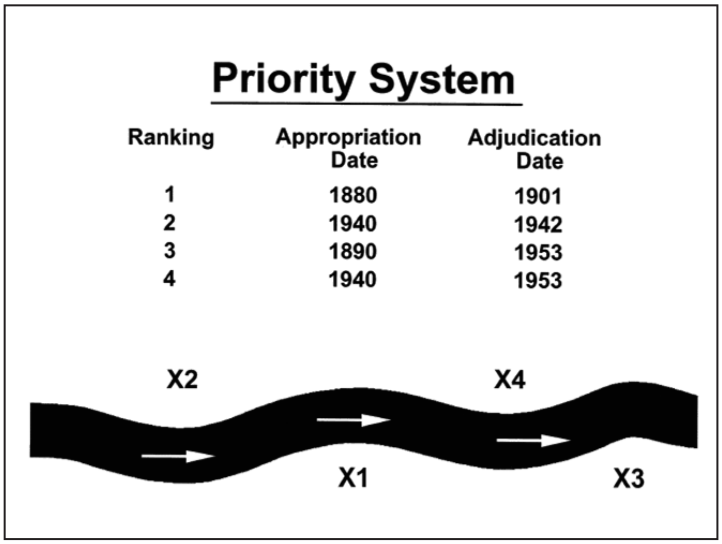


**Figure 2. Priority System**

In this diagram, we have a stream segment with four priorities. As you can see, the rank of the four priorities is based on their adjudication date or the date at which the application was filed. If you have two applications in the same year – as in this example with two in 1953 – then you look to the appropriation date. In this scenario, if priority number one needs water, the party can call the water past priority number two. Priority number two may get zero water in order that priority number one gets to divert its full time limit.

Priorities three and four, because of their location, may be in better shape than priority number two. Here's the reasoning: priority one is going to have return flows coming back to the stream, and that will help satisfy the downstream right. It's not just about priority; it's also about location of the water right. You can imagine how thankless the job is of a water commissioner who might have a stream segment with a thousand water rights on it. It's his or her job to decide who gets to divert and who doesn't. Moreover, since Colorado does not prioritize beneficial uses, priority number two could have [filed?] for greater economic benefits than priority number one and still get no water. The senior priority gets to call water past the junior priority.

### Change of Water Rights and Augmentation Plans

In a lot of basins in Colorado, there are actually more water rights than there is water. In the situation of over-appropriated basins, the law has developed a number of different wrinkles to try to increase maximum utilization in Colorado. I don't think it's important to go into a lot of detail on this for purposes of this talk, but I'd like to talk about it just a little bit. For example, you can go out and buy a senior water right and change the location of use. When you do that, you get to divert under that senior priority. That's one way that water rights are still the great bastion of free enterprise: if that water is more valuable to you, you get to go out and buy it. Of course, there are several limitations. When you change a water right, you can't injure the stream conditions for all the junior water rights that have come online. A lot of the work that water lawyers do involves these kinds of changes of water right and making sure that it's not causing injury to other water rights.

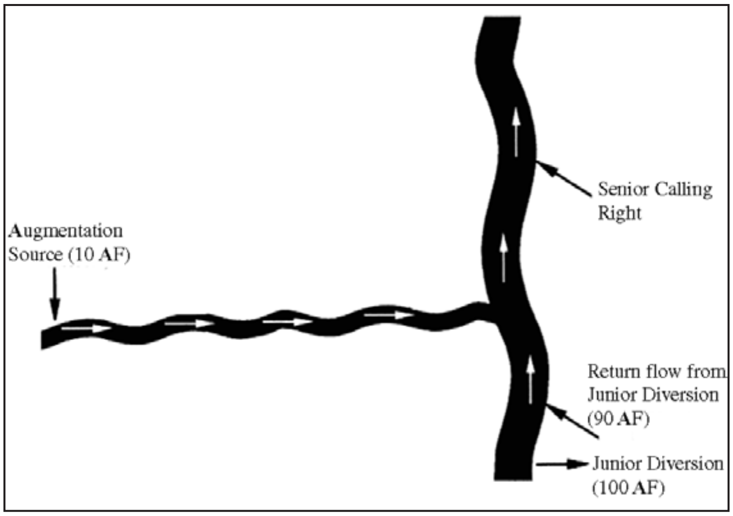


**Figure 3. Illustration of Augmentation Plan**

Another method to remedy the shortcoming of a junior water right is to obtain a court-approved augmentation plan. If you have a junior water right, you can continuously divert out of priority as long as you make sure there is no injury to a downstream water right, by providing replacement water under an augmentation plan. Figure 3 illustrates a simple example. You have a junior water right that diverts 100 acre-feet of water. Let's say it returns 90 acre-feet. Downstream you have a senior calling right that is shorted the difference, ten acre-feet. Without an augmentation plan, if that downstream right is calling, you never get to divert under your junior water right. If we have an augmentation source here on a tributary, an augmentation plan provides for the replacement of the ten acre-feet of depletion to prevent injury to the senior right. Since the downstream senior right is not injured, the junior right can divert out of priority. The bottom line: in this example, with just ten acre-feet of augmentation water, the junior right can divert the entire 100 acre-feet of water. Therein lies the value of an augmentation plan.

To be considered augmentation water, the water has to be either decreed for that purpose or it has to be what is called 'fully consumable water' – including water that is imported into the basin, or non-tributary water. A lot of produced waters are non-tributary water.

### Ground Water

Let's switch over to ground water. What I just provided to you was a cursory review of how we administer and appropriate water for surface streams. There are essentially three principal types of ground water – with several exceptions:

- tributary
- non-tributary
- designated ground water.

### Tributary Ground Water

In Colorado, there is a presumption that ground water is tributary. What that means is that it is in some way hydrologically connected to the surface stream. If it is, then everything we've discussed about prior appropriation doctrine and the constitutional right to divert applies. The reason: if you're diverting ground water that is somehow hydrologically connected to the stream, that action is going to deplete that stream. It may not deplete it instantaneously; it might take a while, but it will deplete the stream. So we treat that water as 'waters of the state,' and it's subject to all the laws I just talked about. There are some different requirements for wells, such as obtaining a well permit in order to construct and operate the well; but generally the prior appropriation doctrine applies.

### Designated Ground Water Basins

We also have in the state what we call designated ground water basins. Generally, these are basins wherein ground water in its natural course would not be required for the fulfillment of decreed rights. Instead of the water court having jurisdiction, you have to go before the Ground Water Commission. The Ground Water Commission will generally allow new wells in the designated basin as long as the proposed well is not going to somehow unreasonably injure other wells. The Commission will consider all the other wells that are in the area, and it will look at whether or not your proposed well is going to reduce the water table. The Ground Water Commission employs, essentially, a modified prior appropriation system for these designated ground water basins.

### Non-Tributary Ground Water

Non-tributary ground water is something I'd like to spend a little more time on. It's treated completely differently in the law from tributary water. As the word implies, this is water that doesn't really have any hydrologic connection to surface streams. Here's the book definition: water located outside the boundaries of a designated ground water basin, the withdrawal of which will not, within 100 years, deplete the flow of a natural stream at an annual rate greater than 1/10 of one percent of the annual rate of withdrawal. It is, essentially, completely separate from the streams. As a result, it's not subject to the constitutional right to appropriate; and it's not subject to the prior appropriation doctrine.

One of the values of this non-tributary water is that it's fully consumable. Once you bring it up to the surface, you have the right to use that water for any beneficial use, including augmentation, and can reuse it and reuse it to extinction. How do you get the right to do that?

- overlying land ownership
- written consent of overlying landowner
- municipal or quasi-municipal ordinance
- mining activities (water produced by dewatering geologic formations)

We allocate non-tributary water in the state of Colorado primarily by land ownership. Owning the overlying land is one way you can get the water. Obtaining written consent from the overlying landowner is another way. The third is somewhat a different animal, based on municipal or quasi-municipal ordinance: for the use of non-tributary water within boundaries in existence as of 1985, in which case the consent of the surface landowners within that municipality or water district is implied.

There are a number of limitations on non-tributary water. The rate of withdrawal is limited to basically one percent of the non-tributary water underlying that land. Further, you need to get a permit from the State Engineer in order to construct a well for non-tributary water. Once permitted, the State Engineer has to determine that there's unappropriated water available and that the intended well is not going to injure other vested rights. Another one of the limitations is that there can't be another well within 600 feet. There are also other limitations that apply to a right for non-tributary water.

Although one needs to get a permit in order to actually construct and operate a non-tributary well, one can go to the water court for recognition of a right even before he or she is ready to construct a well. The right to non-tributary ground water vests when the permit is issued or the decree is granted.

The non-tributary ground water allocation that's probably most important to us in this meeting is through mining activities. One may obtain the right to non-tributary water if it's produced by dewatering geologic formations to facilitate or permit the mining of minerals. The legislative history and the State Engineer's Office are very clear that this allocation applies to oil and gas production. So it is a critical provision for produced waters C.R.S.S. 37-90-137(7).

Under the law, you don't even need a permit if you're just going to waste the produced water. In that case, you can – the way the law is currently situated – do whatever the Oil and Gas Conservation Commission will allow you to do to dispose of the water, including reinjecting it in wells, putting it in discharge pits or evaporation pits, spreading it on roads – with certain limitations – or discharging it to streams with a discharge permit. If you want to put the produced water to beneficial use, the Oil and Gas Conservation Commission allows you to do that, but it requires a permit from the State Engineer's Office.

The limitations on beneficial use of non-tributary water associated with mineral extraction are different in many ways than those applying to surface owners. An oil and gas well that's producing non-tributary water intended for beneficial use is not subject to the 1% rule. In fact, you're only limited by the withdrawal rate that's necessary for dewatering the geological formations. You also don't have the 600-foot spacing requirement. There's also no required finding that unappropriated water is available. If you are generating produced water, you either need to obtain a state permit that allows you to do it, or you can go to court and get a judicial recognition. Oil and gas operators are on the same footing as surface owners in terms of obtaining a right to use non-tributary water.

## Colorado Water Ownership

I realize that was a real fast summary of about 150 years of Colorado water law, but let's now talk about how it applies to ownership. Owning land does not grant you an ownership to water. There was a very recent Colorado case that made this point very clear, stating property rights of a landowner do not include the right to control the use of water in the ground. The same case made it clear that water is not a mineral, either under Colorado law or federal law. Accordingly, owning mineral rights does not necessarily mean you own the right to the water. The right to use water is established by local rules and customs, and the law that I've just described for you is part of the local rules and customs that apply in Colorado.

If it's tributary water, who owns it? Tributary water is subject to the prior appropriation doctrine. If you want to put it to beneficial use, you have to go into water court and get a water right. Once you do that, you have a priority, and it can be administered as such; you can put it to whatever beneficial uses are decreed. In an under-appropriated basin where there's more water than there are water rights, getting a water right and putting the water to beneficial use is a pretty straightforward process. In an over-appropriated basin, obtaining just a water right may not be worth as much because there's little chance to exercise it in priority unless you have an augmentation plan. The way the law is set up currently, the disposal of tributary ground water produced by oil and gas operations doesn't require a water right. It's just subject to Oil and Gas Conservation Commission regulation.

There's a recent case that came up in LaPlata County that raises a real interesting question on that point. It was filed in 2005, and it's called Vance v. Hal Simpson. At issue were a number of surface owners in the vicinity of CBM oil and gas wells. Allegedly, those wells are producing tributary water and disposing of it in a way that's fully consumptive, putting it into deep wells or into evaporation pits. The question: if that water is subject to the constitutional right to appropriate, and the senior rights are protected by the prior appropriation doctrine, do such disposal practices result in injury to the senior rights? The decision in this case will probably have broad applicability throughout the state. I know the State Engineer's Office has sought to dismiss the case, saying produced waters that are not being put to beneficial use are solely the jurisdiction of the Oil and Gas Commission.

If the water is non-tributary, the surface owners have what we call an in? right. It only vests if you get a permit from the State Engineer's Office or you get a judicial decree. Until that right vests, it's always going to be subject to legislative change. It's the same way for oil and gas companies. In order for that right to apply non-tributary water to beneficial use to vest, one needs to get a permit from the State Engineer's office and/or a decree from the water court. Once vested, the right is not subject to legislative change.

The rights of the oil and gas company to use non-tributary ground water are going to be on the same footing as, if not better than, those of the surface landowners, considering how the law currently reads. It's my opinion that non-tributary water is not subject to the type of issue that is raised in the LaPlata County case. The reason: the use and allocation of non-tributary water is purely a statutorily created right, and the statute allows the removal of non-tributary ground water as part of oil and gas operations.

In summary, no one individual owns water. You can own a right to divert the water and put it to beneficial use. For tributary waters, that right vests under the prior appropriations doctrine. For non-tributary waters, that right vests by permit or decree subject to the law that's out there. For designated ground water basins, the right vests by permit that's issued by the Ground Water Commission subject to all its statute and regulations. Most importantly for purposes of produced waters, the law allows an operator to obtain the right to put produced waters to beneficial use, but it requires the operator to step through the various legal procedures that are out there with the exact nature of the procedures dependent on whether the ground water is tributary, designated, or non-tributary.

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**Steve Bushong** has been a partner at the law firm of Porzak, Browning & Bushong, LLP since 1996 where his practice focuses on water rights, water quality, and environmental law. After receiving his law degree from the University of Colorado in 1992, Mr. Bushong clerked for the United States Court of Appeals, Tenth Circuit, and was an associate at the law firm of Holme Roberts & Owen. Prior to receiving his law degree, Mr. Bushong received a B.S. degree in Biology and a M.S. degree in Limnology from Iowa State University, and was a research scientist at the Johns Hopkins University, Applied Physics Laboratory where his research focused on the fate, effect and transport of contaminants in aquatic ecosystems. Mr. Bushong has published numerous articles principally on issues of water quality. Contact him at (phone) 303-443-6800.

## Who Regulates the Quality of Produced Waters – Oil and Gas Commissions or Water Quality Control Commissions?

by Leah Krafft, Wyoming Department of Environmental Quality

I'd like to talk about the NPDES program and how we permit the coalbed methane (CBM) industry in Wyoming. I also want to talk in more detail about a new permitting approach that we started to implement in about the last year or so – our watershed base permitting. This is a new initiative, and it's very exciting for our particular program.

### Regulatory Framework

Let's start by talking about the coordination activities. There are a lot of folks in this room today who, through DEQ and our watershed base permitting and our non-watershed base aspects, do a lot of coordination with different agencies as well as the landowners. In general, if an operator chooses to discharge that produced water to the surface, of course they do need a permit in Wyoming through our program. The legal basis, or regulatory framework that gives us the authority to issue those permits, come from two bases, either the federal or the state regulations. On the federal side, obviously, is the Clean Water Act. On the state side, we have a variety of regulations in Wyoming, including the Environmental Quality Act as well as our water quality rules and regulations.

While we have a variety of different rules and regulations, there are two chapters that specifically apply to the permitting program. The first one is our Chapter One, Water Quality Rules and Regulations. That is the bible of our program because it defines what all the water quality standards that we're trying to achieve. It identifies the designated uses of the receiving streams. For example, is it stock and wildlife that we're trying to protect? Irrigation? Drinking water? Permitting is the avenue for trying to protect those uses. Through the permitting, we're making sure we establish appropriate effluent limits to control the quality of the water and assure we're meeting those different designated uses.

Keep in mind, there's a lot of terminology that gets thrown around in different meetings, yet there's a definite distinction between a designated use such as our irrigation activities or stock and wildlife use, and beneficial use, which was discussed previously and which the State Engineers Office will typically identify. We know that there's a great potential for this produced water to be used in a beneficial manner. In Wyoming, the primary method is through stock and wildlife activities (Figure 1), but it could also be used in managed irrigation.

**Figure 1. Produced Water for Stock and Wildlife in Wyoming'**

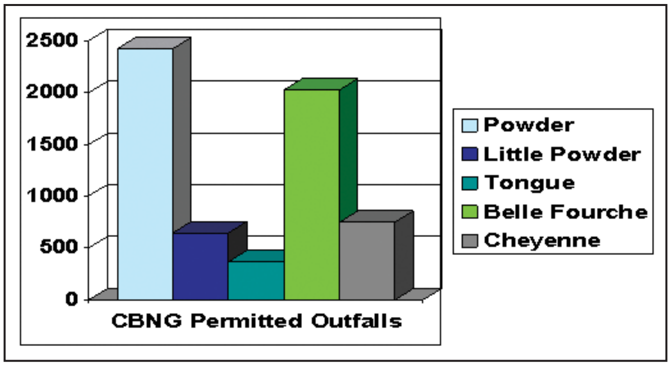


**Figure 2. Permitted CBNG Outfalls in Wyoming**

We also have to consider the state of Wyoming currently has about 5,000 permitted outfalls (Figure 2). That doesn't equate to individual permits. One permit can have multiple outfalls, but we have about 5,000 permitted outfalls in the Powder, Little Powder, Tongue, Belle Fourche, and Cheyenne River basins.

### Watershed Permitting Approach

The DEQ started recognizing the fact that we're experiencing a lot of development in our area. We knew that we had to come up with a different permitting approach to make sure we're still protecting the different designated uses of the receiving streams. The approach we started implementing was the watershed base permitting approach. This approach is very different compared to our previous approach of doing permits on an individual basis. Issuing individual permits made it difficult to look at the total impact of those individual permits and the effect of the different produced waters and their drainage.

.The objective of our new watershed base permitting approach is to conduct a holistic evaluation of individual watersheds. We want to take a look at a reasonably representative sub-watershed basin to identify all of the uses out there. Are there irrigation activities? Are people using that water for stock and wildlife activities? What type of activities is occurring in individual basins? We want to take a holistic perspective, look at how many discharges are out there or how many could potentially be out there, and look at the individual water characteristics of that individual watershed itself.

Another objective is to get an approved permitting process. We think by taking a holistic perspective on permitting, instead of permitting on an individual basis, we'll be able to improve the process. In this manner, we hope to develop either a general permit to cover the individual CBM activities, or we can develop a watershed permitting plan that might apply to individual type of permits. Keep in mind, this new watershed permitting approach is unique to the CBM industry. We have not incorporated this type of permitting approach within other industries. Right now we know there's very concentrated development, in the Powder River Basin and other basins as well. We feel it's appropriate to focus our efforts at this time on the CBM type of discharges.

Obviously, there are going to be a lot of benefits from this watershed permitting approach:

- **Predicted outcome:** For example, we developed a general permit or a watershed plan for a particular basin. This provides the landowners, the operators, as well as just anybody who's interested in that particular basin, an understanding of what type of water quality will be expected to be discharged in that particular basin. In short, this process will help set the game rules and make sure everybody knows what those game rules are when they move into that particular basin.
- **More efficient permitting:** Further, we anticipate a more efficient means of determining what impacts all the discharges that particular sub-basin will have. That will help us be more efficient doing our jobs a DEQ.
- **Improved mechanism for hearing and addressing complaints:** Sometimes it's difficult for landowners to stay on top of all the different permits that could be coming into their particular basin or drainage. This is an up front, stakeholder-based process in which individual stakeholders such as landowners or different organizations can help us develop these watershed general permits or plans. There is a lot of up-front commitment from these individuals that will help them understand and hopefully address some of their concerns.

- **Improved environmental protection:** This will be a more informed decision-making process for DEQ. Not only will all the landowners know what all the game rules are, but also DEQ will have a common set of game rules on which to base permits.

We initiated the watershed permitting approach in early 2000 with our first watershed permitting meetings in November of 2004. This is a new approach, and our initial goal was to try this approach for all of those five different basins within three years – to get this done by December 2007. Frankly, I think this is an ambitious deadline that we've imposed on ourselves. Hopefully we can meet it, but I expect it to take a little bit longer. Some of these processes, like the first watersheds that we're moving into, are taking a little bit longer than we anticipated. We want to make it a reasonable time – less than ten years – to make it effective for everybody.

The watershed permitting process is a stakeholder process, based on informed consent. This is not a process where there's voting involved. Instead, we see at the table different people who are involved with the particular watershed:

- **State and local agencies:** In addition to DEQ, we may see other agencies such as Game and Fish, Fish and Wildlife, the State Engineers Office, and Oil and Gas. We want to make sure we have an understanding of what their requirements are. We want to know, for example, if there is any type of requirement the State Engineers Office has, and we want to make sure that our actions are not directly conflicting with what they're trying to achieve.
- **Landowners:** These are the guys in the trenches. They're living on the land, and they're also living with the discharges on their land. We want to hear their perspective and get an understanding of what they're doing out there. Are they just irrigating natural grasses or, as in the Clear Creek watershed, are they irrigating some very unique vegetables out there? We have to be aware of that type of situation and what's going on. Are they using that water for stock and wildlife purposes? Are they cattle ranchers? We need to know that information so we can get an understanding of what's happening within that basin. The landowners are a great source of information for that.
- **CBM operators:** We need to understand their plans for future development in that particular basin. For example, right now in Fence Creek up near the Wyoming/Montana border, there is very limited development. Same with Clear Creek, with some limiting factors that preclude a lot of development. What we need to do is understand the operators' expectation for potential development in that particular basin. We also need to understand how they plan to manage that water. Are they going to use a variety of different management tools, maybe some managed irrigation activities? Are they going to use storage? Are they going to use reinjection, even as a limited option in some specific areas?
- **Environmental organizations:** We have a variety of different agencies as well as conservation districts at the table as well. Their feedback is important because these folks are the ones who are out in the field. They've been out there, they're dealing with the landowners, and they know what's going on.

What we tried to do is get all these stakeholders together. We want a reasonable number of folks in our stakeholders meetings – not as many as 50 people, but typically targeting 15 to 20 people. Then we try to educate one another on different perspectives and the different requirements of our different agencies. From there, once we get the information, we develop a plan or some type of permitting mechanism that's reasonable and accounts for all the different agencies' perspectives.

### Challenges to Watershed Permitting

This approach looked great on paper in 2004, so we proceeded. Then, with our first watersheds, we realized there are plenty of challenges to this approach –

- **Diversity of stakeholders:** Everybody has different perspectives. They want to use the water for different reasons and dispose of the water or reuse the land for different reasons – and each warranted recognition. We realized we had to identify some different sideboards and general rules under which everybody can work as we move through this particular process.
- **Resolution authority:** We also had to admit that, through this watershed permitting process, we're not going to be able to resolve all of the problems with CBM – and we know there're a lot of them out there. From the DEQ's perspective, we can only address those issues under our jurisdiction. We know that a particular issue might not be dealt by us but instead through another agency such as the State Engineer's Office or Oil and Gas Commission. And, there are a lot of issues that aren't adequately addressed by one particular agency. That is a challenge. How do we address that? One of the most difficult challenges is recognizing the fact that this process was not going to be the answer for all the different problems.

- **New requirements and initiatives:** There're new initiatives and new policies out there. DEQ is continuously growing. Things keep moving; we're learning more. People continue to propose different ideas and different perspectives. And this development of policy, itself, brings with it the challenge of permitting when many of these policies and initiatives are not yet finalized You know upcoming policy work will have some impact on that watershed permit, but you don't know exactly what that impact will be.
- **Self-imposed three-year goal:** There are 30 different watersheds in four different basins, 15 in the Powder, six in the Tongue, seven in the Little Powder, and two in the Cheyenne basin. Essentially, it's taking six to nine months, we hope, for each individual watershed – you do the math. We know we'll be overlapping watersheds. From our perspective, we have to have individual teams that go out there and address different watersheds. That's definitely a challenge to keep the resources and keep things moving so we can try to meet the ambitious goal.

### Current and Future Efforts

The first watershed we did was in late 2004. That was the Willow, Pumpkin, and Four Mile Creek watershed. The initial meeting was in January of 2005, and the process has gone longer than the six-to-nine- month goal. We've had five meetings to identify the different stakeholders uses within those basins, to characterize that watershed, and to look at the potential conditions that could be in the watershed permit or the plan itself. We've developed general permits for two of the three sub-basins and a plan for the third, Fourmile Creek Basin. We're nearing the finalization of these first three sub-basins or watersheds themselves. The permit went to its 45-day public notice on February 16, 2006, with yesterday, April 3 being the closing date of that time period. We've received several comments, and we want to digest them and have a final, sixth meeting, scheduled for April 11 and 12 to not only to discuss the comments and determine if changes should be considered, but, more importantly, to finalize these particular general permits and watershed plans.

The Fence Creek and Clear Creek Basins are the second watersheds we've started work on. The initial meeting for these basins was in August of 2005; again, five meetings where held to identify uses within the drainage, characteristics of the watersheds, and potential conditions for general permits. This set of meetings proceeded somewhat faster than those held on our first watershed, as we applied some lessons learned from the first watershed process to the Clear Creek and Fence Creek Basins. We hope to continue to learn ways to streamline this process and meet our goals. During the five-meeting process, looked at what uses are out there and characterized the watershed. We're nearing the finalization of this general permit. There will be a general permit for both the Clear Creek and Fence Creek, and we hope to put that into public notice around mid-April, with a final meeting and permit issuance before the end of June.

The next basins we'll be moving into will be the Tongue River (Hanging Woman Creek), Prairie Dog Creek, and Badger Creek. Our first meeting is scheduled for April 26 in Sheridan. The next sub- basins that we'll be moving into are Dead Horse Creek and Fortification Creek; we hope to be started sometime in the summer of 2006.

Most importantly, we're continuously learning – learning how to streamline this process and learning different ways to implement permitting activities and the different sub-basins. We believe this is a great initiative that DEQ is implementing. We have a very good web site that provides a summary of what we've been doing and where DEQ is in this particular process; go to http://deq.state.wy.us/wqd/WYPDES_Permitting/WYPDES_cbm/Pages/CBM_Watershed_Permitting/CBM_watershed_permitting.asp.

### New DEQ Issues

- **Reservoirs/permitting of groundwater:** This is a new initiative to take a closer look at ground water issues.
- **Bonding of reservoirs:** Again, we're seeing coordination between different agencies; the location of any particular reservoir dictates what agency you'll get that bonding through. Obviously, the bonding will help to reclamate once the discharge activity is done. DEQ and BLM are working jointly with this bonding type of activity.
- **Treatment/direct discharges:** As development starts moving toward the mainstem of the Powder River, it's more difficult, more challenging, to manage that water. Direct discharge may have to be an option out there, and that may mean some treatment activities. Treatment is definitely something that has to be considered. We have a better handle on water quality activities and what the water quality could be in some of these older drainages of the Powder River.

- **Changing DEQ regulations:** Obviously we're all learning, and as we're learning, hopefully, we're implementing new requirements. Certainly we have to be cognizant of surrounding states such as Montana and South Dakota, to make sure what we do in Wyoming does not have a direct impact on what's happening in those states.

### Coordination Efforts

We coordinate with several agencies. A lot of the folks sitting here today have been working with us, not only on the watershed permitting approach, but also on CBM and general permitting. The BLM is constantly giving us feedback as is USGS, which has a great monitoring network with better than 40 different monitoring stations within the Powder and other basins as well. That network is helping us figure out what's actually happening as water is being discharged in a real world environment. We're also working with the Wyoming Oil and Gas Commission. When their lease holdings start discharging to mainstems, they and the State Engineer's Office and Game and Fish are involved.

In general, the watershed permitting approach is a great initiative that DEQ is implementing. We think it's going to be a more effective permitting approach, especially for the CBM industry centered in a couple of different areas. The watershed approach aims to make sure we're permitting in an effective and efficient way and making sure that we're protecting not only surrounding states, but all of our designated uses.

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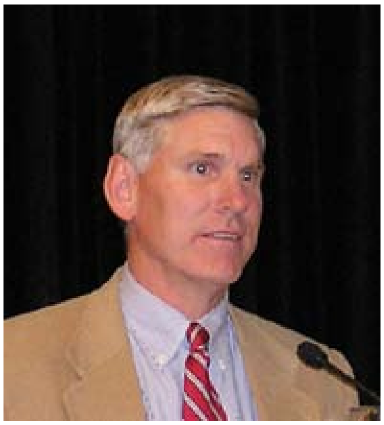
**Leah Krafft** has been with the Wyoming Pollutant Discharge Elimination System (WYPDES) Program for 14 years, initially managing the data systems for the program, then serving as the program's compliance officer, then drafting WYPDES permits for CBM and non-CBM operations. Currently, she is the program supervisor for the permitting staff. Contact her at the Wyoming Department of Environmental Quality, Department of Water Quality, in Cheyenne.

## What Is the Role of Produced Waters in Mitigating the Impacts of Oil and Gas Production on Surface Land Owners?

by Steve Degenfelder, Double Eagle Petroleum, Casper, WY



Double Eagle Petroleum is a small company listed on NASDAQ, with 14 full-time employees including a geologist and hydrologist I employ to help with our water issues. Most of our operations are in the state of Wyoming, but we don't operate any wells in the Powder River Basin. I'm humbled by the pedigrees and scientists and educated people here, and I think everybody's got one up on me, other than that tiny oil and gas company guy over there. Yet, I'd like to offer a different perspective for those of you who aren't with a public company, and that's the perspective of full disclosure – security exchange commissions and implementations. In other words, I'm not held responsible for anything I say!

### Oil and Gas Company Perspectives

I'd like you to consider a bit of our stark reality, especially in Wyoming, and invite you to include three issues in your future conversations and discussions. First, the state of Wyoming over the next two years is expected to enjoy a $1.8 billion surplus in tax revenues, nearly all related to the taxation of oil and gas, primarily natural gas and CBM. We've got a population of about 500,000 people in our state, and every man, woman, and child in the state receives over $2,000 in tax-derived benefits courtesy of oil and gas revenues. It is my opinion that this level of taxation has encouraged irreversible spending commitments by the legislature, to the point that Wyoming will rank #2 in the nation on education spending per student.

Second, we've heard that oil and gas companies have their own agendas and don't seem to be that cooperative. Oil and gas companies, whether they are tiny or very large like Anadarko, all operate their business in a proprietary manner; from the earliest geological idea, to the seismic tests we perform, to obtaining leases, even to how we dispose of our water – all can be very proprietary.

Third, we're trying to make our company as competitive as we can and also generate profits that make us attractive to investors like yourself with an IRA portfolio. Investment managers compare our costs to our rate of return to determine whether they want to buy our stock or not. It's a very, very competitive industry that we're in. Utilities, water associations, and governmental agencies can consider a cost as an expenditure that ultimately gets passed down to the consumer or the rate payer. As an oil and gas operator, if you incur too many costs above your revenues, you go broke. You lose your job.

### Limited Non-Treated-Water Discharge

The area that my company is most active in is south of Rawlins, known as the Eastern Washakie Basin in the Muddy Creek drainage. If you draw a line from Rawlins down to Baggs, Wyoming, that's basically the area – quite an arid area. We're planning to develop CBM in a 310,000-acre area that's predominantly federally owned surface. In the northern part, it's in the railroad checker board; in the southern part, there's more private land around the town of Baggs, mostly towards the edge of the play. Most of the play is in federal mineral surface.

In our area we're going to drill wells ranging from 1,500 to 2,500 feet deep. The water that we will extract with the CBM is not being consumed by area ranchers right now. In the CBM area, we're conducting, along with Anadarko, the Atlantic Rim Environmental Impact Study that assesses the impacts on drilling about 1,800 CBM wells over the coming ten to 20 years. To give you an idea of what's involved, assuming 1,000 out of those CBM wells are producing an average 1,000 barrels a day, I calculate the production of about 120 acre-feet of water per day, or 47,000 acre-feet per year. After the CBM is produced, we have to look for alternatives for water disposal or management – terms people use interchangeably.

I see that we have three alternatives: reinjection into underground reservoirs, surface discharge of untreated water, and surface discharge of treated water. Each of those options has different sub-options that I'll get into later on. From a non-scientist view, 5,000 mg/L TDS is the cutoff for good quality water compared to bad quality water – another person here mentioned as high as 10,000 mg/L TDS. Our water is 1,700 mg/L TDS. However, we're in the Colorado River drainage, so we have to adhere to standards imposed by the Colorado River Salinity Forum that represents the upper-basin and lower-basin states. They require water discharged to the surface have no more than 500 mg/L TDS, basically the same quality of your drinking water.

**Figure 1. View at Double Eagle Petroleum Compressor Site**

**Figure 2. Vegetation Above Permitted Outfall**


**Figure 3. Salt Tolerant Grass in Discharge Area**

Our CBM area is considered arid, with about six to nine inches of total rainfall per year. Figure 1 shows some of the landscape as seen from an office trailer on our compressor site.

We're currently allowed to discharge a maximum of about 4,000 barrels a day, or the salt equivalent, of untreated water through an old NPDES permit. Because it is an existing NPDES permit, we're allowed to discharge that into the Colorado River drainage. I mentioned 4,000 barrels a day, but it's the salt equivalent that's key. Figure 2 gives you an idea of what the drainage looks like above our outfall.

**Figure 4. Results of Discharge of 1,700-mg/L-TDS Water**

Compare that to the next picture, Figure 3, showing our tank battery in the upper right hand corner – you can see in the middle of the picture the growing grass. It is a salt-tolerant grass, I believe its called Alkali Bull Rush. While this water may not be appropriate for irrigating some sensitive crops, there is a vegetation that seems to grow quite handsomely in this drainage. Figure 4 is a great picture showing the results of discharge of untreated CBM water at 1,700 mg/L TDS.

### Treatment Investigation

Because we're limited on our water discharge in the drainage, about 95% of our CBM water is reinjected into underground reservoirs, into both Class 5 and Class 2 injection wells. One is at 9,000 feet and the other one is at about 3,500 to 4,500 feet. We are also exploring water treatment as a real opportunity for us, as a producer and as a supplier of beneficial use water, and we expect in a year's time we will be able to address the actual cost of treatment. We have identified the cost of one plant and have submitted it to DEQ for approval.

We're going to continue to look for the most economic method of water treatment that we can, looking at how costs can be offset by potential users of that water. We will consider plant costs, electrical costs, disposal of a waste stream – volumes that can run anywhere from 1% to 25%, plus the costs of people needed to run the treatment plant. I hope to assemble this itemization by the end of the year or first quarter of next year.

There are a number of ways that produced water can be put to beneficial use. The first is municipal consumption, which would, of course, require treated water. That's probably the most important possible application, considering some communities such as Las Vegas and others in Nevada that have big-time restrictions on water consumption. They're out of water. When these communities truly run out of water, their growth rate is going to level off or start shrinking. They've approached us about treatment of our produced waters, how they can appropriate it, and if it will augment their existing supplies. They know that this might be limited, but they also know that in a drought period the flow of the Colorado River is about half as much as it was in the dustbowl years of the 1930 to 1937. So, augmentation is of interest – not for agricultural interests that could benefit from this water in the immediate area, but for municipal consumption, an issue that seems to be on a lot of people's minds, especially in the lower basin states.

Another place where treated water could really help out is on water guarantees. As I mentioned earlier, there is a project diverting water from the Little Snake River to the Platte River Basin to give water to the city of Cheyenne. Treated water could augment the volume as the Little Snake leaves Wyoming. Volumes of water could also possibly augment the United States volume requirements at the international boundary.

Now, the traditional use of untreated water is for livestock water. We've also had good luck with putting water in facilities at a higher elevation out of riparian areas to limit impact from livestock in the riparian area. Wildlife watering with untreated water has been done extensively throughout the West. Even during the winter when everything else is frozen or unavailable, that water is still flowing. I realize there is concern about the wildlife habitat, wetlands, and forage once this CBM production ceases, more perhaps in other areas than it is in our area. Treated and untreated water can also have a big impact on recreation with reservoirs for fishing, boating, and animal viewing.

Finally, I feel reinjection is perhaps the most economic option right now for untreated water. There should be a better use for this water; yet, the costs associated with better use have to compete with reinjection of that water. We're spending a lot of money reinjecting the water, running electric pumps to drive that water back into the ground. Perhaps sharing the cost of treatment with the community, or similar arrangement, would make it more economic than the reinjection alternative.

### Concerns Addressed

Let's address a couple of the myths or concerns that have been voiced about produced water. The first is that produced water has a short-term life. In this area, that doesn't seem to be the case. We have some terrific water drives, just in the coals. Our wells, by the way, are not like those in the Powder River Basin schematic shown to you earlier where there are open hole completions. Ours are drilled with a more conventional drilling rig that has a substructure and blowout preventer on it, not a truck-mounted rig. The casing is cemented from the surface all the way down to the total depth of the well. The steel casing is perforated. In our case we've even done some nitrogen fracing to open up our coals, which are very thin, the thickest coals having been about ten feet. Our gas content seems to be higher than that of the Powder River basin, which has one big thick seam of coal. And that's why we think our area holds a lot of promise compared to the open hole completions.

Another concern is that CBM will deplete underground reservoirs, dovetailing with the concern of short-term life. The State Engineer's Office reminds people that in most cases only ten percent of the water head has to be removed to produce the gas, leaving behind 90% of the water in place of the coal seams. That percentage does not include the water that is associated with the sands in which the coals are interbedded. There are some extremely highly charged sands and coals in our area, and we have to be extremely selective in our perforating and our fracture stimulations. The first thing we must pay attention to in our area is a good cement job to isolate those water sands. If we have communication with those water sands either by a bad cement job or a perforation or a fracture stimulation that exceeds the area of the coal, we produce many times the amount of water that we really should.

Another concern is that the surface discharge, whether it be treated or untreated, would promote the growth of unwanted species, especially fish. We've looked into that and wondered if that concern can be mitigated by installing devices or impounding the water and having regulated releases that do not promote the growth of any of those undesired species. Treated and untreated water alike will pick up soil constituents as it moves down the discharge area. Some people suggest that, just like in the Muddy Creek area water which looks nice during the summer, drainages will reach a point where they will flush out. I don't know how long that takes. We have yet to consider utilizing long drainage inpiping and releasing to a perennial stream instead of going down an ephemeral drainage.

Let me leave you with this note of interest in my area in south central Wyoming: it is almost exactly the opposite as the Powder River Basin. During the talks you've heard today, some of the differences have been mentioned. The state of Montana has taken a very narrow stand on water coming across its borders. At the same time, we're seeing down-basin states that are sending representatives here trying to find new sources of water. In the Powder River Basin, some have suggested that reinjection be employed, and it is my opinion they call for reinjection because anything else will increase costs to the point of curtailing drilling. In our area, the underground reservoirs are an excellent place to reinject the water. The agricultural interests would like to put that water to use before it gets out of the state. The state is scratching its head wondering if it can tie a revenue stream to this and, in some form, lease or sell it to a lower-basin state. This unique situation will play out in the years to come.

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**Steve Degenfelder** is currently Vice President for Land with Double Eagle Petroleum Company in Casper, Wyoming, serves on the Board of Directors for the Petroleum Association of Wyoming, and is Chairman of the Natrona County Planning and Zoning Commission. Steve has lived in Wyoming since 1979. He started his career in the oil and gas industry as a roustabout in Southeast New Mexico and has worked in various land management positions for Marathon Oil Company, Paintbrush Petroleum Corporation, and Tyrex Oil Company and has served as Deputy Director of the Wyoming Office of State Lands and Investments. Steve received his Business Degree from Texas Tech University in 1979 and is a Certified Professional Landman. Contact him at (phone) 307-237-9330.

*Produced Waters Workshop –*

# Lessons Learned?

Moderator: Gretchen Rupp,
Montana State University,
Bozeman, MT

## Two Desalination Projects: Providing Fresh Water for Municipal Use, Texas Case Studies

by Dave Burnett, Texas A&M University

I'll talk about two produced water projects and some of the lessons that I've learned. I'll talk about the half million dollars I've spent over the five years working on desalination of brackish ground water and the use of reverse osmosis (RO) concentrate in reject saline concentrate into an oil field water flood. So that is a definite beneficial reuse. The second project I'll talk about is desalination of oil field brine and its use for municipal water needs.

### Study #1 – The City of Andrews Partnership

Andrews, Texas, is a city of about 11,000. Andrews County is the second largest oil and gas producing county in the state of Texas. Andrews has a lot of money and is very forward thinking. It sits on top of the Ogallala Aquifer, and it also sits on several million barrels of oil and gas. The Ogallala offers about ten or 15 years of water supply, then it is out of water. Since there's no surface water in Andrews; indeed, there are no more surface water sources in the state of Texas, so it will have to find another source of water. Desalination is an opportunity.

Andrews also sits directly on top of the Means Oil Field. You guys talk about how long an oil and gas field lasts. The Means Oil Field started producing around 1925 to 1929. It's still a very productive and profitable oil field for Exxon Mobile. Exxon Mobile will take our brackish saltwater reject from the RO concentrate and use it in their water flow. I have zero cost for disposal on my reverse osmosis. That operation is less than a quarter of a mile from where the water field is for the city of Andrews. Andrews sits on the Docken Aquifer. Docken has about six million acre-feet. Docken Aquifer runs from about 1,500 TDS to about 3,000 TDS. There's enough water there to drought-proof West Texas communities.

Yet, reverse osmosis desalination isn't cheap. You can't grow alfalfa with it, but it can supply municipalities' needs. Think about distributed water as a process rather than an infrastructure, similar to how you would consider distributed power generation and energy security. What I'm focusing on is trying to establish small units that'll make fresh water where you need it and where the source water can be found. That's a lesson I learned: concentrate on something you're good at. My pretreatment cost is about $0.50 per 1,000 gallons. Reverse osmosis is about $1.25 per 1,000 gallons. My brine concentrate management costs are less than a penny per thousand gallons. I challenge you to find anybody else who can do that.

When you put water in a deep well, from 4,000 to 7,000 feet, it's gone. When I was in elementary school, I learned about the water cycle. It goes up, it rains, it comes down and runs, and so on. We're taking it out of the water cycle when we do deep well disposal. When you put stuff down the well, you want to make sure you've got all the fresh water you can out of it. You want to make it as saline as possible. Oil and gas people need saline; it works better as long as it's compatible and chemically stable.

### Study #2 – the Central Texas Project

The second case study is the Central Texas Project, in the hill country of Texas. If you are familiar with that area, you know about the population boom. I'm starting a project that Gretchen referred to a little earlier as a study in low-impact oil and gas drilling in environmentally sensitive areas. There are no more areas in the U.S. that are not environmentally sensitive. It's all environmentally sensitive. Oil and gas drilling needs low-impact oil and gas. I don't care where you are in Texas, we've got problems. We need to help solve them. We need to get fresh water for people, and we need to cut down on the impact of oil and gas operations. On the other hand, we need to get the regulatory agencies to give us permission to do this. One reason it's taken me five years to get where I am is that half of my time is spent trying to get the rules and regulations set.

In this particular project, I had a two million gallon a day RO desalination facility. The treated water will be sold to communities that need it. They have 900 barrels a day of oil and gas production shut in. That's about 1,000,000 barrels of reserves that are shut in right now. The 1,000 barrels a day that could put on production because it doesn't have to be managed will pay for the capital cost of that plant. The ejection concentrate is put back in the field for enhanced recovery.

This project works because the gentlemen's grandmother leased her ranch to Exxon Mobile back in the 1930's. They still own the ranch, they own the mineral rights, and they are third-generation neighbors of everybody in central Texas so they can accommodate the rules and regulations. John Vail and I sat in a meeting in January and convinced two Texas regulatory agencies to handle the permitting for the operations. It's still not in writing.

Figure 1 shows the portable treatment unit for on-site testing. I use it because, first of all, it gives me a platform to preach from, which is really fun, and it demonstrates that you can do the water treatment. I had ten to 12 Anadarko field foremen watching me take some of the water from a well. When the fresh water came out the front, I asked the group for a volunteer to drink it. Fifteen field foremen all pointed to this one guy. "He'll drink it! He's our lawyer!"

**Figure 1. Portable Desalination Unit for On-Site Testing**

The client is looking at creating 1,000,000 bbl of economically recoverable reserves for about $3 a barrel. That's pretty cheap. My pretreatment cost is about $2 per 1,000 gallons. That's pretty high, but this is oil field brine. My contribution to this technology is my experience as a water chemist and a water engineer for 20 years. I've been treating oil field water for reinjection back into rock and reservoirs. If you don't treat it properly, you plug your injection wells up. We know how to treat water; we know how to precondition it. I'm looking at about $6.20 total treatment cost per 1,000 gallons. That's pretty high, but when you're in water-starved areas, when it's a guaranteed source of water and nobody else has a claim on it, and if you got the right project, it makes a lot of sense for everybody.

In conclusion, Figure 2 shows the various brackish water production sites in Texas, as well as the regional water planning groups, shown in different colors. You can see more than 300 of these well sites are producing brackish water. They're near areas where I could put it into streams that are impaired because of low water volume. There are areas where you could augment the wetland habitat. A friend on McFadden Ranch gets $50,000 a year from Ducks Unlimited to lease that wetlands. He would like a source of water. If he didn't get a tropical storm to come through in September, he'd be dry.

There are a lot of opportunities from this. You've got to have more than one arrow in your quiver. There's not one solution, and there's not one regulation that will fix all this. Sweeping regulations scare me. You need to find a way to provide incentives, whether it's paying more money, or bonuses, or whatever, to get in and solve these problems.


**Figure 2. Regional Water Planning Groups in Texas**

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**David B. Burnett** is the Director of Technology for the Global Petroleum Research Institute (GPRI) and a member of the graduate faculty of the Petroleum Engineering Department at Texas A&M University. For the past four years he has had extensive experience in technology related to oil field produced water management, working with the Texas Water Resources Institute (TWRI). Burnett leads a team of scientists and engineers recovering fresh water from oil field brines and brackish ground water and using it for beneficial purposes. Mr. Burnett has been at the University since 1995 and head of GPRI since 1998. GPRI is a collaboration of major and independent oil and gas companies performing joint venture research projects in drilling and completion, facilities and production engineering, and environmental areas. Burnett coordinates the Department's environmental research programs including produced water desalination, low impact oil and gas drilling, carbon sequestration in low grade coal deposits in Texas, capture of greenhouse gases from petroleum storage and transportation facilities, and use of multiphase pumping and metering in oil field applications to reduce oil and gas separator facilities. Prior to coming to Texas A&M, Burnett was a Project Manager for Westport Technology and BP Exploration, developing and managing research programs for oil and gas joint ventures. He has a B.S. and M.S. in Chemistry from Sam Houston State University and an MBA from Pepperdine University, Malibu, California. Contact him at (phone) 979-845-2274.

# Field Application of the Freeze-Thaw/Evaporation (FTEa) Process for Produced Water Treatment, Disposal and Beneficial Use

## *– A New Mexico Case Study*

by John Boysen, BC Technologies, Laramie, WY

Those of you who know me know I don't agree with too many people. Yet, I have to agree with our previous speaker. Every one of these sites has its own specific problems. There is no generic solution. But there are solutions, and selecting the right one is the key.

Also, I cheated a little bit. We started demonstration of this process in New Mexico, but I'm also going to show you a little bit of data from our commercial operations in Wyoming. The FTE process, since we've commercialized it, has been coming on. I've heard some universities think they invented it, and there are a couple of companies that think they invented it. I'll tell you, I didn't invent it. A guy named Don Stinson, who was Department Head of Chemical and Petroleum Engineering at University of Wyoming back in the '60's and '70's patented this concept in 1968.

What we've done here is, with Don's help, taken his original research and applied it to something that had a little bit better economic drivers than he had back in the '60s and '70s. We started research on this in 1991. Our first commercial plant was built in 1999. Throughout this we had great support from the U.S. Department of Energy and the Gas Research Institute, now called the Gas Technology Institute. In addition, I work with the University of North Dakota. We also had support from Amoco Production Company, which is now British Petroleum. We also had considerable support in the Jonah Field from McMurray Oil Company, which became Alberta Energy Company, which is now Encana Oil and Gas. Interestingly enough, BC Technologies and the U.S. DOE haven't changed names during the course of this research.

### The Process Explained

The FTE® process is conceptually very simple. The freeze-thaw cycle takes advantage of winter climate when the ambient temperature drops below 32° F. We all know that dissolving salts in water depresses the water's freezing point. However, we never spent much time in college looking at what happens if you hold this water below 32° F – the freezing point of pure water – but above the freezing point for the solution itself. Relatively pure ice crystals form, along with an unfrozen solution (brine) that contains elevated concentrations of constituents. The brine's density is greater than that of the ice, so the purified ice and brine are easily separated. Coupling this freeze-thaw cycling with conventional evaporative technology, we can separate the concentrated brine from the pure ice, allowing us to dispose of produced water on a year-round basis. The process is simply illustrated in Figure 1 – and, please, a couple of companies have been burned by trying to mimic this diagram.

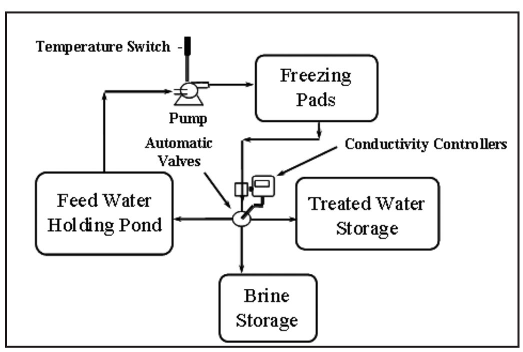



**Figure 1. Block Flow Diagram of the FTE Process**

Throughout the winter months, produced water is pumped to a "freezing pad" or shallow holding pond. It is then sprayed to the center of the pond to create an ice pile. When the sprayed produced water contacts the cold air, a portion of the solution freezes while the heavier brine portion of the solution stays liquid. We look at the electrical conductivity of runoff and we sort it, either recycling it back to be concentrated further or pulling it off as treated water or as concentrated brine. Over time, the spraying results in the creation of large ice piles and a solution of brine containing substantially elevated concentrations of constituents. When brine constituent concentrations are sufficiently elevated, the brine is removed from the freezing pad and placed in a brine storage pond. There are a few bells and whistles between those blocks that are critical to the process, but we won't go into those here.

Whenever the ambient temperature increases above 32° F, partial thawing of the ice pile occurs and the freeze-thaw cycling further cleanses the ice. In the spring, the ice pile ultimately melts into a solution of fresh water. This fresh water can be applied to the land or used for other beneficial purposes.

The evaporation cycle is a disposal process and is used during the late spring, summer and fall months. During this time, the facility is operated like a conventional evaporation facility. Produced fluids and the brine fluids from the freeze cycle are evaporated. No new wastes are generated by the use of the FTE process, and no chemicals are added at any point in this treatment process.

### Experience with the FTE Process

The FTE® process has been successfully demonstrated in the natural gas fields of northern New Mexico and south central and western Wyoming. It is currently utilized successfully in the treatment of natural gas produced water in the Green River Basin of south central Wyoming at Ice Cycles, which is a produced water treatment and disposal facility owned by Samson Resources Company and operated by Crystal Solutions, LLC. The deployment of the process at this site has significantly reduced produced water disposal costs and generated treated water for land application in this arid environment.

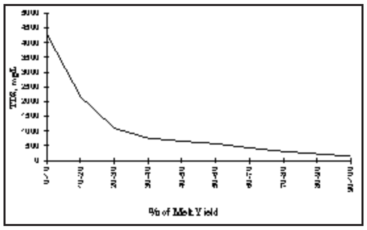
### Case study #1: San Juan Basin

The first case study was conducted during the winters of 1995 through 1996 and 1996 through 1997 at Amoco's Cahn/Schneider con-evaporation pits in the San Juan Basin of New Mexico. We were about on the state line just off the highway between Farmington and Durango. The first year of the evaluation was moderately successful in spite of one of the area's warmest winters on record. During this period, 10,000 bbl of produced water was processed. An ice pile approximately ten feet high was created, and brine was separated from the ice. Composite samples of the ice and brine confirmed that the process is capable of producing clean ice and concentrated brine. Considering these encouraging but limited results, the field evaluation was extended to the winter of 1996 through1997.

The project's second year of operation was directed at four specific objectives. The first of these objectives was to retest the FTE process under conditions that would be more representative of a typical winter in the region. The second objective was to isolate the freezing pad and provide a smaller footprint for the FTE facility so that the process' ability to increase the treatment and/or disposal capacity of typical evaporation ponds in the area could be quantified. The third objective was to modify the FTE facility to allow for continuous, automatic operation and separation of FTE process products. Finally, an investigation of evaporative performance was designed along with research efforts related to finding a beneficial and economic use for the brine and/or solids produced from the brine. Near-normal climatic conditions during the 1996-1997 winter in the San Juan Basin and the revised plant design made a significant difference in the results.

This New Mexico test in 1996-1997 was a small field demonstration; Figure 2 illustrates the San Juan facility and treatment results. Once we started harvesting the treated water, the icemelt progressively got cleaner; when we cut at 4,000 to 5,000 ppm TDS, we usually got a treated water composite that looks like 1,000 or 900 ppm TDS. We treated 8,000 barrels of water with a TDS concentration of 12,800 mg/L in a 1/4-acre pit. A total of 53% (4,237 bbl) of the feed water was classified as treated water with a TDS concentration of 1,010 mg/L, while 27% (2,160 bbl) of the feed was evaporated. If you just let a pit ice over and don't spray it, you're not going to get any of that during the winter. The net result was an 80 % reduction in the volume of water requiring disposal. Only 20% (1,612 bbl) of the original produced water volume, having a final TDS concentration of 44,900 mg/L remained for disposal. You can see that TDS of feed was 12,000 ppm TDS; treated water was 1,000 ppm TDS; the brine was about 45,000 ppm TDS. ECs are proportional. Alkalinity was reduced similarly.

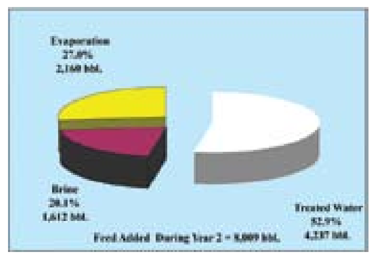
We effectively disposed or treated 80% of the water. Projected water treatment/disposal costs for this application of the process for an owner-operated facility handling an annual average of 1,000 bbl/day were between \$0.24 and \$0.32/bbl (1996 USD)




TDS of Treated Water vs % of Melt Yield, San Juan Basin 1996 -1997

Photo from highway about 1/4 mile away; fence in foreground is about six feet high

24-foot-high ice piles




San Juan FTE Process Product Yield, 1996-1997

| Product Quality from FTE process in San Juan basin, 1996-1997 | | | |
|---|---|---|---|
| | Feed | Treated Water | Brine |
| TDS, mg/L | 12,800 | 1,010 | 44,900 |
| EC, µS | 16,200 | 1,670 | 45,700 |
| Total Alkalinity ($CaCO_3$), mg/L | 9,380 | 700 | 35,550 |
| % of Feed | - | 52.9 | 20.1 |

**Figure 2. FTE Facility and Process Results, San Juan Basin, Winter 1996-1997**

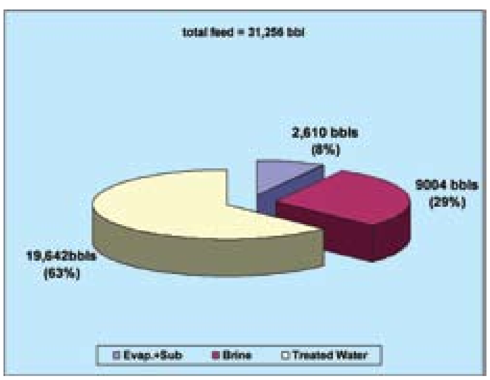
### Case study #2: Jonah Field, WY

Now I want to get to a little larger operation. The success of the FTE Process during the field test in northern New Mexico led to the decision to deploy the process at a commercial scale. McMurray Oil Company (MOC), a producer with gas wells in the Jonah Field of the Green River Basin in Wyoming, agreed to convert a conventional evaporation site into an FTE facility. In 1998, a one-acre brine pond and a one-acre treated water pond were added. The owner-operated deployment of the process at the MOC Jonah FTE facility was initiated in February 1998 with approval from the Wyoming Oil and Gas Conservation Commission. Since that time, the facility has changed ownership twice.

In the winter of 2000, we put 31,000 barrels out on the 1 acre pit and of that, we got 63% of what we call treated water. We saw about eight percent evaporate or sublime – can't tell which – less than what we observed in New Mexico. And we had 29% brine stream. This particular winter we started with a feed that was about 31,000 bbl and about 10,000 ppm TDS. Total petroleum hydrocarbons (TPH) were about 11 ppm. The treated water exhibited about 600 ppm TDS and total recoverable petroleum hydrocarbons were reduced by half.

Operator next to ice pile

Trailers dwarfed by ice piles




Product Yield from FTE process
in Jonah Field, 2000-2001

Holding pond, also used
for evaporation in the summer

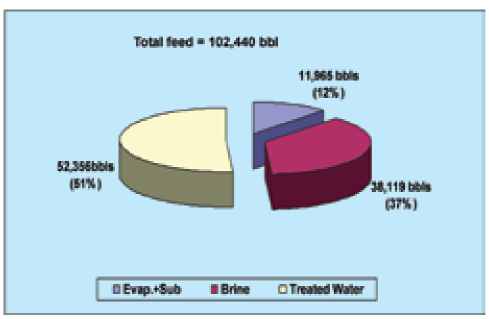
| Product Quality from FTE Process in Jonah Basin, WY, 2000-2001 | | | |
|---|---|---|---|
| | bbl | TDS, mg/L | TPH, mg/L |
| Feed | 31,256 | 9,750 | 11 |
| Brine | 9,004 | 48,800 | 4.9 |
| Treated Water | 19,642 | 589 | 4.2 |
| Sub + Evap. | 2,610 | 52.9 | 20.1 |

**Figure 3. FTE Facility and Process Results, Jonah Field, WY, Winter 2000-2001**

### Case Study #3:

Following the success of the FTE technology at the owner-operated Jonah Facility, Crystal Solutions, LLC (a joint venture of BCT and Gas Research International), was formed in May 1999. In October 1999, the Wyoming Department of Environmental Quality issued a construction permit to Crystal Solutions (CS) for a commercial FTE produced water treatment facility in south central Wyoming in the Great Divide Basin, near Wamsutter.

In November 2000, the CS facility began its first full season of operation as a commercial FTE facility. In the winter of 2001 through 2002, we fed 102,000 bbl to three freezing pads. Of that, 51% came out as treated water, 12% was lost to evaporation and sublimation, and 37% was brine. We measured about 10,000 ppm TDS in the feed, with about 40 mg/L on the total recoverable petroleum hydrocarbons. The treated water composite showed 1,000 ppm TDS and 3.1 mg/L on the total recoverable petroleum hydrocarbons.




Product Yield from FTE process at CS Wamsutter, WY, 2001-2002

Summertime

| Product Quality from FTE process at CS Wamsutter, WY, 2001-2002 | | | |
|---|---|---|---|
| | bbl | TDS, mg/L | TPH, mg/L |
| Feed | 102,440 | 9,790 | 39,1 |
| Brine | 38,119 | 44,900 | 63.2 |
| Treated Water | 52,356 | 1,000 | 3.1 |
| Sub + Evap. | 11,965 | | |

**Figure 4. FTE Facility and Process Results, CS Wamsutter, WY; Winter 2000-2001**

### Benefits of the FTE Process

In the Jonah Field, the treated water was used for roadspray on a regular basis through a temporary NPDES permit. Then, they used the water for drilling and stimulation. Consequently, they don't need us any more, as it's all going back down the hole. But when they quit drilling, something like FTE will be very applicable.

In the Wamsutter area, we've used the water for drilling, for dust abatement, for construction purposes, and compaction and such. We've also have a land application permit and have land-applied this water each year for the last four years.

Benefits of the FTE process include:

- **Reduced produced water management costs –** particularly compared to evaporation alone. In Wyoming, application of this process will effectively double the capacity of evaporation pits. In New Mexico, it will increase by about 50%.
- **Extended injection well performance –** Coupling this treatment process with an injection well will allow an operation to extend the injection well life considerably when only disposing of the brine stream.
- **Extended production from economically marginal fields**
- **Expand CBM resources and other non conventional resources**

We are experiencing water treatment costs – excluding the oil we recover – of less than 50 cents a barrel. At the present time, we recover about two percent of the feed stream in the case of condensate, so it turns out to be our largest revenue stream at the plant and more than the disposal fees. However, our costs are location specific.

In conclusion, the FTE process has a definite economic advantage over conventional evaporation technology where there are seasonal subfreezing ambient temperatures. Since the process requires essentially the same equipment as conventional evaporation, it allows more water to be processed in an evaporation facility by operating at times of the year when evaporation is ineffective. The increase in treatment/disposal capacity that can be achieved by applying FTE in each climate considered is strongly dependent upon the number of hours per year the ambient temperature is below freezing.

The results of the second year of the FTE field evaluation treating coalbed methane produced water in the San Juan Basin of New Mexico clearly indicate that the process is technically feasible and capable of producing high quality water suitable for a wide variety of beneficial uses. In addition, the economics of the process are better than those of conventional evaporative disposal in climates where subfreezing temperatures occur. Further, the produced water processing costs are significantly less than current disposal operations in two of the climates considered. In New Mexico, the current disposal cost for produced water at a commercial evaporation facility is in the range of $1.00 to $2.00 / bbl; in southwestern Wyoming, the current cost is more than $2.00 / bbl.

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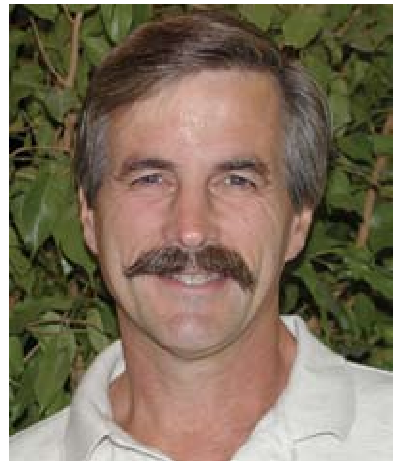
**John Boysen** is the president of B.C. Technologies, Ltd. which is an environmental consulting firm located in Laramie, Wyoming. Mr. Boysen graduated from the University of Wyoming and holds a B.S. (1975) and an M.S. (1978) in Chemical Engineering. Over the past 15 years, Mr. Boysen has focused on the development and commercialization of the Freeze-Thaw/ Evaporation (FTE®) process to treat and dispose of oil field and industrial wastewater. The technique for applying FTE® technology to conventional evaporation pits has been successfully field tested at the Amoco Production Company Evaporation Facility in the San Juan Basin of New Mexico and commercially deployed at the McMurray Oil Company Evaporation Facility in the Jonah Field of southwestern Wyoming. This process was also successfully demonstrated in Devils Lake, North Dakota for municipal water treatment. Mr. Boysen also designed, permitted, built, and operated a commercial produced water treatment and disposal facility in south central Wyoming that utilizes the FTE® technology. The treated water from the facilities that he has managed has been utilized for a variety of beneficial purposes including dust abatement, drilling, construction and compaction. Mr. Boysen has 49 professional publications, has consulted on an international basis, and holds two U.S. patents. Contact him at (phone) 307-742-5651.

# Conjunctive Use of Oilfield Produced Water for Irrigation in the Southern San Joaquin Valley of California

## *– A California Case Study*

by Blake Sanden, University of California Cooperative Extension; Dave Ansolabehere, Cawelo Water District; Hung Le, Paramount Farming Co., CA

### Introduction



Situated in the southern end of the San Joaquin Valley of California, Kern County occupies an area about the size of the state of Delaware. The eastern half is made up of the Tehachapi Mountains (the southern end of the great Sierra Mountain chain) with the high desert beyond. The western half is the heart of the irrigated agricultural area, averaging 850,000 acres of active farming.

Soils are mostly deep alluvial sediments with sandy loams dominating the eastern part of the valley and gradually increasing clay content to the west. Kern County alternates between the third- and fourth-highest producing agricultural output in the nation with a little over $3 billion annually. Signature crops, representing the greatest production of any area in the nation and in order of their dollar value, are grapes, almonds, carrots and pistachios. Figure 1 shows the acreage of various crop types for 2003.

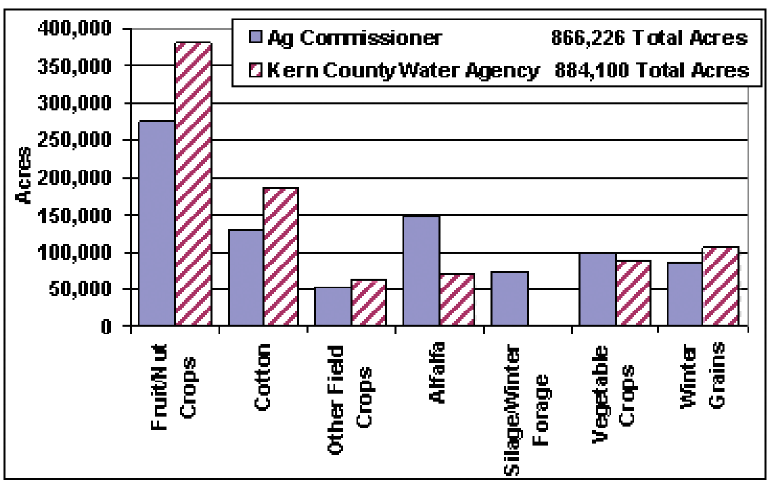



**Figure 1. Crop Type Diversity and Acreage for Kern County**

Estimated demand and water supplies to Kern are:

- **Demand:** 2.75 acre-feet/ac, 33 inches
- **Requirement (@ 850,000 ac):** 2.3 to 2.5 MAF/year

**Average Supply:**

| | |
|---|---|
| Kern River: | 650,000 acre-feet |
| USBR Friant Project: | 800,000 acre-feet |
| State Water Project: | 900,000 acre-feet |
| **Total:** | **2.35 MAF/year** |

In reality, flows from all three sources are highly variable, and stability of supply to area farmers is only possible through conjunctive use of ground water and water banking/recharge programs utilizing high water year surface flows. At the same time, grower cost for water has increased five- to ten-fold in the last 30 years. In addition, full contract entitlement for State Water Project (SWP) water and USBR Friant Project water has not been delivered due to environmental and legislative mandates placed on these systems. Figure 2 shows the variability of supply and cost for the SWP.

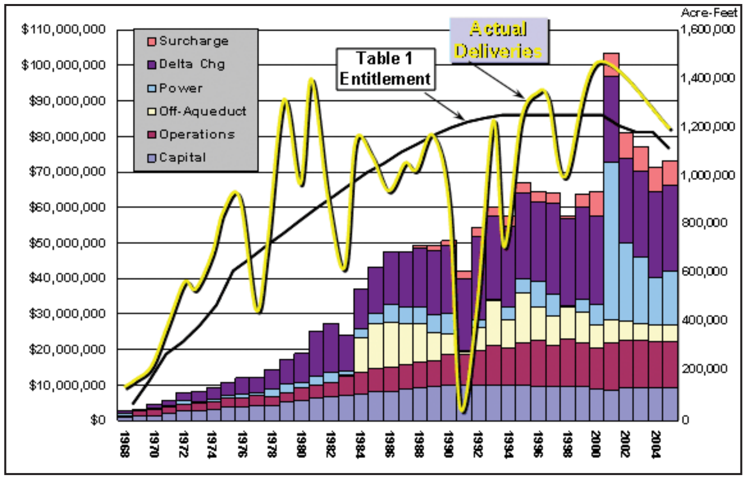



**Figure 2. Change in Cost, Entitlement, and Actual Supply for the State Water Project in Kern County**

As water costs, along with other farming costs, have climbed and field crop commodity prices have stagnated, farmers have gone to higher-value permanent and double-cropped vegetable crops as indicated in Figure 1. This has resulted in a higher net demand for water, while the import of surface water has not increased (except for occasional "wet" years). Irrigation system efficiencies have improved to help provide some of this water, but the balance is drawn from ground water reserves. The result is a current ground water basin deficit of about five million acre-feet. The bottom line: irrigation districts are thirsty and making deals with anyone who has available water of reasonable quality at a reasonable cost.

### Cawelo Water District and Chevron/Texaco Partnership

The Cawelo Water District is located on the eastern edge of the irrigated valley portion of Kern County and adjacent to the oilfields that are scattered over the rolling foothills just east of the district boundary (Figure 3). The district is about seven miles long with the western boundary delineated by Interstate Highway 99. A regulation reservoir is located near the SE corner of the district; this reservoir is where produced oilfield water is collected and blended with fresh Kern River or SWP water; from here it is discharged into the canal that runs north along the east boundary of the district, to be distributed through buried laterals with turnouts at grower's fields. Total area within district boundaries is 45,317 acres, with 33,247 acres actually in the district service area receiving allocation. Of the difference, only about 2,000 acres is cropped and the rest is comprised of fallow lands, recharge basins, M&I, and miscellaneous.

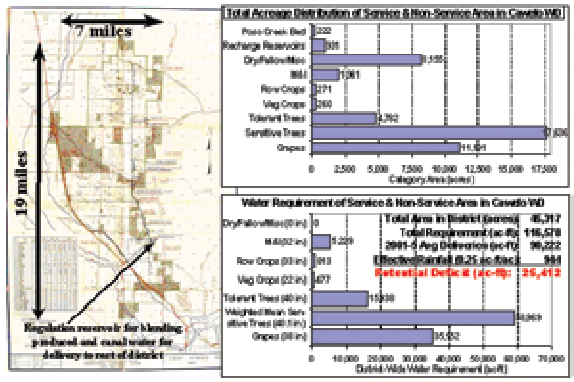



**Figure 3. Cawelo Water District: District Map, Crop Diversity, Acreage Distribution, and Approximate Demand by Crop**

Actual deliveries for the period 2001 through 2005 are given in Table 1. Produced water comes from three separate oil companies, with Chevron/Texaco supplying the largest quantity. The quality of these waters is excellent (Table 2) – when considering the salinity typical of most produced waters – and requires no treatment. A temporary holding basin above the main reservoir receives the Texaco/Chevron water. Two floating barriers provide for additional separation of oil film and floating organics before discharge into the main pool. The incoming water is about 140º F. Table 1 reveals that the produced water is about 24% of the total supply for the district. A potential deficit of 25,000 acre-feet for the district region as a whole (even with the addition of the produced water) underscores the importance of this added water supply.

| ENTITY / USE | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| CHEVRON / TEXACO | 22,259 | 19,988 | 17,910 | 20,181 | 17,096 |
| VALLEY WASTE | 879 | 585 | 1,065 | 2,853 | 3,812 |
| SCHAEFER | 1,186 | 1,274 | 1,457 | 1,441 | 1,293 |
| **TOTAL PRODUCED WATER** | **24,324** | **21,847** | **20,432** | **24,475** | **22,201** |
| **TOTAL WELLS TO DISTRICT** | **13,058** | **10,055** | **5,425** | **11,203** | **2,661** |
| **TOTAL IMPORTED CANAL** | **47,807** | **55,955** | **62,396** | **54,248** | **75,025** |
| **TOTAL SUPPLY** | **85,189** | **87,857** | **88,253** | **89,926** | **99,886** |
| **BANKING AND CONVEYANCE LOSSES** | **8,711** | **6,598** | **7,584** | **11,197** | **18,837** |
| **TOTAL TO LANDOWNERS** | **76,479** | **81,259** | **80,669** | **78,729** | **81,049** |
| PRODUCED / TOTAL (%) | 28.6% | 24.9% | 23.2% | 27.2% | 22.2% |

**Table 1. Distribution of Supply, Source, and Produced Water as a Percentage of Total Supply for Cawelo WD for 2001 through 2005**

| | pH | EC | Ca | Mg | Na | HCO3 | Adj SAR | Cl | B |
|---|---|---|---|---|---|---|---|---|---|
| | | (dS/m) | (meq/l) | (meq/l) | (meq/l) | (meq/l) | (%) | (meq/l) | (ppm) |
| **Lerdo Canal** | 8.5 | 0.19 | 0.82 | 0.28 | 0.82 | 1.03 | 1.11 | 0.50 | 0.13 |
| **Produced** | 7.7 | 0.89 | 1.40 | 0.38 | 6.93 | 4.34 | 12.78 | 3.92 | 0.96 |
| **Current Blend** | **8.0** | **0.51** | **0.96** | **0.30** | **3.94** | **2.72** | **7.05** | **2.26** | **0.52** |
| **Quarterly C.V.** | 3.1% | 41% | 30% | 44% | 48% | 40.9% | 52.2% | 50.6% | 51.3% |
| **PreBlend (1995)** | | 0.34 | 0.78 | 0.06 | 2.50 | 1.40 | 3.95 | 0.47 | 0.05 |
| **FAO 29 "Sensitive" Crop Thresholds** | | **0.7** | | | **3.0** | | **5*EC** | **4.0** | **0.7** |
| **June 2004 grab samples for subsurface drip Almond Block 3050** | | | | | | | | | |
| **District Plus Gypsum** | 7.9 | 1.77 | 17.17 | 0.46 | 1.98 | 4.30 | 0.67 | 0.90 | 0.57 |
| **Well** | 7.9 | 1.11 | 5.74 | 0.13 | 5.22 | 0.70 | 3.05 | 6.20 | 0.21 |

**Table 2. Water Quality of Various Supplies to Cawelo WD and General Salinity Thresholds for Sensitive Crops**

For the sensitive crops (citrus, grapes, and almonds) that dominate the district, the produced water by itself would be unsuitable over the long term. But as a general rule, the blended water supplied to farmers is about three parts fresh canal water to one part produced water, resulting in a reasonable-quality irrigation water with the exception of sodium. Values of 4 meq/L (92 ppm) and an adjusted SAR of 7 results in soil structural problems on these predominantly sandy loam soils with low clay content. To prevent severe water penetration problems, growers apply gypsum broadcast and/or through the irrigation system. Of course, this also adds salt to the system and can contribute to an increase in total rootzone salinity.

### High Irrigation Efficiency and Salinity Impacts to Almonds

With virtually all permanent crops in the district using microsprinkler or drip systems, fields are generally irrigated at a very high efficiency – often going deficit by mid-season. Five years of soil moisture monitoring and irrigation scheduling demonstrations across Kern County have been conducted since 2001 on over 11,781 acres in 136 fields with 30 different growers in 14 different crops on 11 soil textures using nine different irrigation system types. The greatest number of instrumented fields were those with almonds, with 34 of the blocks with a mature full cover canopy (>6 years old). Table 3 shows these almond data. Three of these orchards were border strip irrigation with tailwater return systems; the balance used microsprinklers. Using measured depletion of soil moisture in the crop rootzone divided by applied water at a specific site in the orchard, the mean water use efficiency (WUE) was 97% for these 34 mature almond blocks covering more than 3,800 acres. Mean soil water tension (recorded by datalogger three times a day; measured with calibrated electrical resistance sensors -Watermark(r) blocks – to five feet) was -52 centibars. Mean soil water content (measured weekly with the neutron probe) over the season was 56% field capacity. Both measurements indicate a profile that is slowly drying and not allowing water to percolate below the rootzone. Thus, while a 97% WUE for microsystems seems impossibly high, it is corroborated by other data from this regional test.

| | |
|---|---|
| Blocks instrumented, 42 total: | 34 >6th leaf |
| Average available water to 6 feet | 56% |
| Average soil moisture “tension” | -52 centibars |
| 2002-2005 average applied water | 46.8 inches |
| Average neutron probe ET | 45.7 inches |
| Average Water Use Efficiency | 97% |

**Table 3. Summary of Soil Moisture and Water Use Efficiency Characteristics for 34 Mature Almond Blocks (3,838 acres) in Kern County**

This level of WUE eventually resulted in a significant increase in total salinity along chloride ($Cl^-$) and sodium ($Na^+$) in the rootzone in some almonds farmed by a large company in the Cawelo Water District (Table 4). The average rootzone ECe using these samples is 2.28 dS/m. At an average blended irrigation salinity of 0.51 dS/m, this equals a 4.5 concentration factor. Using the *Leaching Fraction* (LF) calculations of Hoffman (1996), this level of salinity under long-term conditions would equal an LF < 5%.

| Location | EC dS/m | pH | Ca meq/l | Mg meq/l | Na meq/l | Cl meq/l | ESP% (CEC) | B ppm | NO3 ppm | P ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20" under edge of Berm next to hose | 1.7 | 5.4 | 3.3 | 0.4 | 13.1 | 4.3 | 25.4 | 0.27 | 350 | 67 | 76 |
| 30" under tree | 2.8 | 7.1 | 7.1 | 1.6 | 21.8 | 16.0 | 25.3 | 0.37 | 205 | 21 | 98 |
| 20" under Mid of row 4' from SDI hose @20" | 0.8 | 7.2 | 1.9 | 0.6 | 5.7 | 2.0 | 17.9 | 0.18 | 290 | 22 | 126 |
| 48" under Mid of row | 3.8 | 7.7 | 10.0 | 1.8 | 30.0 | 16.6 | 19.2 | 0.30 | 205 | 15 | 144 |

**Table 4. Salinity Levels as of June 2004 in Almond Rootzone of Highly Efficient Subsurface Drip Irrigation (SDI) System Following 6 Years of Irrigation with Blended Water**

The combined impact of elevated salinity and specific ion toxicity caused significant defoliation, increased difficulty in nut removal at harvest, and probable yield loss in this block in 2004. Table 5 lists various salinity and specific ion thresholds for the sensitive crops of concern in the Cawelo Water District as well as thresholds for salt tolerant cotton and pistachio for comparison. These relationships are graphically represented in Figure 4.

| Crop | $EC_{thresh}$ (dS/m) | Slope (%) | Sodium (meq/l) | Chloride (meq/l) | Boron (ppm) |
|---|---|---|---|---|---|
| Almond | 1.5 | 19 | S | S | 0.5-1.0 |
| Grape | 1.5 | 9.6 | 10-30 | 0.5-1.0 | |
| Orange | 1.7 | 16 | S | 10-15 | 0.5-0.75 |
| Cotton | 7.7 | 5.2 | T | T | T |
| Pistachio | 9.4 | 8.4 | 20-50 | 20-40 | 3-6 |

**Table 5. Summary of Published Tolerance Limits for Various Permanent Crops**

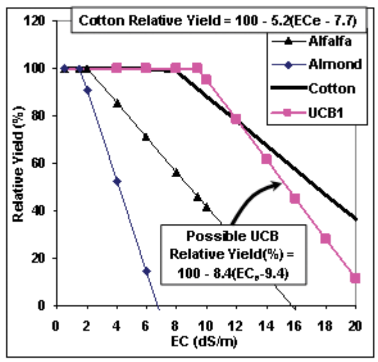



**Figure 4. Relative Yield Decline by Rootzone $EC_e$**

From these numbers it is clear that the long-term use of the blended produced water under extremely efficient irrigation poses a potential hazard to maximum crop production. Using the threshold values for almonds in Table 5 and the average rootzone $EC_e$ from the above analyses, we can calculate yield loss:

$$\textbf{Relative Yield } EC_e \text{ @ 2.28 dS/m} = 100-19(2.28-1.5) = 85.2\%$$

A 15% yield loss may indeed have occurred in this area of the orchard in 2004, but this is impossible to document.

### Remediation

Correction of this problem was achieved with eight inches of winter irrigation delivered through microsprinklers installed in this orchard, plus about four inches of effective rainfall. Soil analyses to four feet the following March averaged: $EC_e$ = 0.6 dS/m, $Na^+$ = 4.8 meq/L, and $Cl^-$ = 0.6 meq/L. Permeability problems persist and require nearly continuous injection of gypsum into the irrigation water. Table 6 shows that a seven to ten percent LF would be sufficient to maintain acceptable levels of rootzone salinity over the long-term.

### Economic consequences

The cost of this water to Cawelo Water District is only one tenth the cost of fresh water – a $2.39 million benefit (Table 7). On a per acre basis, this equals $71.89/acre or 24 lbs of almonds @ $3/lb. On the other hand, a 15% yield loss to the grower can exceed $1,000/acre. But with proper management and leaching this should not be a problem with these produced waters.

| EC Irrigation Water (dS/m) | Leachin Fraction (LF) above actual crop ET 0.05 | 0.1 | 0.15 | 0.2 | 0.3 |
|---|---|---|---|---|---|
| 0.05 | | | | | |
| 0.1 | | | | | |
| 0.2 | 0.63 | | | | |
| 0.3 | 0.95 | 0.62 | | | |
| 0.4 | 1.26 | 0.83 | 0.64 | | |
| 0.5 | 1.58 | 1.03 | 0.81 | 0.68 | |
| 0.6 | 1.89 | 1.24 | 0.97 | 0.81 | 0.63 |
| 0.7 | 2.21 | 1.45 | 1.13 | 0.95 | 0.74 |
| 0.8 | 2.52 | 1.65 | 1.29 | 1.08 | 0.84 |
| 0.9 | 2.84 | 1.86 | 1.45 | 1.22 | 0.95 |
| 1 | 3.15 | 2.06 | 1.61 | 1.35 | 1.06 |
| 1.2 | 3.78 | 2.48 | 1.93 | 1.62 | 1.27 |

Regressing the concentration factors in FAO29 and rearranging to solve for Leaching Requirement (LR):

**LR = 0.326 (Desired ECe/ECirr)^ -1.64**

After Ayers and Westcott, 1989

**Table 6. Average Rootzone Saturation Extract EC (dS/m) After Long-Term Irrigation with a Given Salinity of Water and Leaching Fraction**

2005 ECONOMICS OF SUPPLY

**81,049 ac-ft @ $120 grower cost: $9.73 M**

| | |
|---|---|
| **VALUE OF PRODUCED WATER** | |
| – 22,201 ac-ft of Produced Water @ $120: | $2.66M |
| – Payment for Produced Water @ $12: | $0.27M |
| **– NET BENEFIT TO DISTRICT:** | **$2.39M** |
| **– SERVICE AREA @ 33,247 ACRES** | |
| • NET BENEFIT / ACRE: | **$71.89** |
| **VALUE OF WATER IN CROP EQUIVALENT** | |
| **• Equivalent orange boxes @ $10:** | **7 boxes** |
| **• Equivalent grape boxes @ $8:** | **9 boxes** |
| **• Equivalent almond meats @ $3/lb:** | **24 lbs** |

**15% almond yield loss/acre @ max yield of 2,500 lb/ac, 375 lbs, and $3/lb: $1,125**

**Table 7. Economic Value of Produced Water, Crop Equivalent, and Possible Losses Due to Excess Salinity**

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**Blake Sanden** is the Irrigation and Agronomy Farm Advisor with the University of California Cooperative Extension, stationed in Kern County at the southern end of the San Joaquin Valley. He conducts county-based, applied research and extension programs focusing on irrigation, soils, salinity/fertility management, and field crop production. Blake has a BS in International Agricultural Development, MS in Irrigation and Drainage from the University of California, Davis, and more than 25 years of practical experience in production agriculture, overseas development, research and ag extension work. Contact him at (phone) 661-868-6218.

## Production Water as New Water Resource? – *a Colorado Case Study*

by Dave Stewart, Stewart Environmental Consultants, Inc., Fort Collins, CO

What we're going to talk about is an alternative water supply. In Northern Colorado, we're running out of water, and we know that. We're going to talk about drought, the characteristics of production water that we're working with, and a real example – a treatment plant we will tour on Thursday. And, I'd like to recognize two oil field partners, Brad Pomeroy and Richard Seaworth, who have both stepped off this cliff and deserve a lot of credit.

Because 97% of the Earth's water is ocean and 2% is ice and polar cap, we are looking at only 1% of the planet's water being usable (Figure 1).

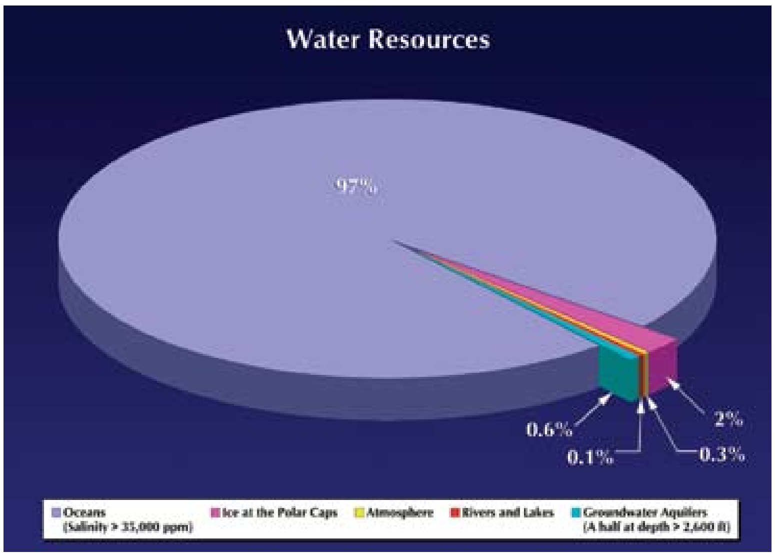


**Figure 1. Global Water Resources**

A state water supply initiative completed by the state of Colorado concluded that "nothing in the future will have greater impact on our way to sustain life than our water resources." The prolonged drought in Colorado is key to the issue of production water. One of the beautiful things about production water is that it comes up regardless of whether or not there's a drought going on at the surface.

### Significance of Non-Tributary Water

Here, I'm defining production water as water that is associated with the production of oil, natural gas, or coalbed methane (CBM) water. The TDS ranges between 1,000 and 3,000 mg/L. We are seeing about 1,500 to 1800 mg/L. Our SAR's are usually less than two units. Heavy metals can be a factor; we've seen heavy metals in water from one oil field and not in a second. And, most regulatory agencies are going to require removal of organics such as benzene, toluene, and xylene.

We are working on a project in Northern Colorado where, presently, production water is being reinjected to a Class 2 injection well that goes down to a depth of about 5,000 feet. That injection well becomes a constraint. Not being able to get rid of that water fast enough will limit how much oil you can bring out of the ground. The whole business of that oil field depends on how fast Brad can move water, and he'll talk about that tomorrow in his presentation. What we needed to do was find out a way to solve that problem.

We have another problem in that we've got a lot of pressures in Northern Colorado to convert ag land into municipality. One of the things that Richard, as a farmer, was interested in was preserving the ag land as well. We were trying to see if we could solve two problems for the price of one. Richard wanted to make sure they kept that farm in production, and we discussed how that water could be used for agriculture.

Water quality in the tributary streams also runs about 1,500 TDS. It exhibits low boron and low heavy metals. First thing we had to do, as Steve Bushong talked about, was go to the State Engineer and get this permit. Under Rule 907 of the Colorado Oil and Gas Conservation Commission, we can beneficially use that water if we can get the State Engineer to determine that it's non-tributary water. That's about a two-year process for us. Logically, you'd think because it's 5,000 feet to the surface that it would not be tributary to a stream, but it took quite a bit of effort to demonstrate that. Consider the geology of the project (Figure 2).

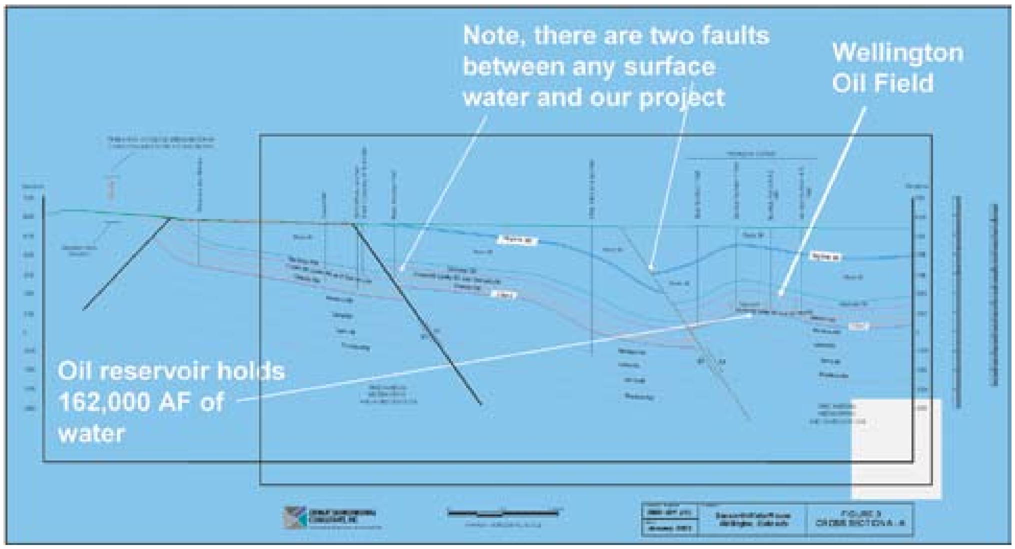


**Figure 2. Geology of Northern Colorado Project**

The oil is located between 4,000 and 5,000 feet below the surface. We have two offsetting faults of about 700 feet each. The tributary stream that this muddy formation runs over is the Boxelder Creek. This is about a distance of four or five miles. The Wellington oil field holds about 162,000 acre-feet of water – a low-end estimate. Brad has another reservoir study that shows the volume is about 350,000 acre-feet of water.

Why is this geology important? We had to get that water classified as non-tributary. The state of Colorado uses what's called a Glover Analysis to do that. Glover Analysis is applicable in non-confined systems. It doesn't really work well in a confined aquifer. We were able to use that program and get the water classified as non-tributary. We talked to the surface owners about this classification, to assure they understood that oil production water, because it's associated with minerals, is only available to the oil company. If, as a landowner, I wanted water, I couldn't go into the Muddy Formation and get water out because there is oil associated with it, and the mineral rights prevent me from doing that. The only entity that has availability to the waters is the oil company.

However, the surface owners do have rights associated with that water if the oil production ever stops. While this field has a life of somewhere between 500 and 1,000 years, we did go back to the surface owners and ask them to turn over those rights, which several did.

The other thing we have to do is get a discharge permit from the Colorado Department of Public Health and Environment, another lengthy process. We went through this whole process with the CDPHE, only to hear, "We can't really issue it; Colorado Oil and Gas has to issue it." So we started over with the Colorado Oil and gas Conservation Commission.

Getting the water classified as non-tributary water means that you can consume 100% of it. If you limit that water to indoor use only, you can supply ten to 20 homes – a pretty big deal. This is where the economics start to play into this project, where the value of the water lies. We got the necessary Water Quality Control Division permit, which requires removal of all the BTEX, and we had to remove all the heavy metals. The treatment system that you'll see on Thursday is a dissolved air floatation unit. It's followed by ceramic microfiltration, activated carbon, and ground water discharge. We piloted the system three different times, and each pilot confirmed we met the required discharge limits.

### How Can Production Water Help?

There are a lot of uses for this water. We can sell it to the power plant, not far away, for augmentation of its existing supplies. We've looked at irrigation of crops or augmentation of wells for irrigation. The water could be used to offset supply for drinking water diversions for Northern Colorado communities such as the Towns of Wellington, Pierce, Ault, and Nunn. We're planning to build a reverse osmosis plant.

Why do all this? The cost of this project is about $4,500 per acre-foot. If we do nothing else and just sell it as augmentation water, in Northern Colorado this augmentation water sells for about $20,000 per acre-foot – nearly five times increase in value. If we build it out with the RO plant, then that water becomes worth about $30,000 to $40,000 per acre-foot. The economics drive this project – and our interest in it.

Northern Colorado must come up with additional water resources. We're running out of water. In this project, we've developed a new water resource that will provide augmentation water. This process meets all the environmental and State Engineer's Office requirements. The water that we're talking about can only be accessed by oil companies. We believe that this is going to preserve agricultural land, because we're developing a non-tributary source. This is very compatible with sustainable concepts of using local resources to solve local problems.

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**David Stewart** has over 29 years of experience in the environmental infrastructure industry. He started his career with the U.S. Public Health Service working on Indian Reservations and public health issues. He then joined CH2M Hill, one of the largest environmental engineering firms in the world. He has expertise in the air, water, wastewater, hazardous waste, and solid waste areas. He currently has several patents awarded or pending on his various industrial wastewater treatment systems. Dr. Stewart received his M.S. from the University of Arizona, and his M.B.A. and Ph.D. from Colorado State University in Environmental Engineering. He teaches industrial wastewater treatment as well as hazardous waste treatment and management at Colorado State University. Contact him at (phone) 970-226-5500.

*Produced Waters Workshop –*

# Practically, How Do We Do This?

Moderator: John Duda
Department of Energy

*Produced Waters Workshop –*

# Practically, How Do We Do This?

## Practically, How Do We Determine Who Has the Right to Beneficially Use Treated Produced Waters, and How Do They Obtain the Right?

by Dick Wolfe, Colorado State Engineer's Office, Denver, CO

Let me preface my presentation by saying that all oil and gas wells, as far as produced water goes in Colorado, are treated the same from a state regulatory standpoint. Dave Akers, who will be following later, will be talking about regulation from the Health Department viewpoint. I'm going to focus mainly on a water-rights and beneficial-use standpoint as far as the Division of Water Resources is concerned. Hopefully I can make clear our regulatory jurisdiction and how it may contrast with a couple of other jurisdictions and regulatory agencies at the state level.

Since we treat all produced water from oil and gas wells the same, I thought it would be important to point out that we currently have over 29,000 active oil and gas wells in Colorado that produce water to varying degrees. The ones we talk about most in Colorado now are the coalbed methane (CBM) wells (Figure 1). They typically have higher quality water than the conventional deeper oil and gas wells out there, and we see more interest in them when trying to put produced waters to beneficial use. We put this map together with the Oil and Gas Conservation Commission about September 2005. I know the numbers have certainly increased, and most likely more than 4,000 of those 29,000 active oil and gas wells are CBM wells.

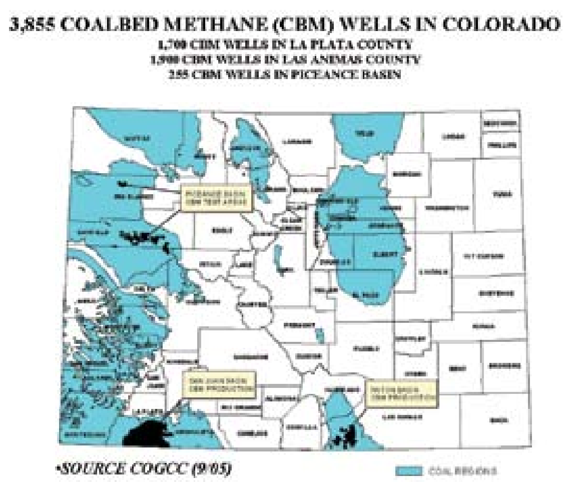


**Figure 1. Location of CBM Wells in Colorado**

You can see the distribution of these wells between the three major producing basins in the state. The San Juan Basin in the southwest part of the state is the most active and highest producing CBM gas basin in North America. Behind that we have the Raton Basin in Las Animas County just west of Trinidad. Then, on the West Slope in the Piceance Basin, is a relatively new basin as far as CBM-well development goes.

I want to point out the magnitude of produced waters we're talking about. As of last September, we have about 171 acre-feet per day of produced water from all oil and gas wells just in Colorado. This number probably is the same today. The majority of it, 135 acre-feet per day, comes from non-CBM wells, and about 36 acre-feet per day comes from CBM wells. About 19.6 acre-feet of that CBM well produced water is discharged to the streams. That aspect of produced water disposal comes under the Water Quality Division, and Dave Akers will speak further about it. Keep in mind the bulk of that 19.6 acre-feet comes from one control site in Heurfano County. About 6.7 acre-feet per day is injected into deep disposal wells, and about 9.5 acre-feet per day on a statewide basis see other disposal methods such as pits, commercial disposal, and centralized E&P waste management facilities.

I know statewide numbers can be a little deceiving when we're talking about localized producing basins. Across the state, on average, we generate about 16 million acre-feet of water from all sources, most from precipitation as tributary water. Of that, 2.3 million acre-feet comes from ground water wells in the state. Relatively, the amount of water produced from non-CBM wells as well as CBM wells is minor, 0.049 million acre-feet/year and 0.013 million acre-feet/year, respectively. On a statewide basis, we're talking about a very small fraction of water, even as these wells develop in the basins. Yet, that small amount is quite significant to those who want to use it on an individual, well-by-well basis or in some locality, like the project that Dave Stewart talked about at Wellington Water Works. I don't want to minimize that effort, just putting it in perspective.

Who regulates this produced water? From a state standpoint there are three primary agencies that have jurisdiction over produced water: the Colorado Department of Public Health and Environment, Water Quality Control Division; the Oil and Gas Conservation Commission; and the Colorado Division of Water Resources. There are regulated alternatives in disposing of the water produced at a typical gas well site (Figure 2).

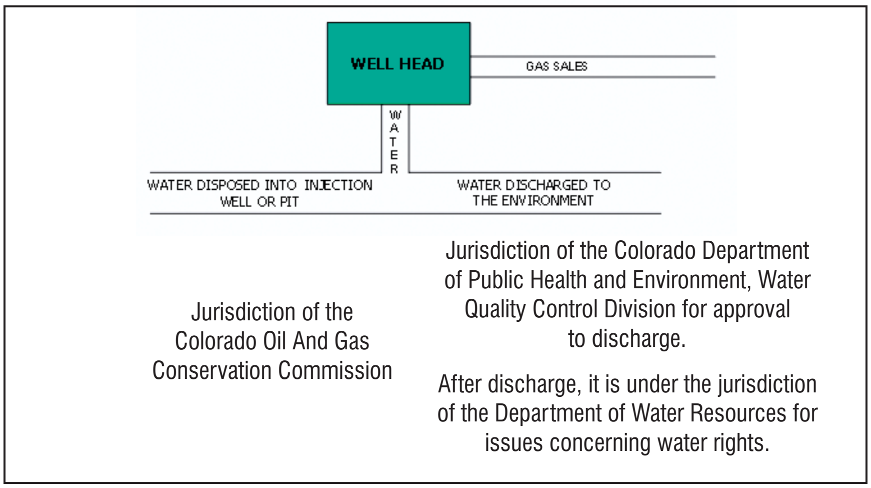


**Figure 2. Who Regulates Produced Water?**

Typically, this water is disposed of by techniques controlled by oil and gas regulations. Alternatively, the water can be discharged to the natural stream system by virtue of a discharge permit issued by the Health Department. Of course, there's more interest of late in taking this produced water beyond historical disposition methods and putting it to some type of beneficial use. Of the 29,000 active oil and gas wells in the state, the Division of Water Resources has only permitted one to be used for beneficial purposes – the well Dave Stewart described at Wellington Water Works.

### Regulatory and Use Considerations

Some of regulatory aspects to keep in mind when we're talking about putting this water to beneficial use:

- CBM wells are treated just like any other O&G wells in Colorado as produced water goes. There's no distinction in terms of what laws are in place when someone wants to take that water and put it to beneficial use.
- To discharge produced water, the operator must have a permit from the CDPHE-WQCD
- If water is discharged and beneficially used, it is subject to Water Rights Acts (Ground Water Management Act, Water Right and Determination and Administration Act). In the Colorado Division of Water Resources, there are two key acts passed by the legislature that come into play. One is the Groundwater Management Act, which was passed in 1965. The other is the Water Right Determination and Administration Act, passed in 1969, which integrates the administration of the ground water wells into the priority system with surface water.
- Most basins in Colorado are over-appropriated, meaning there's more demand for water than there is supply of water. We operate under the doctrine of prior appropriation, which is 'first in time, first in right.' That's really the key link into those two water rights acts, in terms of how we regulate this water. When putting the water to beneficial use, the doctrine of prior appropriation is a key consideration that we've got to keep in mind.

- Produced water is unreliable as a long-term source. Most of these CBM wells produce very early on, in the first several months, then taper off to a very low amount. They may produce at that very low amount for many years, ten to 20 years, but it's not like a renewable source that someone would rely on, say, for a perpetual source for a subdivision. It might have an interim purpose and use.
- Water quality is poor. Unless it's treated, it can't be used for many purposes.

Under the Oil and Gas Conservation Commission Rule 907, there're various means by which operators can dispose of this water. They're primarily interested in getting the oil and gas out, and they view this water as a waste product. Until recently there has been no interest in using produced water.

Under Rule 907, they can:

- inject it into a disposal well
- place it in a lined or unlined pit
- dispose of it at a commercial wastewater treatment facility
- use it for dust control on their leased roads to the well sites
- discharge it into the waters of the state under discharge permit through the Health Department
- use it for recovery, recycling and drilling additional wells
- use it for mitigation – a recently added measure. If there's belief that these operations are going to cause any impacts to domestic wells in a particular field, the operator has the option under this mitigation measure to actually treat that water and serve it to those individuals whose wells may've been impacted. This mitigation hasn't been used for that purpose, although in 2002 there was some development where springs had gone dry and one of the operators took some produced water over to that development. In this case, the water wasn't delivered because they believed there was injury or impaction to the springs by CBM well, but, instead, to help folks impacted by drought.

When we talk about putting water to beneficial use, the uses well defined by case law and statutes are irrigation, municipal, domestic, and stock watering. Right now, most of the produced water from these wells is of such a quality that it can be used for nothing more than stock watering. With treatment, it can be used for other purposes. Certainly there's always interest in using this produced water for augmentation purposes.

### CBM Water Rights and Ownership

When you discharge water to the streams, the waters of the state, you can lose dominion control of it. It becomes waters of the state, and anyone who wants to divert water from a stream must comply with the Water Rights Act, legislation for determination and administration of water rights.

The act of diverting water under the Water Rights Act has a number of restrictions:

- You must have an intent to use that water.
- You must divert it in priority – first in time, first in right – so if it's put into the stream and flowing with all the other water, it is diverted within the priority system.
- There must be a beneficial purpose, such as irrigation or livestock purposes, and can not be wasted.
- You must prevent material injury to vested water rights. That's all tied in to this first-in-time, first-in-right.

In addition to stream discharge and diversion, water can be taken directly from the well and used for a beneficial purpose. There're two ways to do that. In Colorado all water is presumed to be tributary until proven otherwise. Under statute ?37-90-137(1) & (2), CRS (2005), it is necessary to have a permit issued by our office. In issuing that permit, our office has to consider whether there's unappropriated water available to do so. Most basins of the state are over-appropriated, so there's really no water available unless they're going to do this through an augmentation plan approved by the water court – thereby preventing injury to these vested water rights. There are a few areas of the state on the West Slope and, in particular, some areas of the San Juan Basin, where there is water available for appropriation. Here, someone could come in underneath this provision and get a permit to beneficially use this water without a plan for augmentation. If they're in one of the basins on the eastern slope, and it's considered tributary water, they're going to need a plan for augmentation.

The second way to use produced water directly is to create a model showing that this produced water is non-tributary. This approach falls under statute 37-90-137(7), CRS (2005). No permit would be required unless there is intended beneficial use. It's not based on land ownership, and I say that because in Colorado most other claims for non-tributary ground water are based on land ownership. There is a specific exclusion in this statute when operators are getting water as a result of mining for oil and gas. Because it's non-tributary, we don't have to determine if appropriated water is available. However, the operator must demonstrate that it's non-tributary through modeling.

### Coalbed Methane Stream Depletion Assessment Study: Northern San Juan Basin, Colorado

I want to finish up with just a little discussion about a study that was just published yesterday. It's on our web site if you're interested in how all this plays out from a regulatory standpoint. This was a CBM stream depletion assessment study that was done in the Northern San Juan Basin in Colorado. The consultant contracted by the Department of Natural Resources was S.S. Papadopolous out of Boulder. If you're interested in it, go to our web site; there's a link there and you can download the report. We're soliciting comments for another month.

Figure 3 gives you a perspective of the San Juan Basin. We're just talking about the northern portion that's in Colorado. Figure 4 is a cross-sectional view of that basin to show the Fruitland coals where they're producing the CBM gas.

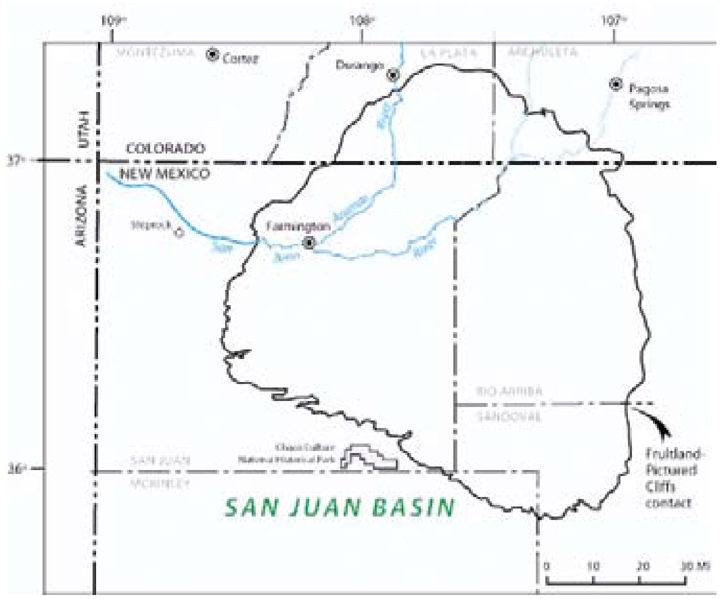


**Figure 3. San Juan Basin Regional Setting**

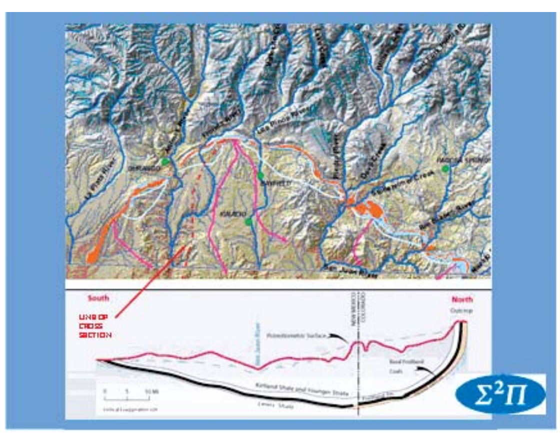


**Figure 4. Cross-sectional View of the San Juan Basin, Colorado**

Figure 5 shows us there're about 4.5 trillion cubic feet of gas being produced out of that basin annually and about 3,000 acre-feet of produced water coming out of those 1,700 wells.

Figure 6 depicts what the Division of Water Resources looks at to determine whether the water is tributary or non-tributary, and, therefore, how it is to be regulated. In this modeling of water flowing through these coal seams in the cleats, the consultant showed, basically, where the tributary/non-tributary line relates to the outcrop and stream systems.

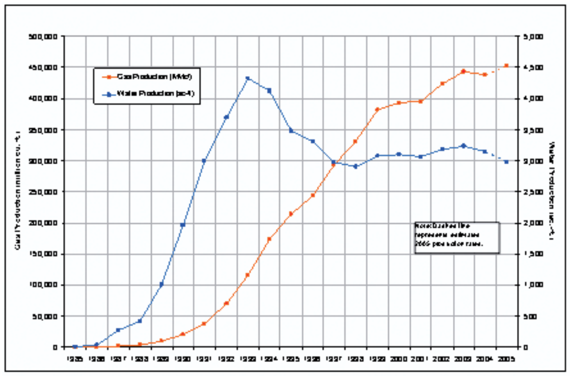

**Figure 5. San Juan Basin Annual CBM Gas and Water Production Rates in Colorado**

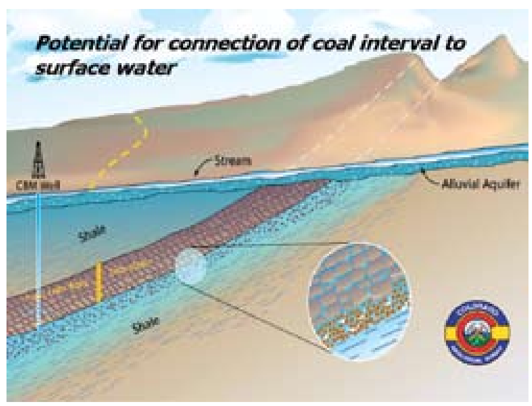


**Figure 6. Determination of Tributary/Non-Tributary Status of Water**

Figure 7 shows that the tributary zone is identified in that shaded area and it's about nine to ten miles from the outcrop. Through this modeling effort we were able to show where this tributary/non-tributary line exists. That's a regulatory tool we would use if someone wanted to permit one of these wells for beneficial purposes. Again, whether or not they're on the tributary/non tributary side would dictate how we would permit and allow them to use that water.

Figure 8 gives you an idea of the amount of stream depletion that occurs from the operation of those wells. Under current productions we're about 150 acre-feet a year of stream depletions out of that 3,000 acre feet that's pumped. The other curves show under different scenarios if some infield development were to come into play or if there were to be a lot of wells constructed within a mile and a half of the stream.

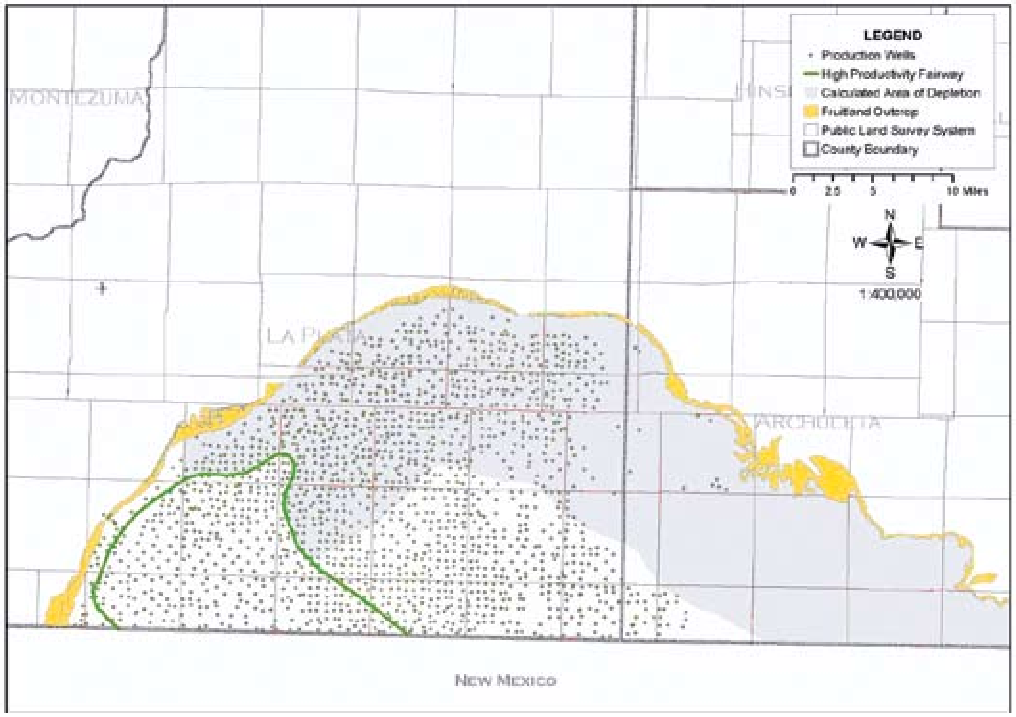


**Figure 7 Area With Calculated Depletions Exceeding 0.1% in 100 Years**

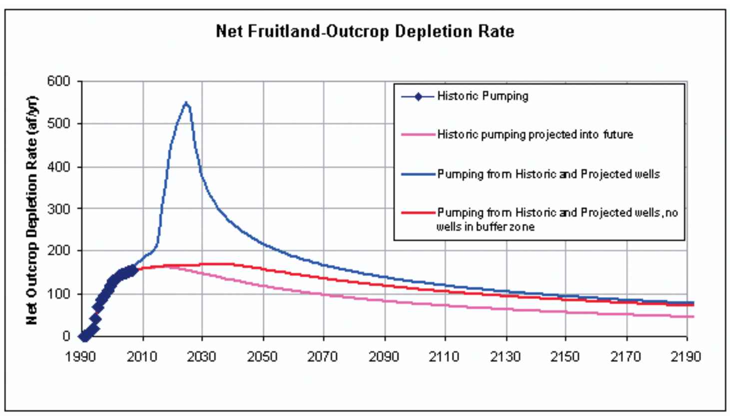


**Figure 8. Net Depletions of Outcrop Due to CBM Water Production**

Those seeking additional information, can go to these three websites:

- Division of Water Resources web site at www.water.state.co.us
- Colorado Oil and Gas Conservation Commission web site at www.oil-gas.state.co.us
- Colorado Department of Public Health and Environment web site at www.cdphe.state.co.us

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**Dick Wolfe** is a native of Colorado and was raised on a farm in Weld County. He obtained his B.S. and M.S. degrees in agricultural engineering from Colorado State University. Dick was a partner with Spronk Water Engineers for seven years specializing in water resources on various water right issues in Colorado, Kansas, Arizona, and New Mexico. For the past 12 years, Dick has been with the Colorado Division of Water Resources and is currently the Assistant State Engineer. Contact him at (phone) 303-866-3581.

*Produced Waters Workshop –*

# Practically, How Do We Do This?

## The Wellington Oil Field: A Case Study of the Beneficial Use of Produced Water from an Oil Field in Colorado

by Brad Pomeroy, Wellington Operating Company, Denver, CO

Interesting – we have oil guys talking to water guys, and the government's listening in!

The first oil was discovered in Colorado down in the Florence/Canon City area by some water guy trying to water his cattle and water his crops and water his family, and he got this nasty oil, a by-product of water production. We were burning sticks and coal back then. Now, particularly in the United States where we are so good at what we do, we've been producing oil fields for a long time. Most oil fields reverse their production performance: you get lots of oil at the beginning and a little oil at the end, a little bit of water at the beginning and then an oil cut of about five percent and a water cut of 95%. The water that we produce in Colorado is point-how-many-zeros-43% of how much water that passes through the state. Water that is classified as non-tributary has a lot of flexibility on how it can be used.

### "Only the stout-of-heart need apply."

Consider the Front Range of Colorado, from Pueblo to Cheyenne, one of the fastest growing residential and commercial corridors in the United States – and the Wellington Oil Field is right up in here. It's been that way for a while and will probably continue to be for a while as well. The fact that all the water in Colorado is over-subscribed makes a new source of water exciting. You've got to have geography hooked into availability. A new source of water in the middle of the red desert is a disposal challenge. A new source of water smack dab in the middle of the Front Range of Colorado is an interesting opportunity.

The Wellington Oil Field is the first oil well that's been permitted by the State Engineer's Office for beneficial use and is categorized as a non-tributary water source after way too much work and a lot of effort that the next people don't want to go through. We have done that in a number of different arenas. When we were motivated to do this, our first job was to make sure that the water was treatable; that we could afford to treat the water. If I'd known then what I know now, I'd have realized we probably can't, but we're way too far down the road on that.

The second thing was to make sure that the State of Colorado would allow us to use this beneficially so we'd have some hope of recovering our investment. We made a huge investment in an area where others have either have not been comfortable or were not motivated enough. Anadarko and Yates are big oil companies. They have multi-state operations, and they have shareholders to respond to, and they have a business plan to stick to. It's hard for a large company like that to step out of line. There are just too many divisions that have to agree with your plan, lawyers being the last. The job of these companies is to operate and make money for the shareholders. A company like mine is extremely small and has a little bit more flexibility in trying things that others might not try. I always enjoy a new challenge, and this has certainly been that. There are reasons why we, as a group, haven't investigated the opportunity of using produced water. It's not really a clear opportunity, and that's why it is so exciting to get everybody together in a workshop environment and explore things that haven't been explored before.

The Wellington Oil Field (Figure 1) was discovered in 1923 by Union Oil in California. The discovery well blew out for 82 million cubic feet of gas a day. If you go back and read the old newspapers like the *Denver Post* – before they did photos in the newspaper – you'll see eight drawings on the front page, because the governor of Colorado thought he'd finally caught up with Texas, y'all. It was exciting for the State of Colorado.

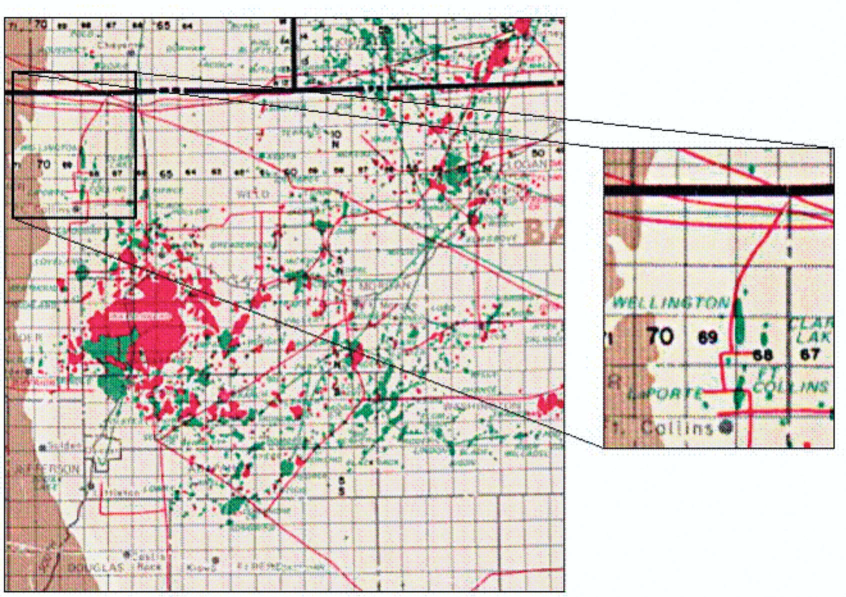

**Figure 1. Wellington Oil Field, CO**

One of the reasons I'm showing you this slide is to illustrate how many oil fields can fit on a little section. These are six-mile-square sections. The Denver/Julesberg Petroleum Basin continues to the east, north and west. We cover southeastern Wyoming and southwestern Nebraska. We go out almost to the Kansas state line. There are hundreds of oil fields out there that, I guarantee you, are making more water than oil. We own and operate the Fort Collins Field, which produces from the same formation that the Wellington does – the Muddy Formation – at a depth between 42 and 4,900 feet (Figure 2). It's a steeply dipping anticline, and the net pay is 70 feet thick – that's like a seven-story building covering six miles, 1-1/2 miles wide – and it has a pore space in which the oil resides.

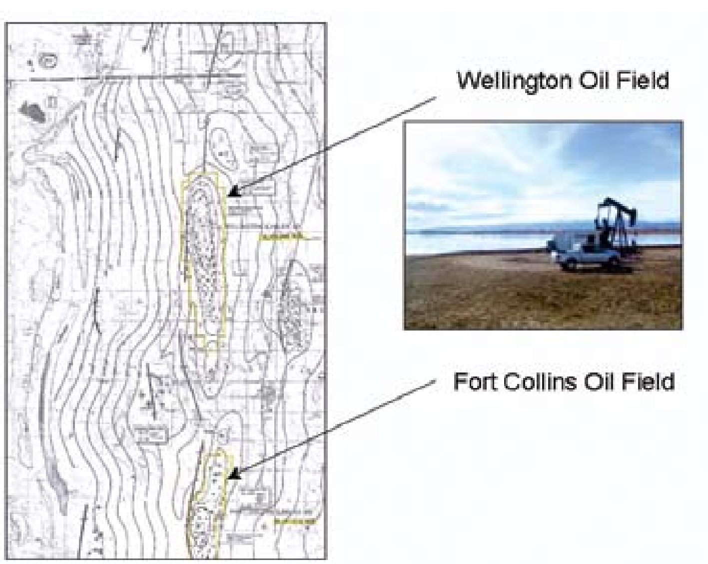


**Figure 2. Wellington Oil Field in Muddy Formation**

It's been estimated that there were between 90 and 110 million barrels of oil in this structure when it was discovered. Because the discovery well blew out and the confirmation well blew out, a wad of the reservoir energy was lost – and that encourages fluids to migrate up into where the gas left.

### A natural wedding

The Wellington Field started producing water pretty early in its life. We're the ninth operator in this oil field, so there've been a lot of people in front of us trying to deal with this problem. It's been sold twice for scrap; once by Conoco and once by a Fort Collins production company. If we did not have this confluence of high oil prices and a desperate need for water, I would still be operating this field the same way that my predecessors had been – producing water; separating the oil, gas, and water; and reinjecting the water into the subsurface. Believe me, when 98.5% of your recovery is waste by-product and you're a little guy, it's very expensive to conduct this operation.

Let me introduce Richard Seaworth, my partner in this operation. He's the president of Seaworth Ag Enterprises and has land immediately adjacent to the well, which gives us the opportunity to discharge under Rule 907. Richard wants to build some houses on his 600-acre farm where the land is not quite as productive and the development would increase the value of his house. I'm trying to get rid of water. This is a pretty natural wedding, wouldn't you say? Richard needed about six acre-feet of water to get his development done, and I'm trying to get rid of two or three acre-feet every couple of days.

### Trial-and-Error Permitting

We went through the process of making sure the water was fiscally treatable. The State Engineer said we could use it beneficially. Then we went to the Colorado Department of Health, which is where we thought we'd get our discharge permit. After preparing a lengthy document, the Colorado Department of Health Water Quality Control Division said, "We're not the governing authority on water discharge from oil fields." It was incredibly expensive to re-permit for the Colorado Oil and Gas Conservation Commission, who, like the State Engineer, had never issued a permit for a direct beneficial use. It was counter-intuitive: the COGCC aims to protect the waters of the state from nasty produced water, and you can truck it, reinject it, and evaporate it, but you can't leak it. If we can't leak the water and get it back into the aquifer, we can't get any credit for it, so there's really no point in pursuing the project.

To make a long, painful story short, the Commission was very receptive to our request for a rapid infiltration basin or a pit permit that would allow discharge into the alluvium. The staff, however, was a little less excited because they were under-manned. They'd never done it before, and they really ratcheted down requirements so that there was never a question as to whether we would comply or not. We now have a leaky pit permit, and we have a non-tributary designation for our produced water. We are attempting to solve, in a micro-environment, a problem that is going to be repeated all along the Front Range: how can we use waste water from an oil field beneficially? We hope to make some money at it; but believe me, we did not enter into this scenario trying to make money. We did it to solve mutual problems. Dave Stewart with Stewart Environmental has been involved from the beginning on this. He's the facilitator, and he has been, indeed, very helpful. Those of you who join us tomorrow on the field trip will be very impressed at what VTO has managed to do with its wastewater.

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**Brad Pomeroy** is President and Manager of Operations of Wellington Operating Company in Denver. Brad is responsible for production of the Fort Collins Field, the Wellington Field, and the Cobb Lake Field – all in Larimer County, Colorado – including all drilling, completion, production and sales. He is a certified petroleum geologist and has degrees in geology and forestry. Brad has 25 years experience in the petroleum business as a geologist, operator and driller. Contact him at (phone) 303-220-5399.

*Produced Waters Workshop –*

# Practically, How Do We Do This?

## Practically, How Do We Permit the Introduction of Treated Produced Waters into Integrated Water Resource Management Developments?

by Dave Akers, Colorado Department of Public Health and Environment, Water Quality Control Division, Denver, CO

The State Engineer's Office, the Oil and Gas Conservation Commission, and the Division Of Minerals and Geology are among the agencies that are designated as implementing agencies under a statute passed in 1989 called Senate Bill 181. That statute is codified in the Colorado Water Quality Control Act, and it provides for these implementing agencies to oversee activities such as oil and gas production. These agencies are authorized to implement a program to protect ground water standards that are adopted by our Water Quality Control Commission. The wrinkle: if it's a discharge to surface waters, then a discharge permit issued by the Water Quality Control Division, is required; if it's a discharge to ground water for an activity that is otherwise overseen by one of these implementing agencies, then that agency is responsible for implementing some sort of a mechanism – you can call it a permit or other regulatory mechanism – that would result in protection of ground water standards.

### In-Stream Quality Standards

Deep oil injection was the historic option that was always practiced. Total retention and evaporation is not very practical. From our perspective, total retention is an option if the water couldn't be discharged to surface waters. And, there are options to discharge to ground water or discharge to surface water.

When you're discharging to surface waters, there are a number of considerations. First are the industry standards. Those standards in Colorado are adopted by our Water Quality Control Commission to protect the beneficial uses of the waters. The four categories of beneficial uses that the Commission adopts standards to protect are:

- aquatic life
- drinking water supply
- agricultural use
- recreational use

We have standards, and we have these identified beneficial uses that the standards protect. In our permitting program, we do allow dilution of a discharge. So, you can allow water in the receiving stream to dilute the discharge to the point where downstream of that discharge – what we call a mixing zone – the water quality standards would be met. Upstream water quality has to be taken into account: if the upstream water has a quality parameter at the standard level, then there can be no dilution effect for that parameter, in spite of there being wet water in the stream, because we've already got water that's at the maximum level.

Finally, what are the potential pollutants of concern? TDS is a pollutant of concern in produced waters, which is interesting because we don't have a water quality standard for TDS. Other pollutants of concern might include iron, manganese, chloride, and sulfate, depending on the kind of produced water. In streams, standards depend on the stream classification. Typically, most streams in Colorado are going to be classified to protect aquatic life and agricultural use; there are very few that aren't classified to protect both of those uses. The parameters that I've identified here are just examples. The entity that proposes to discharge to surface waters would need to do a pretty thorough examination of that produced water to determine what types of compounds or contaminants might be in the water.

A principal driver as to whether produced waters are discharged to surface waters is the set of narrative standards that the Commission has adopted. You may have heard of these. There can be no discharge of toxics in toxic concentrations. The way the narrative standard is implemented in Colorado, with respect to protection of the aquatic life use, is through a whole effluent toxicity, or WET, evaluation. Further, there are two types of tests, the acute and chronic tests, which depend on the specific circumstances of the discharge. And, if the discharge is to the Colorado River Basin, then permit regulations require that TDS/salinity discharge be limited to one ton per day; additional work would have to be done to justify a higher level discharge of TDS.

### Low Flows and In-Stream Water Quality

If you have high low flows, and a small design flow, you're going to have considerable dilution. Probably, you're not going to have a problem. Most likely a problem arises when the intended receiving stream has a low, low flow, or the proposed produced water discharge has a high large design flow relative to the intended receiving stream. The end result would be less dilution potential, and in effect, your discharge permit would be issued at or near the standards. The same concept applies to upstream parameter concentrations: higher upstream concentrations drive tolerance limits low.

### Potential Pollutants of Concern

The source waters dictate what pollutants we're going to have to be concerned about; that is, in-stream standards and downstream classifications and uses can dictate some pollutants. If you're in the Colorado River Basin, you're going to have to worry about total dissolved solids. If the stream is classified for a water supply use, then there are going to be standards for chloride and sulfate that apply. It is important to understand the concentrations of those constituents. For the engineers in the crowd, maybe the geologists who get into a little math, here is the equation we use to determine Water Quality-Based Effluent Limits (WQBELs) for permits:

$$M_2 = \frac{M_3Q_3 - M_1Q_1}{Q_2}$$

Where:

- $Q_1$ =Upstream Low Flow (1E3 or 30E3)
- $Q_2$ = Average daily effluent flow (design capacity)
- $Q_3$ = Downstream flow ($Q_1 + Q_2$)
- $M_1$ = In-stream background pollutant concentration
- $M_2$ = Calculated WQBEL
- $M_3$ = Maximum allowable in-stream pollutant concentration (water quality standard)

It's a pretty simple concept: the maximum allowable concentration in the discharge depends on what's upstream, what's downstream, and how much is delivered by flow. Because most of the parameters of concern with produced waters are "conservative," we rarely have to do modeling.

### Antidegradation

There is yet another wrinkle that applies to certain waters, and that is our antidegradation regulation. Without going through this in a lot of detail, the antidegradation regulation strives to maintain water quality at existing levels where feasible:

- It applies to reviewable (undesignated) waters.
- It establishes baseline water quality (BWQ) concentrations downstream as of September 30, 2000.
- Facility existing contributions and permitted allocations are considered IF in existence as of September 30, 2000; otherwise, a non-impact limit (NIL) of zero is used as permitted allocation.
- Antidegradation-based average concentrations (ADBACs) are calculated by allowing 15% incremental increase between BWQ concentration and the standard.
- Facility may choose NIL, ADBAC or complete an alternatives analysis.

If a stream is designated and it's reviewable by the Water Quality Control Commission, so that the antidegradation regulation applies, the entity would only be allowed to use a fraction of the available assimilative capacity of the stream. If it was desired, for generally economic reasons, to be able to use the full assimilative capacity of the stream, additional studies would have to be conducted. Here's how that antidegradation rule might apply to determine what the smaller assimilative stream capacity would be:

$$ADBAC = \frac{[0.15(WQS - BWQ) + BWQ]Q_3 - M_1Q_1}{Q_2}$$

Where:

- $Q_1$ =Upstream low flow (1E3 or 30E3)
- $Q_2$ = Average daily effluent flow (design capacity)
- $Q_3$ = Downstream flow ($Q_1 + Q_2$)
- M1 = In-stream background pollutant concentration
- BWQ = Baseline Water Quality concentration
- WQS = Water Quality Standard concentration
- ADBAC = Antidegradation-based average concentration

In terms of TDS, if the discharge was to be in the Colorado River Basin, there would probably have to be a salt-reduction study, unless the discharge would be at one ton of salt per day or less. There also is a regulatory provision recently passed based on a policy adopted by the Colorado River Basin Salinity Control Forum that limits or applies that one ton per day limit to the scope of the entire operation for any new field that might be developed. Previously we would've allowed one ton per day for each discharge point in that field; now the limit is one ton per day for the whole field. That's likely going to drive treatment requirements and/or trading requirements, which are allowed under that regulation.

The acute WET limit is the LD50, or the concentration that is the lethal dose for 50% of the test organisms. Two organisms typically tested are a fish, such as a fat head minnow, and an invertebrate, such as the Ceriodaphnia. They're very sensitive to salinity, so discharge of high saline waters is probably not going to be able to pass a WET test without some treatment. Depending on what the other compounds are in the discharge, there could be sensitivity to fish species as well. Our division has approved an alternate species, an invertebrate called Daphniomagda that is less sensitive to TDS, for use in acute testing.

There might be a case where there is selenium in the produced water. There are a number of streams in Colorado that are listed as impaired for selenium, particularly in western and southeastern Colorado, so they would not be good candidates for receiving this produced water. This reiterates the importance of understanding the quality of the produced water before you get too far down the road of planning for surface water discharge. Options that could be considered in the case of selenium in the produced water would be treatment or even discharging during non-low-flow months, presuming that the low-flow in the stream is greater than zero so there could be a storage and timed discharge option there. Of course, reinjection or use of percolation ponds is an option.

### Who's Got the Authority?

I'll mention here the overlapping jurisdictions on produced waters. The State Engineer's Office is looking at water rights. Our Division is looking at water quality protection, and the OGCC is looking at the provisions to allow production of the resource. Consider Scenario #1: a farmer wants to use produced water for irrigation. The Division would argue that a discharge permit would be required for that water, based on the fact that it would be put immediately to beneficial use. OGCC authority does not cover water put immediately to beneficial use, so they would not have the authority as an implementing agency to oversee the protection of the ground water standards through their regulatory structure. Consequently, the permitting responsibility would fall to the Water Quality Control Division. While the produced water is of sufficient quality to be put to beneficial use, it is still considered a "waste."

Here are more examples of when we had to determine which agency had authority. Someone wants to use cooling water at a power plant. If it is a zero-discharge power plant, and it's just being put into a lined pond and then recirculated through the cooling tower, such use would not require a permit. Brine water used in a flow-through system at a shrimp farm and discharged as a flow-through to surface waters would require a discharge permit from our Division. In a situation of aquifer recharge, our Attorney General's office ultimately determined the Oil and Gas Conservation Commission has the authority for disposal. There are complications in terms of substitute supply plans and exchanges in augmentation plans.

So, you might conclude that you're getting yourself into an extremely complicated situation if you want to discharge produced waters to surface waters . Our Division has close to a ten-year history of issuing permits for produced waters. Most of those are in the Las Animas County area, where we have found ways to simplify the permit-issuing process by permitting an entire field and defining simple conditions for bringing wells on without having to go through a much more complex process. Remember, many factors affect the potential effluent limits applied to discharges of high saline wastes. Site-specific factors have significant impacts and cause significant variability among effluent limits. The costs to treat high-saline wastes to meet effluent limits for discharge to surface waters may be prohibitive in some cases.

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**Dave Akers** manages the Clean Water Facilities Program in the Water Quality Control Division. His responsibilities include oversight of Colorado's discharge permitting and compliance programs. Dave has a B.S. in Civil Engineering and began work with the Division in 1979, first as a staff engineer and then in various supervisory and management positions in the Division's permit section. Contact him at (phone) 303-692-3591.

*Produced Waters Workshop –*

# Practically, How Do We Do This?

## Practically, How Do We Mitigate the Environmental Impact of Using the Regular Western Water Delivery Systems to Move Treated Produced Waters to Beneficial Uses?

by Jill Morrison, Powder River Basin Resource Council, Sheridan, WY

First, I want to start with the basics that have been addressed. The reason we want to make sure we don't waste this water is because we know water is valuable – arguably as valuable as oil and gas. We also know that there is a great need for water both now and in the future – as evidenced in the 2003 findings from the Department of Interior's "Water 2025: Preventing Crisis and Conflict in the West." Some of the main findings in that report:

- Population is exploding
- Water shortages exist
- Water shortages result in conflict
- Aging water facilities limit options
- Crisis management is not effective

I want to focus on the Powder River Basin since that is my home and where I've worked to bring responsible CBM development for the last 15 years. In the Powder River Basin, we have a great potential for building a lemonade stand that we believe can mitigate environmental impacts, move treated produced water, and put it to a beneficial use. Unfortunately, we have failed to do that so far, and it is resulting in some serious environmental impacts. We need to push ourselves to ensure that water is actually put to a real beneficial use.

To put this in perspective, I want to highlight the volumes of water we are talking about, past, present, and future, shown in Figure 1. Produced CBM water in the Powder River Basin, according to figures from the Wyoming Oil and Gas Conservation Commission, is averaging about 1.5 million barrels of water per day – or about 74,000 acre-feet a year. Projections from both BLM and the Ruckelshaus Institute for Environmental and Natural Resources indicate that we will produce between four and five million acre-feet of water in order to develop the CBM. The rule of thumb is that one acre-foot is enough water for a family of four. Using that calculation the CBM water projected to be produced in the Powder River Basin is enough water for over 16 million people.

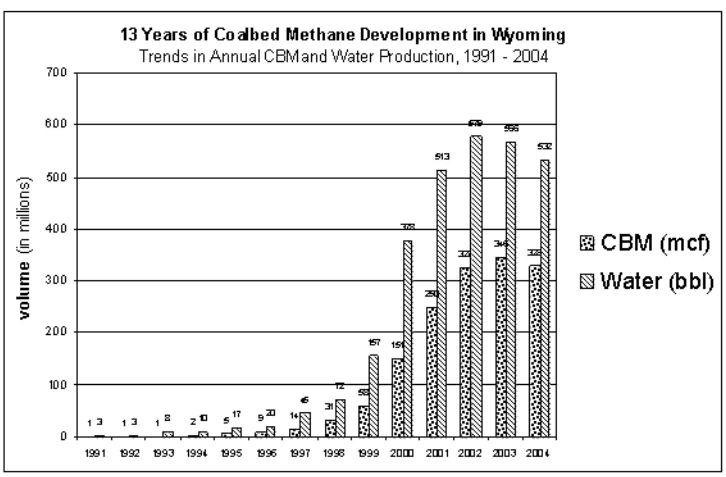


**Figure 1. Trends in Annual CBM and Water Production in Wyoming**

To address mitigating the environmental impacts of using typical western water delivery systems, let's look at the impacts now in the Powder River Basin. These photos will show you why we need to stop the waste of the majority of this resource, which in the process will also stop the damage being caused by the direct discharge of this water. It is also the reason we have initiated a rulemaking petition in our state to require that this CBM discharge water be put to real and actual beneficial uses.

Clabaugh Ranch Wild Horse Creek CBM Discharge Water Flooding – March 2005

CBM Reservoirs Overflowing and Flooding Wild Horse Creek

Clabaugh Ranch Salt & Iron Damage to Soil by CBM Waste Water

Downstream Soil and Vegetation Damage from CBM Discharge in Dead Horse Creek on Barlow Ranch

CBM Flooding in Spotted Horse Creek and on Meadows on the West Ranch

West Ranch, Spotted Horse Creek Meadows: Salts Deposited and Leached from Soil Caused by CBM Flooding

**Figure 2. Damage Caused by CBM Water Discharges**

As you see in Figure 2 photos, CBM water is being discharged to ephemeral drainages and it is having some very damaging impacts. These drainages are not capable of handling these volumes of discharge water. Such discharge floods meadows and destroys native vegetation, replacing it with non-palatable vegetation, and loads the stream and soils with salts – likely causing some irreversible impacts and creating big problems for ranchers and other landowners.

This type of discharge creates unwanted downstream impacts when CBM reservoirs overflow onto downstream users. In addition to those in Wild Horse Creek, I've worked with landowners who have problems with CBM discharge water on Dead Horse Creek, SA Creek, Spotted Horse Creek, Wildcat Creek, Four Mile Creek, and Cat Creek. In all these places landowners are experiencing the loss of good vegetation, damage to soil, and losing the ability to use the natural flow of good water for irrigation since many of the CBM reservoirs intercept the natural flow of rain and snowmelt and interfere with water rights.

We cannot use our ephemeral drainages in the Powder River Basin as delivery systems without long-term irreversible impacts. There are over half a dozen ephemeral streams that are now running perennial to the Powder River.

As you can see in Figure 3, erosion is another problem caused by the discharge of steady and large volumes of water in these ephemeral drainages that usually only run water once or maybe twice a year. The discharge of CBM water down these ephemeral drainages turned perennial by CBM water is also a concern due to the loss and damage to native aquatic life and fisheries in the Powder River and other streams.

**Figure 3. Erosion in Ephemeral Drainage**

**Figure 4. CBM Water Reservoir**

The other problem we've created by not bringing this water to beneficial use is building these very large off-channel pits like the one shown in Figure 4. This pit will be lined to keep from contaminating ground water and will be fenced due to the dangers to livestock and wildlife. It will also take a lot of good rangeland out of productive use.

Figure 5 shows more pits and reservoirs. The problem we are beginning to see and be concerned about is the contamination of shallow ground water as evidenced by monitoring wells. The water infiltrating through the pits and reservoirs mobilizes salts, sulfates and other constituents that can contaminate ground water.

**Figure 5. Aerial View of CBM Pits and Reservoirs**

Finally, the other impact we are concerned about is the loss of our ground water resource as we pump this water out in order to get the coalbed methane gas to release.

The loss of ground water can be mitigated by the reinjection of produced water for future use. We need to locate places where we can reinject this water for storage for our future generations in the Powder River Basin. Anadarko took the initiative to build a pipeline for CBM discharge water to reinject it in a location 40 miles south of their field in an area that will store the water for future use.

So how else can we get this water to beneficial use and mitigate these impacts? Pipelines.

This industry is dependent on pipelines and is very good at building pipelines (Figure 6). Industry already has an extensive network of infrastructure for both gas and water. The gas is taken to market in pipelines – water could be also be moved in pipelines to nearby municipalities that can use this water.

**Figure 6. Pipelines Can Move Gas and Water**

We are in need of water in the Powder River Basin both now and in the future, on our ranches and in our nearby towns. We need to begin making plans to build the infrastructure to ensure we beneficially use this water on our ranches and combine what is left and take it to our municipalities. Gillette is already implementing water conservation measures and looking to drill more water wells to supply water to that city. Buffalo and Sheridan also are looking for new water supplies.

There is great possibility to move this water through pipelines to beneficial uses in our own basin. It is a valuable resource worth an estimated $2 billion to $10 billion – let's stop wasting it. We look forward to working with the industry, the state, and the federal government to make this happen.

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**Jill Morrison** joined the Powder River Basin Resource Council as a community organizer in 1990. Since then she has been working with Wyoming landowners and citizens to address energy development impacts and to ensure good stewardship of land, water, and air while engaging citizens in civic participation. In 2004, she was recognized as one of 18 individuals across the country who received the Ford Foundation's "Leadership for a Changing World" award. Morrison and her husband operate a ranching and outfitting business in Northeast Wyoming and have two daughters. Prior to her work with Powder River, Morrison was an award-winning investigative journalist. She holds a B.A. in English from Arizona State University and was born and raised on a farm in Western Nebraska. Contact her at (phone) 307-672-5809.

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

Presenting: Paul Beels, Sandra Stavnes, John Duda, Bill Carswell, Michael Gabaldon, Don Simpson

Moderator: Harold Bergman, Director, Ruckelshaus Institute, University of Wyoming

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

## BLM's Powder River Basin Interagency Working Group, and Adaptive Management Approach

by Paul Beels, BLM Interagency Working Group

We are at ground zero of coal bed and natural gas development. You might say we are in the trenches. When I came over to the office in the summer of 1999, I was the 23rd person there, and today we have close to 90 on the staff. So there has been a lot of activity. We have actually built on to the office four different times. The majority of that effort has been on the permitting side of the development.

But I want to talk today about a prototype of the working group that may have some applicability in other areas. This group focuses primarily on monitoring related to the environment statements that were done in Wyoming and Montana, worked on simultaneously, and completed in April 2003. So the Interagency Working Group really is a product of a commitment made in these two EIS processes, one in Wyoming and the other in Montana. Figure 1 shows a little perspective, to add to the perspective everyone else has provided on the amount of development in Wyoming.

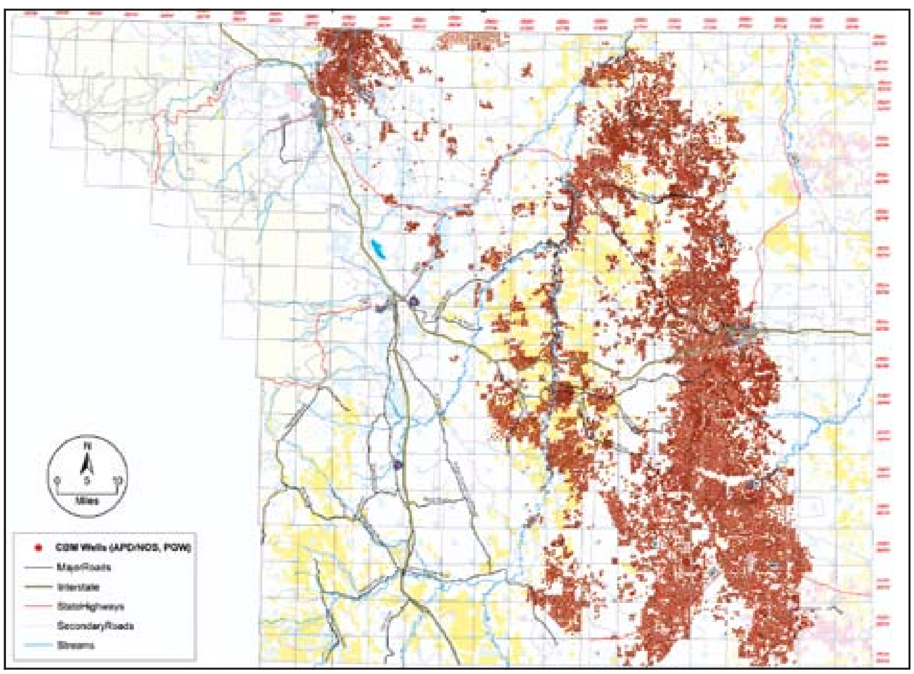


**Figure 1. CBM Development of the Powder River, Tongue, and Belle Fourche Rivers**

These are the wells right now that are either on-record applications for permit to drill through the Oil and Gas Conservation Commission, or they are producing gas wells. Most of the wells are north and south of Gillette. We've got a lot of development now around Sheridan as well. In the center of the basin, the Big George coal is now being developed and is likely where most of the activity is occurring. Eight million acres is what you see pictured here in the Powder River Basin.

The Wyoming EIS basically looked at the impacts of 51,000 coal bed natural gas wells over a ten-year period, 15,000 of which are in production today. Since 2001, an average of 50,000 acre-feet of water are produced each year, a number that is somewhat in line with some of the figures you've seen here; yet, I'm somewhat surprised at the variation in some of these numbers. Compare that to the 116,000-acre-feet storage capacity of Horsetooth Reservoir here in Fort Collins.

Also let me share actual excerpts out of the record of decision for the Wyoming PRB EIS:

> "*Information gathered from this monitoring will guide mid-course corrections in adapting to the inevitable changes that will occur because of new information. A monitoring program has been outlined and will be further developed and implemented in accordance with the guidelines provided in Appendix D.*"

This pretty much sets the stage for this interagency working group. There are a couple of things in this statement that are pretty key. First of all, this is about monitoring, for the most part. And adapting to the inevitable changes. This EIS took about two and a half years to complete. When we started the EIS, we really didn't know in a lot of cases what kind of ground water monitoring and surface water monitoring effects we were looking at. So we wanted to devise something through implementation to be able to react to changes we might see out there as a result of the development. We made assumptions and we wanted to see if those assumptions would play out.

Appendix D in the record of decision basically laid out the framework for how this Interagency Working Group would be put together and what its function would be. This is a fairly new concept in the BLM, actually, and this adaptive management approach is kind of a buzz word here. It has been difficult to implement.

Here's another statement from the EIS:

> "*The Interagency Working Group will function as oversight for the monitoring adopted for the PRB to assure that the decisions and required measures are carried out; to inform cooperating agencies on progress in carrying out mitigation measures; and to make available to the public the results of relevant monitoring.*"

An important point is in this last sentence: what we're trying to accomplish is to keep people informed, with a public report on an annual basis on the monitoring that is being done, and updates at our web site: http://www.wy.blm.gov/bfo/prbgroup/index.htm (Figure 2). The mission of the Powder River Basin Interagency Working Group (PRBIWG) is to:

(1) provide for environmentally sound energy development
(2) develop coordinated and complementary best management practices, guidelines, and programs related to CBNG activities to conserve and protect resources
(3) monitor the impact of CBNG activities and assess the effectiveness of mitigating measures
(4) develop and integrate the databases and scientific studies needed for effective resource management and planning, and to make that information readily available, and
(5) promote compatibility in the application of each agency's mission

Figure 3 shows the three-tier organization of the group. A Memorandum of Understanding (MOU) and a Charter were developed to help guide the group. There are 24 signatories representing federal, state, and tribal interests; public entities are not a part of the group but may attend meetings.

- **The Interagency Coordinating Committee (ICC), or Level 3,** consists of the heads of three agencies: the EPA Region 8 Director, the Wyoming and Montana DEQ State Directors , and then the State Directors from the BLM in Wyoming and Montana. They are briefed on activity and issues at least once a year and are called on to resolve any impasses that may occur at lower levels.
- **The Mid-Level Group, Level 2,** is made up of representatives from both of the states, primarily the field managers for the various agencies.
- The Task Group, Level 1, is comprised mostly of specialists and meets frequently. Its **highest-priority task was to develop more specific monitoring plans, which have been completed and implementation of them beginning.** Because of the issues we face with the Powder River, we ended up with four different task groups: wildlife, air, water, and aquatics.


Buffalo Field Office
Powder River Basin
Interagency Working Group
Bureau of Land Management Wyoming

*Updated January 18, 2005*

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*Meeting Minutes updated 01/18/05*

**The Powder River Basin** (PRB) contains millions of acres of public land in northeastern Wyoming and southeastern Montana. The Basin holds an extensive natural gas resource associated with the regional coal deposits.

Development of coalbed natural gas (CBNG) on federal lands requires a lease issued from the Bureau of Land Management (BLM) and approval of an application for permit to drill along with associated permits, approvals or reviews from the Montana Department of Environmental Quality or the Wyoming Department of Environmental Quality, and from other State and Federal agencies.

The PRB Interagency Working Group (PRB IWG) was established as the forum for government agencies to address and discuss issues of common concern to all parties involved in permitting and monitoring of CBNG development. Additionally, attention will be given to those issues that may result in cross-border effects requiring close coordination among the State and Federal agencies in Montana and Wyoming, and with Tribal governments. Through this cooperative management effort, each agency will achieve greater operational efficiency, enhance resource protection and better serve the public.

**Vision Statement**

To work together to protect the air, water, land, fish, wildlife, plants and cultural resources in the PRB for current and future generations while providing for natural gas development to address the nation's energy needs.

**Mission Statement**

- Develop coordinated and complimentary best management practices, guidelines and programs related to CBNG activities to conserve and protect resources.
- Monitor the impact of CBNG activities and assess the effectiveness of mitigating measures.
- Provide for environmentally sound energy development.
- Develop and integrate the databases and scientific studies needed for effective resource management and planning.
- Promote compatibility in the application of each agency's mission.

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FIRSTGOV

www.wy.blm.gov/bfo/prbgroup
Created by BLM Wyoming
Please contact the wy_webteam with any questions relating to accessibility of documents.

**Figure 2. Home page for the Powder River Basin Interagency Working Group (http://www.wy.blm.gov/bfo/prbgroup/index.htm)**

The Wildlife Task Group monitoring plan is comprised of three components:

- Basin-scale (EIS required) monitoring; emphasis of taskforce
- Project scale monitoring (compliance); individual PODs
- Ongoing research and needs

The Air Task Group monitoring plan includes:

1. Assessment of Existing Monitoring
   - Specific monitoring information from each member has been assembled. NPS, DEQs, EPA, BLM, Tribes.
   - Maps of the existing and historic monitor locations have been completed.
2. Discussion of additional monitoring needs
3. Assembling a complete Monitoring Plan including maps, monitoring information and costs, and general recommendations and annual report output

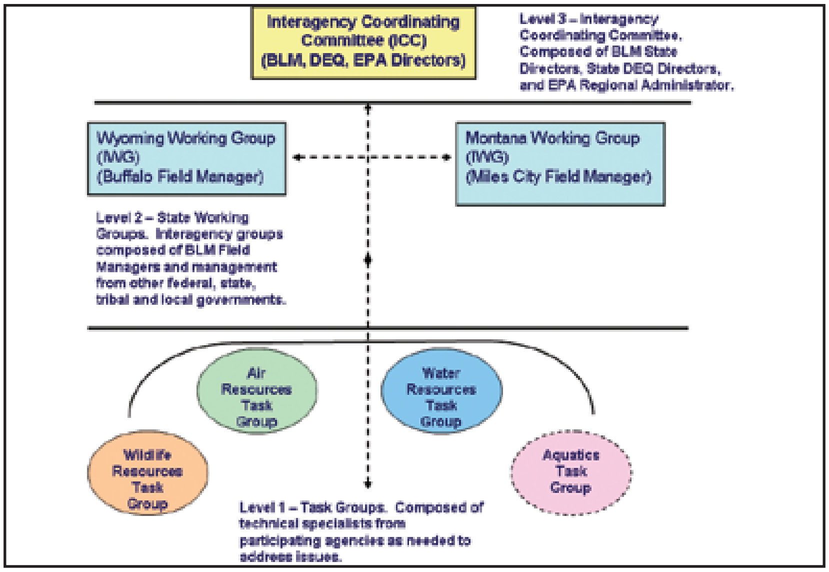


**Figure 3. Three-tier Organization of the PRB Interagency Working Group**

The Aquatics Task Group materialized after the fact, and since coming on board has come quite far. Its monitoring plan includes:

- Establishing baseline conditions for aquatic biota and their habitat, including aquatic habitat, riparian habitat, fish, and macro-invertebrates
- Evaluating existing or potential effects of CBNG water discharge on aquatic life

Wyoming Game and Fish Department began the fisheries and aquatic habitat work in 2004, and USGS joined in last year doing macro-invertebrate and riparian habitat mapping. An interpretive report is scheduled to be produced next winter, and we will re-evaluate the task group in two years. The targeted research includes:

1. Literature review and study plan to assess the effects of CBNG activities on fish assemblages
2. Development of a prairie fish index of biotic integrity for streams in MT and WY
3. Impacts to amphibians and reptiles

The Water Task Group has primarily focused on surface water monitoring with a network of 36 monitoring stations in both Wyoming and Montana collecting stream flow and water quality. The total cost to implement has been $1.2 million; in the past two years it has only been funded at 65%. Its monitoring plan also includes:

- monitoring a series of deep ground water wells; BLM has 122 in place around the basin in Wyoming with more in Montana
- shallow ground water monitoring occurring throughout the basin in relation to impoundments (see Figure 4)
- a protocol for "Compliance Monitoring for GW Protection Beneath unlined CBM Produced Water Impoundments"

The salinity (as measured by EC) and sodium adsorption ratio (SAR) are anticipated to be the constituents most likely to be altered by CBNG discharges. To date, noticeable increases in these parameters have not been observed (Figure 5). More detailed interpretations are available at http://www.mt.blm.gov/mcfo/cbng/CBNG-Monitoring.htm, and http://tonguerivermonitoring.cr.usgs.gov/2004waterqualitysummary.htm

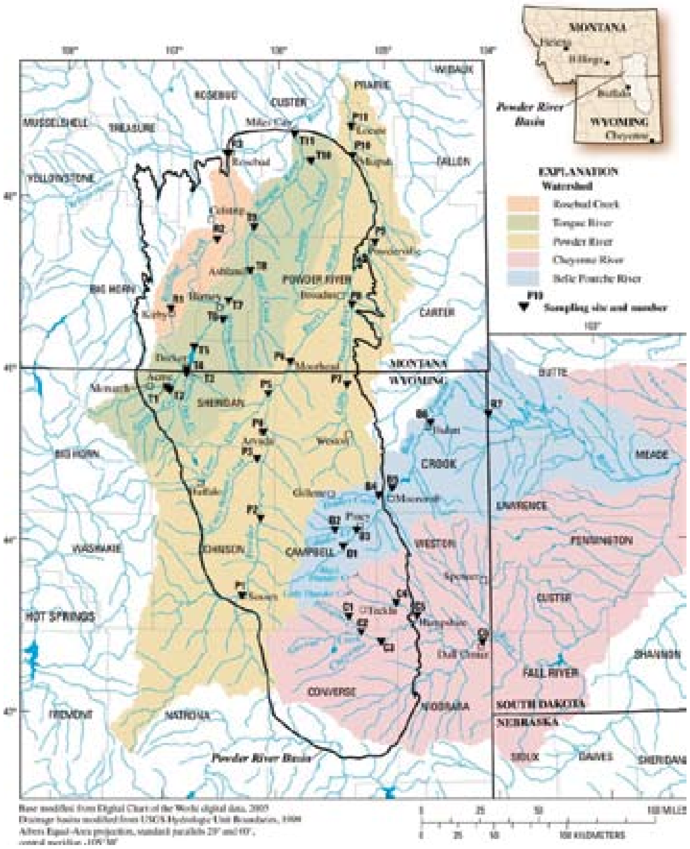


**Figure 4. Surface and Ground Water Monitoring Sites throughout the Powder River Basin**

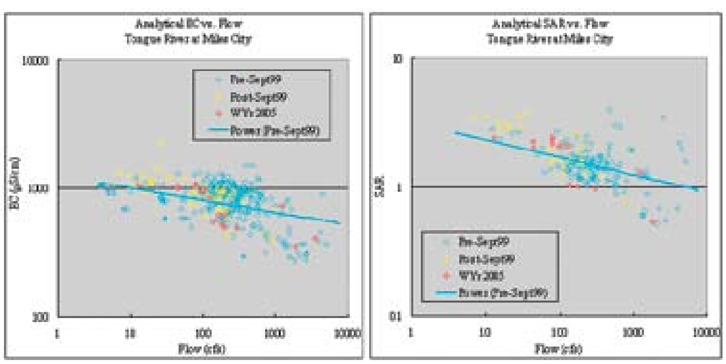


**Figure 5. EC and SAR Monitoring Results of PRB IWG Water Task Group**

PRB IWG: What Works and What Doesn't

1. Complexities of multiple agency coordination
   - No control over accountability
   - Many task members already with full work load.
2. Difficulty in securing funding
   - Differing agency budget cycles
   - Arduous to secure outside funding sources
   - Positive when presented as collaborative
3. FACA issue
   - Charter approved by the Secretary
   - Makes meetings more cumbersome
4. All in all, has worked surprisingly well

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**Paul Beels** is the BLM's Interagency Working Group leader from the state of Wyoming. Paul is a 30-year government employee. He's managed natural resources in four different states with both the U.S. Forest Service and now the Bureau of Land Management. He has an undergraduate degree in wildlife management. In recent years, he's been Project Manager for the Powder River Basin Environmental Impact Statement. He's currently Environmental Coordinator for the Buffalo Field office of BLM. and coordinator for the Interagency Working Group that has responsibility for cooperation among state, federal, and local agencies. Contact him at: paul_beels@blm.gov; phone: (307) 684-1168.

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

## The Roles, Responsibility, and Capabilities of Federal Agencies

by Sandra Stavnes, Chief, Wastewater Unit

**Panel Discussion:** Roles, responsibility, and capabilities of federal agencies
**Agency:** Environmental Protection Agency, Region 8
**Panel Member:** Sandra Stavnes, Chief, Wastewater Unit

### EPA's Mission and Regulatory Role

The United States Environmental Protection Agency (EPA) implements Federal laws designed to promote public health by protecting our Nation's air, water, and land from harmful pollution. EPA accomplishes its mission by a variety of research, monitoring, standard setting, permitting, and enforcement activities. EPA was created by consolidating 15 Federal Government environmental regulatory components into a single agency. EPA was chartered on December 2, 1970.

EPA's Region 8 office in Denver covers Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming and 27 sovereign tribal nations. Public lands comprise over one-third of the land area in our Region. Our Region encompasses the heart of the American West, including much of the Rocky Mountains, Great Plains and Colorado Plateau. Tribal nations collectively cover and area greater than the size of Tennessee. EPA Region 8 works closely with our sister federal agencies, the states, and each of those 27 sovereign nations to protect human health and safeguard the natural environment. Over two-thirds of our roughly 10 million people live in two distinct bands of urban development – Colorado's Front Range and Utah's Wasatch Front. The Region is also home to some of the most rural counties in the nation. Characterized by vast open spaces- mountains, plains, canyons and deserts – and small, concentrated population centers, these areas still maintain some of the wild, frontier character that many associate with the West. In addition to many of our nation's most recognizable landscapes, national parks and monuments, the Region is host to many rivers including the Missouri, Rio Grande, Colorado, Arkansas and Platte Rivers. These waters are vital sources of life for people, plants and animals.

### EPA's Role in Energy Development

Region 8 currently accounts for about one half of domestic coal production, more than 10 percent of natural gas productions (with an additional estimated 30 percent in reserves), and nearly 10 percent of oil production. Oil and gas production and coal production are concentrated through the middle section of the Region on both flanks of the Rocky Mountains. Coalbed methane production currently is centered in the Powder River, Uinta, San Juan and Raton Basins. Currently the Region produces about 8 percent of the nation's ethanol. The Region also produces a modest amount of the nation's wind power, about five percent, a share that is also expected to increase as wind projects are developed.

EPA supports increased and expedited energy development, production, transmission and conservation efforts which serve the Nation's needs, and which take place in a manner protective of human health and the environment.

EPA Region 8's Draft Energy Strategy was finalized in March 2003 and has four major components.

- Ensure efficient and timely decisions on energy projects
- Continue to meet Federal environmental requirements which maintain or improve environmental quality
- Promote energy efficiency and renewable energy efforts
- Strengthen environmental and energy partnerships with co-regulators and other stakeholders.

| Regulatory Program | CO | MT | ND | SD | UT | WY | IC |
|---|---|---|---|---|---|---|---|
| CAA – MACTS | Y | Y | Y | Y | Y | Y | N |
| CAA – Acid Rain | Y | Y | Y | Y | Y | Y | N |
| CAA – Prevention of Sig. Det. | SIP | SIP | SIP | Y | SIP | SIP | N |
| CAA – Air Permitting | Y | Y | Y | Y | Y | Y | N |
| CAA – New Source Review | SIP | SIP | SIP | SIP | SIP | SIP | N |
| CWA – NPDES Base/General | Y | Y | Y | Y | Y | Y | N |
| CWA – Water Quality Standards | SIP | SIP | SIP | SIP | SIP | SIP | (3) IN<br>(3) APP |
| CWA – Wetlands | N | N | N | N | N | N | N |
| CWA – TMDLs | ND | ND | ND | ND | ND | ND | ND |
| CWA – Non-Point Source | ND | ND | ND | ND | ND | ND | ND |
| National Environmental. Policy Act | ND | ND | ND | ND | ND | ND | ND |
| SDWA – Source Water | SIP | SIP | SIP | SIP | SIP | SIP | N |
| SDWA – Wellhead | SIP | SIP | SIP | SIP | SIP | SIP | N |
| SDWA – Underground Injection Control V | N | N | Y | N | Y | Y | (1) IN |
| SDWA – UIC II – Petroleum | Y | Y | Y | Y | Y | Y | N |

**Table 1. An overview of the regulatory responsibilities and energy activities.**

CAA: Clean Air Act; CWA: Clean Water Act; NPDES: National Pollutant Discharge Elimination System; TMDL: Total Maximum Discharge Limit; SWDA: Safe Water Drinking Act; UIC II: Underground Injection Control Class 2 Program

| Legend: | |
|---|---|
| IC | Indian Country |
| Y | Delegated |
| IN | Interim/In Process |
| APP | Tribes with Approved Standards |
| SIP | State Implementation Plan |
| N | Not delegated |
| ND | Not delegable |

## Guidance for Developing Environmentally Protective Permits for Produced Water Discharges

EPA's Best Professional Judgment Study for Coalbed Methane Produced Waters

("*Guidance for Developing Technology-Based Limits for Coal bed Methane Operations: Economic Analysis of the Powder River Basin*") was being developed to assist EPA with the issuance of coalbed methane permits in Indian country. In 2001 it appeared that coalbed methane development was imminent on one Indian reservation where EPA has direct responsibility for permitting. However, the development has not occurred and EPA has not taken steps to finalize the study. To date we have not received any permit applications for coalbed methane produced water discharges in Indian country. The timing of EPA drawing final conclusions with respect to permit limitations is tied to the receipt of permit applications in areas where EPA has direct CWA or SDWA permitting responsibilities (i.e. Indian country).

We should now draw any conclusions from the draft 2001 BPJ study. The document was unofficially released in the early drafting stages. Due to the changing economic conditions associated with coalbed methane development, EPA will need to evaluate the feasibility of treatment at the time a permit application is received for coalbed methane development in Indian country.

Authorized states perform their own analysis to determine appropriate treatment alternatives for coalbed methane produced waters. EPA has authorized all states in Region 8 to implement the Clean Water Act requirements for surface water permitting. Authorized states are responsible for establishing effluent limitations for discharges in their jurisdiction.

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**Sandra Stavnes presentation for EPA –**

I'm sitting in for David Hoagle, our Region 8 Energy Advisor, who couldn't make this meeting. On his counsel, I'm going to give you a big picture of energy activities in Region 8, which is composed of Colorado, Wyoming, Montana, Utah, North Dakota, and South Dakota. Then I'll talk a little bit about Region 8's Draft Energy Strategy, which is posted on our web site. Finally, I want to talk a bit about our role and regulatory responsibilities, what we actually regulate with respect to produced waters in this region, and how our states play a role and what statute responsibilities they have been delegated.

Our mission at Region 8 and within the EPA in general is to be supportive of energy development and encourage energy development. Yet, we also want to make sure that energy development is environmentally responsible and protective. That's the underlying foundation for some of the points I want to make this morning.

Region 8's view of energy goes beyond CBM. Our states produce about 15% of the national natural gas production. We have about 20% percent of non-tribal gas reserves in this region and about ten percent of tribal gas reserves. We have about seven percent of the national crude petroleum production and about 52% of the national coal production. Interestingly, that's a bit less than 20% of the world's coal production. The region also produces about five percent of the nation's wind power and17.8% of ethanol.

EPA Region 8's involvement in water management and environmental regulations for produced waters is with the Clean Water Act (CWA), which deals principally with surface water permitting, and the Safe Drinking Water Act (SDWA), which deals with injection permitting or underground injection control. The intent of Congress, with both of these acts, was to delegate authority to the states upon the states' establishing appropriate authorities, statutes, and regulations and capability to carry out the functions of those acts and be equivalent and no less stringent than the federal government.

Produced Water issues not only coalbed methane but also coal production and oil and gas production. EPA anticipates there may be some produced water issues with oil shale as production in that sector kicks in.

The second thing I wanted to touch on was our energy policy and strategy. Our drafted energy policy was posted to our web site in March, 2003. The agency's aim is to retain it in draft form so that it can be updated and remain pertinent as issues evolve.

There are four key points that the energy strategy addresses:

- The first issue is that we will have efficient and timely decisions for energy related issues to encourage environmentally protective and responsible energy development while ensuring that energy development moves forward in an efficient manner.
- We will meet the federal and state requirements, to promote energy efficiency and renewable energy options.
- This EPA document goes into a lot of different types of energy development and production.
- Finally, and one of the more important issues from my perspective, is to continue to strengthen our partnerships with our co-regulators and other stakeholders interested in these issues.

The last major area I wanted to talk about briefly is delegation of the programs and what role we play and what role our states may play in regulating produced waters. Table 1 above sets forth who is responsible for which aspect of the various acts. For the NPDES – the Clean Water Act side of the house – all of the states in this region have been delegated. We still retain permitting authority for Indian Country. The underground injection control side of things is the other big water arena where we have regulatory authority over the states. For the Class 2 Program dealing with conventional oil and gas re-injection of produced waters, authority has been delegated to all of our states. Coalbed methane re-injection, depending on the water quality, would largely fall into Class 2 Programs. Here, Region 8 retains permitting authority for Indian Country. Responsibility for a shallow injection well program has been delegated for three of the region's states, and EPA retains permitting authority for Indian Country, Colorado, Montana, and South Dakota.

We are always interested in supporting our states and assisting them; as you can see with respect to regulation of waters, most of the regulatory work is being done by the states. We also are interested in supporting states when they are dealing with cross-boundary issues with respects to standards and permitting; for example, the Montana and Wyoming situation..

I do want to mention that in 2001, EPA developed a Best Professional Judgment (BPJ) approach to looking at effluent limits and technology and treatment options for coalbed methane produced water, in order to manage anticipated permitting actions in Indian Country. That study was unofficially released around 2003. Of course, the landscape with respect to economics and treatment technology has changed since then, and we have not dealt with that study since, nor do we intend to. As manager of the NPDES program in Indian Country and in the region, I can tell you that we do not have any pending application in house for an NPDES permit in Indian Country. We will apply the BPJ approach for permit limits on a case-by-case basis so we can address local water quality issues.

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**Sandra Stavnes** has been Chief of the Wastewater Unit in the EPA Region 8 office for the last six months. Prior to that, she was Program Manager in Region 8 for Underground Injection Control and Underground Storage Team programs. She has been with EPA for 13 years and worked for a number of years prior to that in the private sector, mostly in the oil industry. Contact her at stavnes.sandra@epa.gov; (phone) 303-312-6117.

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

**Department of Energy/Office of Fossil Energy, National Energy Technology Laboratory**

by John Duda, Office of Systems, Analyses, and Planning

**Panel Discussion:** The roles, responsibilities, and capabilities of federal agencies
**Agency:** U.S. Department of Energy/Office of Fossil Energy
National Energy Technology Laboratory
**Panel Member:** John R. Duda

## *What are the role, responsibility, and priorities of your agency in general and relative to produced waters?*

### Past and Recent Involvement in Produced Waters

The Department of Energy's Office of Fossil Energy (DOE/FE) carries out an integrated research, development, and demonstration (RD&D) effort that cuts across its coal, oil, and natural gas programs to specifically focus on the nexus between energy and water. The National Energy Technology Laboratory (NETL) has been providing solutions to produced water issues by approaching the topic from multiple directions. A short list of these activities includes:

- Supporting development of a produced water management handbook
- Using produced water for power plant cooling/operations
- Conducting airborne geophysical mapping of groundwater systems in Northeastern Wyoming
- Completing studies related to hydraulic fracturing and potential effluent limitation guidelines for CBM produced water – in coordination with EPA, et al.
- Sponsoring investigations on the use of phyto-remediation of produced water, and
- Improving the performance of multiple water treatment systems including membrane filtration

**Department of Energy** is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex.

**Office of Fossil Energy**[1] is to ensure that the United States can continue to rely on clean, affordable energy from our traditional fuel resources.

**National Energy Technology Laboratory** is to implement a research, development, and demonstration program to resolve the environmental, supply, and reliability constraints of producing and using fossil resources.

### Role, Responsibility, and Priorities

Fossil fuels – coal, oil, and natural gas – currently provide more than 85% of all the energy consumed in the United States, nearly two-thirds of our electricity, and virtually all of our transportation fuels. Moreover, it is likely that the Nation's reliance on fossil fuels to power an expanding economy will actually increase over at least the next two decades even with aggressive development and deployment of new renewable and nuclear technologies. Because our

[1] The Energy Department's Fossil Energy organization is made up of about 1000 scientists, engineers, technicians and administrative staff. Its headquarters offices are in downtown Washington, DC, and in Germantown, Maryland. The organization also includes the National Energy Technology Laboratory with offices in Morgantown, WV; Pittsburgh, PA; Tulsa, OK; Albany, OR; and Fairbanks, AK; the Strategic Petroleum Reserve based in New Orleans, LA; and the Rocky Mountain Oilfield Testing Center in Casper, Wyoming.

economic health depends on the continued availability of reliable and affordable fossil fuels, the DOE's Office of Fossil Energy oversees two major efforts:

- Emergency stockpiles of crude oil and heating oil, and
- RD&D of future fossil energy technologies.

One of DOE's primary strategic goals is "to protect our national and economic security by promoting a diverse supply and delivery of reliable, affordable, and environmentally sound energy." The National Energy Technology Laboratory contributes to this strategic goal through cutting-edge research and development, focused on the clean production and use of our Nation's domestic fossil energy resources. Advanced technologies provide policymakers with expanded options for meeting vital national energy, environmental, and security needs.

Energy and water related RD&D crosscuts multiple offices and programs at the Laboratory. These efforts are summarized as follows.

Under the Strategic Center for Coal, the Innovations for Existing Plants Program is a comprehensive R&D effort focused on the development of advanced technologies to enhance the environmental performance of the existing fleet of coal-fired power plants, with application to new plants as well. In 2002, the program was broadened to include research directed at energy-water issues, focusing specifically on the following areas: Non-Traditional Sources of Process and Cooling Water; Innovative Water Reuse and Recovery; Advanced Cooling Technology; and Advanced Water Treatment and Detection Technology.

The Geosciences Division within the Office of Research and Development conducts research directed at water issues related to the cradle-to-grave use of fossil energy. These activities focus on developing a comprehensive understanding of hydrological and geological systems that are impacted by the extraction and use of fossil fuels. Remote sensing systems and advanced technologies that reduce the cost and complexity of Acid Mine Drainage treatment operations, and make use of the beneficial properties of mine and produced waters are program foci.

Under the Strategic Center for Natural Gas and Oil, the Environmental Program addresses water related issues including the injection of water for oil recovery, produced water and its effects on the environment, treatment of process/produced waters, and the availability of water in arid lands.

The Office of Systems, Analyses, and Planning performs studies and assessments of complex, large systems and interactions among those systems. Such studies are conducted on issues related to resource use, energy security and environmental policies – *water inclusive* – at national and regional levels.

### What could be the role of your agency to help convert produced waters into beneficial use?

NETL has significant expertise in fossil energy technologies, contract and project management, analysis of energy systems, and international energy issues. In addition to conducting research and technology development onsite, NETL shapes, funds, and manages contracted research in 47 states and more than 40 foreign countries. The Laboratory's research portfolio includes more than 1,400 projects with a total value approaching $12 billion. These projects are carried out though various contracting arrangements with corporations, small businesses, universities, non-profit organizations, and other national laboratories and government agencies.

In general, enhanced coordination/collaborations with multiple organizations can be expected to advance water management options as well as make new sources of water available for myriad uses. Much of RD&D conducted at NETL has direct [and indirect] applicability to produced water issues. The laboratory is well positioned to:

- Conduct analyses that estimate future water needs associated with energy projects including water requirements associated with emerging fossil resources, e.g., CTL
- Plan, implement, and evaluate new paradigms for produced water management including identifying and pursuing water-related synergies across industries and industry sectors – e.g., NETL's project with Public Service of New Mexico (PNM) to assess the feasibility of using oil/natural gas produced water to offset freshwater withdrawals from the San Juan River for cooling of PNM's San Juan Generating Station in New Mexico.
- Develop and demonstrate lower-cost technology options for treating produced water
- Provide solutions to water issues as related to development of the federal mineral estate
- Assess the impacts of [water related] regulation/policy on energy availability and cost, and how technological advances can preclude the need for overly prescriptive regulation.

**John Duda presentation for DOE –**

I won't keep my personal motives veiled from you all: I want to market DOE and our laboratory in terms of energy and water. I hope by the end of the talk it becomes very clear why we are involved and why we should be a major player. We do not have a direct water mission.

First I'll go through who we are, what we do, how we do it, and succinctly talk about the program integrated across our coal power generation and oil and gas technology areas, and then wrap up with just a few factoids.

Coming out of the Department of Energy, we have very broad responsibilities in terms of energy security. We address nuclear, fossil energy, energy efficiency and conservation,. I work in Fossil energy. We all speak toward energy security, with two primary missions: performing R&D related to coal, oil and gas, and other fossil fuels and operating the nation's petroleum reserve (SPR) which is, right now, more than 700 million barrels going to a billion, and the northeast heating reserve.

Our laboratory, National Energy Technology Laboratory (NETL) implements the R&D program. We run well over half a billion dollars of R&D through the laboratory every year. There are about 1,400 R&D projects, and if you count both the public funding and the cost share from the private sector, in aggregate, we are approaching nearly $12 billion in R&D, so we are a player.

We hope to sell our laboratory to you. We are a unique, government-owned, government-operated laboratory with five locations – Tulsa, Oklahoma; Albany, Oregon; Pittsburg, Pennsylvania; Worbetown, West Virginia; and Fairbanks, Alaska. We work at levels from fundamental research up to demonstrations. You may have heard about FutureGen, a zero-emissions power plant, hydrogen generation facility with coal as a primary fuel. Fossils fuels provide 85% of our energy needs, and that's not going to change in the next couple of decades. We are working through other kinds of fuels, but you've got to bank on this for the next couple of decades, if not longer.

Our water research cross-cut is an integrated approach that incorporates four different technology areas -- coal-mining, power generation, oil and gas, and a systems type of operation. I'll highlight where produced waters and water issues show up in each of these technology areas.

**Innovation for existing plants and new plants already in the works. There are several different aspects, but I picked out the water management element with four areas of interest:**

- Using non-traditional sources of water for process and cooling needs – a big part of the activity. Some sources are flooded mine pool waters and coalbed methane waters.
- Innovative water reuse and recovery – looking at extracting water from high moisture coals and pulling moisture out of flue gases, for example
- Advanced cooling technology – looking at new schemes of wet and dry cooling towers
- Advanced water treatment options and detection technology in terms of blow-down water, including discharges from power plants, where we're looking at heavy metals such as selenium, arsenic, and mercury – an area becoming more important.)

Think about it, when you get up in the morning you want hot water for your shower, you want the lights to come on. For fossil generation of power, you need 25 gallons of water per kilowatt hour, or 136 billion gallons of water per day for power generation. That's a lot of water, second only to agricultural use.

**Coal mining** is another area of concern in the Power River Basin, and we have several people working in this area, including Terry Ackland and George Recanvic.

- We're looking at airborne geophysical mapping to monitor slurry imbalance, mine pools, and fate and transport of CBM waters. They do some flyovers, some EM work in the Powder, looking at some of the shallow hydrology and looking for leaky impoundments. There are publications on this, and we'd like to get ahead of the problem. Wouldn't it be great to do flyover ahead of the CBM works and get a baseline on shallow aquifers and what goes on hydrologically?
- Mine pool treatment and beneficial use – including treatment systems and geothermal applications

In the area of **oil and gas** environmental solutions, we're looking at water management approaches such as phytoremediation, RO units, new technologies, new concepts, and development of scientific information in order to help make informed decisions on the management of produced water, especially in the Powder.

The Systems group contributes to **energy security goals** with forecasts, what-if scenarios, and analysis – trying to think ahead about core issues, facilities, oil shale development, and help provide some guidance and direction to R&D and the technology programs themselves.

Figure 1 shows the latest forecast for CBM, from 2006 to 2030. Total CBM production is expected to work its way upward from 1.6 tcf up towards 2 tcf per year. The latest scenario is that 80 to 85% will continue to come out of the Rocky Basin. You've got yourself another 25 years of revenues and water issues to deal with.

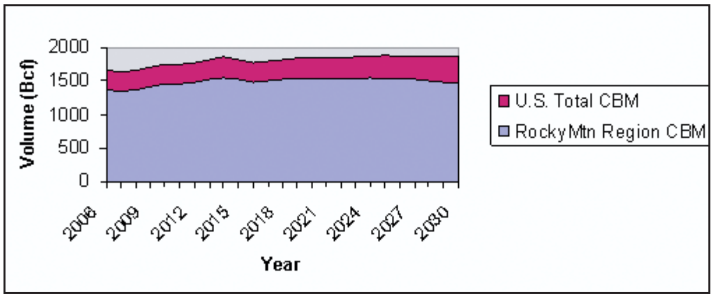


**Figure 1. Projected U.S. Coalbed Methane Supply**

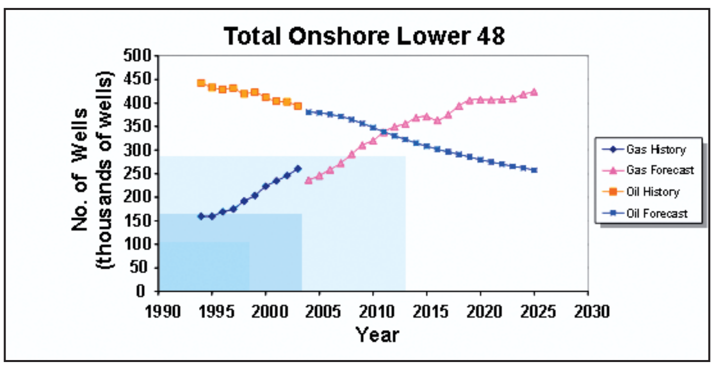


**Figure 2. Marginal Well Counts, Historical and Forecast**

You will hear a bit about marginal wells and restricted wells, which produce less than 60 mcf per day. We did a cursory forecast and, because of the type of drilling going on now in the lower 48 states, found the number of gas wells is going to go out of sight. Figure 2 shows the 260,000 stripper gas wells in 2004 are expected to increase to well over 400,000. If you are producing a small amount of water at these different distributed areas, you have to deal with costly treatment: I heard yesterday $2 to $5 per barrel to capture, transport, pay the disposal company, etc.

Let's think forward about mining. The country will continue to grow. We mine over a billion ton of coal per year, and we are expecting a 50% increase. There will be water impacts in terms of volume and quality. Coal cleaning and prep both impact quality. Natural gas and crude oil production will continue to increase due to commodity prices. Power generation will increase – subdivisions want water, but they want electricity, too. You need water to generate power. Coal liquefaction is of interest to various governors, those in Montana, and West Virginia, for example and that involves mining, liquefaction facilities, and processing IGCC – all requiring water. Oil shale development in the Colorado River Basin requires 2 to 5 barrels of water per barrel of oil shale according to the 1980 data, which might be outdated due to new technologies.

Innovation is key to anticipation. We want to be forward thinking so we can continue our dependence on fossil fuels in this country without crisis. I'd like to hear what you, as participants, want to see from DOE, what you need from our laboratories, and what you need to help solve the problems you have. You can see more by visiting the Office of Fossil Energy web site www.fe.doe.gov and the NETL web site www.netl.doe.gov.

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**John Duda** is a Team Lead in the Office of Systems, Analyses and Planning at the U.S. Department of Energy's (DOE) National Energy Technology Laboratory. John earned a Master of Science Degree in Petroleum and Natural Gas Engineering from West Virginia University and has over 25 years of experience – the last 21 as an R&D manager and professional in DOE's Fossil Energy and Environmental Management Programs. Prior to joining the Energy Department, John worked in the private sector in various engineering and managerial capacities, including assignments in South and East Texas developing low permeability natural gas resources. In his current position, Mr. Duda coordinates analyses across multiple program areas at the laboratory including natural gas and oil supply, coal gasification and liquefaction,CO2 sequestration, and energy-water issues. Contact him at john.duda@netl.doe.gov; (phone) 304-285-4217.

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

**U.S. Geological Survey (USGS)**

by William Carswell, Regional Executive for Hydrology in Central Region

**Panel Discussion:** The roles, responsibility, and capabilities of federal agencies
**Agency:** U.S. Geological Survey (USGS)
**Panel Member:** William Carswell

## *What are the responsibility, authority, and priorities of your agency in general and relative to produced waters?*

### Past and Recent Involvement in Produced Waters

A study of CBM produced water is being conducted by the USGS in the Powder River Basin (PRB) where over 200 samples of CBM water from wells across the basin are being analyzed for their chemical and isotopic composition and the data then combined with the coal geology and gas content from cores of coalbed gas source rocks. In addition to the basin-wide sampling of produced water in the PRB, the USGS is conducting integrated science activities to determine present and future impacts of CBM development in the PRB. The USGS Mapping Discipline is providing landscape change analysis and predictions for selected areas impacted by CBM, Biologic Resources Discipline is investigating the introduction of non-native plant species in areas of development; and the Water Resources and Geologic Disciplines are investigating water flux and hydrogeologic alterations to the subsurface from surface impoundments of CBM water.

The USGS has developed an online national produced water geochemistry database derived from a database originally compiled at the DOE Fossil Energy Research Center that was located in Bartlesville, Oklahoma. It focuses on the widely distributed conventional oil and gas producing fields and describes the major dissolved solids present in these waters and how they vary within and among geologic basins. The composition of the co-produced water provides information relevant to understanding limits on disposal and beneficial use options. Currently (2006), the USGS is developing a web-based information database/clearing house on CBM production water that will also have links to related USGS CBM information including resource assessments.

State USGS Water Science Centers are actively engaged with providing States where CBM production is occurring information concerning increased stream flow, aquifer characteristics, and ground-water monitoring as requested.

The USGS conducted an assessment of CBM resources in coals of the Cretaceous Ferron Sandstone near Price, Utah that incorporated a detailed examination of the water co-produced from CBM wells, the first systematic study of CBM produced waters from the Ferron. The chemical and isotopic composition of the produced water was combined with data acquired on gas chemistry, hydrology, geomorphic structure, and coal characteristics to produce an integrated assessment of the resource. In Montana, the USGS is collaborating with Ft. Peck tribal authorities and the USEPA to investigate ground water contamination associated with produced water releases from past oilfield operations and threats to a public water supply. In northeast Oklahoma, the USGS has been conducting in-depth investigations of two produced-water release sites on Lake Skiatook, a flood-control, water-supply, and recreation reservoir, to develop an understanding of the impacts to ground water, surface water, and the ecosystems they support.

### USGS' Core Mission

The USGS is an unbiased, multi-disciplinary science organization that focuses on biology, geography, geology, geospatial information, and water, and is dedicated to the timely, relevant, and impartial study of the landscape, our natural resources, and the natural hazards that threaten us. Water is essential for life: for drinking, domestic use, agriculture, industry, and ecosystems. The USGS conducts water-related studies in every State and provides water information that benefits the Nation's citizens through publications, data, maps, and applications software.

As the primary Federal science agency for water-resource information, the USGS monitors the quantity and quality of water in the Nation's rivers and aquifers, assesses the sources and fate of contaminants in aquatic systems, develops tools to improve the application of hydrologic information, and ensures that its information and tools are available to all potential users. This broad, diverse mission is accomplished, in part, through the Cooperative Water Program, a highly successful cost-sharing partnership between the USGS and water-resource agencies at the State, local, and tribal levels. Throughout its history, the Program has made important contributions to meeting USGS mission requirements, developing meaningful partnerships, sharing Federal and non-Federal financial resources, and keeping the agency focused on real-world problems. Through the Water Information Coordination Program the USGS ensures collaborative efforts among Federal agencies to improve water information for decision making about natural resources management and environmental protection.

Through its Energy Resources Program the USGS conducts fossil energy resource assessments. These assessments are conducted at the National, regional, and local scale, commonly in collaboration with a variety of partners. Much of this effort focuses on Federal lands, State waters, and other areas of critical national and international interest. In 1995 the USGS issued an oil and gas resource assessment for the U.S. and since then has updated this resource assessment to identify undiscovered resources in oil and gas basins throughout the U.S. including several basins in the arid western U.S. Future energy production from these same basins may provide additional water resources, thus these energy assessments are potentially linked to future water availability for beneficial use.

### USGS' Responsibility, Authorities, and Priorities

The USGS provides scientific data and interpretation to aid other Federal agencies with implementation of their responsibilities, authorities, and priorities and collaborates with State, local, and tribal authorities where such information may also be required for science-based decision-making. The USGS analyses of water quality and quantity help water managers of other organizations develop, regulate, and monitor management practices to ensure the continued availability of water resources for human consumption, agriculture, business, recreation, and fish and wildlife and habitat. Thus the USGS has no direct responsibility or authority for providing water supplies or ensuring water quality but provides critical data useful to these activities by other agencies with those responsibilities and authorities. The USGS priorities and its programs focus on meeting the needs for reliable data and analyses.

### What could be the role of your agency to help convert Produced Waters into beneficial use?

The USGS mission does not include direct responsibility for conversion of produced waters to beneficial use; however, the USGS has many capabilities that can contribute to developing useful information for resource managers and decision makers about beneficial uses of produced waters. Technical capabilities of the USGS include: (1) providing relevant data on the quality of oil and gas produced waters, especially coalbed methane produced waters, to help managers determine the most suitable uses for the waters and to evaluate best cleanup technologies; (2) evaluating the potential future supplies of produced waters that may be associated with oil and gas resources not yet developed; (3) evaluating the impacts of produced waters on aquifers, streams, soils, and ecosystems as these waters are moved from the oil-and-gas producing formations to the near-surface environment for disposal or beneficial use; (4) evaluating the best means and possible impacts of disposal methods where desalination technologies develop wastes that must be disposed of; and (5) supporting the Water Resource Research Institute programs that conduct investigations in support of beneficial use.

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### Bill Carswell presentation for USGS

The U.S. Geological Survey is the science agency within the Department of Interior. We provide scientific support for the Interior agencies, but we have the responsibility to provide water information for the nation. We are a multi-disciplinary science organization that focuses on biology, geology, geography, geospatial information, and water. We're dedicated to timely, relevant, unbiased information. We provide information to others to understand, manage, and conserve the nation's natural resources. We do not have management or regulatory responsibilities, and I've found that very comforting over my over my 41-year career, quite frankly, especially when I attend meetings.

Several participants have mentioned the importance of water, at this meeting, and the U.S. Geological Survey is the primary federal agency for water resources information. We monitor the quality and quantity of the nation's waters, the aquifers, and the source and fate and transport of contaminants in aquatic systems. Then we provide the information and tools to all potential users. An example of one of the tools we developed that is widely used is MODFLOW, a ground water model. One of the major programs where we produce this information is the Cooperative Water Program, a cost sharing program involving partnerships between the USGS, state and local agencies, and tribal authorities. In that program, we develop partnerships, share information federal and non-federal, and share financial resources. The partnerships keep the USGS focused on real world problems. The USGS Information and Coordination Program helps insure cooperative efforts among federal agencies

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**Bill Carswell** has served 41-years with the U.S. Geological Survey, Department of the Interior, in a wide variety of positions associated with water data collection, investigations, program management and executive leadership. Scientific and technical accomplishments include authoring more than 30 reports and teaching sections of technical training courses at the USGS National Training Center. Since 2000, he has been the Regional Executive for Hydrology in Central Region located in Denver, CO. In this position, he is responsible for hydrology programs in the 15 Central Region states. Prior to his current assignment he was the Regional Executive for Hydrology in Northeastern Region from 1995 to 2000. From May 1995 to January 2003, Bill also served by appointment of the U.S. Supreme Court as the Delaware River Master. He has a Bachelor of business administration degree, a Master of science in water resources science, and a Ph.D. in engineering. He is married and has a son and two daughters. Contact him at carswell@usgs.gov; (phone) 303-445-4644.

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

**Bureau of Reclamation**

by Maryanne Bach,

presented by Michael Gabaldon,
Director of Technical Service Center

**Panel Discussion:** The roles, responsibility, and capabilities of federal agencies
**Agency:** Bureau of Reclamation
**Panel Member:** Maryanne Bach

## *What is the role of responsibility, authority, and priorities of your agency in general and relative to produced waters?*

### Past and Recent Involvement in Produced Waters

Reclamation has not been involved in managing produced waters, or developing produced waters for beneficial uses. Reclamation's primary intersection with produced waters has recently been within the context of the technological capabilities and advancements that could support the water purification processes that are used to convert produced waters to qualities that support beneficial uses. Reclamation has extensive expertise and capabilities in water purification technologies, especially as applied to desalination. Reclamation has also become more aware of the important role that the states, BLM, and others play in managing produced waters so that the quality of Reclamation and other Western water supplies are not degraded by impaired produced waters.

### Reclamation's Core Mission

Established in 1902, the Bureau of Reclamation is best known for the dams, powerplants, and canals it constructed in the 17 western states. Our water supply backbone relies on capturing annual mountain snowmelt in our reservoirs. These water projects led to homesteading and promoted the economic development of the West. Reclamation has constructed more than 600 dams and reservoirs including Hoover Dam on the Colorado River and Grand Coulee on the Columbia River.

Today, we are the largest wholesaler of water in the country. We bring water to more than 31 million people, and provide one out of five Western farmers (140,000) with irrigation water for 10 million acres of farmland that produce 60% of the nation's vegetables and 25% of its fruits and nuts.

Today, Reclamation is a contemporary water management agency. Our mission is to assist in meeting the increasing water demands of the West while protecting the environment and the public's investment in Reclamation's water storage and delivery infrastructure.

### Reclamation's Responsibility, Authorities, and Priorities

Reclamation's water and hydropower projects were authorized by Congress to provide benefits to the authorized project beneficiaries. The authorized beneficiaries are typically those entities that were identified in authorizing project legislation and are the entities that reimburse the federal government for Reclamation's cost to design, build, and maintain the water and power infrastructure that serves their needs. Reclamation's responsibilities, authorities, and budget priorities are linked to managing Reclamation's water and hydropower infrastructure, and delivering Reclamation project waters and power to authorized project beneficiaries.

While we place great emphasis on fulfilling our water storage and delivery obligations to Reclamation's project beneficiaries; we also emphasize developing partnerships with our customers, states, and Indian Tribes, and in finding ways to bring together the variety of interests to address the competing needs for our limited water resources through water use efficiencies.

As such, the Department of the Interior through the Bureau of Reclamation started the Water 2025 program in 2004. Water 2025 is a commitment by Interior to work with States, Tribes, local governments, and the public to address water supply challenges in the West. These decisions cannot and should not be driven from a Federal level. They should be based on – and will require – local and regional support." A few of the guiding principles associated with Water 2025 that could pertain to produced water issues are:

1) Use collaborative approaches to minimize conflicts
2) Improve water treatment technology, such as desalination to help increase water supplies
3) Use existing water supply infrastructure to provide additional benefits to meet water needs
4) Remove institutional barriers and increase interagency cooperation

### What could be the role of your agency to help convert Produced Waters into beneficial use?

Reclamation has the expertise to assist with the planning, design, and construction of water storage and delivery infrastructure on a local, watershed, or regional scale. As such, if basin-wide water supplies become more dependent on being augmented by converting produced waters into beneficial uses, Reclamation has the expertise to evaluate the needs for new infrastructure and the potential to expand the use of existing water infrastructure to integrate produced waters into the overall usable water supply inventory. The cost of providing that expertise for a specific project would have to be reimbursed by project beneficiaries.

Reclamation also has extensive expertise in desalination and other forms of water purification technologies. This expertise is very applicable to the technologies that treat produced waters so that they are suitable for beneficial uses. As such, Reclamation also has the capability to provide technical assistance in this area, which is also on a cost-reimbursable basis.

Reclamation also supports programs that award competitive, external, cost-shared R&D grants to non-federal entities primarily for the advancement of desalination technologies. These technology advancements can typically be applied to other categories of water purification technologies such as those used for treating produced waters. However, other categories of water purification technologies are also considered when awarding these grants.

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**Maryanne Bach** is located in Denver, CO and reports to the Deputy Commissioner, Operations. Dr. Bach is responsible for the scientific, engineering, and research services related to Reclamation's water resource management and development, including engineering and scientific programs in the Technical Services Center; the Research and Development Program; a new power liaison function with the U.S. Army Corps of Engineers and Tennessee Valley Authority; and Dam Safety and Design, Estimates and Construction (DSO/DEC) oversight. From 1998 to 2004, she served as the Regional Director for Reclamation's Great Plains Region, consisting of all of the States of North and South Dakota, Nebraska, Kansas, Oklahoma, and most of Texas, Colorado, Wyoming, and Montana. Contact her at mbach@do.usbr.gov; (phone) 303-445-3750.

**Michael Gabaldon** assumed the position of Director of the Technical Service Center in the Denver office of the Bureau of Reclamation in January, 2006. From 2003 to 2006, he served as the Director of Policy, Management, and Technical Services headquartered in Washington. He began his career with Reclamation in 1982 in the Montrose Projects Office in Colorado. In 1991, Mr. Gabaldon moved to the Bend Construction Office in the Pacific Northwest Region, working as both a Lead Engineer and a Supervisory Civil Engineer in the Contract Administration Branch. From 1996-98, he served as Reclamation's Pacific Northwest Regional Liaison Officer in Washington. In 1998, he was selected as the Area Manager for one of Reclamation's largest area offices, the Albuquerque Area Office. His experience on key Reclamation projects and his in-depth knowledge of Reclamation's programs and policies have allowed him to serve as a highly visible member of Reclamation leadership. He is well-versed in technical, administrative, operational, Congressional, and policy issues and is a valued source of information and consultation regarding Reclamation's role in the Department of the Interior. Contact him at mgabaldon@do.usbr.gov; (phone) 303-445-2750.

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

**Bureau of Land Management**

by Don Simpson, Acting Associate Director, Wyoming

**Panel Discussion:** The roles, responsibility, and capabilities of federal agencies
**Agency:** Bureau of Land Management
**Panel Member:** Don Simpson

### Bureau of Land Management's Authorities and Responsibilities for Oil and Gas Development

The Bureau of Land Management (BLM) is responsible for the regulation and development of federal Oil and Gas (O&G) mineral resources under the authority of a variety of federal laws including the Mineral Leasing Act of 1920, as amended, the Federal Land Policy and Management Act of 1976, National Materials and Minerals Policy, Research, and Development Act of 1980, and Federal Onshore O&G Leasing Reform Act of 1987.

BLM is required to protect financial interest of the U.S. by preventing drainage of federal minerals (gas resources being drained by development of neighboring state or private gas resources). Valid federal leases to extract O&G resources create contractual and property rights for development. When companies submit proposals for the development of their coal bed natural gas (CBNG), the surface use plan required by regulation, will also include a description of the preferred water handling approaches they deem technically and economically feasible. Water is produced in most oil and natural gas developments and the amount of water produced varies between formations and fields.

Under the provisions of the National Environmental Policy Act (NEPA) of 1969, federal agencies are to consider the impact of federal undertakings. The leasing and development of the federal minerals requires preparation of a NEPA document (generally an environmental assessment (EA) or environmental impact statement (EIS)) in which BLM analyzes and discloses the potential environmental impacts associated with the action and identifies approaches to mitigate effects of planned development.

### Industry Responsibilities

The O&G operator is required to conduct operations in a manner that protects the mineral resources, other natural resources, and environmental quality. In that respect, the operator shall comply with the pertinent orders of the authorized officer, and other standards and procedures set forth in the applicable federal laws, federal regulations, and lease terms and conditions.

### Bureau of Land Management's Authorities and Responsibilities for Water Resources Management

The Director of the BLM is authorized to issue Onshore Oil and Gas Orders when necessary to implement and supplement the regulations found at 43 Code of Federal Regulations (CFR) 3160. According to BLM's O&G regulations (43 CFR 3164) these Orders are binding on operators.

To address the management of produced water, Onshore Oil and Gas Order No. 7 [58 FR 47354, October 1993] was implemented and states the oil and gas operator may not dispose of produced water unless and until approval is obtained from the authorized officer. The Order also states that all produced water from federal oil and gas wells to be disposed of in three general methods; 1) injection into the subsurface (which is the preferred method), 2) discharge into pits (unlined or lined), and 3) other methods approved by the authorized officer. Basically this means surface discharge under a National Pollutant Discharge Elimination System (NPDES) permit.

Onshore Oil and Gas Order No. 7 recognizes that operations from the point of origin (usually the well head) to the point of discharge are under the jurisdiction of the BLM. Operations from the point of discharge downstream are under the jurisdiction of EPA or Primacy State.

As stated in its preamble, part of the intent of Onshore Order No. 7 is to "provide specific standards and requirements for disposal of produced water relative to the BLM's authority under various mineral laws, but must also meet the objectives of several environmental laws including NEPA. So while BLM has no authority to approve or disapprove permits regulated by the state, even if federal wells are involved, BLM must ultimately approve the disposal of water produced as a result of federal oil and gas operations after considering potential impacts and preparing the appropriate level of NEPA documentation.

**Bureau of Land Management's Authorities and Responsibilities Guiding Cooperation and Coordination with Other Agencies**

Collectively, the Clean Water Act, Federal Land Policy and Management Act, and related Executive Orders guiding BLM's management of Public Lands and their related resources require BLM to comply with all federal and state laws and regulations governing the control and abatement of water pollution that may result from BLM initiated and permitted uses, programs, and activities. The respective State Engineer regulates the development and appropriation of surface and groundwater in each state. Similarly, each state's Department of Environmental Quality has EPA delegated authority to administer and regulate its water quality program for the protection of all "Waters of the State". BLM defers to the States in the matter of regulating the quality, beneficial uses, and appropriation of "Waters of the State" which are produced in the course of developing CBNG.

As standard practice, BLM is coordinating with other federal agencies and various state water regulatory agencies in cooperative surface and groundwater monitoring and studies. Trends in resource data will be assessed, compared to state and federal established water standards, and management changes made to stay within these standards.

BLM will continue to work with industry and other state and federal water regulatory agencies to develop federal minerals in a timely and environmentally responsible fashion. This will include appropriate NEPA analysis and management of O&G development to respond to CBNG produced water use and appropriation as mandated by State regulatory requirements.

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### Don Simpson presentation for BLM –

Let me start out with a little introduction to Wyoming, since that's where we eat, sleep, and breathe. We heard a little bit about the Powder River Basin. Wyoming is a state that's predominately federal, and our bureau has a fairly significant role. We manage 18 million surface acres in Wyoming and, more importantly, 40 million subsurface acres – probably 60% of the state. With this significant role, we try to be a good partner with the state agencies and.

While the land ownership pattern sounds pretty straightforward – federal land, not federal land – we have three land patterns we deal with in Wyoming. One is the pattern where we're pretty much all federal surface, all federal subsurface. We have another pattern where we're predominately private surface, a federal subsurface – this is a situation you heard about yesterday. Then we have the railroad checkerboard lands in the southern part of the state where every other section is federal and every other section is private.

Consultation, coordination, and all the other "C" words you can think of are pretty important to us as we manage the public lands. Let's look at how we do that in Wyoming. I'm in the state office. Our ten field offices are not exactly divvied up by acres. They're divvied up more geographically by location, by county. Each has an authorized officer in charge of that office; the field manager, who basically sanctions and approves the actions on the public lands.

What's the magnitude of BLM Wyoming as it relates to oil and gas? We authorized 3,500 drilling permits a last fiscal year, and we expect to approve 5,000 APDs this fiscal year, through September. We're looking at roughly 10% increases [per year]. That's what we're forecasting for budget purposes for activities on public lands. Keep adding about 500, 600, or 700 wells to those numbers each year for the near future.

How do we manage those lands? The very first law was passed in 1976, the Federal Land Policy and Management Act. Up to then, BLM was the caretaker of pending final dispensation of the otherwise unwanted public lands. In 1976, Congress decided to hang on to that land and manage it with a multiple-use approach. We're one of the few agencies, if not the only one in the United States of America besides the IRS, that makes money. We deal with every issue known to man. We have missiles out there, we have fish, water, wildlife, wild horses, you name it, we get to manage it. Water is just one of the many things that we have to deal with. Not only do we need to do that in a multiple-use format, but we need to consult the folks when we do that. We execute the big-look picture that we call Resource Management Plans; they include the allocations that are going to be on those public lands.

The Mineral Leasing Act of 1920, passed 50 years prior to the law that said all land shall be managed in an equal format, didn't embrace that management philosophy. It said that we should conserve the gas resource. In this case, conserve didn't mean 'save it for tomorrow.' Instead, the act intended we aggressively seek out leasing and development for the gas resource. It would seem that we have a bit of an issue there, managing by those two laws.

The Energy Act passed by Congress last fall gave BLM 30 days to approve an APD. We can't dally. While we're thinking things through in the long term, we've got some shorter-term actions required by law. The Energy Act instituted the pilot office, eight of them around the Bureau. Two of those offices are in Wyoming, one is in Buffalo and one is in Rawlins. The purpose of those pilot projects is to take a look at one-stop shopping, a way to address all of the state, federal and local requirements that the APD and the bigger issues of transportation, planning, pipelines, and water reuse. Congress envisioned those pilot project offices taking a look at some methods to become more effective at managing the interagency responsibilities.

Finally, the great big law that I've heard mentioned by a lot of folks is NEPA, the National Environmental Policy Act. That's where I'll concentrate the discussion on how BLM does business. Initially, we have the resource management plan required by the 1976 law for each of our offices. We have ten offices in Wyoming, ten Resource Management Plans. Analyzing 40 million acres in ten plans gives us four million acres per office. With that issue of scale, you're not going to get too deep into the weeds.

We try to use the NEPA process at the RMP level to take a look at allocations: are we going to lease gas or not? The water requirement is going to be on that RMP for the areas where we are going to lease gas. We put stipulations into that lease, some generic, that relate to water, wildlife, etc. The certainty that some of the industry folks have talked about are in the language of those RMP's. Then, in the NEPA process, we move down from that four- million-acre view. Then we find an acre where we see there will be development, the Powder River Basin is one. We've got about 25 Environmental Impact Statements (EIS's) right now looking at that full-field development of gas fields as they start to mature. I could say with certainty that the number 1, 2, and 3 issues are always going to be looking at the cumulative impacts to wildlife, air quality, and water. It's the universal equation right now in Wyoming.

There are other issues that come up, depending on where you are locally. We work ahead of the curve with transportation planning. We need to look at where the roads and pipelines are going to go. We need to look at spacing the number of wells that need to be drilled. One of the things BLM is trying to get away from at that level of analysis is addressing the number of wells. The number of wells is not the issue; rather, it's the amount of water and the amount of acres disturbed. If industry can reduce the footprint, then the number of wells is likely immaterial. At this point we're addressing almost 20,000 wells. As soon as we put one or two EIS's away, we get two more. We're not gaining ground, but we're not losing ground.

The next step is to take a look at each application, from permit to drill. It's a giant tiering process. We start with the RNP, we allocate lands; then we move down to full field assessment, we do that EIS; then when you get to the APD, you're really kicking rock, you're looking for arrowheads, looking for endangered species, and trying to apply those outward requirements down to that document. There is where we have to do more work in 30 days. The moral to the story is: if we're going to work together on produced waters, we've got to do it at the higher level, at the land-use-plan level.

More importantly, we need to do it in full-field development. This is an area that not everybody's aware of; BLM is painfully aware of it, and industry probably is painfully aware of it. BLM has a series of regulations defined in 43 CFR 3100, and they are supplemented by on-shore orders. Onshore order number 7 deals with the produced waters issue. I believe the version that is on the street right now was updated in 1993. It requires the authorized officer, one of the ten field managers, to make a choice as to how the produced waters are dealt with. The current onshore order identifies the preferred method as reinjection. Because the preferred was chosen in 1993, it might not be the preferred method today, and the authorizing officer doesn't have to go with that method. The second method is discharge in the pits, lined and unlined. The third method is surface discharge through the NPDES program. That's what our ten field offices worry about, their responsibility in making that decision.

The BLM jurisdiction is at the point of origin – the wellhead – and at point of discharge, where the water sees the light of day. Think of all the tricks involved when water sees the light of day; that's the area of responsibility assigned to BLM under that onshore order. BLM tries to work with the state on addressing the discharge water: do we reinject the water, or do we put it on the surface? BLM works very well with the state. The Engineer does much of the appropriation on the development side for surface and ground water. And, we've got DEQ addressing water quality issues; it does the NPDES permits for the surface water.. The Oil and Gas Commission addresses injection permits. Those three groups are our friends, and we keep them very busy. The Oil and Gas Commission would like to keep us moving faster, but we work well together and try to work those issues out.

I'll leave you with an observation: we need to take a look at processes that can take us out of the courtroom, and out on the ground. If we're wearing wingtips when we're having these discussions, we're probably in the wrong place. We should be out there in our boots and jeans figuring this stuff out. The companies, the groups, the counties, the state agencies, the federal agencies that spend the time working on mitigation in the field – as opposed to litigation in the court room – are getting a lot done. We're spending the same amount of money, whether we're getting it done on the ground or whether we're buying a bunch of folks at $400 an hour. (We pay our hydrologists a lot less than that.)

I'd propose that's the area where we need to work. Number one: let's get everybody with a dog in the fight out on the ground. It's pretty straightforward and easy. We call these people 'onsites.' Working on the upper level NEPA documents is a great time to get together to iron things out, to look at alternatives that are technically feasible and reasonable to all the folks involved. Number two: we need to monitor what we've decided on, to see if it works. Adaptive management means you're able to adjust if the approach cited in the NEPA document isn't working.

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**Don Simpson** currently serves as the Acting Associate State Director for the BLM in Wyoming. In this position, he is responsible for all aspects of planning and managing BLM lands, renewable resources, and federal minerals. Wyoming BLM manages over 18 million surface acres of public land and an additional 23 million acres of federal mineral estate. There are currently 10 field offices in Wyoming with nearly 800 employees. Upon completion of this term assignment Don will return to his duties as the Deputy State Director for the Division of Resource Policy and Management in the Wyoming State Office. In that position, Don is responsible for land use planning projects, environmental impact statements for oil and gas projects, developing policy and guidance for renewable resource management, and implementing annual budget directives for renewable resources programs. Don took on the duties of Wyoming's Deputy State Director for Resource Policy and Management in 1998. Prior to that, he had served as: a realty specialist, a land acquisition program lead, a legislative specialist and a legislative fellow for the U.S. Senate. He has a bachelor's degree in forest management from Colorado State University.

*Produced Waters Workshop –*

# Can Coordination of Federal Agencies with State and Local Agencies Help Make Produced Water 'Lemons' Into Lemonade?

## Ability of Future Water Developments to Incorporate Treated Produced Waters into Their Development Plans

*April 5, 2006, Luncheon Speaker:*

Mike Besson, Director,
Wyoming Water Development Commission

I am the director of the Water Development Program, a small agency. When I first started we had about 18 full-time employees and about 20 projects a year. Now we have 70 to 75 projects a year. Our resources – about $70 million a year – come from severance taxes on minerals, oil, gas, and coal in particular, including coalbed methane (CBM).

Originally we started out with a single planning division that had 7 or 8 planners dedicated to project-specific activities. Then the legislature adopted a more holistic planning effort in each one of the seven major drainages or river basins in Wyoming to get a handle on what each resource can stand as far as development. CBM is part of that resource. The other division is construction. We have a lot of engineers and technical expertise when it comes to building pipelines and assisting with permits.

The National Environmental Policy Act (NEPA) is something we work with all the time. My mission is to put Wyoming's water to beneficial use and to take care of existing infrastructure that is dedicated to that same beneficial use. An insightful friend wondered why we are doing that, reminding me that the State Engineer had declared back in 1997 that CBM discharge in these co-produced waters is of beneficial use. The Ruckelshaus Institute reported we have discharged on the surface 380,000 acre-feet.

We've heard that CBM should be considered a resource and not a liability. It shouldn't be considered a waste. Energy really is important to the United States. Everybody has a responsibility for development that's acceptable and does not cause environmental consequences. Treatment might be required. Without treatment, we might need to consider enhanced oil recovery. I question how much space is really available for reinjection over the course of time, when you're talking about seven million acre feet of water. Some of the water from that side of Wyoming does have to be treated if you want to use it on the surface. The resulting brine might be an issue. The waste stream is the bottom line for me. What can you do with the waste stream? It gets back to this reinjection to the aquifers. Of seven million acre-feet of water, you would have a waste stream of 700,000 acre-feet if you use reverse osmosis. You can get rid of about ten percent of that by reinjection; perhaps five percent, depending on the targeted water quality. People need to understand what that means as far as continuing development of this resource, and money figures largely into that.

There are regulations specific to the Powder River Basin, created by the Wyoming legislature at the urging of the governor and the industry. I think the catalyst was the recent stiffening of the environmental law, the zero-degradation standards that were adopted by Montana at the end of last month. There is an interest in trying to do something different in the management of that CBM water. We'll narrow the focus here on the opportunities, the feasibility, of taking CBM from the Powder River to the North Platte River. There is a demand there, a demand due to a ten-year-old endangered-species program in Nebraska involving four species threatened and requiring a whole lot of water to create habitat.

This particular situation has two issues. One is the endangered species issue; the other is the settlement of Nebraska v. Wyoming. The new demand on Wyoming associated with those two issues is about 33,000 acre-feet. Before the settlement, we had some room for development that equated to about 8,000 to10,000 acre-feet. The settlement determined that the state's new obligation – if historical irrigation practices were maintained -is about 8,000 to 10,000 acre-feet. Part of that obligation, 5,000 acre-feet, is water that can be used for creation of habitat for Whooping Cranes, Piping Glovers, and Least Terns in the Big Bend region of Nebraska, around Kearney. That's the state's obligation. There's even more obligation, and more opportunity, than that.

I initiated discussion about this in 1997 to learn if people were really interested in this resource benefiting this endangered species program. I know there are people from the DOI here; you can help with this. We have targeted an incrementally based program, a 13-year program. One of the things that's really difficult in managing CBM water is its temporary nature. It plays havoc on seizing opportunities to beneficially use that water. How do you get there? We're look at taking water in the pipeline, doing a lot of engineering, hydraulics, and cost estimating, to assess the options.

I am still looking for a source of water to meet the long-term demands associated with either the endangered-species program or with the settlement of Nebraska v. Wyoming. By Colorado's definition, withdrawal of non tributary water will not deplete the flow of a natural stream by more than 0.1% over 100 years. The modified North Platte decree of Wyoming provides a little more liberal definition, allowing no more than 28% in 40 years. If I develop that resource, depending on the quantity, I start chipping away at those new obligations imposed by either the endangered species issue or the Platte River settlement. We have to go through NEPA.

We're just coming through a record draught. It's incumbent upon us to get beyond the rhetoric and figure out how best to use the water supply for the state of Wyoming and for the whole nation so this energy development can continue in a timely fashion. We've done some studies on expanding beneficial use associated with discharged or co-produced water, and one of the things we looked at was partnering with conservation districts.

Working with the City of Gillette, I'm on the vanguard that is trying to figure out ways we could do this. Some of the producers were involved in the conversation as well, helping us figure out how to recharge the Fort Union Aquifer that has been mined by the city of Gillette to meet its drinking water demands. We put together a project that the legislature approved. By the time we got everything in place, we had a downturn in price per mcf of CBM water. Some of those wells were shut in. By the time the price came back up the quantity of the water evaporated – we didn't have a source by the time we were ready to go again. Now, a ground water development program is planned for the city of Gillette to meet its drinking water needs. With an almost exponential increase in construction costs and material prices, the $35 million program is now probably $50 million. CBM could potentially be used as a source of that water.

Even in the Platte valley there have been proposals to take the CBM water to the city of Casper. The state spent $70 million, in addition to the funds provided by our program, improving the water treatment facilities in Casper. This improvement included an extensive analysis and a pilot treatment based on the quality of the raw water at the head of the plant. Imposing a different quality of water might burden that existing infrastructure and require redesign, reconfiguring, and rebuilding to be able to treat a different quality of raw water. Couple that with that the fact the supply may be available ten or 15 years and you can see potential obstacles for beneficial use of this water.

Another obstacle to CBM water relates to the Western Governors' report, discussing the sustainability of water development throughout the entire Rocky Mountain West. That really is where the water development program is: sustaining and maximizing opportunities available over time. CBM is going to be here a fraction of that time. We have to figure out ways to take advantage of its availability; maybe there are ways we can use the water in Gillette, by either reinjecting it back in the Fort Union Aquifer for later withdrawal or treating it directly to supplement the ground water currently relied on from the Fort Union Aquifer and the Madison Formation.

At the Governor's office, our charge will be limited to the engineering, critically important to the state of Wyoming. Wyoming has surplus capital to do a lot of good things. Largely it's attributed to the oil and gas and this CBM play. We're talking about billions of dollars worth of value in severance taxes and mineral royalties for the states of Montana and Wyoming. We're charged with maintaining that production. Looking at different options of using water locally will be coordinated by the Governor's Planning Office, which will make them more involved in the NEPA process.

If I'm going to design a pipeline, I need to know what volume is expected, and currently we only have estimates: maybe 20,000 acre-feet a year, maybe 50,000, maybe 100,000 acre-feet. I'll need some assurance when I go to the legislature to report costs, as they will have to consider what's fiscally responsible over the long haul. I need a commitment from industry as to how much water is actually going to be provided. And more information is needed: how do the operators intend to gather the resource? I need to know; otherwise, I don't know where to start. Once we get this pipeline design, I need to know the potential for using that water in the original basin and the most feasible option. Then, I need to know how much water is going to be leftover. What's the diameter needed? What's the cost going to be? This is a hydraulic engineer's dream challenge, made interesting with factors such as transient flow water hammer which has to be considered when you're trying to pump 100,000 acre-feet. One report done by industry over the course of this play recommended a four-foot-diameter pipe to come to the Platte. With 100,000 acre-feet, that results in about 137 cfs, almost 11 feet per second in the pipeline. Knowing there will be power outages, you might end up with an eight-foot-diameter pipeline to reduce velocity down to two or three feet per second.

There could be a competition for this resource, and I think that is a good thing. Price will come into play. The quality of the Platte during the seven-month low-flow years at 7Q10 criteria allows a lot of assimilative capacity. There are three water quality constituents that can easily be addressed by aeration or, maybe, just storage and settling in a small reservoir at the end of the system. If you think about it from industry's perspective, it's another surface water discharge doesn't require much treatment cost. If you look at the end-basin uses, there will be treatment costs – and competition in those costs.

There's going to be concerns downstream. I've already had calls from Nebraska, inquiring about salty water discussed in an article in the Omaha World Herald, and I re-iterated that the water must meet water quality standards or I can't introduce it into the North Platte River. I've talked with concerned people from the Wyoming Game and Fish Department. Even though you know what the TDS might be at discharge, changing water chemistry can impact the aquatic ecosystem.

The Wyoming Game and Fish suggestion to discharge at the Wyoming/Nebraska state line probably will be questioned by Nebraska. The issue of assimilative capacity resulted in the zero-discharge standard in Montana – we start to adversely impact the opportunities lower in the basin, in the next state. With a big, new demand in Nebraska, there could be a real opportunity for Wyoming: they might help pay for that water. You know Nebraska pretty well after the years and years of negotiations and the settlement in Nebraska v. Wyoming. We've been arguing with Nebraska for about 25 years over water. Then you throw Colorado in the mix, and it really gets interesting. After it was assured through the public involvement process that there are safe guards, Nebraska asked if we would sell it some water to meet the demand brought on by agriculture and the drought.

Just another thought about treatment costs: reverse osmosis costs about $25 to$2,600 an acre-foot. We've had dam and reservoir projects that have come in under that amount. That's a pretty expensive burden to put on cities and towns. You can drive that cost down, but compare it to an mcf of natural gas, and the water costs $0.33 a barrel. If you use numbers from the Ruckelshaus Institute report, which cites 1.752 barrels of water produced per mcf and a subsequent gas cost of $0.66, then you're only going to have to produce maybe 30 to 40%, making the cost of treatment per mcf in the neighborhood of $0.23 to $0.25. There are other processes out there that can treat in the range of $0.09 to $0.11 per mcf. We've seen prognostications that we're going to have X amount of water produced at $3.00 per mcf. Nine or ten cents isn't much of a percentage of that $3.00 production cost. In Wyoming we've had prices per mcf of $9.00. What's really going to be critical is the waste stream associated with water treatment and how to get rid of that. Amending the waste stream can really increase the costs and reduce the opportunities for reinjection now done in the Powder River Basin.

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**Mike Besson** is currently employed as the Director of the Wyoming Water Development Commission and has been appointed by the Governor to represent the state on water-related endangered-species issues in the Platte River Basin. Mike grew up in the Big Horn Basin in north central Wyoming and attended the University of Wyoming where he obtained a Bachelor of Arts degree in secondary education and a Bachelor of Science degree in civil engineering. Mike is a Professional Engineer registered in the states of Wyoming and Colorado. Prior to his tenure with the Wyoming Water Development Office, Mike taught school and practiced as a consulting engineer.

*Produced Waters Workshop –*

# Can't We All Just Get Along?

Moderator: Mark Squillace,
Natural Resources Law Center,
University of Colorado at Boulder

# Can't We All Just Get Along?

## What Liability Means to an Energy Company

Jack Palma, Holland & Hart, LLC, Cheyenne, WY

I notice that the over-arching goal for the conference is to enhance our understanding of the opportunities and challenges involved in converting produced water to beneficial use. My original topic was what liabilities mean to companies. Frankly, I'll acknowledge that by spending about ten seconds on it. Then, I want to get to the larger issue that Mark raised: what stands in the way of us solving these problems? How can we better address them?

If a producer of water was to attempt to make water available to a city like Gillette, I think the Safe Drinking Water Act would loom as a potential issue for the operators. Of course, on top of all that, there's the common law issues of strict liability; nuisance; and, potentially, trespass. Those are all issues that come into play when we talk about the issue of discharging water or trying to find ways to put it to beneficial use or to make it available for somebody who might want to aggregate it.

### The subjective aspect of problem solving

I want to focus more on process than substance. Why? My premise is this: I think we can get along. I think we can make lemonade. I think we can resolve most of the challenges and seize the opportunities, some of which Mike Besson alluded to at our luncheon. The stakeholders need to act more responsibly than I've seen over the last ten or 15 years. I'm talking about corporate, surface owner, and governmental responsibility, and, certainly, public interest group responsibility.

I'm not naive enough to suggest this challenge is not a tall order. I think I'm idealistic and pragmatic enough to say it does provide our best alternative. It does offer us a hope for a win-win solution to the issues we've been talking about and to avoid or minimize the win-lose outcomes. Those win-lose situations have resulted in a great expense for parties; stress for landowners; discord; uncertainty, in terms of regulatory environment and the landscape for the companies; and also, most importantly, lost opportunities to put the water that we're talking about to beneficial use.

Let me give you my thumbnail sketch of what acting responsibly would look like. It'd be a willingness to sacrifice short-term self-interest for the longer-term gain, to work collaboratively rather than adversarily, to abandon extreme positions in favor of problem solving, to trust one another.

All the stakeholders I've identified have been prone from time to time to act in a different way. That is to suggest that it's not my problem if another party tells half-truths, uses hyperbole, makes inflated claims. With all due respect to some of my public interest groups in Wyoming, I'm tired of seeing the same, now-yellowed slides of problems that occurred back in the early 1990's and hear suggestions that they represent the norm, because they don't. I'm tired of junk science and alarmist predictions and accusations. It just isn't helpful for any of the stakeholders to act that way. It's not productive. I don't think it promotes sustainable development, which I think is a really important aspect of this CBM play. We can, instead, talk about the demand of natural gas – which is real, which we all use, which is important to this country. We recognize that there are environmental components to that, as well as a water resource issue. The key for all the stakeholders is to find a way for all that mix to work together.

Here's an example of the problem we face: an environmental appeal was logged by one of the major environmental groups in the state of Wyoming regarding a surface water discharge. The allegations in the appeal were that the water quality would violate South Dakota's water quality standards, that it wasn't being beneficially used, and that it violated the protection of agricultural uses downstream. Let me point out the actual facts. The water traveled less than a mile before being totally consumed by irrigation and infiltration. The irrigator that was making use of the water was literally begging for the producer to provide even more water than he had. Of course, the water ceased flowing some 70 miles upstream from the South Dakota border. We were able to settle that case, finally, when the environmental group decided it was going to concede. It wasn't an issue. My client's question to me was, "Isn't this a waste of time and money and expense? What are we accomplishing here?"

A petition has recently been filed in Wyoming that would require the Department of Environmental Quality to more fully consider the impact of CBM water on agriculture and wildlife. The petition, in its essence, seeks to limit the discharge of CBM produced water to only that amount which can be beneficially used. I recall the press release that went out by the Powder River Basin Resource Council when that petition was filed. It suggested that its intent was to assist in maximizing the beneficial use of produced water from CBM. I think this petition will do a lot of things, and I'm here to say maximizing the beneficial use of produced water is not one of them. The reason I say that is because the Powder River Basin, in particular in northeast Wyoming, is very dry, and there are a lot of ephemeral drainages. Basically, when irrigation or use of water occurs, it is because of snowmelt runoff or significant storm events. It's a very opportunistic approach to irrigation and use of water. I submit that the use of CBM water in those drainages will be the same. If the water exists in those drainages, it's going to get used. To suggest that the only way to put it in a drainage is to assure the use up front, is putting the cart before the horse.

At the initial hearing on this petition, the vast majority of the landowners who came in to speak of their own volition spoke about how the discharge water had saved them during the recent seven-year drought. If we restrict the discharge of that water through reinjection, that water isn't going to be available for those landowners. If you're going to spend the money to reinject and you find the capacity, you're going to put it all in there. You're not going to release a portion for stock water, or a portion for someone to use for irrigation. I submit, that once the water goes down hole, it's not going to come back. It's going to be condemned because perhaps it's going to be in a saline formation. I don't think anybody's really looking at the cost-benefit analysis that should drive the management of produced water.

I hope Kate will address her perspective on it. She and I have met privately, and I know she has a perspective. I know she has something she wants to accomplish by the petition. I think a holistic approach might have revealed another way to approach this legitimate concern. I think the real concern for some of the landowners was that, from time to time, so much water was being sent downstream that it was overtopping the banks or interfering with their use.

Laurie was instrumental in gaining the passage of a surface owner protection law in Wyoming that established a notice process and also a process related to handling damages. I suggest such a process should be part of any responsible CBM operator's standard operating procedures, with or without the law in place. I think that a lot of the conflict between surface owners and CBM operators was the result of the fact that there's a lack of acknowledgement by some surface owners of the mineral or oil and gas leasees' right to the reasonable use of surface. We need a two-way recognition of the property rights. I understand that the people who have been out there since the land was first homesteaded treat it as their own and as their sole domain. CBM resources lay dormant for close to 100 years before technology allowed it to be produced. However, that doesn't mean that the right to the reasonable use of surface didn't exist.

The vast majority of operators have been able to come to a reasonable accommodation with surface owners. There are some folks out there that just want it to go away, don't want to deal with the problem, and, therefore, don't want to reach an accommodation. I have asked my friends in the environmental community and public interest groups to show me the real problems. I have an opportunity as a legal representative of CBM operators to try to resolve these problems. We can't resolve them if we don't understand them. Nobody's taken me up on that invitation yet. Some of the landowners won't even let the operators on the land to assess the issue, let alone cooperate with those CBM companies to try to solve the problems. What you end up with is the CBM operator having made an investment in a federal or private oil and gas lease and having no choice but to go to court to protect these interests in its investment. That becomes very adversarial. You often get outcomes that are win-lose; sometimes even lose-lose.

What I'd like to see us all do is to dedicate the time, money, and resources that are going toward litigation or the kinds of fights and regulatory solutions that I mentioned; instead, to looking at the opportunities that might exist for this water, solving the challenges, and minimizing the conflicts. I think if we do all that we don't have to throw the lemons; we can make lemonade.

**Jack Palma** is a partner with Holland and Hart law firm in Cheyenne, WY. He has over 25 years experience in natural resources and environmental law, including extensive work in federal and state public land law, National Environmental Protection Act (NEPA), environmental regulatory compliance and permitting, oil and gas, minerals, and water. He has worked on environmental and regulatory permitting associated with coalbed methane development, as well as with conventional oil exploration production, natural gas processing, and pipeline facilities within Wyoming. He has been an adviser to oil and gas producers with respect to day-to-day legal issues. Mr. Palma has written numerous articles and papers on natural resources, public lands, and environmental issues, water rights and water quality issues, including Indian water rights. He can be contacted at (phone) 307-778-4200.

*Produced Waters Workshop –*

# Can't We All Just Get Along?

## Liability Is Ignoring, or Not Including, Watershed Stakeholders and Environmental Interests?

by Laurie Goodman, Trout Unlimited, Jackson, WY

The people involved in this workshop make me realize what a big problem we have. People have flown in from Washington, D.C. – Assistant Secretaries, different political appointees – talking about what each one of their agencies is able to do. I think, "How on earth are we ever going to get any of this straightened out?" If I didn't like Jack, I would have ignored what he said just now and think that he is so wrong – that he 'so doesn't get it.' But I like him, so I'm wondering how somebody that I know and respect, someone who is kind and is a good human being, can see it so differently from me? Then I realize the government agency representatives are all just human beings, too, and we're all just trying to do the best that we can from very different perspectives. If we lose the ability to respect each person and the ability to keep listening to him or her – whether we know each other or not – the barriers will stay up and government won't change.

I am the former State Director of the Trout Unlimited program. I recently resigned, and Cathy Purvis, in the audience, is the new State Director. Trout Unlimited has launched an entire initiative dedicated to public land issues, including water – and CBM is a big issue. We are an organization with hundreds of thousands of members nationwide who've always been dedicated to the protection and enhancement of coldwater fisheries. We sat out of the CBM issue in the Powder River Basin because it was a warm water fishery. Now there are many plays in the state of Wyoming, particularly with movement into the Western side of the state, that are beginning to get into coldwater fisheries. We take a look at how the discharge of CBM produced water changes the natural hydrograph of water, changes the micro-invertebrates, changes a lot of that ecosystem. We're very concerned about what that may ultimately do to some of our coldwater fisheries.

I also wear the hat for the Landowners Association of Wyoming. I worked for Al Simpson as his legislative assistant for public lands and energy issues. I worked very closely with the petroleum association of Wyoming; in fact, my educational background was as a petroleum land man. Then I was offered a job by Bill Riley over at the Environmental Protection Agency. I'm not sure who was more confused by that one; Senator Simpson or my father, who was chagrined that I would go to work for environmentalists. Then I came home when Clinton was elected, and I began to do environmental consulting. One of the things I've learned through this experience is that energy development can happen in sustainable ways. There are so many barriers, due to federal government responsibilities, and agency and state responsibilities, that often prohibit an approach to sustainable development. The barriers encourage people to stay in their corners.

I agree that with a lot of Jack's concerns. My opinion is that it's easy for all of us who work in these issues, whether we be lawyers or public agencies or advocacy groups, to beat up on the agencies, because they're the ones who seem to be making the decisions. I would venture to bet that if you ask John Barnes or Mike Besson, they'll say they don't feel like they're in that much control – and sometimes they aren't. They only have so much room that they can move in, as well.

The state of Wyoming has produced about 70,000 wells in the approximately 100 years from statehood to the year 2000. The Bureau of Land Management (BLM) is now predicting to issue anywhere between 100,000 to 120,000 permits in the next ten years. We're venturing into an area of development where we have never been before. If those 100,000 wells are going to occur on the 50% of lands that are federally owned, they're occurring in very different ways than we've ever seen before. Traditionally, you get wells on 160 or 80 acres per section, about eight wells per square mile. The BLM just authorized a development in Pine Dale, Wyoming, that allows wells to be placed on every five acres, which is 128 wells per square mile. That's all on federal land. That was a choice the BLM made to expedite the extraction of that oil and gas.

Can you imagine what landowners who neighbor that parcel of land look at and feel, imagining if that gas had been drilled on their private property – even while understanding that the minerals were owned by the federal government? I would argue that the landowners never, in their wildest dreams, imagined that there were going to be 128 wells on their ranch. It's not right, it's not wrong. It's just a changing reality that we're all struggling to come to terms with.

The CBM water issue is another of those brand new, changing realities. We've never been here before. When Jack talked about a lot of the landowners who showed up at a hearing to talk about the produced water that they used, the majority of those landowners used produced water from traditional oil and gas wells. It's a very moderate amount of water – not an overwhelming amount – that they usually use for stock watering. It is not discharged on their land, and the use has been working well for them. That's great; nobody has an issue with that. CBM discharge water, on the other hand, is not working for a lot of people. It might be working for some, and that's great, but when it's not working for some, for whatever reasons, we assume we know why they're unhappy and dismiss them as uncooperative. Do they not want to recognize the rights of the industry? Do they just want to be naysayers? Do they just want it to go away? I would offer that type of thinking doesn't help issues. Maybe, in reality, they have some long-term connections to that land and some legitimate reasons for having problems with manner of discharge of water. If they don't have a way to have their concerns heard and legitimized – because everything is so prioritized and streamlined to get the drilling done within 30 days or whenever, they have nowhere to go.

Environmental groups suffer the same frustration. If nobody listens to you because you don't have a stake in the political process, you fight your way out of a corner, do everything you can to defend yourself and to be heard. For the record, my pet peeve is the industry saying, this isn't their problem. We heard yesterday from several industry people. I'm not always good at this either. Sometimes, I am so empassioned about the subject, that I say things in a way that are hard for others to hear – and I'm working on that. When industry stands up and says, "We are oil and gas producers; that's what we do; that's our job; I don't care what happens to the water." Well, guess who does care – the downstream guy who has to deal with that water. He cares a lot.

In this room, we have that very situation. You can't have a corporate executive speak in public and say "I don't care," then ask the downstream landowner for his buy-in when and the company representative wants to work out a surface use agreement, saying, "We really want to work with you." All that landowner can think is, "No you don't. I heard the president of your company. You don't care". And the fight is on.

I have seen the whole reason for the split estate issue that was passed in the state of Wyoming. One of Jack's clients and one of my landowners got in a huge fight over a mediation, and the fight was on. The landowner offered, during the mediation, to sell his ranch to this company, which was being allowed to drill on every ten acres. The company was not interested in the land, just the mineral right. The landowner believed in his right, and now we have a surface use accommodation act in the state of Wyoming. Those are the things that happen. They happen on very human levels.

I would argue that a case that just was determined, involving a landowner and one of Jack's clients over the discharge of water, is going to have significant implications on the management of Wyoming's water. I got started in this issue over a surface use agreement. The company couldn't come to terms with the landowner; the landowner dug in and the company said, "Take it or leave it." The landowner did not concede, and here we are all those years later. Was that good? I do agree with Jack that litigation is not the best thing.

Nor is it productive for industry to make the relatively idle threat of leaving if costs get too high, or regulatory burdens are too high, or landowners are too rude and won't allow access. There's an awful lot of money being made off of this resource. Wyoming has been poor before and will be poor again.

A company that is not committed enough to responsible extraction and makes such a threat can be bought out by another operator. Further, such threats fall on deaf ears. With oil at $60 a barrel, that company isn't going anywhere. We have the resource. Making threats is not productive.

Another issue: people are pointing at somebody else as being responsible for the problem. There comes a point in time where we, as citizens of the state of Wyoming and as federal agencies (I've been a federal bureaucrat charged with the public good) realize it's not the responsibility of federal employees to ensure that profits are maximized for a private corporation or industry. It is the responsibility of federal employees – and I embraced that responsibility very seriously when I was there – to make sure that our federal assets are managed in a sustainable way, including the extraction of oil and gas. It's okay for Mr. Duda, who's not here anymore, to believe that when he goes to work at the Department of Energy. He is responsible for managing the condition of the land and the condition of the water and the air that are impacted by the development of energy.

If we have a government that doesn't honor that premise and, instead, is told that its job is to maximize oil and gas extraction at the expense of other resources, we've got a problem. We're going to have 100,000 wells in Wyoming in the next 20 or 30 years on federal land. On a 30,000-acre parcel of land called the Jonah Field, the sage grouse no longer use that parcel of land for reproduction. They didn't die, but they're somewhere else. We have documented that the survival rates of mule deer migrating through some of these oil and gas fields has gone down by 46% – documented based on six years' worth of good science. We now are seeing air quality modeling up in the Wind River Mountains where we're observing precursors to acid rain. That is stunning.

We are monitoring. I'm not sure if we're supposed to monitor the trends right on down to the end or to a point where people realize we need to do this differently. We can't just keep monitoring and watch some of these adverse impacts. We have to make some proactive decisions, and I think those proactive decision makers are private landowners. Where do those sage grouse go? They go onto the private land. Where does the wildlife go when it can't winter on the federal acreage any more? It goes to the private land. This situation has put Trout Unlimited in a very interesting situation; we want to be an advocate group and advise private landowners how to use their water, and advise federal and state agencies in water management issues, when the truth of the matter is, the protection of coldwater fisheries may fall onto the private landowners more than ever before. We need to start looking at those people as our partners in this issue. Trout Unlimited has always valued private landownership partnerships, although I'm sure there are people who would argue with me.

It takes a long time for federal and state agencies and governors' offices to react and figure out what to do. It doesn't take that long for a private landowner because it happens right away on his land and he sees it. He has to begin making adjustments. He tends to be the squeaky wheel because he sees it first and he deals with the ramifications the longest having the longest-term investment. It is paramount we all respect private property rights and the role the landowner is going to play in energy development, in CBM development, in the discharge of water. I'm speaking to Jeff Cline, of Anadarko, who mentioned that Anadarko is a large land owner – and that's true. However, Anardarko is discharging water to its ranch that is not its livelihood. I would argue that the cattle that they run on that ranch are an insignificant return to the company. They have a management interest in that land because of some drained aquifers and some erosion problems with the previous landowners, and that is all fine. I'm not saying that Anadarko is bad lot of managers; they manage that land with a different sense of expectations and need for returns than people who are managing their lands to grow the grass, to pay for the cattle, to feed the country.

We have to honor the different uses of this land, not discredit people whose use is different. We need to listen to them and ask how we can produce the gas in a sustainable way. How can we do it in honoring other people? Part of the solution, and I've heard it throughout this entire conference, is to attach a value to the CBM produced water. Not valuing this resource is sending the wrong signals to everybody. It's sending the wrong signals to Brad Pomeroy, who sees produced waters as just a cost to him, an expense, something he wants to get rid of. If there was a value attributed to that water, he'd probably treat it a little bit differently. The gentleman who said he didn't care what happened to the water, because he just wanted to produce natural gas, would care if he made money from it.

When you think about the infrastructure that this oil and gas industry has brought to the country, it really is stunning and unbelievably impressive. I have toured off-shore rigs and have seen what they're doing. We could drill miles toward the core of the earth and produce unbelievable reserves without being able to see a thing. It's phenomenal. Yet, we can't figure out how to come up with a pipeline network that can transport this produced water for beneficial use. In Wyoming we have a pipeline authority that just received $2 billion of additional authority to bonding to build more natural gas pipelines out of Wyoming. But poor Mike Besson is back there with 25 people trying to figure out what to do with the CBM water and nobody wants to put any money up for the pipelines because they're not sure how long it's going to last, and on and on and on. There's no value to that water.

When that water doesn't have a value, the oil and gas companies treat it strictly as an expense, and the whole process is geared toward trying to get rid of that water at the least cost. Discharge, or whatever disposal is the cheapest, may, in fact, be the most damaging and the most expensive course to the landowner or the fish and wildlife advocacy group. If the governments or the industries can put a commodity value on that water, it will change quickly how everybody begins to think about that. The landowners who complain about it will be given a value of that water, either on their place or on getting rid of it. Companies can make money off of that.

I can truly envision a system in Wyoming where we'll have a water pipeline authority similar to the natural gas pipeline authority. That would be an alternative to group therapy to make us nicer to each other and listen to each other. The truth is, we really have to consider the capitalist nature that makes this country so strong, that has driven the oil and gas industry to the success it enjoys. If part of that process includes production water that has an equal or greater value than any other product, perhaps all of that intelligence and talent can focus on it. I think that approach will move us toward behaving better – and behaving more responsibly with this water.

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**Laurie Goodman,** until recently, was the director of Trout Unlimited's Wyoming Water Project. Since April 2004, Goodman has been the President of the Landowner's Association of Wyoming. She has worked for Al Simpson on public lands and energy issues, the Petroleum Association of Wyoming, and for Bill Riley and the Environmental Protection Agency. Laurie can be reached at (phone) 307-734-1905.

*Produced Waters Workshop –*

# Can't We All Just Get Along?

## Where Can Liabilities (Legal and/or Economic) for One Participant Be Turned into an Advantage for Another Participant?

by Kate Fox, Davis and Cannon,Cheyenne, WY

I represent landowners in Wyoming, and I'll tell you the real deal. We're talking about why we can't get along. Jack says we could, if we acted better. I think asking industry and landowners to get along is like putting your cat in the canary cage and saying, "Now you two get along." It's not naturally going to occur. Industry is in the business of extracting gas and oil and doing so at the lowest possible cost. That's the nature of that beast. Landowners are there to try to preserve the lifestyle that they've had over many generations; when industry's objectives interfere, they're going to object. That's just the way it's going to be. It isn't a matter of whether we have good manners or not. Jack thinks maybe we could all get along if we put the cat in the canary cage and the canaries would just roll over and let them eat them!

I think the real problem is reflected in the comment that Mark Squillace made at the very beginning: where are the regulators? In Wyoming, we have an absolute policy and regulatory void. It's because of that void that the cat and the canaries aren't getting along. I'm not a great believer of more regulation, but I think it's absolutely mandatory in the case of CBM water.

There are many reasons for regulatory involvement in CBM water issues. First, consider what we keep hearing over and over again, and the truth I learned growing up – water is a scarce resource and we should treat it like that. Let's not continue to treat it, as we do in Wyoming, as some by-product that's got to be disposed of as cheaply as possible. Let's recognize that, on the Front Range of Colorado, I think water is selling in some places for $15,000 an acre-foot. Even on the Platte in Wyoming, water rights senior to 1904 can bring $4,000 to $5000 an acre-foot for water. Yet in the Powder River Basin we're treating it like garbage that's dumped into the backyards of my clients, the landowners. The state needs to step in and treat water like the valuable natural resource that it is. No one else but the state will do it.

The kind of things that Mike Besson was talking about at lunch today – plans for piping, for example, plans for reinjection, possible plans for treatment and use in municipalities finding a true beneficial use – these are all processes that the state is going to have to play a major role in. I don't think the state should pay for this. I think industries should be a major contributor to those payments. Yet, until the state recognizes that water is the valuable resource we all know it is, and begins to treat that water as something that needs to be put to beneficial use, we're going to continue to have these conflicts.

### Old rules, new world

The irony of our Wyoming experience is that considering water as a scarce resource has also been a license for waste, at least for what we've seen happening in the Powder River Basin. Let me explain: we often have heard, because there's always been a water shortage in Wyoming, that more water is, naturally, going to be a better thing. We started with that assumption – more water can only be better. That's something we've historically believed in Wyoming because there's never been enough water. It's not true.

We and our regulators need to see our new world, and it isn't a world of not-enough-water. All of our water regulation laws and our water quality laws in Wyoming, naturally, and in most of the Western states, have been based on an assumption of a shortage of water. For example, the State Engineer in Wyoming typically doesn't regulate water rights unless there's not enough water and someone's calling out a junior appropriator. That's how all of our laws have been developed. That's how we've looked at water issues: there's not enough. Now we have too much water.

Our old regulations don't work in a situation where there's too much water. We need to take a step back and take a fresh look at the application of those regulations in circumstances where there's too much water. For example, early on in the Powder River Basin in the drainage where Jack and I did some battles, industry built a number of on-channel reservoirs. My client, who was downstream in Wild Cat Creek and was a senior irrigator, objected to the fact that those dams in the channel were obstructing the natural flow of waters that he used for irrigation. The State Engineer conceded there may be impeded flow, but the reservoirs were releasing a large quantity of CBM water, enough to satisfy the water right. In effect, "We're only looking at quantity. You have all the water that you need; in fact, more than you need. We don't really care if you can use it or not." My client took the position that the salinity was too high to apply to his alfalfa fields. Jim Bauder may have talked about salinity issues involving alfalfa, which is very sensitive to salty water. This Engineer's position was, "Sorry, that's not our issue. We don't care if the water is of a quality to be put to its permitted use as long as the quantity is there to satisfy your appropriated right."

That's not an issue that's ever come up in Wyoming before. It's here now. If you can't use the water for its permitted purpose because of quality, then the quantity is irrelevant. It's something that, if the State Engineer hasn't thought about it before, he should be thinking of it now.

### More is not necessarily better

A lot of the issues that we have been facing in Wyoming, as Jack knows, have to do with the failure of the regulators to consider the inner section of quality and quantity of water. In Wyoming, as I think in many states, the water quantity regulation has to do with administration of water rights. That's part of the State Engineer's jurisdiction. The Department of Environmental Quality is charged primarily under the Clean Water Act with regulation of water quality. The State Engineer stands at the edge of this great chasm and says the office can't talk about quality. The DEQ stands at the other side of this great chasm and says it can't talk about quantity. In between, where quality and quantity intersect, is where all the problems occur. In Wyoming, both agencies have refused to go in between and pursue any regulation that has significance. Jack and some other people have mentioned this rulemaking petition that we filed; the purpose of which is to encourage the Wyoming DEQ to consider that quality is impacted by quantity, that quantity itself is a quality parameter. There has got to be recognition that quality and quantity are intertwined, as the U.S. Supreme Court has said.

I want to touch on the comment that Jack and Laurie both made regarding people who came to the rulemaking petition commenting they truly enjoyed the water. Those people were largely people in the Big Horn Basin who had grown accustomed to produced water from traditional oil and gas, largely not people from the Powder River Basin who are stunned to find the quantities of water that they're seeing from CBM gas. That difference in reaction illustrates the issue: in one case, there's not that much water; in the other case, you have huge quantities, such as the 75,000 acre-feet produced by CBM in 2003. It becomes a whole different issue, and has to be treated in a different way. In each of the states where CBM development is occurring, there has to be serious consideration of the quantity of the water, and adjust policy accordingly.

The water has to be considered a resource with its own value, not just a by-product for disposal, and treated that way. Reagan asked me if we were going to talk in this panel about the legal issues associated with disposing of the brine, the by-product from water treatment. I wish that was the issue I'm concerned with in Wyoming, but it's not. We haven't even gotten there yet. We're still arguing the question of whether surface discharge is a beneficial use. There are many people who think everyone should be happy about the water just being there. That's not true. The lesson that we've learned in the Powder River Basin is, simply: with a little more water, you might see some ducks landing in the reservoir, you might have cattle who don't have to go so far to get water; yet, nobody talks about how much more water you need for there to be a benefit; anything beyond that amount is not beneficial

The myth that we've lived with in Wyoming for many years – and that we're working to dispel – is that because a little more water is a good thing, a lot more water is an even better thing. There is a point of diminishing returns. With the quantities of water associated with CBM, that point of diminishing returns is going to be reached. I don't know if there's still hope in Wyoming; we're still working on it. But I urge the rest of you from other states to think seriously about forming intelligent policy that has to do with dealing with the question of too much water.

**Kate Fox** is a partner with the firm of Davis & Cannon, practicing in general litigation and environmental issues. She represents landowners in matters pertaining to CBM development, and has been involved in protracted litigation in federal court and before the Wyoming Environmental Quality Council arising from CBM water issues. She is the attorney for the petitioners in a rulemaking petition now pending before the Wyoming Environmental Quality Council that would require the DEQ to more fully consider the impacts of CBM discharges on the agriculture and wildlife of Wyoming. Contact her at (phone) 307-634-3210.

*Appendix A –*

# Poster Presentations/ Abstracts

# Poster 1

### Multi-Beneficial Use of Produced Water Through High Pressure Membranes and Capacitive Deionization Technology

Pei Xu and Jörg E. Drewes
Environmental Science & Engineering Division, Colorado School of Mines

Large volumes of produced water are generated during natural gas production. Beneficial use of produced water has become an attractive solution to produced water management by providing additional and reliable water supplies and reducing the cost for disposal. Methane exploration from sandstone aquifers is a new technique in gas exploration and produced water generated from these operations is characterized by the absence of hydrocarbons and elevated concentrations of iodide. Recovering iodide from the processed concentrate represents additional benefits besides methane gas, water reuse and reduced brine discharge.

The objectives of this research project funded through the U.S. Bureau of Reclamation were to investigate the viability of ultra-low pressure reverse osmosis (ULPRO)/nanofiltration (NF) membranes and capacitive deionization (CDI) as potential techniques to treat produced water meeting non-potable and potable water quality standards and providing conditions which allow an economical recovery of iodide.

The advent of ULPRO and NF membranes could offer a viable option for produced water treatment because they can be as effective as RO in removing certain solutes from water while requiring considerably less feed pressure. CDI with carbon-aerogel electrodes represents a novel process in desalination of brackish source water as compared to technologies like reverse osmosis or electrodialysis. The ions are removed by charge separation and thus common scaling problems associated with membrane and thermal processes can be avoided. The CDI process operates at ambient conditions and low voltages. It uses electrostatic regeneration rather than the harsh chemicals used for regeneration in related adsorptive treatment system.

The study included laboratory and field-scale tests with make-up water representing various produced water chemistries and with water produced at a gas field to identify key operational parameters and performance. The two technologies proposed were assessed with regard to technical and economic criteria.

# Poster 2

### Smart Membranes for Treatment of Produced Water

Ranil Wickramasinghe, Department of Chemical & Biological Engineering, Colorado State University
Scott Husson, Department of Chemical and Biomolecular Engineering, Clemson University

Coal bed methane is natural gas associated with coal deposits. The existence of this gas has been known for a long time; however, only recently have economical methods been developed to collect it. In Wyoming in 2003, the total value of coal bed methane production was about $1.5 billion. The recent rapid increase in production of coal bed methane has lead to serious concerns regarding the management and disposal of the large volumes of water that are co produced (produced water) with the coal bed methane. The quality of this produced water is highly variable.

We are currently developing smart membranes for low pressure reverse osmosis and nanofiltration applications by growing polymer brushes from the surface of the membranes. By controlling both the chemical and environmentally responsive conformational properties of these polymer films at the nanoscale, we will limit biofilm formation and provide an easy way to remove attached foulants. These membranes could be used to treat produced waters.

Our unique surface modification of commercially available thin film polyamide RO and NF membranes consists of growing block copolymer brushes comprising polymers known to spontaneously detach adsorbed microorganisms at lower temperatures and to reduce the adsorption of foulants in the first place. For example a diblock copolymer where the lower block consists of poly (N-isopropylacrylamide) (PNIPAAM), which exhibits a lower critical solution temperature of 32 °C could be attached to the membrane surface. Microorganisms that attach to PNIPAAM at temperatures above 32 °C detach when the temperature is reduced below 32 °C. The upper block represents poly (PEG methacrylate), which suppresses attachment of foulants.

A critical component of our research is the ability to accurately tailor the surface of RO and NF membranes. Bioadhesion resistance is achieved primarily by having high enough (but not too high) graft densities. We expect that there will be an optimum density of polymer chains that minimizes fouling. We can vary graft density and layer thickness independently using atom transfer radical polymerization, a relatively new and highly controllable technique for growing polymer brushes for the surface of commercial membranes in aqueous solution.

# Poster 3

## Geochemical Constraints on Selection of CBM Product Water Management Strategies

Ron Drake, Drake Engineering, Helena, MT

Water co-produced from biogenically methane-rich coal seams of the Powder River Basin in Montana and Wyoming is chemically unstable when released to atmospheric conditions. Consequently, water co-produced with coal bed methane extraction and recovery may exhibit profound changes in composition after withdrawal from the aquifer. Understanding the fundamental chemical behavior of CBM product water is key to designing and implementing successful water management strategies at any desired scale. Spontaneous changes in CBM product water composition, which are primarily near-instantaneous increases in SAR (the ratio of sodium in solution to the sum of calcium and magnesium in solution), pH, and alkalinity, are likely to implicate its suitability for beneficial use on the landscape without co-mingling or conjunctive applications. Another alternative is intensive soil solution and soil matrix chemical modification: pH modification, soluble salt concentration elevation, and increased availability of soluble-source calcium. This poster presentation provides a step-by-step sequence of chemical equilibria reactions which can be expected in sodium-bicarbonate rich water of modest to low salinity and co-produced during coalbed methane recovery. Laboratory investigations confirm results of geochemical modeling that show the co-produced water equilibrium sodium adsorption ratio (SAR) is controlled by concentration of bicarbonate. Liquid/gas mass transfer of carbon dioxide (sourced from the atmosphere) controls the rate of approach to chemical equilibrium. This reaction-driving bicarbonate, a signature common to biogenic coal bed methane co-produced water, suppresses solubility of Ca and Mg and results in significant precipitation of relatively insoluble calcium and magnesium carbonates (dolomitic limestone). Not surprisingly, this precipitation serves as a significant barrier, cementing, and inhibition of channel, stream-bottom, and pond bottom infiltration. Such chemical behavior will likely have significant adverse impact on fluid transmissivity characteristics in soil exposed to sustained wetting with co-produced water of a chemical signature comparable to that of the coal bed methane reserves of the Powder River Basin. (The research reported here was jointly sponsored by the U.S. Department of Energy, the U.S. Department of Interior-Bureau of Land Management, the Montana Department of Commerce and Technology Transfer, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 4

## Coal Bed Methane (CBM) Development – A Regional Water Quality Issue: Platform for Integrated Research, Education, and Extension.

Montana State University Water Quality Extension Team
Montana State University – Bozeman, MT

Global energy consumption, homeland security interests, rising energy prices, and new coalbed methane gas extraction and recovery techniques have resulted in accelerated attention and effort to identification of coal bed methane reserves and corresponding development of this relatively clean energy source. The Rocky Mountain Region has extensive coal deposits which constitute significant storage of biogenically sourced coalbed methan gas – a source of domestic natural gas. The coalbed methane extraction and marketing industry has expanded from a mere few hundred wells to more than 55,000 methane and water-producing wells in the region in the past decade. Unlike conventional, dry-source natural gas, extraction of coalbed methane (CBM) requires withdrawal and disposal of large amounts of typically modestly saline x sodic water. Water pumping from hydrologically submerged coal seams is prerequisite to methane release from coal cleats – and fluid flow also facilitates gas migration to well bores, where gas is recovered to the land surface and piping infrastructure. Projections from a number of sources call for the disposal and/or management of ¼ million acre feet of water annually from the Powder River Basin alone over the next 10 to 15 years. Increasing emphasis on gas recovery from other methane-bearing basins in the western U.S. has fostered projections of co-produced water volumes of as much as 40 million acre feet in the next 15-20 years. A multitude of land surface issues face water resource managers attempting to deal with growing volumes of co-produced CBM water. Some of these issues include perennial and ephemeral stream channel management, soil responsiveness to inundation by CBM water, and education of landowners and natural resource management specialists. This poster outlines some of the multi-state efforts of land grant research, education, and extension institutions in the Northern Plains and Intermountain region to provide research based education and outreach addressing CBM product water management. (The research reported here was jointly sponsored by the U.S. Department of Energy, the U.S. Department of Interior-Bureau of Land Management, the Montana Department of Commerce and Technology Transfer, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 5

## Diverse Soil Responses – Chemical and Physical – to Repeated Irrigation with Saline/Sodic Water

Kimberly Hershberger, J.W. Bauder
Montana State University – Bozeman, MT

There is frequently voiced concern among irrigators and land managers in the drainages of the Powder River Basin regarding the potential or perception of impact of discharges of slightly to modestly saline-sodic water from coal bed methane development sites into surface waters and onto irrigated acreages. These concerns, although not unanimous, are expressed by land owners and managers both within the immediate vicinity of produced water discharge points and significantly down-gradient along higher order streams into which ephemeral and permitted discharges are occurring or may occur. In order to address questions regarding soil responsiveness to wetting by produced waters, a two-year study was conducted to assess chemical and physical responses of a multitude of soil materials upon wetting with simulations of produced water. Soil material, representing 54 textural materials, was collected from 16 agricultural sites within the Powder River Basin. Each soil material was treated with various combinations of two water qualities and three wetting/irrigation regimes. Repeated irrigation with saline-sodic water or water with a chemical signature comparable to CBM produced water used in the study resulted in an overall general increase in soil salinity and sodicity. The results of this study suggest that it is probable that soil salinity levels can become substantially greater than published salt tolerance thresholds for some irrigated crops. When soil previously wetted with produced water were exposed to rainfall, the influence of rainfall on reducing soil solution EC and SAR was most predominant when soil solution salt concentrations were high and soils rained on were coarse in texture, i.e., sandy, well-drained. Simulated rainfall on soils wetted with produced water resulted in a more significant reduction in soil solution salinity than the reduction in SAR. Water content determinations following repeated wetting with simulated, produced water indicated that coarser textured soils (sands and sandy loams) tended to exhibit exaggerated drought characteristics. In contrast, finer textured soils (clays, clay and silt loams) exhibited reductions in drainage characteristics and exaggerated water-logging characteristics. Statistically significant differences in soil water holding properties and residual chemical properties were detected among water quality treatments. However, differences were not considered large enough to have a significant ecological impact on a field-scale basis. (The research reported here was jointly sponsored by the U.S. Department of Energy, the U.S. Department of Interior-Bureau of Land Management, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 6

## Applied Science for the Management and Beneficial Use of Saline-Sodic Water

Krista E. Pearson, James W. Bauder
Montana State University – Bozeman

Due to increasing interest in coal bed methane exploration and development throughout the Rocky Mountain Region, management and beneficial use of modestly saline x variable sodicity water has become an emerging water quality issue. Considerable amounts of moderately saline-sodic water are co-produced during CBM extraction. Recent CBM development in the Powder River Basin of Montana and Wyoming has prompted researchers at MSU-Bozeman to investigate new ways to manage large amounts of saline-sodic water. This poster provides an overview of water production in major basins of the region and highlights beneficial use options being researched at MSU. (The research reported here was jointly sponsored by the U.S. Department of Energy, the U.S. Department of Interior-Bureau of Land Management, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 7

## From Prehistory to the Pipeline – the Genealogy and Fingerprint of Coal Bed Methane

Suzanna Roffe, James W. Bauder
Montana State University – Bozeman

The Powder River Basin, a geologic structural basin of north central Wyoming and south east Montana, is transected by several significant surface water resources, including the Tongue and Powder Rivers, Rosebud and Caballo Creeks. The basin is also the location of one of the most substantial – and most rapidly being developed – coalbed methane reserves in North America. The basin itself was carved out during the Laramide Orogeny, which included a series of mountain building events in western North America that occurred in the Late Cretaceous and Tertiary time. During this time, the climate of Wyoming and Montana was semi-tropical and conducive to the growth of lush forests that would eventually become the present-day coal fields. Coalbed methane development (methanogenesis) within the basin consequent to coal bed burial was biogenic, occurring shortly after overburden deposition during a time of rapid subsidence in the Laramide Orogeny. This poster provides an overview of the coalification and methane production processes, coal bed methane world-wide resources, projections of major U.S. coal bed methane reserve developments, and geochemistry of water associated with biogenic methane production, particularly in the Powder River Basin. . (The information collected for this report and the preparation of this report was made possible with funding provided by the U.S. Department of Energy, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 8

## Selected Plant Species Tolerance for Irrigation with Saline-Sodic Water

Allison Levy, Montana State University – Bozeman

Coal bed methane extraction produces large volumes of a geographically dispersed by-product water, which has traditionally been viewed as and managed as a easily disposable waste product. The typical signature of water co-produced during biogenic methane extraction is modest salinity x variable sodicity. A nearly decade-long drought within the Powder River Basin, public and regulatory concerns about receiving streams impairment, industry concerns about cost of treatment of co-produced water, and a desire to identify beneficial uses of this energy-extraction by-product water has put substantial attention on research addressing irrigation as a viable water management option. Use of produced water from coalbed methane extraction operations to enhance rangeland productivity and livestock forage could prove to be a beneficial use of produced water in areas where water availability is limited. The objective of this project was to determine survivability and plant biomass of forage species irrigated with water of quality comparable to that of water co-produced during methane recovery in the Powder River Basin. Screening for salt tolerant forage species may facilitate opportunities for more extensive use of produced water supplies. A germination screening was conducted to determine survivability and early plant biomass of sixteen different forage species commonly occurring in the Powder River Basin. These species were irrigated with water qualities that were chosen to represent conditions of co-mingled or junctive use surface water supplies that could result from blending of coalbed methane produced waters with existing surface water resources. From this initial screening, a short list of salt-tolerant forage species was determined, based on survivability and biomass production. Selected plant species were then established in large-scale field scale demonstration sites, which were flood irrigated with coalbed methane produced water. Results of this research demonstrate that on selected soils and with high-level irrigator management, coalbed methane production water can be used on a limited basis in conjunction with other management strategies which capitalize on the selected forage species. (The research reported here was jointly sponsored by the Montana Department of Commerce and Technology Transfer, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 9

## Land and Water Inventory Guide for Landowners in Areas of Coal Bed Methane Development

Holly Sessoms, Kristen Keith, Matt Neibauer, Quentin Skinner, Jim Bauder,
Reagan Waskom, and Nancy Mesner
Montana State University – Bozeman, Colorado State University,
University of Wyoming, and Utah State University

Land and water resource managers, land owners, and irrigators downstream of coalbed methane extraction and produced water discharge in the Powder River Basin have repeatedly expressed mixed concerns about water management issues associated with coalbed methane production. To address natural resource issues associated with CBM development in the western U.S., the CSREES Northern Plains and Mountains Regional Water Quality Program (a USDA-CSREES funded entity), Prairie County Conservation District (MT), and Environmental Protection Agency Region 8 partners have co-developed the "Land and Water Inventory Guide for Landowners in Areas of Coal Bed Methane Development". The guide is intended to empower landowners within CBM development areas of Montana, Utah, Wyoming, and Colorado to initiate a watershed approach to soil, water, and vegetation monitoring. Goals of the project include enabling landowners to: 1) understand baseline conditions of soil, water, and vegetation resources; 2) understand potential impacts of CBM development prior to contracting with a developer; and 3) monitor resource changes over time as a result of CBM development. The guide addresses steps to mitigate and prevent degradation of natural resources, emphasizes landowner education regarding surface and mineral rights, describes how to develop an inventory map, and outlines baseline data collection and simple protocols for implementing an ongoing monitoring program including site selection, sampling protocol, and data interpretation. To ensure that the guide was regionally appropriate, drafts were extensively reviewed by CSREES partners along with industry and agency professionals in Utah, Colorado, Wyoming, and Montana. To ensure the monitoring protocols described were meaningful, yet monetarily and time efficient, the guide was reviewed by a number of landowners throughout the region. The resulting document is a concise and timely tool for landowners and resource managers throughout the Northern Plains and Mountains region. (The project reported here was jointly sponsored by the U.S. Department of Energy, Prairie County Conservation District – Montana Department of Natural Resources and Conservation, the U.S. Department of Interior-Bureau of Land Management, the Environmental Protection Agency Region 8 regional initiative project, Montana State University – Bozeman, and the U.S. Department of Agriculture – CSREES.)

# Poster 10

## TransformingTransforming CBM Produced Water to Beneficial Use Through Electrodialysis Processing

Thomas Hayes, Paula Moon, and Seth Snyder
Gas Technology Institute
1700 S. Mount Prospect Rd, Des Plaines, IL 60018
Tom.Hayes@gastechnology.org

The Colorado Energy Research Institute (CERI) at the Colorado School of Mines, has brought together a team of scientists and engineers to address many aspects of produced water management from production through treatment and /beneficial use. In support of this project, a collaborative effort between the Gas Technology Institute and Argonne National Laboratory is using an integrated electrodialysis (ED) process for water treatment. The anticipated benefits are enhanced coalbed methane (CBM) produced water quality, extended life of injection wells by 10-fold, reduced treatment cost to 10-15 cents per barrel and reclamation of 90% of the water for beneficial use. If treatment system effluent is to be made available for beneficial use (such as irrigation, livestock operations, groundwater recharge, etc.), the water stream must comply with certain water quality criteria; some of these guidelines are defined by State regulations. Beneficial use criteria that are applicable to CBM produced water mainly focus on three parameters: total dissolved solids (TDS), sodium absorption ratio (SAR) and pH.

The effort to develop ED processing for the conditioning of produced water for beneficial use is currently employing laboratory scale ED prototype equipment. The treatment concept, results, benefits, achievements, and next steps will be highlighted in this poster. Experimental results with actual CBM produced water using selective and non-selective electrodialysis membranes and power requirements will be discussed. Technical results will highlight degree of desalination of the product water as it relates to SAR, pH and TDS values suitable for beneficial use targets (livestock drinking and water irrigation in the Power River Basin) as well as an estimate of the upper salt concentration in the rejected stream.

# Poster 11

## An Exciting New Technology for Making Lemonade Inexpensively: AltelaRain™ – State of the Art Produced Water Treatment Technology

Altela, Inc.
Ned A. Godshall, CEO
1155 University Blvd. SE
Albuquerque, NM 87106
(505) 843-4197/ned.godshall@altelainc.com

Altela, Inc. is a new high-technology company providing produced water purification and remediation services to the oil, natural gas, and mineral extraction industries. Our patented AltelaRain™ products and related services provide a novel and complete produced water management solution. Altela's new patented technology is radically different from conventional reverse osmosis and other high pressure membrane technologies (ultra-filtration and nano-filtration). Altela's technology requires no high temperatures and no pressure to operate, unlike conventional processes. In addition, the AltelaRainTM system requires no expensive pre-treatment or post-treatment processes. Following treatment, the purified AltelaRain water meets water quality standards acceptable for irrigation, livestock watering, power plant cooling, or dust suppression.

The patented AltelaRainTM revolutionary technique is a derivative of the humidification-dehumidification desalination process. The process uses low grade steam as the energy source and can be operated at standard atmospheric temperature and pressure. Each AltelaRainTM tower is capable of processing 150-250 gallons per day of water with salt concentration in excess of 150,000 ppm. The AltelaRainTM system can reduce effluent disposal volumes by as much as 80%. Key advantages include:

- Extremely high quality of treated water
- Relatively low cost
- High thermal efficiency
- Unattended operation
- No fouling
- No scaling
- Relatively low cost
- High thermal efficiency
- Unattended operation
- No fouling
- No scaling
- No membranes to replace

A field pilot test using real oil-field produced water was conducted by Altela, Inc. employing the AltelaRain™ system for a conventional oil well located in southeastern New Mexico in early 2006. The water quality test results received from an independent water quality lab demonstrate the very high quality of treated water obtained from this simple, elegant technology for the treatment of highly challenged produced water. Total dissolved solids were reduced from 41,700 mg/L to 106 mg/L. Chloride was reduced from 25,300 mg/L to 59 mg/L. Similarly, benzene levels were reduced from 450 ug/L to non-detectable following AltelaRainTM treatment. Complete, detailed water quality data following AltelaRain™ treatment is available upon request.

# Poster 12

## Planning Support Systems in Natural Resources Management: Aggregation of CBM Gas and Water Production by Watershed

Scott Lieske
Wyoming Geographic Information Science Center (WyGISC)
Ruckelshaus Institute of Environment and Natural Resources
P.O. Box 4008
1000 E. University Ave.
Laramie, WY 82071-4008
Phone: (307) 766-3709/E-mail: lieske@uwyo.edu

While originally designed for rural and small town planning, the geographic analysis capabilities of planning decision support systems extend the capabilities of geographic information systems (GIS) in ways that are useful to a variety of research applications and disciplines.

The Community Viz® planning support system can be though of as a “spatial spreadsheet” which performs numerical computations on geographic data in much the same way as a spreadsheet works with numbers. This functionality is extremely useful in automating the processing of large volumes of spatially referenced data and analyzing associated numeric attributes.

This poster presents an example of the computational and analysis strength of CommunityViz in addressing a natural resources issue: acquiring, processing and analyzing Coal Bed Methane (CBM) gas and water production data. The analysis illustrates automating the processing of Wyoming CBM well locations statewide as well as gas and water production information and ends by determining gas and water production for specific geographic areas, in this case major watersheds.

The flexibility and computational strength of planning support systems, even those specifically designed for localized planning issues, can be a valuable tool for processing and analyzing natural resources data sets as well as data sets from any number of research areas or disciplines.

*Appendix B –*

# PowerPoint Presentations

## Dave Akers

- Practically, how do we permit the introduction of treated produced waters into integrated water resource management developments?

## Produced Water Discharge to Waters of the State

Dave Akers
Colorado Department of Public Health and Environment, Water Quality Control Division

## Produced Water Disposal Options

- Deep Well Injection
- Total Retention
- Discharge to Groundwater
- Discharge to Surface Water

## Discharge to Surface Water Considerations

- In-stream Standards
- Low Flows
- In-stream Water Quality
- Potential Pollutants of Concern

## In-Stream Standards

- Dependent on stream classification and/or existing water supply
  - Iron, chloride, etc.
- Narrative standards including WET
  - Acute
  - Chronic
- TDS/Salinity minimization for discharges ultimately reaching the Colorado River

## Low Flows and In-Stream Water Quality

- In-stream dilution
  - High low flows, small design flow = greater dilution
  - Low low flows, large design flow = lesser dilution
- Upstream water quality concentrations
  - High upstream concentrations = lesser limits
  - Lower upstream concentration = higher limits

## Potential Pollutants of Concern

- Source waters dictate pollutants
- In-stream standards, downstream classifications and downstream water uses dictate some pollutants
  - TDS (Colorado River)
  - Chloride and sulfate (Water supply classification)

## Water Quality-Based Effluent Limits (WQBELs)

$$M_2 = \frac{M_3Q_3 - M_1Q_1}{Q_2}$$

- $Q_1$ =Upstream Low Flow (1E3 or 30E3)
- $Q_2$ = Average daily effluent flow (design capacity)
- $Q_3$ = Downstream flow ($Q_1$ + $Q_2$)
- $M_1$ = In-stream background pollutant concentration
- $M_2$ = Calculated WQBEL
- $M_3$ = Maximum allowable in-stream pollutant concentration (water quality standard)

## Antidegradation

- Applies to reviewable (undesignated) waters
- Establishes baseline water quality (BWQ) concentrations downstream as of September 30, 2000.
- Facility existing contributions and permitted allocations are considered IF in existence as of September 30, 2000; otherwise, a non-impact limit (NIL) of zero is used as permitted allocation
- Antidegradation-based average concentrations (ADBACs) calculated by allowing 15% incremental increase between BWQ concentration and the standard
- Facility may choose NIL, ADBAC or complete an alternatives analysis

## Antidegradation-Based Average Concentrations (ADBACs)

$$ADBAC = \frac{[0.15(WQS - BWQ) + BWQ]Q_3 - M_1Q_1}{Q_2}$$

- $Q_1$ =Upstream low flow (1E3 or 30E3)
- $Q_2$ = Average daily effluent flow (design capacity)
- $Q_3$ = Downstream flow ($Q_1$ + $Q_2$)
- $M_1$ = In-stream background pollutant concentration
- *BWQ* = Baseline Water Quality concentration
- *WQS* = Water Quality Standard concentration
- *ADBAC* = Antidegradation-based average concentration

## Other Issues

- TDS requirements
  - Salt reduction study and long term TDS monitoring
  - Can feasibility of discharging vs. not discharging be demonstrated
- Acute WET limits LC50>100
  - Ceriodaphnia sensitivity to salinity
  - Other species sensitivity to high concentrations (e.g., chlorine, metals)
  - One time test failures

## What If …

- High selenium source water concentrations
  - Treatment prior to discharge
  - Discharge during non-low flow months (requires discharge detention)
  - Re-inject or percolation ponds

## What If …

- New discharger to Undesignated (reviewable) stream
  - Alternatives analysis
- Salinity causes Acute WET test failure
  - Species substitution
  - Other test methodologies ($CO_2$)

## Produced Waters

- Overlapping jurisdictions between the Division, the State Engineer's Office (SEO), and the Colorado Oil and Gas Conservation Commission (COGCC)
- Water rights, water quality protection and oil and gas exploration and mining laws

## Recent Decisions

- Scenario 1: Farmer wants to use produced water for irrigation
  - CDPS permit required for "discharge of wastes" after irrigation
  - While produced water is of sufficient quality to be put to beneficial uses, but that does not take it out of the realm of being a "waste."

## Recent Decisions (Continued)

- Scenario 2 – Water rights and uses for produced water will dictate the regulating agency
  - Cooling water at a power plant
  - Brine water for a shrimp farm
  - Aquifer recharge
- Substitute supply plans
- Decreed exchanges and augmentation plans

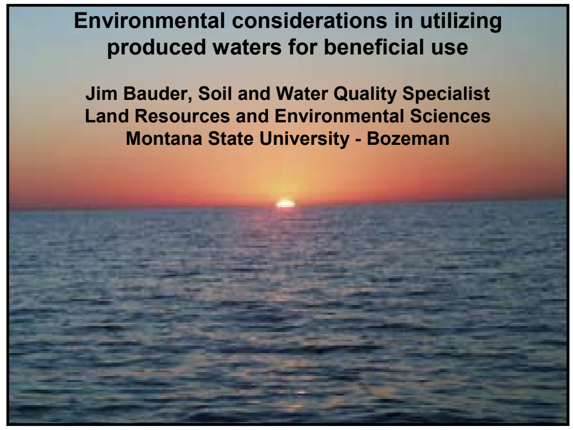
## Conclusion

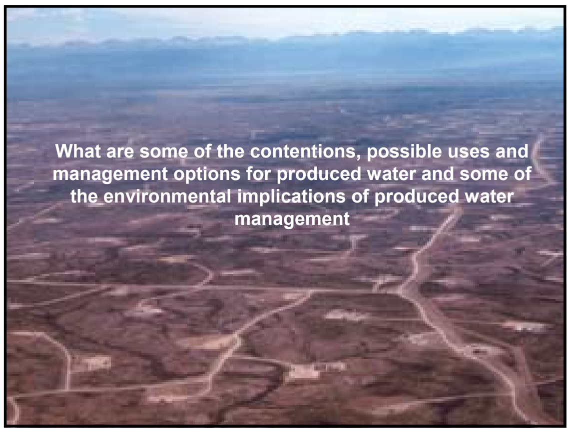
- Many factors affect the potential effluent limits applied to discharges of high saline wastes
- Site-specific factors have significant impacts and cause significant variability among effluent limits
- Costs to treat high saline wastes to meet effluent limits for discharge to surface waters may be prohibitive in some cases

# Jim Bauder

- Environmental Considerations in Utilizing Produced Waters for Beneficial Use

1





In the context of this presentation, I will be referring to produced water associated primarily with coalbed methane recovery – since most recent statistics on significant amounts of produced water are associated with coalbed methane production

4

My wife asked me, just before I left the house yesterday: "What are you talking about at this conference?" I told her – lemonade – which didn't make a lot of sense to her. She then told me not to tell any jokes that had anything to do with alcoholic beverages or bad water! But, I was thinking of something else at the time!

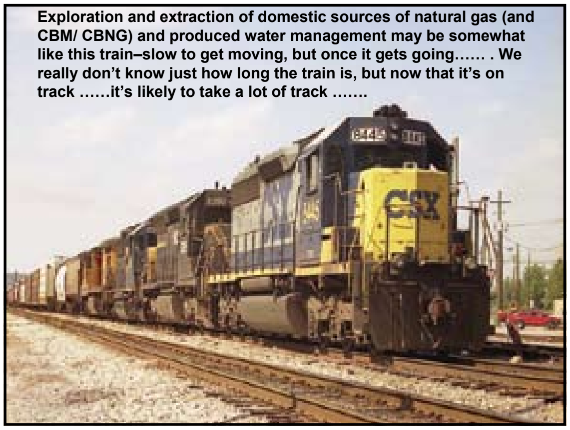

5

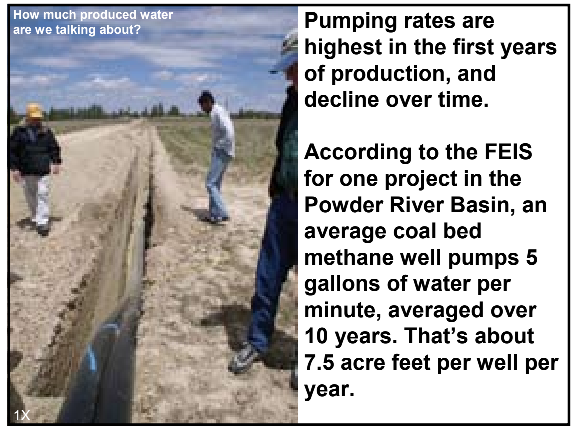
**What are some of the environmental considerations in utilizing produced waters for beneficial use**

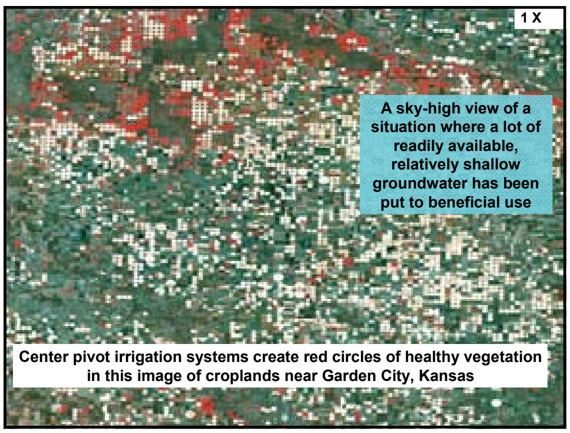
**The answer to that question is based on defining what constitutes beneficial use and the criteria you use to define which or whose environment.**
**There are a lot of venues to produced water management**

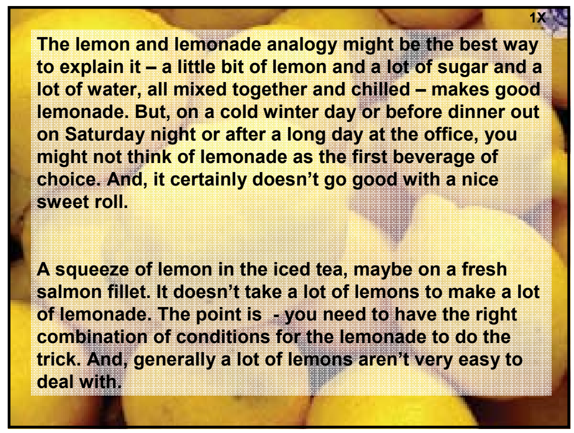
On-site natural resource manager's environment
Natural resource regulatory agency
Down-stream natural resource manager
Down-stream water user
Energy extraction industry
Down-stream aquatic environment
Economic environment
Mineral right owner's environment

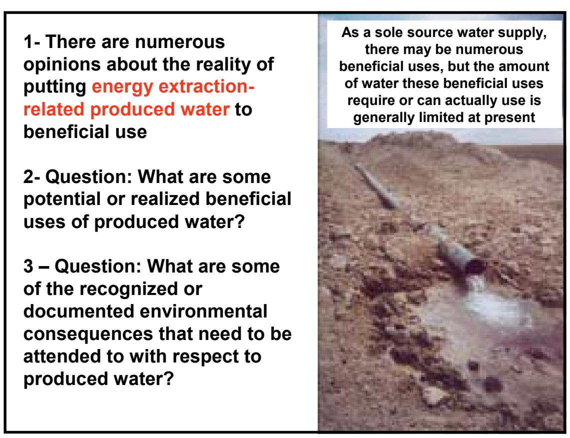
6


Exploration and extraction of domestic sources of natural gas (and CBM/ CBNG) and produced water management may be somewhat like this train–slow to get moving, but once it gets going…… . We really don't know just how long the train is, but now that it's on track ……it's likely to take a lot of track …….
CSX


How much produced water are we talking about?
Pumping rates are highest in the first years of production, and decline over time.
According to the FEIS for one project in the Powder River Basin, an average coal bed methane well pumps 5 gallons of water per minute, averaged over 10 years. That's about 7.5 acre feet per well per year.
1X

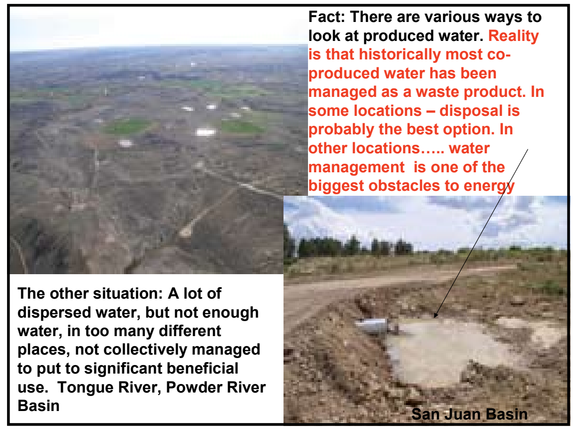

1 X
A sky-high view of a situation where a lot of readily available, relatively shallow groundwater has been put to beneficial use
Center pivot irrigation systems create red circles of healthy vegetation in this image of croplands near Garden City, Kansas


1X
The lemon and lemonade analogy might be the best way to explain it – a little bit of lemon and a lot of sugar and a lot of water, all mixed together and chilled – makes good lemonade. But, on a cold winter day or before dinner out on Saturday night or after a long day at the office, you might not think of lemonade as the first beverage of choice. And, it certainly doesn't go good with a nice sweet roll.
A squeeze of lemon in the iced tea, maybe on a fresh salmon fillet. It doesn't take a lot of lemons to make a lot of lemonade. The point is - you need to have the right combination of conditions for the lemonade to do the trick. And, generally a lot of lemons aren't very easy to deal with.

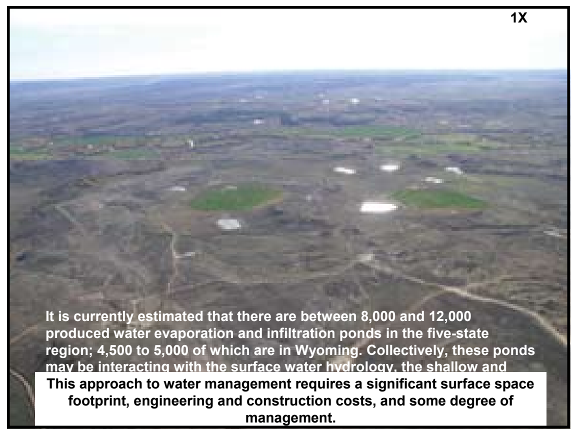

1- There are numerous opinions about the reality of putting energy extraction-related produced water to beneficial use
2- Question: What are some potential or realized beneficial uses of produced water?
3 – Question: What are some of the recognized or documented environmental consequences that need to be attended to with respect to produced water?
As a sole source water supply, there may be numerous beneficial uses, but the amount of water these beneficial uses require or can actually use is generally limited at present

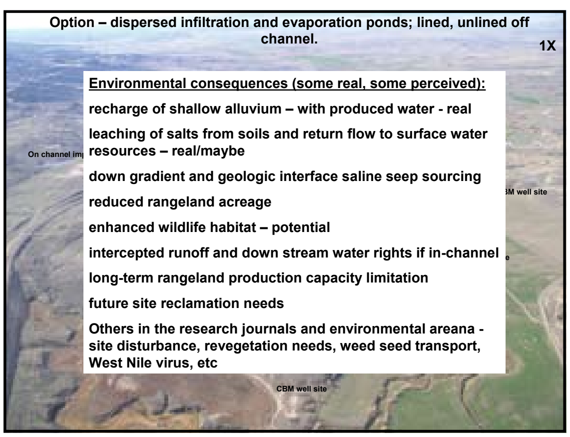

The point – produced water management won't work with 'one-size fits all'


1X
Number of Records by State in Reviewed Database
I wasn't sure about the cart and the horse, but this might answer a question about produced water.
Alaska = 60
Hawaii = 0
Offshore = 578
number of records in the produced water database listed for each state

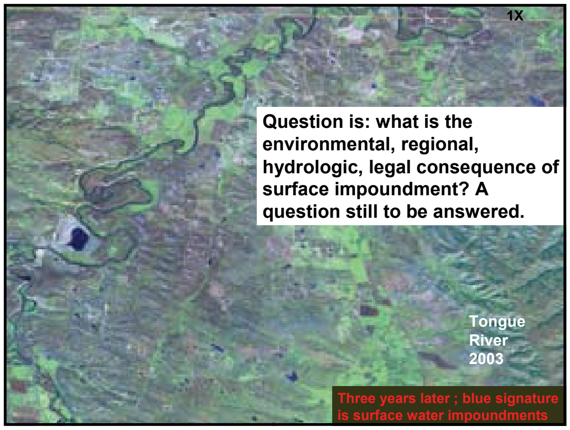

Fact: There are various ways to look at produced water. Reality is that historically most co-produced water has been managed as a waste product. In some locations – disposal is probably the best option. In other locations….. water management is one of the biggest obstacles to energy
The other situation: A lot of dispersed water, but not enough water, in too many different places, not collectively managed to put to significant beneficial use. Tongue River, Powder River Basin
San Juan Basin


In many locations water is either being managed on site or close to the site..
Option – infiltration pond, providing wetland/wildlife enhancement, ephemeral channel recharge


1X
It is currently estimated that there are between 8,000 and 12,000 produced water evaporation and infiltration ponds in the five-state region; 4,500 to 5,000 of which are in Wyoming. Collectively, these ponds may be interacting with the surface water hydrology, the shallow and
This approach to water management requires a significant surface space footprint, engineering and construction costs, and some degree of management.


Option – dispersed infiltration and evaporation ponds; lined, unlined off channel.
1X
Environmental consequences (some real, some perceived):
recharge of shallow alluvium – with produced water - real
leaching of salts from soils and return flow to surface water resources – real/maybe
down gradient and geologic interface saline seep sourcing
reduced rangeland acreage
enhanced wildlife habitat – potential
intercepted runoff and down stream water rights if in-channel
long-term rangeland production capacity limitation
future site reclamation needs
Others in the research journals and environmental areana - site disturbance, revegetation needs, weed seed transport, West Nile virus, etc
CBM well site


Tongue River 1999
Source: NPRC, Billings, MT



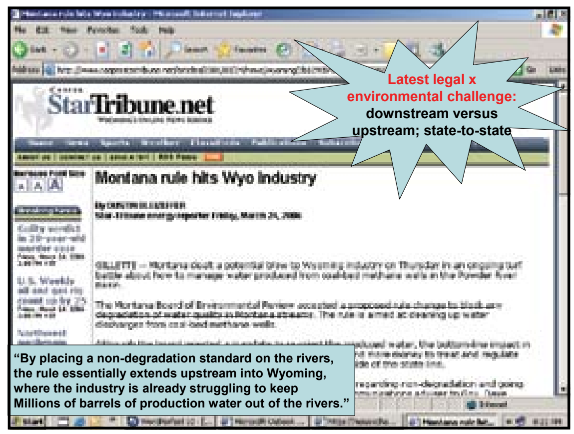


Judicial system is even confused about what water is appropriate for beneficial use or how produced water should be managed.

**Judge: coal bed methane discharges not pollutant under Clean Water Act. (Montana). Clean Water Report September, 2002 Judge dismisses suit, ruling that methane wastewater is not a pollutant under the Clean Water Act (CWA) and noting that even if it were a pollutant, Montana law exempts unaltered groundwater from permitting requirements.**

**Subsequently, the Ninth Circuit Court of Appeals ruled that "groundwater produced in association with methane gas extraction, and discharged into the river, is a pollutant" under CWA and that states cannot create exemptions.**

21




1X

Montana rule hits Wyo industry
By DUSTIN BLEIZEFFER
Star-Tribune energy reporter Friday, March 24, 2006

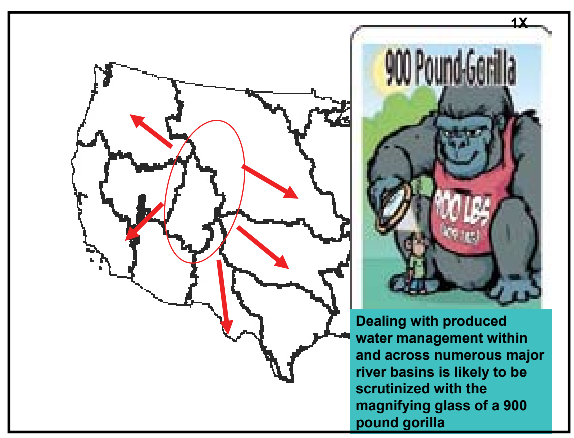
What else the media has to say about this issue

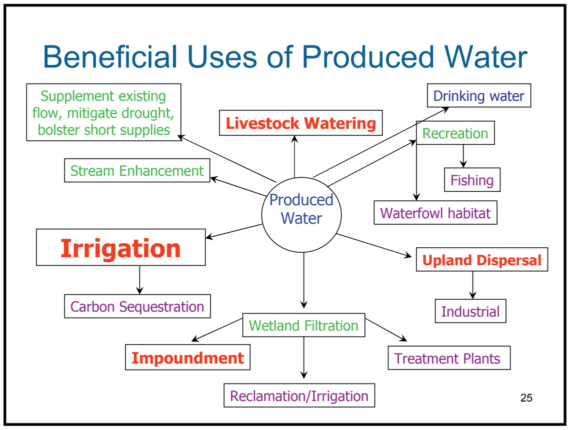
The WY-CBM industry is feeling pressure within Wyoming's borders, too. To keep the water out of the Montana-bound rivers, producers here are carving hundreds of new holding reservoirs and washing the water through upland ephemeral drainages. That has caused headaches for many ranchers here because the large number of reservoirs are cutting into their pastures, and the discharges are washing out their low-lying grazing lands.

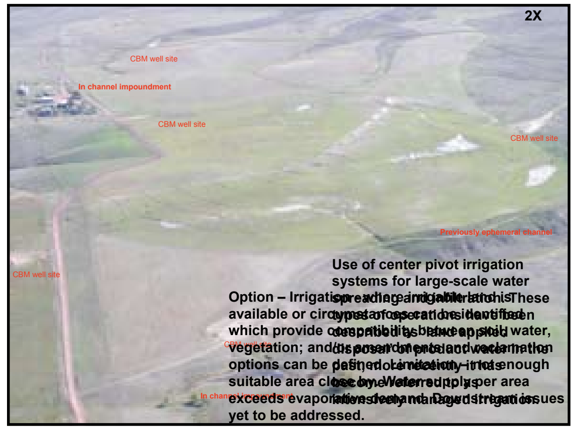
To fight those disp… ource Council and severa… state to require a measur… -bed methane water disp… Environmental Qua… rulemaking process… s

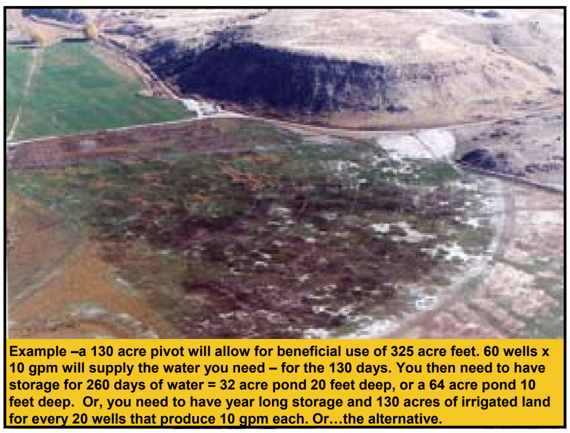
**The judicial and regulatory systems are also wondering about what constitutes beneficial use of produced water and how to deal with it.**

23

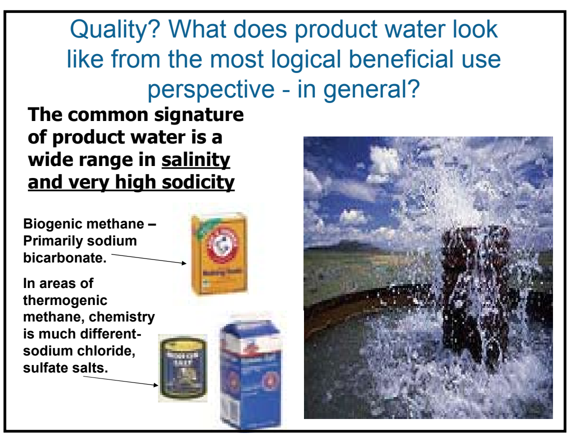



Beneficial Uses of Produced Water
Supplement existing flow, mitigate drought, bolster short supplies
Livestock Watering
Drinking water
Recreation
Fishing
Stream Enhancement
Produced Water
Waterfowl habitat
Irrigation
Upland Dispersal
Carbon Sequestration
Industrial
Wetland Filtration
Impoundment
Treatment Plants
Reclamation/Irrigation
25

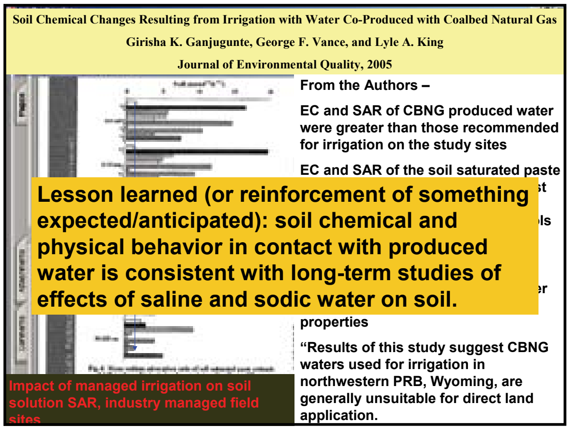

2X
CBM well site
In channel impoundment
CBM well site
CBM well site
Previously ephemeral channel
CBM well site
Use of center pivot irrigation systems for large-scale water spreading and infiltration. These types of operations have been described as "land applied" disposal of product water in the past; more recently it has become referred to as intensively managed irrigation.
Option – Irrigation, where irrigable land is available or circumstances can be identified which provide compatibility between soil, water, vegetation; and/or amendments and reclamation options can be defined. Limitation – not enough suitable area close by. Water supply per area exceeds evaporative demand. Downstream issues yet to be addressed.

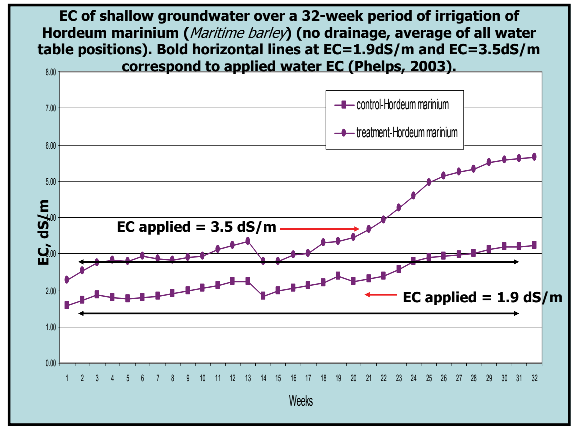

Example –a 130 acre pivot will allow for beneficial use of 325 acre feet. 60 wells x 10 gpm will supply the water you need – for the 130 days. You then need to have storage for 260 days of water = 32 acre pond 20 feet deep, or a 64 acre pond 10 feet deep. Or, you need to have year long storage and 130 acres of irrigated land for every 20 wells that produce 10 gpm each. Or…the alternative.


Irrigating with CBM product water
Limited water quality information exists for new energy development areas outside the PRB, e.g., in southern and southwestern Wyoming, in various locations in Colorado. The small amount of information available so far suggests that quality of produced water in at least some of these fields will be more impaired than CBM water in the PRB.
Most of the emerging data suggests that produced water needs to be mixed with better quality water if it is going to be used for sustainable irrigation.
I'm just the messenger

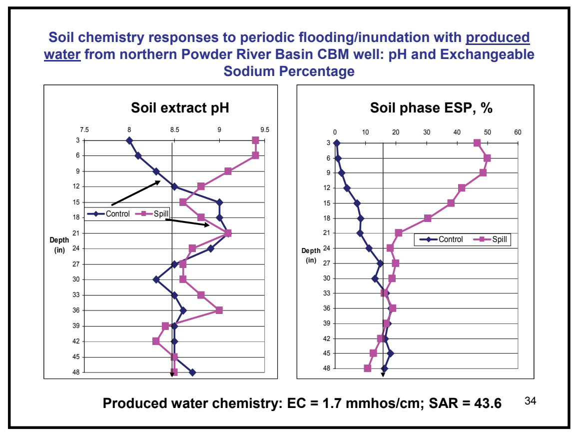

Quality? What does product water look like from the most logical beneficial use perspective - in general?
The common signature of product water is a wide range in salinity and very high sodicity
Biogenic methane – Primarily sodium bicarbonate.
In areas of thermogenic methane, chemistry is much different- sodium chloride, sulfate salts.

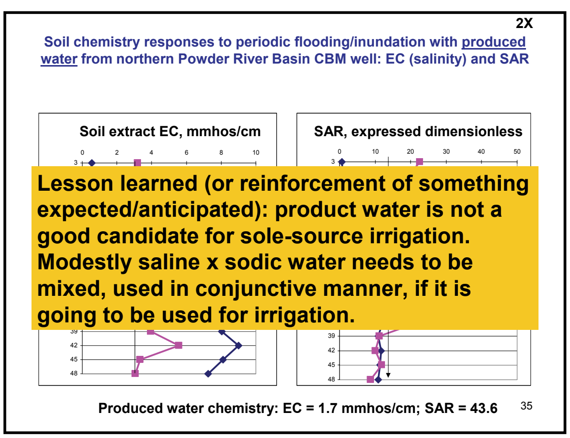

Irrigated solely with non-saline, non-sodic water comparable to Yellowstone River at Terry, MT
Irrigated solely with simulated CBM product water from northern portion of PRB basin


Soil Chemical Changes Resulting from Irrigation with Water Co-Produced with Coalbed Natural Gas
Girisha K. Ganjugunte, George F. Vance, and Lyle A. King
Journal of Environmental Quality, 2005
From the Authors –
EC and SAR of CBNG produced water were greater than those recommended for irrigation on the study sites
EC and SAR of the soil saturated paste
properties
"Results of this study suggest CBNG waters used for irrigation in northwestern PRB, Wyoming, are generally unsuitable for direct land application.
Lesson learned (or reinforcement of something expected/anticipated): soil chemical and physical behavior in contact with produced water is consistent with long-term studies of effects of saline and sodic water on soil.
Impact of managed irrigation on soil solution SAR, industry managed field sites


EC of shallow groundwater over a 32-week period of irrigation of Hordeum marinium (Maritime barley) (no drainage, average of all water table positions). Bold horizontal lines at EC=1.9dS/m and EC=3.5dS/m correspond to applied water EC (Phelps, 2003).
control-Hordeum marinium
treatment-Hordeum marinium
EC applied = 3.5 dS/m
EC applied = 1.9 dS/m
EC, dS/m
Weeks


Soil responses to accidental spills, intentional long-term discharges, ponding
Question - Long term discharge onto the landscape,ponding – what happens?


Soil chemistry responses to periodic flooding/inundation with produced water from northern Powder River Basin CBM well: pH and Exchangeable Sodium Percentage
Soil extract pH
Soil phase ESP, %
Control
Spill
Depth (in)
Produced water chemistry: EC = 1.7 mmhos/cm; SAR = 43.6
34


2X
Soil chemistry responses to periodic flooding/inundation with produced water from northern Powder River Basin CBM well: EC (salinity) and SAR
Soil extract EC, mmhos/cm
SAR, expressed dimensionless
Lesson learned (or reinforcement of something expected/anticipated): product water is not a good candidate for sole-source irrigation. Modestly saline x sodic water needs to be mixed, used in conjunctive manner, if it is going to be used for irrigation.
Produced water chemistry: EC = 1.7 mmhos/cm; SAR = 43.6
35


Lesson Learned
+
+
=
Source: NPRC, Billings, MT

Potential for stream augmentation and discharge during low flow periods; augmenting flow for down-stream irrigation

Tongue River overlook, Circle 3 Ranch, Birney, MT.

1X

**Chemical Changes in Coal Bed Methane Product Water Over Time**

Some things about certain produced water are reasonably predictable – only to be validated by investigation and research.

For example – one would predict that when sodium bicarbonate-rich product water is discharged to an ephemeral stream

- the salt concentration of the water will increase
- the soluble calcium concentration will decrease, and
- the SAR will increase.

$Ca(HCO_3)_2 \rightarrow CaCO_3^+$ (calcite or limestone) + $H_2O$ + $CO_2$

SAR = Na+ / √ (Ca2+ + Mg2+) / 2

What that translates to is: the chemistry of product water between the point of discharge and the site of irrigation needs to be monitored. Considerations for in-stream changes to the chemistry of product water (mainly pH, EC, and SAR) need to be made when defining the beneficial use of produced water.

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**Change in water chemistry for three water qualities over a 9 day time period (subject to evapoconcentration).**

| | Initial vs. Final pH | Initial vs. Final EC (dS/m) | Initial vs. Final SAR | % Change EC | % Change SAR | % Change pH |
|---|---|---|---|---|---|---|
| Powder River | 7.4 / 8.1 | 3.07 / 3.75 | 3.7 / 4.4 | 22.15 | 18.92 | 9.5 |
| CBM | 7.7 / 8.4 | 3.36 / 4.01 | 12.5 / 18.0 | 19.35 | 44.00 | 9.1 |
| Saline-sodic CBM | 7.5 / 9.1 | 5.42 / 6.71 | 20.7 / 33.8 | 23.80 | 63.29 | 21.3 |
| | | | Average % Change: | 21.77 | 42.07 | 13.3 |

39

**CHEMISTRY OF COALBED METHANE DISCHARGE WATER INTERACTING WITH SEMI-ARID EPHEMERAL STREAM CHANNELS**

Journal of the American Water Resources Association, Oct 2004 by Patz, Marji J, Reddy, Katta J, Skinner, Quentin D

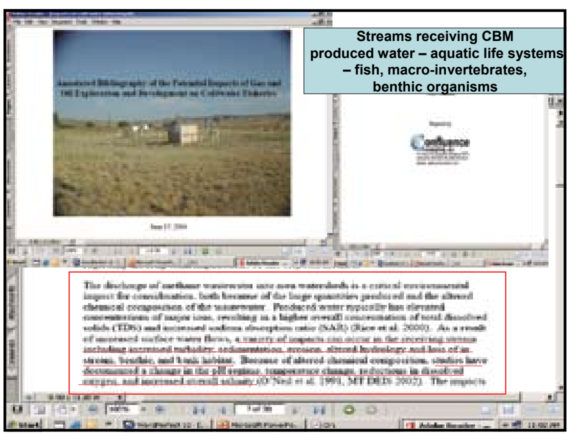
Water source: produced water from CBM wells in Wyoming
Location: Powder River Basin, Wyoming
Situation: water discharged to ephemeral stream

Outcome: pH (basicity) of CBM discharge water increased significantly (from 7.1 to 8.84) in the downstream channel of before the produced water joined the river.

Outcome: Dissolved calcium concentration of CBM discharge water decreased significantly in the downstream channel water.

Outcome: SARp increased approximately from 24 to 29; the SARt also increased significantly in the downstream channel water.

40



Streams receiving CBM produced water – aquatic life systems – fish, macro-invertebrates, benthic organisms

1X

Powder River biological survey and implications for coalbed methane development. 2004. Confluence Consulting, Bozeman, MT

**Lesson learned: product water is not a good candidate for large contribution stream flow augmentation, without the expectation of some measurable impacts on the aquatic environment.**

were in excess of historic values in U.S.G.S. database for the receiving stream

→ reduction in some fish species – population numbers and diversity – down gradient of the point of discharge

→ enhanced encroachment of tamarisk, a salt tolerant, introduced and invasive shrub, down gradient of the point of discharge

42

Potential ground-water drawdown and recovery from coalbed methane development in the Powder River Basin, Montana. 2002. Wheaton, J., and J. M. Metesh. Montana Bureau of Mines and Geology, Open-File Report 458

A modeling assessment of cumulative CBM water production and responsiveness of the Anderson, Canyon and Wall coals in southeastern MT.

→ drawdown (lowering) of the potentiometric head (artesian pressure) was predictable; ranging from 220 to 550 feet within the field of active CBM recovery

→ drawdowns exceeding 10 feet were projected to extend to a range of 5 to 10 miles outside the CBM development/recovery field

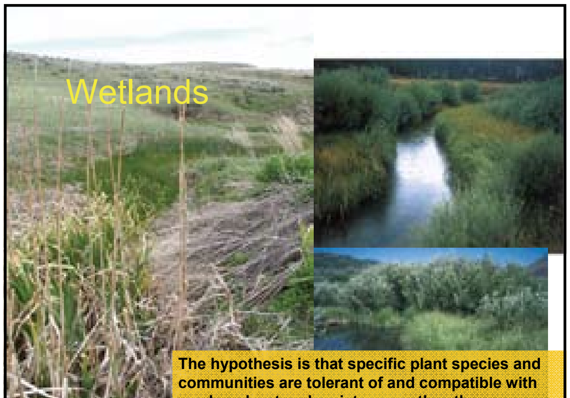
43

Potential ground-water drawdown and recovery from coalbed methane development in the Powder River Basin, Montana. 2002. Wheaton, J., and J. M. Metesh. Montana Bureau of Mines and Geology, Open-File Report 458

**Lesson learned: withdrawals of large volumes of produced are likely to have measurable impact on the local groundwater hydrology; this impact may possibly translate to alterations in surface water hydrology.**

→ relative to fisheries, CBM production may lead to reduced stream base flow during and following CBM production

44




The hypothesis is that specific plant species and communities are tolerant of and compatible with produced water chemistry – are they the communities you seek to enhance?

Native species have established hydrologically distinct communities in ephemeral channels now running with produced water

WILDCAT CREEK
CAMPBELL COUNTY WYO

- With addition of produced water these plants will invade/occupy moist to wet zones of the channel bank
- Inland saltgrass (Distichlis spicata)
- Prairie and alkali cordgrass (Spatina pectinata/gracilis)
- Baltic rush (Juncus balticus)
- Nuttalls alkaligrass (Pucinellia nuttalliana – not very competitive, colonizer)
- Foxtail barley (Hordium jubatum – not very competitive, colonizer)

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**The water issue – and a brief look at some of the real and potential or perceived environmental consequences**

- Many 'small' amounts of water in many different places
- Too dispersed to easily manage collectively
- Debatable suitability of quality to be used exclusively as a sole source water supply
- Uncertainties of longer-term availability and consequences of long-term use on site
- Questionable short and long-term cumulative impacts – to existing water resources and to down stream water rights holders, down stream water users

47

…. Strongly held disagreements and difficulties about CBM development, and water management specifically, have grown to the point that continued growth in CBM production may be under some threat.

Cumulative CBM water production from 1987 through December 2004 in the PRB is estimated at 380,000 acre … pres… 75,0…

The … sinc … the a… Lake DeSmet or one-half the annual storage of Buffalo Bill Reservoir (both in WY).

If one were to assume that all the CBM produced water in Wyoming could be blended with the combined storage of Lake DeSmet, Buffalo Bill Reservoir, and Glendo Reservoir,

1X

the co-produced water volume would constitute only 1.4% of the aggregate storage of these three … ed … ual storage capacity of these three water bodies.

**One example of produced water management option – it's really not that many lemons, when you put it into perspective. It's just a matter of how you squeeze and mix the lemons with the sugar and water – or whether the water can be managed collectively.**

*I'm just the messenger*

Ruckelshaus Institute of Environment and Natural Resources, UWYO, December, 2005

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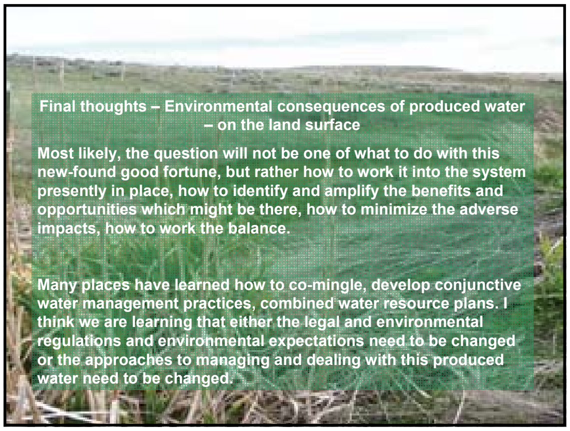




**Thank you**

**Jim Bauder**

**Montana State University**

http://waterquality.montana.edu

Now, about that train…..

51

## Paul Beels

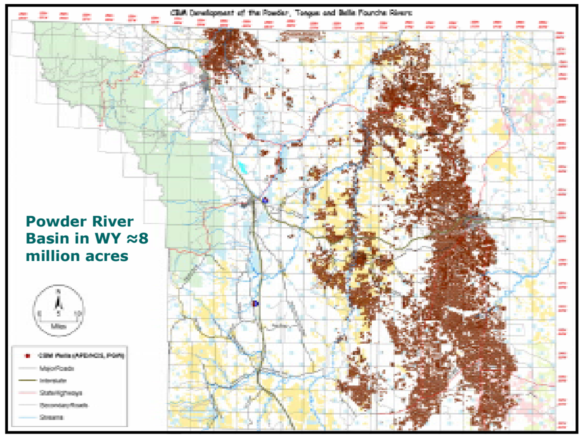
- Panel of state and federal agency representatives
- Can Coordination of Federal agencies with State and Local agencies help make produced water lemons into lemonade?

## Interagency Working Group
Powder River Basin
Wyoming

**The IWG is a product of a commitment made in the:**

- Powder River Basin Oil and Gas Project EIS (Wyoming) and
- Statewide Oil and Gas EIS (Montana)

Both EIS's approved in April 2003.




## Perspective

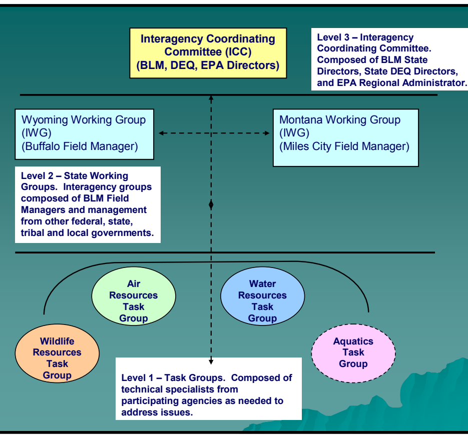
Wyoming EIS analyzed and disclosed the environmental impacts of drilling 51,000 CBNG wells over a 10 year period.

- 15,000 CBNG wells in production
- Since 2001, average of 50,000 ac/ft of water produced each year.
- Storage capacity of Horsetooth Reservoir – 116,000 ac/ft

Excerpts from WY PRB EIS
Record of Decision

"Information gathered from this monitoring will guide mid- course corrections in adapting to the inevitable changes that will occur because of new information. A monitoring program has been outlined and will be further developed and implemented in accordance with the guidelines provided in Appendix D."

"The Interagency Working Group will function as oversight for the monitoring adopted for the PRB to assure that the decisions and required measures are carried out; to inform cooperating agencies on progress in carrying out mitigation measures; and to make available to the public the results of relevant monitoring."




- ❖ An MOU and a Charter were developed to help guide the group.
- ❖ A number of agencies are involved Federal, State, counties and tribes. There are 24 signatories.
- ❖ Public entities are not a part of the group but may attend meetings.

## Coordinating Committee (Level III)

- ❖ Brief on activity and issues at least once a year.
- ❖ Are to resolve any impasses that may occur at lower levels.

## IWG (level 2) Activity

Met Five Times

- ✓ 6/03/03
- ✓ 9/17/03
- ✓ 2/18/04
- ✓ 6/16/04
- ✓ 6/1/05

## http://www.wy.blm.gov/bfo/prbgroup/index.htm

BUFFALO FIELD OFFICE
Powder River Basin
Interagency Working Group
Bureau of Land Management Wyoming

*Updated January 18, 2005*

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**Members**
**Charter & MOU**
**Meeting Schedule**
**Meeting Minutes**
**Monitoring Reports**
**Links**

*Meeting Minutes updated 01/18/05*

**The Powder River Basin** (PRB) contains millions of acres of public land in northeastern Wyoming and southeastern Montana. The Basin holds an extensive natural gas resource associated with the regional coal deposits.

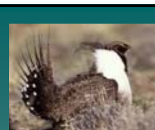
Development of coalbed natural gas (CBNG) on federal lands requires a lease issued from the Bureau of Land Management (BLM) and approval of an application for permit to drill along with associated permits, approvals or reviews from the Montana Department of Environmental Quality or the Wyoming Department of Environmental Quality, and from other State and Federal agencies.

The PRB Interagency Working Group (PRB IWG) was established as the forum for government agencies to address and discuss issues of common concern to all parties involved in permitting and monitoring of CBNG development. Additionally, attention will be given to those issues that may result in cross-border effects requiring close coordination among the State and Federal agencies in Montana and Wyoming, and

## Task Group (level 1) Activity

- **Met numerous times**
  - **Highest priority task was to develop more specific monitoring plans**
  - **Monitoring plans have been completed**
  - **Implementation beginning**

## Wildlife



- Have completed comprehensive monitoring plan comprised of three components:
  - Basin scale (EIS required) monitoring
    - Emphasis of taskforce
  - Project scale monitoring (compliance)
    - Individual PODs
  - Ongoing research and needs

## Wildlife cont.

| Task | Project | Basin | Responsible Party | Cost Estimate | Status | Priority |
|---|---|---|---|---|---|---|
| Landcover change (sagebrush) | X | 2 yrs (change detection) | BLM USDAFS | $15,000 | New | High MT (1) |
| Sage grouse winter use | X | 3 yrs | F&G BLM USDAFS | $30,000 | New | High MT (2) |
| Mountain plover nesting | X | 5 yrs (control) | BLM USDAFS | $15,000 | Scheduled 2004 | High MT (3) |
| Herp. Trend | X | 5 yrs | BLM USDAFS | $15,000 | Partial current | High MT (4) |
| Migratory Bird Trend | | 5 yrs | BLM USDAFS USFWS | $65,000 | Partial current | High MT (5) |
| Small Mammal Trend | | 5 yrs | BLM USDAFS | $25,000 | New | High MT (6) |
| Total | | | | $165,000 | | |

## Wildlife cont.

| Task | Project | Basin | Responsible Party | Cost Estimate | Status | Priority |
|---|---|---|---|---|---|---|
| Landcover (sagebrush) change | X | 2 yrs (change detection) | BLM USDAFS | $15,000 | New | High WY (1) |
| Migratory Bird Trend | | 5 yrs | BLM USDAFS USFWS | $65,000 | Partial current | High WY (2) |
| Small Mammal Trend | | 5 yrs | BLM USDAFS | $25,000 | New | High WY (3) |
| Ute ladies'-tresses habitat | X | Baseline needed | BLM USDAFS | $20,000 | New | High WY (4) |
| Herp. Trend | X | 5 yrs | BLM USDAFS | $15,000 | Partial current | High WY (5) |
| Sage grouse winter use | X | 3 yrs | F&G BLM USDAFS | $30,000 | New | High WY (6) |
| Total | | | | $170,000 | | |

## Air

Tasks–

1. Assessment of Existing Monitoring

- Specific monitoring information from each member has been assembled. NPS, DEQs, EPA, BLM, Tribes.
- Maps of the existing and historic monitor locations have been completed.

## Air cont.

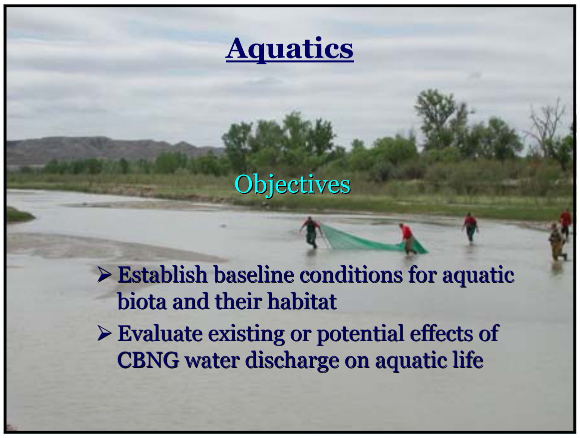
2. Discussion of additional monitoring needs.
3. Assembled a complete Monitoring Plan including: Maps, Monitor Information Monitoring Costs, General recommendations and annual report output.

## Monitored Pollutants:

- Nitrogen oxides (NOx)
- PM2.5
- PM10
- Ozone (O3)
- SO2

## Meteorological Data:

- Temperature
- Anemometer
- Relative humidity
- Precipitation gauge




## Monitoring Plan

consists of four primary subsections:

- Aquatic Habitat
- Riparian Habitat
- Fish
- Macroinvertebrates

- WY Game and Fish Department began fisheries and aquatic habitat work in 2004.
- USGS jumped in last year doing macroinvertebrate and riparian habitat mapping.
- Interpretive report scheduled to be produced next winter.
- Will re-evaluate in two years next steps.

## Monitoring Plan Cont.

- 41 total sites
  - Rosebud Creek (MT): 3 sites
  - Tongue River (MT & WY): 9 MT/3WY
  - Powder River (MT & WY): 4MT/14WY
  - Cheyenne River (Wyoming): 6 sites
  - Belle Fourche (Wyoming): 2 sites

Each of the subsection components would be assessed at each site.

Estimated Cost
FY 05 - Total: $413,700
FY 06 - Total: $192,500

## Research

Three subsections

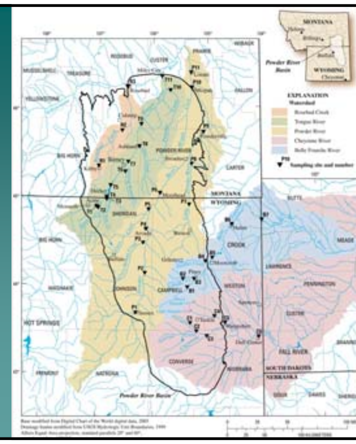
1. Literature review and study plan to assess the effects of CBNG activities on fish assemblages.
2. Development of a prairie fish index of biotic integrity for streams in MT and WY.
3. Impacts to amphibians and reptiles

## Water

- Primary focus has been on surface water monitoring.
- Network of 36 monitoring stations in both WY and MT collecting stream flow and water quality.
- Total cost to implement $1.2 million
- Past 2 years only funded at 65%.

---

- Also monitoring a series of deep groundwater wells. BLM has 122 in place around the basin in WY and there are also some in MT.
- There is also shallow ground water monitoring occurring throughout the basin in relation to impoundments.
- Protocol for “Compliance Monitoring for GW Protection Beneath unlined CBM Produced Water Impoundments”.

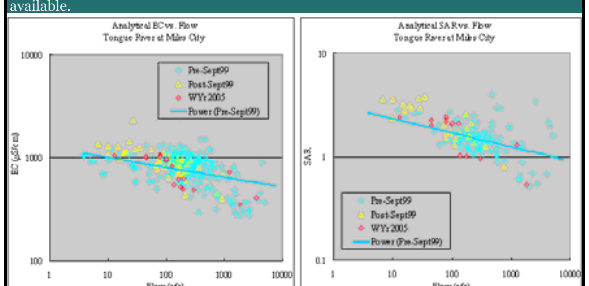


## Sampling Strategy

| Stream Type | Sampling Frequency | Constituent Class |
|---|---|---|
| Mainstem | Continuous | Stream flow |
| | 12 times per year | Field measurements |
| | 12 times per year | Major ions |
| | 2 times per year | Nutrients |
| | 12 times per year | Trace elements, primary |
| | 2 times per year | Trace elements, secondary |
| | 12 times per year | Suspended Sediment |
| Tributary | Continuous | Stream flow |
| | 6 times per year | Field measurements |
| | 6 times per year | Major ions |
| | 2 times per year | Nutrients |
| | 6 times per year | Trace elements, primary |
| | 2 times per year | Trace elements, secondary |
| | 6 times per year | Suspended Sediment |

## Results

The salinity (as measured by EC) and sodium adsorption ratio (SAR) are anticipated to be the constituents most likely to be altered by CBNG discharges. To date, noticeable increases in these parameters have not been observed. More detailed interpretations are available.



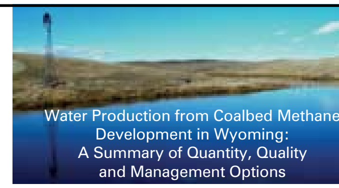

http://www.mt.blm.gov/mcfo/cbng/CBNG-Monitoring.htm
http://tonguerivermonitoring.cr.usgs.gov/2004waterqualitysummary.htm

## What Works and What Doesn't

1. Complexities of multiple agency coordination
   - No control over accountability
   - Many task members already with full work load.
2. Difficulty in securing funding
   - Differing agency budget cycles
   - Arduous to secure outside funding sources
   - Positive when presented as collaborative
3. FACA issue
   - Charter approved by the Secretary
   - Makes meetings more cumbersome
4. All in all, has worked surprisingly well

# Harold Bergman

- Opening remarks; Can coordination of Federal agencies with State and Local agencies help make produced water lemons into lemonade?




www.uwyo.edu/enr

Prepared by

The Ruckelshaus Institute of Environment and Natural Resources
With contributions from

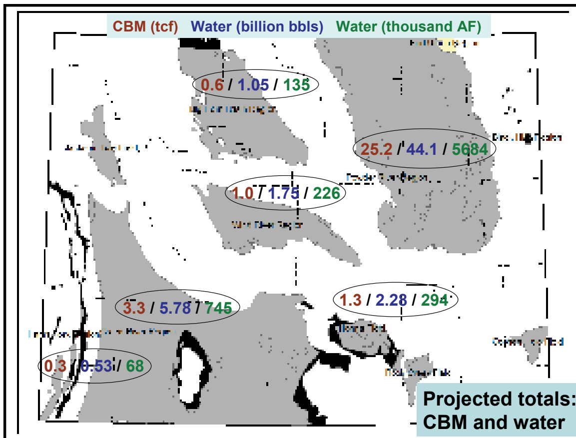
Faculty, Staff, and Students at The University of Wyoming

December, 2005

UNIVERSITY OF WYOMING

## CBM Gas & Water Production

| | Gas (tcf) | Water (million bbls) |
|---|---|---|
| **Cumulative** | **1.5** | **2,802** |
| **Projected** | **31.7** | **55,475** |
| **Percent Produced** | **5%** | **5%?** |



## John Boysen

- Case study: Sweet Lemonade and Sour Lemons…Lessons Learned? (New Mexico)

## Field Application of the Freeze-Thaw/Evaporation (FTE®) Process for Produced Water Treatment, Disposal and Beneficial Use – Case Studies

John Boysen – BC Technologies, ltd.
715 Grand Ave., Laramie, WY 82070
(307) 742-5651

## Acknowledgements

- Original research in the freeze/thaw process development conducted by Dr. Donald Stinson - Department Head of Chemical and Petroleum Engineering, University of Wyoming.

- Process Development Sponsored by:
  - UND-EERC
  - GRI (now GTI)
  - USDOE
  - Amoco Production Company (now BP)
  - McMurry Oil Company (now Encana, USA)

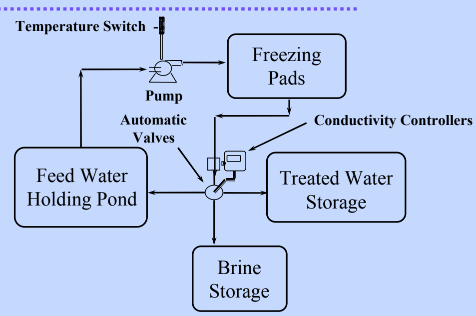
## The FTE® Process - Conceptually Simple

- Salts or other constituents that are dissolved in water lower the freezing point of the solution below 32 °F.
- Partial freezing occurs when the solution is cooled below 32 °F, but not below the depressed freezing point of the solution.
- Relatively pure ice crystals form, and an unfrozen solution (brine), containing elevated concentrations of the dissolved constituents, drains from the ice.

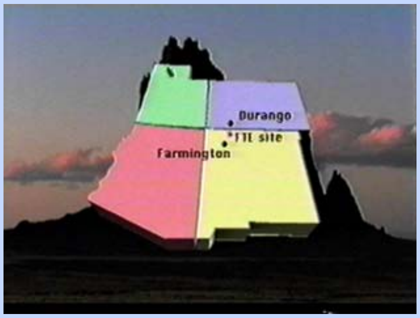
## The FTE® Process

- Coupling this freeze / thaw cycling with conventional evaporative technology allows treatment / disposal on a year round basis.

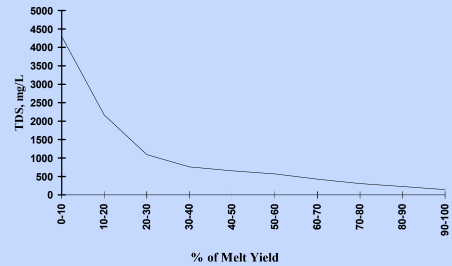
## Block Flow Diagram of the FTE® Process



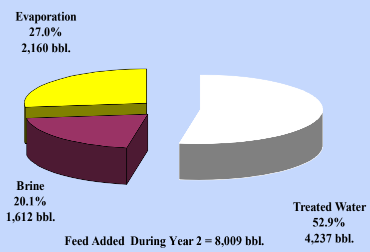
## Case Studies of FTE® Field Performance
## San Juan Basin, New Mexico 1996-1997




## Case Studies of FTE® Field Performance
## San Juan Basin, New Mexico 1996-1997
### TDS of Treated Water vs % of Melt Yield



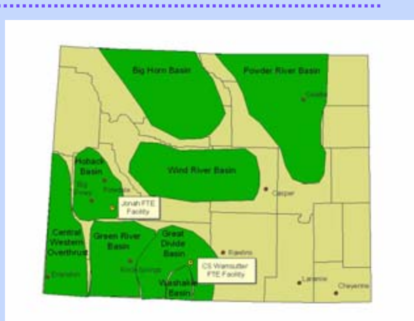

## Case Studies of FTE® Field Performance
## San Juan Basin, New Mexico 1996-1997
### Product Yield



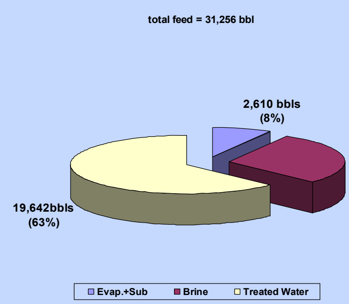

## Case Studies of FTE® Field Performance
## San Juan Basin, New Mexico 1996-1997
### Product Quality

| | Feed | Treated Water | Brine |
|---|---|---|---|
| TDS, mg/L | 12,800 | 1,010 | 44,900 |
| EC, µS | 16,200 | 1,670 | 45,700 |
| Total Alkalinity ($CaCO_3$), mg/L | 9,380 | 700 | 35,550 |
| % of Feed | - | 52.9 | 20.1 |

## Case Studies of FTE® Field Performance
## Jonah Field, Wyoming 1998-present




## Case Studies of FTE® Field Performance
## Jonah Field, Wyoming 1998-present
### 2000-2001 Winter FTE® Product Yield Summary



## Case Studies of FTE® Field Performance
## Jonah Field, Wyoming 1998-present

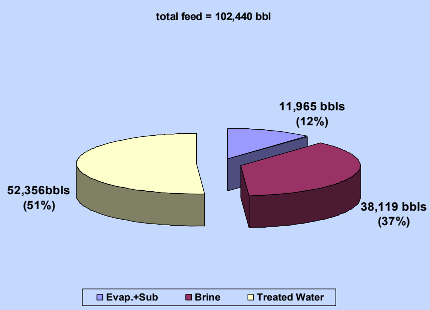
2000-2001 Winter FTE® Product Quality

| | bbl | TDS, mg/L | TPH, mg/L |
|---|---|---|---|
| Feed | 31,256 | 9,750 | 11 |
| Brine | 9,004 | 48,800 | 4.9 |
| Treated Water | 19,642 | 589 | 4.2 |
| Sub. + Evap. | 2,610 | | |

## Case Studies of FTE® Field Performance
## Wamsutter, Wyoming 1999-present


## Case Studies of FTE® Field Performance
## Wamsutter, Wyoming 1999-present

2001-2002 Winter FTE® Product Yield Summary



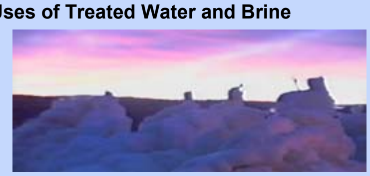

## Case Studies of FTE® Field Performance
## Wamsutter, Wyoming 1999-present

2001-2002 Winter FTE® Product Quality

| | bbl | TDS, mg/L | TPH, mg/L |
|---|---|---|---|
| Feed | 102,440 | 9,790 | 39.1 |
| Brine | 38,119 | 44,900 | 63.2 |
| Treated Water | 52,356 | 1,000 | 3.1 |
| Sub. + Evap. | 11,965 | | |

## Benefits of the FTE® Process

- Reduced Produced Water Management Costs
- Extend Injection Well Performance
- Extend Production in Economically Marginal Fields
- Expansion of Non-Conventional Resources (CBM)
- Beneficial Uses of Treated Water and Brine Products



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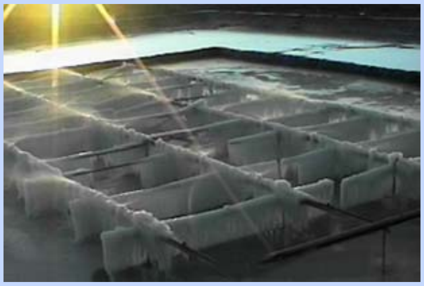

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## Wamsutter, Wyoming 1999-present

## Gary Bryner

- Energy outlook in the West relative to extractive industries and disposition of produced waters

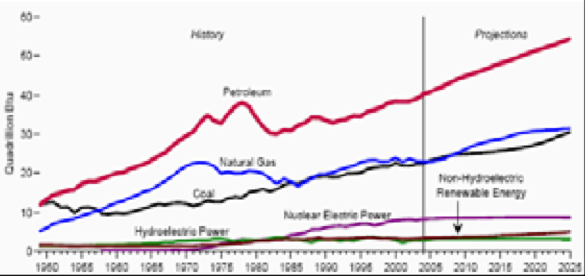
## Energy Outlook in the West: Extractive Industries and the Disposition of Produced Waters

Produced Waters Workshop
April 4-5, 2006

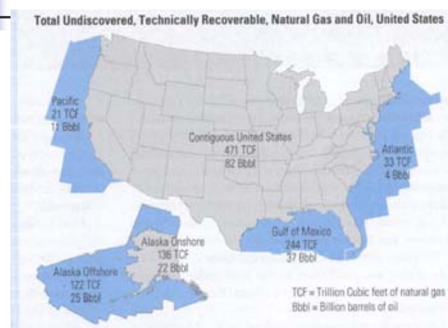
Gary Bryner
Natural Resources Law Center, University of Colorado School of Law
Public Policy Program, Brigham Young University

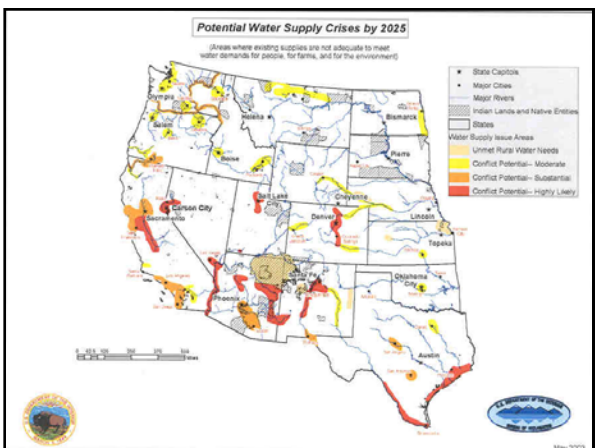
## The growing pressure to expand energy production in the Western United States

**U.S. Energy Consumption History and Outlook,1949-2025**

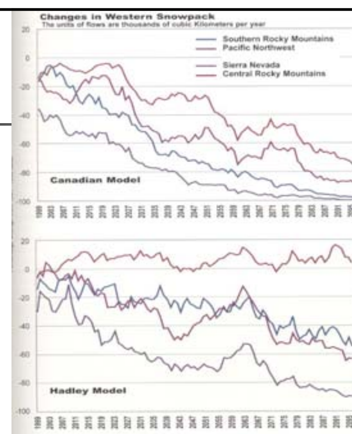



## How much of the recoverable oil and gas are under protected lands?




What will be the impacts of climate change on Western water supplies?



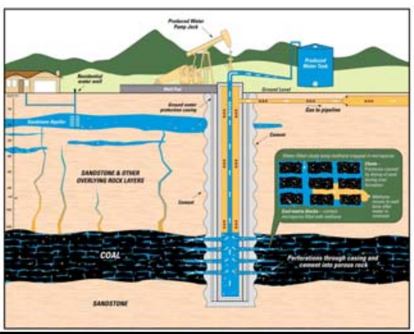
## CBM is a key energy and economic resource in the West

- Natural gas provides 24% of the nation's energy and represents 27% of its domestic energy production
- The US produces 85% of the gas it uses and imports the rest from Canada
- The US uses about 23 trillion cubic feet annually and demand is growing about 1 T/yr; intensified production is required to meet demand
- Coalbed Methane accounts for 7% of total natural gas production and 8% of gas reserves

## Managing the rapid pace of CBM development is daunting

- Drilling of CBM wells is completed much more quickly, sometimes within a matter of hours or days, than conventional drilling
- Landowners and communities may be unprepared to deal with construction, noise, produced water, air pollution, traffic, demands on services
- Impact fees, tax revenues, and royalties help communities cope with development, but they come after impacts and costs are incurred

## CBM development is designed to avoid contamination of water supplies



## Average Water Production from CBM Wells, gal./well/day

- Powder River 16,800
- Raton 11,172
- San Juan 1,050
- Uinta 9,030
- San Juan Basin: 1,200 wells have produced 36 billion gallons of water
- Wyoming portion of the Powder River Basin: in the next 15 years, approximately 51,000 wells will have produced over 1.4 trillion gallons of water.

## Options for managing produced water include the following (costs generally increase as one moves down the list):

- Traditional surface discharge: water is allowed to travel downstream and be absorbed or evaporate as it moves;
- Irrigation: water released to agricultural areas;
- Treatment: water is treated to improve quality;
- Containment with reservoirs: water is piped to a surface impoundment where it is absorbed or evaporates, or may be used to water cattle;
- Atomization: water evaporates more quickly than normal through the use of misters placed in surface impoundments;
- Shallow injection or aquifer recharge: water is pumped into freshwater aquifers;
- Deep injection: salty water is typically re-injected.

## CBM-produced water is dealt with differently across the major basins

- San Juan: 99.9% of produced water is re-injected
- 3% Uinta: 97% re-injected, evaporation
- Powder River: 99.9% surface discharge
- Raton Basin
  - Colorado: 70% surface, 28% re-injected
  - New Mexico: 100% injected

## Conflicts between Landowners and Companies

- Great variety in company practices concerning surface use agreements and consultation with split estate land owners
- Differences in well density: from 1 well/640 acres to 1/40
- Differences in drilling techniques
- Impacts from development on adjacent lands
- Impact on land values
- Disputes over location and extent of infrastructure
- Remediation, bonding
- Rule of Accommodation vs primacy of mineral rights

## Different Approaches to Regulating CBM and Produced Water:

- Wyoming
  - CBM produced water is defined as a beneficial use
    - Applications for withdrawal granted as a matter of purpose; can deny if not in the public interest
    - 2006: PRBC Petition to require produced water be put to measurable beneficial use
    - State district court, 2006: water not discharged into natural watercourse, so surface owner has more control over it
  - CBM Permits take 3-6 months to process
  - 2005: Split Estates Act to give surface owners more rights
    - BLM studying the issue; does it apply to federal minerals?

- Montana
  - Board of Environmental Review decided not to require industry to re-inject produced water but to require no degradation of stream water quality
  - Environmental council is studying split estate issue
  - CBM permits take up to 2 years to process
    - Montana moratorium on CBM development

- Colorado
  - CBM produced water is considered exploration and production waste
    - No beneficial use is required, no withdrawal permit is required
    - Permit is required for disposal
    - Surface owners can use water and get beneficial use permit Colorado
  - Considering split estates bill

## Some Principles and Processes for Addressing CBM Challenges:

- Ecologically sustainable development that balances extraction and other values and balances concerns of current and future generations
- 4 Cs: communication, cooperation, consultation, for conservation; Enlibra-balance, stewardship; consensus-based decision making
- Integrated planning and adaptive management
- Ensure prices reflect more of the costs of producing gas
  - Compensation to surface landowners for impacts
  - Ensure reclamation through bonding, funds from lease revenues, and effective standards
- National environmental standards to be pursued in light of local conditions
- Clarify legal ownership of produced water and ensure beneficial use

## Need a strong commitment to make consensus-based problem solving work

- Focus on a limited set of problems
- Provide community stakeholders with technical and other resources so they can participate effectively
- Secure strong leadership
- Ensure participation by all industries
- Promote compliance with environmental standards
- Reduce threat of litigation
- Create incentives for implementation

## Problem-solving workshops

- Workshops in each CBM basin to produce recommendations and guidelines
  - Best management practices to minimize impacts
  - Water management, ensure beneficial use
  - Company-landowner relations, dispute resolution; Ensure surface owners are involved in decisions concerning the discharge of water onto their lands
  - Aggregate experience and lessons
- Ecosystem or watershed planning to develop water management plans and integrate CBM with other land use decisions
  - Produce accurate baselines for water quality and quantity
  - Review compliance with testing and monitoring requirements and regularly assess requirements Coordinate CBM permitting with other regulatory decisions

## Need to solve immediate problems and also explore ecologically sustainable energy production

How to encourage more conservation and efficient use of natural gas to conserve resources and reduce pressure for development?

How do costs and benefits of CBM development compare with other forms of energy production? What mix of fossil fuel and renewable energy production is most sustainable for communities?

## Dave Burnett

- Case study: Sweet Lemonade and Sour Lemons…Lessons Learned? (Texas)

## *Two Desalination Projects: Providing Fresh Water For Municipal Use*

- *Study 1: Desalination of Brackish Groundwater: Use of RO Concentrate in* ***Oil Field Water Flood***
- *Study 2:* ***Desalination of Oil Field Brine*** *to Supply Municipal Water Needs*

David B. Burnett
Texas A&M Desalination Team; Texas A&M University
979 845 2274
http://www.gpri.org burnett@pe.tamu.edu

## *Study 1. The City of Andrews Partnership*

- *Background*
  - *Ogallala aquifer supplies 100% of county's needs. Less than 20 years water supply remaining.*
  - *The Dockum BGW aquifer underlies the county and represents a readily available source of treatable water.*
- *Project*
  - *Perform a demonstration project of desal of Dockum water with discharge into the ExxonMobil Means Field Water Flood.*
  - *Disposal of the concentrate into an existing oil and gas water injection operations will significantly decrease desalination costs, both in capital expense and in operating expense.*

## Economics of Andrews Desalination

- Dockum Aquifer Source Water (6 MM ac.ft in area)
- Operating Cost Estimates (based on mobile unit tests)
  - Pre-Treatment - $.50 per 1,000 gal.
  - RO –Treatment - $1.25 per 1,000 gal.
- Brine Concentrate Management Costs
  - Less than $0.01

## *Study 2: The Central Texas Project*

- *Proposed Project*
  - *A 2 MMGD RO Desalination Facility to provide water to Central Texas communities with unmet water needs.*
  - *Water to come from Oil Field East of Seguin Texas.*
  - *Injection of Concentrate back in to Field for enhanced recovery.*

## Portable Desalination Unit for On-Site Testing

## Economics of Central Texas Desalination

- Oil Field Brine Management
  - Creation of 1,000,000 bbl economically recoverable reserves.
- Desal Operating Cost Estimates (based on mobile unit tests)
  - Pre-Treatment - $2.00 per 1,000 gal.
  - RO–Treatment - $4.20 per 1,000 gal.
- Brine Concentrate Management Costs
  - Less than $0.01

## In Conclusion;

Opportunities in Texas for Brackish Oil Field Brine Desalination

Questions?

http://www.gpri.org

## Steve Bushong

- Who Owns the Right to Treated "Produced Waters?"

## OWNERSHIP OF "PRODUCED WATER" FROM OIL AND GAS OPERATIONS IN COLORADO

by
Steven J. Bushong
Porzak Browning & Bushong LLP

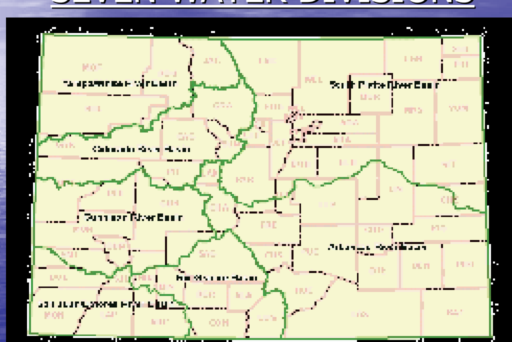
## COLORADO CONSTITUTION

- Water of every natural stream is property of the public subject to appropriation.
- The right to appropriate unappropriated water of any natural stream shall never be denied.

## REQUIREMENTS FOR A WATER RIGHT

- DIVERSION (CONTROL)
- BENEFICIAL USE

## SEVEN WATER DIVISIONS



## COMPONENTS OF A WATER RIGHT

- THE POINT OF DIVERSION
- THE QUANTITY OF FLOW RATE OR DIVERSION
- THE PLACE OF USE
- THE PERIOD OF USE
- THE TYPE OF BENEFICIAL USE

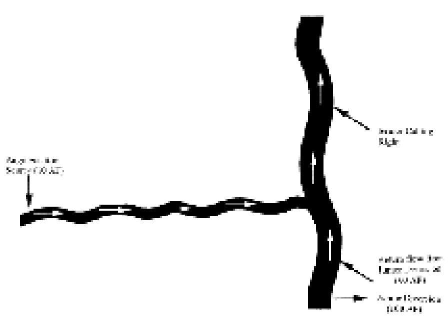
## PRIOR APPROPRIATION SYSTEM

- First in time, first in right
- Seniors fully satisfied prior to juniors

## Priority System

| Ranking | Appropriation Date | Adjudication Date |
|---|---|---|
| 1 | 1880 | 1901 |
| 2 | 1940 | 1942 |
| 3 | 1890 | 1953 |
| 4 | 1940 | 1953 |


ILLUSTRATION OF AUGMENTATION PLAN



## TYPES OF GROUND WATER

- TRIBUTARY
- NON-TRIBUTARY
- DESIGNATED GROUND WATER

## ALLOCATION OF NONTRIBUTARY WATER

- Overlying Land Ownership
- Written Consent of Overlying Landowner
- Municipal or Quasi-municipal Ordinance
- Mining Activities (water produced by dewatering geologic formations)

## OWNERSHIP OF PRODUCED WATERS

- Owning land or minerals does not grant ownership of the water
- Tributary waters – rights vest under the prior appropriation doctrine
- Non-tributary waters – rights vest by permit or decree subject to applicable statutes and regulations
- Designated ground water basins – rights vest by permit issued by Ground Water Commission subject to applicable statutes and regulations

# Bill Carswell

- Panel of state and federal agency representatives
- Can Coordination of Federal agencies with State and Local agencies help make produced water lemons into lemonade?


# OPPORTUNITIES AND LIABILITIES FOR PRODUCED WATERS


Jeffrey T. Cline, Ph. D.

Anadarko Petroleum Co.


April 2006

## TABLE OF CONTENTS

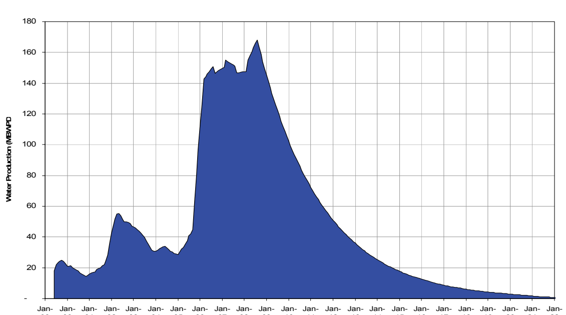


## Wyoming Areas of Interest


## INTRODUCTION
## CBNG Produced Water

- Coal Bed Natural Gas (CBNG) produced water discharges began in 1990s
- CBNG water production releases pressure / produces gas
- Water produced about 10 years; Diminishes 1/3 per year from start; Maintain production of water to produce gas
- CBNG water discharge permitted under Clean Water Act – NPDES permit
- Water quality typically improved vs traditional;
  - Sulfates = 0
  - Chlorides < 50 mg/L
  - Total dissolved solids - 1500 to 3000 mg/L
  - Low heavy metals
- Water production volumes can be 0 to 1500 bbl/day/well
- Used for ranching and agricultural (irrigation) applications

## TYPICAL WATER PRODUCTION IN CBNG FIELD




## INTRODUCTION
## Traditional Produced Water

- Produced water from traditional oil & gas operations discharged for 65 years
- Discharged under permit (NPDES; Clean Water Act; Beneficial Use Waters)
- Water quality:
  - TDS < 5000 mg/L,
  - Sulfates 300 – 3000 mg/L
  - Chlorides – 200 – 2000 mg/L
- Ranching and many Agricultural operations are dependent on the water
- Water quantity slowly increases as oil decreases

## INTRODUCTION
## Oil & Gas Development - Investment

- Oil & Gas fields developed to economically bring energy products to market
- CBNG field development costs:
  - Many years to obtain authorizations (EIS, NPDES) and moving regulatory targets
  - Invest millions to drill, build infrastructure – roads, pipelines, compressors, water facilities
  - Up to 2 years water production until gas to market
- High price volatility for product = high economic risk
- Oil & gas competes with other investment opportunities; High risk = other investment

## OPTIONS FOR MANAGING PRODUCED WATER

- Commonly used today
  - Injection
  - Infiltration impoundments
  - Irrigation
  - Treat & discharge to draws
    - Aeration
    - Barium adsorption/precipitation
    - SAR managed with gypsum
    - Piloting high cost treatment – RO, ion exchange
  - Other; typically transportation issues
- Constantly improving
  - Investigate new water management technologies
  - Meet new regulatory requirements
  - Meet changing operations' needs

## PERSPECTIVES ON PRODUCED WATER USE

- Traditional O&G produced water used and considered necessary by ranching & agricultural communities
- CBNG produced water used and sought by most ranchers, disliked by some
- Environmental effects of each is similar:
- Drainages; from intermittent to perennial
  - Vegetation becomes wetlands/reparian
  - Subsequent use by fish, water fowl, big game, livestock

## FEASIBILITY OF WATER MANAGEMENT OPTIONS

- Regulatory changes cause risk to investment
  - Effluent dominated streams; rules/applications
  - Siting of impoundments
  - Change of limits for SAR, toxicity, etc.
- Traditional O&G produced water feasibility
  - Continue discharge or typically shut-in field
  - Initiate injection if economics apply; enhanced recovery typically needed
- CBNG produced water feasibility
  - Continue discharge > impound > irrigate > enhanced treatment
  - Injection may not be feasible (i.e. PRB)

## WATER MANAGEMENT OPTIONS COMPARED

| OPTION | COST | ECONOMIC RISK |
|---|---|---|
| **Injection** | med-high | **low** |
| Impoundment | low-med | med-high |
| Irrigation | med | med |
| Minor treat/Discharge | low | high |
| Major treat/Discharge | very high | low-med |

## SOLUTIONS; **STRATEGY OF WATER MANAGEMENT**

- Inject the CBNG and conventional produced water when feasible, while supporting the local community needs if low risk
- Goal for water injection is storage in formation of similar class; i.e. Class III water for livestock stored in reservoir having Class III water.

## SOLUTIONS; **IMPROVED REGULATORY CERTAINTY**

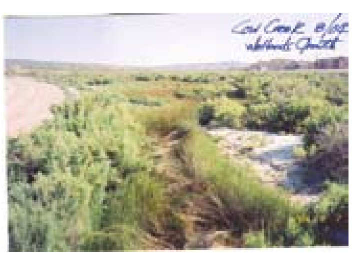
A company investing hundreds of millions in development infrastructure, cannot tolerate rapid regulation changes antiquating the investment

- Conditions of permits should be consistent & not change unless actual serious threat discovered
- Prescribed rule making processes should be adhered to for altering conditions of permits
- Permitting process & results should be standardized across States and Agencies (including federal) so stakeholders can anticipate result and timing.

## POTENTIAL SOLUTIONS; SEEK WATER USES

- Manage beneficial use water as a resource rather than a waste
- States manage excess produced water to provide inter and intra-State beneficial use opportunities (i.e. drinking water, cooling water, other energy development)
- ??


DRAINAGE ABOVE



## John Duda

- Panel of state and federal agency representatives
- Can Coordination of Federal agencies with State and Local agencies help make produced water lemons into lemonade?



## National Energy Technology Laboratory

*Produced Water Workshop*

*U.S. DOE – "Federal Panel"*

*John R. Duda*

*Office of Systems, Analyses and Planning*

*April 4-5, 2006*

National Energy Technology Laboratory

Office of Fossil Energy

## Fossil Energy Mission Statement

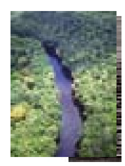
*To enhance U.S. economic and energy security by:*

- Managing and performing energy-related research
- Supporting development of information and policy options that benefit the American public
- Ensuring that FE technology is used in market
- Operating our nation's petroleum reserves



## National Energy Technology Laboratory's Mission

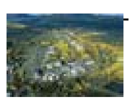
**Implement a research, development, and demonstration program to resolve the environmental, supply, and reliability constraints of producing and using fossil resources**





## National Energy Technology Laboratory

- **Only DOE national lab dedicated to fossil energy**
  - Fossil fuels provide 85% of U.S. energy supply
- **One lab, five locations, one management structure**
- **1,200 Federal and support-contractor employees**
- **Research spans fundamental science to technology demonstrations**

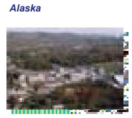


*Alaska*

*Oklahoma*

*Oregon*

*Pennsylvania*



*West Virginia*



## Innovations for Existing Plants

- **Develop affordable environmental control technologies for existing coal plants**
  - Water management
    - Non-traditional sources of process and cooling water
    - Innovative water reuse and recovery
    - Advanced cooling technology
    - Advanced water treatment and detection technology
- **Provide quality technical data for policy makers**

## Coal Mining

- Airborne geophysical mapping
  - –Mine pools
  - –Slurry impoundments
  - –Fate and transport of CBM waters
- Mine pool treatment and beneficial use
  - –Treatment systems
  - –Geothermal applications

NETL

2006 Overview, Harbaugh

## Natural Gas and Oil Environmental Solutions

- Water management approaches and analysis
- Produced water management technology and beneficial use

NETL

2006 Overview, Harbaugh

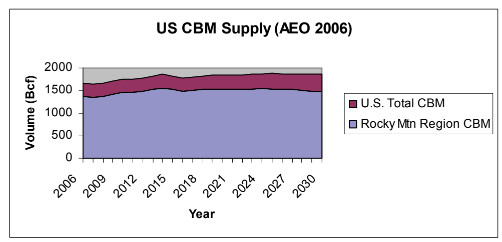
## Systems Analyses Contributing To Energy Security Goals

- Forecasts of [water] requirements
- Impact analyses
- Technical review/inputs

NETL

2006 Overview, Harbaugh

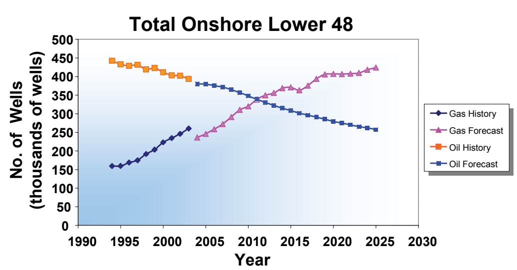
## Coalbed Methane Majority Expected from the Rockies




NETL

2006 Overview, Harbaugh

## Marginal Well Counts *Historical and Forecast*




NETL

2006 Overview, Harbaugh

## Advanced Energy Technologies Can Resolve the Environmental, Supply, and Reliability Constraints of Producing and Using Fossil Fuels

- Forward thinking
  - –Mining
  - –Natural gas and crude oil production
  - –Power generation
  - –Coal liquefaction
  - –Oil shale
- Leveraged opportunities

NETL

2006 Overview, Harbaugh

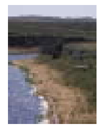

Visit Our Websites
Office of Fossil Energy's website:
www.fe.doe.gov
NETL's website:
www.netl.doe.gov
NETL
2006 Overview, Harbaugh

# Leah Krafft

- Who regulates the quality of produced waters—oil and gas commissions or water quality control commissions?

# Wyoming Pollutant Discharge Elimination System (WYPDES) Permitting Program

## How the WYPDES Program Regulates the Coal Bed Natural Gas Industry

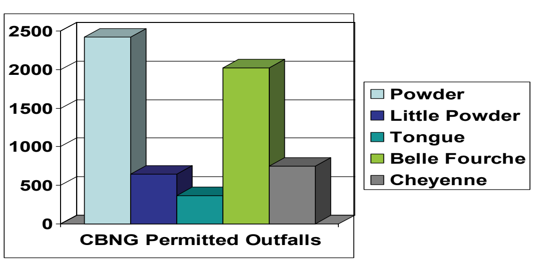


Leah Krafft
Water Quality Division
Department of Environmental Quality
April 4, 2006
(307) 777-7093
lkraff@state.wy.us

# Regulatory Framework

- federal Clean Water Act
- Wyoming Environmental Quality Act
- Water Quality Rule and Regulations
  - Chapter 1
    - Water quality standards and designated uses
  - Chapter 2
    - Process to issue a permit
    - Appendix H

# Permitting of CBNG Facilities




# Watershed Permitting Approach

- Objective
  - Holistic Evaluation of a Watershed
  - Improved Permitting Process through the development of a general permit or watershed plan
- Benefits
  - Predictable Outcomes
  - More Efficient Permitting
  - Improved Mechanism to Hear and Address Concerns
  - Improved Environmental Protection
  - More Informed Decisions

## Watershed Permitting Approach

- 3 Year Process
  - Initiation (November 2004)
  - Target Completion (December 2007)

- Stakeholder involvement based upon informed consent
  - State and Local Agencies
  - Landowners
  - CBNG Operators
  - Environmental Organizations

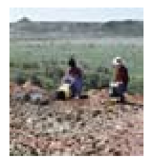
## Challenges

- Diverse Stakeholders
  - Sideboards and Ground Rules
  - Will not resolve all known problems
  - New requirements and initiatives
    - » Section 20 Implementation Policy
    - » Petitions to EQC
    - » Court Rulings
- Watershed Permit/Plan Development Timing
  - 30 Watersheds
    - » 15 Powder
    - » 6 Tongue
    - » 7 Little Powder
    - » 2 Cheyenne
  - 9 months for each drainage with overlapping watersheds

## Current Efforts

- Willow, Pumpkin and Fourmile Creeks
  - Initial meeting was in January 2005
  - Five meetings designed to identify:
    - uses within drainage
    - characteristics of the watersheds
    - potential conditions for permits and plan (Plan for Fourmile Creek)
  - Permits/Plan advertised in February 16, 2006 public notice
    - 45 day public notice
    - Last day to submit comments was April 3, 2006
  - Final meetings on April 11th and 12th to discuss public notice comments and finalize the general permits/plan before issuance.

## Current Efforts



- Clear and Fence Creeks
  - Initial meeting was in August 2005
  - Five meetings designed to identify:
    - uses within drainage
    - characteristics of the watersheds
    - potential conditions for general permits
  - Permits will be advertised in public notice mid-April
  - Final meetings will be scheduled for mid-June

## Future Efforts

- Prairie Dog, Badger and Hanging Woman Creeks (Tongue River)
  - Initial meeting is scheduled for April 26th and 27th

- Dead Horse and Fortification Creeks (Powder River)
  - Initial meeting is scheduled for Summer 2006

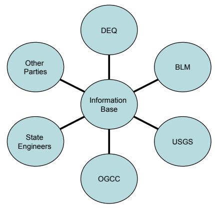
- Information available on DEQ website
  - http://deq.state.wy.us/wqd/WYPDES_Permitting/WYPDES_cbm/Pages/CBM_Watershed_Permitting/CBM_watershed_permitting.asp

## New DEQ Issues

1. Reservoirs (Groundwater Reviews)
2. Bonding of Reservoirs
3. Treatment/Direct Discharge/Game and Fish
4. New areas of Development (Hanna Draw)
5. Change in DEQ Regulations
6. Inter-State Issues
   - MT rulings
   - TMDL Development

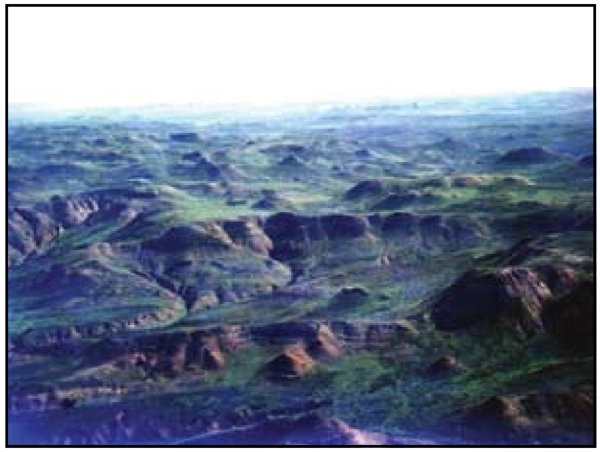
# Coordination Efforts

- BLM
- USGS
- Wyoming Oil and Gas Conservation Commission
- State Engineers Office
- Game and Fish
- Surrounding States
- Other Parties



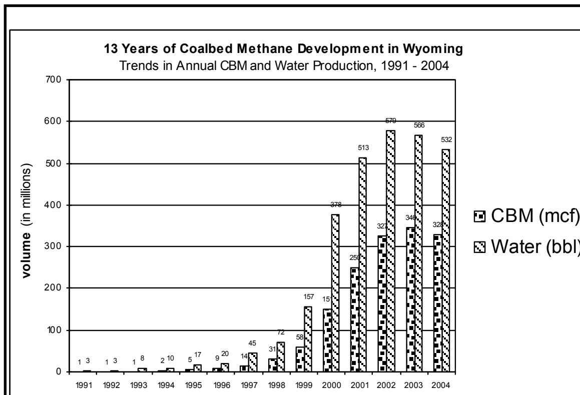
## Jill Morrison

- Practically, how do we mitigate the environmental impact of using the regular western water delivery systems to move treated produced waters to beneficial uses?



## 2003 Conference “Water 2025: Preventing Crises and Conflict in the West”

- Population is exploding.
- Water shortages exist.
- Water shortages result in conflict.
- Aging water facilities limit options.
- Crisis management is not effective.




## How Much Water in the PRB

- The Bureau of Land Management predicts over 1.4 trillion gallons of water or about 4 million acre feet will be produced and discharged for Powder River Basin CBM production. The IENR report projects over 5 million acre feet.
- 1 Acre foot will supply a family of four for one year
- Enough water for over 16 million people or all of Wyoming at current population for 30 years.

Clabaugh Ranch Wild Horse Creek CBM Discharge Water Flooding – March 2005

CBM Reservoirs Overflowing
and Flooding Wild Horse Creek

Clabaugh Ranch Meadows
Flooded by CBM Water
January 2006

Clabaugh Ranch Meadows Transformed
by CBM Waste Water to
Non-Palatable Foxtail and Slough Grass

Clabaugh Ranch Salt & Iron Damage to
Soil by CBM Waste Water

CBM Reservoirs on Dead Horse Creek
Above Barlow Ranch

Downstream Soil and Vegetation Damage from
CBM Discharge in Dead Horse Creek on Barlow Ranch

CBM Discharge Water in SA Creek on Rogers Ranch

CBM Flooding in Spotted Horse Creek
and on Meadows on the West Ranch

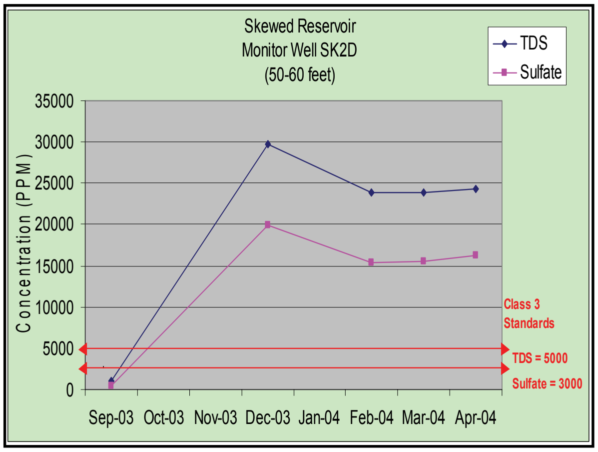
CBM Flooding in Spotted Horse Creek
and on Meadows on the West Ranch

West Ranch, Spotted Horse Creek Meadows:
Salts Deposited and Leached from Soil Caused by CBM Flooding

West Ranch: Dead Cottonwood Trees along Spotted Horse Creek from CBM Flooding






"My husband will soon be 84 years old and I am nearly 71, and we have been hauling water in gallon jugs from the neighbor's for our house use, and the neighbor hauls water to put in a tank for our horses. We travel 40 miles to Buffalo to do our laundry. The value of our little ranch has dropped to practically nothing with no water supply."

**Roland & Bev Landrey**

# Estimated volume and quality of produced water associated with projected energy resources in the western U.S.

Presented at the Produced Waters Workshop:
Energy & water
Ft. Collins, CO April 4, 2006

James K. Otton
U.S. Geological Survey

## Topics

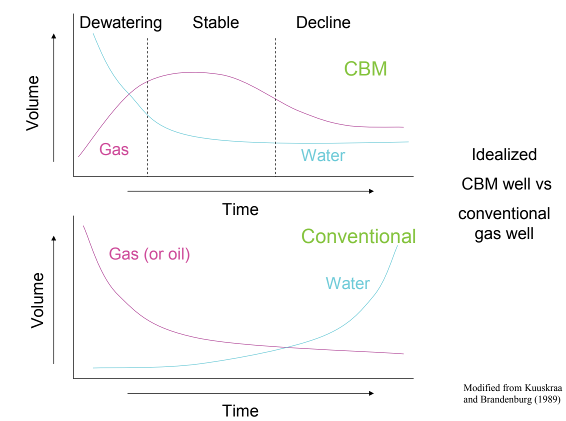
- Current energy-water production
  - Conventional oil and gas resources
  - Unconventional resources, especially coalbed methane
- Potential for future energy-water production
  - From ongoing conventional energy production
  - From ongoing and expanding unconventional energy production- CBM example
  - From "new" oil and gas resource E&P –brief summary

## Some conversions/ definitions

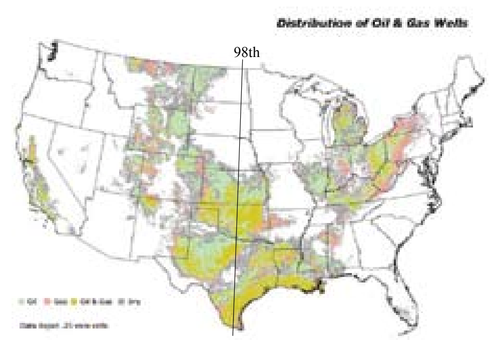
1 barrel (bbl)= 42 U.S. gallons
1 acre-foot = 7760 barrels

Conventional- oil and gas held in structural and stratigraphic traps where a water-petroleum interface formed.

Unconventional- oil and gas held in broadly disseminated or "continuous" form within the formation, usually with richer "sweet spots" or "fairways".




## Current water resource availability from conventional energy production

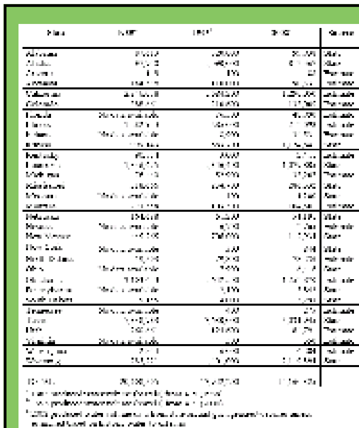



Conventional production

Source: USGS

## Water production information-conventional production

- Data on water production are difficult to come by, except for injected waters.
- About 20 billion bbls of produced water were generated from 1,868,990,000 barrels of crude oil production and 23.4 Tcf of gas production in 2005 (sources: DOE-NETL, EIA).
- Overall, conventional oil production generates more water than gas production.



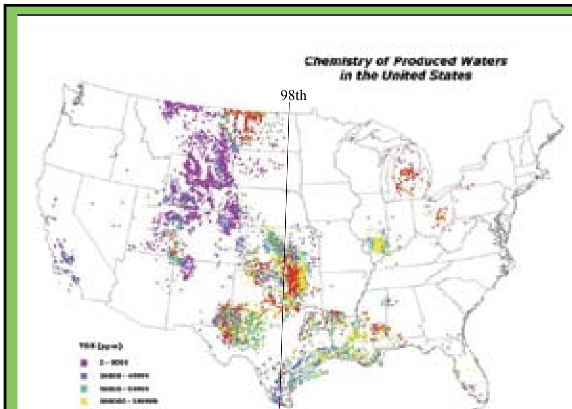
State-by-state PW volume data 1985, 1995, 2002 (1000 bbls)

Declines

Increases

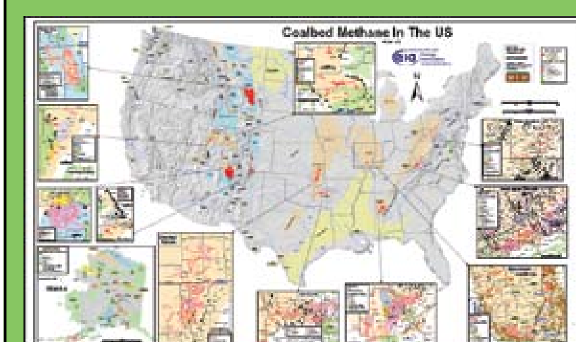
Source: ANL/DOE, 2004

## Water quality of conventional oil and gas PW




Source: USGS

## Current water resource availability from unconventional energy production- CBM




Source- Energy Information Administration webpage

## Volume of Water in Major CBM Basins

| Basin | State | No. of Wells | Avg Water bbl/Day/Well | Water/Gas bbl/Mcf |
|---|---|---|---|---|
| Black | AL | 4,369 | 41 | 0.58 |
| Powder | WY | 15,200 | 1230 | 1.66 |
| Raton | CO | 1892 | 234 | 5.90 |
| San Juan | CO | 1671 | 42 | 0.44 |
| | NM | 1621 | 12 | 0.33 |
| Uinta | UT | 488 | 58 | 0.20 |

USA Total for 2003 ~one billion bbl @ 500 bbl/MMCF

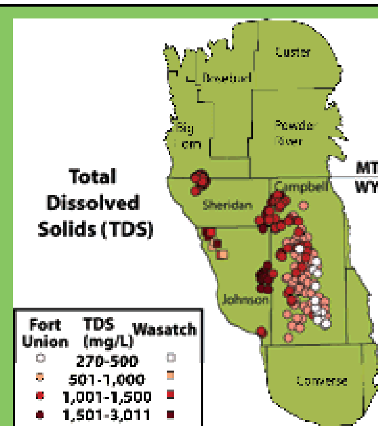
* data are for 2005 from state sources. PRB CBM wells generated 548 million bbls of PW in 2005.

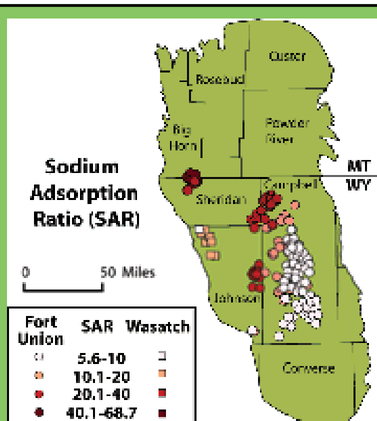
## Composition of Water in Major CBM Basins

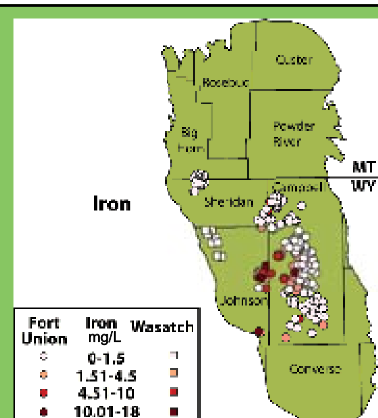
| Basin | State | Type | Total Dissolved Solids (mg/L) | pH |
|---|---|---|---|---|
| Black | Al | Na-Cl-$HCO_3$ | 160-31,000 | 5.4-9.9 |
| Powder | WY | Na-$HCO_3$ | 270-4,000 | 6.7-8.0 |
| Raton | CO | Na-$HCO_3$ | 530-6,000 | ND |
| San Juan | CO | Na-$HCO_3$-Cl | 410-170,000 | 5.2-9.2 |
| Uinta | UT | Na-$HCO_3$-Cl | 6,350-43,000 | 7.0-8.2 |

## Components of CBM Produced Water

- Dissolved inorganic species
  - Major ions—Na, K, Ca, Mg, $HCO_3$, Cl, $SO_4$
  - Minor species—$NH_4$, B, Li
- Dissolved metals
  - Fe, Ba, Mn, Se, Zn, Cu, Cd, Mo, Cr, As
- Dissolved organic species
  - Phenols and volatile aromatic compounds
- Dissolved and dispersed hydrocarbons
  - Condensates and oil
- Dissolved and sorbed radionuclides
- Drilling and workover additives



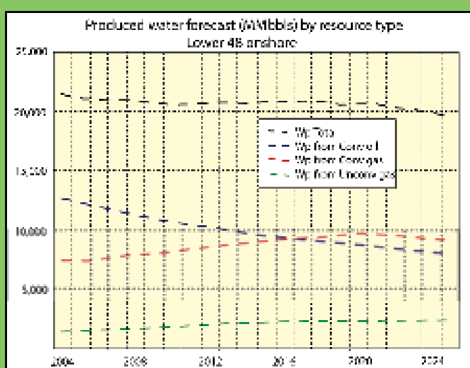



## Water quality impacts

- Water quality limits the immediate uses of the water without beneficiation.
- Water quality affects the types of beneficiation that needs to be performed for the proposed beneficial use.
  - Cleanup for DW may require reducing all major and minor salts, and eliminating trace elements, organics.
  - Cleanup for irrigation may require lowering SAR and eliminating phytotoxic trace elements.
- Water quality affects the ability of cleanup technologies to perform- Fe, Mn fouling

## Potential water resources

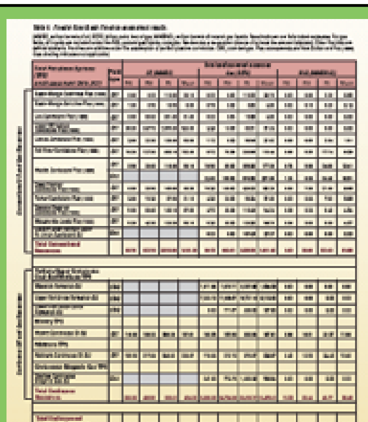
- Ongoing conventional production
- Ongoing and expanding unconventional production
- From "new" oil and gas resource E&P




Source: National Energy Technology Lab, DOE, 2005

USGS estimates a mean of 16.5 Tcf undiscovered natural gas, and 1.5 B bbls of undiscovered oil in the Powder River basin.

USGS, 2002

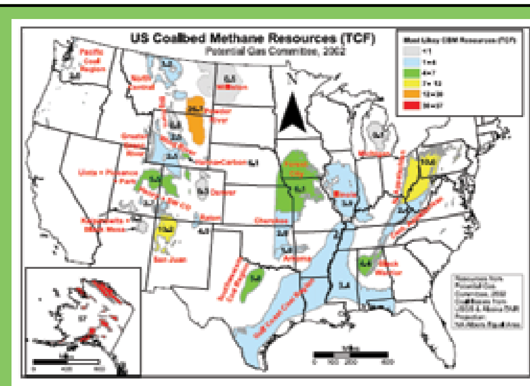


## Future PRB water resources

- Using the 2005 reported water/gas ratio of 1.66 bbls per Mcf and the 16.5 Tcf CBM gas resource number one could estimate that about 28 billion barrels of water would be available over the productive life of the PRB from CBM. Error bars on such a number are substantial.
- Oil production could be an additional significant contributor to PRB water supply, perhaps 5-15 B barrels, but it is more difficult to estimate and water quality is likely to be lower.

## Cautions

- Estimates of future water production are affected by the varying water/gas and water/oil ratios observed in different coalbeds or formations in the same basin. For example, in the PRB, a shift to production from the deeper, more gas-rich Big George coal could increase the volumes of produced water available as the water to gas ratios in that coalbed are higher.




Total resources: 163.3 Tcf

## Future water resources in western energy basins

- Basin-centered gas- some mature basins, a great deal of development presently underway in selected basins. Data are available to make some projections.
- Shale gas- some eastern basins developed, some western basins are under development. Low water yields however.
- Oil shale- if retorted in place, unknown water availability, possibly substantial, and unknown quality. If mined, will compete for water supplies.

## Conclusions

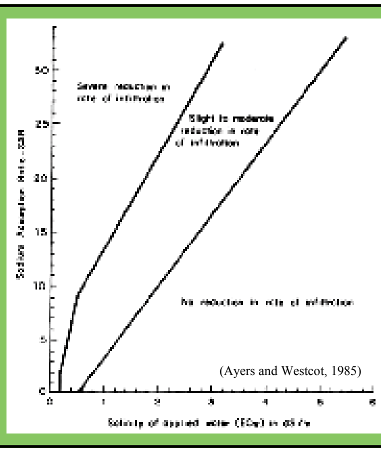
- Produced water resources are substantial in many western basins and are a significant present-day and potential source for water available for beneficial use.
- CBM waters are generally fresher than conventional oil and gas waters in the same basin and will require less $$ for cleanup.
- Some precautions must be taken to conduct thorough geochemical analyses to establish the appropriate cleanup technologies.

## Conclusions (2)

- Cleanup technologies must be specific to the water quality of the PW and the proposed use of the PW
- PW storage and transmission systems should be monitored for unanticipated consequences especially where the PW interact with shallow bedrock, alluvial aquifers, and soils

## Extras for discussion follow

Effects of SAR and Salinity on soils



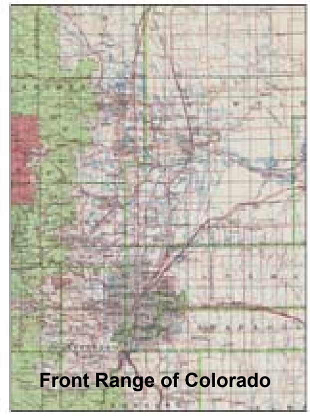

(Ayers and Westcot, 1985)

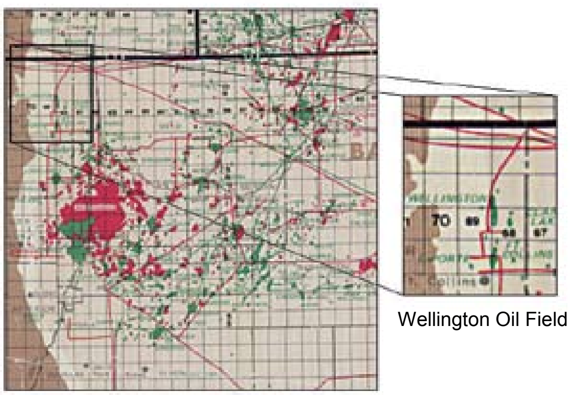
| Effluent Characteristic | Daily Maximum Limit |
|---|---|
| Chlorides, mg/l | 46 |
| Dissolved Iron, µg/l | 1000 |
| Dissolved Manganese, µg/l | 650 |
| pH, standard units | 6.5 - 8.5 |
| Specific Conductance, micromhos/cm | 7500 |
| Sulfates, mg/l | 3000 |
| Total Arsenic, µg/l | 7 |
| Total Barium, µg/l | 1800 |
| Total Dissolved Solids, mg/l | 5000 |
| Total Petroleum Hydrocarbons (TPH), mg/l* | 10 |
| Total Radium 226, pCi/l* | 1 |
| Total Flow, MGD** | 0.2 |

Wyoming DEQ discharge permit monitoring requirements

# Brad Pomeroy

- The Wellington Oil Field: A case study of the beneficial use of produced water from an oil field in Colorado



Wellington Oil Field

Wellington Oil Field

Fort Collins Oil Field

Contoured on the top of the Muddy Sandstone

Location of the Wellington Produced Water Treatment Plant

## Blake Sanden

- Case study: Sweet Lemonade and Sour Lemons…Lessons Learned? (California)

*UNIVERSITY of CALIFORNIA COOPERATIVE EXTENSION*

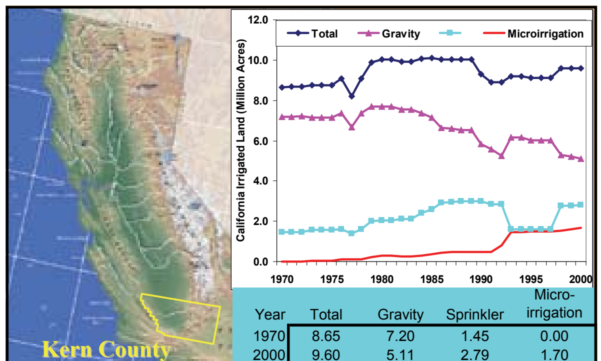
## *Conjunctive Use of Oilfield Produced Water for Irrigation in the Southern San Joaquin Valley of California*

***Prepared for PRODUCED WATERS WORKSHOP***
***Fort Collins, Colorado April 4-5, 2006***

**Blake Sanden -- Irrig & Agron Farm Advisor Kern Cnty**
**Dave Ansolabehere – Manager, Cawelo Water District**
**Hung Le – Irrigation Manager, Paramount Farming Co.**

## 3-POINT SERMON

1. WATER SUPPLY
2. CHANGING CROP DYNAMICS
3. SALT



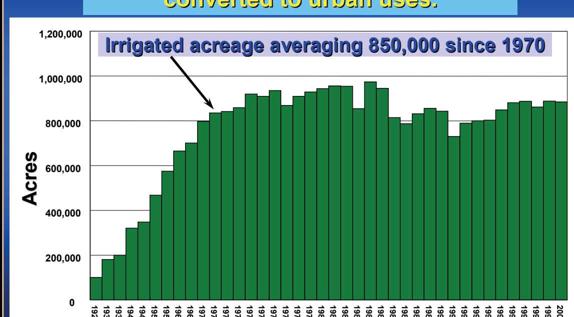

| Year | Total | Gravity | Sprinkler | Micro-irrigation |
|---|---|---|---|---|
| 1970 | 8.65 | 7.20 | 1.45 | 0.00 |
| 2000 | 9.60 | 5.11 | 2.79 | 1.70 |

**Irrigated Acreage and Methods in California, 1970 to 2000 (MAc)**

**Kern County Water Agency**

*Irrigated Acreage in Kern County*

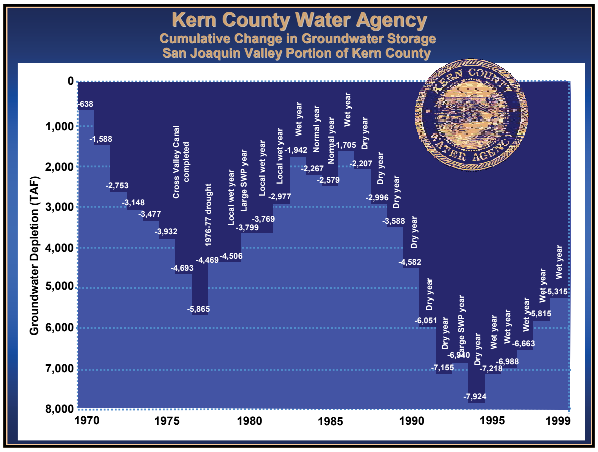
**Roughly 1,000 acres annually are converted to urban uses.**

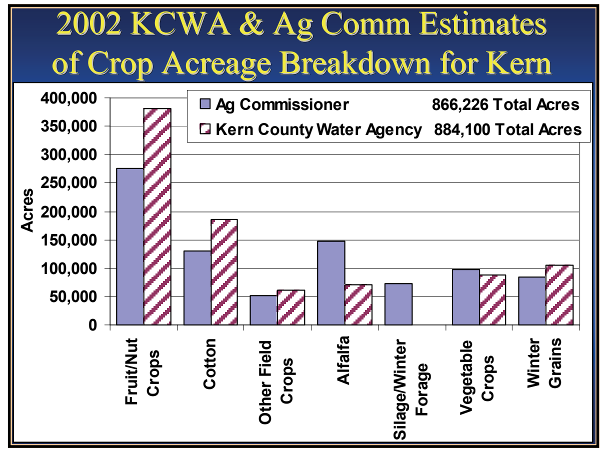


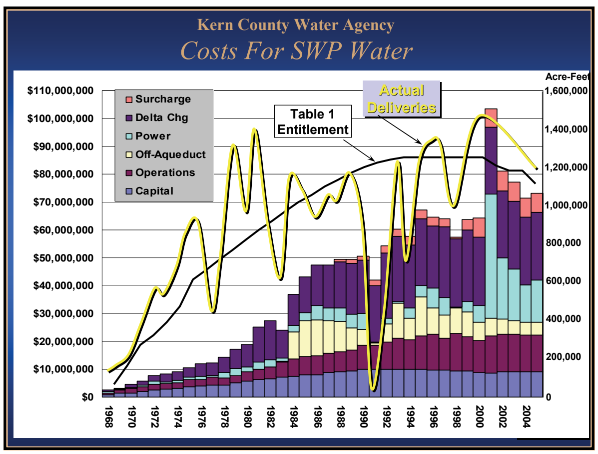

## POTENTIAL REGIONAL DEMAND

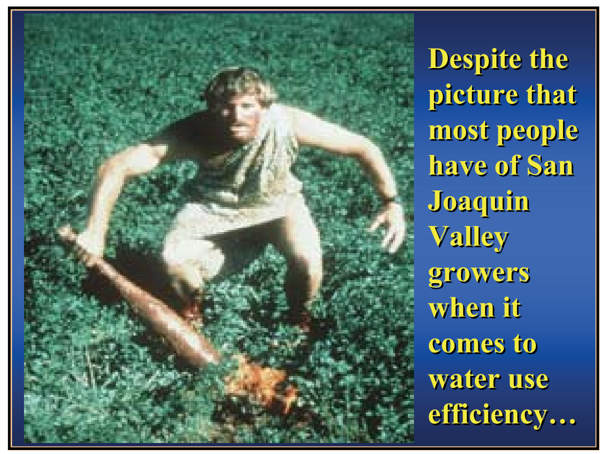
- OLD STANDARD: 2.75 ac-ft/ac, 33 inches
  - WHY: Cotton was king – 450,000 acres, ET 29 in.
- KERN REQUIREMENT (@ 850,000 ac): 2.3 to 2.5 MAF/yr
- AVERAGE PROJECTED SUPPLY:
  - Kern River: 650,000 ac-ft
  - USBR Friant (Eastside Sierra): 800,000 ac-ft
  - State Water Project (Westside): 900,000 ac-ft

**TOTAL: 2.35 MAF**


Kern County Water Agency
Cumulative Change in Groundwater Storage
San Joaquin Valley Portion of Kern County
Groundwater Depletion (TAF)
Cross Valley Canal completed
1976-77 drought
1970
1975
1980
1985
1990
1995
1999

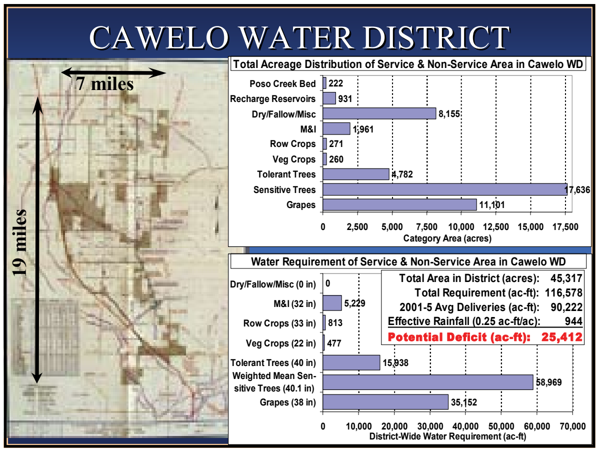

2002 KCWA & Ag Comm Estimates of Crop Acreage Breakdown for Kern
Ag Commissioner 866,226 Total Acres
Kern County Water Agency 884,100 Total Acres
Acres
Fruit/Nut Crops
Cotton
Other Field Crops
Alfalfa
Silage/Winter Forage
Vegetable Crops
Winter Grains


Kern County Water Agency
Costs For SWP Water
Surcharge
Delta Chg
Power
Off-Aqueduct
Operations
Capital
Table 1 Entitlement
Actual Deliveries
Acre-Feet

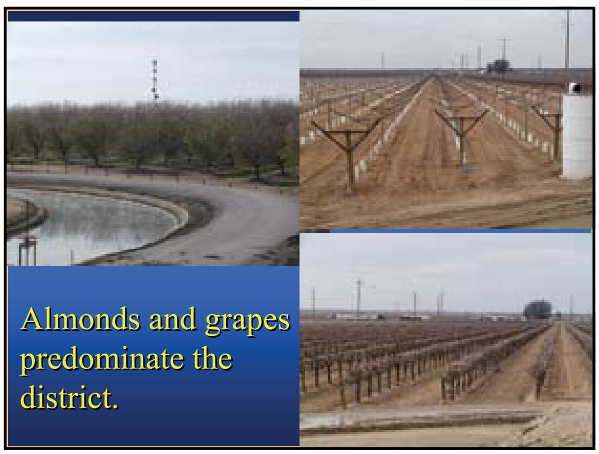

Despite the picture that most people have of San Joaquin Valley growers when it comes to water use efficiency…


…they have proven very innovative by switching to higher value permanent crops, maximizing the efficiency of older irrigation systems and…

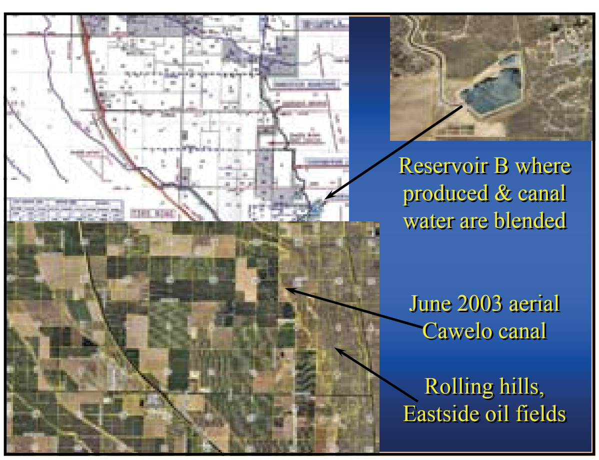

… and developing new methods needed to maximize yields and stay in business while paying $70 to $190/ac-ft for irrigation water.


CAWELO WATER DISTRICT
7 miles
19 miles
Total Acreage Distribution of Service & Non-Service Area in Cawelo WD
Poso Creek Bed 222
Recharge Reservoirs 931
Dry/Fallow/Misc 8,155
M&I 1,961
Row Crops 271
Veg Crops 260
Tolerant Trees 4,782
Sensitive Trees 17,636
Grapes 11,101
0 2,500 5,000 7,500 10,000 12,500 15,000 17,500
Category Area (acres)
Water Requirement of Service & Non-Service Area in Cawelo WD
Dry/Fallow/Misc (0 in) 0
M&I (32 in) 5,229
Row Crops (33 in) 813
Veg Crops (22 in) 477
Tolerant Trees (40 in) 15,938
Weighted Mean Sensitive Trees (40.1 in) 58,969
Grapes (38 in) 35,152
Total Area in District (acres): 45,317
Total Requirement (ac-ft): 116,578
2001-5 Avg Deliveries (ac-ft): 90,222
Effective Rainfall (0.25 ac-ft/ac): 944
Potential Deficit (ac-ft): 25,412
0 10,000 20,000 30,000 40,000 50,000 60,000 70,000
District-Wide Water Requirement (ac-ft)


INCREASING COSTS AND DEMAND REQUIRE INNOVATIVE SOLUTIONS
• CAWELO WD & CHEVRON/TEXACO PARTNERSHIP
CAWELO WATER DISTRICT
WATER IS THE KEY TO LIFE


Almonds and grapes predominate the district.


Most water is delivered by buried laterals running downslope from canal.
Nearly all permanent crops are now irrigated with microsprinklers or drip.


Reservoir B where produced & canal water are blended
June 2003 aerial Cawelo canal
Rolling hills, Eastside oil fields


Produced water is collected across thousands of acres of well field and eventually transported through a 16 inch pipe…
… and discharged into Regulation Reservoir B (~25 acres) for mixing with Kern River and project water.


## CAWELO WATER DISTRICT SUPPLY AND DISTRIBUTION (AC-FT)

| ENTITY / USE | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| CHEVRON / TEXACO | 22,259 | 19,988 | 17,910 | 20,181 | 17,096 |
| VALLEYWASTE | 879 | 585 | 1,065 | 2,853 | 3,812 |
| SCHAEFER | 1,186 | 1,274 | 1,457 | 1,441 | 1,293 |
| **TOTAL PRODUCED WATER** | **24,324** | **21,847** | **20,432** | **24,475** | **22,201** |
| **TOTAL WELLS TO DISTRICT** | **13,058** | **10,055** | **5,425** | **11,203** | **2,661** |
| **TOTAL IMPORTED CANAL** | **47,807** | **55,955** | **62,396** | **54,248** | **75,025** |
| **TOTAL SUPPLY** | **85,189** | **87,857** | **88,253** | **89,926** | **99,886** |
| **BANKING AND CONVEYANCE LOSSES** | **8,711** | **6,598** | **7,584** | **11,197** | **18,837** |
| **TOTAL TO LANDOWNERS** | **76,479** | **81,259** | **80,669** | **78,729** | **81,049** |
| **PRODUCED / TOTAL (%)** | **28.6%** | **24.9%** | **23.2%** | **27.2%** | **22.2%** |

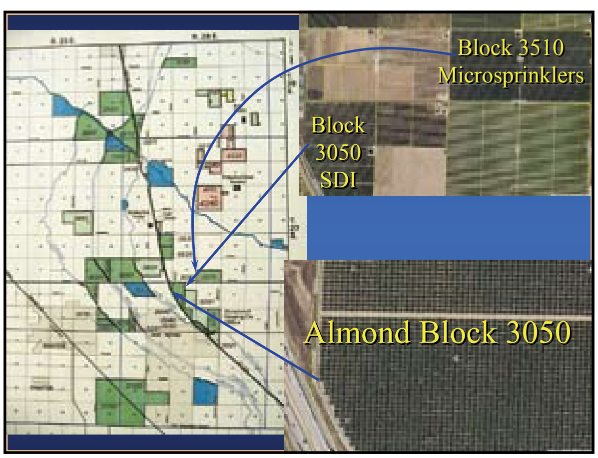
## PRODUCED WATER FLOW

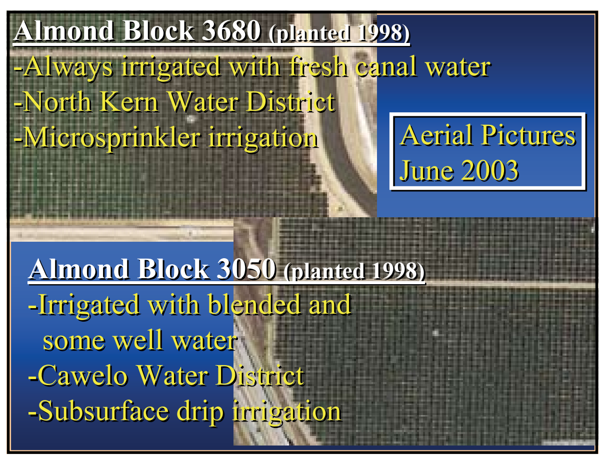
Average 23,000 ac-ft/yr
= 63 ac-ft/day
= 488,986 bbl/day
= sufficient irrigation for 5,750 acres @ 4 ac-ft/ac
= 13.8 million pounds of almonds @ 2,400 lb/ac

**= 3.2 bbl water/4 oz can almonds**

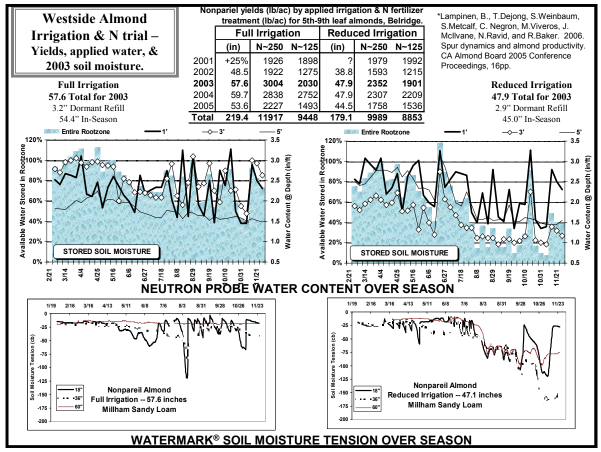
## AVERAGE WATER QUALITY
(quarterly samples 2001-5, except as noted)

| | pH | EC (dS/m) | Ca (meq/l) | Mg (meq/l) | Na (meq/l) | HCO3 (meq/l) | Adj SAR (%) | Cl (meq/l) | B (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| Lerdo Canal | 8.5 | 0.19 | 0.82 | 0.28 | 0.82 | 1.03 | 1.11 | 0.50 | 0.13 |
| Produced | 7.7 | 0.89 | 1.40 | 0.38 | 6.93 | 4.34 | 12.78 | 3.92 | 0.96 |
| **Current Blend** | **8.0** | **0.51** | **0.96** | **0.30** | **3.94** | **2.72** | **7.05** | **2.26** | **0.52** |
| **Quarterly C.V.** | 3.1% | 41% | 30% | 44% | 48% | 40.9% | 52.2% | 50.6% | 51.3% |
| **PreBlend (1995)** | | 0.34 | 0.78 | 0.06 | 2.50 | 1.40 | 3.95 | 0.47 | 0.05 |
| **FAO 29 "Sensitive" Crop Thresholds** | | **0.7** | | | **3.0** | | **5*EC** | **4.0** | **0.7** |
| **June 2004 grab samples for subsurface drip Almond Block 3050** | | | | | | | | | |
| **District Plus Gypsum** | 7.9 | 1.77 | 17.17 | 0.46 | 1.98 | 4.30 | 0.67 | 0.90 | 0.57 |
| **Well** | 7.9 | 1.11 | 5.74 | 0.13 | 5.22 | 0.70 | 3.05 | 6.20 | 0.21 |



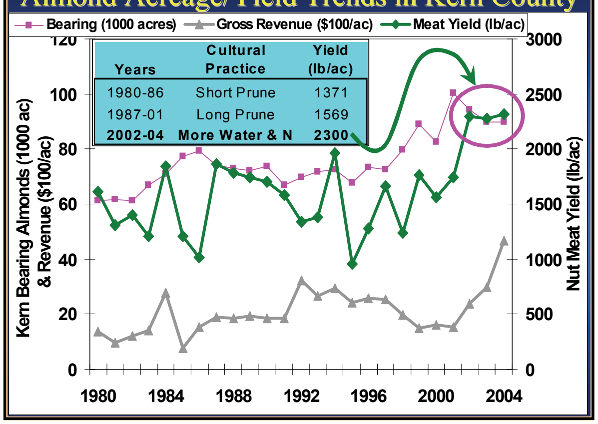



The Observation:
some orchards visibly stress and defoliate just before harvest…




| | Full Irrigation | | | Reduced Irrigation | | |
|---|---|---|---|---|---|---|
| | (in) | N~250 | N~125 | (in) | N~250 | N~125 |
| 2001 | +25% | 1926 | 1898 | ? | 1979 | 1992 |
| 2002 | 48.5 | 1922 | 1275 | 38.8 | 1593 | 1215 |
| **2003** | **57.6** | **3004** | **2030** | **47.9** | **2352** | **1901** |
| 2004 | 59.7 | 2838 | 2752 | 47.9 | 2307 | 2209 |
| 2005 | 53.6 | 2227 | 1493 | 44.5 | 1758 | 1536 |
| **Total** | **219.4** | **11917** | **9448** | **179.1** | **9989** | **8853** |

## Almond Acreage/Yield Trends in Kern County

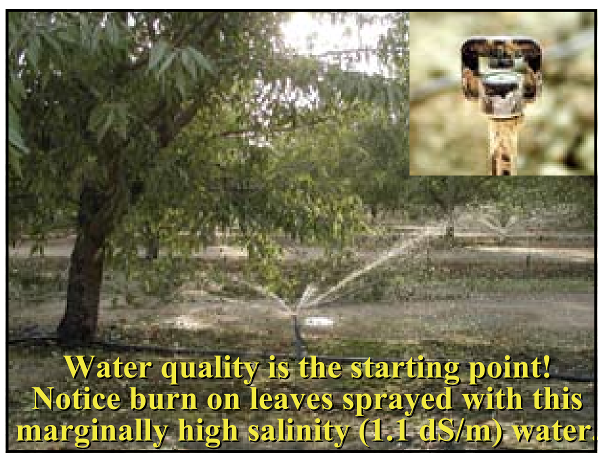



## UC Kern County Irrigation/Grower Irrigation Projects Fall 2000 to Fall 2005

- 11,781 acres over 136 fields
- 30 different growers
- 14 different crops
- 11 soil textures
- 9 different irrigation system types

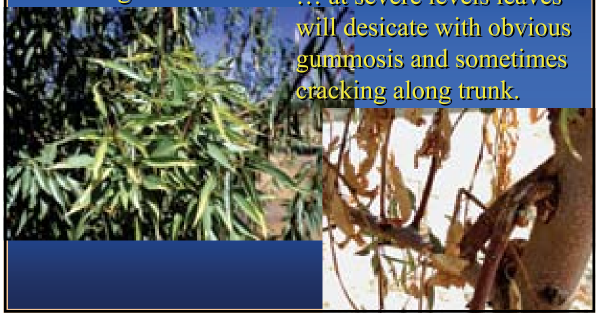
## ALMOND IRRIGATION MONITORING SUMMARY

- Blocks instrumented: 42 total, **34 >6th leaf**
- Average available water to 6 feet: **56%**
- Average soil moisture "tension": **-52** centibars
- 2002-2005 average applied water: **46.8 inches**
- Calculated CIMIS ET: **47.9 inches**
- Average neutron probe ET: **45.7 inches**
- **Average Water Use Efficiency: 97%**



Chloride Toxicity: often accompanied by excess salinity and sodium. Marginal toxicity results in cupped leaves, slight yellowing and eventual burning of the margins…

… at severe levels leaves will desicate with obvious gummosis and sometimes cracking along trunk.



## SOIL SALINITY & SPECIFIC ION TOXICITY THRESHOLDS

Summary of published tolerance limits for various permanent crops. S = sensitive, <5-10 meq/l. MT = moderately tolerant, <20-30 meq/l (Ayers and Westcott, 1989, [1]Sanden, et al., 2004)

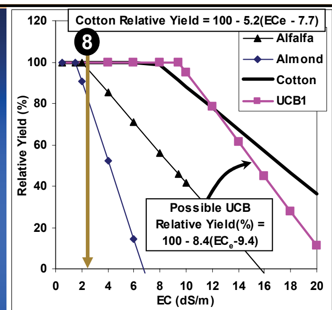
| Crop | $EC_{thresh}$ (dS/m) | Slope (%) | Sodium (meq/l) | Chloride (meq/l) | Boron (ppm) |
|---|---|---|---|---|---|
| Almond | 1.5 | 19 | S | S | 0.5-1.0 |
| Grape | 1.5 | 9.6 | | 10-30 | 0.5-1.0 |
| Orange | 1.7 | 16 | S | 10-15 | 0.5-0.75 |
| Pistachio[1] | 9.4 | 8.4 | 20-50 | 20-40 | 3-6 |

Almond Block 3050 (SDI) June 2004 Soil Samples

| Location | EC dS/m | pH | Ca meq/l | Mg meq/l | Na meq/l | Cl meq/l | ESP% (CEC) | B ppm | NO3 ppm | P ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20" under edge of Berm next to hose | 1.7 | 5.4 | 3.3 | 0.4 | 13.1 | 4.3 | 25.4 | 0.27 | 350 | 67 | 76 |
| 30" under tree | 2.8 | 7.1 | 7.1 | 1.6 | 21.8 | 16.0 | 25.3 | 0.37 | 205 | 21 | 98 |
| 20" under Mid of row 4' from SDI hose @20" | 0.8 | 7.2 | 1.9 | 0.6 | 5.7 | 2.0 | 17.9 | 0.18 | 290 | 22 | 126 |
| 48" under Mid of row | 3.8 | 7.7 | 10.0 | 1.8 | 30.0 | 16.6 | 19.2 | 0.30 | 205 | 15 | 144 |

Mean $EC_e$ of Block 3050 samples = 2.28 dS/m

Mean blended $EC_{irrigation\ water}$ = 0.51 dS/m




Long-term $EC_{rootzone} \sim 6*EC_{irr}$ @ <5% LF

Long-term $EC_{rootzone} \sim 3*EC_{irr}$ @ 10% LF

Long-term $EC_{rootzone} \sim 2*EC_{irr}$ @ 15% LF

(Adapted from Hoffman, G.J. 1996)

## Almond Relative Yield = 100 – slope($EC_{thresh}$ – $EC_e$)

**Relative Yield $EC_e$ @ 2.28 dS/m = 100-19(2.28-1.5) = 85.2%**

**POINT:**

**A 10-15% leaching fraction is required to maintain adequate soil water quality**

## Block 3050 after winter leaching (8 inches refill, 4 inches plus effective rainfall for actual leaching)

Almond Block 3050 after winter leaching using microsprinklers and 12 inches of District water (Saturated paste extract and fertility March 2005 soil samples)

| Location | EC dS/m | pH | Ca meq/l | Mg meq/l | Na meq/l | Cl meq/l | ESP% (CEC) | B ppm | NO3 ppm | P ppm | K ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A 0-1ft | 0.4 | 7.2 | 1.1 | 1.0 | 1.5 | 0.7 | 8.8 | 0.90 | 2 | 18 | -- |
| 1-2 ft | 0.2 | 7.8 | 0.5 | 0.2 | 1.6 | 0.2 | 9.0 | 1.19 | 2 | 6 | -- |
| 2-3 ft | 0.8 | 8.6 | 0.5 | 0.1 | 7.4 | 0.2 | 20.5 | 1.77 | 2 | 5 | -- |
| 3-4 ft | 0.3 | 8.2 | 0.5 | 0.2 | 2.3 | 0.2 | 19.2 | 1.24 | 2 | 2 | -- |
| B 0-1ft | 0.4 | 7.6 | 1.1 | 0.3 | 2.4 | 0.2 | 5.6 | 0.50 | 2 | 9 | -- |
| 1-2 ft | 0.8 | 8 | 0.9 | 0.2 | 7.2 | 0.6 | 11.7 | 0.64 | 2 | 9 | -- |
| 2-3 ft | 1.0 | 8.3 | 0.9 | 0.2 | 8.5 | 0.9 | 16.4 | 0.57 | 2 | 12 | -- |
| 3-4 ft | 0.9 | 8.6 | 0.8 | 0.2 | 7.4 | 1.5 | 12.6 | 0.53 | 2 | 1 | -- |

## 2005 ECONOMICS OF SUPPLY

- **81,049 ac-ft @ $120 grower cost: $9.73 M**
  - **VALUE OF PRODUCED WATER**
  - 22,201 ac-ft of Produced Water @ $120: $2.66M
  - Payment for Produced Water @ $12: $0.27M
  - **NET BENEFIT TO DISTRICT: $2.39M**
  - **SERVICE AREA @ 33,247 ACRES**
    - **NET BENEFIT / ACRE: $71.89**

## 2005 ECONOMICS OF SUPPLY

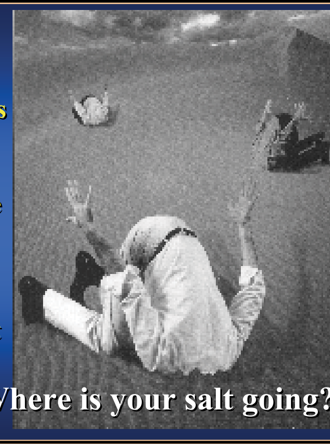
- VALUE OF WATER IN CROP EQUIVALENT
  - NET BENEFIT / ACRE: $71.89
  - Equivalent orange boxes @ $10: 7 boxes
  - Equivalent grape boxes @ $8: 9 boxes
  - Equivalent almond meats @ $3/lb: 24 lbs

15% almond yield loss/acre @ max yield of 2,500 lb/ac, 375 lbs, and $3/lb: $1,125

Alternatively 54” vs. 45” applied water increased yield 386 lbs, @ $3/lb: $1,158

**POINT:**

Growers, engineers and water managers cannot stick their heads in the sand to either hide from the issue or fool themselves into thinking one quick look and a spot shot solution will fix the problem …



Where is your salt going?

## WATER CONSERVATION PLANNING IN THE WEST:

- Which one is the farmer and which one is the water policy planner?

## Dave Stewart

- Case studies: Sweet Lemonade and Sour Lemons…Lessons Learned? (Colorado)

## Production Water – A new water resource?

### A Colorado Case Study

By

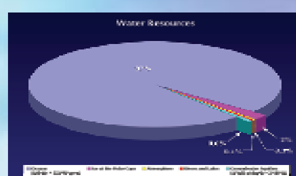
David R. Stewart, PhD, PE

Stewart Environmental Consultants, Inc

## Presentation Outline

- Alternative water supply?
- Drought protection?
- What is production water
- What are the characteristics of production water
- Example of this technology

## Alternative Water Supply



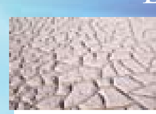

- We need alternative water supplies to limit impacts on agriculture
- Water as a resource
  - 97% seawater
  - 2 % ice and polar caps
  - 1% is for all other uses

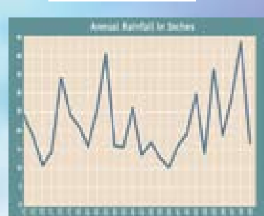
## Colorado State Water Supply Initiative Study

“Nothing in the future will have a greater impact on our ability to sustain our way of life and preserve our environment for future generations than water.”

*The Statewide Water Supply Initiative, Colorado Department of Natural Resources*

## Drought protection






- Prolonged drought
  - Not a matter of if, but when
  - Global climate change is shifting rain patterns
  - Water suppliers need to be prepared and proactive

## How can production water help?

- Definition of production water
  - Water that is associated with the production of oil, natural gas or coal bed methane water
- Oil production – 5% oil, 95% water
- Coal Bed Methane – water removal to obtain the methane – large flows at the beginning of the project that are reduced with time

## Water quality of production water

- TDS – range between 1,000 and 3,000 mg/l
- SAR's can range from 0.5 to 10
- Heavy metals can be a factor
- Removal of organics, such as benzene, toluene, xylene

## Example of how this technology can be used

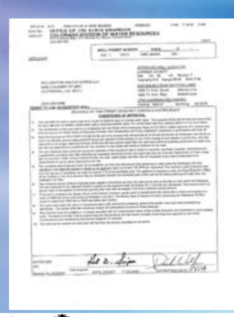
- Local project in northern Colorado
- Oil field that was disposing of production water into a Class 2 injection well – depth of 5,000 feet
- In order to increase oil production, needed to find a new technique for disposal of production water

## Local farmer wanted to keep farm in production

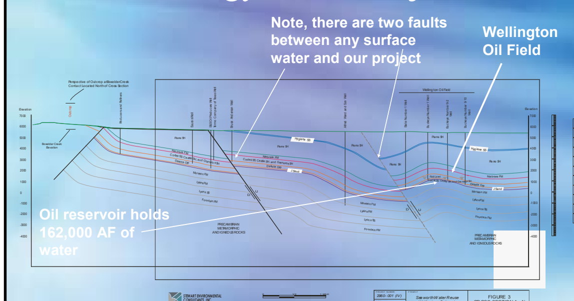
- Discussed how water could be used for agriculture
- Water quality
  - **1,500 mg/l TDS**
  - **Low boron values**
  - **Low heavy metals**

## Rules for oil wells

- Colorado Oil & Gas Conservation Commission Rule 907
- Beneficial use if water in classified as non-tributary
- Need to obtain permits from the State Engineer, the Water Quality Control Division and the COGCC



## Geology of the Project



# Why is the geology important?

- This non-tributary water is only associated with the oil field – the oil company is the only entity that has access to this water
- This water is physically separated from any surface water (as permitted by the State Engineer of Colorado) – therefore, this project does not injure any existing water users in Northern Colorado

# Augmentation Water

- Oil Production Water
  - This water is only available to the oil company at this time
- COGCC Rule 907
  - Allows for the beneficial use of groundwater if it is determined to be non-tributary by the State Engineer
  - 3W has proven the non-tributary status to the Colorado State Engineer
  - Must obtain a discharge permit from the Colorado Department of Public Health and Environment – reviewed by the department – issued by COGCC

# Augmentation Water

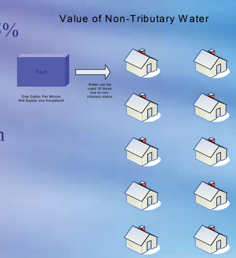
- Groundwater Rights under 505
  - We have obtained the deep groundwater rights as well from the surface water owners
  - Obtaining the water court decree – in process
  - Water Court decree will allow use of the water regardless of the status of the oil production

# Value of Non-tributary Water

Indoor use of water within home consumes between 5% to 10% of the water

The remaining water is returned back to the stream

This allows non-tributary water to be used 20 to 10 times




# Requirement for water quality permit

- Water quality permit required from the Water Quality Control Division
- BTEX removal was required
- Heavy metal removal was also required

# Treatment system

- Dissolved air floatation
- Ceramic microfiltration
- Activated carbon
- Groundwater discharge

## Pilot Plan Experiments for the confirmation of treatment technology

- 3 different pilot plant experiments were performed
- Experiments confirmed the treatment technology

## What are the uses for new sources of water

- Power plant could use the water for augmentation of their existing water supplies
- The water could be used for irrigation of crops or augmentation of wells for irrigation to preserve our agricultural lands
- The water could be used to offset water for drinking water diversions for Northern Colorado homes, such as the Towns of Wellington, Pierce, Ault, Nunn, etc
- Industrial processes could use the water for augmentation of their water sources

## Proposed uses for this project

- Build a Reverse Osmosis plant for domestic water use
- Three different rural & urban domestic water providers in the area of the plant

## Goals of the Project

Provide a new water source for northern Colorado

- **Utilization of existing water from a non-tributary source**
- **Oil Production water has been coming to the surface for more than 81 years from this aquifer**
- **Presently, the water is pumped back into the ground through a permitted deep well injection system**

## Why do all of this work?

- Financial benefits
  - Cost of development of the water is approximately $4,500 per acre foot
  - Augmentation water in Northern Colorado has a value of $20,000 per acre foot
  - At build out with the RO plant, the value of the water will be between $30,000 to $40,000 per acre foot

## Conclusions

- Northern Colorado must obtain additional water resources
- We have developed a new water resource that will provide augmentation water to the area to increase water utilization
- This process meets all of the environmental and State Engineers office requirements
- Utilization of this water is available only to the oil company
- This process will preserve agricultural land
- This is compatible with sustainable development concepts of using local resources to solve local problems

Produced Water Workshop

*Can Technology Transform Produced Waters Into New Supplies, at a Competitive Cost and Without Environmental Damage or Added Liability?*

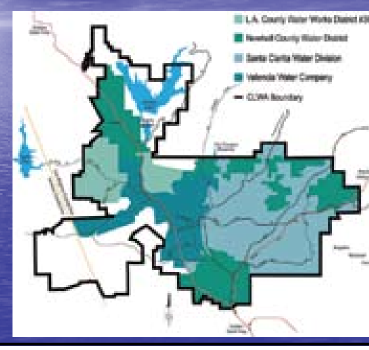
Lynn Takaichi
Kennedy/Jenks Consultants

April 4, 2006

## CLWA Overview

- Service Area: 195 sq. mi. (NW LA County and Eastern Ventura County)
- Service Area Population: 240,000
- Wholesaler of SWP and RW
- Owner of 1 of 4 Retail Purveyors
- Current Water Demand: 90,000 AFY (50,000 AFY SWP)
- Current Growth Rate: 2,500 Housing Units (2,200 AFY)
- Future Water Supplies:
  - Over 65,000 AFY of Water Transfers
  - Participation in 2 Water Banks
  - 17,000 AFY RW Program


## Santa Clarita Valley and CLWA Service Area




## Placerita Oilfield


## History of Produced Water Reuse at CLWA

- Early 1990's: Received call from Arco and explored concept
- 1993: First CLWA RW Master Plan
- Mid 1990's: Received DOE grant to evaluate treatment technologies; Oil prices decline
- Late 1990's: Arco sells Placerita Oilfield
- Early 2000's: Berry reinitiates discussions; Oil prices recover
- 2002: RW Master Plan Update includes produced water
- 2004: EIR initiated (not complete)

## Project Funding

- Department of Energy
- ARCO Western Energy
- Kennedy/Jenks Consultants
- Southern California Edison
- Electric Power Research Institute, Chemicals and Petroleum Office
- Castaic Lake Water Agency
- National Water Research Institute

## Project Benefits

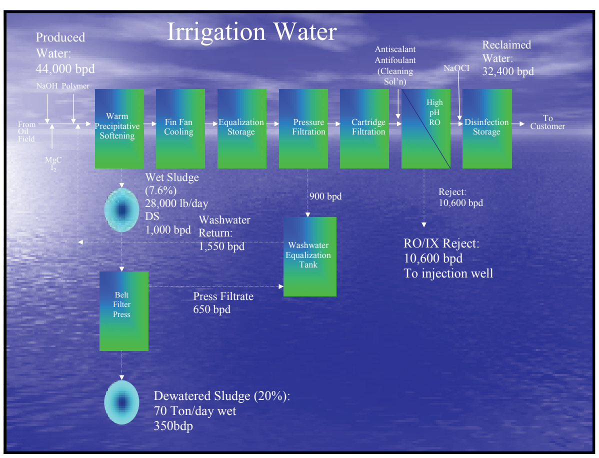
- Improve Thermal Recovery Efficiencies
- Lower Produced Water Handling Costs
- Reduce Water Recirculation
- Reduce Potential for Reservoir Damage
- Recover More Oil in Place
- New Water Resource

## Produced Water Flow Estimates

- Los Angeles - 64 MGD
- Coastal - 27 MGD
- Kern County - 129 MGD

## Parameters of Concern

| | |
|---|---|
| TDS | ~5,500 mg/L |
| Temperature | 150-175 F |
| Boron | ~17 mg/L |
| Silica | 255 mg/L |
| Hardness | ~1,100 |
| Ammonia | ~9 mg/L |
| Total Organic Carbon | 120 mg/L |




## Water Quality Results

| Parameter | Initial, mg/L. | Final, mg/L |
|---|---|---|
| TDS | ~6,000 | 145 |
| Temp, F | 150-175 | 90 |
| Boron | ~16 | 1-2 |
| Ammonia | 9.3 | 2-11 |
| Silica | ~10 | ND |
| Hardness | 1-5 | ND |
| TOC | 120 | 2 |

## Total Project Costs

Capital $10.6 million

Treated 16.6¢ / bbl

## Technical Conclusions

- Can Meet Water Quality Objectives
- Competitive With Current Disposal Costs
- More Expensive Than Imported Water But Only Slightly Higher Than Local Recycled Water Supply
- Avoids Environmental Issues Associated With Imported and Recycled Water Supplies

## So, Why Has It Taken So Long?

| Cause | Water | Petroleum |
|---|---|---|
| Priority | Relatively Small Supply<br>Competing Issues<br>Local Focus | Oil Price Fluctuations<br>Competing Issues<br>National Focus |
| Expectations | Not Familiar With Produced Water<br>Long Time Frame<br>Perception of Value<br>Risk Adverse | Not Familiar With Water Supplies<br>Short Time Fame<br>Perception of Value<br>Willing to Take Risk |
| Communication | Little Outreach to Petroleum<br>Prior Relationship Based on Contamination Issues<br>Primary Federal Agencies: USBR & ACOE<br>Primary State Agency: Health | Little Outreach to Water<br>Prior Relationship Based on Contamination Issues<br>Primary Federal Agency: DOE<br>Primary State Agency: Resources |

## What Should Be Done?

1. Research (S 1860)
   - Technology
   - Social Sciences
2. State-By-State Implementation Roadmaps
3. Demonstration Projects
   - New DOE-DOI Program
4. Leadership and Communication

# Dick Wolfe

- Practically, how do we determine who has the right to beneficially use treated produced waters and how do they obtain the right?

## Water Rights and Beneficial Use of Produced Water From Oil and Gas Wells in Colorado

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***PRODUCED WATERS WORKSHOP***

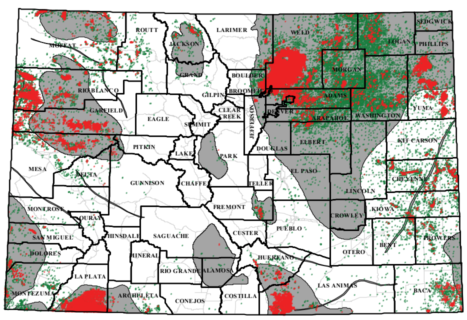
Fort Collins, Colorado

April 5, 2006

*Dick Wolfe, P.E.*

COLORADO DIVISION OF WATER RESOURCES

DEPARTMENT OF NATURAL RESOURCES




**OIL & GAS WELLS OF COLORADO**

**Approximately 29,000 Active O&G Wells**

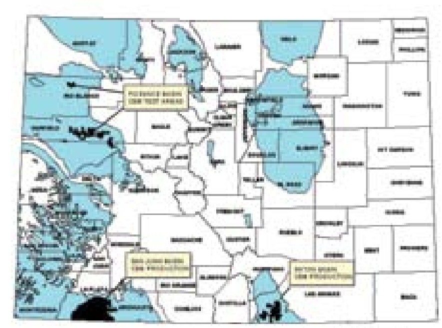
***SOURCE COGCC (9/05)***

**3,855 COALBED METHANE (CBM) WELLS IN COLORADO**

**1,700 CBM WELLS IN LA PLATA COUNTY**

**1,900 CBM WELLS IN LAS ANIMAS COUNTY**

**255 CBM WELLS IN PICEANCE BASIN**

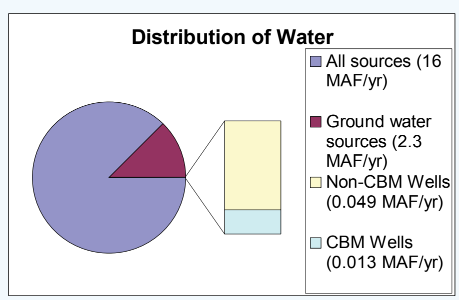


*•SOURCE COGCC (9/05)*

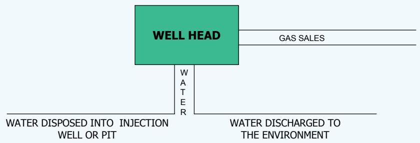
## PRODUCED WATER

**AS OF 9/05**

- *APPROX. 170.8 ACRE-FT/DAY FROM ALL O&G WELLS*
  - 35.8 ACRE-FT/DAY FROM CBM WELLS
  - 135 ACRE-FT/DAY FROM NON-CBM WELLS
- *CBM WATER DISPOSAL METHODS*
  - 19.6 ACRE-FT/DAY DISCHARGED
  - 6.7 ACRE-FT/DAY INJECTED
  - 9.5 ACRE-FT/DAY OTHER (Pits, Commercial Disposal, Centralized E&P Waste Management Facilities)



## *Who Regulates Produced Water?*




THESE WATER DISPOSAL METHODS ARE UNDER THE JURISDICTION OF THE COLORADO OIL AND GAS CONSERVATON COMMISSION.

THIS METHOD OF WATER DISPOSAL IS UNDER THE JURISDICTION OF THE COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIROMENTAL - WATER QUALITY CONTROL DIVISION FOR APPROVAL TO DISCHARGE WATER. AFTER THE WATER IS DISCHARGED IT IS UNDER THE JURISDICTION OF THE DEPARTMENT OF WATER RESOURCES FOR ISSUES CONCERNING WATER RIGHTS.

## *Regulatory & Use Considerations*

- CBM wells are treated just like any other O&G wells in Colorado
- To discharge produced water operator must have a permit from the CDPHE-WQCD
- If water is discharged and beneficially used it is subject to Water Rights Acts (Ground Water Management Act, Water Right and Determination and Administration Act)
- Most basins are over-appropriated-- "First in time, first in right"
- Unreliable as long-term source
- Water quality is poor

## *Methods of Use and Disposal*

- **COGCC Rule 907**
  - Inject into a disposal well
  - Place in lined or unlined pit
  - Dispose at a commercial facility
  - Road spreading
  - Discharge into waters of the state
  - Reuse for recovery, recycling and drilling
  - Mitigation

## Methods of Use and Disposal

- **Types of Beneficial Uses**
  - Irrigation
  - Municipal
  - Domestic
  - Stock watering

## *CBM Water Rights and Ownership*

- **Surface Water Discharge**
  - Must comply with Water Rights Act
    - Must have intent to use
    - Must be diverted in priority
    - Must be beneficially used
    - Must not waste
    - Must prevent material injury to vested water rights

## *CBM Water Rights and Ownership*

- **Beneficial Use by Well-Tributary**
  - §37-90-137(1) & (2), CRS (2005)
    - Permit required
    - Must determine if unappropriated water is available
    - Must prevent material injury to vested water rights (may require augmentation)

## *CBM Water Rights and Ownership*

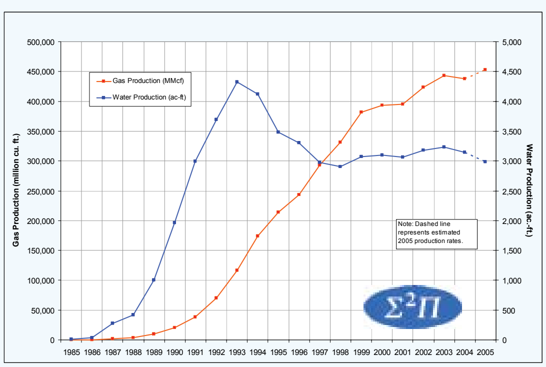
- **Beneficial Use by Well-Nontributary**
  - §37-90-137(7), CRS (2005)
    - No permit required unless beneficially used
    - Use not based on land ownership
    - Do not need to determine if unappropriated water is available
    - Must determine by modeling if nontributary

## Coalbed Methane Stream Depletion Assessment Study Northern San Juan Basin Colorado

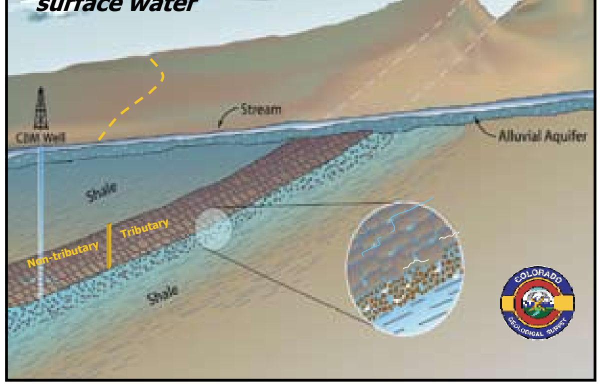
## San Juan Basin Regional Setting



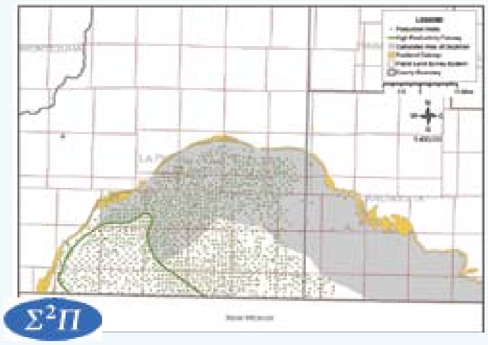
## San Juan Basin Annual CBM Gas and Water Production Rates in Colorado



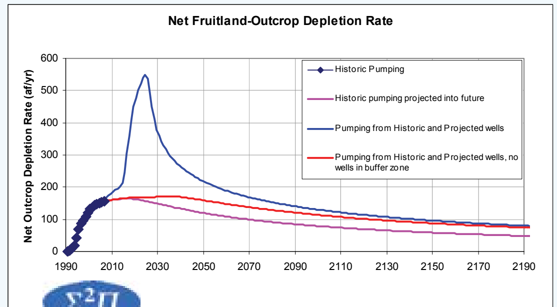

## *Potential for connection of coal interval to surface water*



**Area With Calculated Depletions Exceeding 0.1% in 100 Years**



**Net Depletions of Outcrop due to CBM Water Production**




# Additional Information

- Division of Water Resources website at www.water.state.co.us
- Colorado Oil and Gas Conservation Commission website at www.oil-gas.state.co.us
- Colorado Department of Public Health and Environment website at www.cdphe.state.co.us


Presented by
Dick Wolfe, P.E.
Assistant State Engineer

Phone: (303) 866-3581 ext. 8241

Fax: (303) 866-3589

E-mail: dick.wolfe@state.co.us


Division of Water Resources Web Site

www.water.state.co.us

*Appendix C –*

# Speakers and Attendees

| Speaker name | Organization | Address 1 | Address 2 | City | State | Phone | email |
|---|---|---|---|---|---|---|---|
| Earl Cassidy | USGS | PO Box 25046, MS 415 | Denver Federal Center | Lakewood | CO | 303-236-4882x230 | ecassidy@usgs.gov |
| Pat O'Toole | Ladder Livestock | PO Box 26 | | Savery | WY | 307-383-2418 | h2otoole@hotmail.com |
| Sharon O'Toole | Ladder Livestock | PO Box 26 | | Savery | WY | 307-380-8065 | |
| Dave Stewart | Stewart Environmental Consult. | 3801 Automation Way | Ste 200 | Ft. Collins | CO | 970-226-5500 | dave.stewart@stewartenv.com |
| Chuck Hennig | U.S. Bureau of Reclamation | PO Box 25007 | Denver Federal Center | Denver | CO | 303-445-2134 | chennig@do.usbr.gov |
| Steve Kasower | U.S. Bureau of Reclamation | 1720 Que Street | | Sacramento | CA | 916-444-7195 | skasower@att.net |
| Katie Benko | U.S. Bureau of Reclamation | PO Box 25007 | Denver Federal Center | Denver | CO | 303-445-2013 | kbenko@do.usbr.gov |
| Jim Otton | USGS | Box 25046 | Denver Federal Center Mail Stop 939 | Lakewood | CO | 303-236-8020 | jkotton@usgs.gov |
| David Burnett | Texas A&M University | 3116 TAMU | 710 Ricardson Bldg | College Station | TX | 979-845-2274 | david.burnett@pe.tamu.edu |
| Harold Bergman | University of Wyoming Dept. 3971 | School of Environment and Natural Resources | 1000 E. University Avenue | Laramie | WY | 307-766-5080 | bergman@uwyo.edu |
| Jill Lovato | University of Wyoming Dept. 3971 | School of Environment and Natural Resources | 1000 E. University Avenue | Laramie | WY | 307-766-5146 | jillberg@uwyo.edu |
| Greg Kerr | University of Wyoming | PO Box 3295 | Civil & Architectural Eng | Laramie | WY | 307-766-2221 | rrek@uwyo.edu |
| Gretchen Rupp | Montana State University | Montana Water Center | 101 Huffman Bldg. | Bozeman | MT | 406-994-6690 | wwwrc@montana.edu |
| Karl Wood | New Mexico State University | Water Resources Research Institute MSC 3167 | Box 30001 | Las Cruces | NM | 505-646-4337 | kawood@nmsu.edu |
| Alan Jones | Texas A&M University | Texas Water Resources Institute | | College Station | TX | | cajones@tamu.edu |
| Andrew Chang | University of California | Center for Water Resources | Rubidoux Hall - 094 | Riverside | CA | 951-827-4327 | andrew.chang@ucr.edu |
| Thomas Feeley | National Energy Technology Lab | PO Box 10940 | 626 Cochrans Mill Road | Pittsburgh | PA | 412-386-6134 | feeley@netl.doe.gov |
| Mark Limbaugh | Department of the Interior | 1849 C Street N.W. | | Washington | DC | 202-208-3186 | Mark_Limbaugh@ios.doi.gov |
| Lynn Takaichi | Kennedy Jenks Consultants | 1000 Hill Road #200 | | Ventura | CA | 805-658-0607 | lynntakaichi@kennedyjenks.com |
| Gary Bryner | University of Colorado | Natural Resources Law Center | 401 UCB | Boulder | CO | 303-492-1287 | gary_bryner@byu.edu |
| Jim Bauder | Montana State University | WQ Program Coordinator | 806 Leon Johnson Hall | Bozeman | MT | 406-994-5685 | jbauder@montana.edu |
| Steven Bushong | Porzak, Browning & Bushong | 929 Pearl Street | Suite 300 | Boulder | CO | 303-443-6800 | sjbushong@pbblaw.com |
| Todd Parfitt | Wyoming Dept. of Env. Quality | Water Quality Division | 122 West 25th St., 4th Floor, West | Cheyenne | WY | 307-777-6709 | tparfi@state.wy.us |
| B.J. Kristiansen | CoalBed Methane Coord. Coalition | 760 West Fetterman | | Buffalo | WY | 307-684-7614 | cbmbj@vcn.com |
| Blake Sanden | University of California | Cooperative Extension | 1031 S. Mt. Vernon Avenue | Bakersfield | CA | 661-868-6218 | blsanden@ucdavis.edu |
| Dick Wolfe | Colorado Dept. of Nat. Resources | Water Resources Division | 1313 Sherman St., Room 818 | Denver | CO | 303-866-3581 | Dick.Wolfe@state.co.us |
| Brad Pomeroy | Wellington Operating Company | 6065 South Quebec Street | Suite 201 | Englewood | CO | 303-220-5399 | pomoco@msn.com |
| Dave Akers | Colorado Dept. of Public Health & Env. | 4300 Cherry Creek South Drive | WQCD-WQP-B2 | Denver | CO | 303-692-3591 | daakers@smtpgate.dphe.state.co.us |
| Jill Morrison | Powder River Basin Resource Council | 23 North Scott | Suite 27 | Sheridan | WY | 307-672-5809 | resources@powderriverbasin.org |
| Paul Beels | | 1425 Fort Street | | Buffalo | WY | 307-684-1168 | paul_beels@blm.gov |
| Larry Hicks | Little Snake River Cons. District | PO Box 355 | 285 N. Penland | Baggs | WY | 307-383-7860 | lsrcd@yahoo.com |
| Mike Beeson | Wyoming Water Development Comm | 6920 Yellowtail Road | | Cheyenne | WY | 307-777-7626 | LBESSO@state.wy.us |
| Steve Degenfelder | Double Eagle Petroleum | PO Box 766 | | Casper | WY | 307-237-9330 | |
| Laurie Goodman | Trout Unlimited | Director, WY Western Water Project | 1300 N. 17th, Suite 500 | Arlington | VA | 307-733-3581 | ldgoodman1@aol.com |
| Kate Fox | Davis and Cannon | 422 W. 26th | PO Box 43 | Cheyenne | WY | 307-634-3210 | |
| Brian Macke | | 1120 Lincoln Street | Suite 801 | Denver | CO | 303-894-2100 | brian.macke@state.co.us |
| Ranil Wickramasinghe | Colorado State University | Dept. of Chemical & Biological Engineering | | Fort Collins | CO | 970-491-5276 | Ranil.Wickramasinghe@ColoState.EDU |
| Robert Ward | Colorado State University | Dept. of Civil Engineering | | Fort Collins | CO | 970-491-6308 | robert.Ward@colostate.edu |
| Matt Neibauer | Colorado State University | Dept. of Soil & Crop Sciences | | Fort Collins | CO | 970-491-5124 | Matthew.Neibauer@ColoState.EDU |
| Reagan Waskom | Colorado State University | Colorado Water Resources Research Institute | E102 Engineering Bldg | Fort Collins | CO | 970-491-6308 | Reagan.Waskom@ColoState.edu |
| Frank Yates | Yates Petroleum | 105 South 4th Street | | Artesia | NM | | |
| John Boysen | BC Technologies | 715 Grand Avenue | | Laramie | WY | 307-742-5651 | kate@davisandcannonchey.com |
| Jeff Cline | Anadarko Petroleum | 1201 Lake Robbins Drive | | The Woodlands | TX | 832-636-1000 | |
| Jack Palma | Holland & Hart | 2515 Warren Avenue | | Cheyenne | WY | 307-778-4200 | jpalma@hollandhart.com |
| Troy Bauder | Colorado State University | Dept. of Soil & Crop Sciences | | Fort Collins | CO | 491-4923 | Troy.Bauder@ColoState.EDU |
| Sandy Sorenson | Colorado State University | Colorado Water Resources Research Institute | | Fort Collins | CO | 491-6308 | |
| Tony Frank | Colorado State University | Provost's Office | | Fort Collins | CO | | tony.Frank@ColoState.EDU |

| Name | Organization | Department | City | State | Phone | E-mail | Fax |
|---|---|---|---|---|---|---|---|
| Akers, Dave | CO Department of Public Health & Env. | | Denver | CO | 303-692-3591 | | |
| Ash, Margaret | Colorado Oil & Gas Conservation Comm. | | Denver | CO | 303-894-2100 | Margaret.Ash@state.co.us | 303-894-2109 |
| Austin, Wayne | WRS Infrastructure & Environment | | Fort Collins | CO | 970-590-1903 | austinww1@aol.com | 970-221-9461 |
| Bach, Maryanne | U.S. Bureau of Reclamation | | Denver | CO | 303-445-3750 | mbach@do.usbr.gov | 303-445-6750 |
| Bansal, Kris M. | ConocoPhillips | | Houston | TX | 281-293-1223 | Kris.M.Bansal@conocophillips.com | 281-293-3424 |
| Barkmann, Peter | CGS | | Denver | CO | 303-866-2002 | peter.barkmann@state.co.us | |
| Barlow, Bernadette | Colorado State University | | Gillette | WY | 307-682-9858 | bernieb@vsn.com | |
| Barnes, John | WY State Engineer's Offices | Ground Water Division | Cheyenne | WY | 307-777-5063 | | 307-777-5451 |
| Bartos, Tim | U.S. Geological Survey | | Cheyenne | WY | 307-775-9160 | ttbartos@usgs.gov | |
| Bauder, Jim | Montana State University | | Bozeman | MT | 406-994-5685 | | |
| Bauder, Troy | Colorado State University | Soil & Crop Sciences | Fort Collins | CO | 970-491-4923 | | |
| Beek, Jaralyn | U.S. Department of the Interior | Bureau of Reclamation | Denver | CO | 303-445-3070 | jbeek@do.usbr.gov | 720-544-4220 |
| Beels, Paul | | | Buffalo | WY | 307-684-1168 | | |
| Beeson, Mike | WY Water Development Commission | | Cheyenne | WY | 307-777-7623 | LBESSO@state.wy.us | |
| Benko, Katie | U.S. Bureau of Reclamation | Denver Federal Center | Denver | CO | 303-445-2013 | | |
| Bensel, Bill | WY Water Development Commission | | Ranchester | WY | 307-655-3320 | bensel@ccorb.com | 307-655-3320 |
| Bergman, Harold | University of Wyoming | School of Environment & Natural Resources | Laramie | WY | 307-766-5080 | | |
| Bjorkman, Bjorn | Retec | | Fort Colliins | CO | 970-493-3700 | bbjorkmanr@retec.com | 919-380-7299 |
| Boysen, John | BC Technologies | | Laramie | WY | 307-742-5651 | | |
| Brewster, Anne | Senator Wayne Allard's Office | | Loveland | CO | 974-461-3530 | anne_brewster@allard.senate.gov | 970-461-3658 |
| Bruff, Matthew | Altela, Inc. | Denver Technology Center | Englewood | CO | 303-228-1605 | matthew.bruff@altelainc.com | 303-228-1655 |
| Bryner, Gary | University of Colorado | Natural Resources Law Center | Boulder | CO | 303-492-1287 | | |
| Burnett, David | Texas A & M University | | College Station | TX | 979-845-2274 | burnett@pe.tamu.edu | |
| Bushong, Steven | Porzac, Browning & Bushong | | Boulder | CO | 303-443-6800 | sjbushong@pbblaw.com | |
| Butcher, Dale | | | Greeley | CO | 970-351-7737 | dalebutche@aol.com | |
| Carswell, Bill | U.S. Geological Survey | Denver Federal Center | Lakewood | CO | 303-445-4644 | carswell@usgs.gov | 303-445-4656 |
| Carter, Peggy | Williams Production | | Gillette | WY | 307-686-1636 | peggy.carter@williams.com | 307-686-7574 |
| Cassidy, Earl | U.S. Geological Survey | Denver Federal Center | Lakewood | CO | 303-236-4882, ext. 230 | | |
| Castle, Jim | Clemson University | School of the Environment | Clemson | SC | 864-656-5015 | jcastle@clemson.edu | 864-656-1041 |
| Chang, Andrew | University of California | Center for Water Resources | Riverside | CA | 951-827-4327 | | |
| Chapman, Michelle | U.S. Bureau of Reclamation | | Denver | CO | 303-445-2264 | mchapman@do.usbr.gov | |
| Cline, Jeff | Anadarko Petroleum Corporation | | The Woodlands | TX | 832-636-1000 | jeff_cline@anadarko.com | |
| Crissup, Jake | ALL Consulting | | Tulsa | OK | 918-382-7581 | jcrissup@all-llc.com | |
| Davies, Amalia | CSU - DARE | | Fort Collins | CO | 970 491-6955 | Stephen.Davies@ColoState.EDU | 970 491-2067 |

| Name | Organization | Department | City | State | Phone | E-mail | Fax |
|---|---|---|---|---|---|---|---|
| Davies, Stephen | CSU-DARE | | Fort Collins | CO | 970 491-6955 | Stephen.Davies@ColoState.EDU | 970 491-2067 |
| Dees, Dewitt | | | Houston | TX | 713-862-8788 | ddees@zenon.com | 713-862-8788 |
| Degenfelder, Steve | Double Eagle Petroleum | | Casper | WY | 307-237-9330 | sdegenfedler@qwest.net | |
| Dickerson, Kimberly | U.S. Fish & Wildlife Service | | Cheyenne | WY | 307-772-2374 | kimberly_dickerson@fws.gov | 307-772-2358 |
| Diehl, Howard | | | Carr | Co | 970-568-3334 | | |
| Duda, John R. | U.S. Department of Energy | | Morgantown | WV | 304-285-4217 | john.duda@netl.doe.gov | 304-285-4216 |
| Dundas, Bob | Trihydro Corp. | | Casper | WY | 307-262-0480 | rdundas@trihydro.com | |
| Eddy, Jim | | | Fort Collins | CO | | opllc@msn.com | |
| Ellingson, Lindsey | CSU-DARE | | Fort Collins | CO | 970 491-6955 | Lindsey.Ellingson@ColoState.EDU | 970 491-2067 |
| Fanning, Jerry | Yates Petroleum Corporation | | Artesia | NM | 505-748-4407 | dorothyr@ypcnm.com | 505-748-4586 |
| Feeley, Thomas | National Energy Technology Lab | | Pittsburgh | PA | 412-386-6134 | | |
| Ferguson, Randall | Colorado Oil & Gas Conservation Comm. | | Denver | CO | 303-894-2100 | randall.ferguson@state.co.us | 303-894-2109 |
| Ferraro, Mike | M-I SWACO | | Houston | TX | 832-295-2610 | mferraro@miswaco.com | 832-295-2660 |
| Fesmire, Mark E. | NM Oil Conservation Commission | | Sante Fe | NM | 505-476-3460 | mark.fesmire@state.nm.us | 505-476-3462 |
| Florentin, Brad | Geomatrix Consultants | | Denver | CO | 303-534-8722 | bflorentin@geomatrix.com | 303-534-8733 |
| Ford, John | U.S. Department of Energy | | Sand Springs | OK | 918-699-2061 | john.ford@netl.doe.gov | 918-699-2005 |
| Forsting, Kate | Energy Laboratories, Inc. | | Casper | WY | 888-235-0515 | kforsting@energylab.com | 307-234-1639 |
| Fox, Kate | Davis and Cannon | | Cheyenne | WY | 307-634-3210 | | |
| Frank, Tony | Colorado State University | Provost's Office | Fort Collins | CO | | | |
| Fritz, Jack | WWC Engineering | | Sheridan | WY | 307-672-0761 | jfritz@wwcengineering.com | 307-674-4265 |
| Gabaldon, Michael | USBR | | Denver | CO | 303-445-2750 | mgabaldon@do.usbr.gov | |
| Gage, Dave | | | Greeley | CO | 970-506-0209 | | |
| Garcia, Jesse | U. S. Department of Energy | | Tulsa | OK | 918-699-2036 | jesse.garcia@netl.doe.gov | |
| Goddard | | | Greeley | CO | 970-352-0018 | | |
| Godshall | Altela, Inc. | One Technology Center | Albuquerque | NM | 505-843-4209 | ned.godshall@altelainc.com | 505-843-4208 |
| Goodman | Trout Unlimited | WY Water Project | Jackson | WY | 307-733-3581 | | |
| Grigsby | S.S. Papadopulos & Associates | | Boulder | CO | 303-939-8880 | bgrigsby@sspa.com | 303-939-8877 |
| Guerin | Los Alamos National Laboratory | | Carlsbad | NM | 505-628-2384 | dcguerin@lanl.gov | 505-628-3438 |
| Hallberg | U.S. Geological Survey | Wyoming WSC | Cheyenne | WY | 307-775-9165 | lhallber@usgs.gov | |
| Harju | WY State Engineer's Offices | Ground Water Division | Cheyenne | WY | 307-777-5063 | jharju@seo.wyo.gov | 307-777-5451 |
| Haswell | Pearl Development Company | | Sheridan | WY | 307-672-8090 | rhinesmith_rb@pearldc.com | 307-672-8091 |
| Hayes | Gas Technology Institute | | Mount Prospect | IL | 847-768-0722 | tom.hayes@gastechnology.org | 847-768-0501 |
| Healy | U.S. Geological Survey | Denver Federal Center | Lakewood | CO | 303-236-5392 | rwhealy@usgs.gov | 303-236-5034 |
| Henderson | | | Aspen | CO | 210-216-5966 | k_henderson@mac.com | |

| Name | Organization | Department | City | State | Phone | E-mail | Fax |
|---|---|---|---|---|---|---|---|
| Hennig | U.S. Bureau of Reclamation | | Denver | CO | 303-445-2134 | chennig@do.usbr.gov | |
| Hicks | Little Snake River Cons. District | | Baggs | WY | 307-383-7860 | | |
| Hoffmeyer | Primary National Resources, Inc. | | Casper | WY | 307-237-5055 | rhoffmeyer@primarynatural.com | 307-237-5455 |
| Holliday | Holliday Env. Serv., Inc. | | Bellaire | TX | 713-668-7640 | ghh@houston.rr.com | |
| Holm | USDA Forest Service | | Lakewood | CO | 303-275-5094 | mholm@fs.fed.us | |
| Hood | CBM Associates Inc. | | Laramie | WY | 307-742-4991 | ghood@cbmainc.com | 307-745-1582 |
| Hoyt | | | Gillette | WY | 307-685-5618 | jhoyt@marathonoil.com | 307-682-7621 |
| Hurless | WY Governor's Office | | Cheyenne | WY | 307-777-8521 | rhurle@state.wy.us | 307-777-8586 |
| Irwin | National Park Service | | Fort Collins | CO | 970-225-3520 | roy_irwin@nps.gov | |
| Jessen | | | Cheyenne | WY | 307-634-7848 | cjessen@stateswest.com | 307-634-7851 |
| Jin | Western Research Institute | | Laramie | WY | 307-721-2404 | sjin@uwyo.edu | 307-721-2256 |
| Johnson | U.S. Army Corps of Engineers | | Cheyenne | WY | 307-772-2300 | Thomas.B.Johnson@usace.army.mil | 307-772-2920 |
| Jones | Texas A & M University | Texas Water Resources Institute | College Station | TX | | | |
| Jones | East Larimer County Water District | | Fort Collins | CO | 970-493-2044 | hwebster@frii.com | 970-493-1801 |
| Jorgensen | U.S. Bureau of Reclamation | | Denver | CO | 303-445-3604 | ejorgensen@do.usbr.gov | |
| Kasower | U.S. Bureau of Reclamation | Denver Federal Center | Sacramento | CA | 916-444-7195 | | |
| Kelley | Rosebud Conservation District | | Forsyth | MT | 406-346-7479 | laurie.kelley@mt.nacdnet.net | 406-346-7479 |
| Kerr | University of Wyoming | Civil & Architectural Engineering | Laramie | WY | 307-766-2221 | | |
| Kohler | Williams Production | | Gillette | WY | 307-686-1636 | gretchen.kohler@williams.com | 307-686-7574 |
| Kohut | Environmental Water Technology | | Deland | FL | 386-216-2425 | | |
| Kottenstette | Sandia National Laboratories | | Albuquerque | NM | 505-845-3270 | rkotten@sandia.gov | |
| Krafft | WY Division of Environmental Quality | Department of Water Quality | Cheyenne | WY | | lkraff@state.wy.us | |
| Kristiansen | Coal Bed Methane Coord. Coalition | | Buffalo | WY | 307-684-7614 | | |
| Lamb | WY Dept. of Environmental Quality | | Casper | WY | 307-473-3452 | dlamb@state.wy.us | 307-473-3458 |
| Leong | Kennedy/Jenks Consultants | | Irvine | CA | 949-261-1577 | LarryLeong@KennedyJenks.com | |
| Limbaugh | U.S. Department of the Interior | | Washington | DC | 202-208-3186 | | |
| Lindblom | Colorado Oil & Gas Conservation Comm. | | Denver | CO | 303-894-2100 | steven.lindblom@state.co.us | |
| Logan | RTW Engineering | | Denver | CO | 720-931-9314 | ajl@rtweng.com | |
| Lovato | University of Wyoming | School of Environment & Natural Resources | Laramie | WY | 307-766-5146 | | |
| Lovett | Wyoming DEQ | | Cheyenne | WY | 307-777-5630 | blovet@state.wy.us | |
| Lyon | U. S. Representative Barbara Cubin | | Casper | WY | 307-261-6585 | Chris.lyon@mail.house.gov | 307-261-6597 |
| Macke | | | Denver | CO | 303-894-2100 | | |
| MacKinnon | WY Water Development Commission | | Casper | Wy | 307-472-4930 | | 307-472-4930 |
| Madrid | | | Cheyenne | WY | 307-775-6201 | michael_madrid@blm.gov | |

| Name | Organization | Department | City | State | Phone | E-mail | Fax |
|---|---|---|---|---|---|---|---|
| Manzanares | Las Animas County | | Trinidad | CO | 719-845-2599 | jcm3@sensonics.org | 719-846-0150 |
| Marinelli | Telesto Solutions, Inc. | | Fort Collins | CO | 970-484-7704 | fmarinelli@telesto-inc.com | |
| Markey | U.S. Senator Ken Salazar | North Central Region | Fort Collins | CO | 970-224-2200 | Betsy_Markey@salazar.senate.gov | 970-224-2205 |
| Marrone | U.S. Department of the Interior | Bureau of Reclamation | Denver | CO | 303-445-3070 | dmarrone@do.usbr.gov | 720-544-4220 |
| Mason | U.S. Geological Survey | | Cheyenne | WY | 307-775-9166 | jpmason@usgs.gov | |
| McKay | CDR Associates | | Boulder | CO | 303-442-7367 | jmckay@mediate.org | 303-442-7442 |
| Miller | Colorado Water Conservation Board | | Denver | CO | 303-866-3532 | steve.miller@state.co.us | 303-866-4474 |
| Million | Colorado State University | | Fort Collins | CO | 970-215-2603 | | |
| Misegadis | | | Centennial | CO | 303-263-0228 | jmisegadis@brockeasley.com | |
| Moncure | Nance Petroleum | | Billings | MT | 406-869-8701 | gmoncure@nancepetro.com | |
| Moon | Argonne National Laboratory | | Argonne | IL | 630-252-8683 | pmoon@anl.gov | |
| Morris | Western Research Institute | | Laramie | WY | 307-721-2404 | jmorris@uwyo.edu | 307-721-2256 |
| Morrison | Powder River Basin Resource Council | | Sheridan | WY | 307-672-5809 | | |
| Naddy | ENSR | | Fort Collins | CO | 970-416-0916 | rnaddy@ensr.com | |
| Neibauer | Colorado State University | Soil & Crop Sciences | Fort Collins | CO | 970-491-5124 | | |
| Nelson | U.S. Fish & Wildlife Service | | Helena | MT | 406-449-5225 | karen_nelson | 406-449-5339 |
| Nichols | RHN Water Resources Consultations | | Montrose | CO | 970-252-0278 | rhnwater@montrose.net | |
| Nuccio | U.S. Geological Survey | Denver Federal Center | Denver | CO | 303-236-1654 | Vnuccio@usgs.gov | |
| Oatman | Las Animas County Coop. Extn. | | Trinidad | CO | 719-846-6881 | dean.oatman@colostate.edu | 719-846-4257 |
| O'Toole | Ladder Livestock | | Savery | WY | 307-383-2418 | | |
| O'Toole | Ladder Livestock | | Savery | WY | 307-380-8065 | | |
| Otton | U.S. Geological Survey | Denver Federal Center | Lakewood | CO | 303-236-8020 | | |
| Palma | Holland & Hart | | Cheyenne | WY | 307-778-4200 | | |
| Parfitt | WY Dept. of Environmental Quality | Water Quality Division | Cheyenne | WY | 307-777-6709 | | |
| Paxson | U. S. Senator Craig Thomas | | Cheyenne | WY | 307-772-2451 | | 307-638-3512 |
| Pearson | | | Greeley | CO | 970-539-5169 | pearson420@msn.com | |
| Pearson | | | Greeley | CO | 970-539-5168 | rpearson19@juno.com | |
| Penoyer | National Park Service | | Fort Collins | CO | 970-225-3535 | pete_penoyer@nps.gov | 970-225-9965 |
| Phelps | The SeaCrest Group | | Louisville | CO | 303-249-5496 | sphelps@seacrestgroup.com | 303-661-9325 |
| Pillard | ENSR | | Fort Collins | CO | 970-416-0916 | dpillard@ensr.aecom.com | 970-490-2963 |
| Pochop | University of Wyoming | Civil & Architectural Engineering | Laramie | WY | 307-766-3326 | pochop@uwyo.edu | 307-766-2221 |
| Pohl | Sandia National Laboratories | | Albuquerque | NM | 505-844-2992 | pipohl@sandia.gov | 505-844-2348 |
| Pomeroy | Wellington Operating Company | | Englewood | CO | 303-220-5399 | | |
| Ponce | USGS | | Reston | VA | 703-648-7043 | sponce@usgs.gov | 703-648-7031 |

| Name | Organization | Department | City | State | Phone | E-mail | Fax |
|---|---|---|---|---|---|---|---|
| Pratt | U.S. Environmental Protection Agency | Ecosystems Protection and Remediation | Denver | CO | 303-312-6575 | | |
| Price | U. S. Bureau of Reclamation | | Denver | CO | 303-445-2260 | kprice@do.usbr.gov | 303-445-6329 |
| Price | CGRS, Inc. | | Fort Collins | CO | 970-493-7780 | randy@cgrs.com | 970-493-7986 |
| Purves | Trout Unlimited | | Lander | WY | 307-332-6700 | cpurves@tu.org | 307-332-9299 |
| Redlinger | U.S. Bureau of Reclamation | | Boulder City | NV | 702-293-8129 | jredlinger@lc.usbr.gov | 702-293-8023 |
| Rehder | U.S. Environmental Protection Agency | Region 8 | Denver | CO | 303-312-6293 | rehder.timothy@epa.gov | |
| Rice | U. S. Geological Survey | | Denver | CO | 303-236-1989 | crice@usgs.gov | |
| Rumbold | U.S. Bureau of Land Management | | Lakewood | CO | 303-239-3722 | Edward_Rumbold@co.blm.gov | 303-239-3808 |
| Rupp | Montana Water Center | | Bozeman | MT | 406-994-6690 | grupp@montana.edu | 406-994-1774 |
| Rynearson | EnCana Oil & Gas | | Denver | CO | 720-876-5337 | Michael.Rynearson@EnCana.com | 720-876-6337 |
| Sanden | University of California | Cooperative Extension | Bakersfield | CA | 661-868-6218 | | |
| Sanford | Colorado State University | Department of Geosciences | Fort Collins | CO | 970-491-5929 | | |
| Schreck | Pioneer Natural Resources | | Denver | CO | 303-675-2782 | stephen.schreck@pxd.com | 303-294-1275 |
| Schuckman | BeneTerra, LLC | | Dodge City | KS | 620-225-4637 | deketa@beneterra.com | 316-462-0606 |
| Seaworth | Wellington Water Works | | Wellington | CO | | | |
| Shah | CDR Associates | | Boulder | CO | 303-442-7367 | mshah@mediate.org | 303-442-7442 |
| Simpson | Colorado State University | Continuing Education | Fort Collins | CO | 970-491-1129 | rsimpson@learn.colostate.edu | 970-491-7886 |
| Slaughter | U.S. Geological Survey | Rocky Mountain Arsenal | Commerce City | CO | 303-389-0370 | cslaught@usgs.gov | 303-389-0937 |
| Smith | Trihydro Corp. | | Casper | WY | 307-258-2668 | csmith@trihydro.com | |
| Smith | SEPCO Corp. | | Fort Collins | CO | 970-282-9015 | sepcoiii@earthlink.net | |
| Smith | Aqua Engineering, Inc. | | Fort Collins | CO | 970-229-9668 | swsmith@aquaengr.com | |
| Snow | | | Arvada | CO | 303-421-1167 | dtsnow@comcast.net | |
| Snyder | Argonne National Laboratory | Chemical and Biological Technology | Argonne | IL | 630-252-7939 | seth@anl.gov | 630-252-1342 |
| Soeth | U.S. Bureau of Reclamation | | Denver | CO | 303-445-3615 | psoeth@do.usbr.gov | |
| Somermeyer | Retec | | Fort Colliins | CO | 970-493-3700 | gsomermeyer@retec.com | 919-380-7299 |
| Sommers | Colorado State University | Agriculture Experiment Station | Fort Collins | CO | | | |
| Sorenson | | | Arvada | WY | 307-736-2251 | rnsorenson@rangeweb.net | |
| Sorenson | Colorado State University | Colorado Water Resources Research Inst. | Fort Collins | CO | 970-491-6308 | | |
| Sosebee | O&G Environmental Consulting, LLC | | Englewood | CO | 720-529-9777 | jsosebee@ogenvironmental.com | 720-529-9798 |
| Spellman | | | Arvada | WY | 307-736-2464 | dkspellman@rangeweb.net | 307-736-2474 |
| Squillace | University of Colorado | Natural Resources Law Center | Boulder | CO | | | |
| Stavnes | USEPA Region 8 | Wastewater Unit | Denver | CO | 303-312-6117 | stavnes.sandra@epa.gov | |

| Name | Organization | Department | City | State | Phone | E-mail | Fax |
|---|---|---|---|---|---|---|---|
| Stednick | Colorado State University | Forest, Rangeland & Watershed Steward. | Fort Collins | CO | 970-491-7248 | | |
| Stewart | WY Game & Fish Dept. | | Sheridan | WY | 307-672-8003. ext. 237 | Bud.Stewart@wgf.state.wy.us | |
| Stewart | Stewart Environmental Consultations | | Fort Collins | CO | 970-226-5500 | | |
| Stone | U.S. Bureau of Land Management | | Rawlins | WY | 307-328-4314 | andy_stone@blm.gov | |
| Sutton | MD Campbell and Associates | | Loveland | CO | 970-635-2508 | tsutgeol@cs.com | |
| Sweat | U. S. Geological Survey | Wyoming WSC | Cheyenne | WY | 307-775-9165 | | |
| Taggart | Tercio Ranch | | Weston | CO | 719-868-2245 | craig.taggart@tercioranch.com | 719-868-2225 |
| Takaichi | Kennedy Jenks Consultants | | Ventura | CA | 805-658-0607 | | |
| Tate | CDR Associates | | Boulder | CO | 303-442-7367 | dtate@mediate.org | |
| Temple | Southern Nevada Water Authority | | Las Vegas | NV | 702-822-3378 | colby.temple@snwa.com | 702-862-3751 |
| Thamke | U.S. Geological Survey | | Helena | MT | 406-457-5923 | jothamke@usgs.gov | |
| Thrush | EnCana Oil & Gas (USA) Inc. | | Denver | CO | 720-876-5012 | mark.thrush@encana.com | 720-876-6012 |
| Thyne | Colorado Energy Research Institute | | Golden | CO | 303-273-3104 | gthyne@mines.edu | 303-273-3859 |
| Topper | Colorado Geological Survey | | Denver | CO | 303-866-2029 | ralf.topper@state.co.us | |
| Torres | Las Animas County | | Trinidad | CO | 719-845-2568 | lasanimascounty@sensonics.org | 719-845-2598 |
| Trout | USDA - ARS | | Fort Collins | CO | 970-492-7419 | thomas.trout@ars.usda.gov | |
| Tyrrell | Fort Peck Assiniboine & Sioux Tribes | | Poplar | MT | 406-768-5155 | tyrrell@nemont.net | 406-768-5606 |
| Veil | Argonne National Laboratory | | Washington | DC | 202-488-24550 | jveil.@anl.gov | 202-488-2413 |
| Vrooman | Petro-Canada | | Denver | CO | 303-350-1171 | alan.vrooman@petro-canada.com | |
| Ward | Colorado State University | Civil Engineering | Fort Collins | CO | 970-491-6308 | | |
| Waskom | Colorado State University | Colorado Water Resources Research Inst. | Fort Collins | CO | 970-491-6308 | | |
| Watzlaf | U.S. Department of Energy | NETL | Pittsburgh | PA | 412-386-6754 | watzlaf@netl.doe.gov | |
| Welch | Montana DEQ | | Helena | MT | 406-444-4964 | swelch@mt.gov | 406-444-1923 |
| Wickramsinghe | Colorado State University | Chemical & Biological Engineering | Fort Collins | CO | 970-491-5276 | | |
| Wilson | U.S. Environmental Protection Agency | Ecosystems Protection and Remediation | Denver | CO | 303-312-6562 | | |
| Wolfe | CO Department of Natural Resources | Water Resource Division | Denver | CO | 303-866-3581 | | |
| Wood | NM Water Res. Research Institute | | Las Cruces | NM | 505-646-4337 | kwood@wrri.nmsu.edu | 505-646-6418 |
| Xu | Colorado School of Mines | Envir. Science & Engineering | Golden | CO | 303-273-3932 | pxu@mines.edu | 303-273-3413 |
| Yates | Yates Petroleum Corporation | | Artesia | NM | 505-748-4407 | dorothyr@ypcnm.com | 505-748-4586 |
| Zielinski | U. S. Geological Survey | | Lakewood | CO | 303-236-4719 | rzielinski@usgs.gov | 303-232-3200 |
| Zupancic | BeneTerra LLC | | Sheridan | WY | 307-751-6805 | jwz@beneterra.com | |
| Zvonar | U.S. Department of Energy | | Carlsbad | NM | 505-234-7495 | cynthia.zvonar@wipp.ws | 505-234-7061 |

Colorado State University

Colorado Water Resources Research Institute
E-102 Engineering Building
Colorado State University
Fort Collins, CO 80523-2033
(970) 491-6308
e-mail: cwrri@colostate.edu
http://cwrri.colostate.edu.