Produced Water in Southern Colorado: Charting a New Course

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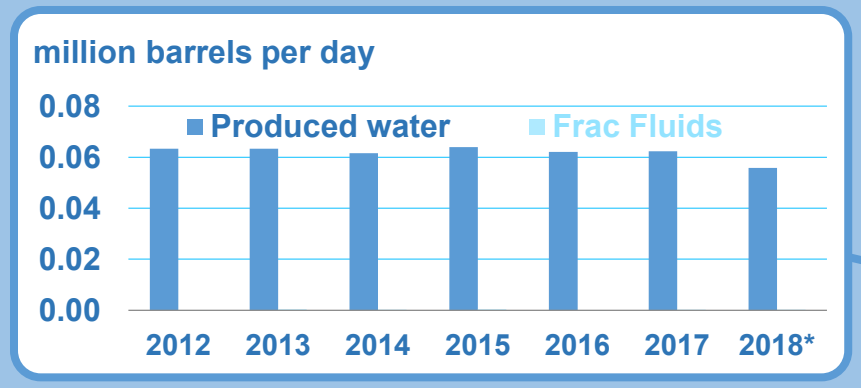
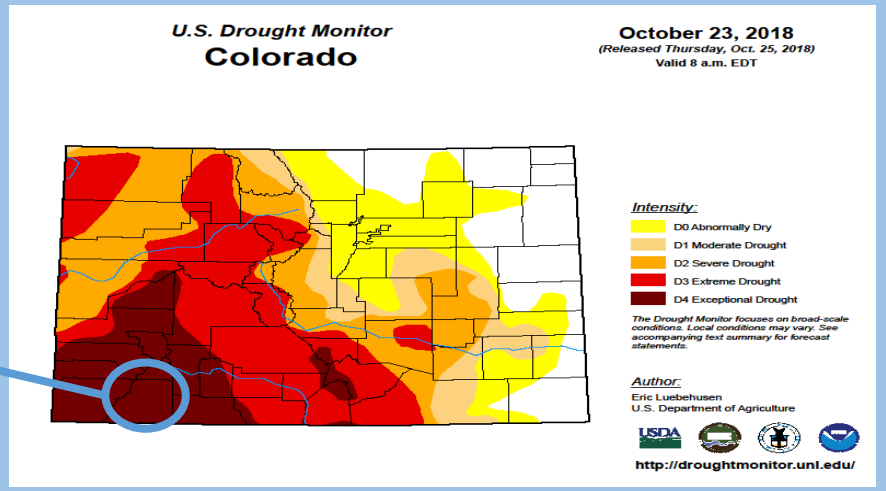
***This presentation is done in my capacity as a private individual and does not reflect the views of my employer, the Bureau of Land Management.**

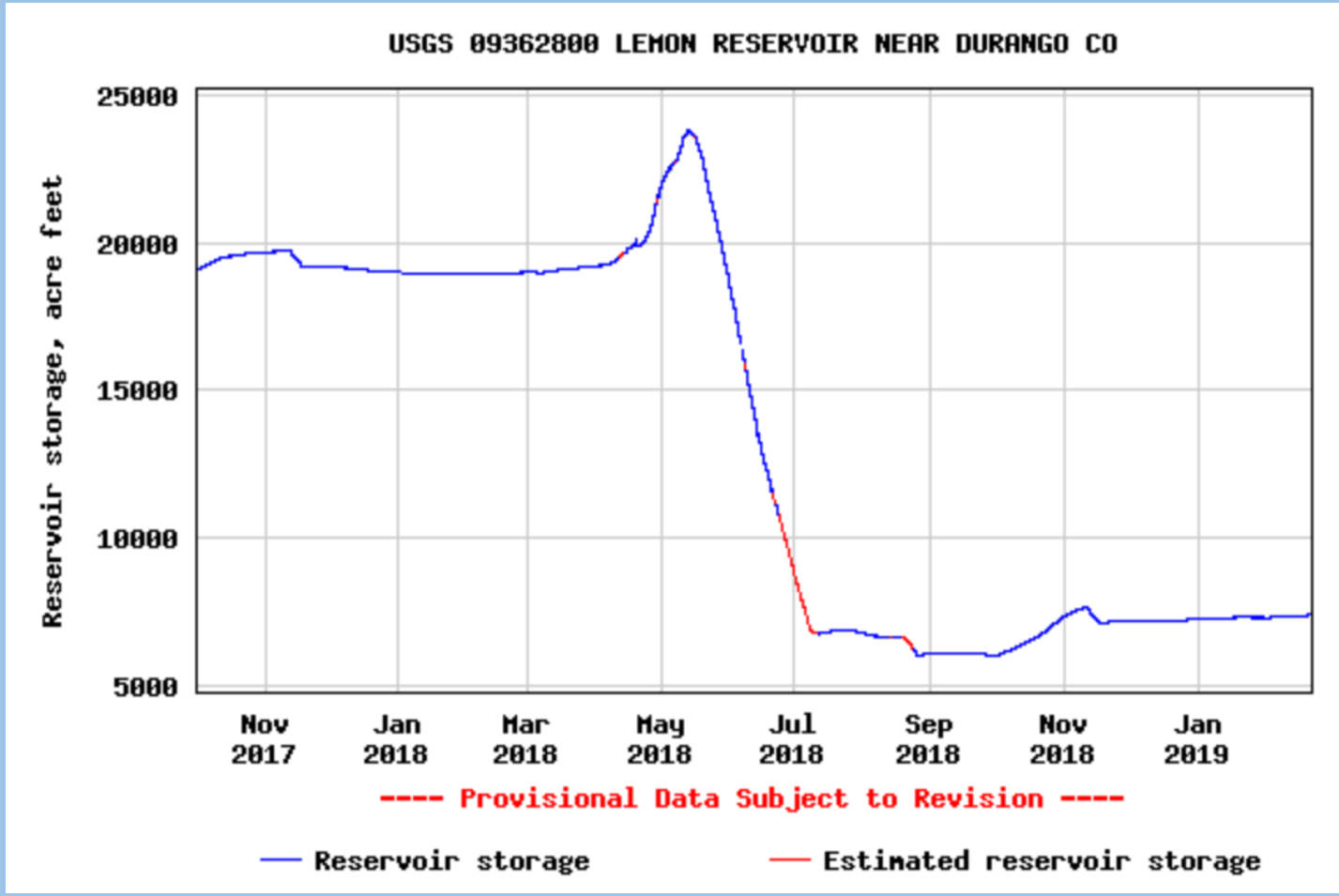
Why southern Colorado?

- Produced water volumes high outstrip onsite needs
- Exposure to severe drought for agriculture, industry
- Fruitland: Largely fresh water (<10,000 mg/l TDS)
- Demand growth from residential population increase





Dangerously low levels at Lemon Dam



- Operated by Florida Water Conservancy District.
- Uses include irrigation, livestock watering, recreation (USFS), but increasingly residential.
- At 17% of capacity in Summer 2018

Graph source: U.S. Geological Survey (USGS). Additional information from the Water Information Program (WIP).

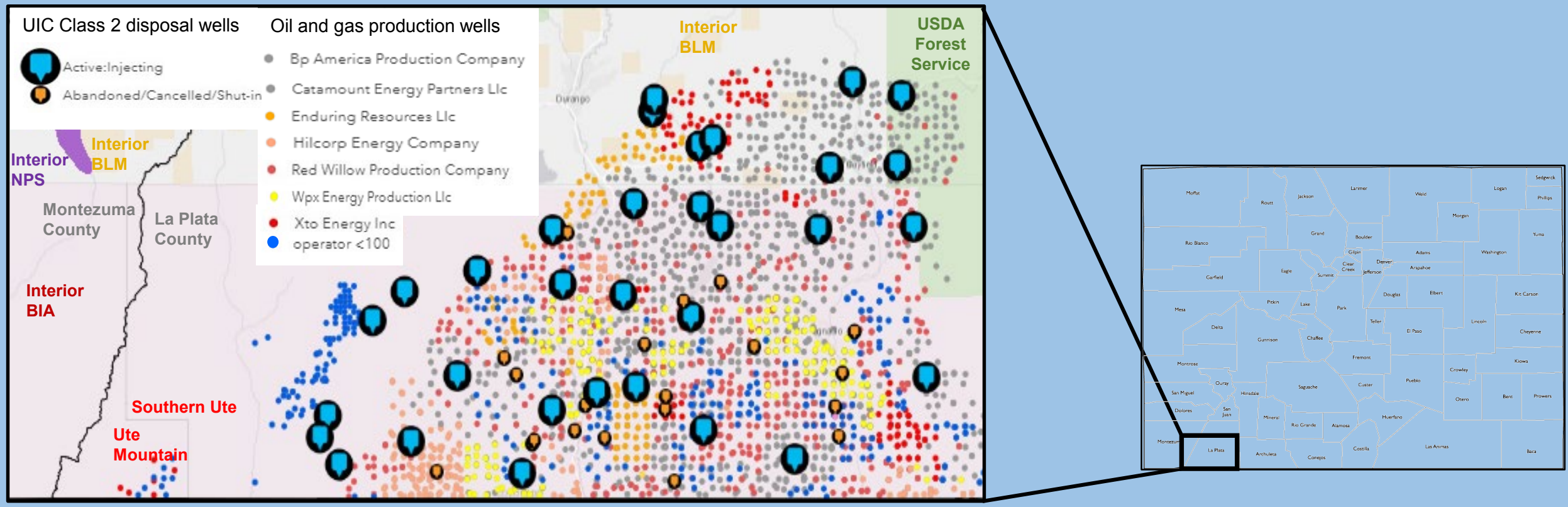
USGS link: https://nwis.waterdata.usgs.gov/co/nwis/uv?cb_00054=on&format=gif_default&site_no=09362800&period=&begin_date=2017-10-01&end_date=2019-02-22

WIP link: https://waterinfo.org/program-partners/florida-water-conservancy-district/

What do we need to know?

- Operator needs and conditions
- Water quality parameters
- Treatment needs
- Potential buyers

Operator needs and conditions: UIC



Source: Well data imported from imported from the EIA and Ground Water Protection Council's National Oil and Gas Gateway Initiative.

- 34 active, injecting C2d wells, none being permitted. No known capacity constraints.
- Most pipe PW to their own UIC wells.
- Some smaller operators truck PW to SWD wells; can be expensive: $.03/bbl/mile (Coday, 2015).

Water quality parameters

Source: AquaMatrix International, 2007.

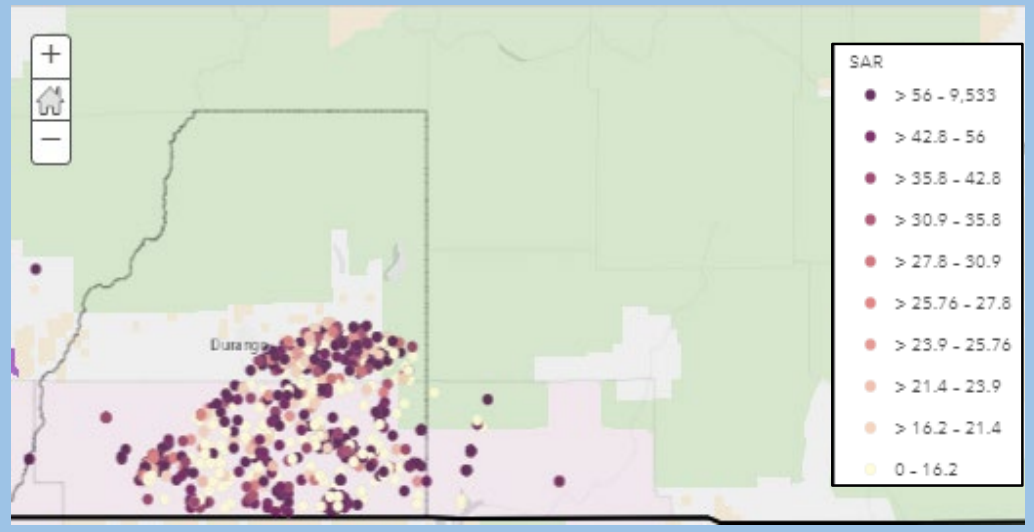
- **Free methane** Dissolves oxygen, creates IRBs (precipitation), SRBs (corrosion) (Gorody, 2001).
- **Polycyclic aromatic hydrocarbons** (Orem, Tatu, Lerch, 2007).
  - Some low-weight, non-carcinogenic PAHs found in some CBM produced water from Gilette, Wyoming. Long-term effects unclear.
- **Dissolved BTEX**
  - Benzene, Toluene, Ethyl benzene, Xylene) organics.
- **Other elements to test for**
  - Iron, manganese, dissolved nitrogen, bromine, and fluorine, select potentially hazardous metals.

Treatment needs

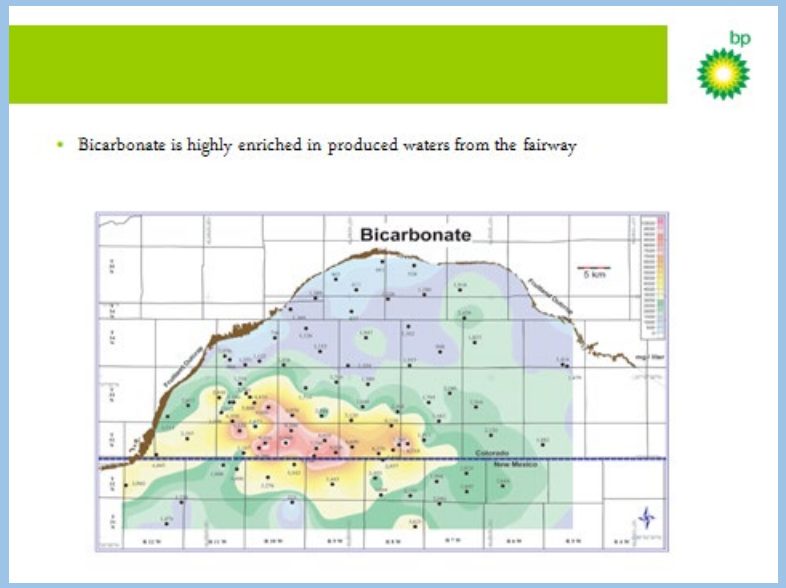
- Special samples for dissolved methane – isotopic analysis, chromatography.
- Need to test for sodicity (for irrigation).
- Heterogeneous bicarbonate content. How to handle aggregation across wells?

SAR*
Purple = issue

*Sodium Adsorption Ratio
[Na] / {[(Ca+Mg)/2]^(½)}

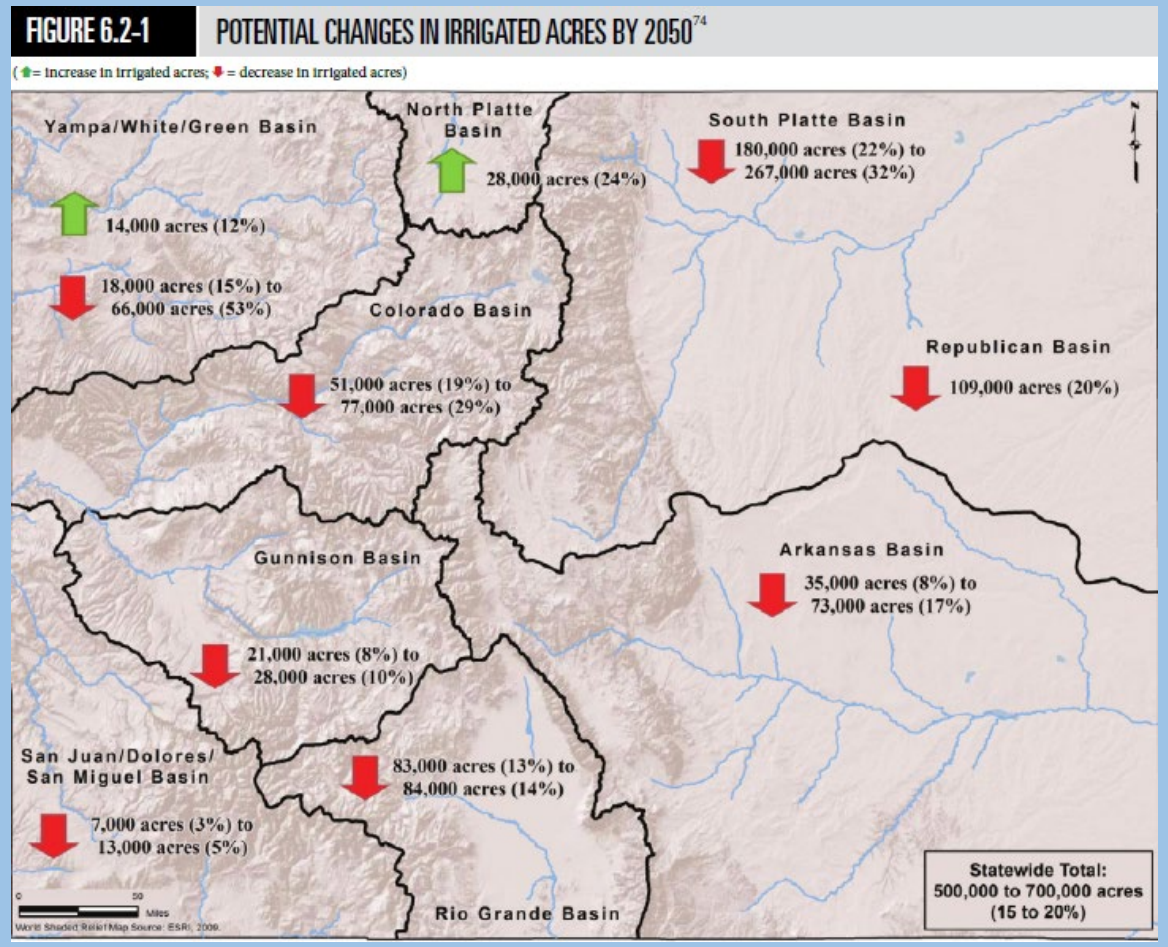


Source: U.S. Geological Survey Produced Water Database.
SAR calculations done with USGS produced water data.



Source: Presentation from British Petroleum.

Potential buyers: Agriculture



Source: “Colorado’s State Water Plan”. Colorado Water Conservation Board, 2015.

- 3.9-BBbl irrigation supply gap by 2050. Growth in buy-and-dry a major problem (CWCB, 2015).
- Surface-drip irrigation works in Wyoming PRB (National Academy of Sciences, 2010).
- $1,000/acre foot would be “too much” (about $0.13/barrel).
- Dolan, Cath, Hague (2018): Full CBM water treatment train for San Juan:* $0.37/barrel.

*Includes deoiling, air stripping, nanofiltration, sodium adjustment, evap ponds, brine disposal.

Potential buyers: Ranchers

- Sodicity (SAR) not an issue. Prices likely still are.
- TDS <1,000 mg/L best, works with some issues at up to 7,000 mg/L.
- La Plata County: 2nd statewide in horse, pony, mule, burro sales.

Tire tank used for stock watering. Overflow of treated CBM produced water can supply livestock over greater area.

Table 4-1
Water Quality Guide for Livestock Use

TDS (ppm)*	Livestock Watering Comments
Less than 1,000 (EC < 1.5 mmhhos/cm)	Excellent for all classes of livestock.
1,000 to 2,999 (EC = 1.5-5 mmhos/cm)	Very satisfactory for all classes of livestock. May cause temporary and mild diarrhea in livestock not accustomed to them.
3,000 to 4,999 (EC = 5-8 mmhos/cm)	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them.
5,000 to 6,999 (EC = 8-11 mmhos/cm)	Can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses. Avoid use for pregnant or lactating animals.
7,000 to 10,000 (EC = 11-16 mmhos/cm)	Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10.000 (EC > 16 mmhos/cm)	This water is considered unsatisfactory for all classes of livestock.

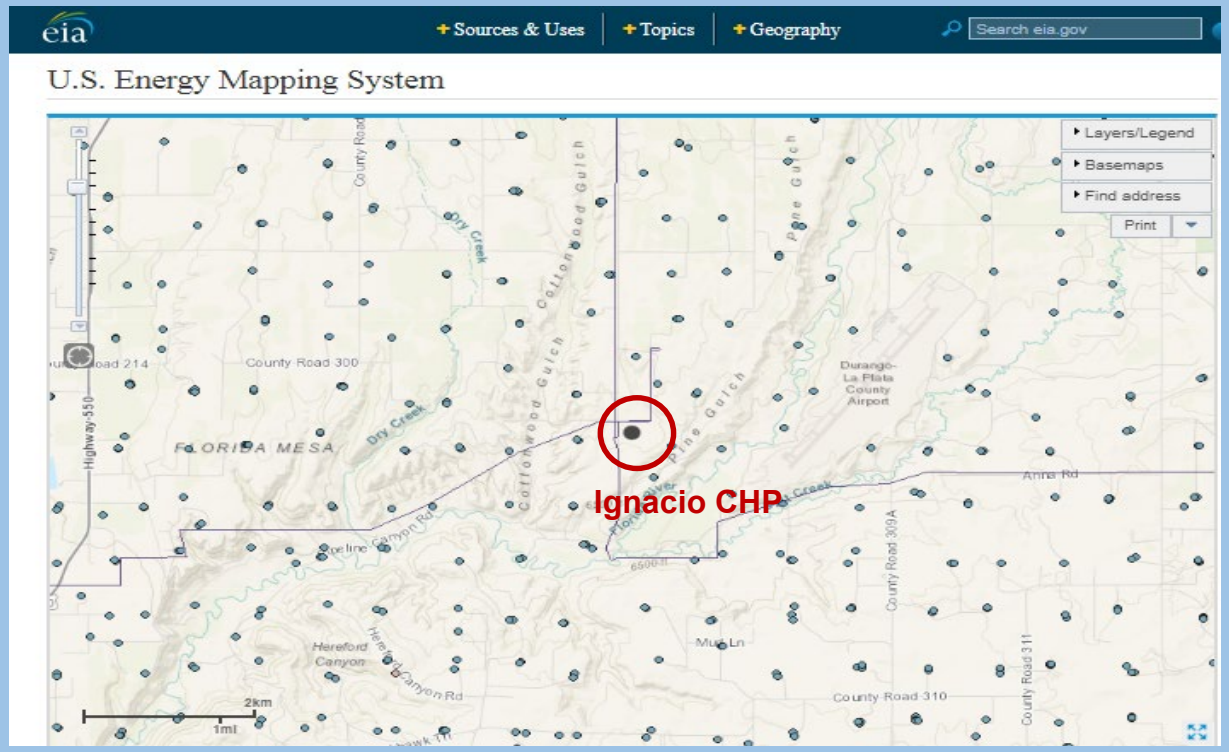
Note: Electrical conductivity (EC) expressed in micromhos per centimeter at 25°C can be substituted for t dissolved solids without introducing a great error in interpretation. Source: NAS, 1974

Effect on livestock at different TDS levels.

Source for both photos: ALL Consulting, Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives. July 2003.

Potential Buyers: Power Plants

- Ignacio combined heat and power (CHP) plant at Harvest Midstream processing plant – presents great possibility.
- Uses Florida River for cooling. Some water captured onsite entrained in gas stream.
- Low calcium content an advantage – less likely to scale on stainless steel.



Source: U.S. Energy Information Administration, Energy Mapping System.

- San Juan Generating Station (National Energy Technology Laboratory, 2006): Worked with $1,000/acre-foot ($0.13/bbl) tax credit under higher-recovery scenarios.

Conclusions

- **Operator Needs and Conditions** Revenue alone not enough of an incentive. Must also provide avoided transportation and injection costs.
- **Water Quality Parameters** Low-TDS, but BTEX, PAH, SAR, methane all issues.
- **Treatment Needs** Heterogeneity creates complications. Aggregation an issue.
- **Potential Buyers** Power plant reuse may be economic w/o desal, and/or with state/Federal credits. May not require desalination (Co-Vap).
- Continued demand, drought issues, could bring alternative reuse back in-play.
- Whole testing suite costs about $800 per sample, 25 well samples = $20,000. Potential benefit for industry, agriculture, developers, conservation, CWCB goals.

Questions?

Bonus slides

Legal / Regulatory Issues

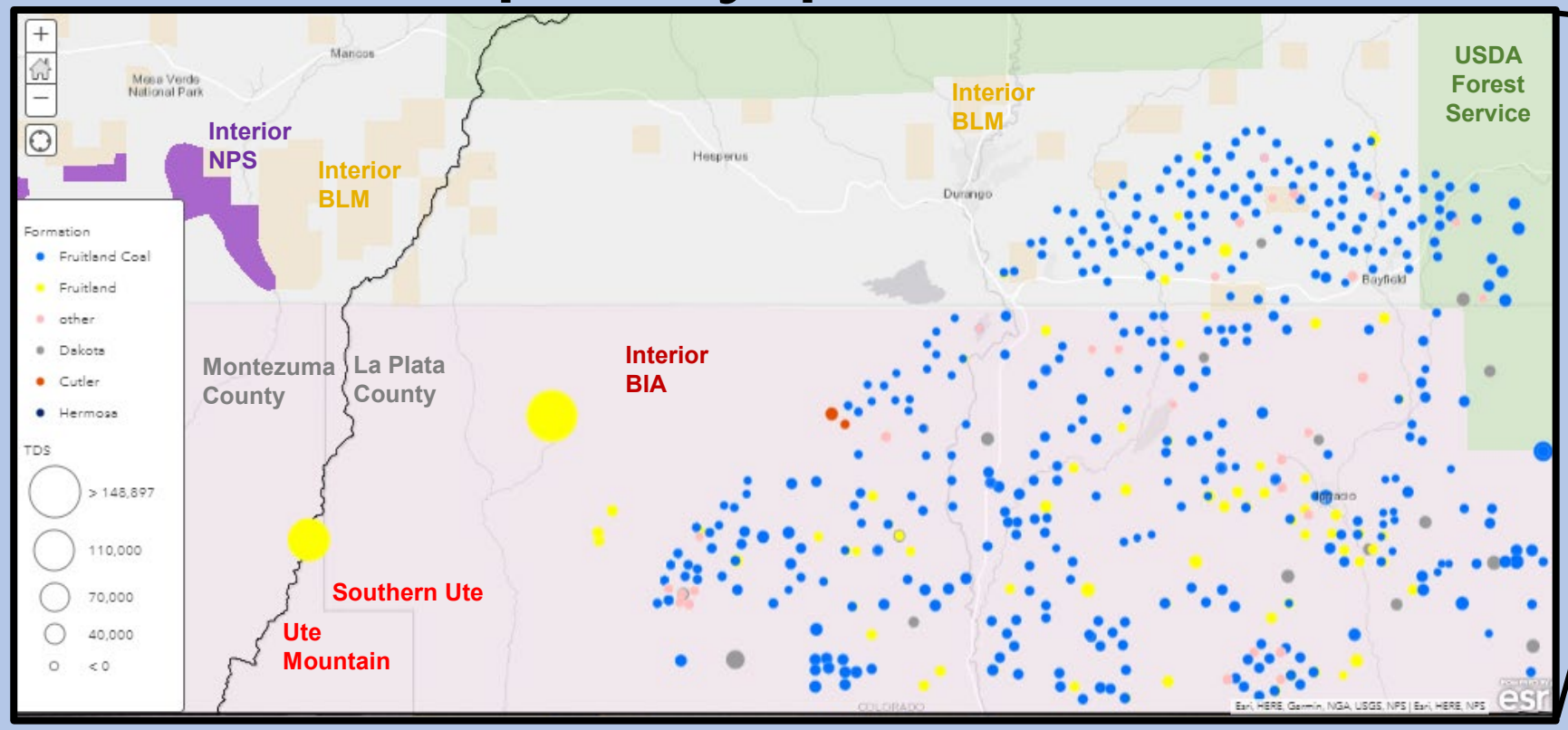
Drivers

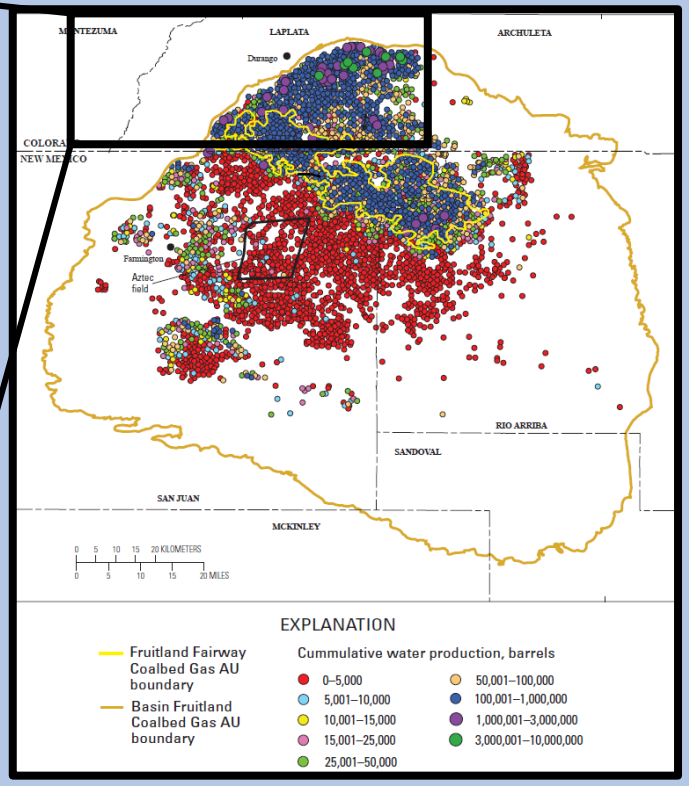
- Rule 907 (2 CRR 404-1 907)
  - “Waste minimization” plan approval from COGCC for beneficial use.
  - Discharge, evaporation ponds are allowed as disposal methods.
- Vance v. Wolfe
  - 2009 (CO Supreme Court).
  - Dewatering is beneficial use.
    - If tributary, requires permit, augmentation plan from CDPHE.

Obstacles

- Revenue split
  - Lease owners typically get a split of any revenue (part of contract).
- Tort litigation
  - Has followed CBM development.
  - Most claims unsubstantiated, but operators lack baseline data for defense. Need an environmental management system (EMS) in-place (Glantz, Gorody, and Mueller, 2002).

Water quality parameters



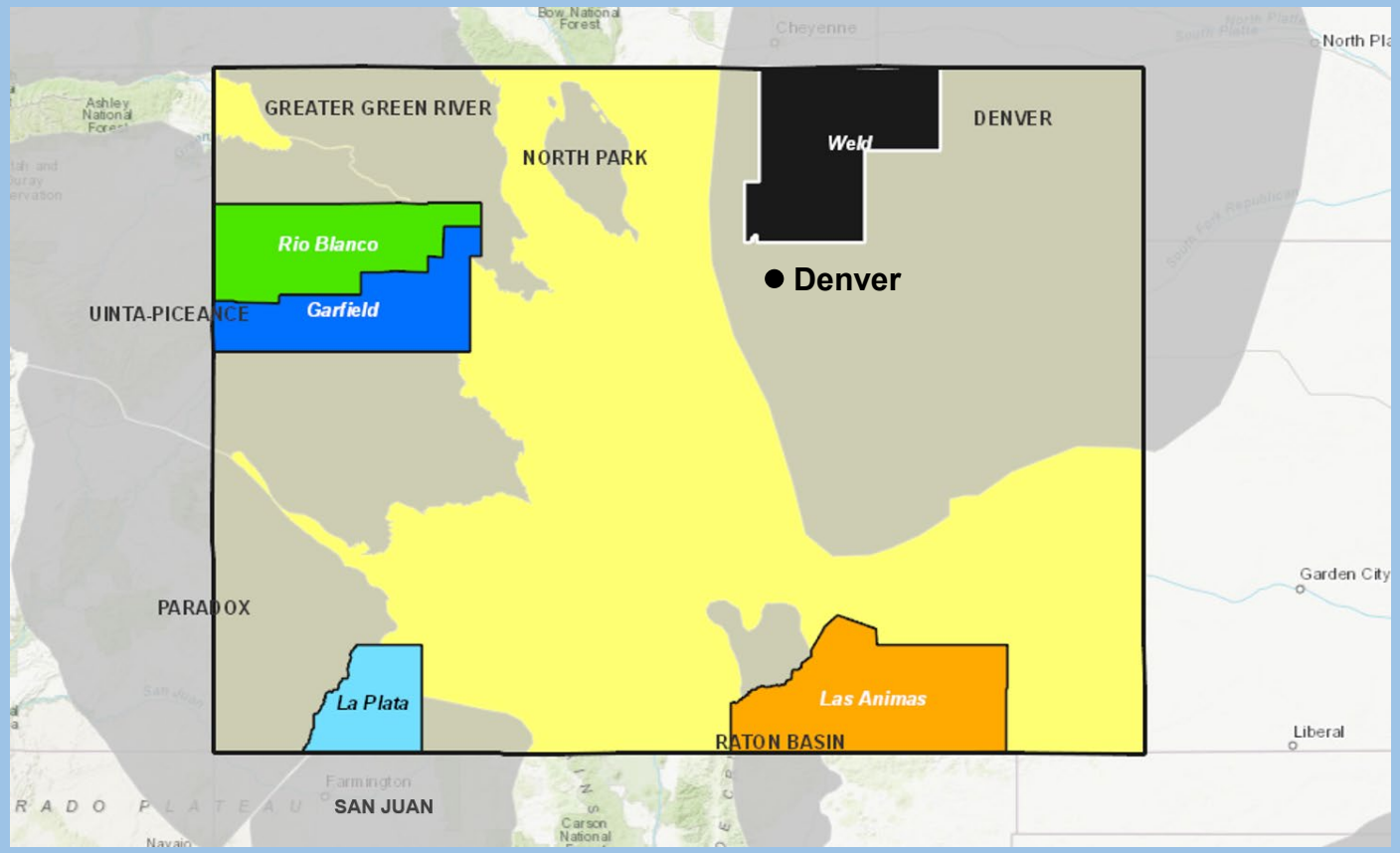


Source: U.S. Geological Survey Produced Water Database.

Ridgely, J.L., S.M. Condon, and J.R. Hatch. Geology and Oil and Gas Assessment of the Fruitland Total Petroleum System, San Juan Basin, New Mexico and Colorado. U.S. Geological Survey, 2013. **Figure 34.** Production data from IHS Energy Group (2002).

- Approximately two-thirds of 3,300 wells in Fruitland Coal formation.
- Additional conventional gas wells in Fruitland, Dakota, Hermosa, and Cutler.
- TDS<10,000 mg/l in 85% of well samples, <5,000 mg/l in 56% of samples.

Top-five produced water counties in Colorado



Basins layer from U.S. Energy Information Administration (EIA), U.S. Shale Plays Map.

Tight oil

Weld County – Denver-Julesburg

Conventional Gas

Rio Blanco County – Uinta/Piceance

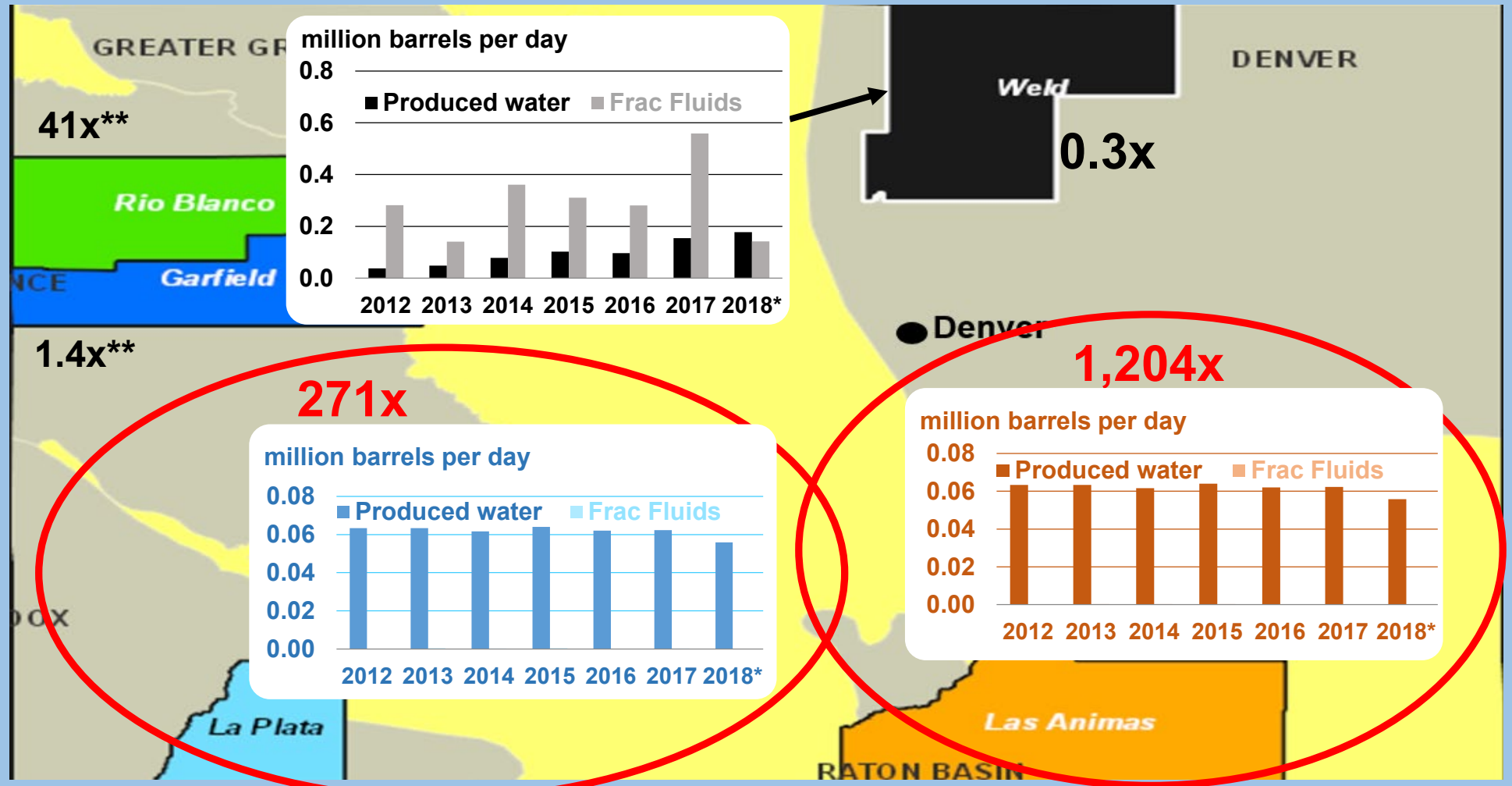
Garfield County – Uinta/Piceance

Coal Bed Methane / Conventional gas

La Plata County – San Juan/Fruitland

Las Animas County – Raton/Vermejo

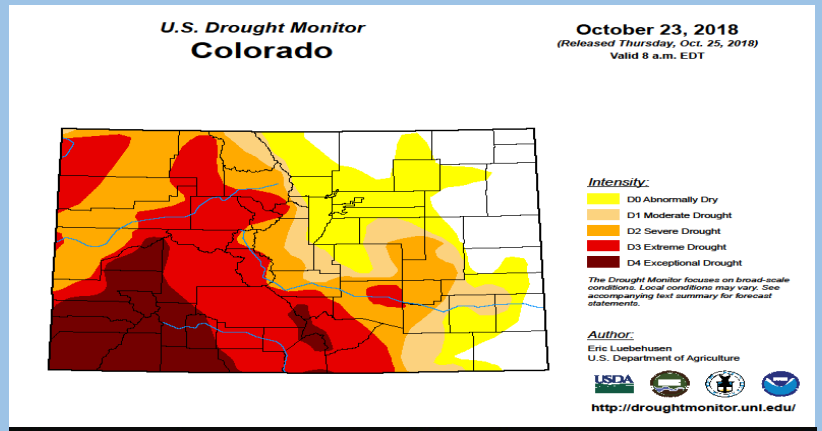
Volumes exceed onsite demand



Steady PW volumes in Fruitland, Raton CBM fields despite almost no new wells since 2014; contrasts with narrative from Powder River Basin

Basins layer from U.S. Energy Information Administration (EIA), U.S. Shale Plays Map.
Graph info from Colorado Oil and Gas Conservation Commission, county data and FracFocus data
Imported from the EIA and Ground Water Protection Council's National Oil and Gas Gateway Initiative.
*2018 data is January-June. Reporting delays impact completeness of July-December totals.
Note: Water volumes for hydraulic fracturing include only freshwater and recycled water for well completions. They do not include acids, foam, carbon dioxide, or other materials.
**Rio Blanco produced water volumes include multiple counting of water cycled for enhanced recovery at Chevron-Rangely field. Actual produced water-frac ratio likely much lower.

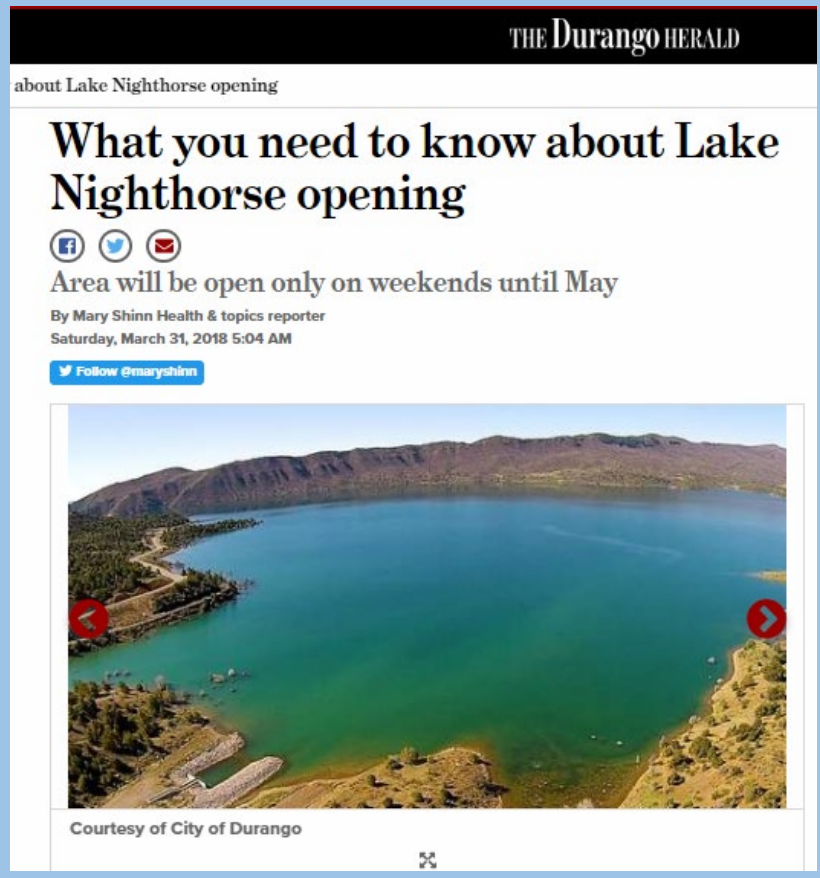
La Plata: Drought risk drives demand



- USDA U.S. Drought Monitor map, 10/23/2018.
- Article from the Durango Herald by Jonathan Romeo, 2/15/2019.

Western La Plata County – Potable and recreational (Animas – La Plata) pipelines

$5 million pipeline to deliver water to 150 homes west of Durango next year ($30k/home).



Authorized in 1968, delayed decades and scaled back to just serve Ute reservations. FSEIS in 2000, construction in 2001, $500MM (Rogers, 2013). Completed in 2013.

Potential Buyers: Power Plants (cont.)

- Power plants in arid regions can pay up to $6/1,000 gallons ($0.22/bbl) for cooling tower water (but most pay much less – Palo Verde < $0.10/bbl).
- Could be economic if desal avoided.
- Testing would have to focus on meeting power plant specs.

Table 12. Equivalent cost of water

Site	Item	Combined Cycle Wet Cooling	Combined Cycle Dry Cooling	Equivalent Water Cost ($/1,000 gallons)
Desert	Water Used, ac-ft/yr	2,593	98.5	3.75
	Capital Cost, MM$	195.6	213.6	
	Annual Revenue, MM$	165.6	163.9	
Valley	Water Used, ac-ft/yr	2,356	86.2	6.08
	Capital Cost, MM$	197.0	223.7	
	Annual Revenue, MM$	167.4	164.9	
Coast	Water Used, ac-ft/yr	2,455	73	3.39
	Capital Cost, MM$	212.8	238.6	
	Annual Revenue, MM$	172.4	171.7	
Mountain	Water Used, ac-ft/yr	2,089	78.4	5.36
	Capital Cost, MM$	202.0	210.2	
	Annual Revenue, MM$	151.7	148.8	

Equivalent Water Cost: Cap Cost x .075 plus difference in annual revenue divided by annual water use

Source: Maulbetsch, John and Michael DiFilippo. “Cost and Value of Water use at Combined-Cycle Power Plants”.Public Interest Energy Research Program report prepared for the California Energy Commission. April 2006.

Parameter	Units	Basic Parameters
Ca	mg/l_{CaCO3}	900 (max)(5)
Ca x SO_4	$(mg/l)^2$	500,000
Ca with PO_4 present	mg/l_{CaCO3}	(Refer to Table 2-3b)
Mg x SiO_2	mg/l_{CaCO3} x mg/l_{SiO2}	35,000 (2) 75,000 (3)
$HCO_3 + CO_3$	mg/l_{CaCO3}	30-50 (2) 200-250 (3)
SO_4	mg/l	(Note 5)
SiO_2	mg/l	150
Fe (Total)	mg/l	<0.5
Mn	mg/l	<0.5
Cu	mg/l	<0.1
Al	mg/l	<1
S	mg/l	5
NH_3	mg/l	<2 (9)
pH		6.8-7.2 (2) 7.8-8.4 (3)
pH with PO_4 present		7.0-7.5 (4)
TDS	mg/l	70,000
TSS	mg/l	<100 (6) - <300 (7)
BOD	mg/l	<100 (4)
COD	mg/l	<100 (4)
Langelier SI (8)		<0
Rysnar SI (8)		>6

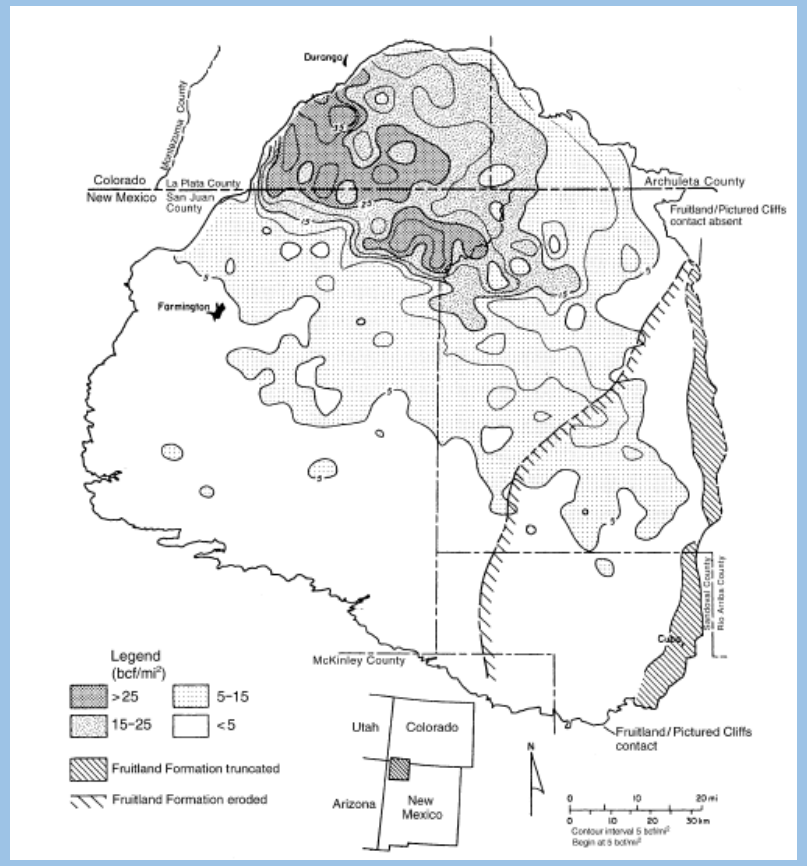
Notes.....

1. Cooling tower circulating water concentrations. PO_4 refers to total phosphate concentration. Refer to Table 3-1 and for detailed calculation pocedures.
2. Without scale inhibitor.
3. Assumes scale inhibitor is present.
4. Consult with specialty chemical provider before finalizing control parameters.
5. Refer to the $CaSO_4$ limit.
6. <100 mg/l TSS with film fill.
7. <300 mg/l TSS with open fill.
8. Refer to Appendix A for a discussion of the Langelier and Ryznar Saturation Indices for calcium carbonate.
9. <2 mg/l NH_3 applies when copper bearing alloys are present in the cooling system. This does not apply to 70-30 or 90-10 copper nickel.

Source: Veil, John. “Use of Reclaimed Water for Power Plant Cooling”. Argonne National Laboratory Report commissioned by the Department of Energy National Energy Technology Laboratory. August 2007.

Fruitland water and gas production history

Density of Fruitland gas-in-place, 1994

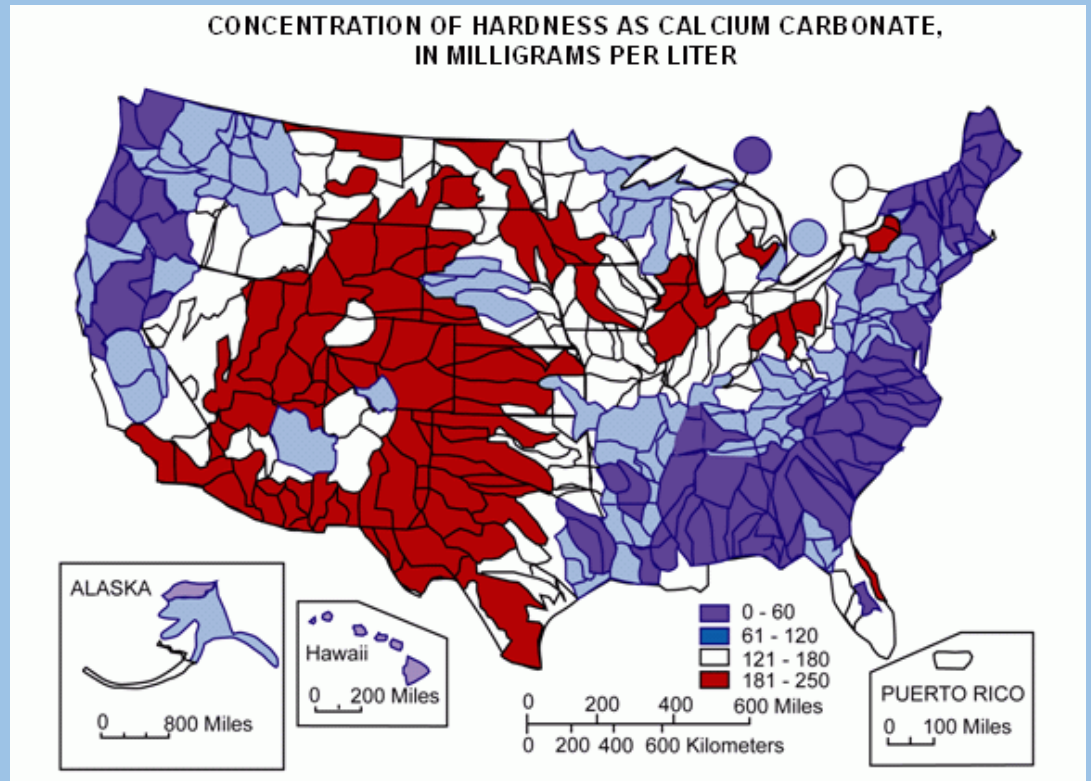


William B. Ayers, “Coalbed methane in the Fruitland Formation, San Juan Basin, Western United States: A giant unconventional gas play”. in M. T. Halbouty, ed., Giant oil and gas fields of the decade 1990– 1999, American Association of Petroleum Geologiests Memoir 78, 2014.

- “Fairway” has thick, northwest-trending, high-rank coal deposits with coalbed methane (CBM) gas near Durango.
- Dugan, Williams begin commingled production in early 1970s, Aamco (now BP) begins drilling in mid-70s. Thousands of wells drilled by the early 90s.
- CBM gas released by dewatering. High (2,000 bbl/d) production of low-chloride, alkaline water continues near Durango. Injected or evaporated with brine injection.
- Drilling all but ceases with expiration of Windfall Tax Credit (2002), lower gas prices (post-2008).

Handling sodium through chlor-alkalai

- Electrolysis reaction transforms NaCl, H_20 into chlorine and caustic soda.
- Many uses for caustics: Paper/aluminum making, flue gas desulfurization, cleaning, water treatment.
- Can add a hydrochloric acid resin that will absorb excess sodium, make use of all TDS and leave behind fresh water for agricultural, other uses.
- Question of whether TDS is high ***enough***: may be in parts of the Fruitland.
- Amec Foster Wheeler (2017) recommends against chlor-alkalai with Paradox Valley brine – prefers roadspreading. Worth revisiting.



Mean hardness as calcium carbonate at NASQAN water-monitoring sites during 1975 water year.
Colors represent site data representing streamflow from the hydrologic-unit rea.
(Map edited by USEPA, 2005)

Properties of prime farmland soils

Symbol	Name	Acres	Parent material	Specifications
76	Witt loam, 3 to 8 percent slopes	52,421	Calcareous silty loess	*Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)*
66	Tefton loam	6,151	Mixed alluvium	

Source: U.S. Department of Agriculture, Soil Surveys for La Plata County Area (CO669).

Cost of inaction

- “At present, however, water coproduced with CBM has been largely neglected for beneficial use, even where concentrations of dissolved solids and other contaminants are within regulatory guidelines for potable agricultural or livestock use.”

- “The societal and economic costs that may be incurred by not considering CBM water for beneficial use in an arid part of the United States are not usually discussed with regard to CBM produced water management.” (National Academy of Sciences, 2010)