Supporting Information

1.0 Produced Water Regulatory Framework for WY and NM

As there is no national water rights system, water rights and allocations are governed at the state level. In western states, water rights are based on the prior appropriation system; the earliest water users (appropriators) have priority over later users in times of water shortage. Water rights are appropriated when the water is diverted from its source and is applied to a beneficial use. Regulatory requirements for beneficial use of produced water vary widely by state.

1.1 Wyoming

In Wyoming, oil and gas exploration and associated production wastes are regulated by the Wyoming Oil and Gas Conservation Commission (WOGCC). The Wyoming Department of Environmental Quality (DEQ) is responsible for environmental protection, and the State Engineer's Office (SEO) regulates state water resources [1-4]. The primary options for produced water disposal in the state of Wyoming are direct discharge to surface waters with or without treatment depending on water quality, injection (such as into deep wells or using shallow, subsurface drip systems), or disposal into impoundments referred to as "pits" or "reservoirs" in Wyoming regulations [1-4].

With respect to beneficial use, produced water and other natural waters within the Wyoming boundary are considered property of the state. Water rights can be issued by the SEO to anyone who plans to beneficially use the water. Irrigation, municipal, industrial, recreational, power generation, stock, domestic, pollution control, and instream flow (to sustain instream

values such as fish habitat and recreation) uses are all recognized beneficial uses in Wyoming [1, 5]. Because production of water from a CBM well is necessary to produce the gas resource, the SEO has designated the co-production of water from CBM wells to be a beneficial use of the water. Operators of CBM wells must obtain groundwater appropriation permits from the SEO [1].

The Wyoming DEQ Water Quality Division administers National Pollutant Discharge Elimination System (NPDES) permits on behalf of the United States Environmental Protection Agency (EPA), referred to as WYPDES, to regulate discharge of produced water (a point source) to surface waters [1]. Because EPA's current NPDES technology-based effluent guidelines do not consider CBM production (as the regulations pre-date CBM production), the guidelines do not apply to CBM produced water discharges. Therefore, the effluent limitations established currently by a NPDES permit (or WYPDES permit) for produced water discharges are based on the best professional judgment of the issuer (Wyoming DEQ)[1]. Under WYPDES, the state established a policy for discharges of CBM produced water to the Powder River based on the "assimilative capacity" of the river. This policy regulates TDS and sodium in produced water discharges to the river because these were the two chemical constituents in produced water identified as having the potential to exceed Montana water quality standards where the Powder River crosses the state line from Wyoming to Montana[2] [1].

With respect to injection of produced water, injection wells are regulated at the federal level through the Safe Drinking Water Act (SDWA) in order to protect groundwater supplies of drinking water. Underground Injection Control (UIC) permits are required and depend on the well class (Class I through V). However, states have largely been delegated primacy of the UIC program, including Wyoming, where UIC permits are regulated by the Wyoming DEQ Water

[1] According to federal regulations, if the water quality of a receiving water body is still considered impaired after application of technology-based effluent limitations (standards) in a NPDES (or WYPDES) permit, the permitting agency (in this case, Wyoming DEQ) must add water quality-based effluent standards to the permit. These standards are set depending upon the designated uses for the receiving water body.

[2] Wyoming uses Montana's numerical standards for EC (as a surrogate for TDS) and SAR to prevent degradation of uses of surface waters and to avoid exceeding the Powder River assimilative capacity, though Wyoming itself has no numerical (only narrative) standards for these parameters. Application of Montana water quality standards to upstream surface water discharges in Wyoming is based on 2003 US EPA regulations that approved Montana's adoption of the EC and SAR water quality standards and applied them to the Powder River Basin (which extends between both states). Additional Montana standards that similarly regulate upstream Wyoming discharges were added in 2006, which append the 2003 regulations with "nondegradation" provisions regarding levels of salinity, SAR, and sodicity. Both the 2003 and 2006 regulations are currently being litigated due to lawsuits brought by both Montana and Wyoming energy companies, with the state of Wyoming also intervening on the side of the companies (NRC 2010).

Quality Division for Class I, III, and V wells and by the WOGCC for Class II wells. Oil and gas industry injection wells, including the majority of CBM produced water injection wells, are considered Class II wells. In Wyoming, in contrast to other western states, a significant number of CBM injection wells are considered Class V wells; this class is used for permitting injection through underground drip irrigation ("horizontal injection") [1] and aquifer storage and recovery [6].

In the Wyoming regulatory framework, unlined surface impoundments used for disposal of produced water consist of either "on-channel" reservoirs or "off-channel" pits. An "on-channel" impoundment (reservoir) is an impoundment sited within a designated water feature (e.g. perennial and ephemeral streams, dry washes, and lakes) or within the floodplain or alluvium of a water feature. An "off-channel" impoundment (pit) is not located within a designated water feature or its natural flow path and is not directly connected to any surface flow paths. Permits for "on-channel" reservoirs must be obtained from the SEO, whereas permits for "off-channel" pits are obtained from the WOGCC[3]. Impoundments may not be sited over Class I or Class II groundwater; most CBM produced water impoundments in Wyoming are sited over Class III or greater. To discharge to the impoundment, WYPDES discharge permits are required by the Wyoming DEQ. Additionally, the DEQ requires groundwater protection permits under the Wyoming Groundwater Pollution Control (GPC) Program, with monitoring requirements that are dependent upon factors such as depth to groundwater and the water quality beneath the impoundment. The Wyoming DEQ may issue groundwater monitoring exemptions if groundwater is not encountered within a specified depth below the impoundment or if the groundwater is Class IV (industrial) quality. In some cases, off-channel impoundments are required to be lined to minimize infiltration into shallow alluvial groundwater. Most impoundments in the Powder River Basin of Wyoming are on-channel (which are unlined), and the remaining are lined and unlined off-channel [1].

When siting a new impoundment (infiltration pond), local groundwater quality is considered according to regulatory requirements; areas with lower groundwater quality are preferable for reduced monitoring requirements and to avoid degradation of the local groundwater. According to interviews and literature [1], this has occurred in some instances, e.g., Class of Use of groundwater changed from Class III (livestock use) to Class IV (industrial use) because of TDS, selenium, and sulfate standard exceedances. Fencing of produced water impoundments is

[3] If the impoundment is located on federal land, authorization must be obtained from the United States Bureau of Land Management (BLM).

required by Wyoming regulations, unless the water may provide a benefit to the landowner, such as for livestock [5, 7]. However, some operators have found that fencing off the impoundments, and therefore preventing beneficial use of this water for livestock, has been preferable given the additional water quality-related regulatory requirements applicable to impoundments that are accessible to livestock.

The average annual allocation of produced water disposal methods shifts somewhat during the year. As specified by Wyoming's assimilatory policy, operators are allowed to discharge greater volumes to the Powder River when the flows are greater. During these times, operators may discharge (and therefore treat) 50 to 60% of the produced water flows from the well field. During the winter, a reduced number of infiltration ponds are usable, and so the portion of produced water disposed or used otherwise (such as for subsurface irrigation) may be increased.

In order to use produced water directly from the well head for surface irrigation, a permit is required from the Wyoming DEQ. Otherwise (i.e., if the produced water is sourced from a permitted surface impoundment), no permit is required.

1.2 New Mexico

Like other western states, the water rights doctrine in New Mexico is that of prior appropriation. The state agencies involved in produced water management and permitting in New Mexico are the Oil Conservation Division (OCD) of the New Mexico Department of Energy, Minerals, and Natural Resources, the New Mexico Environment Department (NMED), and the NMED's Water Quality Control Commission (WQCC).

The State Engineer is responsible for water rights and supervision of all surface water and groundwater resources. Water rights are appropriated when the water is diverted from its source and is applied to a beneficial use. Though there are no official beneficial use designations in New Mexico, past beneficial uses have included agriculture, commercial, domestic, industrial, recreational, state conservation goals, and stock watering. An exception to the State Engineer's authority is aquifers located at a depth of 2,500 feet or greater that contain nonpotable water – this describes the great majority of CBM wells in New Mexico and therefore pumping water from these wells does not require a permit from the State Engineer [1].

The OCD of the NMED is responsible for produced water management and permitting, including the regulation and permitting of surface and subsurface disposal to protect freshwater

resources, as delegated to it by the WQCC. This includes requirements for groundwater monitoring. Unlined pits are prohibited in New Mexico. Allowed disposal methods are lined pits, below-grade storage tanks, subsurface injection, and treatment and discharge for beneficial use. The NMED is responsible for NPDES permits with respect to surface water discharge [1, 8, 9]. The vast majority of produced water disposal in New Mexico is deep well injection. Injection wells are regulated at the federal level in order to protect groundwater supplies of drinking water through the UIC program; however, states have largely been delegated primacy of the UIC program. UIC permits are required and depend on the well class. The OCD administers the UIC program in New Mexico, with deep well injection occurring in Class II wells. Treatment by chlorination is required prior to injection to address bacterial contamination [1].

2.0 Background on Interstate Water Marketing Using Produced Water

Produced water can potentially be discharged to nearby rivers and marketed (sold) to downstream water users, such as through a long-term lease [10]. Such an arrangement across state lines would constitute interstate water marketing, which is of particular interest in the Colorado River Basin where limited water supplies from the Colorado River are allocated between seven states. Marketing produced water to in- or out-of-state users must comply with complex regulations regarding water transfers and water rights; therefore an interested operator would very likely need to hire a water lawyer [11].

2.1 Augmenting Colorado River Supplies with Produced Water

The Colorado River Compact of 1922 allocated use of Colorado River water between the Upper Colorado River Basin (Upper Basin) and Lower Colorado River Basin (Lower Basin). The Upper and Lower Basins consist of the seven states through which the river and/or its tributaries flow. The Colorado River originates in the Rocky Mountains of Wyoming and Colorado, flows southwest through Utah and Arizona to southern Nevada and California, and crosses into Mexico. Additionally, some tributaries to the Colorado River originate in New Mexico. Currently, the Upper Basin states (Wyoming, Colorado, and portions of Utah, New Mexico, and Arizona) do not use their full allocation and the surplus is available to the downstream Lower Basin states (California, Nevada, and portions of Utah, New Mexico, and Arizona) [12]. This surplus water is primarily stored in Lake Powell (Utah and Arizona) and Lake Mead (Nevada and Arizona). The Lower Basin states, particularly California, have historically used a greater portion or all of their Colorado River allocation, and in fact rely on the unused Upper Basin apportionments [12, 13].

Because the states in the Upper Basin do not use their full allocation and the Lower Basin states are experiencing increased demand for water, interstate water marketing in the Colorado River Basin has been recognized as having the potential to provide greater certainty for the Lower Basin and compensation to the Upper Basin. However, it is a controversial issue in Colorado and other states [13]. While these discussions have focused on the potential for interstate water transfers of Colorado River supplies (thereby representing a form of reallocation), produced water is an additional, separate potential source of water that could be transferred and marketed between areas and even state lines. Produced water has been determined *not* to be subject to the Colorado River Compact as it is not tributary to the waters of the Colorado River (it only becomes available via oil and gas mining). This is important because it allows produced water from Wyoming, for example, to be used in Las Vegas or Southern California, representing the first time Upper Basin water on the Colorado River can be moved to the Lower Basin [14].

The Upper Basin is experiencing increased water demand, such that surplus Colorado River supplies may not be available to the Lower Basin in the future. Produced water discharged to the Colorado River or its tributaries therefore represents an important potential option as a new water source. An additional benefit would be the instream flow of high quality treated water. The economic value of water that is already discharged for disposal and/or to maintain instream flows could in this way be recouped [13].

Produced water discharged to rivers could be beneficially used downstream by direct withdrawals from the river or via storage in an on-stream reservoir. With increased water supply, reservoir managers could maintain higher reservoir volumes to benefit fisheries and aquatic life and/or release more water to downstream users. For example, most of the water stored in Upper Basin reservoirs (such as Lake Powell) is used to satisfy Compact guarantees to the Lower Basin [12]. Discharge of produced water to reservoirs has occurred in areas near Wyoming's Powder River Basin [15]. The long-term availability and reliability of produced water is a potential obstacle for successfully marketing such a water transfer [16]. However, even a relatively short-term supply (e.g. 5, 10, 20 years) may be of interest to water agencies; for example, the Southern Nevada Water Authority actively pursues short-term water supplies while continuing pursuit of long-term supplies [12]. For an intra- or interstate water transfer of produced water, the discharge flow rate would need to be large enough that the transfer volume would be of significance to a potential reservoir operator or other smaller-scale user.

Stream discharge of CBM produced water to the Colorado River is one of twelve potential river augmentation options that was considered by a recent study [17] to address the persistent drought affecting local water supply: in 2002, stored water in the Lake Mead and Lake Powell reservoirs declined to less than 50% of capacity. The study recognized that produced water could provide new water from a highly saline, but treatable source.

2.2 Regulatory and Legal Framework for Interstate Produced Water Marketing

The regulatory issues and legal framework for the interstate marketing of produced water varies by state. Some information is available from limited reports and is reviewed herein.

Much of the debate about interstate water transfers and marketing in western states has focused on transfers of Colorado River supplies that are apportioned by the Upper and Lower Basin Compacts, and whether such transfers would be limited by these and other compacts [12, 13, 18, 19]. Regardless of the ongoing debate, an Arizona-Nevada water banking arrangement that was agreed upon in 2001 shows that interstate water marketing (even of allocated Colorado River water) can be done[4] [18, 20]. For non-Colorado River water, such as groundwater and other sources, the normal state laws (separate from the compacts) on water transfers and rights apply [19].

In the interest of keeping water within their boundaries for in-state use, state officials often resist water transfers out-of-state [19]. Similarly, residents may protest the transfer of water from their watershed to another, whether in or out-of-state [15]. However, some argue (and courts have held) that denying such permits and prohibiting interstate transfers is unconstitutional. For example, a 1982 court decision (*Sporhase v. Nebraska*) stated that water transfers outside the state must be allowed under the same circumstances as within the state; other states later changed their transfer statutes to comply. Most state laws have provisions that specify how water transfers to out-of-state users can be made. These include criteria of reasonableness, conservation, and public welfare found in New Mexico, Arizona, Utah, Colorado, and other

[4] A recent arrangement between Arizona and Nevada represents a significant demonstration of interstate water marketing in the Colorado River Basin. Nevada pays Arizona to “bank” unused Colorado River water from Arizona’s entitlement via aquifer storage and recovery facilities in Arizona, and Nevada receives credits for the stored water. When the water is needed, Nevada makes withdrawals from Lake Mead for use in nearby Las Vegas and surrounding areas, and Arizona withdraws the same amount from the aquifer. The water is charged as consumptively used in Arizona. The project required new federal regulations and involved several agreements. Nevada pays Arizona for use of the water ($100 million in 2005 and ten installments of $23 million beginning 2009), which will amount to 1.25 million acre feet over the project life (200,000 acre feet per year). Nevada’s purpose was to utilize an interim water supply while developing long-term, non-Colorado River water resources.

states' statutes. The state law of the upstream state (where the source/seller is located) applies [19].

Based on the above analysis, produced water (groundwater) may be marketed within a state or across state lines according to state laws governing water transfers. Marketed produced water requires a non-tributary designation; this determination by the State Engineer is dependent on site hydrogeology and establishes that the water is not physically connected to surface water, thereby avoiding potential injury to any surface water rights. The non-tributary groundwater may then be permitted for use for industrial, municipal, irrigation, commercial, and augmentation purposes [14, 21]. In many cases, produced water may likely be a combination of tributary and non-tributary groundwater. An augmentation plan may therefore be necessary to return some water to the river with the remainder available for marketing [11].

In New Mexico, out-of-state water transfers are allowed according to certain conditions. Transfers are allowed by the State Engineer that do not injure other water rights and are not detrimental to conservation or the public welfare. Further, the state water supply and demand in both New Mexico and the state receiving the transfer must be evaluated with respect to whether the water could instead be used to address water shortages in New Mexico[5]. Although downstream users would withdraw the transferred water from rivers or reservoirs (e.g. San Juan River or Lake Powell) that are subject to the Upper Colorado River Basin Compact, these withdrawals would not be charged to the state's apportionment: many compacts, including the Upper Basin's, have provisions stating that imported water is not charged to the state's apportionment[6] [19].

2.3 Economic Feasibility of Interstate Produced Water Marketing

The economic feasibility of interstate produced water marketing is project-specific. However, if a buyer is available, it is likely to be economically feasible due to the high value of water in the arid southwest, taking into account water treatment costs and potentially water transfer (delivery) costs depending upon the site location and approach.

[5] Matthews and Pease (2006) note that this statute could likely be successfully challenged in court by an existing water rights holder who wishes to transfer those rights (as opposed to one who still needs to acquire the rights).

[6] However, the compacts do not specify how the state would avoid this withdrawal being counted toward their apportionment – it would likely require some accounting with respect to gage measurements (Matthews and Pease, 2006).

For example, the value of water in Reno, Nevada recently rose from $1,000 to $35,000 per acre foot. In the North Front Range of Colorado, the value of water is estimated as $15,000 to $20,000 per acre foot, and Las Vegas, Nevada is currently leasing water on a short-term basis for $20,000 per acre foot [21]. In the Atlantic Rim area near southern Wyoming and northern Colorado, the market price for a long term lease by downstream users of treated, CBM produced water that is stream discharged has been estimated at approximately $20,000 per acre foot. This compares to an estimated cost of treatment ranging approximately $2,000 to $8,000 per acre foot for CBM produced water from this site. The cost of an alternative disposal option, deep well injection, is estimated at approximately $16,000 per acre foot [10].

Though it does not involve an interstate water transfer, a related example is the treatment and municipal use of oil production water in Wellington, Colorado. The water (non-tributary) is treated and used to augment shallow aquifers to prevent injury to users with senior water rights, and a portion is then extracted, treated, and used to augment drinking water supplies. The oil field owner was disposing of the water via Class II well injection at a cost of over $8,000 per acre foot when the owner was approached by a developer about the possibility of treating and selling the water. The water is treated at a cost of approximately $4,000 to $6,000 per acre foot including the production water treatment plant and, prior to use for drinking water, reverse osmosis treatment. The market value for the water is $20,000 per acre foot with an additional $15,000 per acre foot for the finished drinking water [10]. While the project was economically feasible, permitting the operation was complex and expensive. Over two years were required to gather data and determine that all of the production wells were non-tributary, and additional permitting was required to discharge the water to shallow pits (i.e. aquifer recharge ponds) with a variance to allow the pits to be unlined. The total cost for permitting, engineering, and hydrogeological studies was over $1,000,000, though the estimated cost for future projects in Colorado is estimated as $500,000 now that the required state agencies have clarified the permitting requirements and their respective responsibilities [22].

3.0 References

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